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Geotechnical Review of Building Damage and Landslide After Cianjur Earthquake 2022

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Abstrak Pada hari Senin, 21 November 2022, gempa bumi dengan magnitudo 5,6 SR mengguncang Kabupaten Cianjur, Provinsi Jawa Barat. Gempa tersebut merusak bangunan hunian dan menyebabkan tanah longsor di daerah padat penduduk yang penting. Dataran tinggi timur Desa Sarampad mengalami pergeseran tanah yang panjang. Di Desa Sarampad, retakan-retakan telah menyebabkan pergeseran fisik tanah yang mengakibatkan pengungsian rumah-rumah di ladang-ladang yang jauh. Di daerah sepatu kuda jalan nasional antara Kota Cianjur dan Puncak, terjadi tanah longsor dengan lereng curam di lereng atas jalan raya dan lereng di sisi jalan raya yang menuju ke sungai di bawah jalan. Adanya sungai berarti air di permukaan tanah yang digunakan oleh masyarakat dan asrama militer. Tanah menjadi jenuh air, sehingga membuat tanah longsor mudah terjadi saat gempa. Gabion batu dan terracing telah memperkuat tanah longsor di punggung jalan raya. Sementara itu, tanah longsor di jalur jalan tidak diperkuat. Cacat lain pada bagian jalan secara melintang pada badan jalan dekat Sepatu Kuda dengan kontur melengkung harus diperhatikan secara serius.

Abstract On Monday, November 21, 2022, a 5.6 SR earthquake hit Cianjur Regency, West Java Province. The earthquake damaged residential buildings and caused landslides in crucial, densely inhabited areas. The eastern plateau of Sarampad Village had a long land shift fault. In Sarampad Village, faults have caused physical ground shifts that have displaced the cottages in the fields far away. In the horseshoe area of the national road between Cianjur City and Puncak, landslides occurred with a steep slope on the upper slope of the highway and a slope on the side of the highway leading to the river below the road. Having a river means the water at the land's surface that the community and army dormitories use. The soil becomes water-saturated soil, making landslides easy in an earthquake. Stone gabions and terracing have strengthened landslides on the highway ridge. Meanwhile, roadway landslides are unreinforced. Other defects on road sections transversely on the road body near the Horseshoe with curved contours must be taken seriously.

Keywords: landslides; faults; horseshoe area; surface water layers; water-saturated soil

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INTRODUCTION

The 2022 Cianjur Earthquake caused damage to residential buildings and caused landslides in vital and densely populated areas. According to BMKG statistics, the Cugenang Fault is active in the vicinity (Hutabarat, 2022). The mapping validation results contain three seismic danger zones, as illustrated in Figure 2, namely the red, orange, and yellow. The red zone denotes the active Cugenang Fault border area, which extends between 0 and 10 meters to the right and left perpendicular to the fault movement. The no-entry zone is in place due to the significant risk of deformation, seismic vibrations, and ground movement in this area. The red zone encompasses various areas, namely Cilaku District, with a particular emphasis on Rancagoong Village; Nagrak Village, which is a constituent component of Cianjur Regency; and Cugenang District, which encompasses portions of Cibulakan, Benjot, Sarampad, Gasol, Mangunkarta, Cijedil, Nyalindung, and Cibeureum. Parts of the villages of Ciputri and Ciherang are located within the Pacet District, and the Prohibited Area spans 2,63 square kilometers, spanning four districts and 12 settlements (Natawidjaja, 2021).

Figure 1. Damage houses due to landslide after Cianjur Earathquake 2022

In a crisis emergency like this, local academics must assist the community with technical and non-technical concerns (PUPR, 2021; Rizky, A. & Tuhuteru, 2020; Sutresna et al., 2021; Wekke, 2021; Zhafira et al., 2023). The Cianjur earthquake occurred in West Java Province, at the border of the DKI Jakarta area. As a result, the Civil Engineering Study Program at Indonesian Christian University urges conducting Community Service activities such as geotechnical surveys and reviews of building damage and landslides to mitigate natural disasters (Hutabarat et al., 2021; LPPM UKI, 2018). The team consisted of lecturers and students who assisted with measurements in the field. The activity aims to inform locals about high-risk landslide regions of Cugenang Fault Cianjur West Java (Figure 2).

