NCREE Special Newsletter

Summary of the March 23, 2022 Hualien-Taitung Offshore Earthquake Event

1 - Introduction

A local magnitude (M_L) 6.7 event occurred at 01:41 on March 23 (local time) this year (2022). The Central Weather Bureau (CWB) of Taiwan announced the real-time solution for the epicenter location: 23.40°N and 121.61°E with a focal depth of 25.7 km (Fig. 1). Seismic intensities of 6 were observed in Changbin Township (長濱鄉), Taitung County, with disastrous effects, including damage to the Yuxing (玉興) Bridge. The Taiwan Early Seismic Loss Estimation module of the Taiwan Earthquake Loss Estimation System (TELES) developed by the National Center for Research on Earthquake Engineering (NCREE) can perform seismic loss estimations and send text messages (Fig. 2) within two minutes after receiving the earthquake report from the CWB via email. The estimation results show that no casualties occurred as a result of this seismic event, but 64 villages needed alerting to be vigilant.

On March 23, the NCREE began to conduct disaster investigations in Hualien County and Taitung County. One bridge, three school buildings, two fire department buildings, three medical facilities, two religious buildings, one “other public” building, four residential buildings, and two non-building structures were investigated in this on-site disaster investigation.

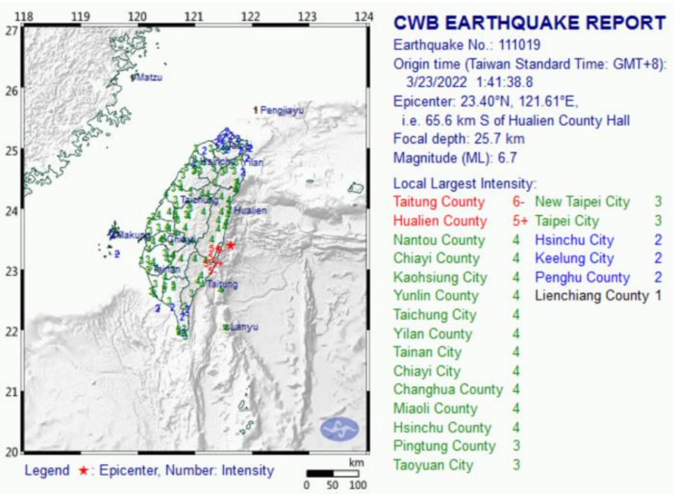

Fig. 1 Event report of the March 23 M_L-6.7 earthquake occurring offshore of the Hualien-Taitung region.

Fig. 2 A text message sent by the Taiwan Early Seismic Loss Estimation module of TELES developed by the NCREE (in Chinese).

2 - Evaluation of the Seismic Source and Strong Ground Motions

The M_L 6.7 (moment magnitude M_W 6.4) Hualien-Taitung offshore earthquake had a reverse-fault mechanism with a small strike-slip component, and the focal depth was 25.7 km according to the moment tensor solution of the Taiwan CWB. Similar solutions of this event were obtained by United States Geological Survey (USGS), Incorporated Research Institutions for Seismology (IRIS), and the Global Centroid-Moment-Tensor (GCMT) as shown in Fig. 3.

The source was located on a suture zone (a deeper portion in the Longitudinal Valley Fault) at the junction of the Eurasian Plate and the Philippine Sea Plate. Historically, two large earthquakes (M_L > 6) that occurred in this area are the 2003 Chengkung (成功) earthquake (M_L 6.4) and the 2013 Ruisui (瑞穗) earthquake (M_L 6.4). According to the tectonic and geological setup, the focal mechanism, and its related seismicity, the Taiwan Earthquake Research Center (TEC) presumed that the rupture plane of this event was a NE-SW trending fault with a high angle east-dipping thrust beneath the Coastal Range, which may be associated with activities along the deep portion of the northern segment of the Chihshang (池上) fault.

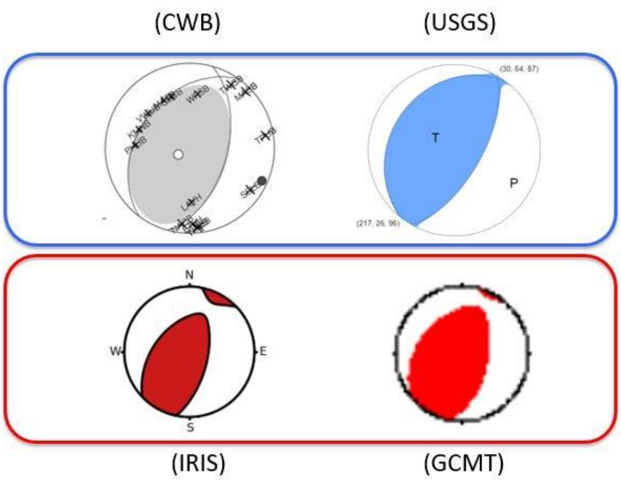

Fig. 3 Similar focal mechanisms from CWB, USGS, IRIS, and GCMT indicate the same orientation of the rupture plane for this event.

