Developing Optimal Pedestrian Evacuation Networks for Seismic Events: A Spatial Analysis and AHP Approach in Uptown Cagayan de Oro City

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Abstract: This study developed optimized seismic evacuation routes for pedestrians in Cagayan de Oro City's Uptown Central Business District, addressing the urgent need for safe evacuation during unpredictable earthquakes. Building selection criteria, including height and occupancy, identified key structures. Routes and obstructions were mapped in GIS and the evaluation employed the Analytical Hierarchy Process (AHP), prioritizing factors like obstruction and accessibility. Pairwise comparisons weighted criteria, determining optimal routes. Results from the AHP analysis provided a clear pathway for safe pedestrian movement. This research delivers a practical framework for urban disaster risk reduction, enhancing pedestrian safety during seismic events. The developed routes and methodology serve as a vital tool for city planners and emergency responders, promoting effective evacuation strategies in high-density urban areas.

Keywords: Seismic Evacuation, Analytical Hierarchy Process, Disaster Routes, Route optimization, Pedestrian Safety, Philippines

1. INTRODUCTION

Cagayan de Oro City, the capital of Region X and a thriving urban hub in Northern Mindanao, Philippines, faces challenges due to its rapid economic growth, particularly in the construction of high-rise buildings. This urbanization increases vulnerability to earthquakes, with the Central Business District of the Uptown Area being approximately 23.3 km from the Tagoloan Fault Line. According to HazardHunterPH, the study area is said to be prone to ground shaking further complicating the evacuation process. With this, the study's objective is to create a seismic evacuation plan for the area, focusing on gathering baseline data, identifying evacuation routes using GIS, determining optimal routes through AHP, and finally developing evacuation plans for selected buildings.

The results and outcome of this study will greatly benefit the building occupants as this will serve as a guide for seismic evacuation, the local government, and emergency response agencies as the study adds additional information about the study area, the government regulatory bodies, and the local community. Existing studies of disaster routes locally has been focused on flooding, such as the works of Abuzo et al. (2024) and Gamboa et al. (2021) in their research that determined flood routes comparing normal and flooding conditions. The paper would like to consider pedestrian safety when an earthquake happens. This paper also contributes to improving the disaster routes and evacuation routes in place for Uptown Cagayan de Oro.

2. METHODOLOGY

This study focuses on developing seismic evacuation routes from the selected buildings to the selected evacuation areas in the Central Business District of the Uptown Area, Cagayan de Oro City. Moreover, the development of seismic evacuation routes considers factors that are highly relevant to the safety of the building occupants.

This study involves three main phases as illustrated in Figure 1, the data collection, data processing and analysis, and interpretation and visualization. (1) The first phase is data collection in which primary and secondary data will be collected. In the secondary data collection, the researchers will acquire baseline data such as building height, building floor area, number of floors, estimated building capacity, number of exits, and location of exits for the selected buildings. In the primary data collection phase, researchers will gather data on road characteristics, including road length, width, pavement condition, and the number of intersections. This will be achieved through the use of QGIS software or through direct assessment in the study area. Next, the researchers will identify structures adjacent to the road by counting the number of street furniture items and buildings. Lastly, they will determine the optimal open area, considering the factors prepared by the researchers, to identify potential evacuation areas. (2) The second phase is the data processing and analysis in which the researchers will select the routes of the selected building through GIS. The researchers will apply the criteria, which include ground-level roadside obstruction, falling object obstruction, pavement condition, route accessibility and explosive/electrical/thermal hazards, to the predetermined routes to be used in AHP (Analytic Hierarchy Process) analysis. Additionally, researchers will conduct a site survey in Central Business District of the Uptown Area to collect data on various sub-criteria, including utility poles, street lamps, transformers, parking lots, water tanks, commercial signage, gas stations, intersections, speed humps, and the length of concrete fences, vertical parking areas, electrical wires,, road cracks, potholes, and raveling.

