Bulletin of the New Zealand Society for Earthquake Engineering, Vol. 59, No. 2, June 2026

THE 2024 HUALIEN, TAIWAN EARTHQUAKE: NZSEE LEARNING FROM EARTHQUAKES RECONNAISSANCE REPORT

Bo-Yao Lee[1], Julian Rincon[2], Doug Mason[3], Julian Benito[4], Alice Chang-Richards[5], Ke Jiang[6], Patrick Cummuskey[7], Joe Byrne[8], Jason Chiou[9], Lucas Hogan[10], Jonathan Monical[11], Alex Shegay[12] and Tomomi Suzuki[13]

(Submitted *June 2025*; Reviewed *July 2025*; Accepted *February 2026)*

ABSTRACT

A M_w 7.4 earthquake struck off the east coast of Taiwan on 3 April 2024. Strong ground shaking was felt across Taiwan, with the highest intensities recorded in Hualien County, resulting in 18 fatalities, three people missing, over 1,100 injuries, the collapse of several buildings, and significant disruptions to infrastructure. Compared with other major recent earthquakes in Taiwan, such as 1999 Chi-Chi Earthquake (M_w 7.6), and 2016 Meinong Earthquake (M_w 6.4), the overall damage and casualty levels were relatively low, demonstrating the benefits of important advancements in seismic resilience in Taiwan since the Chi-Chi Earthquake. To gain a detailed understanding of the impacts of the earthquake and of Taiwan's seismic resilience developments over the past two decades, a New Zealand Society for Earthquake Engineering (NZSEE) Learning from Earthquakes (LFE) team was deployed to Taiwan between May and June 2024. This journal article reports the observations and key insights from field inspections, meetings with government officials, and discussions with researchers and professors at local universities. The lessons learned from Taiwan's experience provide valuable insights for New Zealand, highlighting the importance of pragmatic, cost-effective retrofit schemes, proactive emergency management, and rapid functional recovery strategies.

https://doi.org/10.5459/bnzsee.1762

INTRODUCTION

Taiwan has a long history of major earthquakes, including the devastating Chi-Chi Earthquake in 1999 [1] and Meinong Earthquake in 2016 [2] (Figure 1). On 3 April 2024, a moment magnitude M_w 7.4 (local magnitude M_L 7.2) earthquake struck off the coast of Hualien County, eastern Taiwan. The epicentre was located approximately 25 km southeast of Hualien City (which is within Hualien County), at a focal depth of 15.5 km. It was the strongest earthquake to affect Taiwan since the Chi-Chi Earthquake and was followed by a series of aftershocks, including a M_w 6.4 aftershock 13 minutes later. By 10 May 2024, more than one thousand aftershocks had been recorded, including two exceeding magnitude 6.0 on 23 April that caused additional property damage in Hualien City [3].

The Hualien Earthquake sequence resulted in the collapse of several buildings, 18 fatalities, over 1,100 injuries, and three people missing. Landslides and rockfalls were triggered across the steep terrain of the East Central Range, cutting off the main transport routes for Hualien and isolating Taroko National Park. In low-lying areas of Hualien County, minimal liquefaction or surface fault rupture was observed. The earthquake also impacted northern Taiwan, including one building collapse and reports of ground damage in extending as far as Taipei. In New Taipei City, a section of the Mass Rapid Transit (MRT) tracks sustained severe damage. Initial repair estimates suggested the work would take up to one year [4], but by December 2024 (8 months later) that MRT section was fully repaired and resumed operation [5].

Reconstruction costs for state highways were projected to be approximately NZ$85 million, with completion anticipated by the end of 2026 [6]. The economic repercussions of the 2024 Hualien Earthquake are expected to persist for the foreseeable future, particularly given Hualien's dependence on tourism around the Taroko National Park.

The Hualien Earthquake offered a valuable opportunity for New Zealand to learn directly from Taiwan's experience and to gain insights into its evolving strategies for natural disaster resilience. A NZSEE LFE team compromising researchers and professionals, with financial support from the Natural Hazards Commission Toka Tū Ake, was deployed in Hualien from 29 May to 3 June and in Taipei from 3 to 6 June 2024. The mission covered key areas in Hualien County, Taroko National Park, and Taipei City.

---

[1] *Corresponding Author, Chief Advisor – Technical Design Standards, Ministry of Justice, Wellington, bo-yao.lee@justice.govt.nz (Fellow)*
[2] *Postdoctoral fellow, University of Canterbury, Christchurch, julian.rincongil@canterbury.ac.nz (Member)*
[3] *Principal Engineering Geologist, WSP, Wellington, doug.mason@wsp.com (Member)*
[4] *Technical Principal in Earthquake Engineering, WSP, Taupo, julian.benito@wsp.com (Member)*
[5] *Associate Professor, University of Auckland, Auckland (Member)*
[6] *Senior Lecturer, University of Canterbury, Christchurch (Member)*
[7] *Senior Building Emergency Management Specialist, Ministry of Business, Innovation and Employment, Wellington (Member)*
[8] *Technical Director, Lewis Bradford Consulting Engineers, Christchurch*
[9] *Research Fellow, National Center for Research on Earthquake Engineering, Taipei, Taiwan*
[10] *Senior Lecturer, University of Auckland, Auckland (Member)*
[11] *Assistant Professor, Tohoku University, Sendai, Japan*
[12] *Lecturer, University of Auckland, Auckland (Member)*
[13] *Associate Professor, Hiroshima University, Hiroshima*

Figure 1: Map of Taiwan with locations of recent destructive earthquakes.

In Hualien, the team met with local officials from the Hualien County Government, Hualien Emergency Operations Centre, and the Taroko National Park Headquarters. The team also conducted inspections of infrastructure and buildings and met with representatives of building owners including from a regional hospital, a high-rise hotel, and large residential complexes. A field visit was made to Taroko National Park, with inspections undertaken at the sites near its headquarters and along Highway 9. Access to Taroko Gorge via Highway 8 was restricted due to ongoing repairs. Figure 2 shows the areas visited in Hualien County.

Figure 2: Reconnaissance areas in Hualien County.

In Taipei, meetings were held with national research organisations and central government agencies, including National Centre for Research on Earthquake Engineering (NCREE), National Science and Technology Center for Disaster Reduction (NCDR), Taiwan Residential Earthquake Insurance Fund (TREIF), Highway Bureau, Central Weather Administration (CWA), Agency of Rural Development and Soil and Water Conservation (ARDSWC), and Office of Disaster Management under the Executive Yuan (Cabinet).

In parallel, a separate group of New Zealand structural engineers, funded by the Royal Society of New Zealand Te Apārangi (RSNZ) and QuakeCoRE (the New Zealand Centre for Earthquake Resilience), conducted a reconnaissance visit from 7 to 14 May 2024. That group collaborated with Japanese and Taiwanese researchers to investigate the seismic performance of buildings. Two members of the NZSEE LFE team participated in that mission.

Findings from both teams are presented in a series of journal articles. This article provides a broad overview of:

- Taiwan's geological setting
- The characteristics of the earthquake shaking
- Observed impacts on ground conditions, lifeline infrastructure, buildings and socio-economic systems
- The national retrofit programmes for public and private buildings
- Taiwan's emergency management framework and its use of technological tools to improve seismic resilience
- Key lessons for improving New Zealand's seismic resilience.

GEOLOGICAL SETTING

Taiwan is located on the boundary between the Philippine Sea Plate and the Eurasian Plate on the Pacific 'Ring of Fire'. The average relative plate movement is 85 mm per year [7], nearly double that of New Zealand [8]. This has produced a series of folds and thrust faults that divide the country into several geological provinces: Penghu Island Group, Coastal Plain, Western Foothills, Central Range, and the Coastal Range.

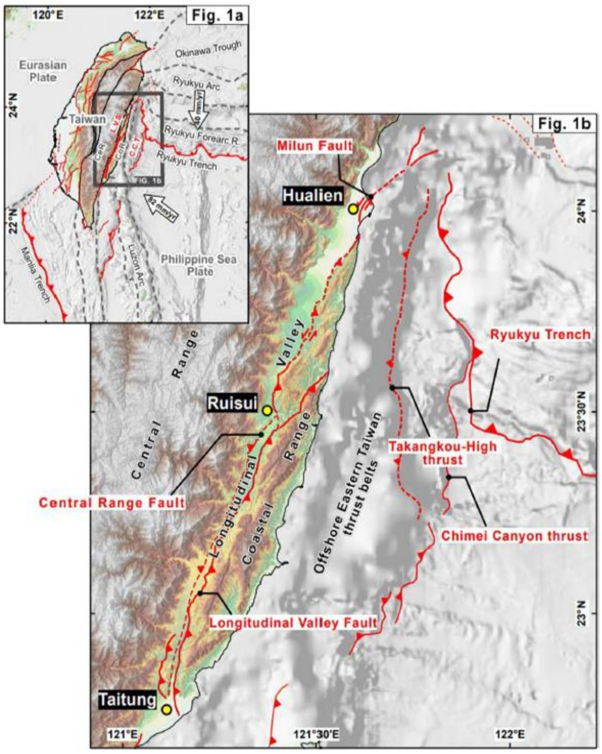


Figure 3: General tectonic map of Taiwan showing active tectonic elements near eastern Taiwan [10].

Hualien County, situated on the eastern side of Taiwan, is one of the island's most seismically active regions [9]. Figure 3 shows a tectonic map of Taiwan and the area south of Hualien City. Hualien County sits close to the boundary between the

Central Range and the Coastal Range, characterised by a series of faults of which the Longitudinal Valley Fault and Central Range Fault accommodate most of the tectonic movement [10].

In Hualien County, the NZSEE LFE reconnaissance focused on Hualien City and Taroko National Park, which were the two areas most affected by the earthquake. Hualien City is located at the northern end of the Longitudinal Valley, which runs northeast-southwest parallel to the coast, and is situated on alluvial terraces surrounding the Meilun and Jian Rivers (Figure 4). These terraces are underlain by recent alluvial gravels, deposited on outwash fans from the East Central Range. Older cemented Pleistocene conglomerate underlies the Meilun Mountain in the eastern part of the city, which has been uplifted by vertical displacement on the active Milun Fault. Marine and beach deposits are exposed along the coast [11].

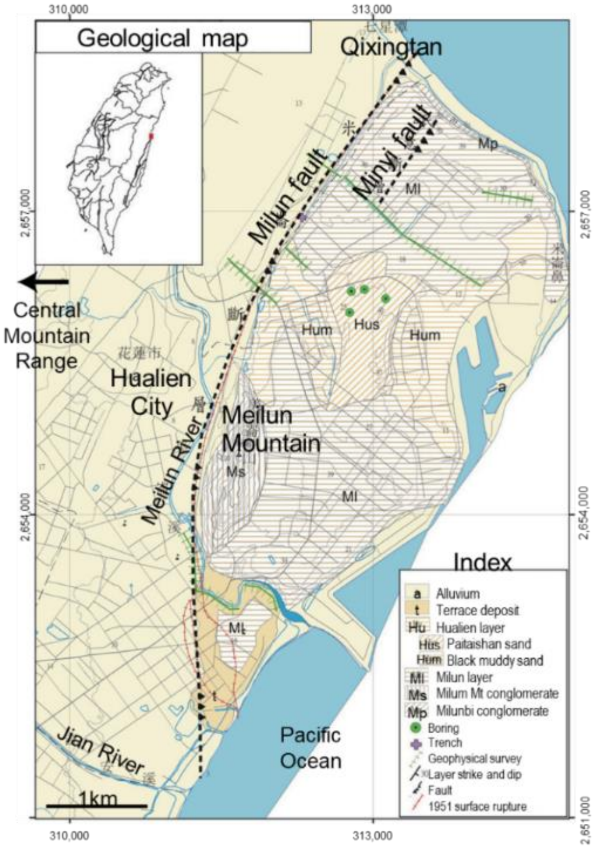


Figure 4: Geological map of Hualien City** [11]**. Its location is shown by the red dot on the inserted map of Taiwan.