The largest peak ground acceleration (PGA) and peak ground velocity (PGV) recordings observed at Station ECB (長濱) were approximately 335.2 gal and 53.6 cm/s, respectively, by referring to the 502 real-time observation stations from the seismic networks operated by the CWB and NCREE. Figure 4 shows the three components of the acceleration time series recorded at the ECB station. Figure 5 shows ground motion shake maps, including the real-time observations and Taiwan’s new ground motion model, which was developed using observed ground motions (Chao et al., 2020). The shake maps provide ground motion information, including PGA and PGV, as well as the spectral acceleration at 0.3 s (Sa0.3) and 1 s (Sa1.0), which can help evaluate the correlation between strong ground motions, their cause, and building responses. The PGA shake map is a reference that indicates the approximate PGA values for comparison with damage to buildings due to the earthquake. The seismic shaking (shown in Figure 5) in the southern part of the East Rift Valley is higher than in the northern part, which may be related to the rupture directivity of the fault. Figure 6 compares the design spectra with the observed response spectra of the ECB station having the largest observed intensity (i.e., 6-moderate in CWB-defined scale) and the HWA041 station having the highest spectral acceleration at 1-second oscillator period. From the observed response spectra, it is evident that Station ECB exhibits a high spectral acceleration value in the very short period, but the values in the range of medium to long oscillator periods are lower than the design spectra. The maximum spectral accelerations observed at Station HWA041 are close to the MCE at about 1 second oscillator period. Comparison of the response spectra shows that the spectral accelerations exceed the design spectra at a few oscillator periods, which means that buildings may be slightly damaged if their predominant periods are close to these resonant periods.

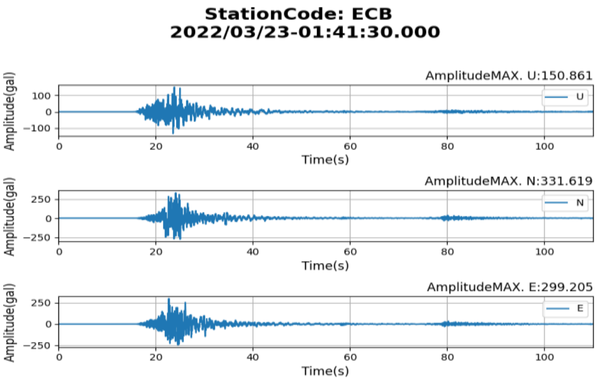

Fig. 4 Three components of the acceleration time series recording at Station ECB. Upper panel: vertical direction; middle panel: NS horizontal direction; lower panel: EW horizontal direction.

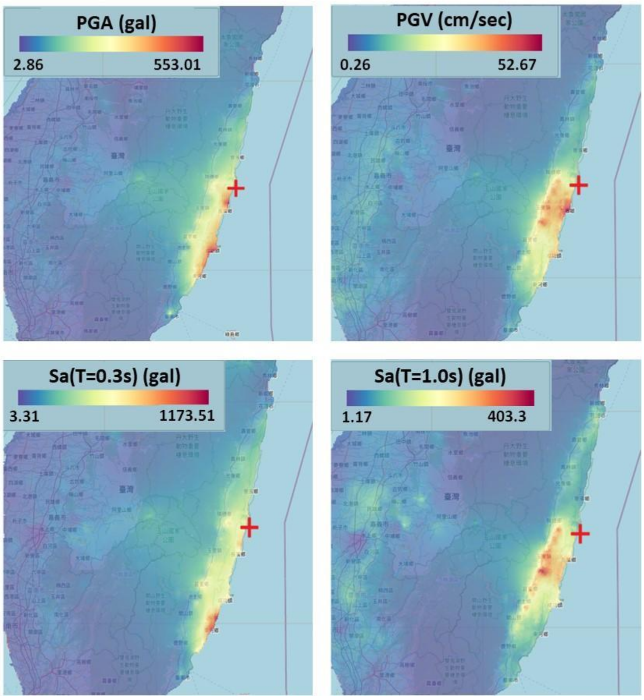

Fig. 5 Shake maps from the real-time NCREE platform for ground motion information, which gathered information from several seismic observation networks, including CWBSN, TSMIP, SANTA, and EEWS. Upper left: peak ground acceleration (PGA); upper right: peak ground velocity (PGV); lower left: spectral acceleration at 0.3 s (Sa0.3); lower right: spectral acceleration at 1.0 s (Sa1.0).

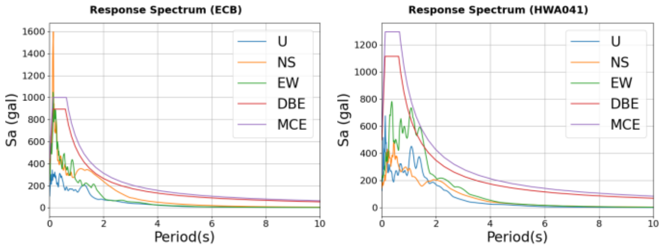

Fig. 6 Comparison of the observed response spectrum and the design response spectrum of two stations: the station ECB with the largest seismic intensity (left) and the station HWA041 with the maximum 1-second period spectral acceleration (right).

3 - Quick Report from Hybrid Earthquake Early Warning System

The on-site earthquake early warning system (EEWS) provided early warnings for this earthquake within 4 to 13 seconds around the area of the epicenter (Fig. 7). Information from the on-site EEW stations near the epicenter is detailed in Fig. 8.

According to the report from the hybrid EEWS platform, the earthquake occurred at 01:41:39 local time. The first message at the nearest station (approximately 15.4 km away from the epicenter) was received at 01:41:49.6 (Fig. 9), and indicated an estimated intensity of 6-moderate for Yuli Township (玉里), Ruisui Township (瑞穗), Zhuoxi Township (卓溪), and Changbin Township (長濱) in Taitung County. The second message was sent at 01:41:50.4 to Fenglin Township (鳳林), Guangfu Township (光復), Fengbin Township (豐濱), and Wanrong Township (萬榮) in Hualien County. The third message was sent at 01:41:50.4 to Fuli Township (富里) in Hualien County and Chenggong Township (成功) in Taitung County. The fourth to eighth messages were for Hualien County and Taitung County and indicated an intensity of 4 to 5. At 01:41:56, the ninth message added warning information from the CWB for an intensity of 4 in other counties and cities (Fig. 10).