In this study, a questionnaire will be developed to gather insights from experts in government agencies like the City Disaster Risk Reduction Management Office (CDRRMO), City Planning and Development Office (CPDO), Roads and Traffic Administration (RTA), Department of Public Works and Highways (DPWH), and other professionals in the Uptown Area. This survey aims to establish an AHP hierarchy and calculate raw weight values for each criterion. It includes a pairwise comparison matrix to assess the criteria's relative importance, leading to the computation of an overall weight vector and priority values. The consistency ratio, based on the number of criteria, helps determine the total weight value for each criterion, which in turn ranks the optimal routes in the study area. (3) The last phase is the interpretation and visualization of data. The chosen optimal routes will be visualized and analyzed with the use of QGIS software. This step will culminate conclusions and insightful recommendations.

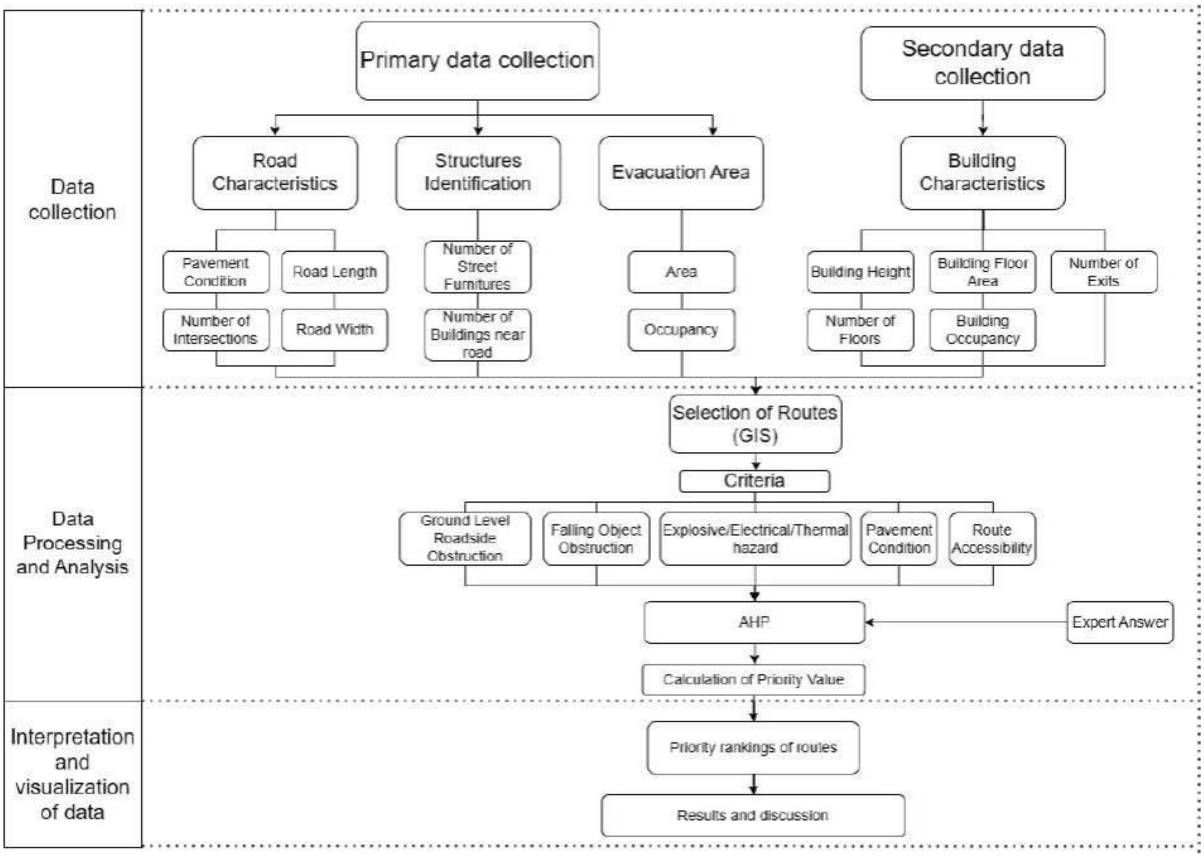

Figure 1. Seismic Evacuation Route Research Design

2.1 Traffic Noise Research Location

Analytical Hierarchy Process (AHP) will be used as a main tool for the research analysis. AHP is a structured decision-making process used to solve complex problems using criteria and sub-criteria (Saaty, 1970). It will be employed to determine the weight of each parameter associated with the available routes. Moreover, Saaty introduced a numerical scale to compare the importance of elements relative to each other (Russo & Camanho, 2015). The conclusion will yield the identification of the safest and most optimal routes.