Taroko National Park lies 20 km north of Hualien City on the eastern part of the East Central Range. The geology of this area consists of Permian metamorphic basement rocks, including marble, schist, and gneiss, which tend to be very strong in their unweathered state. Consequently, very steep topography has resulted from the uplift and incision of these resistant rock units, resulting in formation of the park's dramatic topography (Figure 5). This area is very significant to Hualien County as it is a popular tourist destination and also contains critical transport links to the western and northern parts of Taiwan. This area experienced the more intense recorded ground shaking in the 2024 Hualien Earthquake, and the strong bedrock formations and steep and high topography resulted in particular characteristics of landsliding and infrastructure damage that are useful to consider for application to similar settings in New Zealand.

Figure 5: Steep incised topography of Taroko Gorge.

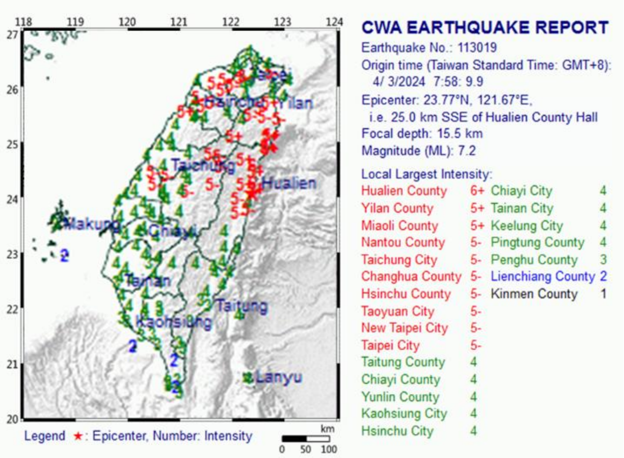
EARTHQUAKE CHARACTERISTICS

Seismicity and Ground Shaking

The mainshock occurred at 7:58 AM local time on 3 April 2024. The earthquake had a moment magnitude of M_w 7.4 and a focal depth of 15.5 km, with the epicentre located approximately 25 km southeast of Hualien City. The epicentre was proximate to the dipping plane of the Longitudinal Valley Fault, but only minimal surficial fault rupture was observed [12]. The observed overall GPS displacements before and after the event indicate movement compatible with reverse-faulting in a north-northeast direction with measured total horizontal displacements in the order of 585 mm and a maximum uplift of approximately 482 mm north of Hualien [13]. According to the earthquake report by the United States Geological Survey [14], the fault plane associated with the mainshock strikes N19°E, dips 54°, and has a rake of 73°, consistent with a reverse faulting mechanism.

The Central Weather Administration (CWA) of Taiwan reported peak ground shaking intensities using Taiwan's local intensity scale, which ranges from 1 to 7 with intermediate "+" and "–" designations for intensity 5 and 6 [15]. Hualien County experienced the highest intensity, rated at 6+ (corresponding to a peak ground velocity of 80–140 cm/s), indicative of very strong to severe shaking typically associated with damage to vulnerable structures as discussed in a later section about the earthquake impacts [16].

Figure 6 shows the geographic distribution of reported shaking intensities by the CWA across Taiwan. Severe shaking concentrated primarily along Taiwan's eastern and northern regions. Notably, strong shaking (intensity 5 or higher) extended well beyond Hualien into the greater Taipei metropolitan area and parts of central Taiwan.



CWA EARTHQUAKE REPORT

Earthquake No.: 113019

Origin time (Taiwan Standard Time: GMT+8):
4/ 3/2024 7:58: 9.9

Epicenter: 23.77°N, 121.67°E,
i.e. 25.0 km SSE of Hualien County Hall

Focal depth: 15.5 km

Magnitude (ML): 7.2

Local Largest Intensity:

Hualien County	6+	Chiayi City	4
Yilan County	5+	Tainan City	4
Miaoli County	5+	Keelung City	4
Nantou County	5-	Pingtung County	4
Taichung City	5-	Penghu County	3
Changhua County	5-	Lienchiang County	2
Hsinchu County	5-	Kinmen County	1
Taoyuan City	5-		
New Taipei City	5-		
Taipei City	5-		
Taitung County	4		
Chiayi County	4		
Yunlin County	4		
Kaohsiung City	4		
Hsinchu City	4		

Figure 6: Seismic intensity map of the M_w 7.4 mainshock (from Central Weather Administration).

Figure 7 displays the distribution of Peak Ground Accelerations (PGA) recorded during the earthquake. The highest PGA values were observed in and around Taroko National Park. Figure 8 shows the distribution of Peak Ground Velocities (PGV), with the highest PGVs recorded at 66 cm/s in Heping Township and 56 cm/s in Hualien City [17].

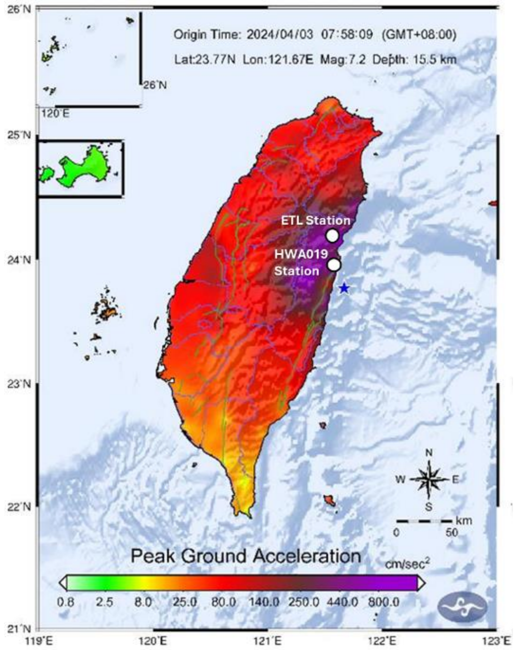


Figure 7: PGA shaking map (from Central Weather Administration).

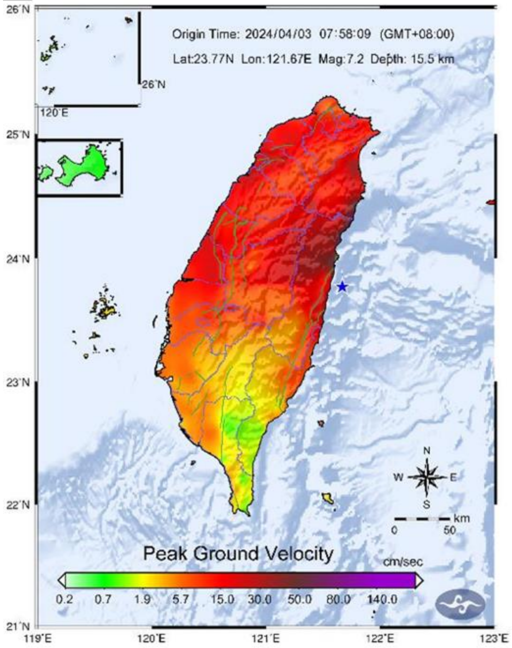
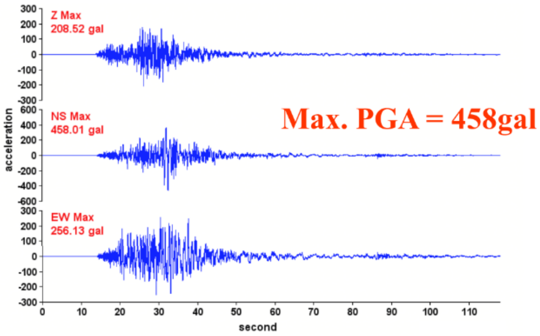
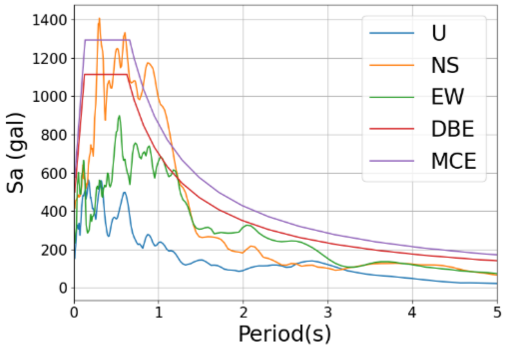


Figure 8: PGV shaking map (from Central Weather Administration).

Locations for station HWA019 near Hualien Hospital (Longitude 121.61°E, Latitude 23.98°N) and station ETL near Taroko National Park Visitor Centre (Longitude 121.62°E, Latitude 24.16°N) are approximately shown on Figure 7. Figures 9 and 10 illustrate the strong ground motion records and corresponding 5%-damped response spectra for these two stations.

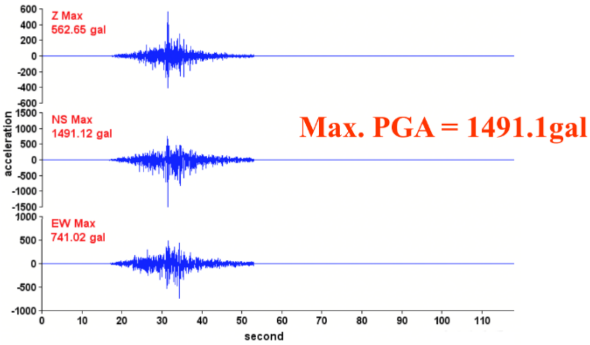


a) Acceleration record in Hualien City (Station HWA019).

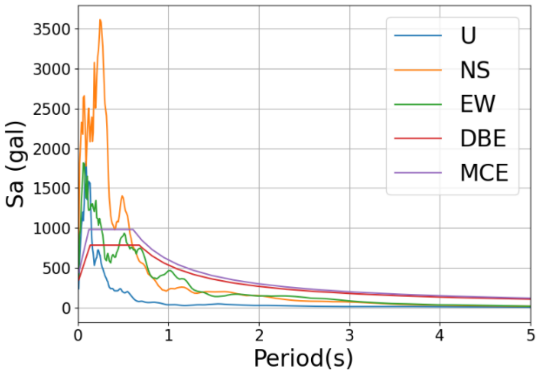


b) Response spectra (5% damping) in Hualien City (Station HWA019).

Figure 9: Acceleration record and spectra in Hualien City at station HWA019 [17]. *Note: 1 gal = 1 cm/s².*



a) Acceleration record in Taroko National Park (Station ETL).



b) Response spectra (5% damping) in Taroko National Park (Station ETL).

Figure 10: Acceleration record and spectra in Taroko National Park at station ETL [17]. *Note: 1 gal = 1 cm/s².*

The mainshock lasted for more than 30 seconds, with a maximum PGA of approximately 0.5g (458 cm/s²) recorded in Hualien City. In Taroko National Park, a peak PGA of approximately 1.5g (1491 cm/s²) was recorded.

In Figure 9b and Figure 10b, response spectra are plotted separately for each principal direction: "U" denotes vertical, "NS" north–south, and "EW" east–west directions. The "DBE" curve represents the Design Basis Earthquake spectrum (475-year return period), while the "MCE" curve represents the Maximum Credible Earthquake spectrum (2500-year return period) based on Taiwan's current seismic code [18].

The response spectra at both stations showed significantly larger accelerations in the north–south direction compared to other directions. At station HWA019 in Hualien City, the spectral demands in the NS direction exceeded both the DBE and MCE spectra for periods near 1.0 s. At station ETL in Taroko National Park, the spectrum shows a peak spectral acceleration of approximately 3.6g at a period of about 0.3 s, reflecting extremely high short-period demands consistent with near-fault effects.

