NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING

Post-earthquake building safety evaluation training, Palu, Indonesia

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ABSTRACT

Palu City and other parts of Central Sulawesi were severely impacted by a M_W 7.5 earthquake and tsunamis on 28 September 2018 as a result of a rupture of the Palu–Koro Fault. The earthquake resulted in 4,400 deaths and ~US$910M of damage. The official building assessment process, immediately following the earthquake, was primarily a damage and loss assessment to determine compensation for home-owners. Safety was not a high priority and there was no official placarding. Public buildings were assessed by National Public Works engineers, but the assessment method used is unknown.

An MFAT funded team from New Zealand, with Indonesian partners Universitas of Gadja Mada (UGM) travelled to Palu in March 2020 to facilitate training of local engineers to carry out post-earthquake rapid building assessments. 18 months after the earthquake, there were still numerous damaged buildings in Palu. To provide case examples, a selection of buildings were assessed using an evaluation form developed by UGM and based on ATC-20-2. Despite the training being postponed due to Covid-19, several recommendations have been made to improve the UGM process, form and associated building placarding. These include more focus on being 'rapid,' an emphasis on safety, and one placard per building.

The buildings assessed were typical reinforced concrete frames with unreinforced masonry infill walls, and recurring observations were made of construction detailing that led to poor seismic performance or made post-earthquake assessment difficult. Significant improvements in seismic resilience could be gained from relatively minor changes to building construction and the consideration of seismic design for non-structural elements.

1 INTRODUCTION

Parts of Central Sulawesi were impacted by a magnitude M_W 7.5 earthquake and a series of tsunamis on 28 September 2018 as a result of a rupture of the Palu-Koro Fault (Figure 1). The earthquake resulted in 4,400 deaths and approximately US$910M (~IRD13T) of damage. Nearly 70,000 houses were reported to be damaged and hundreds of office and commercial buildings were badly damaged by the earthquake shaking and tsunamis.

To assist with recovery, the New Zealand Ministry of Foreign Affairs and Trade (MFAT) funded the Recovery Support for Central Sulawesi project implemented by GNS Science and supported by Universitas Gadjah Mada (UGM), Beca International Consultants Ltd (Beca), Miyamoto International New Zealand Ltd (Miyamoto) and Universitas Tadulako (UNTAD). The project has two output activities: (i) Earthquake Damage Building Assessments and Training, and (ii) Training to Improve Earthquake Resistant Design, Permitting and Construction in Palu ('Build Back Better').

The project team travelled to Palu in March 2020; however, due to the outbreak of COVID-19 had to depart prior to delivering the training associated with output activity 1. This is now intended to be delivered at a later date in conjunction with output activity 2. This paper provides an overview of the activities and findings to date, starting with a summary of the earthquake and its impacts, then followed by observations of earthquake damage to structures made by the team, and discussion of post-earthquake response. A more comprehensive report is provided in Glassey et al. (2020).

2 THE 2018 PALU-DONGGALA EARTHQUAKE AND TSUNAMIS

The 2018 Palu-Donggala earthquake was a M_W 7.5 event that occurred on 28 September 2018 at 18:02 local time (10:02 UTC) in the Central Sulawesi province of Indonesia. The epicentre of the earthquake was 72 km north of Palu City at a depth of 10 km, with a fault rupture length of 150 km along the Palu-Koro Fault. Figure 1 shows the epicentral location of the mainshock. The mainshock was preceded by a series of foreshocks, including a M_W 6.1 event at 15:00 local time, and was followed by 14 aftershocks with magnitude greater than M_W 5.0 in the first 24 hours.

