Mw 5.6 Indonesia Earthquake

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PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

Virtual Assessment Structural Team (VAST) Lead:
Henry Burton, University of California, Los Angeles

Virtual Assessment Structural Team (VAST) Authors:
(in alphabetical order)
Samuel Dwima, University of California, Los Angeles
Danny Gho, National Taiwan University of Science and Technology
Xingquan Guan, ZEST AI
Selim Gunay, University of California, Berkeley
Abhineet Gupta, Marqueta
Zeyad Khalil, Imperial College London
Novia Kusumayani, Ganesha University of Education (Undiksha) (Indonesia)
Marko Marinković, University of Belgrade, Serbia
Yvonne Merino-Pena, Pontificia Universidad Católica de Chile, Chile
Chukwuebuka Nweke, University of Southern California
Amir Safiey, Auburn University

PVRR Editors:
(in alphabetical order)
Khalid M. Mosalam, University of California, Berkeley

PREFACE

The National Science Foundation (NSF) awarded an EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network (see https://www.steer.network for more details). StEER was renewed through a second award (CMMI 2103550) to further enhance its operational model and develop new capabilities for more efficient and impactful post-event reconnaissance. StEER builds societal resilience by generating new knowledge on the performance of the built environment through impactful post-disaster reconnaissance disseminated to affected communities. StEER achieves this vision by: (1) deepening structural engineers' capacity for post-event reconnaissance by promoting community-driven standards, best practices, and training, as well as their understanding of the effect of natural hazards on society; (2) coordination leveraging its distributed network of members and partners for early, efficient and impactful responses to disasters; and (3) collaboration that broadly engages communities of research, practice and policy to accelerate learning from disasters.

Under the banner of the Natural Hazards Engineering Research Infrastructure (NHERI) CONVERGE node, StEER works closely with the wider Extreme Events Reconnaissance consortium to promote interdisciplinary disaster reconnaissance and research. The consortium includes the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Interdisciplinary Science and Engineering Extreme Events Research (ISEEER), Nearshore Extreme Event Reconnaissance (NEER), Operations and Systems Engineering Extreme Events Research (OSEEER), Social Science Extreme Events Research (SSEER), and Sustainable Material Management Extreme Events Reconnaissance (SUMMEER), as well as the NHERI RAPID equipment facility, the NHERI Network Coordination Office (NCO), and NHERI DesignSafe CI, curation site for all StEER products.

While the StEER network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Southeast Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER is currently expanding its network of regional nodes worldwide to enable swift and high-quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for each of the primary hazards as well as cross-cutting areas of Assessment Technologies and Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI),** University of Notre Dame, serves as StEER Director responsible for overseeing the design and operationalization of the network and representing StEER in the NHERI Converge Leadership Corps.
- **Khalid Mosalam (co-PI),** University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, serving as primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI),** University of Florida, serves as StEER Associate Director for Wind Hazards, serving as primary liaison to the Wind Engineering community.
- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Coastal Hazards, serving as a primary liaison to the coastal engineering community and ensuring a robust capacity for multi-hazard assessments.
- **David Roueche (co-PI),** Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data suitable for re-use by the community.

This core leadership team works closely with StEER Research Associates, Data Librarians and its Student Administrator in event responses, in consultation with its Advisory Boards for Coastal, Seismic and Wind Hazards.

ATTRIBUTION GUIDANCE

Reference to PVRR Analyses, Discussions or Recommendations

Reference to the analyses, discussions or recommendations within this report should be cited using the full citation information and DOI from DesignSafe (these are available at https://www.steer.network/products).

Citing Images from this PVRR

Images in this report are taken from public sources. Each figure caption specifies the source; re-use of the image should cite that source directly. Note that public sources might still have copyright issues and depending on the use case, the user may need to secure additional permissions/rights from the original copyright owner.

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This material is based upon work supported by the National Science Foundation under Grant No. CMMI 2103550. Any opinions, findings, and conclusions or recommendations expressed in this material are those of StEER and do not necessarily reflect the views of the National Science Foundation. All authors and editors listed on the cover page participate as volunteer professionals. Thus, any opinions, findings, and conclusions or recommendations expressed herein are those of the individual contributors and do not necessarily reflect the views of their employer or other institutions and organizations with which they affiliate.

Special thanks also go to our Student Administrator, Ella, for monitoring outage/access and restoration data used in this report.

The sharing of videos, damage reports and briefings via Slack by the entire NHERI community was tremendously helpful and much appreciated. StEER recognizes the efforts of the DesignSafe CI team who continuously supported and responded to StEER's emerging needs.

For a full listing of all StEER products (briefings, reports and datasets) please visit the StEER website: https://www.steer.network/products

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EXECUTIVE SUMMARY

A magnitude 5.6 earthquake occurred in West Java, Indonesia, on November 22, 2022. While most of the damage was limited to the town of Cianjur, the shaking caused by the earthquake was felt as far as the capital city of Jakarta. At the time of writing this report, a total of 169 aftershocks were reported with the largest magnitude being 4.2. The epicenter of the earthquake is in the Cimandiri Fault Zone and the depth of the rupture is approximately 11 km. The shaking from the event was recorded by 57 ground motion stations operated by the Badan Meteorologi, Klimatologi, dan Geofisika. The highest peak ground acceleration value recorded by the event was approximately 0.15 g at a station located approximately 14 km from the epicenter. A comparison of the response spectra from the recording at the same location showed that the shaking intensity did not exceed the design values in the most recent seismic code.

The death toll from the earthquake at the time of writing this report was 310, with approximately 1/3 of the fatalities being children. The damage to residential buildings, schools and government buildings was widespread. The National Disaster Mitigation Agency (NDMA) of Indonesia reported that a total of 63,219 residential units in the Cianjur Region were affected. A report from the Indonesian government indicated that more than 500 schools were damaged, ranging from kindergarten to the university level. Indonesia has well-established building codes that explicitly address the issue of seismic design. However, much of the observed damage appears to have been due to non-compliance between the constructed buildings and the regulating building standards. Lack of quality control, limited knowledge of the standards, and limited budgets appear to have contributed to the widespread damage. Most of the affected structures were 1- and 2-story buildings constructed using masonry infills, some of which are surrounded by concrete frames (intended as confined masonry). A preliminary assessment based on the photos of damaged buildings showed that in many cases, the masonry infill was unreinforced and not properly secured to the surrounding frame. Also, poor detailing of the concrete frames appears to be the cause of many catastrophic failures.

In addition to building damage, the earthquake caused the disruption of several lifeline facilities. For instance, while there is not yet documented damage to the transmission and distribution system, various reports have confirmed that there is a shortage of clear water that is attributed to earthquake damage to facilities. While power outages caused by the earthquake affected more than 300,000 customers, the electricity in approximately 89% of the affected area was restored within days of the earthquake. There was also disruption to the ground transportation caused by both direct damage to pavements and roadways as well as landslides, fallen trees and electricity poles.

The objectives of this report are to (1) provide details of the November 22 M 5.6 earthquake, (2) summarize the tectonic features of the event, (3) synthesize the recording ground motions and provide comparisons with design-level shaking, (4) briefly encapsulate the local building codes and construction practices and (5) provide a preliminary assessment of the damage to buildings and other infrastructure as well as the broader societal impacts.

1. Introduction

A magnitude 5.6 earthquake occurred in West Java, Indonesia on 11/21/2022 at 1:21 pm local time causing significant damage to the town of Cianjur. The earthquake, referred to herein as the West Java earthquake, was felt as far as Jakarta, the nation's capital which is located more than 60 miles from the epicenter (NYT, 2022). As of November 23, 2022, a total of 169 aftershocks were reported, ranging in magnitude from 1.2 to 4.2.

1.1. Social Impact and Loss of Life and Injuries

At the time of the writing of this report, the death toll from the earthquake was 310 with tens of thousands of homes destroyed and dozens of individuals still missing (NYT, 2022). There was widespread damage to residential buildings, schools, and some government buildings. The Indonesian government data reports that more than 500 schools, ranging from kindergarten to university, were impacted by the earthquake (Sinaga, 2022). Reports have indicated that as much as 1/3 of the casualties were school aged children below the age of 15 (UNICEF, 2022).

