The sample below illustrates the final product. If you wish to see the original Word document with edits in tracked changes, please email alice@crealitygroup.org.

Geotechnical Review and Recommendations

The 2018 Central Sulawesi earthquake and tsunami generated multiple landslides (flow slides) along the area affected by strong ground motions. Most human losses in the Central Sulawesi Region are attributed to km-size, massive slides of the alluvial valley sediments. Most of the large slides within the Palu valley are located in the eastern and northern parts of the valley. The northernmost slide occurred on the west side of the valley, in the densely populated Balaroa neighborhood (Valkaniotis et al. 2018).

With the exception of the areas where major and catastrophic flow failure took place (namely Balaroa, Petobo, Jono Oge/Sigi, and Sibalaya), foundations performed well for the level of shaking, with very little (if any) noticeable contribution to the superstructure damage and/or collapse. The overall effects of liquefaction-related hazards appeared relatively minor compared to the damage caused by shaking fault rupture and sliding (block sliding).

Following the joint Miyamoto International and World Bank site visits in January and February 2019, a third visit was organized between April 1 and 3, 2019 in the areas affected by the earthquake.

This visit provided an invaluable learning experience, as it allowed rapid access to the sites of interest, enabled the observation of key geotechnical and geological features, and offered an opportunity for valuable technical discussions and further understanding of the nature, extent, and damaging mechanism of the earthquake.

The team's primary objectives were to (1) collect data that may be used to understand the sequence of events and general failure mechanisms resulting in large landslides and ground movements and (2) provide general geotechnical recommendations for the seismic strengthening of public schools, hospitals, and healthcare buildings.

To facilitate this work, the team:

- Undertook a review of the existing hazard map—i.e., the December 2018 Palu Disaster Zone Map (Peta Zona Ruang Rawan Bencana Palu Dan Sekitarnya (Alternatif 1))—for liquefaction-related hazards, as well as the background technical documentation used to develop those maps
- Compiled a geotechnical recommendations report for necessary geotechnical investigations with a view to constructing or rebuilding of public schools and healthcare facilities (clinics and hospitals)

The present report provides a reconnaissance-level description of the types and extent of landslides and other ground damage triggered by the September 28, 2018 Central Sulawesi earthquake and tsunami, as well as the consequent damage to infrastructure and the built environment.

The team used the December 2018 Palu Disaster Zone Map as a critical and valuable starting point for the geotechnical procedure recommended in this study. However, the map requires immediate revision as soon as the detailed geotechnical investigation, evaluation, and assessment are completed.

The Indonesian National Standard (SNI) 8460:2017 "Geotechnical Design Requirements" establishes the requirements for geotechnical design in the country. According to the Standard, simple design procedures can be used for structures and earthworks with low levels of complexity and risk. The preliminary recommendations contained in this document were developed according to Geotechnical Categories 1, 2, and 3 detailed in the Standard.

The comments and preliminary suggestions included in this report for the hazard zones identified in the December 2018 Palu Disaster Zone Map are based on Indonesian geotechnical practice and SNI 8460:2017.

Review of Existing Seismic Upgrade and Engineering Code Documents

The review focused on structural seismic upgrade and engineering code documents issued by the Government of Indonesia. While the present report is not specifically aimed at code review or development, its objective is to highlight elements of the code that should be reviewed. Such revision should be based on updates to or deviations from international standards such as the International Building Code and referenced standards, as well as observations made during the visitation of over two hundred sites in the first phase followed by the seismic strengthening assessments of almost three thousand school, healthcare, and commerce (market) buildings and the subsequent analysis.

Section 3 and Appendix A highlight specific code sections and items that are recommended to be reviewed. The high-level items identified are as follows:

- Indonesia needs a national-level document centered on structural seismic strengthening, analysis, and rehabilitation similar to the American Society of Civil Engineers 41.[1] Establishing a single referenced document for this purpose would provide clarity on requirements both for the engineering and design industry and code enforcement officials.
- Material specification and identification sections are needed. While portions of international codes have been adopted, the parallel material definition documents are not defined. For example, ASTM provides many of the material specifications for concrete (such as portland cement, by type) to be used in structural applications.
- Much of the building code components draw on foreign code documents. When adapting codes, it is important to ensure that the assumptions within the base code are applicable in the location of adoption. For example, building construction practices and the availability of building materials often vary regionally, as do the properties and behaviors of materials such as steel.