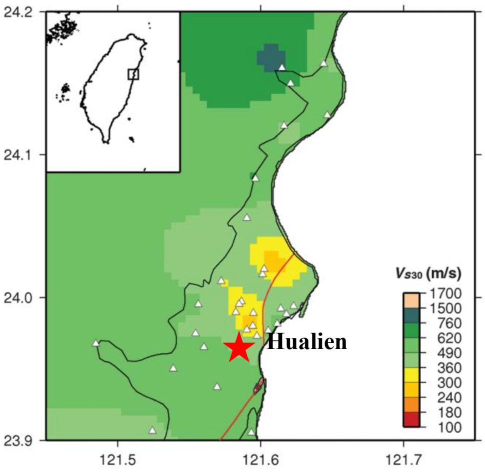
In Taipei City, the maximum shaking intensity was reported as 5− on the CWA scale (Figure 6). The recorded maximum PGA was approximately 0.25g, with spectral accelerations at 0.3 s and 1.0 s both reaching about 0.3g.

Site Response Effects and Local Effects

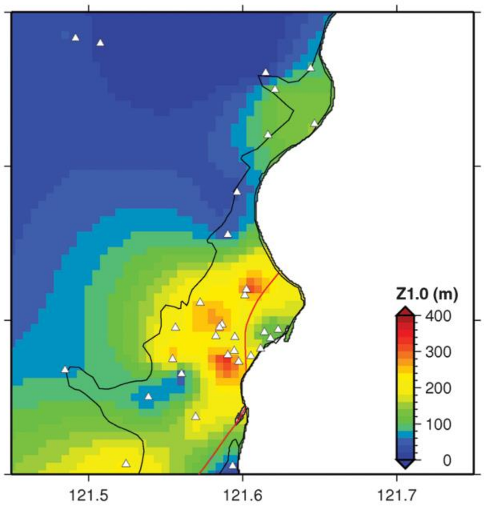
The Hualien Central Business District (CBD) is situated on alluvial deposits that infill the Hualien plain (Figure 4). The 2018 Hualien Earthquake, which had a moment magnitude M_w of 6.4, provided a detailed dataset to evaluate site effects in the Hualien region. Figures 11 and 12, adapted from Kuo et al. [19] following the 2018 event, illustrate key subsurface conditions in Hualien. Figure 11 presents a) the spatial distribution of shear wave velocity (Vs30), and b) Z1.0 (depth to Vs = 1,000 m/s). The Hualien CBD is indicated with a star in Figure 11a.

Figure 12 shows microtremor horizontal-to-vertical spectral ratio (MHVSR) results. Predominant site frequencies in the CBD range from 0.8 to 1.5 Hz, increasing westward and exceeding 1.5 Hz in mountainous areas. These site frequencies correspond to periods where high spectral accelerations were recorded during the 2024 Hualien Earthquake, particularly in the north–south direction at station HWA019 (Figure 9b).

At present, basin effects in Hualien are not explicitly incorporated into seismic design provisions beyond general soil class categorisations [18]. On the other hand, basin effects in Taipei are well documented and codified. The Taipei Basin is divided into four distinct regions; each associated with elongated corner periods in the design response spectra to account for local amplification. This distinction is evident when comparing the recorded spectra from two stations in Taipei: station TAP044 and station TAP014. The location of these stations is shown in Figure 13. The two stations are only 14 km apart and are located approximately at the same distance from the epicentre. Nevertheless, as shown in Figures 14 and 15, there is a notable difference in the spectral shape between the two locations. Station TAP014 is located near the centre of the Taipei Basin, therefore, it is in an area more susceptible to local site effects.



a) Distribution of Vs30 (shear wave velocity in m/s).



b) Distribution of Z1.0 (depth to 1000 m/s shear wave velocity).

Figure 11: Distribution of (a) Vs30 values and (b) Z1.0 depths in Hualien County [19].

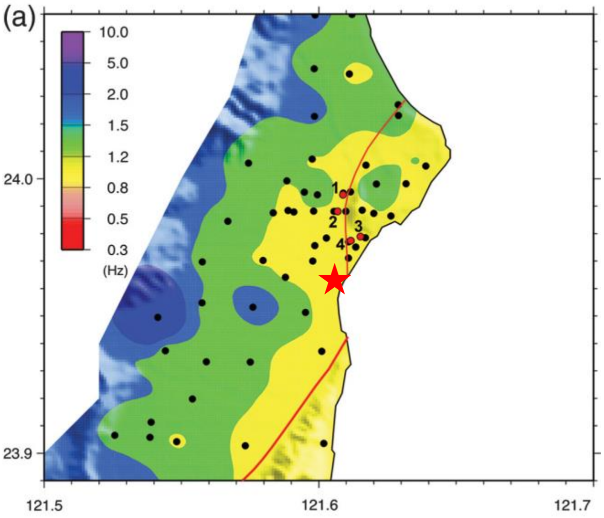


Figure 12: Microtremor horizontal-to-vertical spectral ratio (MHVSR) results for Hualien County (with the star indicating the location of Hualien City).

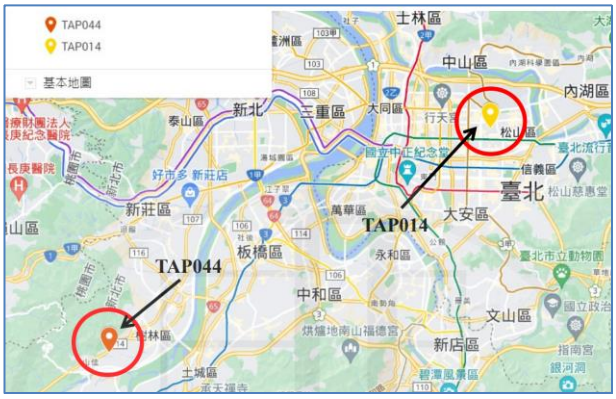


Figure 13: Location of stations TAP044 and TAP014 in Taipei City.

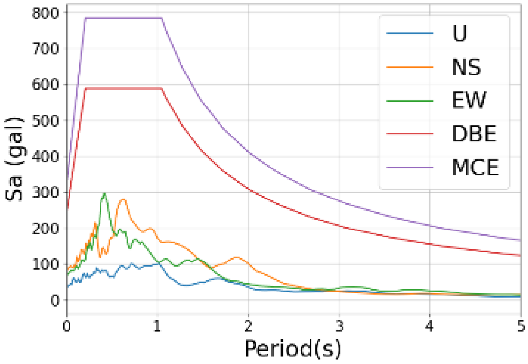


Figure 14: Response spectra (5% damping) in Taipei (Station TAP044) [17]

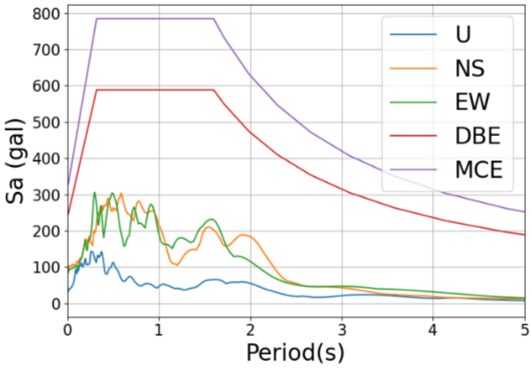


Figure 15: Response spectra (5% damping) in Taipei (Station TAP044) (TAP014) [17]*. Note: 1 gal = 1 cm/s².*

EARTHQUAKE IMPACTS

Ground Damage

Ground damage within Hualien City was generally localised and minor [11]. Although sand boils and lateral spreading occurred at the riverbanks of the Meilun River during previous earthquakes in Hualien [20], the 2024 earthquake resulted in only very limited effects. Small, isolated sand boils were observed by the NZSEE LFE team along riverbanks (Figure 16). Minor ground surface cracking was also observed adjacent to coastal water bodies.

Taiwan's Geological Survey and Mining Management Agency (GSMMA) reported minor liquefaction ejecta within the Port of Hualien and in braided riverbeds south of Hualien City. In addition, localised damage to concrete retaining walls—such as minor cracking and bulging—was observed on the western slopes of Meilun Mountain. No evidence of large-scale deformation or deep-seated slope movement was observed elsewhere around the city [13].

Figure 16: Localised sand boils along the banks of the Meilun river.

In contrast to the relatively minor ground effects observed in Hualien City, ground damage within Taroko National Park was severe. In affected areas of the East Central Range, recorded ground shaking reached horizontal accelerations of up to 1.5 g and vertical accelerations of up to 0.5 g (Figure 10), triggering widespread landslides and rockfalls across steep mountainous terrain. These slope failures blocked multiple sections of Highway 8 through Taroko Gorge, resulting in immediate closure. Similarly, landslides and debris avalanches occurred along the Coastal Range facing Highway 9, causing significant disruption to transportation corridors serving the region (Figure 17).

The direct impacts of these slope failures were primarily caused by high-energy impacts from falling rocks and debris, rather than by structural failures of retaining walls or embankments, of which only a limited number were reported. Although Taroko Gorge was closed to access during the team's visit, observations along the coastal hillslopes, combined with a review of early post-earthquake reports, indicated that most of the triggered landslides were shallow and initiated in the upper parts of the hillslopes. This failure pattern is consistent with observations from previous earthquakes in Taiwan [22] and in other steep mountainous regions worldwide [23].

Lifeline Infrastructure

Highways

Highways were severely impacted by rockfalls and landslides triggered by the mainshock and following aftershocks (Figure 18). Similar to the New Zealand experience in the 2016 Kaikōura Earthquake, the cumulative impacts of a large number of landslides along the narrow highway corridors situated at the base of very steep and high hillslopes meant that access along the highways was completely cut off. According to the Highway Bureau, rockfall protection measures such as tunnels, shelters, barriers, and fences generally performed satisfactorily. Nevertheless, some impacted areas were located outside the previously identified high-risk zones. At the time of the earthquake, many motorists travelling on Highways 8 and 9 were able to take shelter inside tunnels and rockfall galleries, which likely reduced casualties.

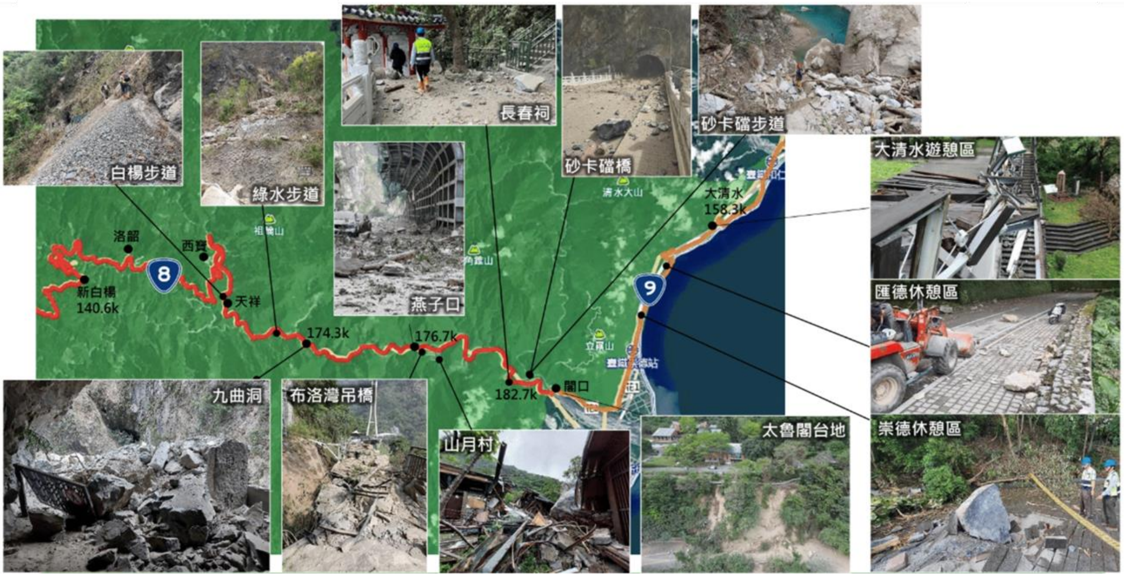


Figure 17: Landslides and rockfalls at multiple locations of Highways 8 and 9 [21].