The USGS PAGER tool estimated fatalities to be 1 to 10, 10 to 100, 100 to 1000, and over 1000 with probabilities of 8%, 34%, 41%, and 15%, respectively, which is in line with the death toll reported in the above paragraph. PAGER estimated economic losses to be between $1 and $10 million, between $10 and $100 million, between $100 and $1,000 million, and between $1,000 and $10,000 million with probabilities of 6%, 31%, 44%, and 17% respectively. No published estimates of actual losses were available at the time of this report.

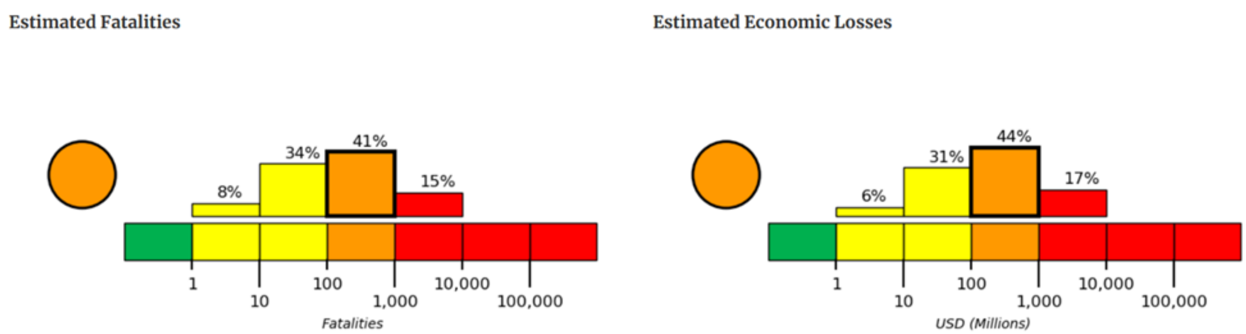


Figure 1.1 PAGER estimated probability of fatalities and economic losses (USGS, 2022a).

1.2. Official Response

As of one week following the earthquake, rescue operations continued but were hampered by heavy rains, landslide-blocked roads, and down communication lines (NYT, 2022). Because of a temporary power outage after the earthquake, many were treated in the car park of the Cianjur hospital (BBC, 2022a). The Ministry of Education, Culture, Research and Technology responded by sending tents, emergency family care and educational supplies to the affected region (Sinaga, 2022).

1.3. Report Scope

The initial product of the StEER response to the 2022 West Java earthquake is this Preliminary Virtual Reconnaissance Report (PVRR), which aims at:

1. Providing details of the November 22 M 5.6 earthquake.
2. Summarizing the tectonic features of the earthquake.
3. Synthesizing the recording ground motions and providing comparisons with the value used for design in terms of acceleration response spectra and peak values.
4. Briefly describing the local building codes and construction practices.
5. Summarizing the preliminary reports of damage to buildings and other infrastructure as well as the impacts on the affected region in terms of fatalities, casualties, and service disruption of different types of facilities.

2. Hazard Characteristics

This section has been largely informed by the report prepared by the Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) (translated in English to the Meteorology, Climatology, and Geophysical Agency) (BMKG, 2022) and the information available on the USGS website (USGS, 2022b).

2.1. Earthquake Features and Tectonic Summary

The 2022 Cianjur earthquake occurred on 21 November, 13:21 Jakarta Time (06:21 UTC) with the epicenter of the earthquake located at 6.86° S 107.01° E (Figure 2.1) at a depth of 11 km (Emeria, 2022). The area where the earthquake occurred is in a known seismically active region, with the epicenter located at the nearby Cimandiri Fault Zone (CFZ in Figure 2.2). BMKG reports suggest that the earthquake was caused by the known Cimandiri Fault with strike-slip mechanism. 169 aftershocks, as of 12.30 PM Jakarta Time on November 23, 2022, were reported, with the magnitude ranging from 1.2 to 4.2 (Daryono, 2022).

The Cimandiri fault (Cretaceous age) stretches along 100 km starting from Pelabuhanratu Bay, Sukabumi continuing to the east through the Cimandiri Valley, Cipatat-Rajamandala, Mount Tangkubanprahu-Burangrang and assumed to continue to northeast towards Subang. Overall, this fault path is trending northeast-southwest with fault types ranging from thrust faults to oblique faults (BMKG, 2022).

The earthquake is characterized by a shallow depth of 10 km and occurred because of the strike slip faulting within the crust of the Sunda plate. The USGS ShakeMap estimated a MMI of IX in the epicentral region, as shown in Figure 2.3 (USGS, 2022b). The focal mechanisms indicate that the rupture occurred on either a steeply dipping north-striking, right-lateral strike-slip fault, or a steeply dipping east-striking left-lateral strike-slip fault (USGS, 2022a). Located around 260 km southwest of the event, the Australia plate moves north-northeast at an approximate rate 59 mm/yr with respect to the Sunda plate, subducting at the Sunda Trench.

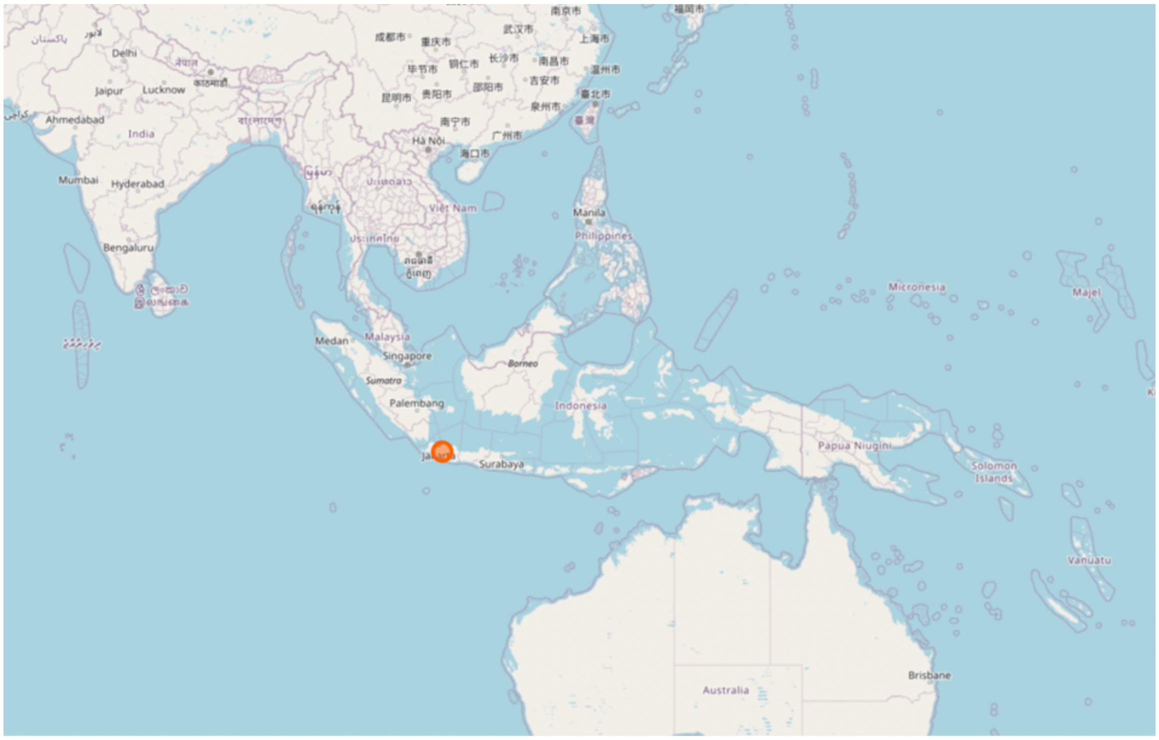


Figure 2.1 - OpenStreetMaps showing the earthquake location with respect to the broader region.

