EVENT BRIEFING

Event:	15 January 2021, Mamuju-Majene Earthquake, West Sulawesi
Region:	Indonesia

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Partially collapsed West Sulawesi Governor's office in Mamuju, Sulawesi, Indonesia

Key Lessons

- ❏ According to the USGS, a ground motion recording station at Mamuju, 33.8 km away from the epicenter, recorded a Peak Ground Acceleration (PGA) of 0.7g and a Peak Ground Velocity (PGV) of 69.8 cm/s. This PGA varies significantly from the early estimates of 0.2g at this location released by the USGS immediately after the event. If these field recordings are reliable, this would help to explain the numerous observed building collapses.
- ❏ Notably these recorded values are much larger than ground motion prediction equations would estimate at this distance and magnitude. Local site conditions may explain this strong ground shaking, and this should be explored in further detail. This apparent underestimation of ground shaking could also have contributed to low fatality and economic loss predictions by the USGS PAGER system immediately after the earthquake.
- ❏ Several photographs capturing intact columns and beams with damaged joints of collapsed buildings suggest that beam-column joint failures initiated some of these collapses.
- ❏ Complete collapse of a hospital structure in Mamuju during the earthquake was clearly an undesirable failure, jeopardizing those in the hospital as well as those injured in the community, for whom this hospital is no longer available. The details behind this collapse should be studied to learn whether there are similar deficiencies in other hospitals in the region and elsewhere in Indonesia. Retrofit of similarly susceptible structures should be a priority to avoid similar consequences during future earthquakes.
- ❏ Collapse of the West Sulawesi Governor’s office building, a government structure constructed in 2010 in Mamuju, may indicate a need for revisiting the definition of seismic hazard and the currently employed seismic design methods and construction practices in Indonesia.
- ❏ Some buildings that provided satisfactory performance according to modern seismic codes experienced heavy component damage, likely warranting downtime of the building and a closure to occupancy for a certain time due to the required repairs. Similar to many previous earthquakes, this observation highlights the need to start considering functionality objectives in seismic design beyond the currently required life safety objective.
- ❏ The earthquake resulted in significant disruptions to the community. In addition to 84 deaths and over 600 injuries, more than 15,000 people have been temporarily displaced in 10 evacuation sites, which is expected to increase as assessments continue. Landslides triggered by the earthquake blocked access between Majene and the provincial capital Mamuju at three different locations. Power, communications and fuel supply have also been disrupted.
- ❏ The 5.7 magnitude foreshock the day before this earthquake might have played a role in reducing fatalities and injuries. This strong foreshock resulted in some damage and might have heightened awareness of the population leading into the night of the 6.2 magnitude earthquake.
- ❏ Damaged and blocked roads and bridges, power outages and lack of heavy equipment slowed down the emergency response and rescue operations. This highlights the importance of continued functionality of various infrastructure components during and after earthquakes, not only for fast recovery of the communities from the earthquake, but also for promptness of emergency response. It also points to the need for identifying critical transportation routes and making it a priority to ensure their post-earthquake functionality or to develop alternative routes.

1.0 Introduction

On January 15, 2021, at approximately 2:28 am local time, a magnitude 6.2 earthquake, with a depth of 18.0 km, struck in West Sulawesi (Sulawesi Barat, or Sulbar) near the border of the regencies of Mamuju and Majene, 32 km south of the city of Mamuju, Indonesia (USGS, 2021a). The earthquake led to the collapse of a number of buildings, at least 84 deaths (Regan & Jamaluddin, 2021), over 600 injuries, and more than 15,000 people displaced (CNN, 2021a, 2021b). Objectives of this Event Briefing are 1) to provide details of the 15 January Mw 6.2 Mamuju-Majene Earthquake, 2) to describe damage to buildings and other infrastructure and disruption to the community in terms of fatalities, downtime, and economic losses, and 3) to list key lessons learned from this event and recommendations for further study.

2.0 Earthquake Details

The epicenter of the earthquake had coordinates of 2.976°S, 118.901°E (Fig. 2.1). The earthquake was preceded by a 5.7 magnitude earthquake (USGS, 2021b) the day before and followed by many aftershocks, including one with a 5.0 magnitude (CNN, 2021b). This earthquake did not generate a tsunami.