The hybrid EEWS functioned well in Taiwan. The on-site EEWS of the NCREE provides early warnings in the area near the epicenter, and the regional EEWS of the CWB sends alerts beyond 70 km from the epicenter. The complementary operation of the two systems allows people who are close to and far from the epicenter to gain more warning time to take refuge. In addition, the equipment that receives the hybrid earthquake early warning message can act automatically and immediately upon receiving the warning message and thus reduce the occurrence of disasters.

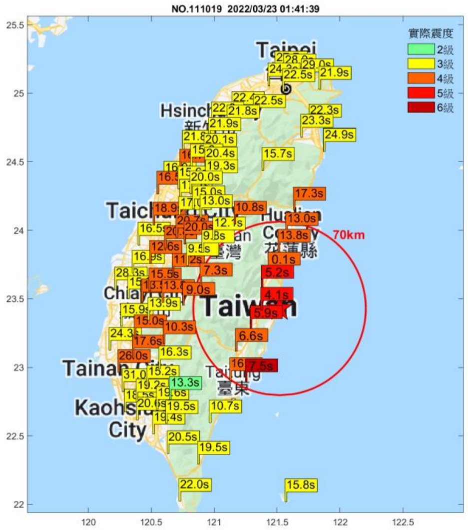

Fig. 7 Warning time from main on-site earthquake early warning stations.

所轄縣市	測站名稱	現地型			區域型			實際 PGA	實際震度	震央距離
		預警時間	預估 PGA	預估震度	預警時間	預估 PGA	預估震度			
花蓮縣	玉東國中	4.1	325.7	6	–	504.5	7	199.1	5	15.4
花蓮縣	富源國小	5.2	290.3	6	–	391.2	6	111.8	5	22.1
花蓮縣	光復國小	0.1	253.8	6	–	355.1	6	76.6	4	28.6
花蓮縣	長良國小	5.9	257.9	6	–	295.4	6	121.6	5	28.9
花蓮縣	豐裡國小	13.8	43.4	4	–	204.4	5	52.3	4	45.6
台東縣	初來國小	6.6	79.5	4	–	178.4	5	61.6	4	49.9
花蓮縣	稻香國小	13.0	56.6	4	–	128.9	5	40.4	4	59.2
台東縣	興隆國小	7.5	88.1	5	–	152.8	5	278.2	6	65.4
南投縣	同富國小	7.3	76.8	4	–	115.2	5	28.1	4	67.1
台東縣	龍田國小	16.6	49.7	4	–	103.8	5	25.5	4	71.0
南投縣	清境國小	10.8	40.9	4	–	82.8	5	27.5	4	77.4
南投縣	麒麟國小	12.1	61.9	4	–	80.0	4	22.6	3	77.4
南投縣	頭社國小	9.8	31.4	4	–	72.2	4	16.6	3	77.5
嘉義縣	達邦國小	9.0	89.0	5	–	75.1	4	65.2	4	78.8
花蓮縣	富世國小	17.3	25.2	4	–	82.3	5	46.8	4	80.3
南投縣	鳳凰國小	9.5	73.4	4	–	77.6	4	18.1	3	83.0

Fig. 8 Information from main on-site earthquake early warning stations near the epicenter (in Chinese).

現地站台: 玉東國中(S00007)
現地時間(UTC+8): 2022-03-23 01:41:49.5
預估震度: 6
實際震度: 4
預估PGA: 325.72
實際PGA: 63.05

複合式來源: S00007
震度: 6-
PGA: 325.7156
縣市: 花蓮縣
鄉鎮市區: 卓溪鄉, 瑞穗鄉, 玉里鎮

Fig. 9 Messages from the nearest on-site earthquake early warning stations (in Chinese).

時 間	觸發主站	縣 市	警報提供新增鄉鎮市區	來源(影響數量)
01:41:49.62	玉東國中	花蓮縣 臺東縣	玉里鎮(6-)、瑞穗鄉(6-)、卓溪鄉(6-) 長濱鄉(6-)	國震中心 (4)
01:41:50.359	光復國小	花蓮縣	鳳林鎮(6-)、光復鄉(6-)、豐濱鄉(6-) 、萬榮鄉(6-)	國震中心 (8)
01:41:50.522	長良國小	花蓮縣 臺東縣	富里鄉(6-) 成功鎮(6-)	國震中心 (10)
01:41:50.947	豐裡國小	花蓮縣	吉安鄉、壽豐鄉、秀林鄉	國震中心 (13)
01:41:52.687	初來國小	臺東縣	關山鎮、池上鄉、海端鄉	國震中心 (16)
01:41:54.766	稻香國小	花蓮縣	花蓮市、新城鄉	國震中心 (18)
01:41:55.315	興隆國小	臺東縣	臺東市(5-)、鹿野鄉(5-)、東河鄉(5-)、綠島鄉(5-)	國震中心 (22)
01:41:55.738	龍田國小	臺東縣	卑南鄉、太麻里鄉、延平鄉	國震中心 (25)
01:41:56.065	氣象局	本島各縣市	氣象局全區加入，本島內皆4級以上 花蓮縣(5-~6+)、臺東縣(4~6+)	氣象局 (334)

註 : 01:41:51 、 01:41:53 (CWB寄出)
01:41: 56.038 、 01:41:56.701(國震收到)

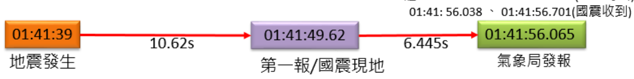

Fig. 10 Report from the hybrid EEWS platform (in Chinese)

4 - Structural Health Monitoring

According to the Taiwan CWB earthquake report on this event, the maximum shaking intensity was equal to 6-moderate and was measured in Chang-Bin (長濱), Taitung County. The second highest intensity was measured in Yuli (玉里), Hualien County. There are two buildings that possess structural health monitoring systems: Taitung Hospital and Taitung County Fire Department. The linear distances from the two buildings to the epicenter of the earthquake are 85.33 km and 83.46 km, respectively.