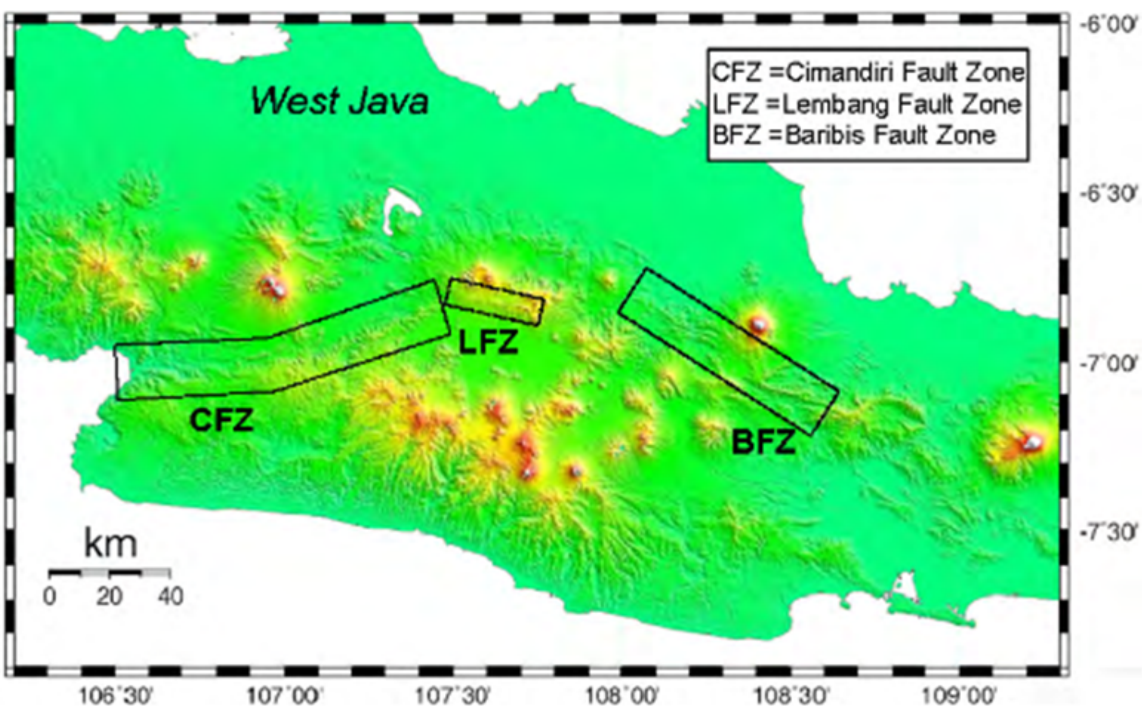
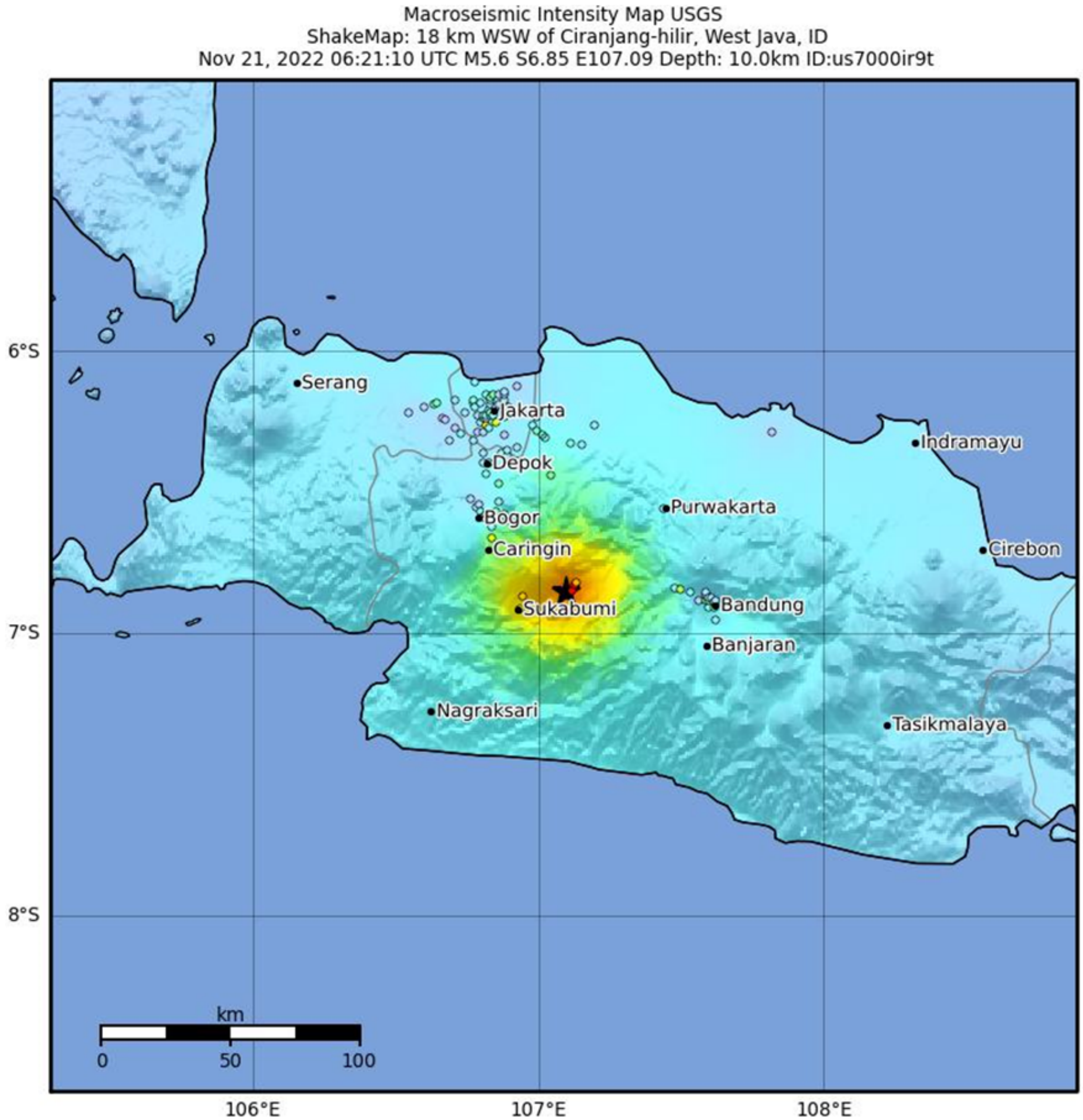


Figure 2.2 Map of faults in the West Java Region. The West Java earthquake epicenter is located nearby the Cimandiri Fault Zone (Abidin et al, 2009)



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 5: Processed 2022-11-22T06:22:41Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter

Figure 2.3 - Intensity map for the November 21, 2022, M 5.6 Indonesia earthquake estimated from ShakeMap obtained on 2022-11-29 (USGS, 2022b).

The region located at the plate boundary between the Sunda and Australia plates is highly seismically active as shown in Figure 2.4, where strong earthquakes have occurred in the past within each of the Australia and Sunda plates, in addition to the plate interface. There have been four earthquakes of M 6.5 or larger events within 250 km of the November 21, 2022, earthquake since 2007, where the largest of these events was a M 7.5 on August 8, 2007, that occurred at a depth of about 280 km within the subducted Australia plate (USGS, 2022a).