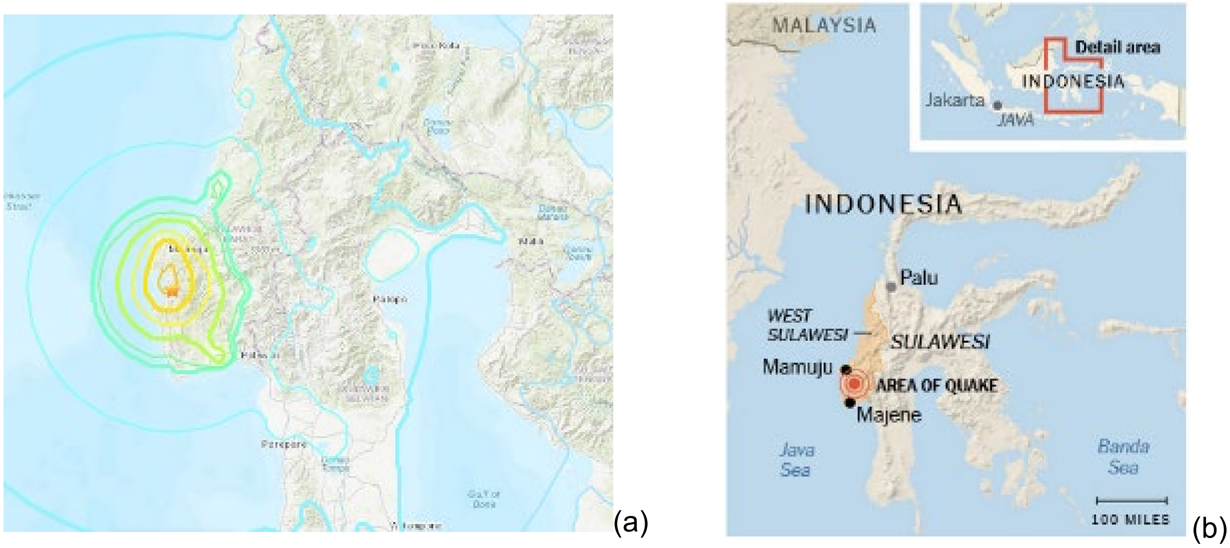

Figure 2.1 Epicenter of the Mw 6.2 Indonesia earthquake (Sources: (a) USGS, 2021a; (b) The New York Times, 2021)

Eastern Indonesia is characterized by complex tectonics, where motions of various small microplates are accommodating large-scale convergence between the Australia, Sunda, Pacific, and Philippine Sea plates (Fig. 2.2). The January 15, Mw 6.2 earthquake occurred as a result of reverse faulting on or near the boundary between the Sunda plate and Banda Sea microplate at shallow depths, where the Sunda plate moves east with respect to the Banda Sea microplate at a velocity of about 21 mm/year (USGS, 2021a). Focal mechanism solutions by USGS indicated that rupture happened on either a shallowly dipping oblique reverse strike-slip fault striking towards the northwest or on a steeply dipping reverse fault striking towards the south, both of which indicate roughly east-west oriented compression.

The USGS ShakeMap (Fig. 2.3) predicts that the PGA is 0.2g roughly 32 km away from the epicenter at Mamuju, which is the capital of the West Sulawesi province of Indonesia. According to the USGS, one of the ground motion recording stations (the red dot next to Mamuju in Fig. 2.3, 33.8 km away from the epicenter) recorded a Peak Ground Acceleration (PGA) of 0.7 g and a Peak Ground Velocity (PGV) of 69.8 cm/s, which are much larger than those estimated by ground motion prediction equations at this distance and magnitude. Therefore, the large ground shaking can be speculated to result from local site conditions (i.e. the muddy soil described in the following paragraph) and should be explored further. If these recordings are reliable, this could explain the numerous observed building collapses. It would also explain the initially low PAGER estimates released by the USGS immediately after the earthquake, but updated later, as discussed in Section 4 of this report.