2.1 Tectonic setting and seismic hazard

The Palu–Koro Fault (Figure 1) is the major active fault in Central Sulawesi, with prominent topographical expression from Palu to some 120 km or more to the south. The fault is a major tectonic boundary. Fault motion is predominantly left lateral strike slip with a lesser vertical component. The slip rate is estimated to be about 35 mm per year and it is interpreted to be connected to the Matano Fault at its southern end (Bellier et al. 2001; Daryono 2016). As a result of this tectonic setting, the Central Sulawesi province, and Palu in particular, has been assessed as having a very high seismic hazard. Instrumented records of earthquake shaking are not readily available, but USGS estimated the maximum shaking was about 0.7 g (GEER, 2019). This intensity slightly exceeds the seismic shaking estimated for a 1:500-year return period.

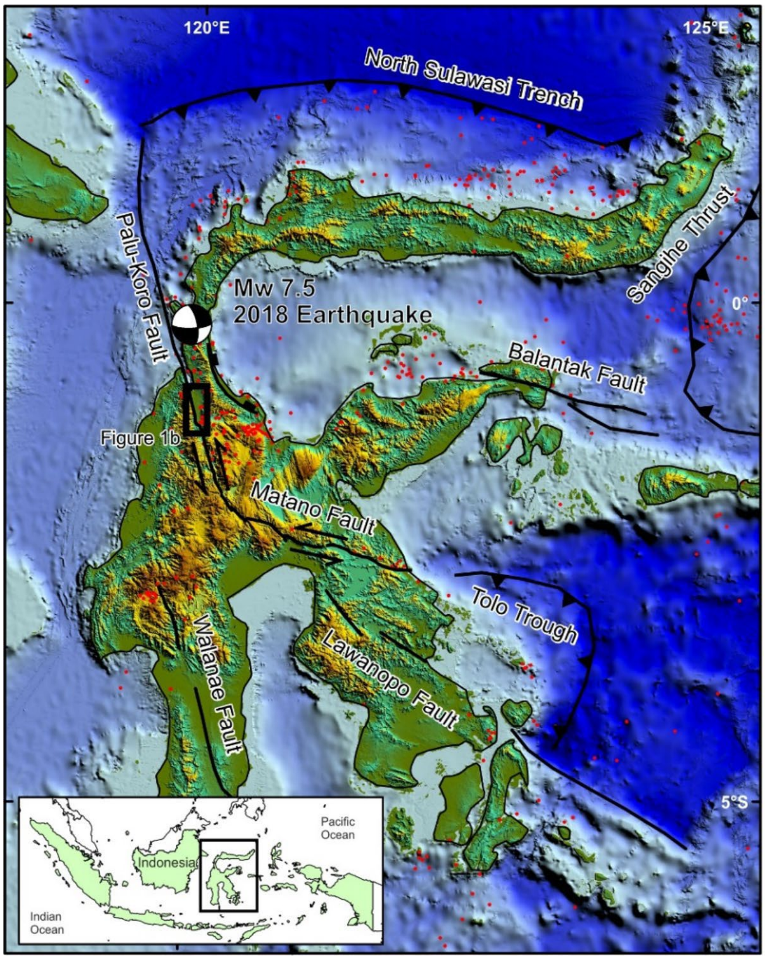

Figure 1: Tectonic map of Sulawesi showing major structures in the region. Red dots indicate earthquake hypocentres with a magnitude greater than 4.5 and a depth less than 30 km between 1980 and 2016 (from the USGS Earthquake Catalogue). Moment tensor of the Mw 7.5 2018 earthquake is also shown.

2.2 Earthquake impacts

The earthquake shaking caused widespread damage to buildings and infrastructure, including several significant collapses of major structures. It also generated liquefaction-induced low angle landslides (defined as flowslides), which buried whole communities, and a series of tsunamis triggered by submarine landslides within the harbour.

Of the 4,400 fatalities, approximately 500 deaths resulted from building collapse; 1,000 as a result of the tsunamis and 2,900 from the earthflows (including 667 people declared missing). There were 4,438 major injuries, damage to 68,451 homes, and displacement of 206,494 people (AHA, 2018). The provincial capital of Palu City, which has a population of approximately 350,000 inhabitants, suffered the most significant human and economic losses. The large loss of life made this earthquake the deadliest natural disaster worldwide in 2018, and the deadliest earthquake to affect Indonesia since the 2006 Yogyakarta earthquake.