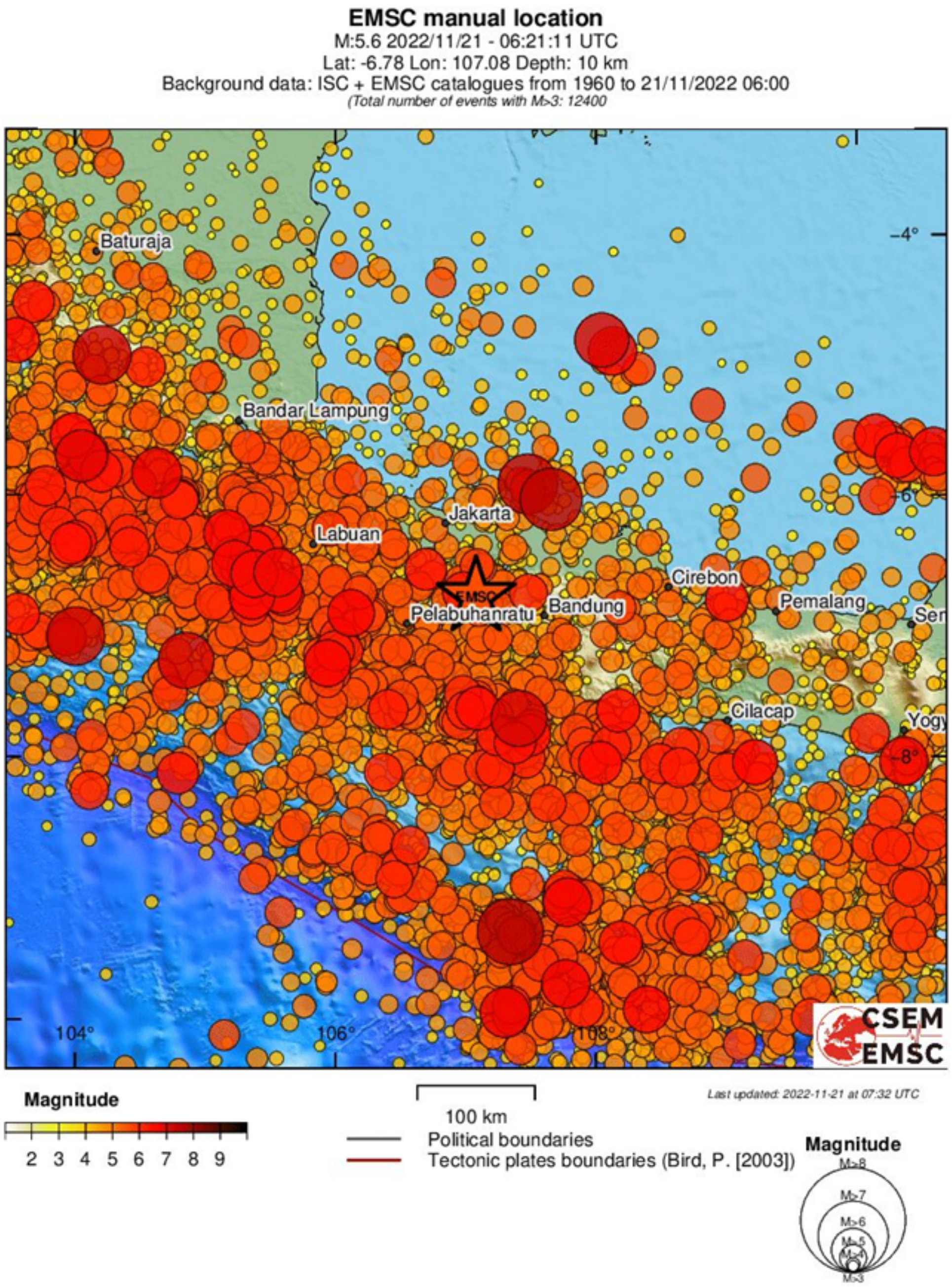


Figure 2.4 - Regional instrumental seismicity in the vicinity of the November 21, 2022, M 5.6 Indonesia earthquake (EMSC, 2022).

2.2. Recorded Ground Motions

57 ground motion stations operated by BMKG recorded the earthquake event, with the nearest station located 13.93 km from the earthquake epicenter and the farthest one located 403.22 km from the epicenter, as shown in Figure 2.5 (BMKG, 2022). An accelerogram of the earthquake motion, from the nearest BMKG station (REIS Kadudampit (DSJR) station), is shown in Figure 2.6.

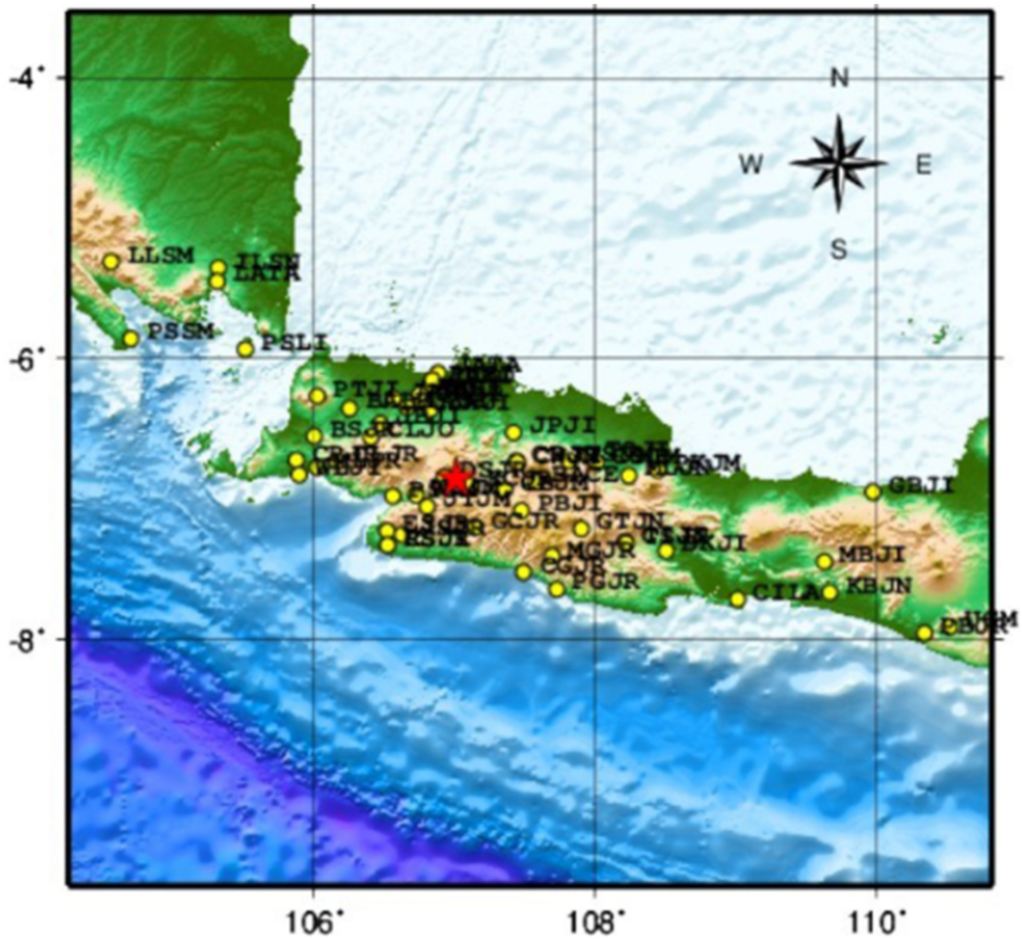


Figure 2.5 - Earthquake epicenter (marked with red star) and the accelerograph station that record the earthquake activities (marked with yellow circle) (BMKG, 2022).