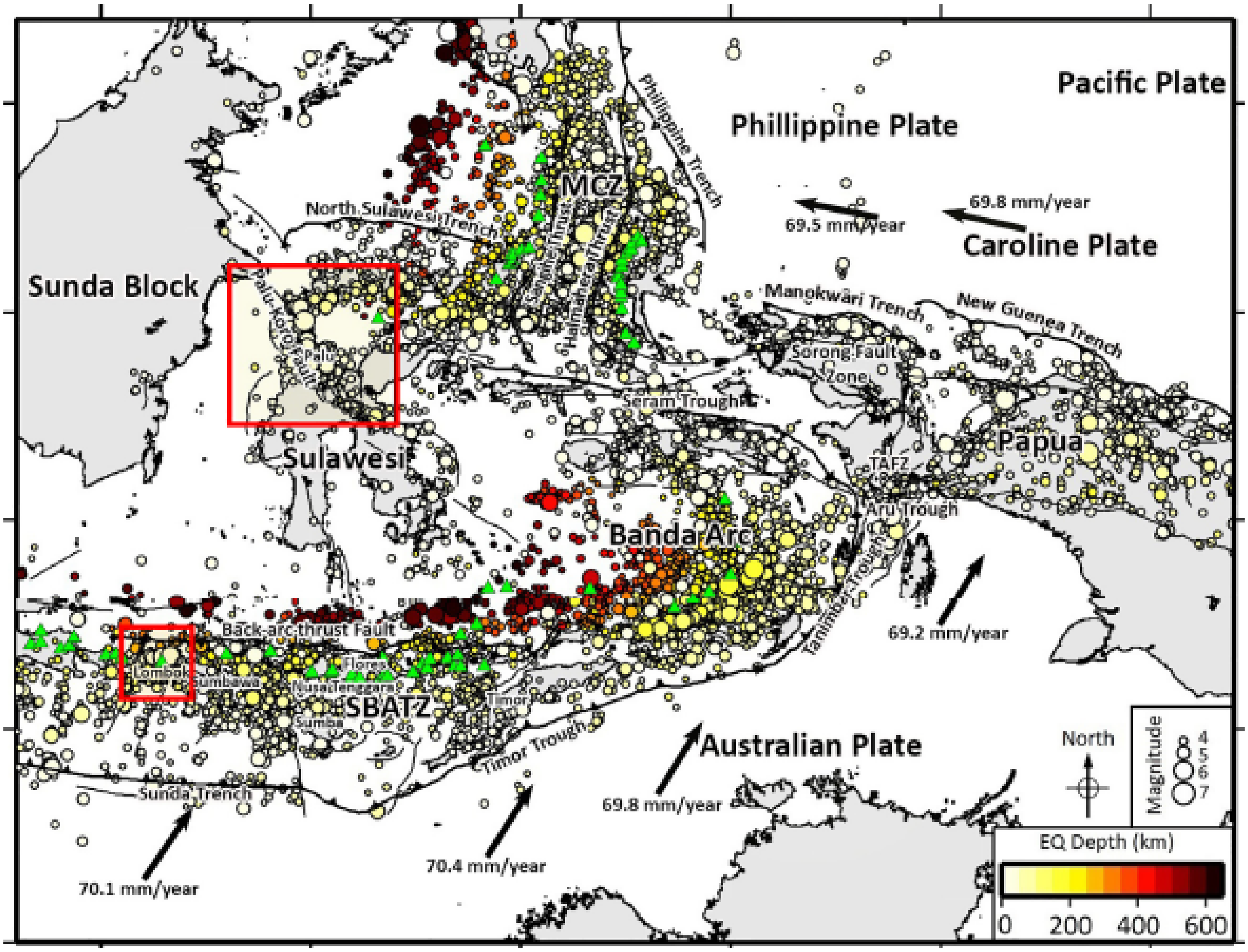

Figure 2.2 Example of complex tectonics in Eastern Indonesia (Supendi et al., 2020)

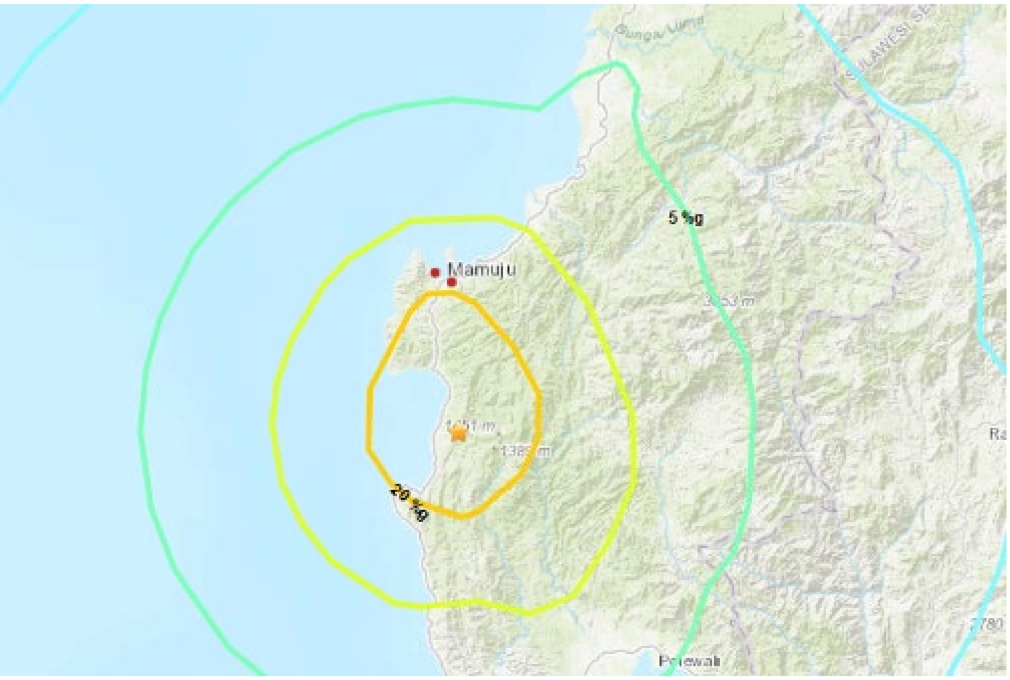

Figure 2.3 PGA contours estimated from ShakeMap (USGS, 2021a)

The 2017 Indonesian seismic hazard maps are shown in Figure 2.4. The Mamuju region has an expected bedrock peak ground acceleration of 0.2-0.3 g with a probability of exceedance of 10% in 50 years (return period of 475 years) and about 0.25-0.4 g with a probability of exceedance of 7% in 75 years (return period of 1000 years). The area is known to have a mangrove ecosystem with swampy, muddy soil. Some known faults in the region are shown in Figure 2.5.