Taitung Hospital is a six-story building, and its structural plan is illustrated in Fig. 11. The configuration of the building is an L shape with an opening downward, so that it is asymmetric with respect to the horizontal axis. The structural monitoring system, including free field seismometers, includes 25 channels that measure horizontal and vertical accelerations. The accelerometers are located in the basement (B1), on the first floor (1F), on the fourth floor (4F), and on the rooftop (RF). To demonstrate the structural response to this seismic event, the accelerometers located at the service core are considered. The peak horizontal accelerations of each story are summarized in Fig. 12. The peak ground acceleration of some 30 gal in the basement (B1) can be considered to be the seismic input of the building under this event. The structural amplification effect becomes more obvious when the story gets higher. The peak ground acceleration in X and Y directions on the rooftop (RF) were 4 and 3.3 times those of the basement (B1), respectively.

The Taitung County Fire Department building can be divided into two sub buildings according to their different service purposes. The six-story building A is an office block, and the four-story building B is the deputy standby room for firemen; the height of the ceilings in building B is adapted to accommodate fire engine parking. The two sub buildings are separated by a 20 cm expansion joint, and the plan view of this building is similar to an L shape, but the opening angle is over 90 degrees. A total of 32 channels are used to monitor the acceleration response of this building. Except for the two channels for the free field, 30 channels are allocated all the way from the basement (B1) to the 6th floor (6F). The accelerometer measurements located near the expansion joint were selected for illustration and the peak horizontal accelerations for each story are shown in Fig. 13. The peak accelerations in the X and Y directions in the basement (B1) were roughly 30 gal under this seismic event, and they were respectively amplified to 89.7 and 68.2 gal on the 6th floor, which is 3.39 and 2.23 times those of the basement (B1). Supposing that buildings A and B are regular in both plan and elevation, and because of the expansion joint, the structural amplification effect of the Taitung County Fire Department is less than that of the Taitung Hospital due to a smaller torsional response.

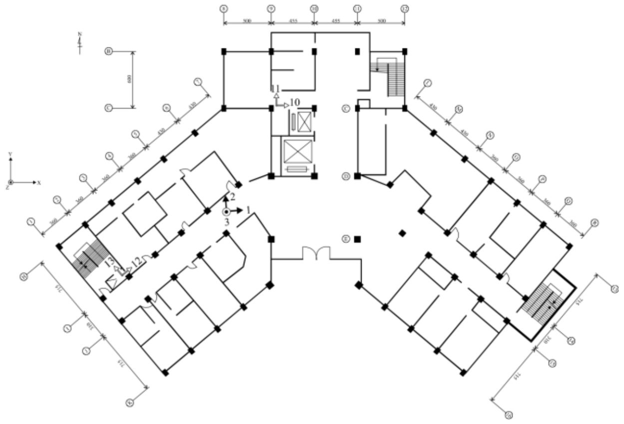

Fig. 11 Plan view of Taitung Hospital (1F).

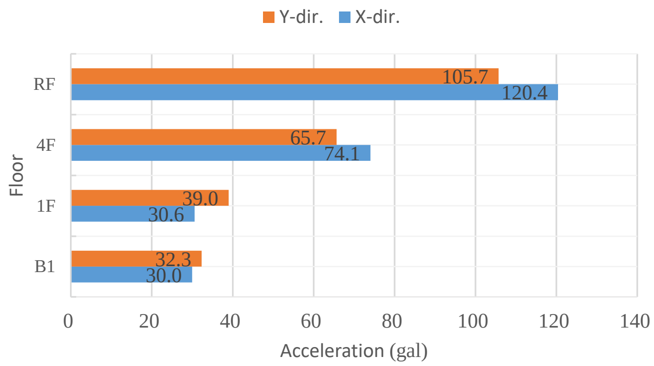

Fig. 12 Peak acceleration of Taitung Hospital.

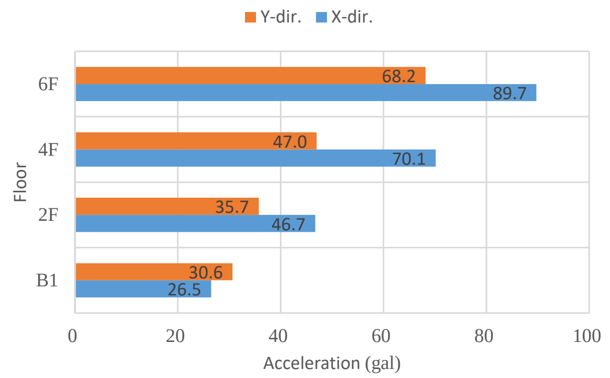

Fig. 13 Peak acceleration of Taitung County Fire Department.