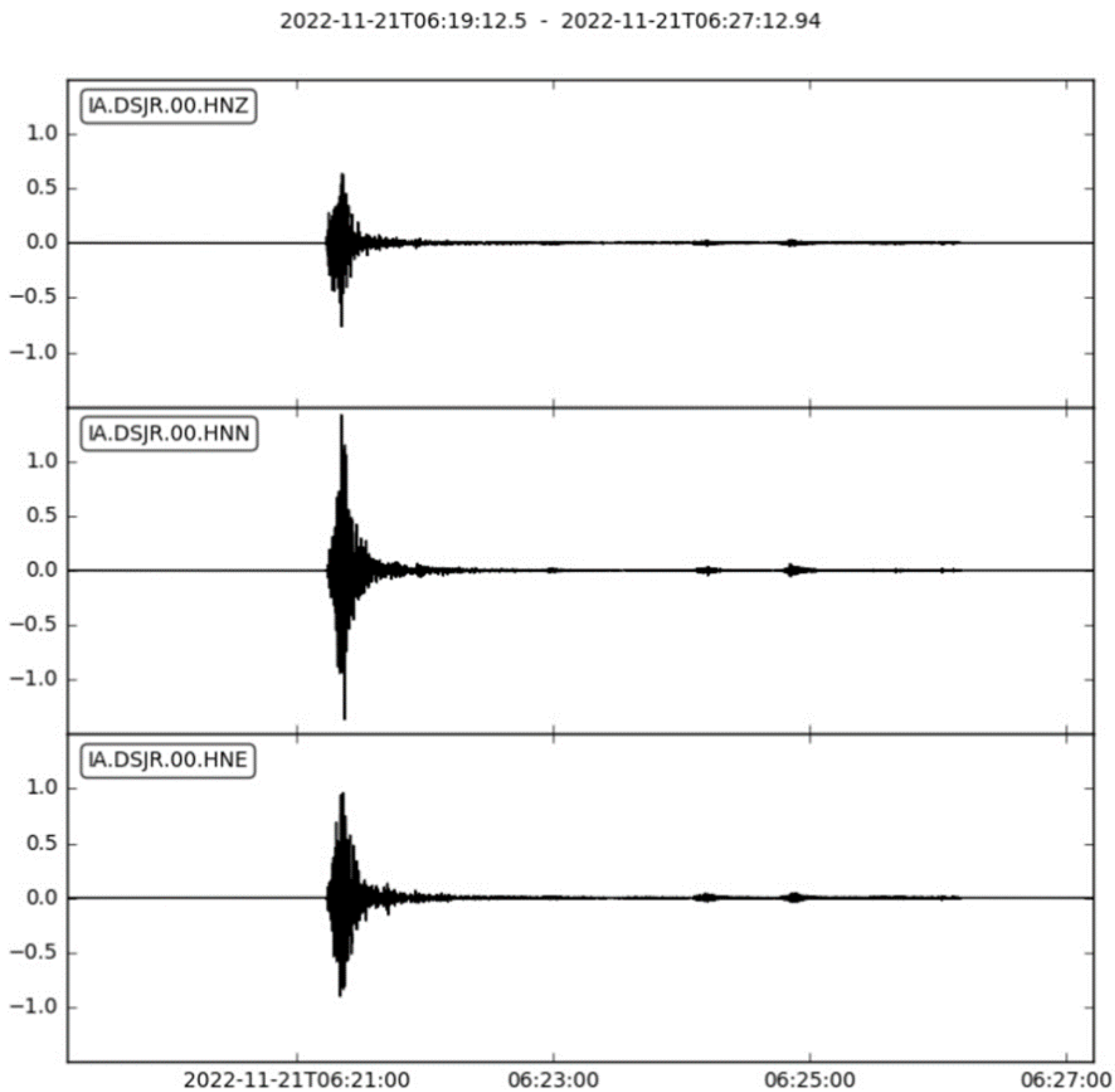


Figure 2.6 - Accelerogram record from Reis Kadudampit Station (BMKG, 2022)

Figure 2.7 shows the list of seismic stations, their distance in km (column Jarak), and the recorded PGA.

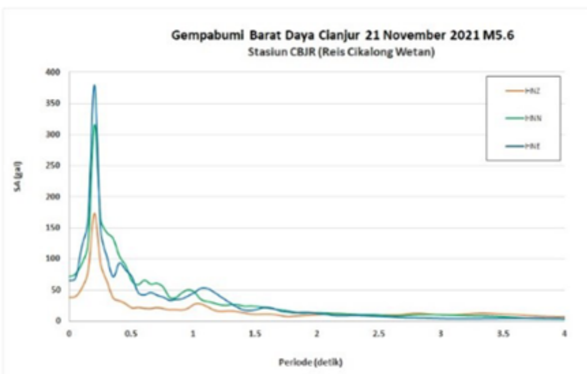
No	IdSta	Stasiun	Latitude	Longitude	Jarak	PGA-EW(gal)	PGA-NS(gal)	PGA-UD(gal)	Site Cl
1	DSJR	REIS Kadudampit	-6.846	106.924	13.93	96.1155	142.5410	76.3900	
2	KCJR	REIS Pasir Kelapa	-6.906	107.111	15.64	25.0890	13.2055	11.5885	
3	JTJM	Jampang Tengah,Sukabumi,Jawa Barat	-7.057	106.802	32.18	13.4319	15.6418	6.1965	
4	WSJM	Warungkiara,Sukabumi,Jawa Barat	-6.975	106.725	34.24	21.8854	18.9787	9.4609	
5	CBJM	Cipongkor,Bandung Barat,Jawa Barat	-6.935	107.355	39.02	20.3654	29.7381	16.8746	
6	GCJR	REIS Pagelaran	-7.206	107.143	41.14	12.1549	13.9640	5.3332	
7	CBJR	REIS Cikalong Wetan	-6.735	107.439	49.02	65.6424	71.7576	38.5983	
8	CWJM	Cikalong Wetan,Bandung Barat,Jawa Barat	-6.742	107.445	49.41	34.4303	26.0063	10.6271	
9	PSJM	Pelabuhan Ratu,Sukabumi,Jawa Barat	-6.985	106.560	51.18	8.3565	5.9819	3.4310	
10	PBJI	Station Type B, Pasir Jambu	-7.087	107.476	56.77	6.4876	4.1670	2.3275	
11	JPJI	Jatiluhur,Purwakarta,Jawa Barat	-6.531	107.418	57.50	2.3775	7.3196	4.9421	
12	JAUI	KAMPUS UI DEPOK	-6.367	106.827	57.84	3.6603	2.5382	2.3814	D
13	JSJR	REIS Jampang Kulon	-7.257	106.625	60.65	9.3080	15.8319	4.4031	
14	BACE	STA GEOF CEMARA BANDUNG	-6.883	107.580	62.33	1.5249	1.4553	1.0084	D
15	JABI	BALAI BESAR WIL II CIPUTAT	-6.303	106.757	67.21	2.2295	2.8920	2.4294	D
16	ESJR	REIS Ciemas	-7.233	106.519	67.48	14.1140	8.6789	4.4374	
17	TASE	KANTOR BAPETEN PUSPITEK SERPONG	-6.352	106.663	67.54	0.9516	1.4288	0.6693	D
18	AMGI	KAMPUS AMKG	-6.265	106.749	71.37	0.8751	0.7497	0.9300	D
19	JAPE	STA KLIM PDK BETUNG	-6.261	106.751	71.67	0.9349	0.9467	0.5890	D
20	JBJI	Jasinga,Bogor,Jawa Barat	-6.470	106.470	72.96	2.5872	2.5647	1.7326	
21	CLJO	RANGKAS - VSAT	-6.566	106.404	73.67	2.1874	1.6758	0.8477	D
22	CSJI	Ciracap,Sukabumi,Jawa Barat	-7.330	106.521	74.31	10.3811	6.0025	2.4069	
23	RSJR	REIS Ciracap	-7.331	106.520	74.42	7.3333	6.2965	2.6656	
24	JAKO	KANTOR BALAI KOTA JAKARTA	-6.181	106.829	77.19	3.7897	1.6170	1.5592	
25	PUSI	KANTOR PUSAT I (FREE FIELD)	-6.156	106.841	79.59	2.6068	1.9571	0.9398	E
26	JARU	STA MET CURUG TANGERANG	-6.287	106.564	79.67	0.9898	0.8428	0.4969	D
27	JATA	STA MAR TANJUNG PRIOK	-6.108	106.881	83.92	0.7811	1.0025	0.9153	E
28	TSJM	Tanjungsiang,Subang,Jawa Barat	-6.732	107.811	88.61	3.7612	3.2644	1.5494	
29	CGJR	REIS Caringin-Garut	-7.523	107.489	89.74	2.0345	2.3765	1.1035	
30	CLJR	REIS Cigemblong	-6.735	106.159	93.97	7.0844	6.9727	2.2334	
31	MGJR	REIS Pamulihan	-7.410	107.692	95.93	2.1531	3.0527	1.0741	
32	BALB	PEMKAB LEBAK	-6.362	106.251	99.46	0.7634	0.8702	0.3518	D
33	TOJI	Tomo,Sumedang,Jawa Barat	-6.702	107.954	104.63	2.4069	3.3702	1.5259	
34	GTJN	BPBD Garut - VSAT	-7.215	107.902	104.98	0.4577	0.5106	0.2401	D
35	MLJR	REIS Malingping	-6.779	106.020	108.58	4.5198	4.9804	2.0198	
36	CSJM	Congeang,Sumedang,Jawa Barat	-6.741	108.010	110.10	1.4867	1.3857	1.0114	
37	BSJR	REIS Banjarsari	-6.558	106.000	115.36	3.0125	3.2320	0.9682	
38	PGJR	REIS Pameungpeuk	-7.646	107.728	116.77	1.1887	1.0035	0.3881	
39	WLJI	Wonosalam,Lebak,Banten	-6.831	105.891	122.42	1.9169	2.0943	0.7615	
40	CPJR	REIS Cikeusik	-6.729	105.872	125.32	3.2703	5.6027	1.2995	
41	PTJI	Pondok Aren,Tangerang Selatan,Banten	-6.273	106.020	126.20	3.0027	3.6358	3.1919	
42	MLJN	BPBD Majalengka	-6.838	108.240	134.61	0.3410	0.3528	0.2940	
43	CIJI	Cipedes,Kota Tasikmalaya,Jawa Barat	-7.306	108.214	140.57	0.6752	0.7448	0.3420	
44	TSJN	BPBD Tasik - VSAT	-7.320	108.220	141.75	0.5625	0.4096	0.2401	D
45	PKJM	Pasawahan,Kuningan,Jawa Barat	-6.799	108.445	157.31	21.9883	13.8582	7.9674	
46	BKJI	Banjar,Kota Banjar,Jawa Barat	-7.372	108.505	173.19	1.7297	1.4416	0.7928	
47	PSLI	Rajabasa P. Sibesi,Lampung Selatan,Lampung	-5.937	105.510	193.60	0.8732	0.6889	0.3322	
48	CILA	STA MET CILACAP	-7.718	109.015	239.48	0.1764	0.2489	0.1245	D
49	LATA	STA MAR TANJUNG KARANG LMPG	-5.455	105.311	242.89	0.1107	0.1225	0.0500	D
50	ILSN	UNIVERSITAS TEKNOLOGI SUMATERA	-5.358	105.315	249.65	0.1999	0.1450	0.1392	
51	PSSM	Pematang Sawah,Tanggamus,Lampung	-5.864	104.695	277.35	0.2724	0.4616	0.8732	
52	MBJI	Station Majalengka Banjarnegara Jawa Indonesia	-7.449	109.632	295.18	0.0627	0.0539	0.0363	
53	KBJN	BPBD KEBUMEN - VSAT	-7.668	109.668	305.22	0.1637	0.1764	0.0951	D
54	LLSM	Limau,Tanggamus,Lampung	-5.313	104.551	320.30	0.2391	0.2048	0.1156	
55	GBJI	Gringsing,Batang,Jawa Tengah	-6.953	109.976	326.14	0.2107	0.2489	0.4292	
56	PBJR	REIS Pundong	-7.956	110.343	385.74	0.3891	0.2705	0.1872	
57	UGM	GEOFON Station Wanagama, Indonesia	-7.912	110.523	403.22	0.0745	0.0578	0.0402	