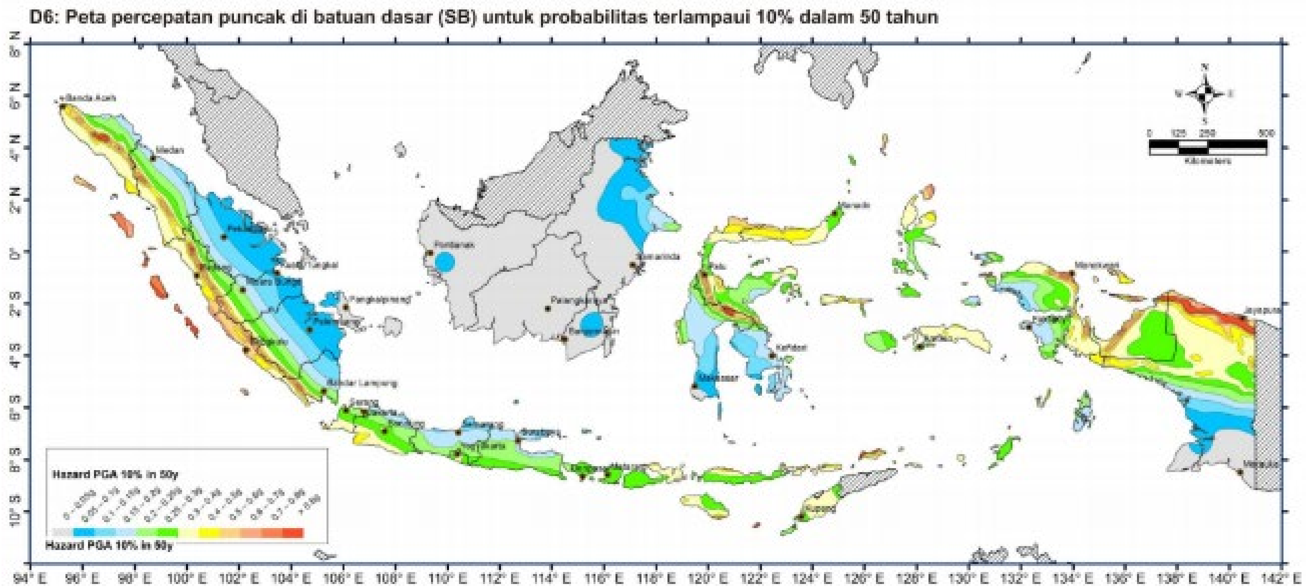

Figure 2.4a Indonesian seismic hazard maps for bedrock acceleration with probabilities of exceedance of 10% in 50 Years (Litbang PUPR, 2017)

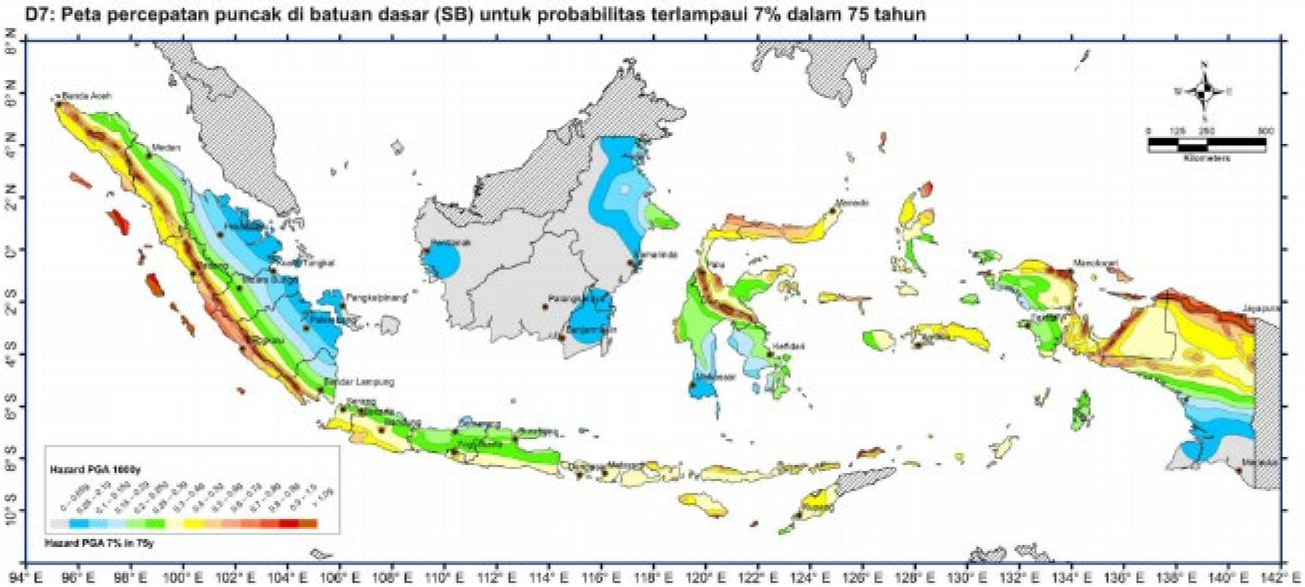

Figure 2.4b Indonesian seismic hazard maps for bedrock acceleration with probabilities of exceedance of 7% in 75 years (Litbang PUPR, 2017)

Figure 2.5 Known local faults in the Sulawesi region (Kompas, 2021)

3.0 Damage to Structures

This earthquake led to significant damage to the built environment. Many collapses and various levels of damage were experienced by buildings and other infrastructure, which are summarized in the sections below. Links to survivor videos of the earthquake shaking and its effects on the impacted communities are provided in the Appendix.

3.1 Residential Buildings

Collapses of reinforced concrete (RC) residential buildings were especially prominent in this earthquake. It is noted that most low-rise residential buildings in Indonesia are made of reinforced concrete (RC), but many are non-engineered. Examples of typical global collapse and component failures are provided in Figures 3.1-3.2. It is apparent that the collapsed buildings are in the category of non-ductile RC buildings, lacking seismic details such as proper confinement in the plastic hinge regions, lack of transverse reinforcement in the beam-column joints, weak columns supporting strong beams, plain reinforcing bars (see Fig. 3.2 top left), etc. Numerous buildings suffered failures because of significant damage at the beam-column connections. Several photos capturing intact columns and beams of collapsed buildings suggest that beam-column joint axial failures initiated the collapse; which is particularly susceptible with joints having large beam to column depth ratios, (Fig. 3.1 right), and is consistent with experimental evidence of joint axial failures (Hassan 2011).