Construction in the region consists of a range of engineered and non-engineered structures. The non-engineered structures are typically single-storey buildings used for residential purposes and are constructed from timber frames with sheet metal walls and roofing. Engineered structures are generally constructed using reinforced concrete frames with unreinforced masonry infill. The StEER (2019) report noted that earthquake shaking affected the entire perimeter of Palu Bay; however, most damage was observed in Palu City, which sits on deep alluvial soil layers. Damage due to earthquake ground shaking was more prevalent in the engineered structures rather than the lightweight non-engineered timber structures.

3 FIELD OBSERVATIONS OF DAMAGE TO BUILDINGS

During the time spent in Palu the project team undertook a number of field trips to view earthquake damaged engineered structures. The primary purpose of these field trips was to evaluate the suitability of these buildings for use in the workshop field exercises the following week; however, it also served as an opportunity to observe the damage they had incurred. Limited observations are reported herein.

3.1 Observations at Universitas Tadulako (UNTAD)

The project team visited UNTAD to observe a number of damaged buildings on the campus. The campus is located to the northeast of Palu City and comprises approximately 200 buildings. Most of the buildings are low-rise reinforced concrete frame structures, typically two to three storeys, and were constructed between 2010 and 2017. Damage ranged from minor damage to non-structural elements through to complete collapse.

Figure 2 shows three of the more significantly damaged buildings on the campus. The auditorium is a large reinforced concrete frame building with clay brick masonry infill. No clear damage was observed in the frame elements; however, the interior could not be viewed due to the risk from falling debris. The majority of damage was observed to relate to non-structural elements – in particular, masonry infill, glazing and lightweight cladding. One of the unreinforced masonry gables had completely collapsed, which was not surprising given its very large out-of-plane span (see Figure 2).

Figure 2: Field observations at Universitas Tadulako. Auditorium with out-of-plane failure of large unreinforced masonry gable (top left), Faculty of Forestry with complete collapse of ground floor (top right), Faculty of Forestry joint shear failure (bottom left), and Faculty of Law ground floor column shear failure (bottom right).

The Faculty of Forestry is a three-storey reinforced concrete frame building used for meetings and lectures. During the earthquake it completely lost its ground storey while the upper two storeys remained relatively intact. Although it is not possible to identify the mechanism that initiated collapse, it would appear that the lack of horizontal joint reinforcing, resulting in joint shear failure, was a significant factor. A near identical building, the Faculty of Law, was located nearby but exhibited markedly different behaviour. Complete collapse did not occur in the Faculty of Law building; however, it appeared to have very little residual capacity. In this case the most obvious failure mechanism was shear failure in the 'short columns' on ground level, adjacent to masonry infill. Severe damage to the exterior beam-column joints was also noted.

3.2 Observations in government buildings

The project team also visited a number of government buildings in close vicinity to one another in Palu City. It is understood that most of the buildings visited were constructed between 2002 and 2015. Damage observed ranged from minor to near collapse. Two buildings of particular interest were the Palu City Mayor's Office and the Main Palu Fire Station, shown in Figure 3.

The Mayor's Office is a two storey RC frame building with masonry infill. It has an approximate figure eight shape in plan and is split into several seismically separate units. Minimal damage was observed from the exterior and was similarly limited in the interior, except at the location of seismic gaps. Masonry infill was typically constructed across the gap, thus resulting is significant damage to the infill, which in itself potentially poses a life safety risk. The area adjacent to the most significant damage was no longer being used, but the remainder of the building was occupied.

The Fire Station is a two storey RC frame and masonry infill building. On the road-facing elevation at ground there is no infill (to allow vehicle access) and on the opposite elevation there is partial height infill. This configuration resulted in virtually all lateral load being carried by 'short columns' on the stiffer side of the building. As shown in Figure 3, these columns appeared to be on the verge of losing their axial load capacity.