Figure 2.7 - Table showing observed PGA at the 57 seismic stations that recorded the mainshock event (BKMG, 2022).

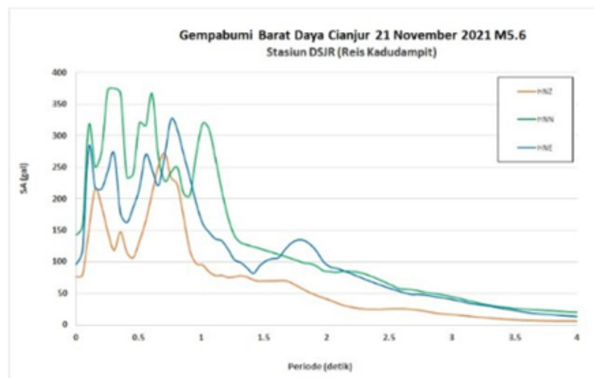
2.3. Response Spectra

BKMG used three ground stations to create the Response Spectrum (RS) shown in Figure 2.8. These stations are: (a) REIS Cikalong Wetan (CBJR), located 49.02 km from the epicenter with PGA of 65.64 gal (0.067 g)(EW), 71.76 gal (0.073 g) (NS) and 38.60 gal (0.039g) (UD), (b) REIS Kadudampit (DSJR), located 13.93 km from the epicenter with PGA of 96.12 gal (0.098 g) (EW), 142.54 gal (0.145 g) (NS) and 76.39 gal (0.078g) (UD), and (c) Cikalong Wetan, Bandung (CWJM), located 49.41 km from the epicenter with PGA of 34.43 gal (0.035) (EW), 26.01 gal (0.027) (NS) and 10.63 gal (0.011g) (UD).

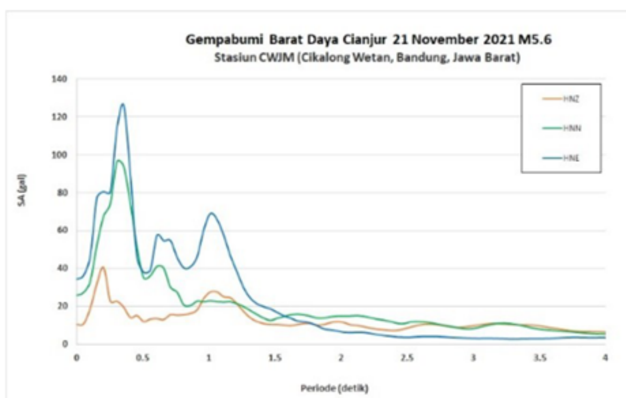
The closest station (DSJR) has high spectral content from ~0.1 to 1 sec. The other two stations have highest spectral content in 0.15 to 0.3 sec, with the CWJM also showing high spectral acceleration at ~1 sec. The CBJR response spectra indicates 310 gal (0.32g) of spectral acceleration in one of the horizontal directions at a period of ~0.2 sec. This implies that a building at the station's location with a first mode period of 0.2 sec will need to have a base shear capacity of 0.32 times its weight to experience no damage. Most buildings in this region are 1-3 stories masonry or RC construction and are expected to have first mode periods of 0.1-0.3 sec. Considering the small cross-section sizes and potentially low levels of material strengths, the base shear capacity normalized by weight was likely much smaller than 0.32, and this, combined with the non-ductile response characteristics not allowing any energy dissipation, could have caused the observed collapses. The high spectral content from the ground motions at the same frequencies as buildings' first mode can create a resonating effect in these buildings, causing high levels of shaking. High spectral acceleration at 1 sec as observed at DSJR and CWJM stations can cause shaking in tall buildings, which have higher first mode periods.



(a)



(b)



(c)

Figure 2.8 - Response Spectra generated from 3 ground motion records (BMKG, 2022). These stations are (a) REIS Cikalong Wetan (CBJR), (b) REIS Kadudampit (DSJR), and (c) Cikalong Wetan, Bandung (CWJM).

BKMG also compared the closest station (DSJR) station RS with the Indonesian code design spectrum (shown in Figure 2.9). It is observed that the acceleration spectrum of each of the horizontal and vertical components does not exceed the SNI 2019 (2/3 SNI) design spectra (unreduced without the response modification factors) for building and structures for each soil class (hard, medium, or soft) (BMKG, 2022). The design spectra from SNI 2019 may be higher than previous design codes (Wyat Engineering, 2020).