Table 1. Scales in Pairwise Comparison

Importance Scale	Definition
1	Equally important
3	Moderately important
5	Strongly important
6	Extremely important
9	Extremely more important
2, 4, 6, 8	Intermediate values between adjacent scale values

This is the pairwise comparison used to calculate the weight of the criteria. The sum of the importance value will then be used to ratio the rating in the pairwise comparison to normal the pairwise matrix.

$$N = \frac{X}{sum\ of\ all\ values\ in\ a\ column} \tag{1}$$

$$Criteria\ Weight = \frac{(sum\ of\ all\ values\ in\ a\ column)}{(Total\ number\ of\ Criterias\ in\ a\ row)} \quad (2)$$

After the calculation of the weight of the criterion, consistency is still needed. Thus, the Consistency Ratio should be calculated. Below is the formula:

$$Consistency\ Index = \frac{(\lambda_{max} - n)}{(n-1)} \quad (3)$$

$$Consistency\ Ratio = \frac{consistency\ index}{random\ index} < 0.1 \quad (4)$$

Table 2. Random Consistency Indices (RI) N=10

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.59

The occupancy load is the maximum number of people allowed in a building or a room based on its size and function. Below is the formula:

$$Maximum\ Building\ Occupancy = \frac{floor\ area}{occupant\ load\ factor}(no.\ of\ floors) \quad (5)$$

Lastly, the researchers modified the Occupant Load Factor from the National Building Code of the Philippines (PD 1096).

The researchers formulated a criterion on the selection of the buildings. The building must be a commercial building with a height of more than 15 meters and the maximum occupancy should be >100. The study focuses on building occupants; people who are already outside are not included (motorist & pedestrians). Subdivisions are not included and future development such as construction are not considered.

Table 3. Occupant Load Factor

Building Classification	Unit Area per Occupant (sq. meters)
Group D: Assembly – Concentrated use without fixed seating	0.65

3. RESULTS AND DISCUSSIONS

3.1 Baseline Date of the Study Area

First baseline data is the road characteristics, which consists of two main groups, pavement condition and road inventory. The pavement condition is determined through the presence of cracking, speed humps, potholes, and raveling. The roads in the study area have 98 visible cracks, 2 speed humps, 21 visible potholes, and 41 raveling. The road inventory consists of the measurement of length, width, and number of intersections of the study area. Pedro N. Roa road has a width of 16.333 m, length of 514.744 m, and 3 intersections. Las Ramblas road has a width of 7.296 m, length of 499.182 m, and 9 intersections. *Granvia* has a width of 15.231 m, length of 482.18 m, and 12 intersections. Paseo de Oro has a width of 11.292 m, length of 471.863 m, and 9 intersections. Masterson Avenue has a width of 12.911 m, length of 549.764 m, and 4 intersections. Trade St. has a width of 11.92 m, length of 189.668 m, and 2 intersections. Commerce St. has a width of 12.003 m, length of 186.861 m, and 3 intersections. *Beacon*

Avenue has a width of 17.336 m, length of 511.104 m, and 4 intersections. *Pacific St*. has a width of 12.093 m, length of 417.847 m, and 5 intersections. Regatta Blvd. has a width of 18.167 m, length of 518.47 m, and 8 intersections. Pedestrian roads have a width of 3.409 m, length of 210.017 m, and 2 intersections. DOJ - *Prawnhouse Road* has a width of 9.885 m, length of 141.229 m, and 4 intersections. *Prawn House Road* has a width of 7.69 m, length of 73.542 m, and 2 intersections. SM Road has a width of 8.538 m, length of 186.639 m, and 2 intersections. *Atlantic St.* has a width of 12.128 m, length of 203.035 m, and 2 intersections. Next baseline data is the structure identification, which are the buildings and street furniture. The buildings with vertical parking areas, buildings that are prone to earthquake-induced fire, the presence of water tanks located on the rooftop of the buildings, and the presence of gas stations. There are 3 buildings with vertical parking spaces, 3 gas stations, and 10 water tanks. Street furniture is classified as: utility poles, transformers, electrical wires, street lamps, parking areas, commercial signage, concrete fences. There are a total of 166 utility poles, 105 street lamps, 20 transformers, 287 parking areas, 22 commercial signages, and 3 fence lines.