Construction Quality Management

While codes and standards establish rules, and detailed engineering documents represent the project construction process, without quality control and assurance, these documents are not representative of the anticipated performance if they are not followed and implemented as intended.

Enforcement is another topic that emerged during visits to construction sites and interviews with industry professionals and university professors. Enforcement mechanisms should be strengthened to compel the industry and builders toward compliance. One of the issues often associated with compliance is cost; however, costs can be counterbalanced by large gains in quality and resilience with (1) the integration of digital tools, (2) the implementation of a tiered quality management system, (3) the institution of self-funding certification systems, and (4) the institutionalization of the practice.

Central Sulawesi Seismic Strengthening Program

In implementing the Central Sulawesi Seismic Strengthening Program, the following key observations were made:

- The implementation of a seismic risk reduction program can be cost-effective and when targeted, can significantly reduce seismic risk of loss of life in the building stock.

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[1] the American Society of Civil Engineers 41 is the governing standard referenced for this purpose under the International Building Code.

- When implementing new construction and seismic strengthening, quality control and assurance are critical.
- A single, national structural seismic strengthening code for use across building types should be developed and implemented as part of the project.
- When adopting a code, the incorporation of unified material specifications under the structural components of a building code is critical, because materials often vary regionally.
- With respect to seismic design requirements, Indonesian structural building codes largely mirror the codes used in the United States of America; however, adaptations should be integrated and reviewed.
- The geotechnical field reconnaissance highlighted the unique geotechnical conditions that resulted in large liquefaction flows. Efforts were made in the months immediately following the 2018 seismic event to develop geotechnical hazard maps. These maps provide guidance and highlight the concern; however, detailed mapping and studies identifying the specific mechanism and triggers should be the basis of geotechnical investigations for recovery and reconstruction.

1. Geotechnical Reconnaissance and Document Evaluation

1.1 Acronyms and Notations

BPTP	Center for Agricultural Technology Studies	www.jakarta.litbang.pertanian.go.id/ind/
GEER	Geotechnical Extreme Events Reconnaissance	www.geerassociation.org
GoI	Government of Indonesia	
MCE_G	maximum considered earthquake	
mCPT	x	
PGA	peak ground acceleration	
PKF	Palu-Koro Fault	
S_1	1-second spectral acceleration	
S_S	short-period spectral acceleration	

1.2 Introduction

According to Geotechnical Extreme Events Reconnaissance (GEER) Association report (Mason et al. 2019), a moment magnitude 7.5 earthquake struck north of Palu, Indonesia on September 28, 2018 at 6:02 p.m. local time (10:02 a.m. UTC). The earthquake caused severe damage to buildings and infrastructure and is responsible for 4,340 fatalities, including 667 people who had been declared missing. The earthquake triggered a series of massive landslides, resulted in the collapse of both unreinforced and reinforced structures, and generated tsunami waves that impacted coastal areas in Palu Bay, devastating Central Sulawesi. A substantial majority of the fatalities were directly related to landslides, making this one of the most significant landslide disasters of the past several decades.