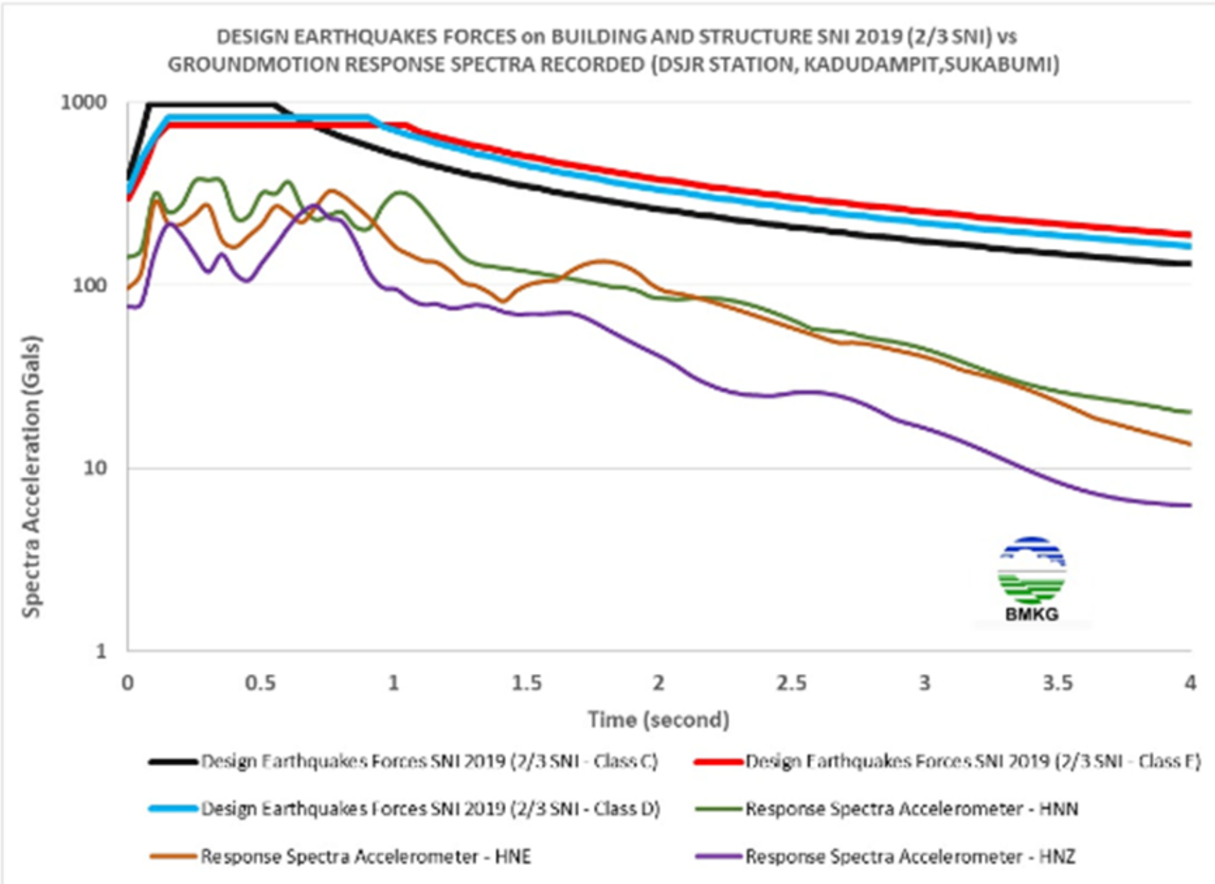


Figure 2.9 - Response Spectra from ground motion records compared with the Design Response Spectra (BMKG, 2022).

3. Local Codes and Construction Practices

As a country located at the intersection of several large tectonic plates, Indonesia faces a high risk of earthquake disasters. This geological condition requires buildings to be designed with adequate performance to withstand earthquake loads. As a result, Indonesia has established several building codes that are required to be implemented in construction practice. However, the implementation of these codes has always been a challenge due to economical, regional, and several other factors. While several big cities in Indonesia have implemented and enforced the use of these codes, many other cities are not aware of their importance. Specifically, large numbers of structures in rural areas, especially for residential housing, were constructed without consideration of the building codes and are often non-engineered, resulting in severe damage to buildings when an earthquake occurs.

3.1. Governing Codes and Standards

Indonesian building codes have been adapting the American building codes, starting from SNI 03-1726-1989 that adopted UBC 1997 to SNI 1726:2019 that adopted ASCE 7-16. The main building design codes in Indonesia are regularly updated with the current version as follow:

1. SNI 1726:2019 Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung (Procedures for earthquake-resistant design for building and non-building structures), which refers to ASCE 7-16.

2. SNI 1727:2020 Beban desain minimum dan kriteria terkait untuk bangunan gedung dan struktur lain (Minimum design loads and related criteria for buildings and other structures), which refers to ASCE 7-16.

3. SNI 2847:2019 Persyaratan Beton Struktural Untuk Bangunan Gedung (Structural Concrete Requirements for Buildings), which refers to ACI 318-14.

4. SNI 1729:2020 Spesifikasi untuk bangunan gedung baja struktural (Specifications for structural steel buildings), which refers to ANSI/AISC 360-16.

5. SNI 8460:2017 Persyaratan perancangan geoteknik (Geotechnical design requirements).

The Indonesian government has also made efforts to ensure the quality of non-engineered buildings by establishing ministerial regulations as guidelines regarding the proper construction practices, such as "Izin mendirikan Bangunan Gedung" regulation from the Ministry of Public Works and Public Housing of Republic of Indonesia (PUPR). These efforts aim to provide simple guidelines that generate adequate building quality, even by informally trained builders. Subsequently, to increase the understanding and implementation of these codes (and updates on the codes), government officials and professional organizations also regularly hold seminars and workshops related to the correct construction practices.

3.2. Dominant Building Typologies

The common structural systems used in Indonesia are reinforced concrete moment frame, steel moment frame, and concrete frames with masonry infills with wooden or cold-formed steel roof structures. Concrete frames are typically used in mid-rise to high-rise buildings, whereas steel moment frames and concrete frames with masonry infills are generally used in low-rise buildings. Buildings in Cianjur are composed of low-rise (1- to 3-storey) structures with concrete frame or concrete frames with masonry infills as the structural system. The common building occupancy types are single family residential, commercial, religious, school, and government buildings.

Looking at the photos of the aftermath of the earthquake, it is observed that most of the damage is in 1- to 2-story buildings constructed using concrete masonry infills, with some of them using a concrete frame. The causes of failure of these systems are mainly the non-compliance between the constructed buildings and the regulating building standards, where the lack of quality control, limited knowledge of the standards, and limited budgets are the main factors. The masonry infills were not secured properly to the concrete frame and the detailing of concrete frames did not satisfy the required provisions leading to catastrophic failures. It can also be seen that most of the collapsed buildings have slender columns at the base resulting in soft-story failure and gravity collapse. This is further exacerbated by the inconsistency of material quality, where concrete mixture is hand-mixed and hand-placed without proper vibration resulting in bad concrete placement in most of the structures.

The other common structural failure in Cianjur is in the roofing structure of the buildings. Roofing structures are often built using wood and cold-formed steel frame with clay roof and Corrugated Galvanized Iron (CGI) sheets. Insufficient design (mainly designed only for gravity loading) and poor maintenance of the roofing structures, and degradation due to environmental conditions and frequent rains, resulted in collapse of the system when an earthquake occurs causing injury to the occupants in the buildings.

Collapse of buildings in Cianjur was also caused by soil/foundation failure. Typically, low-rise buildings in Cianjur use shallow foundations without proper design of the capacity, where most slabs with grade beams and stone masonry are constructed without strength calculation. It is also observed that many landslides occurred during the earthquake resulting in structures toppling over. This indicates that the buildings are often constructed on poor soil without any ground improvement.

4. Building Performance

4.1 Residential Buildings

The Cianjur Earthquake impacted residential buildings in several regions in West Java including the Cianjur Region, Bogor Region, Sukabumi Region, and Sukabumi City (BNBP Indonesia [@bnbp_indonesia], 2022). Cianjur Region has the most residential building damage with the worst area located at Cugenang District (Tribunnews.com, 2022).