3.2 Selected Buildings and Evacuation Area

Figure 2 shows an evacuation area and selected buildings for researchers. The green zone, designated for evacuation, must meet specific criteria: (1) it should be open and not surrounded by structures, with a distance from buildings equal to 1.5 times their height to prevent debris, and (2) it must be easily accessible from the road to aid rescue efforts. However, this area has a limited duration as it is slated for future development, potentially as commercial establishments. The red area shows selected buildings which must meet criteria including a height of at least 15 meters, proximity to the road, a capacity for at least 100 occupants, and designation as commercial establishments. There are 11 such buildings identified.

Figure 2. The Evacuation Area & Selected Buildings in Central Business District, Uptown Area of Cagayan de Oro City, Misamis Oriental

Table 4. The Baseline Data of each of the Selected Buildings

Building ID	Building Height (m.)	Total Area (sq.m.)	Maximum Occupancy	Number of Floors	Number of Exits
A	19.1	87, 837.15	3,000	3	4
B	20.1	8,000	600	4	2
C	19.5	4,388	235	5	2
D	35	26, 142	1,300	10	2
E	15,267	10,670.08	280	4	3
F	19.6	5,250	480	7	2
G	20	1,054	375	5	2
H	15.1	981.21	100	3	2
I	20	1,200	300	4	2
J	38	5,340	500	10	4
K	42.725	24,363	1,300	13	4

The table above shows the baseline data of each selected building that meets the specified criteria in the study area.

Table 5. The Maximum Occupancy of the Selected Evacuation Area

Evacuation Area (sq.m.)	Occupant Load (sq.m./person)	Maximum Occupancy (sq.m./person)
10,630	0.65	16,354

Table 5 shows the evacuation area with the occupant load. The maximum occupancy of the evacuation area can withstand the total maximum occupancy of the selected buildings. This means that the selected evacuation area is suitable since its capacity is 16,354, which is much more than the calculated total occupancy from the building's estimated maximum occupancy, which is 8,470.

3.3 Analytical Hierarchy Process (AHP)

The pairwise comparison of all the main criteria are shown above. The findings showed that out of all the criteria, Ground Level Roadside Obstruction is the most significant and the Route Accessibility is the least significant.

Table 6. Pairwise Comparison of the Criteria

Criteria	Ground Level Roadside Obstruction	Falling Object Obstruction	Explosive/ Electrica/ Thermal Hazard	Pavement Condition	Route Accessibility
Ground Level Road Side Obstruction	1	3	5	5	7
Falling Object Obstruction	0.33	1	3	3	5
Explosive/ Electrica/ Thermal Hazard	0.20	0.33	1	1	3
Pavement Condition	0.20	0.33	1	1	3
Route Accessibility	0.14	0.14	0.33	0.33	1

This means that the Ground Level Roadside Obstruction has the most impact in developing optimal evacuation routes.

Table 7. Weight of Criteria and Sub-Criteria

Criteria	Criteria Weights	Sub-criteria	Local Weight	Global Weight
Ground Level Roadside Obstruction	0.4986	Utility Falling Down	0.4209	0.2099
		Street Lamp Falling Down	0.4209	0.2099
		Collapsed Concrete Fence	0.1064	0.0531
		Parked Vehicles	0.0517	0.0258
Falling Object Obstruction	0.2459	Building with Falling Debris (Metal, Concrete, Glass)	0.5579	0.1372
		Falling Vehicle from Vertical Parking Space	0.2639	0.0648
		Falling Water Tank	0.1219	0.0300
		Falling Commercial Signage	0.0569	0.0140
Explosive/Electrical/Thermal Hazard	0.1055	Gas station explosion	0.5579	0.0588
		Transformer explosion	0.1219	0.0129
		Electrical Wires (Dangling, Tangled, Organized)	0.0569	0.0060
		Earthquake-induced Fire	0.2633	0.0278
Pavement Condition	0.1055	Cracking	0.2633	0.0278
		Speed Humps	0.0569	0.0060
		Pothole	0.5579	0.0568
		Raveling	0.1219	0.0129
Route Accessibility	0.0446	Route Width	0.2605	0.0116
		Route Length	0.6333	0.0282
		Number of Intersections	0.1062	0.0047

The global weight in table 3 represents the overall importance of each sub criteria in the entire decision hierarchy. It is calculated through multiplying the local weight of each sub criteria to its corresponding criteria weight. The weights are used to determine the scores of each route.