Figure 3.1 Photos of collapsed buildings suggesting the initiation of collapse from failed beam-column joints (Indiatimes, 2021).

The bottom right photo in Fig. 3.2 shows failed exterior walls of a residential building. The failures occurring at a mid-story point to the role of in-plane (IP) and out-of-plane (OOP) interaction in these failures. This type of mid-story infill wall failures has also been observed in other previous earthquakes (Mosalam and Günay, 2015).

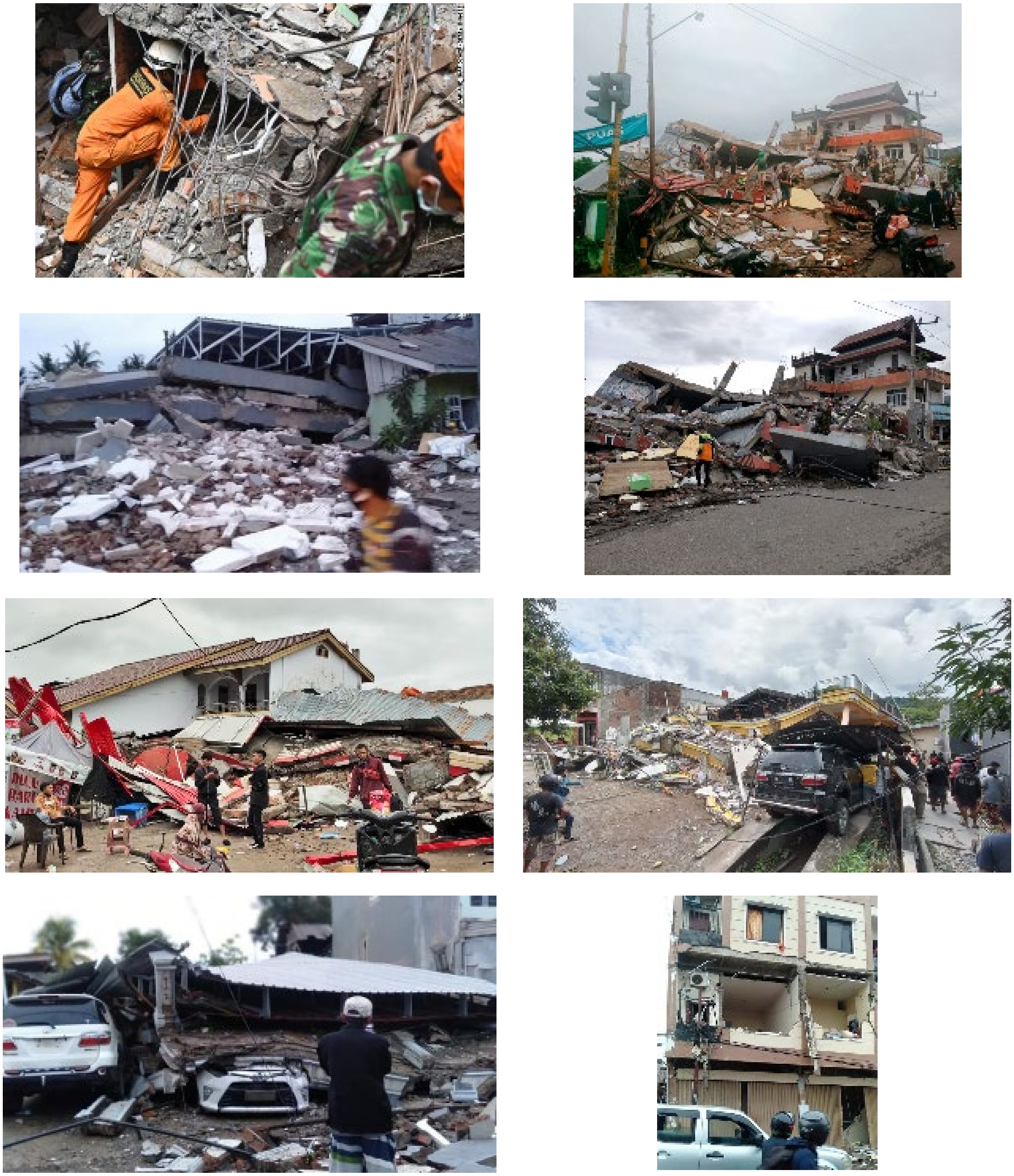

Figure 3.2 Images of collapsed RC residential buildings and one with a failed exterior wall (lower right) located in Mamuju (Sources: CNN 2021b, GettyImages 2021, AP 2021, AP Photo/Rudy Akdyaksyah, Kumparan, 2021, https://pbs.twimg.com/media/Er1PSQuU0AIPcnw.jpg).

3.2 Hospitals

Collapse of and heavy damage to several critical buildings have been reported in the city of Mamuju. The five-story Mitra Manakarra Hospital (Fig. 3.3) collapsed and trapped a number of people inside. Several images of collapse suggest non-ductile concrete details of the Hospital (Fig. 3.4). Similar to the residential buildings described in the previous section, intact columns in the photos in Figure 3.4 indicate that beam-column joint failures might have led to the building collapse. However, more details are required to determine the actual collapse mechanism.