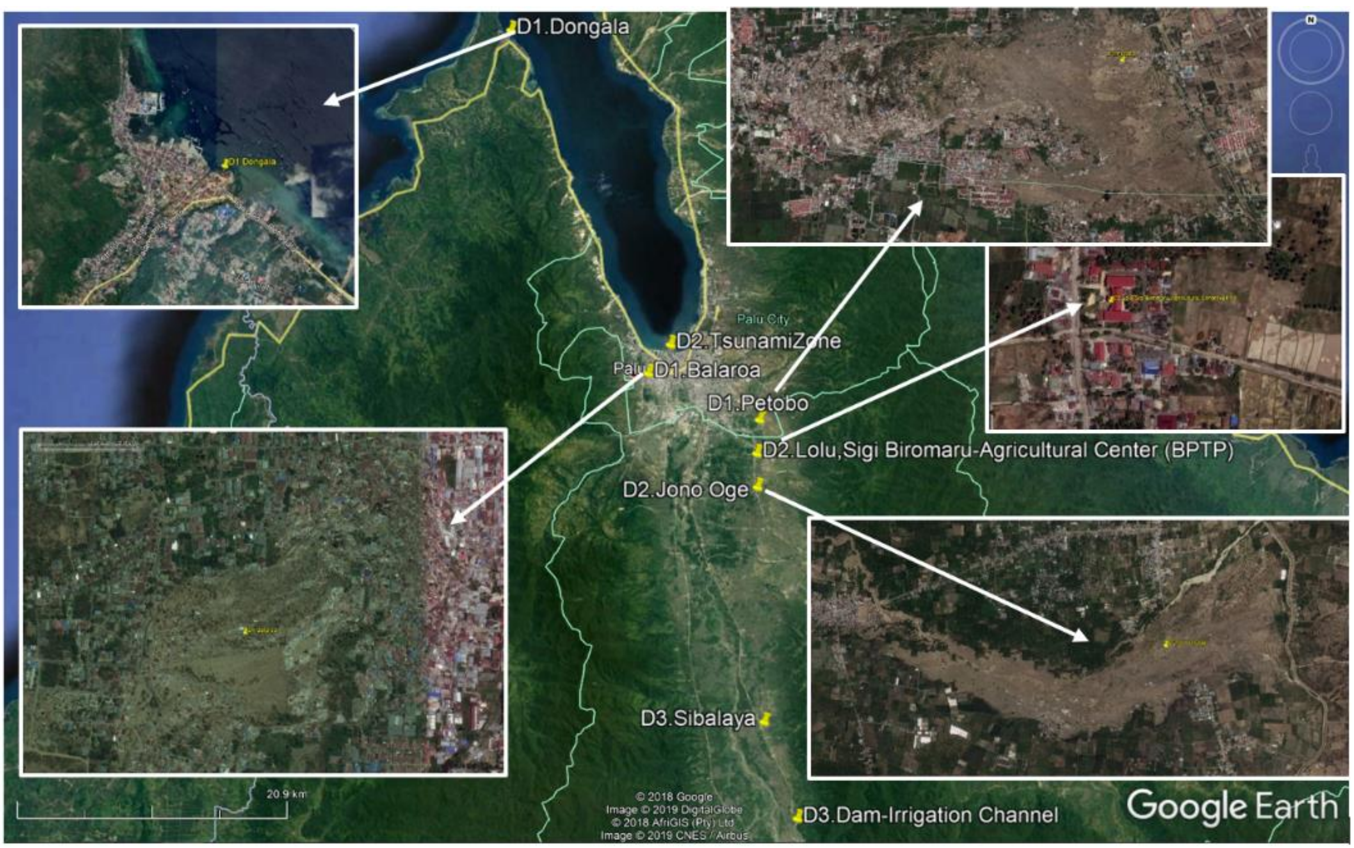

Figure 1. Areas visited by the Miyamoto team

Figure 1 shows the main places of interest that were visited for the purposes of the reconnaissance survey about six months after the earthquake. In addition to the field visits, the team also conducted meetings with regional officials and other stakeholders to obtain further insight into the response and ongoing investigation.

During the reconnaissance survey, the team visited some of the areas affected by the tsunami. However, the team's focus was on the large flow slides and landslides within Palu City, Sigi, and Donggala. The large flows were of major geotechnical interest and required the development of a rehabilitation and reconstruction approach.

The team's primary objectives were to (1) collect field data (observations, visual inspections, discussions with locals, etc.) that may be used to understand the sequence of events and general failure mechanisms resulting in large landslides and ground movements and (2) provide general geotechnical recommendations for the and reconstruction effort and seismic strengthening of public schools, markets, hospitals, and healthcare and government buildings.

To facilitate this work, the team:

- Undertook a review of the existing hazard map—i.e., the December 2018 Palu Disaster Zone Map (Peta Zona Ruang Rawan Bencana Palu Dan Sekitarnya (Alternatif 1))—for liquefaction-related hazards, as well as the background technical documentation used to develop those maps
- Compiled a geotechnical recommendations report for necessary geotechnical investigations with a view to constructing or rebuilding of public schools and healthcare facilities (clinics and hospitals)

The present report provides a reconnaissance-level description of the types and extent of landslides and other ground damage triggered by the 2018 Central Sulawesi earthquake and tsunami, as well as the consequent damage to infrastructure and the built environment. The observation of the performance of the buildings and infrastructure in response to the strong ground motions and associated ground damage also provided a unique opportunity to assess how certain construction methods and materials performed. The team was helped greatly by Indonesian colleagues to understand the background and context of the observed hazards and their impacts.

The team's findings are based on visual analysis of the images and videos, the available publications, and prior studies listed in the reference section. No soil sampling or analysis was conducted as part of this investigation. In addition, event seismic response data was not available for use as part of this study. It is the understanding of Miyamoto that additional in-depth soil mapping and analysis is currently underway with the Government of Indonesia (GoI) and other partners.