Figure 3: Field observations of government buildings. Large crack in a masonry partition wall crossing a seismic joint in the Palu City Mayor's Office (left), and failure of 'short' columns in the Main Palu Fire Station (right).

3.3 Summary of damage observations

Across the range of buildings inspected, there were a number of recurring observations of construction detailing that likely led to poor seismic performance or made post-earthquake assessment challenging. Several examples of these are listed below:

- Lack of horizontal reinforcing in beam-column joints. This appeared to have the most significant impact amongst the limited sample of buildings that were observed.
- Use of plain round bars (where deformed would typically be expected), insufficient embedment/development length of reinforcing, and 90^o stirrup bends.
- Extensive use of masonry infill, which was observed to have led to short column effects in a number of buildings. Furthermore, the stiffness of the infill is unlikely to have been accounted for in the design and thus may have induced behaviour not anticipated by the designer, e.g. vertical stiffness irregularity.
- Very large span unreinforced masonry gables, which suffered from out-of-plane collapse.
- Vulnerable non-structural elements.
- Heavy plaster finishes and cladding around key structural elements. Whilst not a specifically Indonesian issue, it was difficult to ascertain the likely damage state of several buildings due to limited observation of key structural elements.

It is noted that most of the above items are by no means novel and have been observed in past earthquakes in Indonesia (e.g. Bothara et al., 2010).

Most structures visited were relatively modern and would have been required to be designed in accordance with modern Indonesian building standards, which include seismic design requirements. The observed damage would therefore tend to indicate that poor building performance was more related to the implementation of design code requirements (be it during design or construction) rather than the design code itself.

4 POST-EARTHQUAKE RESPONSE

4.1 Overview of the response to the Palu-Donggala earthquake

The evaluation of damaged buildings after the 2018 Palu-Donggala earthquake began a week after the earthquake, which was marked by the arrival of teams from the Ministry of Public Works (PUPR) and from the Research Institute for Human Settlements. The teams worked together with Central Sulawesi Provincial Public Works and Palu City Public Works to evaluate the damaged buildings. The buildings that were prioritized for evaluation were the community houses (residential and typically non-engineered). The main purpose of the evaluation was to determine the level of damage in relation to the government fund assistance programme for the communities whose houses were damaged by the earthquake.

Before conducting the evaluation of the community houses, the Central Government Team firstly gave 2-3 hours training to around 20-25 personnel from the Provincial and City Public Works staff and University of Tadulako Engineers. Practical field demonstrations were held on nearby streets, with training focused on understanding the category of damage level of community houses and the method of filling out the rapid visual screening form. Three damage levels are defined in the form and compensation provided to the owners on the basis of the damage level, as shown in Table 1.

Teams also evaluated damage to engineered buildings owned by the Provincial Government and the City of Palu. For these buildings an evaluation form developed by a private consultant was used. None of these

Table 1: Compensation provided to owners of earthquake-damaged community houses.

Damage state	Compensation
Severely damaged if the quantity of damage is more than 50%	IDR. 50 million
Moderately damaged if the quantity of damage is between 30% to 50%	IDR. 25 million
Lightly damaged if the quantity of damage is 0-30%	IDR. 10 million

buildings were assigned placards, the forms were not provided to the building users and results were only conveyed verbally. Currently, most of the government office buildings, hospitals and trading centres are still being used even though the condition might be slightly damaged to moderately damaged and some hazards may exist.

4.2 Recommendations based on recent NZ experience

In addition to the information provided in Section 4.1, other details regarding the post-earthquake response have been gathered from informal conversations with building occupants, university engineers, and the Emergency Management Agency (BPBD). This information forms the basis of the discussion below; however, it is limited, given that formal discussions have not been held with PUPR to gain a broader understanding of the response. It is noted that post-earthquake response in Indonesia has previously been investigated in response to the 2009 Padang earthquake and is reported in Brunsdon et al. (2010).