Complete collapse of a hospital structure during an earthquake is a clearly undesirable failure, jeopardizing those in the hospital as well as those injured in the community, for whom this hospital is no longer available. The details behind this collapse should be studied to learn whether there are similar deficiencies in other hospitals in the region and elsewhere in Indonesia. Retrofit of similarly susceptible structures, especially hospitals and school buildings, should be a priority to avoid similar consequences during future earthquakes.

Figure 3.3 Google Street view (left) and image (right) (credit: Irmank Aco) of Mitra Manakarra Hospital prior to the earthquake (2.684S, 118.886E).

Figure 3.4 Collapsed Mitra Manakarra Hospital in Mamuju (Sources: Reuters, 2021; Weather, 2021; Gettyimages, 2021; Antara, 2021)

Another government hospital in Mamuju was heavily damaged (Fig. 3.5), with most of the damage in unreinforced masonry walls and the glass facade. A community health center also sustained damage (Reliefweb, 2021).

Figure 3.5 Glass façade and unreinforced masonry walls of a district hospital in Mamuju (2.685S, 118.889E) intact before the earthquake (left) and broken after the earthquake (right) (Sources: Left: Google Street view; Right: https://suryakepri.com/2021/01/16/update-jumlah-korban-gempa-majene-bertambah-jadi-42-orang-meninggal-dunia/).

3.3 Government Buildings

Another notable collapse was observed at the West Sulawesi Governor's office (Fig. 3.6). The building was built in 2010 (Rakyat Demokrasi, 2021) and has many concrete pillars/columns. Two people were reportedly trapped underneath the collapsed structure (Berita Nasional, 2021). It is difficult to draw conclusions about the observed collapse without much information about the details of the building geometry and material characteristics; however, the relatively heavy roof and/or potential weak first or second stories might have contributed to the collapse. Because of the differences in plan, number of stories and framing system, the natural periods of vibration of this building would be different from those of the six adjacent buildings that remained intact. If the dominant frequency of the ground motion were closer to one of the periods of the Governor's office, that could have led to collapse, while the neighboring buildings remained intact. Other government buildings were also reported as collapsed in Mamuju (Fig. 3.7-3.9). Based on the presence of the observed openings, the first story of the local Power Utility Office building in Fig. 3.8 is a potential soft story by visual inspection, however there is not significant damage in this story, the reasons of which may be worth exploring with further numerical simulations.

Figure 3.6 Collapsed Office of the Governor of West Sulawesi, located 21 miles NNW of the epicenter (2.665S, 118.853E); before the earthquake (top left), aerial image after the earthquake (top right) and surface imagery of search for survivors (bottom left, right) (Sources: Google Earth Images, 2021; Reuters, 2021).

Figure 3.7 A collapsed government building in Mamuju (Source: AP Photo/Daus Thobelulu).

Figure 3.8 Local Power Utility Office built in 2017 with significant facade damage. (2.6771S, 118.895E) (Source: PLN/State Electricity Company Documentation, via detikNews, 2021)

Damage experienced by the frame members and infill walls of the Mamuju Tax Office is shown in Fig. 3.9. The infill wall on the right experienced a complex damage mechanism, probably due the presence of openings. The infill wall on the left experienced less damage and the lateral forces transferred from this infill wall to the adjacent column led to the observed shear crack on the column. This is a good example of a strong column / weak beam proportion, where flexural damage is observed at the beam ends with no or less damage observed at the top of the columns. Therefore, the observed damage by the frame members is adequate according to modern seismic codes. However, heavy damage experienced at the beam end is likely to warrant downtime of the building and a closure to occupancy for a certain time due to the required repairs. This observation highlights the need to start considering functionality objectives in seismic design beyond the currently required life safety objective.

Figure 3.9 Damage experienced by the frame members and infill walls of the Mamuju Tax Office (Twitter, 2021a).

3.4 Other Building Classes

The d’Maleo Hotel (Fig. 3.10) sustained damage in Mamuju (Reliefweb, 2021). Not visible in Fig. 3.10, it is possible that a partial collapse of a story could have taken place on the lowered side of the building. External walls of the Matahari Shopping Center in Mamuju experienced significant damage (Fig. 3.11). Beyond the structural damages reported herein, nonstructural suspended ceiling damage was also documented (Fig. 3.12).

Figure 3.10 Google Street view image (top) and partial collapse (bottom) of the d’Maleo Hotel in Mamuju. (2.6728S, 118.8867E) (Source: Arman/a Majene resident, https://kumparan.com/paluposo/foto-bangunan-rusak-dampak-gempa-majene-sulawesi-barat-1uysWeq3YSB)

Figure 3.11 Photographs of the Matahari Shopping Center in Mamuju taken from Google Street view (top) and a video frame taken after the earthquake (bottom) (2.6694S, 118.8918E) (Source: https://twitter.com/fad__id/status/1349863151873925120?s=09)

Figure 3.12 Non-structural suspended ceiling damage observed in a building (Reuters, 2021).