(a) 3 April 2024 – Bridge destroyed by landslides/rock falls

(b) 6th April 2024 – Temporary bridge open for light vehicles

(c) 30 May 2024 – Upgraded temporary bridge open for heavy vehicles

Figure 18: Highway 9 – Lower Qingshui Bridge (photos from National Science and Technology Center for Disaster Reduction, NCDR).

After the mainshock, search and rescue accessed the affected areas immediately. Public access for light vehicles along Highway 9 was re-established three days after the mainshock. Access for heavy machinery (e.g. diggers) used by search and rescue operations along Highway 8 was enabled one week after the mainshock. This relatively rapid restoration of access was made by several factors: (1) effective risk management frameworks and emergency management plans addressing rockfall and landslide hazards triggered by earthquakes and heavy rainfall; (2) the Highway Bureau, contractors, and emergency services' extensive experience responding to frequent typhoons; and (3) event-specific advantages, including the availability of a disused historical bridge on Highway 9 that was quickly repurposed for light vehicle use, and the absence of extremely large-volume landslides that could have completely buried or destroyed key road infrastructure.

Despite the initial success in reopening key routes, subsequent typhoons, heavy rainfall, and aftershocks in the months following the April earthquake caused recurring and severe disruptions to the transport network. Intense rainfall events remobilised earthquake-induced landslide debris, resulting in debris flows that inundated roads and caused scour damage to bridges and culverts. These secondary ground failure hazards, commonly observed after large earthquakes in steep terrain, led to repeated closures and delays in re-establishing stable transport access into Hualien.

Port of Hualien

The most significant impact on the Port of Hualien was a widespread tectonic uplift of approximately 50 cm across much of the port area (Figure 19a). This vertical displacement disrupted docking operations, particularly for small commercial and tourist vessels such as whale-watching boats. Temporary repairs to some wharves were already underway at the time of the NZSEE reconnaissance visit, two months after the event.

Liquefaction-induced ground damage at the port was limited (Figure 19b). Local authorities reported isolated occurrences of sand boils and flotation of buried structures, though these were not directly observed during the field visit. The only ground deformation observed by the team included minor settlement, surface cracking, and lateral displacements on the order of 20–50 mm behind wharf structures and seawalls.

Figure 19: Damage to the port. a) Some of the port areas uplifted up to 50 cm. b) Sand boils and surficial signs of liquefaction.

Utilities

Overall, the earthquake's impact on utility networks across Taiwan was limited, and service was restored rapidly in most of the affected areas. Approximately 373,000 electricity outages were reported immediately after the earthquake. These disruptions were primarily due to equipment failures, transformer blackouts in Hualien and Taipei, and damage to underground power cables caused by road collapses and rockfalls in areas such as Taroko National Park. Restoration efforts progressed swiftly: the number of affected customers fell to 87,000 within 90 minutes, and by the end of the first week, only 43 outages remained, none of which affected domestic households.

Water supply systems experienced similar disruptions, with approximately 125,000 outages reported nationwide. Within one week, this number had dropped to around 14,700, the majority of which (approximately 14,500) were concentrated in Hualien.

Telecommunications infrastructure was also impacted, with a total of 80 cell tower failures recorded. Of these, 51 were repaired within the first week. At the time of the NZSEE team's visit in late May 2024, nine towers, all located in remote and inaccessible parts of Taroko Gorge, remained out of service. To maintain coverage, temporary mobile base stations were deployed in these areas.

Building Damage

Structural Performance

The building stock in Hualien City is predominantly composed of low- to mid-rise reinforced concrete (RC) structures with cast in-situ floor systems. Interior partitions are typically constructed using unreinforced masonry (URM), while exterior walls often consist of singly reinforced concrete. Neither the URM partitions nor the singly reinforced walls are generally considered part of the primary lateral load-resisting system. Instead, lateral loads are primarily resisted by moment-resisting RC frames, shear walls, or a combination of both, depending on the building's design and construction era. Buildings in the region also tend to be relatively heavy, with an estimated gravity load of approximately 10–12 kPa per floor, based on calculations conducted by the reconnaissance team. This relatively high mass is partly a consequence of construction practices developed to withstand frequent typhoons.

As of June 2024, approximately 90 buildings in Hualien had been red-tagged (deemed unsafe for occupancy) and 89 buildings had been yellow-tagged (designated for restricted use due to structural concerns) (Figure 20). Most of the building damage was concentrated in Hualien CBD. In Taipei and surrounding areas, 14 buildings were red-tagged and 19 buildings yellow-tagged [17].

Figure 20: Location of red and yellow tagged buildings in Hualien County.

The buildings inspected by the NZSEE LFE team were multi-storey cast in-situ reinforced concrete structures ranging from 5 to 15 stories, typically featuring moment frames with shear walls around lift shafts and stairwells as their primary lateral-resisting system. Older buildings constructed before the 1999 Chi-Chi Earthquake exhibited poor seismic detailing and construction deficiencies, leading to brittle failure modes. Common deficiencies observed included:

- Lap splices in plastic hinge regions (Figure 21).
- Buckling of longitudinal reinforcement because of lack of transverse reinforcement (Figure 21).
- Lack of beam-column joint transverse reinforcement (Figure 22).
- Hoop fractures probably caused by inadequate bend diameters.
- Improperly placed shear reinforcement, including hoops lumped together and longitudinal bars outside the transverse hoops (Figure 23).
- Use of 90-degree hooks with insufficient development length.
- Conduits and services running through reinforcement cages.
- Low compressive strength of concrete (<15 MPa), based on NZSEE team's measurements using a Schmidt hammer.

Figure 21: Lap-splices and lack of confinement and concrete cover at the base of column.

Figure 22: Lack of shear reinforcement in column and beam column joint.

Many multi-storey residential buildings sustained external reinforced concrete façade wall damage, leading to red- and yellow-tag classifications, even in cases where the structural integrity of the main structure remained intact (Figure 24). Nonetheless, the extent of façade damage posed a serious risk to occupants and passers-by.

Figure 23: Longitudinal reinforcement bars spliced using mechanical couplers cast outside the spiral used as transverse reinforcement.

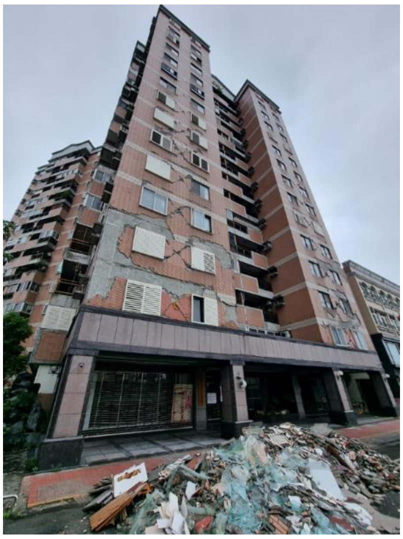


Figure 24: Damage in non-structural concrete façade panels and tiles.

Mixed-use buildings are prevalent in Taiwan, with commercial spaces occupying the ground floor and residential apartments above. This architectural arrangement results in open-plan ground floors with few structural walls, while the upper stories contain more internal partition walls. The uneven distribution of walls leads to a vertical irregularity in the structure, with a significant disparity in stiffness and strength between the ground and upper floors. As a result, during strong shaking, the ground floor is more flexible and tends to experience larger lateral displacements (drift), increasing the risk of soft-storey collapse.

Soft-storey failure was the primary collapse mechanism observed in the four buildings that collapsed on 23 April 2024. The Uranus Building, located in Hualien CBD, is an example of this type of failure (Figure 25). The Uranus Building was a 10-storey reinforced concrete mixed-use structure with commercial spaces on the ground floor and residential apartments above. It featured an irregular “corner-lot” floor plan and an elevated ground floor with a mezzanine addition. The building had few perimeter walls at the ground level, leading to brittle shear failure of the ground floor columns and a soft-storey collapse during the strong shaking.

Structural damage was also frequently observed in buildings with plan irregularities, particularly at corner buildings where asymmetric mass and stiffness distribution caused torsional responses during the earthquake (Figure 26 and Figure 27).

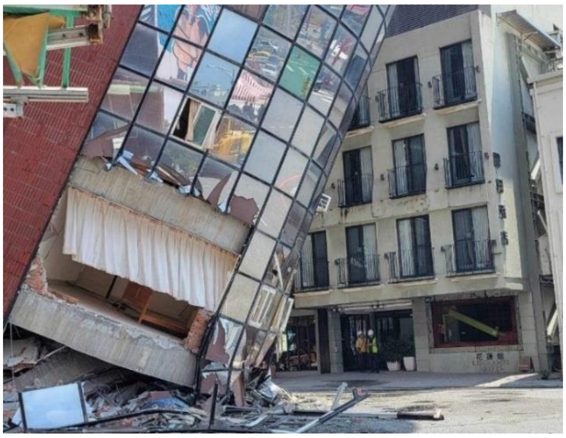


Figure 25: Collapse of the Uranus Building in the front. Retrofitted seven-storey hotel building in the background.

Figure 26: Damaged Building – shoring added after mainshock.

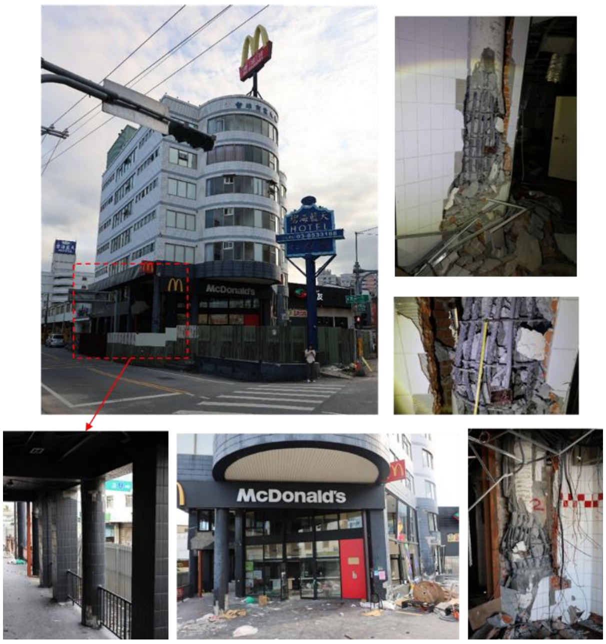


Figure 27: Damage associated with soft-storey weakness combined with torsional irregularity.

Vertical and plan irregularities are characteristic of buildings constructed prior to the adoption of modern seismic design standards following the 1999 Chi-Chi Earthquake. Updates to building codes and construction practices in Taiwan since then have improved the seismic design of new construction.

Further details on the seismic performance of buildings are presented in subsequent journal articles based on observations by the RSNZ team in collaboration with Japanese and Taiwanese peers.

Seismic Performance of Retrofitted Buildings

The NZSEE reconnaissance team inspected a number of retrofitted buildings, which had been strengthened following the 2018 Hualien Earthquake under a government's seismic retrofit programme. This programme, which includes financial and technical support for building owners, is described in the section "*Public and Private Buildings Retrofit Programmes*." The inspected retrofitted buildings performed noticeably well during the 2024 earthquake. Key observations from the field include:

- Retrofit work was simple and practical, with cost-effectiveness serving as a primary consideration.
- Foundation interventions were minimal, with retrofitting efforts focused on increasing the stiffness and strength of the superstructure.
- Diaphragm modifications were limited or absent.
- All retrofit designs were subject to peer review, typically overseen by expert panels that included representatives from NCREE. This review process formed part of the technical support in the context of the government's retrofit programme.
- Seismic monitoring systems were installed in many retrofitted buildings, enabling real-time decision-making about occupancy and providing valuable data on the performance of retrofit measures.
- Government subsidies played a decisive role in enabling and encouraging building owners to carry out seismic strengthening.
- Structural strengthening leading to less seismic drift also resulted in better performance of non-structural elements, reducing damage to interior finishes, fixtures, and services, and facilitating faster functional recovery after the event.