A well planned, coordinated response following a significant earthquake is essential to minimise the impact on the community and speed up the recovery process. Rapid building assessments are a key part of this response, but there is much more involved to coordinate resources and manage the whole process across the impacted area. For reference, an overview of how the wider rapid buildings assessment process is carried out in New Zealand is provided in Figure 4.

4.2.1 Building assessment resources

It is apparent that having sufficient people to perform rapid building assessments immediately following an earthquake has been a big challenge in recent earthquakes in Indonesia. PUPR arrange for assessments to be carried out, but the focus of these is quantifying the level of damage for compensation claims, not public safety – this is discussed further below. Academics from engineering schools around Indonesia appear to be heavily relied on by local government for assessing public buildings. Private engineering consultants responded to their clients on request, but little is known about the quantity of assessments and timeframes for these being carried out.

Building up a resource of trained building assessors throughout Indonesia is recommended to improve the capacity to carry out widespread building assessments in a short period of time. Preferably these people would be distributed about the country but able to mobilise to another part of the country when required.

To enable this, a consistent approach to the assessment procedures should be agreed and implemented. It is also recommended that this procedure has two levels of assessment, the first being an external evaluation that can be carried out as part of the initial triaging of buildings to improve the overall efficiency of the building assessments.

It is also suggested that the large resource of private consultants is utilised more as part of the coordinated response. Past experience in New Zealand is that most private consultants look after their own clients as well as offering some resources on a volunteer basis to assist with the Local Government response. Considerable effort is also made to ensure that the assessment carried out on behalf of the clients is fed back to National

Emergency Management Agency (NEMA) to ensure this effort is part of the coordinated response and building assessments are not duplicated.

4.2.2 Greater focus on safety

4.2.2.1 Public safety

A large number of the building assessments carried out following the 2018 Palu-Donggala Earthquake were focused on quantifying damage for determining the level of compensation. These assessments did not consider whether the building was fit for occupancy, rather this decision was left to the building owners or occupiers. The results of these assessment were only passed on to the building occupants verbally, a placard was not placed on the buildings, and the assessment form was not provided.

After a substantial earthquake, the priority during the immediate response should be public safety. Among other things, this includes determining whether buildings can be safely reoccupied, bearing in mind there will be frequent aftershocks. It is recommended that building assessments that consider public safety and usability are carried about for all public and private buildings within defined affected areas as soon as possible following the event – small, non-engineered structures could be excluded. This should include placarding the buildings as a key way to communicate to the public about the status of each building. These assessments should take priority over determining compensation, which is also important but more appropriate for the recovery stage.