Among the five criteria, the Ground Level Roadside Obstruction ranked first with a criteria weight of 0.4986, while the Route Accessibility ranked last with a criteria weight of 0.0446. This is based on the opinions of experts where the route accessibility is the least significant since the safety of people is their main concern. The majority of the roads in the study area have adjacent street furniture which further validates the criteria of Ground Level Roadside Obstruction.

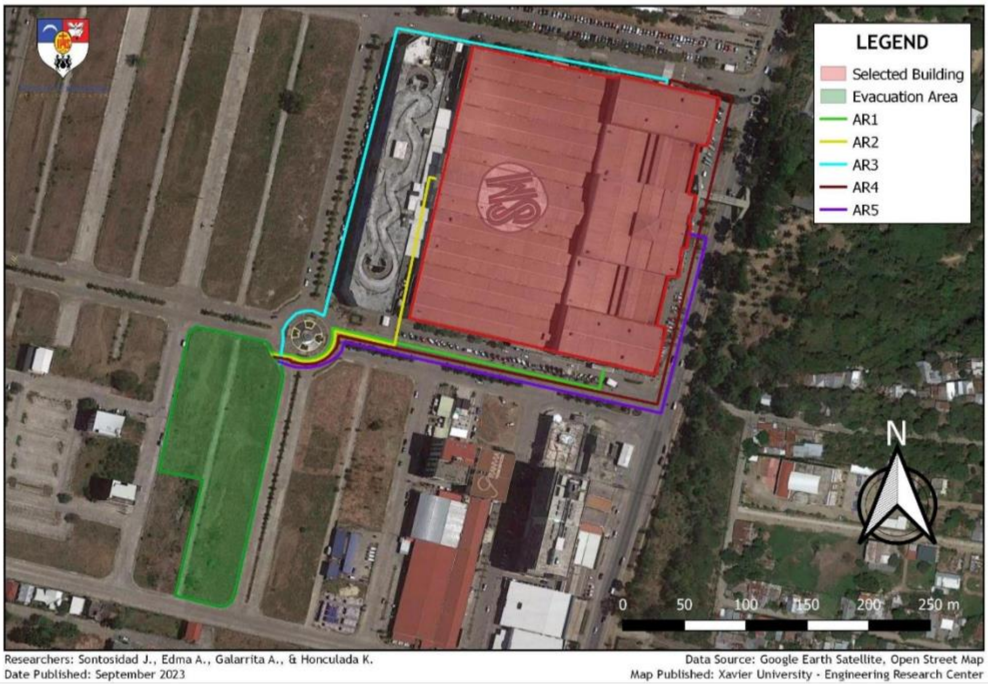

Figure 3. Building A Possible Evacuation Routes

The most optimal route color is yellow, the 2nd is green, 3rd is blue, and the least is purple and red. This color coding is the standard for all route rankings in each buildings

Table 7. AHP Score and Ranking for Building A Routes

Routes	AR1	AR2	AR3	AR4	AR5
AHP Score	5.925	4.894	12.524	18.414	12.802
Ranking	2	1	3	5	4

The table above shows the AHP score for each route of Building A. Based on the results, the lowest AHP score is AR2. Thus, the rankings are: second is AR1, third is AR3, fourth is AR5, and fifth is AR4.

This means that AR2 is the optimal route since it only has a minimal number of street furniture such as utility poles, street lamps, concrete fences, and parked vehicles as compared to the other routes.

3.4 Optimal Routes in Each Building

The map below shows the detailed evacuation plan for the study area, displaying highlighted routes from selected buildings to the evacuation area. The routes shown in each building signifies the optimal routes based on the AHP analysis showing 11 routes (AR2, BR2, CR3, DR2, ER1, FR2, GR1, HR2, IR1, JR3, and KR2) for the 11 buildings. This map serves as a guide for building occupants during evacuations, offering the most effective and efficient paths to safety.