Figure 25 provides a clear contrast for performances of retrofitted and non-retrofitted buildings. Both buildings sustained damage during the 2018 Hualien Earthquake, yet their owners adopted markedly different post-event strategies. The owner of the collapsed building opted for repairs only, without implementing any additional structural strengthening. In contrast, the owner of the seven-storey hotel building accessed subsidies and retrofitted the building using buckling-restrained braces (BRBs) on its front and side elevations. During the 2024 Hualien Earthquake, the hotel building sustained only minor damage and resumed operations after a short period of downtime. This comparison underscores the life-safety and economic benefits of proactive seismic strengthening. The next section provides further details on Taiwan's retrofit programmes for both public and private buildings.

Socio-Economic Impact and Insurance

Following the 1999 Chi-Chi Earthquake, the Taiwanese government established the Taiwan Residential Earthquake Insurance Fund (TREIF) as a public insurance mechanism to provide financial protection for residential property owners. While TREIF is government-backed, participation is not compulsory. Over the past two decades, earthquake insurance coverage in Taiwan has steadily increased. Nevertheless, insurance penetration remains low in Hualien County, where the take-up rate is only 27%, compared to the national average of 37%.

As of 5 August 2024, the majority of claims filed with TREIF had been settled, with total payouts amounting to approximately NZ$25.06 million. Only 10 claims remained unresolved, involving two buildings awaiting a decision on demolition [24].

The earthquake has had a severe socio-economic impact on Hualien, particularly in the tourism sector, which constitutes the region's primary source of revenue. Local officials reported an 85% decline in visitor numbers to scenic attractions compared to the same period the previous year, and the Hualien Hotel Association reported hotel occupancy rates dropping to just 5% in the immediate aftermath of the earthquake [25]. The temporary closure of Taroko Gorge, one of Taiwan's most popular tourist destinations, further exacerbated the economic downturn, as approximately 90% of foreign visitors to Hualien travel specifically to visit the national park.

Tourism numbers began to recover modestly in June 2024, supported by government relief measures aimed at stimulating local economic activity. Additionally, the July–August summer school holidays in Taiwan contributed to a temporary increase in domestic tourism. However, local officials estimate that it may take five to ten years for tourism levels to return to pre-earthquake figures due to the challenges of restoring the tourism attractions of Taroko National Park. The prolonged downturn not only affects the hospitality and accommodation sector but also has broader consequences for employment and small businesses reliant on tourism-related activities throughout the region.

Non-structural Performance and Functional Recovery

Regarding the seismic performance of non-structural elements, the most commonly observed damage included:

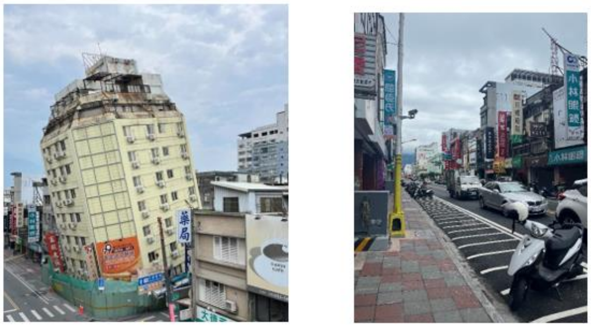
- Debris obstructing egress routes and elevator failures.
- Damage to façades and glazing, creating falling hazards.
- Ceiling damage and partial collapses of ceilings.

In general, building services remained functional after the 2024 Hualien Earthquake. Nevertheless, in some high-rise buildings, significant damage to stairwells and cracking of non-structural reinforced concrete walls raised concerns among residents, particularly where falling tiles posed hazards both inside and outside the buildings.

Although most commercial buildings remained structurally undamaged following the 2024 Hualien Earthquake, the operation of some was temporarily disrupted because of damage sustained by adjacent or nearby buildings. This impact was most noticeable in the period immediately after the mainshock on 3 April and the strong aftershocks on 23 April 2024. Hazards posed by falling exterior concrete façades, tiles, and infill masonry from neighbouring structures led to cordoned-off areas that limited access and interrupted business activities.

The collapse of the Uranus Building following the 3 April mainshock led to cordoning around the site (Figure 28a). The demolition lasted around 13 days, and the surrounding roads were reopened two days later, leading to a total disruption period of approximately 15 days (Figure 28b) [26]. Similarly, the demolition of Hotel Fouquet, which tilted after two aftershocks exceeding magnitude 6.0 on 23 April, required a road closure that lasted approximately 15 days (Figure 28c). Shops in the surrounding area remained closed during that period and were able to reopen only after the cordon was lifted (Figure 28d) [27]. Commercial activity resumed relatively quickly once the cordons were lifted.

a) Cordoned area b) after demolition and repairs



a) Cordoned area d) after demolition and repairs

Figure 28: Impact of building demolitions on commercial functionality: a) Cordoned area around the Uranus Building after the mainshock; b) re-opening of surrounding roads approximately 2 weeks later; c) Cordoned area around Hotel Fouquet after the 23 April 2024 aftershocks; d) surrounding shops reopening approximately 3 weeks later.

PUBLIC AND PRIVATE BUILDINGS RETROFIT PROGRAMMES

The 1999 Chi-Chi Earthquake exposed critical vulnerabilities in Taiwan's building stock, including in public infrastructure such as schools. Nearly half of the school buildings near the epicentre in central Taiwan collapsed or sustained severe damage [28]. As a result, the Taiwanese government launched a nationwide programme to assess and retrofit or rebuild all school buildings. The retrofit efforts were expanded to other public buildings and later to private building stock. The Taiwanese seismic retrofitting strategies have focused on affordability and practicality, aiming to address critical structural vulnerabilities with pragmatic approaches and cost-effective techniques.

Most school building collapses following the Chi-Chi Earthquake were attributed to failures of vertical structural members on the ground floor and excessive drift in the longitudinal (corridor) direction [28]. School buildings were commonly arranged in long rows with corridors along the longitudinal direction. Openings for doors and windows along these corridors prompted the use of reinforced concrete frames, often incorporating short columns formed by intermediate windowsills. This configuration made the buildings highly susceptible to shear failure (Figure 29). In contrast, the transverse direction typically featured vertically continuous masonry walls between classrooms, which contributed lateral stiffness and helped reduce drift demands.

To enable large-scale implementation of retrofitting school buildings, a streamlined assessment process was developed. The initial screening used a simplified seismic vulnerability index based on the total cross-sectional area of vertical structural elements (e.g. columns, walls, infill) relative to the building's floor area. This metric served as a proxy for the demand-to-capacity ratio and helped prioritise buildings for further evaluation and retrofit [30]. This screening, often conducted by school staff under the guidance of the National Center for Research on Earthquake Engineering (NCREE), allowed for rapid identification of vulnerable buildings, which were then flagged for further engineering evaluation.

Figure 29: School building damaged in the 1999 Chi-Chi Earthquake) [29]**.**

The seismic retrofitting strategy focused on affordability and practicality, minimising interventions on foundations and diaphragms while employing traditional, research-backed strengthening techniques to control costs and construction time [31]. In many school buildings, retrofit works concentrated on increasing stiffness and strength in the corridor direction of the building only. This was achieved through the addition of reinforced concrete shear walls or wing walls. Through this decisive retrofit programme, Taiwan strengthened more than 10,000 school buildings nationwide. Since the early 2000s, the government expanded these retrofit efforts to other critical facilities, including hospitals, fire stations, police stations, and administrative offices.

Building on the success of public-sector initiatives, the Taiwanese government has extended its seismic resilience efforts to the private building stock through the *2019 National Seismic Safety Inspection and Reinforcement Guidance Program* [32, 33]. This programme introduces three voluntary retrofit pathways aimed at encouraging and guiding the strengthening of older private buildings:

- Plan A: Address critical structural deficiencies, specifically soft-storey weaknesses.
- Plan B: Proposes the retrofit of the entire structure to achieve at least 80% compliance with the 2011 seismic design code.
- Plan C: Support the repair of earthquake-damaged buildings.

Plan A: Soft-Storey Retrofit

Plan A focuses on addressing the most critical seismic deficiencies, particularly soft-storey mechanisms commonly observed in older apartment buildings. Rather than requiring full structural compliance, this plan allows for targeted strengthening of weak ground-storey columns using cost-effective and relatively non-invasive methods, such as steel jacketing or RC wall infill. The goal is to reduce the collapse risk during earthquakes, even if the entire building does not meet modern code levels. This approach allows owners to address life-safety concerns with lower costs and minimal disruption.

Plan B: Comprehensive Seismic Strengthening

Plan B is typically undertaken alongside or after Plan A and extends retrofit efforts throughout the building height. The goal is to mitigate residual seismic vulnerabilities by strengthening the structure to at least 80% of the 2011 code spectra. The benchmark was deliberately selected to provide a clear and stable target for structural upgrade, avoiding regulatory uncertainty caused by subsequent code updates. This level of performance is considered adequate to prevent collapse and ensure the safety of residents, while still being attainable for most buildings.

A notable example of a retrofitted building under Plan B is the six-storey building shown in Figure 30. This building was retrofitted following the 2018 Hualien Earthquake. The building exhibited satisfactory performance in the 2024 Hualien Earthquake, with no observed damage.

Figure 30: Retrofitted building – strengthened after the 2018 Hualien Earthquake, with no observed damage following the 2024 Hualien Earthquake.

Plan C: Earthquake-Damage Repair

Plan C is specifically intended for buildings that have sustained earthquake damage. It provides guidelines for repair and restoration but does not require the building to be retrofitted to current seismic codes. The primary aim is to enable safe reoccupation and continued use of the structure, especially for owners who may not have the resources or capacity for a full retrofit. While not offering a long-term seismic upgrade, Plan C facilitates post-disaster recovery and minimises displacement of residents.

Financial and Technical Support under Taiwan's Private Building Retrofit Programme

Participation in the programme remains voluntary; however, financial and technical support is available to encourage uptake.

Financial Support

The central and local governments provide substantial financial assistance to encourage private building owners to retrofit their buildings. In addition, public donations after significant earthquakes contribute to recovery activities, which may include seismic strengthening. For example, after the 2018 Hualien Earthquake, the Hualien County Government allocated public donation funds to assist building owners with strengthening their buildings.

For eligible private residential buildings, different levels of subsidies are provided under Plans A, B, and C. Standard subsidy limits cover up to 45% of the total project cost, with caps determined by the building's floor area:

- For Plan A buildings with construction floor area under 500 m^2, the subsidy is capped at NT$3 million.
- For Plan A buildings with construction floor area over 500 m^2 and all Plan B buildings, the subsidy increases progressively with area, up to a maximum of NT$4.5 million.
- For Plan C, the subsidy is capped at NT$500,000 for each residential building with a single owner.

In cases where buildings are assessed as having high seismic risk, through formal seismic assessments or designated by local authorities as posing public safety concerns, larger subsidies are available. These cases may receive up to 85% of the total project cost, with the cap of NT$4.5 million. Further details on the programme, including design examples and case studies, are available through the NCREE's private building retrofit platform [33].

Technical Support

NCREE plays a key role in providing technical support for the programme. It coordinates expert teams to assist with initial screening, detailed evaluation, and retrofit design, particularly under Plan A and Plan B. To facilitate implementation, NCREE has developed simplified vulnerability screening tools and published guidance documents to help building owners and local engineers identify appropriate retrofit strategies. In addition, NCREE has carried out pilot projects and demonstration cases to showcase successful retrofit examples and promote wider uptake.