5 - Building Damage

A stand-alone lavatory (Fig. 14) at Cheng-Gong Elementary School (CGES) in Taitung County located on the north side of the western school building close to the gate was damaged during the earthquake. Because the lavatory is not an area for learning activities, seismic evaluation and retrofit had never been performed. CGES is located 38.9 km from the epicenter of the earthquake (Fig. 15). The PGA recorded by the ChengKung strong ground motion station (1.16 km from the CGES) was about 567 gal (Fig. 16). After the earthquake, the office of the School Seismic Retrofit Project at the NCREE rapidly contacted the responsible person at every county government to collect information on the status of damage of school buildings across Taiwan. The damage to the lavatory was thus reported. Because of a short-column effect, the lavatory sustained shear cracks in the columns with a cover-spalling appearance (Figs. 17 and 18). In contrast, there was no serious structural damage to the eastern and western CGES buildings, which were built in 1988 and 1997, because their corresponding seismic resistance capacity-to-demand ratios are 1.218 and 1.800, respectively.

The western school building at CGES is a three-story reinforced concrete (RC) building with northern and southern parts separated by an expansion joint (Fig. 19). On the two sides of the expansion joint, there are existing RC columns. One RC column supports the southern part, and an added steel column supports the cantilever beam of the northern part, with the RC column and steel column side-by-side and connected with bolts. During this earthquake, the two columns collided with each other. As a result, the bolts at the top of the added steel column on the 3rd story fell away and were missing (Fig. 20).

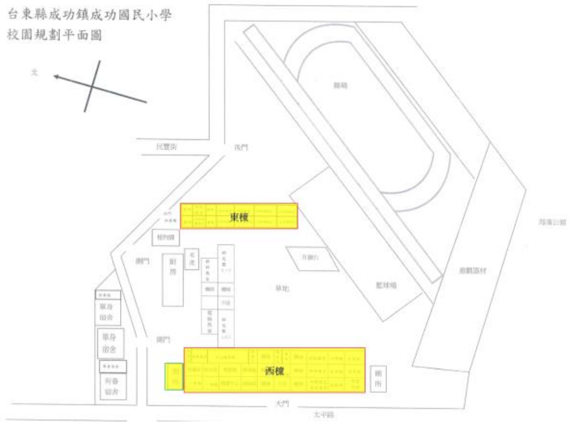

Fig. 14 Layout of CGES.

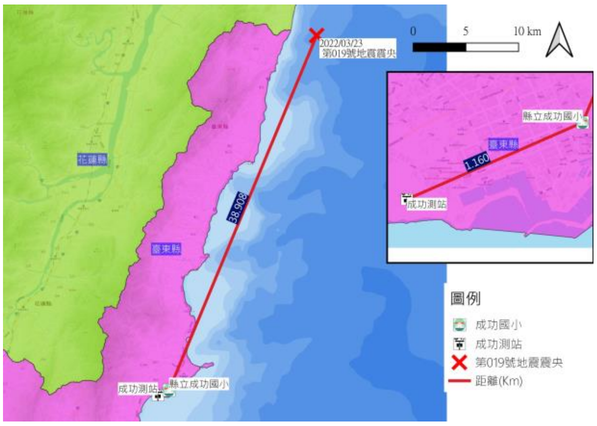

Fig. 15 The position of CGES relative to the epicenter.

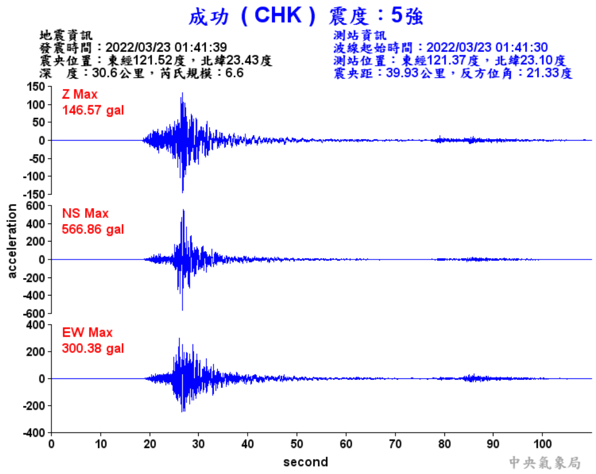

Fig. 16 Ground acceleration histories recorded at the ChengKung strong ground motion station (data source: CWB).

Fig. 17 Appearance of the damaged CGES lavatory (source: Taitung County Government).

Fig. 18 Damaged short column of the CGES lavatory (source: Taitung County Government).

Fig. 19 Expansion joint connecting the northern and southern parts of the western CGES building (PGA: 515 gal).

Fig 20. Top bolts of the added steel column on the 3rd story that had fallen and were missing, CGES building (PGA: 515 gal).

In the case of Zhongxiao (忠孝) Elementary School in Cheng-Gong (成功) Township, Taitung County, the southern school building was built in 1996 and the northern gymnasium was built in 1998. The school is 32.7 km away from the epicenter, and the PGA was estimated to be around 401 gal. The entrance of the gymnasium is on the eastern side of the building, which was seismically retrofitted with shear wall reinforcement. Figure 21 shows the inside of the gymnasium. The damage to the building caused by the earthquake includes a gap between the eastern wall and the roof (Fig. 22), horizontal cracks at the top corners of both sides of the door frame at the entrance (Fig. 23), and cracks with a maximum width of 5 mm on the ground of the gymnasium (Figs. 24 and 25).

Fig. 21 Inside the gymnasium at Zhongxiao Elementary School in Taitung County (PGA: 401 gal).

Fig. 22 The wall on the entrance side suspected of being inclined to the east, causing a gap between the wall and roof, Zhongxiao Elementary School (PGA: 401 gal).

Fig. 23 Horizontal cracks at the top corners of both sides of the door frame at the entrance of Zhongxiao Elementary School (PGA: 401 gal).