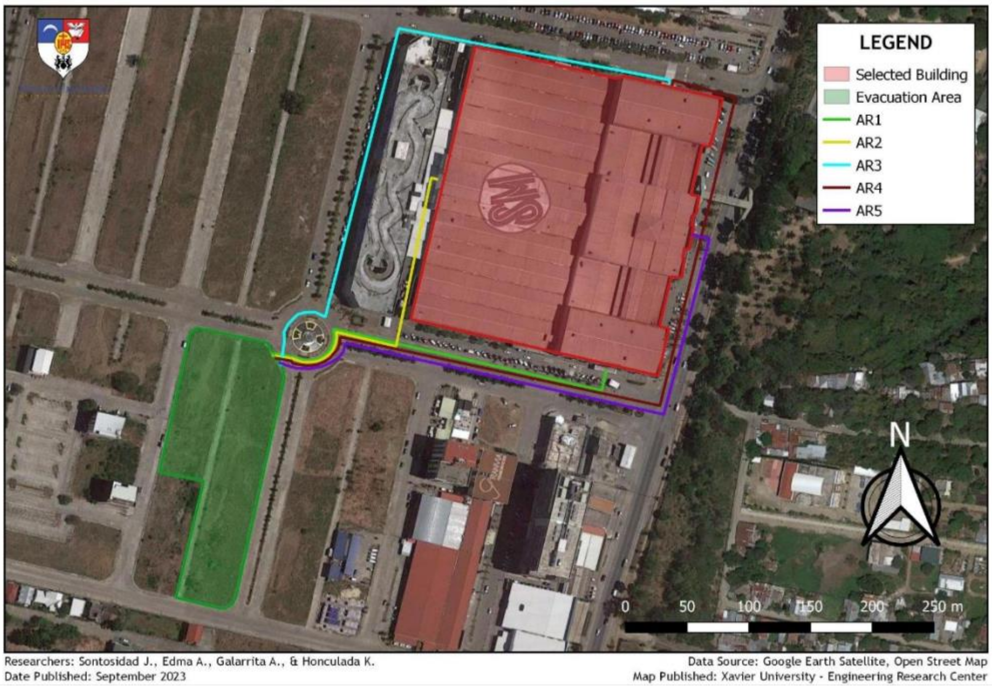

Figure 14. Evacuation Route Plan for the Building Occupants of Uptown Area, Cagayan de Oro City

4. CONCLUSION

First, the selected evacuation area is suitable since its capacity is 16,354 which is much more than the calculated total occupancy from the building's estimated maximum occupancy which is 8,470.

The ranking of each criterion was determined based on the results of their criteria weights. Among the five criteria, the Ground Level Roadside Obstruction ranked first with a criteria weight of 0.4986, while the Route Accessibility ranked last with a criteria weight of 0.0446. This is based on the opinions of experts where the route accessibility is the least significant since the safety of people is their main concern. The majority of the roads in the study area have adjacent street furniture which further validates the criteria of Ground Level Roadside Obstruction.

The identified optimal routes for each selected building are: AR2, BR2, CR3, DR2, ER1, FR2, GR1, HR2, IR1, JR3, and KR2. This means that these routes are the routes that have the lowest AHP score since these routes only have a minimal number of street furniture such as utility poles, street lamps, concrete fences, and parked vehicles as compared to the other routes which correspond to the highest AHP criteria which is the Ground Level Roadside Obstruction.

The importance of the evacuation areas cannot be overlooked as the occurrence of earthquakes is more frequent. There is an inadequate evacuation area in the study area. There are numerous open areas, but did not pass the first rule of the criteria in Chapter 3, section 3.5: Evacuation Area Identification. Despite the efforts of the researchers to identify the optimal routes, they cannot be labeled as completely safe for travel, primarily due to potential obstructions. Despite having minimal presence of obstructions when compared to the alternate routes, building occupants are still exposed when traveling on the optimal routes.

Also, the allowable height or number of floors for rising buildings has increased over time since the closure of Lumbia Airport. Consequently, more high-rise buildings have been constructed. Unfortunately, these high-rise structures have not taken into account the impact they have on traffic conditions in the Uptown Area, contributing to increased traffic congestion. These buildings lack proper seismic evacuation route plans, placing the lives of their occupants at greater risk during disasters. The findings of the study strongly indicate that the study area is not adequately prepared for earthquakes. As a result, it is highly recommended that building owners should strictly implement evacuation route plans and develop evacuation facilities to enhance the safety of occupants in times of seismic events.

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