3.5 Other Infrastructure

In addition to the extensive building damage, the flight control tower at Mamuju's commercial airport was damaged. At least one route into Mamuju has been lost due to a damaged bridge; and at least two other roads were damaged (Twitter, 2021b). Indonesia's disaster agency reported a series of aftershocks that caused at least three landslides, blocking other roads (Twitter, 2021b) (Fig. 3.13). Communications and power infrastructure have been affected leading to disruptions and outages (The Straits Times, 2021). The Indonesian Ministry of Information said that at least 122 BTS (Wireless communication antenna), out of 651 in the region, has lost functionality due to the earthquake (Tempo, 2021). The severity of the BTS damage is still under further investigation, with the possible cause ranging from a power outage to structural damage.

Figure 3.13 Road closures due to landslides (Left source: Liputan.com 2021; Right source: Twitter 2021b)

4.0 Impacts on Community Resilience

The USGS PAGER tool initially estimated the probability of fatalities and economic losses from this earthquake as relatively low and indicated a Green Alert immediately after the earthquake (Fig. 4.1). This is possibly related to the low estimated ground shaking (Fig. 2.3) and the low population density in the immediate vicinity of the epicenter. The day after the earthquake, the USGS PAGER tool estimate was updated with new data, such as the large shaking intensity described in Section 2 or the reported initial number of casualties, as shown in Figure 4.2. The new estimates were that the fatalities would be less than 1, between 1 and 10, between 10 and 100, and between 100 and 1000 with probabilities of 10%, 35%, 40%, and 14%, respectively (Fig. 4.2). There were 84 casualties at the time this briefing was authored, with over 600 more were injured. Economic loss was expected to be less than $1 million, between $1 million and $10 million, between $10 million and $100 million, and between $100 million and $1,000 million with probabilities of 7%, 33%, 43%, and 15%, respectively.

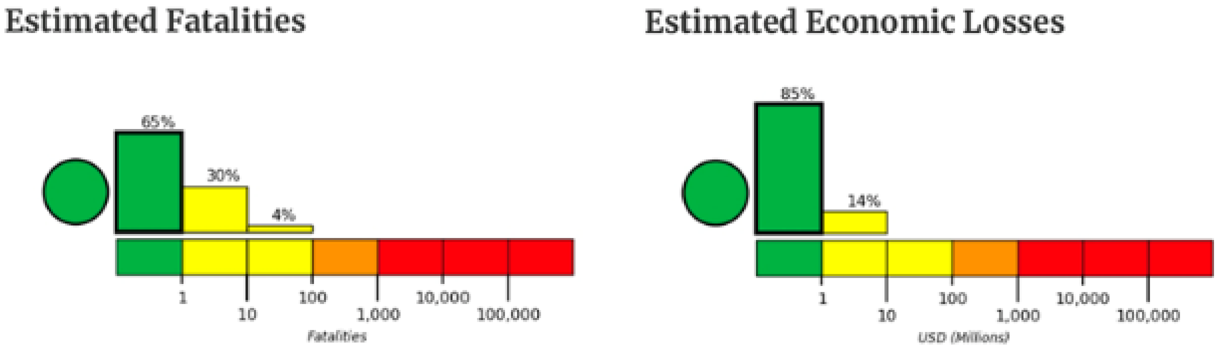

Figure 4.1 Initial USGS PAGER estimated fatalities (left) and economic losses (right) captured at 18:01 UTC on January 15th, one day after the earthquake.

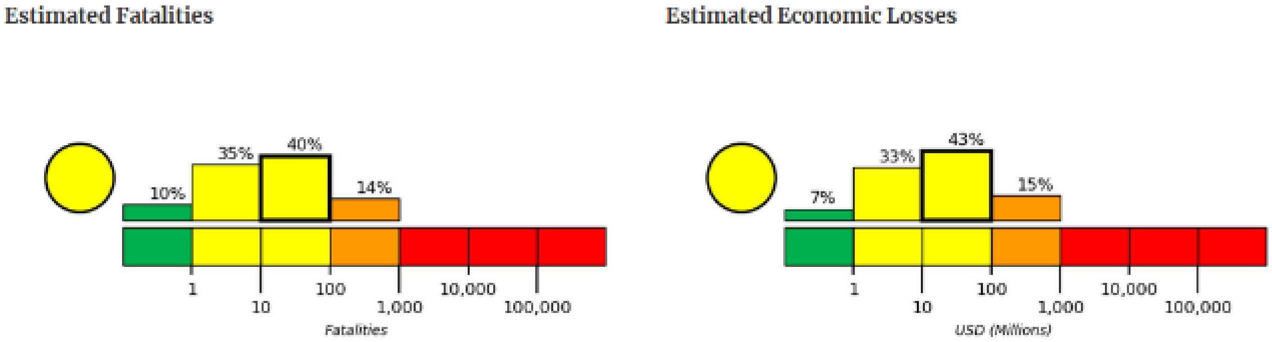

Figure 4.2 Updated USGS PAGER estimated fatalities (left) and economic losses (right) captured at 23:30 UTC on January 15th (USGS, 2021).

The earthquake resulted in significant disruptions to the community. More than 15,000 people have been temporarily displaced in 10 evacuation sites, which is expected to increase as assessments continue. The earthquake interrupted the road between Majene and the provincial capital Mamuju at three different locations, impairing rescue and recovery actions. Power, communications and the fuel supply have also been disrupted (Reliefweb, 2021).