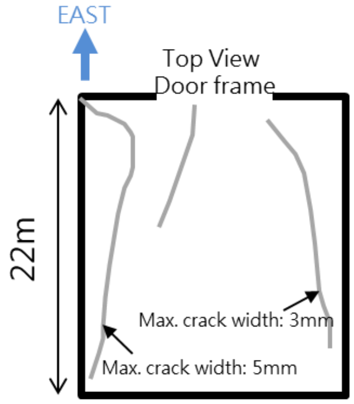

Fig. 24 Illustration of the cracks on the ground of the gymnasium, Zhongxiao Elementary School.

(a) Crack width

(b) Cracks on north side of the ground.

Fig. 25 Cracks on the ground of the gymnasium, Zhongxiao Elementary School (PGA: 401 gal).

The Fude Temple (福德宮) in Cheng-Gong, Taitung County consists of three RC buildings built at different periods. The temple is 39.2 km from the epicenter, and the PGA was estimated to be 524 gal. The earthquake damage that occurred during this event was concentrated in the first building, particularly in the beam-column joints between the front door and roof (Figs. 26 and 27). The beam-column system supports the roof; however, the gable roof design results in a short column effect at the front and the back of the roof. Furthermore, the walls around the front door do not extend to the roof; instead, there are small statues between the roof and the beam above the front door. Therefore, the strength of the structure was suddenly reduced here, and the beam-column joints and statues above the front door were damaged during the shock. In addition, the diaphragms underneath the roof cracked in the southwestern and northeastern corners.

Fig. 26 Small statues instead of walls connect the roof and the beam above the front door of the Fude Temple, resulting in a sudden reduction in strength (PGA: 524 gal).

Fig. 27 Damaged beam-column joints underneath the roof and the cracked diaphragms, Fude Temple. The small statues between the beam and the roof fell apart to the ground (PGA: 524 gal).

6 – Bridge Damage

The Yuxing (玉興) Bridge in Yuli, Hualien County, was undergoing a widening project when the earthquake struck, and the prestressed beams on both sides collapsed. Its location is approximately 22 km from the epicenter. A summary of the on-site investigation is as follows:

This widening project involved adding bridge columns and erecting prestressed beams. On the northbound line of the bridge, the prestressed beam was still under construction and the support had not been fixed. During the earthquake, collapse caused the prestressed beam and the back wall to slide relative to each other. On the southbound line, an elevated prestressed beam had been added, which fell into the main bridge lane when the earthquake struck, but fortunately caused no casualties. The original main bridge structural system had no abnormality in its expansion joints. The Directorate General of Highways has restricted bridge access and carried out demolition of the damaged prestressed beams.

Members of the NCREE went to the site on March 25 2022 to investigate the progress of the demolition work on both sides of the Yuxing Bridge. At that time, the earthquake-damaged structures had been demolished (Figs. 28 and 29).

Fig. 28 The east side of the Yuxing Bridge after demolition (PGA: 135 gal).

Fig. 29 The west side of the Yuxing Bridge after demolition (PGA: 135 gal).

7 - Non-building Structures

The grain storehouse of Nian-Chang rice mill (年昌碾米廠) in Yuli (玉里), Hualien County, was damaged in this earthquake. There were twenty-four 12-m-high grain tanks supported by 3-m-high steel frames inside the storehouse, and each tank weighs 200 tons when fully laden with grain. The first row of tanks collapsed westward during the earthquake, and collided with the storehouse structure and corrugated steel sheets. The southwestern corner of the storehouse is the working area for trucks, and two trucks were destroyed by the tanks (Fig. 30). The structure was deformed westward after the earthquake (Fig. 31). The columns between the overhead doors were tilted, and the doors were damaged due to grain pouring out of the structure. In addition, the roof was deformed during the movement of the exterior wall.

Fig. 30 The Nian-Chang rice mill 15-m-high grain tanks that collapsed westward and collided with the storehouse and trucks (PGA: 140 gal).

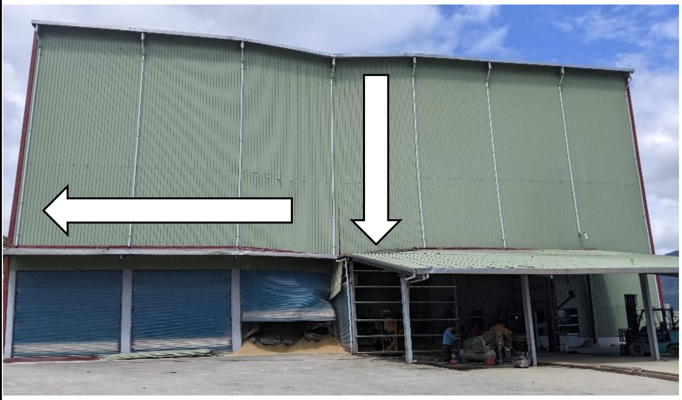

Fig. 31 Deformation of the Nian-Chang storehouse (PGA: 140 gal).

The Da-Yuan sand quarry (大元砂石場) is located alongside the Xiuguluan River (秀姑巒溪) in Yuli, Hualien County and is approximately 22 km from the epicenter. Part of the processing equipment, including an approximately 18-m-high storage tower, conveyor belts, and supporting structures connected to the tower collapsed in the earthquake (Fig. 32). The storage tank was estimated to have contained 1200 tons of sand and gravel, and was supported on 12 tubular steel columns, 26 cm in diameter and 1 cm thick. Most of the columns ruptured neatly during the earthquake (Fig. 33). It is presumed that the strength of the columns was reduced due to rusting at the welding spots between the columns and the tank or base plates. The overturning force induced by the earthquake was so great that the structure ruptured from its weaknesses. Fortunately, nobody was injured in this accident.

Fig. 32 Da-Yuan quarry storage tank and conveyor belts that collapsed and deformed during the earthquake (PGA: 175 gal).