Below are the number of damaged residential buildings in Cianjur Region collected by the National Disaster Mitigation Agency (BNPB, 2022) up until November 28th, 2022, (Sinaga, 2022).

- Total Residential damage: 63,219 units
- Heavily damaged: 26,237 units
- Moderately damaged: 14,196 units
- Lightly damaged: 22,786 units

For areas other than Cianjur Region, there are no reports showing the extent of damage to residential buildings. The number of residential damages in other regions up until November 21st, 2022, are presented below (BNBP, 2022).

- Bogor region: 46 units
- Sukabumi region: 434 units
- Sukabumi city: 14 units

As recently as November 27th, 2022, BNPB recorded 325 locations of displaced residences. Each location has the capacity of maximum 25 people (Yahya, 2022). The displaced residences are housed in emergency tents built by the residents and the volunteers. Those emergency tents are built using a tarpaulin supported by bamboo (see Figure 4.1).

Figure 4.1 – Displaced residences in Cianjur region.

Up to November 30th, 2022, there has been no official report that mentions the typical residential buildings in Cianjur. However, by observing the post-earthquake photos and the pictures of residents' houses on Google maps, most residential houses have a concrete frame structure with masonry infill or concrete brick infill. These types of structures are very common in Indonesia. To maximize the living space and to minimize the construction cost, usually the concrete columns are built by the dimension of 15 cm × 15 cm up to 20 cm × 20 cm.

By looking at the post-earthquake photos, the most common damage that occurred on residential buildings are gravity (pancake) collapses and sideways collapses. The gravity collapses might have occurred because of the soft/weak story formations due to the small column dimensions and the presence of openings at the lower stories. Furthermore, axial force capacities of columns could have been exceeded because of the small column sizes and low concrete strength. Large axial force ratios accompanied by shear failures could have led to the observed gravity collapses. Insufficient reinforcement anchorage at beam-column joints might have also triggered collapse (see Figure 4.2, intact column on the top right photo hints to the beam-column joint failures leading to collapse). The sideway collapses happened mostly because the masonry infill or the brick infill were detached completely from the main structures, or they were collapsing out-of-plane. According to common practice in Indonesia, masonry infills and/or concrete brick infills are bonded with unreinforced mortar. Also, they are rarely anchored to the main structures. Therefore, there is not a proper load path to resist the lateral forces (see Figure 4.3). Other pictures of residential building collapses are shown in Figures 4.4 and 4.5.

Figure 4.2 – Pancake collapses (Project Hope, 2022; BBC, 2022a; tirto.id, 2022; Fadhillah, 2022).

Figure 4.3 – Damage to masonry and concrete brick infills (Project Hope, 2022; Nugraha and Firdaus, 2022).

Figure 4.4 – A collapsed building next to a survived building (Project Hope, 2022).

Figure 4.5 – Before and After Picture of Damaged House in Nyalindung Village, Cianjur Region, West Java Province (BBC, 2022a).

4.2 Schools, Religious and Government Buildings

There was significant damage to schools, religious and government buildings. Of the more than 300 casualties, roughly 1/3 were children below the age of 15 (UNICEF, 2022). This is partly due to the large numbers of damage to school buildings (Hidayat, 2022). Some of the documented damage to school buildings is shown in Figure 4.6. Figure 4.7 shows examples of damage to religious and government buildings.

(a) Collapse of Islamic boarding school in Cianjur (BBC, 2022a). Damage appears to be caused by a combination of soft-story, and soil and foundation failures, leading to a pancake collapse

(b) Damaged classroom in concrete masonry building in Cianjur (BBC, 2022b)

(c) Collapsed school building in Cianjur. The building was constructed with a concrete frame with wood and clay roofing. The concrete frame appears to have collapsed and there was also failure in the wooden roof structure (BBC, 2022b). Presence of observed partial height walls could have led to short columns.

(d) Damage to a school building constructed using concrete masonry infills with wooden roof structure with clay tiles. The wood structure appears to have collapsed and there was heavy damage to the masonry infills. (SuryaMalang, 2022)

Figure 4.6 – Examples of damage to school buildings.

(a) Partially collapsed Mosque located in Cianjur. The type of construction is concrete frames with masonry infills and cold-formed steel. The dome of the mosque partially collapsed and there was also infill damage (Hidayatullah, 2022)

(b) Collapsed mosque located in Kadudampit, Cianjur. The structure consists of concrete frames with masonry infills. The collapse appears to be caused by a soft-story mechanism or pancake failure due to inadequate column detailing (Republika, 2022)

(c) Damage to the police building in Cianjur. The building appears to be a concrete frame with infills and cold-formed steel roofing. Damage included fallen ceiling tiles, damage to the roofing and light damage to the structure (TribbunnewsBogor, 2022)

Figure 4.7 – Damage to religious and government buildings.

5. Infrastructure Performance

5.1. Water Disruption & Restoration

While the online resources do not contain any images or videos directly showing the earthquake damage to water transmission and distribution systems, the severely damaged infrastructures and building systems could pose a problem for drinking water in the earthquake-affected region. Various reports have confirmed that clean water is in shortage (IFRC 2022). As a result, the Indonesian Red Cross relief and emergency teams have been deployed to distribute clean water (Stefanno Sulaiman 2022).

5.2. Power Outages and Restoration

The Cianjur Earthquake caused the disruption of electrical power in the Cianjurto District (CNN Indonesia 2022). Specifically, the earthquake affected 21 customer distributions (power suppliers) and 1957 distribution substations. As a result, 366,675 customers were affected by the power outage. As of the morning of November 22 (18 hours after the earthquake), 17 suppliers and 1802 substations were successfully restored by the local electricity company Perusahaan Listrik Negara (PLN), and the electricity in 89% of the affected area have been restored (Lukihardianti and Murdaningsih2022). Figure 5.1 shows the PLN officials utilizing the heavy equipment to restore the power grid at the Cianjur earthquake disaster site (Budianto 2022).

Figure 5.1 Perusahaan Listrik Negara (PLN) officials are working to restore the power grid at the Cianjur earthquake disaster site (Budianto 2022).

5.3. Transportation Disruptions & Restoration

The Cianjur earthquake significantly disrupted the transportation system through two primary patterns. First, the earthquake caused severe damage to the road foundation in many locations. One example of such damage is shown in Figure 5.2, where the road surface was ruptured into multiple segments and was thus not functional for regular traffic. The earthquake also triggered landslides, which further resulted in fallen trees, electricity poles, and soil from cliff avalanches. These fallen objects and soil blocked the road. The Puncak-Cipanas-Cianjur national road was paralyzed because toppled trees completely blocked the road, as shown in Figure 5.3. According to the collected data, the disruption caused by the landslide was more significant than direct damage to the roadways in the Cianjur district. The Ministry of Public Works and Public Housing has sent personnel and heavy equipment to clean up the national road starting from November 21, 2022. However, at the time of the writing of this report, no successful restoration has been reported.

Figure 5.2 Severe road damage caused by the West Java earthquake (VOA News, 2022).

Figure 5.3 The road access from Cianjur to Puncak is blocked because of a landslide and toppled trees (Arini 2022).

6. Recommendations for Future Study

Based on the information gathered by the team of this Preliminary Virtual Reconnaissance Report (PVRR), StEER offers the following recommendations for future study:

1. Collapse of school buildings and consequent death of students and death of school children in this earthquake of low to moderate shaking is very tragic. Reasons for the school building collapses are known as the non-compliance between the constructed buildings and the regulating building standards, lack of quality control, and limited knowledge of the standards. Beyond these, it should be explored if there are specific issues in the structural systems, such as particular vertical or plan irregularities, presence of short story columns, etc., such that similar collapses of school buildings will not be experienced in future earthquakes.

2. Potential reasons for roof collapses and the effects of material degradation on these collapses is another area that requires attention and further exploration.

3. It is needed to explore cost effective and local retrofit methods of the structurally deficient structures common in the region.

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