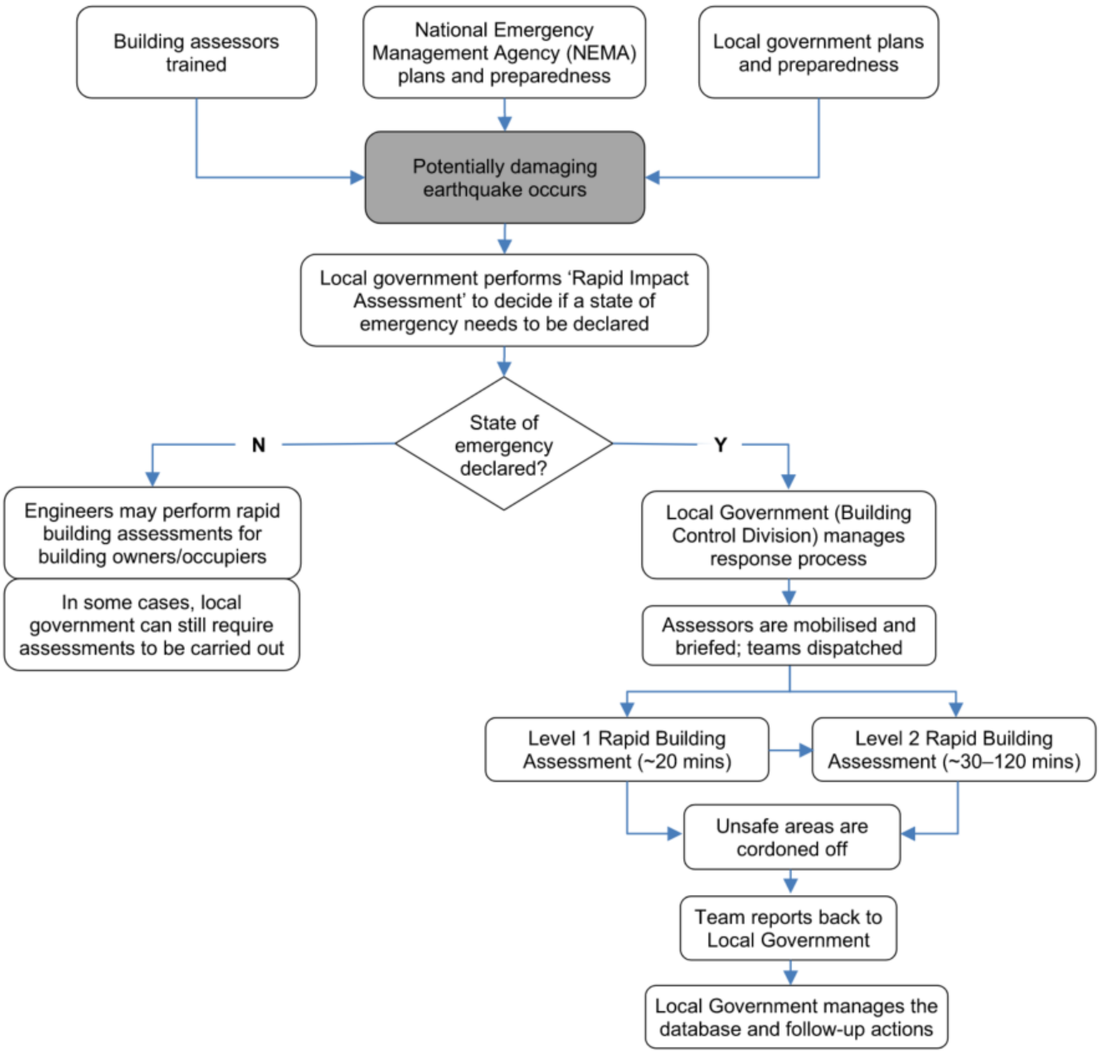

Figure 4: Overview of the New Zealand Rapid Building Assessment procedure.

4.2.2.2 Assessor safety

It is widely known that health and safety in South East Asia is not treated with the same level of importance as it is in most western countries. It was evident during field trips to earthquake damaged buildings that there is often disregard for good health and safety practices. Perhaps the most significant concern was that often people would approach or enter buildings without stopping to consider whether it was safe to do so, or even necessary to enter the building. There appeared to often be a misplaced perception that the risk of future collapse was low, evident by groups of people working in or near to significantly damaged buildings. The project team made four recommendations for improved health and safety practices when undertaking assessments:

- Always undertake a comprehensive external inspection when arriving at a building.
- Have a mandatory hold point where the assessment group comes together, and a group decision can be made as to whether it is necessary to enter the building.
- Continue to assess risk once inside the building.
- Use personal protective equipment (PPE). As a minimum this would preferably include a hardhat, high-visibility vest, steel capped boots, and a mobile phone or other means of communication.

4.2.3 Strong-Motion Data

The project team visited the Palu Office of the Meteorology, Climatology and Geophysics Council (BKMG), which is responsible for operating the strong-motion sensors in the region. During this visit the team asked about obtaining strong motion data for the 2018 Palu-Donggola Earthquake but was informed that it is not publicly available. By comparison, after a significant earthquake in New Zealand, processed strong-motion data is generally available within a day or two of the event. Strong-motion data is an important tool to help engineers and other decision makers understand the severity of the earthquake and the seismic action buildings have been subjected to. It is therefore recommended that strong-motion data is made publicly available as soon as possible following significant earthquakes in Indonesia. It is noted that similar concerns around the paucity of accessible strong-motion data have been raised by other international teams during the immediate post-earthquake response (Mason et al., 2019).