Following the 3 April 2024 Hualien Earthquake, Taiwan's government activated additional funding mechanisms to support private building retrofits. On 11 June 2024, the Government approved special regulations targeted at supporting owners of buildings with red or yellow placards, providing higher levels of subsidies [34]. NCREE was assigned to provide technical leadership, coordinate expert reviews, and conduct pilot retrofit demonstrations. To accelerate uptake, particularly in large-scale residential complexes, NCREE implemented a *pre-review mechanism* to help communities and engineers identify viable retrofit strategies before full design submission. Community engagement meetings were also held to raise awareness and promote participation. These targeted efforts highlight the importance of adaptive implementation strategies that respond to urgent post-earthquake conditions.

By June 2025, subsidies for 143 retrofit projects had been approved under the national programme, with 23 projects completed across the country. Additionally, subsidies were approved for 82 projects for retrofitting buildings with red or yellow placards following the 2024 Hualien Earthquake [35].

EMERGENCY MANAGEMENT AND RESILIENCE

Taiwan's emergency management system follows a public-private cooperation model, in which non-governmental organisations (NGOs) and private-sector entities play active roles in both emergency response and recovery. The Central Emergency Operations Centre (CEOC), based in Taipei, coordinates national-level efforts and provides support to local Emergency Operations Centres (EOCs) across the country.

During the NZSEE reconnaissance mission, the team visited the National Science and Technology Center for Disaster Reduction (NCDR), a government agency responsible for advancing interdisciplinary, evidence-based disaster risk management. NCDR plays a central role within the CEOC during national emergencies by providing real-time data, scientific assessments, and hazard forecasts to support operational decision-making. Beyond crisis response, NCDR also undertakes research initiatives focused on improving disaster preparedness, public awareness, and long-term resilience.

Key takeaways from the meeting with NCDR and CEOC include:

- **Scientific and data-driven decision-making**: Emergency operations rely heavily on real-time hazard assessments and predictive modelling. NCDR's Platform for Risk Information and Safety Management (PRISM) supports rapid situational awareness, allowing emergency managers to tailor response plans in near real-time [36].

- **Integrated agency collaboration:** PRISM plays a crucial role in inter-agency collaboration. Additionally, co-location of critical agencies—including NCDR, the National Fire Agency, and CEOC—fosters real-time communication, operational integration, and streamlined coordination during response phases.
- **Technically proficient leadership:** Senior officials within emergency management agencies often possess backgrounds in science or engineering, which facilitates informed, technically grounded decision-making during emergencies.
- **Commitment to continuous improvement:** Taiwan conducts an annual nationwide emergency exercise around 21 September, the National Disaster Preparedness Day — the anniversary of the Chi-Chi Earthquake. This multi-day drill engages over 500 responders in full-scale disaster simulations. Concurrently, public education initiatives are carried out throughout September and October to strengthen emergency preparedness at the community level.
- **International collaboration:** Taiwan actively engages in global knowledge exchange through partnerships, joint projects, and research collaborations on disaster risk management and emergency planning.
- **Unified information systems:** Inter-agency coordination is underpinned by the use of standardised formats and a shared digital language for data exchange. The quality of how information is shared across agencies is recognised as equally critical as what is shared.
- **Routine training at all levels:** Local authorities and local EOCs carry out annual or biennial training exercises [37]. Rapid Building Inspection volunteers, including architects, civil and structural engineers, must participate in training and exercises annually to remain on the official registers. The list of the inspectors much be reviewed every six months [38].

In response to the 2024 Hualien Earthquake, EOCs were activated across 15 cities and counties in Taiwan [39]. Five EOCs operated at Mode 1 (the highest level of activation), two at Mode 2 and eight at Mode 3 (the lowest level). The Hualien EOC was fully operational within minutes, and emergency shelters were established within two hours, providing rapid assistance to displaced residents and visitors. Urban Search and Rescue (USAR) operations were completed within the first 24 hours in Hualien City.

The most severe impacts occurred within Taroko National Park, where over 500 people were stranded due to blocked roads and ongoing rockfalls. A hotel in the area provided free meals and accommodation to both stranded visitors and emergency responders until a safe evacuation route was secured through the western end of the national park. Nevertheless, the challenging terrain and continued aftershock delayed rescue efforts. The search for three missing people in the park was suspended in mid-May because of adverse weather conditions and safety concerns.

In addition to search and rescue operations, Taiwan also activated its post-earthquake building evaluation system to assess structural safety across affected areas. This system relies on trained volunteers, including architects, civil engineers, and structural engineers, who undergo annual training and simulation exercises. Similar to New Zealand, Taiwan uses a placard system to categorise building safety, with red and yellow placards indicating restricted or prohibited access (Figure 31). However, Taiwan does not issue a green or white placard to explicitly confirm that a building has been cleared for unrestricted use.

Figure 31: Examples of official post-earthquake building evaluation placards, showing yellow- and red-tag classifications.

Earthquake Early Warning System

Taiwan has operated a nationwide public Earthquake Early Warning System (EEWS) since 2016. Prior to its implementation, earthquake alerts were limited to government agencies, public facilities, hospitals, and schools. The current system is managed by the Central Weather Administration (CWA), which oversees both seismic monitoring and public alert dissemination [40].

The system is supported by a dense network of over 600 seismometer stations, equipped with more than 900 instruments, allowing for nationwide real-time detection and analysis of seismic activity. Alerts are triggered based on two key parameters:

- Estimated earthquake magnitude (Local/Richter scale), and
- Estimated ground shaking intensity, using the CWA Intensity Scale, which is correlated with Peak Ground Acceleration (PGA) for intensity ≤4 and Peak Ground Velocity (PGV) for intensity ≥5 [15].

On average, the system can issue alerts within seven seconds of detecting initial seismic waves [40]. This time includes the processes of detecting the earthquake, calculating the epicentre and magnitude, estimating shaking intensity, and issuing the alert through cell broadcast and other channels.

During the April 2024 Hualien Earthquake, the EEWS was triggered when the following conditions were both met:

- Magnitude (M_L) ≥ 5, and
- CWA Intensity ≥ 4, equivalent to PGA ≥ 25 cm/s^2.

While the initial alert was received in Hualien and some other parts of the country, it was not received in Taipei, as the shaking intensity estimated by the system did not reach the threshold for issuing an alert. This led to public debates and a subsequent review of the threshold criteria. From 1 September 2024, in addition to the above threshold, alerts would also be triggered when the following conditions were both met:

- Magnitude (M_L) ≥ 6.5, and
- CWA Intensity ≥ 3, equivalent to PGA ≥ 8 cm/s^2.

This change recognised that large earthquakes could produce longer shaking and low frequency energy release, together with a lower reduction in intensity over distance.

Footage from security cameras and eyewitness accounts confirmed that the EEWS provided critical seconds of lead time, allowing individuals to take life-saving protective actions, such as Drop, Cover, and Hold. The combination of technological capability and high levels of public preparedness is widely considered to have contributed to the relatively low number of casualties in the earthquake.

Debris Flow Land Use Plan and Warning System

Taiwan's mountainous terrain and frequent exposure to natural hazards result in heightened vulnerability to secondary disasters such as landslides and debris flows. These risks are most commonly triggered by typhoons and intense rainfall, but large earthquakes increase susceptibility by destabilising slopes, creating loose debris, and compromising existing protective infrastructure. The 2024 Hualien earthquake raised concerns about post-seismic debris flows, particularly in areas such as Taroko National Park, where slopes were already vulnerable. Recognising the compounded risk from sequential hazards, Taiwan has developed an integrated approach to manage debris flow hazards both in normal conditions and in the aftermath of earthquakes.

Since the 1990s, a comprehensive legal and institutional framework has been established to manage these hazards [41]. The Agency of Rural Development and Soil and Water Conservation (ARDSWC) is the national authority responsible for land-use planning, hazard mitigation, and disaster response in hillslope areas. Taiwan's strategy is built upon two core principles:

- **Avoidance:** Enforcing land-use planning regulations to restrict new development in high-risk debris flow zones.
- **Emergency readiness:** Improving the safety of existing communities in susceptible areas through early warning systems, preparedness and response education, and emergency evacuation protocols.

Debris flow hazard mapping and monitoring began in the mid-1990s, leading to the creation of a national database of susceptible catchments. Since 2005, Taiwan has operated a debris flow early warning system that incorporates rainfall thresholds to trigger alerts [41]. The early warning and response workflow includes:

1. The CWA provides real-time rainfall forecasts to ARDSWC.
2. If predicted rainfall exceeds predefined thresholds for at-risk catchments, ARDSWC issues warnings to relevant local authorities.
3. Local authorities are responsible for initiating evacuations and operating emergency shelters.
4. Trained local personnel, including officials and volunteers, assist with evacuations in remote indigenous communities and other vulnerable areas.

Following the M_w 7.4 mainshock on 3 April 2024 and subsequent aftershocks, authorities conducted rapid landslide mapping using satellite imagery and aerial reconnaissance. These efforts led to significant updates to Taiwan's debris flow risk management systems [42]:

- Forty-nine new debris flow risk areas were identified (as of June 2024) and integrated into the national early warning database.
- Evacuation plans were developed for all newly identified high-risk zones.
- Rainfall thresholds were lowered in 93 existing catchments where shaking intensity was recorded at CWA Intensity 5 or larger, to account for increased slope instability and the higher probability of debris mobilisation under reduced rainfall conditions.

These updates reflect Taiwan's proactive commitment to dynamic hazard management and adaptive risk communication. The system not only increases preparedness in at-risk areas but also demonstrates a robust, science-informed framework for managing cascading geohazards in mountainous terrain. Figure 32 illustrates a mapped debris flow risk zone in one of the newly assessed areas following the 2024 Hualien Earthquake. The red polygon delineates the potential flow-affected area, while the blue line indicates the likely debris flow path.

Figure 32: Debris flow risk assessment following 2024 Hualien Earthquake – site U113-6 [42]**.**

Digital Tools

Taiwan has long been a global hub for technological innovation, supported by its world-leading semiconductor and software development industries. This foundation of technical expertise has been effectively applied to disaster resilience, with advanced digital tools playing a pivotal role in pre-disaster preparedness, rapid assessments during emergency response, and recovery planning for the 2024 Hualien Earthquake. During meetings with NCREE, NCDR, and the Hualien County Government, the NZSEE reconnaissance team observed the widespread use of Digital Twin technologies, real-time analytics, and simulation platforms for impact assessment, emergency operations, and policy planning.

The Taiwan Earthquake Loss Estimation System (TELES) has been under continuous development by NCREE since 1998 [43]. It simulates earthquake scenarios and estimates building damage in near real time and helps national and local authorities with risk mitigation and emergency preparedness. Additionally, it supports Taiwan Residential Earthquake Insurance Fund through the Taiwan Earthquake Risk Assessment (TERA) modules, which allow premium modelling based on worst-case scenarios.

The Taiwan Earthquake Impact Research and Information Application (TERIA), developed by NCDR, operates on a GIS platform with a grid resolution of 500m×500m. TERIA is primarily intended for pre-disaster hazard potential assessment and planning. It estimates earthquake casualties and impacts on buildings and infrastructure during the planning phase, providing intelligence to inform and assist with the development of response resource deployment strategies [44]. While TERIA itself is not deployed for real-time post-event assessment, its underlying data infrastructure – such as environmental and infrastructure datasets – is leveraged by other rapid loss estimation systems. During emergencies, the outputs from these rapid assessment systems, drawing upon comprehensive data similar to TERA's, feed into the Platform for Risk Information and Safety Management (PRISM), facilitating timely and effective decision-making at the Central Emergency Operations Centre.

During the 2024 Hualien Earthquake, TELES and other rapid loss estimation tools, leveraging robust data infrastructures, were successfully deployed. Their initial loss estimates showed close alignment with actual recorded impacts, demonstrating their reliability and predictive capability.