Fig. 33 Top and bottom ends of Da-Yuan steel columns that were ruptured neatly (PGA: 175 gal).

8 - Non-structural Components

1. Suspended ceiling systems

Many cases of ceiling failure were observed as a result of this seismic event, demonstrating the vulnerability of suspended ceilings, which are classified as non-structural components. On-site reconnaissance findings are reported as follows:

(a) Specialty ceilings

A type of specialty ceiling was constructed in the elevator lobbies at the Chenggong branch of Taitung Hospital (臺東醫院成功分院). This specialty ceiling is a combination of an exposed ceiling system and a hinted grid ceiling system (Fig. 34). The main failure pattern was identified to be due to the lack of proper connection strength between the ceiling grids and panels, which resulted in substantial collapse of the panels during the earthquake (Fig. 35). Another failure pattern, presented in Fig. 36, was observed at the interface of the exposed ceiling system and the hinted grid ceiling system. The ceiling grids and panels collapsed once there was relative movement between the two systems.

Fig. 34 The specialty ceiling in the first-floor elevator lobby at Taitung Hospital (PGA: 535 gal).

Fig. 35 The damaged specialty ceiling in the elevator lobby on the third floor of Taitung Hospital (PGA: 535 gal).

Fig. 36 Ceiling failure at the interface of the exposed ceiling system and the hinted grid ceiling system at Taitung Hospital (PGA: 535 gal).

(b) Exposed ceilings

Exposed ceilings experienced widespread and extensive damage in this seismic event. The most serious damage to ceilings was observed at Zhongxiao (忠孝) Elementary School. Figure 37 shows severe damage suffered by the exposed ceilings. Light fixtures fell down, primarily due to the lack of proper seismic design and insufficient ceiling strength capacity. The connection latches of cross tees were pulled out and the grids were deformed visibly (Fig. 38). In addition, a common problem was the unseating failure of the ceiling grids where no edge hanger wire was applied in the ceiling installation (Fig. 39). Another damage pattern, classified as anchorage failure, was observed at Yong-Fu Presbyterian Church (永福基督長老教會天主堂). The damage was concentrated on the anchor device because of insufficient anchorage strength. The size of the screw was too short, so the suspension wires of the ceiling system could only be attached to the wood laths, and not to the floor structure above (Fig. 40).

Fig. 37 Damaged exposed ceiling at Zhongxiao Elementary School (PGA: 401 gal).

Fig. 38 Ceiling grid and grid connection failure, Zhongxiao Elementary School (PGA: 401 gal).

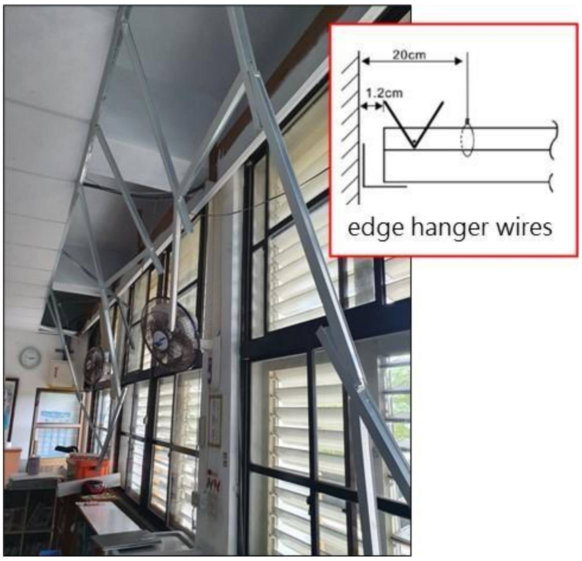

Fig. 39 Ceiling failure due to the lack of edge hanger wires, Zhongxiao Elementary School (PGA: 401 gal).

Fig. 40 Damaged to exposed ceiling in Yong-Fu Presbyterian Church (PGA: 336 gal).

2. Fire sprinkler piping systems

Past earthquakes experiences have shown that even minor damage to fire sprinkler piping systems can result in a substantial reduction in building functionality, which is primarily due to flooding caused by leakage from piping. Two main failure patterns were identified in this seismic event: failure of piping joints and failure of sprinkler heads. Figure 41 shows hydrant water leaking onto the fifth floor of the Chenggong branch of Taitung Hospital after the piping joint failed due to impact by the nearby overhead components. The sprinkler head was found to be damaged primarily due to the interaction between the sprinkler head and the specialty ceiling (Fig. 42).

Fig. 41 The damaged piping joint on the fifth floor of Taitung Hospital, Chenggong branch (PGA: 535 gal).

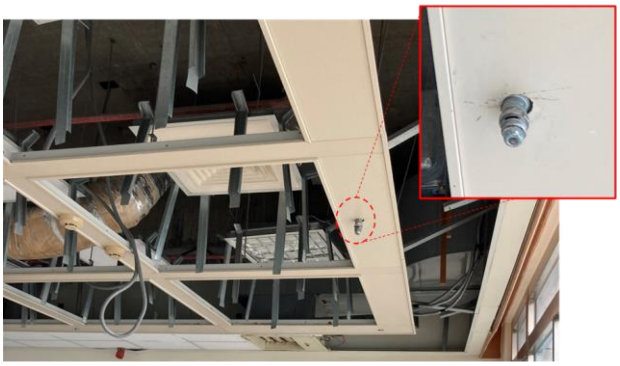

Fig. 42 Failure of the sprinkler head due to interaction with the ceiling, Taitung Hospital (PGA: 535 gal).