The earthquake resulted in at least 84 deaths (Regan & Jamaluddin, 2021) and hundreds of injuries. Notably, the 5.7 magnitude foreshock the day before this earthquake might have played a role in reducing fatalities and injuries. This strong foreshock resulted in some damage (CNN, 2021a) and might have heightened awareness of the population leading into the night of the 6.2 magnitude earthquake.

5.0 Emergency Response

The Government of Indonesia sent the emergency response team to Mamuju right after the earthquake (Jawa Pos, 2021). The Indonesian National Board for Disaster Management (BNPB) coordinated this effort. The military forces (army, navy, and air force) and the National Search and Rescue Agency (Basarnas) were sent to help evacuate the victims and secure the area. Volunteers from the Indonesian Red Cross (PMI) were also sent to the location to assist with victim care. The Ministry of Social Affairs also sent some relief packages, consisting of food, mattresses, tents, etc. to help the victims. Moreover, the government also provided some psychosocial counseling for the affected people.

Damaged roads and bridges, power outages and lack of heavy equipment slowed down the emergency response and rescue operations (Time, 2021). This highlights the importance of continued functionality of various infrastructure after earthquakes, not only for fast recovery of the communities from the earthquake, but also for promptness of emergency response.

6.0 Recommendations for Further Study

At present, StEER has not deemed it necessary to elevate this response to issue a Preliminary Virtual Reconnaissance Report (PVRR) or formally activate a Field Assessment Structural Team (FAST) in response to this event. Rather, StEER's present response takes the form of this Event Briefing, which shares with the community StEER's impressions of the event and implications for natural hazard research and practice. Information provided herein was gathered from various websites. Therefore, this briefing does not include insights from detailed field investigations. Contacts in Indonesia indicate that while field observations will likely be collected, these will be delayed due to the current focus on search and rescue. StEER will continue to monitor this event and should those field observations result in new knowledge to be shared, StEER will reactivate its VAST and compile a PVRR. The notice of these actions will be communicated to the community through StEER's standard channels.

According to the observations herein, several topics may require further investigation:

1. The accuracy of the recording with 0.7g PGA and 69.8 cm/s should be investigated. If this data is found to be reliable, the reasons for such large shaking intensity approximately 33 km from the epicenter should be explored. Furthermore, if found reliable, this data can be used to update seismic hazard maps of Indonesia and/or site coefficients used to amplify the ground shaking based on specific site conditions.
2. Buildings that collapse during strong earthquakes are generally older buildings that are designed and constructed before the modern advances in earthquake engineering. However, one of the collapsed buildings in this earthquake is a government building constructed in 2010, which should have been designed according to current seismic codes. Therefore, it is essential to explore the reasons for this collapse in order to adequately prepare against future earthquakes. Particularly, it should be explored whether this collapse is due to the unexpectedly large shaking or lack of seismic details, adequate ductility or energy dissipation

capacity or issues with the construction such as inadequate quality control.

3. Seismic performance of other new and retrofitted buildings in this earthquake should be documented to be able to assess the adequacy of these new designs and retrofits in potential future earthquakes in Indonesia.
4. The seismic resistance of reinforced concrete structures, particularly non-ductile concrete structures without seismic details, should be carefully assessed in light of the regional seismic hazard in Indonesia. Concrete buildings where beam depth is larger than 1.5 times column depth and lacking proper transverse reinforcement in beam-column joints are susceptible to collapse in even moderate shaking. Several buildings are believed to have collapsed during this event due to shear/axial failure of insufficiently reinforced concrete beam-column joints. Experimental and strength models of seismic vulnerability of such joints experiencing axial failure leading to collapse are presented in (Hassan and Moehle 2012 a, b).
5. Reasons for the relatively good performance of the Mamuju local power utility office building with a seemingly soft story (Fig. 3.8) can be further explored with numerical simulations.
6. New buildings will need to be constructed to replace the collapsed buildings as well as those that are damaged beyond repair. For the design and construction of these new buildings, the feasibility of using protective systems (base isolation, supplemental damping, etc.) needs to be evaluated, which may have significant potential benefits in the medium-long term. Several economic protective systems have been developed (e.g., Jampole et al., 2017), which can be considered to promote a “build back better” strategy for Indonesia.
7. Regional scale simulations (e.g., Xu et al., 2020) should be conducted for identifying critical transportation routes and making it a priority to ensure their post-earthquake functionality or to develop alternative routes.

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Appendix: Videos of Live Earthquake Shaking and Damage

A video taken just after the earthquake can be seen here:
https://video.sindonews.com/play/10554/kondisi-kota-mamuju-pasca-gempa-62-sr-terekam-video-amatir
Another video capturing the damage in the city of Mamuju:
https://www.youtube.com/watch?v=MSFMjg3Q6rg&ab_channel=BangBenOfficial
A video of the damaged mall in Mamuju:
https://www.youtube.com/watch?v=vKVt7t2bYiU&ab_channel=Muh.Ma%27sumIswar
A video taken inside the mall during the foreshock earthquake:
https://www.youtube.com/watch?v=mmqYml3t6Zg&ab_channel=Mlandin6435
A video of an evacuation process: https://www.cnnindonesia.com/tv/20210115104709-400-594086/video-detik-detik-evakuasi-korban-gempa-majene
A video taken inside the governor’s office during the foreshock earthquake:
https://www.dailymotion.com/video/x7yp0jr
A video/recording of the collapsed Governor Office site:
https://www.instagram.com/p/CKDwHe_IqjX/