5 UGM RAPID BUILDING ASSESSMENT PROCEDURE

5.1 The UGM post-earthquake building safety evaluation form

UGM has developed a post-earthquake building safety rapid evaluation form based on ATC-20-2 (1995) using estimated level of damage to structural and non-structural components of buildings that can be seen. It is considered that this form could help form the basis of a standard to be implemented by the Indonesian government for rapid building evaluation.

The form contains general information regarding the structure of the building, location of the building, use of the building, ownership (if known), details of the evaluator and the level of damage to structural and non-structural components.

Any damage to structural components of a building may cause partial or total collapse. Therefore, any obvious signs of damage to structural components of the building are initially assessed - for example has it collapsed or partially collapsed, is it leaning, or has it settled? Any of these conditions make it unsafe and no further assessment is required. If the building is intact, then further assessment of the structural components - columns, beams, beam-column joints, shear walls, bracings, and floor slab - is undertaken.

Non-structural components include stairs, wall partitions, windows, ceiling, roof and architectural ornaments, as well as electrical and mechanical equipment. Damage to non-structural components will not affect the stability of the building but will only reduce the building serviceability. Damage to non-structural components can however be hazardous, particularly in terms of a falling debris hazard, especially in the event of aftershocks, and can endanger occupants as well as those in the surrounding area.

5.1.1 Damage evaluation

Damage is divided into three levels, namely none/minor, moderate, and severe. These three levels of damage in structural and non-structural components are used to categorize the level of safety of the building. The level of damage is used as follows:

- If the level of damage to structural and non-structural components is severe and can cause a total collapse of the building or endanger the occupants, the building is categorized as 'unsafe.'
- If the level of damage to structural and non-structural components is moderate and does not really cause a total collapse of the building or does not endanger the occupants, the building is categorized as 'not so safe.'
- If the level of damage to structural and non-structural components is minor, the building is categorized as 'can be used again.'

It is important to note here that the above evaluation is qualitative. To provide more information on the degree of damage, the quantity of damage can also be estimated as percentages for the structural and non-structural components. However, the percentages do not affect the outcome of the evaluation. Suitably trained persons can carry out post-earthquake building safety evaluation by circling the appropriate answer of the multiple-choice damage questions and estimating the damage on the form. Using these criteria, the status of the building safety can be determined using notes at the end of form.

5.1.2 Placarding

Once the status of the building safety has been determined, it is then necessary to assign the appropriate placard. UGM utilises an "Unsafe" (red), "Restricted Use" (yellow) and "Can Be Used Again" (green) placard system. Damage to the structural components controls the building safety as a whole, whereas non-structural damage may only affect safety in a local area. Therefore, the rules of where to place the placards on buildings is managed are as follows:

- The placard which is determined by structural component damage is located at every building entrance.
- A placard can be located in every affected area or access to the affected areas or rooms which is determined by non-structural component damage.

If the level of structural damage is assessed as severe it is assigned a red placard. There is no need to stick other placards inside the building due to non-structural component damage. Evaluations inside such buildings must be avoided. In some cases, the level of non-structural component damage can be higher than the level of structural component damage and in this case the building would also be assessed as Red.