3. Liquid storage tanks

Many water tanks and heaters were damaged in this earthquake. The reverse osmosis (RO) system of the Chenggong branch of Taitung Hospital was damaged, which included a tilted water tank on the rooftop and a broken pipe on the third floor. These failures led to suspension of kidney dialysis services. Therefore, patients had to be transferred to other facilities kilometers away. Even though the hardware was repaired immediately, kidney dialysis services still had to be suspended until the water quality analysis results were confirmed to conform with the appropriate specifications.

The water tank on the rooftop had a height and diameter of 1.5 m, and was supported on a steel stand consisting of four legs and a ring (Fig. 43). Three of the four legs were anchored to the floor, and the tank was placed on the ring. The unanchored leg survived but the other legs were all deformed due to broken welding joints or buckled members. As a result, the water tank tilted and buckled, and the pipe was broken as well.

Fig. 43 Tilted water tank due to failure of the stand underneath it, Taitung Hospital (PGA: 535 gal).

The Chenggong branch of Taitung Hospital set up an RO processing system on the third floor to purify water for kidney dialysis. Three 140-cm-high filter elements of the RO system were free standing on the floor, and were connected with each other through the UPVC pipes above the filter elements (Fig. 44). The pipe at the southeastern corner was sheared off during the shock and was repaired the day after the earthquake.

Fig. 44 The marked pipe was sheared off, Taitung Hospital (PGA: 535 gal).

The fiberglass reinforced plastic (FRP) expansion water tank of the air-conditioning system anchored on the roof of the Chenggong branch of Taitung Hospital collapsed and was seriously damaged during the earthquake. The overturning of the FRP expansion tank also broke its water supply pipe, causing the entire air-conditioning system to shut down (Fig. 45). The mechanical and electrical manufacturers were carrying out repair work the next day, but the air-conditioning system had not yet resumed operation.

Fig. 45 Seriously damaged FRP expansion water tank on the roof of the Taitung Hospital, Chenggong branch (PGA: 535 gal).

The free-standing water heater on the fifth floor of the Chenggong branch of Taitung Hospital was overturned due to the shock, which resulted in a broken pipe and loss of functionality. After the earthquake, the water heater was temporarily repaired and strengthened by attaching steel angle iron from its top to the nearby column (Fig. 46). The current strengthening method may not be helpful in supporting the weight of the heater; a fixed stand or base and supporting straps at the center of gravity of the heater are recommended (Fig. 47).

Fig. 46 The damaged heater, which was repaired after the earthquake and strengthened by attaching a steel angle iron at its top, Taitung Hospital. This is not a long-term solution for supporting the weight of the heater (PGA: 535 gal).

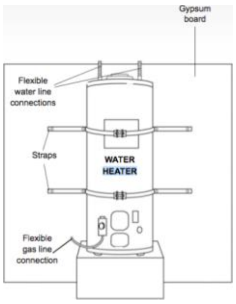

Fig. 47 Recommended practice for improving the seismic resistance of the water heater. (https://buyersask.com/plumbing/water-heater/strapping-of-water-heaters-for-earthquakes/).

4. Non-Structural Walls

Based on the information on the emergency response center website of Taitung County, several non-structural walls in schools, fire departments, and hospitals were cracked in this earthquake. Part of the cracked walls in Dong-He (東河) and Lu-Ye (鹿野) Stations of the Taitung County Fire Department are shown in Fig. 48 and Fig. 49, respectively. In addition, the concrete cover of the floor diaphragm spalled off and collided with the suspension ceilings of the gym on the third floor of Dong-He Station.

Fig. 48 Dong-He Station, Taitung County Fire Department being retrofitted. The brick wall outside the duty room on first floor was cracked, and the door got jammed (PGA: 409 gal).

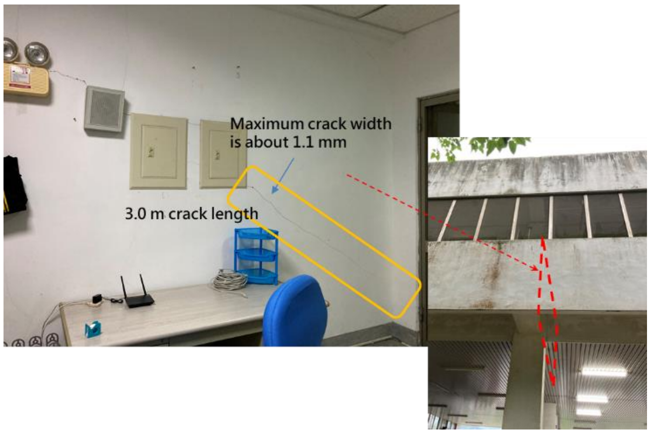

Fig. 49 A few of the partition walls on the second floor of Lu-Ye Station, Taitung County Fire Department were cracked (PGA: 53 gal.).

5. Other Non-Structural Components

Seismic damage to other non-structural components is presented in this section.

A fallen air-conditioning box was observed in the staff mess hall of the Yuli Hospital, the Ministry of Health and Welfare. This failure caused collateral damage to the suspended ceilings because the ceilings were physically connected to the air-conditioning box (Fig. 50).

Fig. 50 Failure of an air-conditioning box and suspended ceilings, Yuli Hospital (PGA: 135 gal).

Broken showcase glass was observed at the Taitung County Museum of Natural History. This failure resulted from the large movements of the rock specimens inside the showcases, which impacted the glass (Fig. 51).

Fig. 51 Broken showcase glass at the Taitung County Museum of Natural History (PGA: 465 gal).

There were no records related to structural damage of elevators reported during this seismic event. However, it was documented that six elevators (three in Taitung and three in Hualien) needed repair and further inspection.

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