The Hualien County Geographic Information Integration Application Platform [45] has been developed by the Hualien County Government since 2018. It integrates interdisciplinary multi-dimensional spatial data from various central and local government sources, including planning and geological information, geotechnical and liquefaction hazard maps, fault location and avoidance zones, building consent records and structural drawings, seismic assessments, and utility networks. Post-earthquake applications of the 3D Digital Twin included assessing collapsed buildings to plan demolition operations and cordoned zones, evaluating structural risks to neighbouring properties and critical infrastructure (Figure 33), optimising crane and demolition equipment positioning by analysing operation footprints.

These platforms, comprising tools for pre-event simulation and/or post-event impact assessment, allow emergency managers to simulate earthquake, landslide, and typhoon impacts with unprecedented spatial and temporal resolution. As a result, authorities are better equipped to estimate potential damage and losses immediately after an event, visualise infrastructure risks and logistics in 3D, and allocate response resources more efficiently and proactively. Further discussions about the developments of PRISM and the Hualien County Geographic Information Integration Application Platform, and their applications in the response to the 2024 Hualien Earthquake, are presented in a subsequent journal article.

Open data sharing and cross-agency integration—including cooperation between central and local authorities, academic institutions, and private-sector technology providers—have proven essential for the success and continuous advancement of these systems. Taiwan's experience demonstrates that early investment in smart modelling tools and shared digital infrastructure is critical to improving emergency preparedness, accelerating response, and strengthening community resilience.

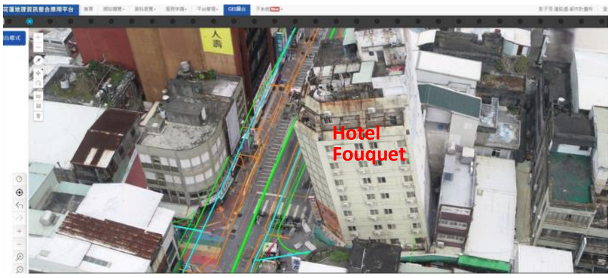


Figure 33: The use of Digital Twin for emergency response showing the severely damaged Hotel Fouquet in relation to the underground lifelines (electricity – orange lines, telecommunications – green lines, water – blue lines) immediately following the two large aftershocks on 23 April 2024 [45].

SUMMARY OBSERVATIONS

National-Level Commitment to Seismic Resilience

Since the 1999 Chi-Chi Earthquake, Taiwan has prioritised seismic risk reduction across all levels of governance. Sustained investments have led to significant advancements in:

- Regulatory frameworks, including regular updates to seismic design codes and construction standards.
- Rapid building safety evaluation protocols, supported by continuous education and annual drills for assessors.
- Urban Search and Rescue (USAR) capabilities, with regular training and institutionalised knowledge transfer.
- Integration of emergency management into government functions, supported by annual inter-agency drills and multi-sectoral exercises.
- Expansion of earthquake insurance coverage through the Taiwan Residential Earthquake Insurance Fund (TREIF).
- Creation of science-driven institutions such as the National Science and Technology Center for Disaster Reduction (NCDR) to bridge research and emergency response.
- Adoption of advanced technologies, including artificial intelligence (AI) and digital twins, to support disaster mitigation, response, and recovery efforts.

Effectiveness of Seismic Retrofit Programmes

Recent earthquakes have shown the effectiveness of seismic retrofitting in reducing building damage and collapse. Notable features of Taiwan's approach include:

- Targeted seismic strengthening of vulnerable buildings, prioritising the most critical structural deficiencies, such as soft-storey mechanisms, to maximise risk reduction. These types of targeted retrofits have shown satisfactory performance, even when other elements of the building (e.g. foundations, diaphragms, or non-structural elements) were not upgraded.
- Affordability barriers are addressed through public subsidies and the development of standardised, cost-effective retrofit techniques.
- Nationwide programmes for schools and public buildings have significantly improved safety outcomes.
- Public oversight mechanisms administered by NCREE ensure technical quality and compliance for subsidised retrofit projects.
- Legal instruments such as liability waivers under Plan A (soft-storey retrofit) help engage engineers by limiting liability to the retrofitted components.

Integration of Technology and Inter-Agency Coordination

Taiwan has built a robust technological and institutional ecosystem for emergency management:

- Geographic Information System (GIS) platforms support building data management, risk mapping, and emergency operations.
- Clear legal frameworks define the responsibilities of each agency and enable timely data sharing.
- Real-time information platforms facilitate seamless coordination between national and local authorities.
- A well-developed national Earthquake Early Warning System (EEWS).
- The use of digital twins is rapidly expanding, providing visual and data-rich tools to guide decision-making during planning, response and recovery.

Comprehensive and Ongoing Emergency Preparedness

Emergency management in Taiwan is not an ad hoc activity but an integrated and continually refined system. Key features include:

- Extensive multi-hazard monitoring systems for earthquakes, typhoons, landslides, and debris flows, enabling anticipatory action.
- Land-use regulations in high-risk areas such as debris flow

catchments, fault rupture zones, and liquefiable soils, to avoid future exposure.

- Institutionalised national and local drills, including a large-scale multi-day exercise each September commemorating the 1999 Chi-Chi Earthquake.
- Use of real hazard events to improve procedures and test institutional readiness.
- Active involvement of non-government organisations, private companies, and civil society in disaster response and recovery.
- Rapid response and post-earthquake recovery, with minimal disruption observed in cities.
- Recognition of secondary hazards, such as rainfall-induced debris flows in earthquake-affected regions, as critical long-term challenges for infrastructure.

CONCLUSIONS

Taiwan's high exposure to natural hazards has fostered a proactive, multi-layered approach to risk reduction, readiness, response, and recovery. The reconnaissance mission provided a valuable opportunity to observe first-hand how institutional coordination, technological advancements, and community engagement have converged to create a robust system for managing seismic risk.

A defining feature of Taiwan's approach is the strength of its public institutions and their clearly defined mandates. For instance, NCDR illustrates how science and technology-based agencies can bridge research, policy, and emergency operations. Its integration of real-time data across government platforms, and use of GIS and 3D technologies for hazard mapping and risk monitoring, demonstrate the benefits of strong data infrastructure and advanced technologies for effective decision support.

Seismic retrofitting is one of the most effective measures to reduce earthquake risk in Taiwan. Two decades of investment in strengthening school and other public buildings have significantly improved building performance in recent earthquakes. More recently, the extension of these efforts to private buildings has shown that targeted retrofits focusing on critical structural deficiencies, such as soft-storey mechanisms, are cost-effective measures for reducing the likelihood of building damage. NCREE plays a crucial role in coordinating the technical components of seismic retrofitting. Its involvement in peer review, design support, and community engagement has enabled the implementation of retrofit strategies that are both technically sound and socially feasible. This role becomes especially critical in post-earthquake contexts, where urgency and public confidence are essential.

The ongoing revision of New Zealand's earthquake-prone building system appears to be moving toward a more risk-based approach, similar to Taiwan's focus on addressing the most critical structural deficiencies. While New Zealand may not have a single predominant deficiency such as soft-storey mechanisms, other high-risk vulnerabilities exist within its building stock, including structures with insufficient stiffness and strength or buildings with precast flooring systems that are susceptible to collapse at relatively low drifts. Prioritising these deficiencies for targeted interventions could deliver significant life-safety benefits and more efficient use of limited resources.

Taiwan's commitment to regular national and local emergency exercises, including a multi-day nationwide drill each September, helps maintain operational readiness. These are complemented by a system of trained volunteers and technical professionals who conduct post-earthquake building evaluations, demonstrating the value of ongoing capacity-building.

Taiwan's experience underscores the importance of strategic investment in early warning systems and integrated geospatial information platforms that enhance information sharing, coordination, and rapid decision-making during emergencies. These systems have been instrumental in Taiwan's ability to respond effectively to large-scale disasters. The continuous improvements across government and non-government sectors in Taiwan offer several lessons that may inform policy and practice in New Zealand as well as other earthquake-prone jurisdictions.

ACKNOWLEDGMENTS

The writers would like to express their sincere gratitude to the many individuals and organisations in Taiwan who generously gave their time, shared their knowledge, and facilitated access to key sites during the NZSEE reconnaissance mission.

Special thanks to the Hualien County Government, NCREE, and NCDR, for hosting the team, sharing their invaluable experiences, and facilitating discussions with other agencies and building owners. Special appreciation is extended to Founding Director of NCDR Liang-Chuan Chen and Distinguished Professor Emeritus Feng-Tyan Lin, whose experiences and support were instrumental to the success of our visit. We also acknowledge the generous support of the following agencies and organisations:

- Hualien Emergency Operations Centre and Hualien Fire Department
- Hualien Architects Association
- Taroko National Park Headquarters, National Park Service, Ministry of the Interior
- Office of Disaster Management, Executive Yuan
- Taiwan Residential Earthquake Insurance Fund (TREIF)
- Highway Bureau, Ministry of Transportation and Communications
- Central Weather Administration (CWA), Ministry of Transportation and Communications
- Agency of Rural Development and Soil and Water Conservation (ARDSWC), Ministry of Agriculture
- Hualien Tzu Chi Hospital and Foundation
- All the building owners, residents, bodies corporate, and professionals who assisted us and provided valuable information during our visits.

The NZSEE team would also like to acknowledge the collaboration and joint building inspections conducted alongside other research and reconnaissance teams. These included: New Zealand researchers funded by RSNZ, Japanese experts from government and academic institutions, and international members of the Earthquake Engineering Research Institute (EERI) from the United States and Indonesia.

Special thanks are extended to Professor Gregory MacRae, leader of the NZSEE LFE programme, and Pathmanathan Brabhaharan (Brabha), President of NZSEE, for their invaluable support throughout the planning and execution of the mission.

Lastly, the writers gratefully acknowledge the Natural Hazards Commission Toka Tū Ake for its continued funding of the LFE programme, which has enabled collaborative international reconnaissance for over 25 years.

REFERENCES

1 Brunsdon DR, Davey RA, Graham CJ, Sidwell GK, Villamor P, White RH and Zhao JX (2000). “The Chi-Chi, Taiwan earthquake of 21 September 1999”. *Bulletin of New Zealand Society for Earthquake Engineering,* **33**(2): 105–67. https://doi.org/10.5459/bnzsee.33.2.105-167

2 Henry RS, Lee BY, McGuigan D, Finnegan J and Ashby G (2017). “The 2016 Meinong Taiwan earthquake”. *Bulletin of New Zealand Society for Earthquake Engineering*, **50**(3): 436–68. https://doi.org/10.5459/bnzsee.50.3.436-468

3 Yang Z and Chen H (2025). “The rupture process of the Hualien M7.3 sequence on April 3, 2024”. *Earthquake Research Advances*, **5**:100333. https://journal.hep.com.cn/era/EN/PDF/10.1016/j.eqrea.2024.100333

4 New Taipei City Government. *“Eleven sections of the MRT Circular Line were severely damaged, and restoration work is estimated to take more than a year.”* Website of the New Taipei City Government, published 24 April 2024. https://www.ntpc.gov.tw/ch/home.jsp?id=e8ca970cde5c00e1&dataserno=d7e2181a099b0d790b20f88d208e64eb

5 New Taipei City Government. *“The New Taipei Circular Line is ready!”* Website of the New Taipei City Government, published 12 December 2024. https://www.ntpc.gov.tw/ch/home.jsp?id=28&dataserno=202412120015

6 Highway Bureau (2025). *“2024 Annual Report of the Highway Bureau, MOTC”*. ISBN 978-986-531-677-8. Highway Bureau, Ministry of Transportation and Communications, Taipei, Taiwan, 131pp. https://ws.thb.gov.tw/Download.ashx?u=LzAwMS9VcGxvYWQvNDM3L3JlbGZpbGUvMTIyODYvMjY4Lzg0NzA4NzQyLWViMjYtNDcyMS1iMjU2LTdmYmUwMzZmMmE1ZS5wZGY%3D&n=5Lqk6YCa6YOo5YWs6Lev5bGAMTEz5bm05bm05aCxLnBkZg%3D%3D&icon=.pdf