1.3 The September 28, 2018 Central Sulawesi Earthquake and Tsunami

1.3.1 Seismicity and tectonic features

As described by Putra et al. (2012),

> The Indonesian archipelago is located at the boundary of three major tectonic plates, the Indo-Australian, Pacific, and Eurasian plates, stretching from Sumatra in the west to Papua in the east. Indonesia is at the collision point of these three crustal plates. The high subduction-related seismicity in this region means that tsunami and other earthquake hazards are also high. […]
>
> Sulawesi Island, one of the eastern islands of the Indonesian region, is located at the junction between the converging Pacific-Philippine, Indo-Australian Plates and the Eurasian Plate. Sulawesi tectonic evolution has resulted from successive collisions of continental slivers, island arcs, and oceanic domains with the Sunda land. Sulawesi is obliquely crossed by one of the main fault systems limiting the Eurasian Plate to the East, the left-lateral Central Sulawesi Fault System (CSFS), which comprises

two fault zones, the NNW-trending Palu- Koro and the WNW trending Matano fault zones, connects, from north-west to south-east, the North Sulawesi Subduction zone (NSS) to the Banda Sea domain.

The most prominent geologic structure in Central Sulawesi is the strike-slip[2] Palu-Koro Fault (PKF), oriented NNW-SSE and extending more than 300 km through Palu Bay and the city itself. The PKF connects to the North Sulawesi Trench subduction zone north of the island (see Figure 2).

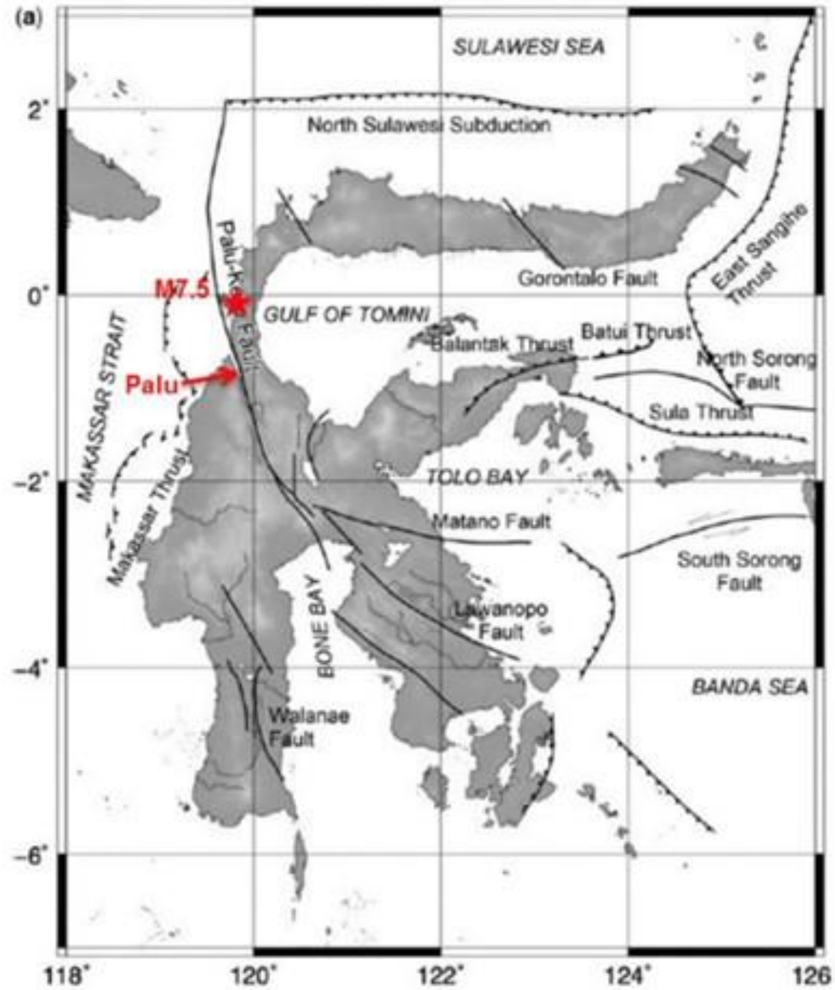

Figure 2. Seismicity of Sulawesi island and September 2018 earthquake location along the PKF (Cipta 2017)

[2] Strike-slip faults are characteristic when movement relative to the other side is parallel and in opposite directions. The rate of slip depends on the fault location.