5.2 Recommendations for the UGM Rapid Building Assessment Procedure based on recent New Zealand experience

One of the key aspirations for this project is to provide input and feedback into the existing assessment procedures to assist towards a universal approach being adopted across Indonesia. The UGM Rapid Building Assessment procedure was reviewed and a number of recommendations for both the assessment form and the associated placards were made. A number of key recommendations for both the UGM form and placards are provided in the bullet points below, and are based on experience and lessons learnt from recent New Zealand earthquakes. It is acknowledged that the New Zealand and Indonesian contexts are very different and what works in New Zealand, may not work in Indonesia. Every attempt has been made to consider the specific

Indonesian context when making these recommendations. Some of these recommendations are aspirational and intentionally challenge the current thinking:

- **One placard per building –** The current UGM approach assigns one overall building placard and then potentially multiple other placards for individual areas of a building. Simple, clear messaging to the public is essential in a time of emergency to give them confidence in the processes that are being undertaken and what is expected of them. Having multiple placards per building increases the chance of confusion about the rating of the building and is more time consuming. It is suggested that a simpler single placarding system, such as that used in New Zealand and the United States, may be more efficient and effective. Unsafe sections of a building could be noted on the placard at the entrances and cordoned off if required.
- **Percentage of damage –** The current UGM approach asks the review to assign a percentage damage to each building element. This is potentially a time-consuming exercise and does not impact the final rating/placard of the buildings (this is assessed on the worst damage, not the distribution). Because the primary focus of the rapid building assessment is speed and maintaining public safety, it is recommended that this is either removed, noted as not compulsory, or encouraged to be a rough estimate only.
- **Cordons/Barriers -** There is currently no provision on the UGM form for noting cordons and barriers. Cordons and barriers can play an important part in reducing the risk to the public or building occupants during aftershocks. For example, if the façade of a building is damaged, the building assessor may decide it's necessary to cordon off the footpath to prevent the public walking under the dangerous façade. Practically, the assessor will only be able carry barrier tape with them during inspections, but more permanent barriers may be necessary, e.g. fences, shipping containers – these can be installed as part of the further actions. It is recommended that some prompting for cordons or barriers is provided on the form to get assessor to think about this.
- **Use of "Safe" (Green) Placard –** The current UGM Green Placard includes the statement "This building is safe but be careful with the following things." Based on experience in New Zealand, and to provide some protection to the assessor, it is recommended that any statement about the building being "safe" should be removed. It could be reworded to say, "No obvious structural problems were observed but be careful with the following things."
- **Restricted Use (Yellow) Placard –** The current UGM Yellow Placard does not state what restricted access means. A clear description of what restricted access means and/or instructions of how to comply should be included on this placard. This is important for the building owner or occupiers as the placard might be the only guidance they have. Restricted access could be to certain areas of the building, or it could mean that it should only be accessed for a limited time to retrieve important items. This should be communicated clearly on this placard.
- **Colour of Green Placard -** Green is the common colour worldwide for this type of placard; however, as a result of lessons learnt from the 2011 Christchurch earthquake, a white placard is now used in New Zealand. This is due to the perceived positive affirmation that the colour green gives to the safety of the building. Whereas because the rapid assessment is looking at damage to the building, not the overall earthquake risk, white was deemed more appropriate to represent that the structure of the building is essential unchanged, i.e. a more neutral colour. Consideration should be given to what is the most appropriate colour in the Indonesian context.

6 CONCLUSIONS

A team of New Zealand and Indonesian engineers has travelled to Palu following the M_W 7.5 Palu-Donggala earthquake in 2018 to assist in post-earthquake response training. Although the training could not be delivered due to the COVID-19 outbreak, valuable observations were made regarding the response of structures and post-earthquake response.

Significant damage was observed in relatively modern reinforced concrete structures and is likely attributable to a number of poor design and construction detailing practices that have been previously reported following earthquakes in Indonesia and elsewhere. These include lack of horizontal joint reinforcement, 'short column' effects caused by non-structural infill, and lack of seismic considerations for non-structural elements. It was also observed that a number of construction practices made post-earthquake inspections challenging, such as the use of heavy plaster finishes.

The post-earthquake response appears to have been focused on evaluating compensation. The project team's view is that it would be preferable for post-earthquake assessments to be able to draw on a greater pool of resources and place greater emphasis on rapid safety evaluation. Most importantly these included clear communication through the use of a single placard per building and greater emphasis on a rapid triaging process, which could then be followed by a more detailed assessment.

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