7 Lai LH, Dorsey RJ, Horng CS, Chi WR, Shea KS and Yen JY (2022). “Extremely rapid up-and-down motions of island arc crust during arc-continent collision”. *Communications Earth & Environment*, **3**: 1–10. https://doi.org/10.1038/s43247-022-00429-2

8 Altamimi Z, Métivier L and Collilieux X (2012). “ITRF2008 plate motion model*”. Journal of Geophysical Research: Solid Earth*, **117**(B7): 1-14. https://doi.org/10.1029/2011JB008930

9 Shyu JB, Sieh K, Chen YG and Liu CS (2005). “Neotectonic architecture of Taiwan and its implications for future large earthquakes”. *Journal of Geophysical Research: Solid Earth,* **110**(B8): 1-33. https://doi.org/10.1029/2004jb003251

10 Huang HH and Wang Y (2022). “Seismogenic structure beneath the northern Longitudinal Valley revealed by the 2018–2021 Hualien earthquake sequences and 3-D velocity model”. *Terrestrial, Atmospheric and Oceanic Science*, **33**. https://doi.org/10.1007/s44195-022-00017-z

11 Yamada M, Cho I, Kuo CH, Lin CM, Miyakoshi K, Guo Y, Hayashida T, Matsumoto Y, Mori J, Yen YT and Kuo KC (2020). “Shallow subsurface structure in the Hualien basin and relevance to the damage pattern and fault rupture during the 2018 Hualien earthquake*”. Bulletin of the Seismological Society of America*, **110**(6): 2939–2952. https://doi.org/10.1785/0120200063

12 National Dong Hua University (2024). *0403 Hualien Earthquake Response Record.* Hualien, Taiwan. https://storymaps.arcgis.com/collections/a50173ac64b34576938f8ae61148199a (Accessed 17 April 2025)

13 Geological Survey and Mining Management Centre (2024). *“0403 Hualien Earthquake Geological Survey Report”.* Ministry of Economic Affairs, Taipei, Taiwan. https://fault.gsmma.gov.tw/ckfinder/connector?command=Proxy&type=Files&currentFolder=/&fileName=20240403%E8%8A%B1%EF%A6%99%E5%9C%B0%E9%9C%87%E5%9C%B0%E8%B3%AA%E8%AA%BF%E6%9F%A5%E5%A0%B1%E5%91%8A.pdf&c=1&p=2c0c1680fabf43bb9c33aa96954a0cc2&l=4

14 United States Geological Survey (2024). *M 7.4 – 15 km S of Hualien City, Taiwan – Earthquake Event Page (M 7.4, 2024-04-02 23:58:12 UTC; depth 40 km)*. https://earthquake.usgs.gov/earthquakes/eventpage/us7000m9g4/dyfi/intensity (Accessed 30 September 2025)

15 Central Weather Administration (amended in 2023). “Guidelines for the Release of Reports on Felt Earthquakes”. Central Weather Administration, Taipei, Taiwan. *https://scweb.cwa.gov.tw/Uploads/Topic/%E4%BA%A4%E9%80%9A%E9%83%A8%E4%B8%AD%E5%A4%AE%E6%B0%A3%E8%B1%A1%E7%BD%B2%E6%9C%89%E6%84%9F%E5%9C%B0%E9%9C%87%E5%A0%B1%E5%91%8A%E7%99%BC%E5%B8%83%E4%BD%9C%E6%A5%AD%E8%A6%81%E9%BB%9E.pdf* (Accessed 20 August 2024)

16 Central Weather Administration Seismological Center (2024). *“CWA Earthquake Report No. 113019 – Hualien Earthquake on 3 April 2024”.* Central Weather Administration, Taipei, Taiwan. *https://scweb.cwa.gov.tw/en-US/earthquake/Imgs/EE2024040307580971019*

17 Chou CC, Wu CL, Chai JF and Yao GC (2024). *“Summary Report of Hualien earthquake in Taiwan on April 3, 2024 (v2.0)”.* National Center for Research on Earthquake Engineering (NCREE), Taipei, Taiwan. https://www.ncree.niar.org.tw/assets/file/20240403_Hualien_TW_EQ_V2.0en.pdf

18 National Land Management Agency (2011). *“Seismic Design Code and Commentary for Buildings”.* Ministry of the Interior, Taipei, Taiwan.

19 Kuo CH, Huang JY, Lin CM, Hsu TY, Chao SH and Wen KL (2019). “Strong ground motion and pulse-like velocity observations in the near-fault region of the 2018 Mw 6.4 Hualien, Taiwan, earthquake*”. Seismological Research Letters*, **90**(1):40-50. https://doi.org/10.1785/0220180195

20 Ko YY, Hsu SY, Yang HC, Lu CC, Hwang YW, Liu CH and Hwang JH (2019). “Soil liquefaction and ground settlements in 6 February 2018 Hualien, Taiwan, Earthquake*.” Seismological Research Letters*, **90**(1): 51-59. https://doi.org/10.1785/0220180196

21 Taroko National Park Headquarters (2024). *“0403 Hualien Earthquake Disaster Damage Report.”* Ministry of the Interior, Hualien, Taiwan.

22 Khazai B and Sitar N (2004). “Evaluation of factors controlling earthquake-induced landslides caused by Chi-Chi earthquake and comparison with the Northridge and Loma Prieta events*.” Engineering Geology*, **71**(1-2): 79–95. https://doi.org/10.1016/s0013-7952(03)00127-3

23 Meunier P, Hovius N and Haines JA (2008). “Topographic site effects and the location of earthquake induced landslides”. *Earth and Planetary Science Letters*, **275**(3-4): 221-232. https://doi.org/10.1016/j.epsl.2008.07.020

24 Taiwan Residential Earthquake Insurance Fund (2024). *“0403 Hualien Shoufeng Earthquake Claim Information Update (as of August 5, 2024)”.* Taiwan Residential Earthquake Insurance Fund (TREIF), Taipei, Taiwan. https://www.treif.org.tw/en/xmdoc/cont?xsmsid=0L314513099842647268&sid=0O208637930802773937 (Accessed 17 April 2025)

25 Broomby JC (2024). *"Everyone is too scared to come: Taiwan's earthquake deals a blow to top tourism hotspot"*. CNBC Travel, published 3 June 2024. https://www.cnbc.com/2024/06/04/taiwans-april-earthquake-deals-another-blow-to-its-tourism-industry.html

26 Strong M. *"Tilting buildings demolished in Taiwan quake aftermath"*. Taiwan News, published 17 April 2024. https://taiwannews.com.tw/news/5667790

27 Chang C (2024). *"Hualien Earthquake caused the Fau Kai Hotel to tilt and threaten collapse."* Central News Agency (CNA), published 23 April 2024 . https://www.cna.com.tw/news/ahel/202404230043.aspx

28 Tsai KC and Hwang SJ (2008). "Seismic retrofit program for Taiwan school buildings after 1999 Chi-Chi earthquake". *14th World Conference on Earthquake Engineering*, October 12-17, Beijing, China. https://wcee.nicee.org/wcee/article/14_C005.pdf

29 Hwang SJ (2021). *"Seismic Retrofitting Program of School Buildings in Taiwan"*, National Center for Research on Earthquake Engineering (NCREE), Taipei, Taiwan. https://www.resilienciasismica.unam.mx/docs/Presentaciones/1-Hwang-Feb24.pdf

30 Hwang SJ, Hsiao FP, Chung LL, Yeh YK, Jean WY, Shen WC, Chiou TC, Chow TK, Yang YS and Chao YF (2010). "Strategy for seismic upgrading of public school". *Australian Earthquake Engineering Society 2010 Conference*, 2010, Perth, Australia, 10 pp. https://aees.org.au/wp-content/uploads/2013/11/23-Hwang.pdf

31 Hwang SJ, Chung LL, Chiou TC and Chen PC (2020). "Current seismic retrofitting programs of school and residential buildings in Taiwan." *17th World Conference on Earthquake Engineering*, September 13-18, Sendai, Japan. 12pp. https://wcee.nicee.org/wcee/article/17WCEE/8g-0002.pdf

32 Ministry of the Interior. *"Nationwide seismic assessment and retrofit program"*. Executive Yuan Website, published 27 May 2019, Taipei, Taiwan. https://english.ey.gov.tw/News3/9E5540D592A5FECD/461891fc-dd6d-48d4-ab94-26ba3ea0f8cb

33 National Centre for Research on Earthquake Engineering (NCREE). *Introduction of seismic weak-storey retrofit.* Taipei, Taiwan. https://privatebuilding.ncree.org.tw/reinforcement-detail/ (Accessed 12 April 2025)

34 Ministry of the Interior (2025). *"Regulations on subsidies for seismic reinforcement of weak residential structures marked as dangerous following the 3 April 2024 earthquake"*. Taipei, Taiwan. https://www.nlma.gov.tw/ch/legislation/law&regunu/7043

35 National Centre for Research on Earthquake Engineering (2025). *"Private Buildings Retrofit Programme Newsletter"*. Issue 15, published June 2025, Taipei, Taiwan. https://privatebuilding.ncree.org.tw/wp-content/uploads/2025/06/%E7%AC%AC15%E6%9C%9F%E9%9B%BB%E5%AD%90%E5%A0%B1-1.pdf

36 National Science and Technology Center for Disaster Reduction (NCDR). *Platform for Risk Information and Safety Management (PRISM) Portal.* https://eocdss.ncdr.nat.gov.tw (Accessed 18 June 2025)

37 Ministry of Interior (2025). *"2025 Disaster Prevention and Rescue Drill Training Order"*. Taipei, Taiwan. https://cdprc.ey.gov.tw/File/A8D49E46A7C4E0DD?A=C

38 Ministry of the Interior (2009). *"Regulations for Emergency Evaluatoin of Post-Disaster Dangerous Buildings"*. Taipei, Taiwan. https://law.moj.gov.tw/LawClass/LawAll.aspx?pcode=D0070177

39 National Fire Agency (2024). *"0403 Hualien Earthquake Post-Disaster Recovery and Reconstruction Work – Search and Rescue Operations and Emergency Response"*. National Fire Agency, Ministry of the Interior, Taipei, Taiwan.

40 Central Weather Administration (2024). *"Real-time Performance of CWA EEW System for the 2024 Hualien Earthquake"*. Central Weather Administration, Taipei, Taiwan.

41 Chen SC and Wu CY (2014). "Debris flow disaster prevention and mitigation of non-structural strategies in Taiwan". *Journal of Mountain Science,* **11**: 308-322. https://doi.org/10.1007/s11629-014-2987-3.

42 Agency of Rural Development and Soil and Water Conservation (ARDSWC) (2024). *"0403 Hualien Earthquake Response – Experience Exchange and Sharing"*. ARDSWC, Ministry of Agriculture, Taiwan.

43 Yeh CH, Loh CH and Tsai KC (2006). "Overview of Taiwan earthquake loss estimation system". *Natural Hazards*, **37**: 23-37. https://doi.org/10.1007/s11069-005-4654-z

44 Wu BR and Ke SS (2017). "Application of a Mesh-based Earthquake Impact Assessment Tool for Water Supply System on Policy Support". *10th JWWA/WRF/CTWWA Water System Seismic Conference*, Taiwan. https://www.ncree.org/conference/UserData/0/I20171018A/Papers/26-23%20Ke.pdf

45 Hualien County Government. *Hualien County Geographic Information Integration Application Platform.* https://map.hl.gov.tw/hlgis/default.aspx (Accessed 18 June 2025)