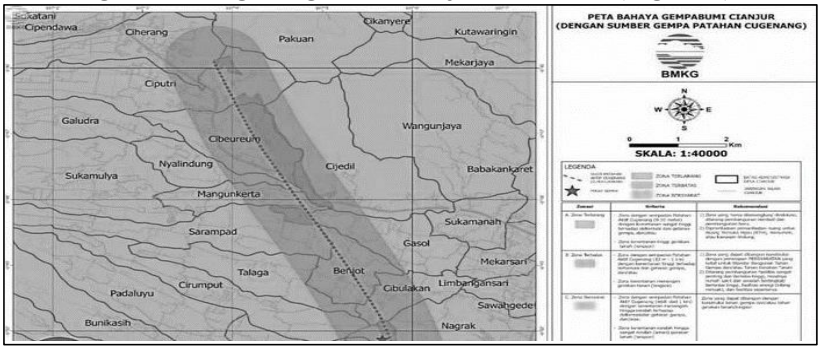

Figure 2. Cugenang Fault Cianjur, West Java - Source (BMKG, 2022)

Maps depicting locations prone to disasters in the Cianjur and Sukabumi regions, with a recurrence interval of 500 years, were created utilizing pertinent information on active fault conditions, basin characteristics, bedrock thickness, subduction processes, and local geological factors. Regions susceptible to earthquakes have the most severe ground movements and structural damage. The longitudinal fault event did not rupture the Earth's surface because of the earthquake's relatively low magnitude. However, it did trigger numerous aftershocks of lesser intensity along a 12 km length and 8 km width, spanning from Warungkondang to Karang Tengah. The area with the most severe building damage was observed in the Rupture Area.

Although the earthquake on the Cugenang Cianjur Fault had relatively low intensity and was classified as a shallow tectonic earthquake compared to the earthquake with an intensity of 7.4 M that occurred in Palu on September 28, 2018, caused by the Palu Koro Fault (Hutabarat et al., 2019), the area experienced building damage covering a reasonably widespread area with levels of damage ranging from light to heavy damage, according to BNPB data. Understanding earthquake-resistant building standards in disaster-prone areas is of utmost significance for individuals present at disaster sites, particularly in light of the recurrent seismic activity experienced by Indonesia across different regions over the past decade. This comprehension is essential for evaluating the extent of damage incurred by residential structures affected by earthquakes (Ariyanto, 2020; Khoeri, 2018; Masdar et al., 2023; Samsunan, 2018; Winarsih, 2010; Yahya & Pradipta, 2022; Zhafira et al., 2023).

Mainshock occurred north of the Cimandiri Fault Rajamandala segment, and aftershocks northeast of the mainshock (Supendi et al., 2022). The Cianjur earthquake was of the mainshock-aftershocks type. According to BKMG data, the following is the intensity scale (Modified Mercalli Insensity-MMI) for big earthquakes (mainshocks), from high to low: Cianjur hosts levels five and six, Garut and Sukabumi levels four and five, Cimahi, Lembang, Bandung City, Cikalong Wetan, Rangkasbitung, Bogor, and Bayah levels two and three, and South Tangerang, Jakarta, and Depok levels two and three. Table 3 provides a classification of the earthquake's magnitude in Indonesia.

Table 1. Indonesia's Richter Scale for Earthquakes Compare to the MMI Scale

MMI Scale	BMKG Scale	Damage Description	Mapping Color
1 – 2	1	All individuals do not subjectively experience the sensation in question but instead are objectively documented through the utilization of diverse instruments.	White
3 – 4	2	The presence of the event was perceptible, yet no tangible harm ensued as a result. The glass windows facilitate light sharing while suspended objects from the ceilings oscillate.	Green
6	3	The building had minor damage to its non-structural elements, such as hairline cracks on the walls, roof sagging, and partial collapse of specific building components.	Yellow
7 – 8	4	The modest structure sustained considerable structural impairment, characterized by numerous wall fissures, partial structural failures, and shattered glass. The plaster on the walls had signs of peeling in certain areas. The majority of roofs experience displacement or detachment. The building structure	Orange

		incurred minimal to moderate damage.	
9 – 12	5	The majority of structural walls comprising permanent buildings experience collapse. The structural framework of the building has incurred substantial damage.	Red

Source: (BMKG, 2022)

The Geological Agency of the Ministry of Mineral Resources analyzed previously collected data (Supartoyo et al., 2014) to determine that the breccia and lava sediment layers of Mount Gede, where the topography of the area is wavy hills, sustained the most damage. Gasol and Serampad villages in the Cugenang subdistrict experienced damage intensity levels of VII-VII MMI, which is highly severe and widespread. Hence, the Cianjur Warungkondang, Gekbrong, and Cilaku sub-districts all experienced magnitude VII MMI. Figure 3 shows that the designated Disaster-Prone Areas are characterized by their susceptibility to earthquakes reaching a maximum intensity of VIII on the Modified Mercalli Intensity (MMI) scale. The geological map shows where most building damage occurs from ground movements: class C rock layers (hard soil) to layer D rock layers (medium soil). The Cianjur region and its environs exhibit a minimum of eight distinct classifications of geological bedrock. The geological composition of the bedrock in the northern region exhibits distinct variations when compared to the bedrock found in the center and southern regions. The Quaternary volcanic bedrock dominates the northern region, identified as the area with the highest concentration of damaged structures. The bedrock in question encompasses nearly seven sub-districts, exhibiting a significant prevalence of dwellings that have incurred damage. The northern region is encompassed by bedrock composed of dacitic and andesitic materials (Asrurifak & Irsyam, 2017; Hall, 2002; PUSGEN, 2017).

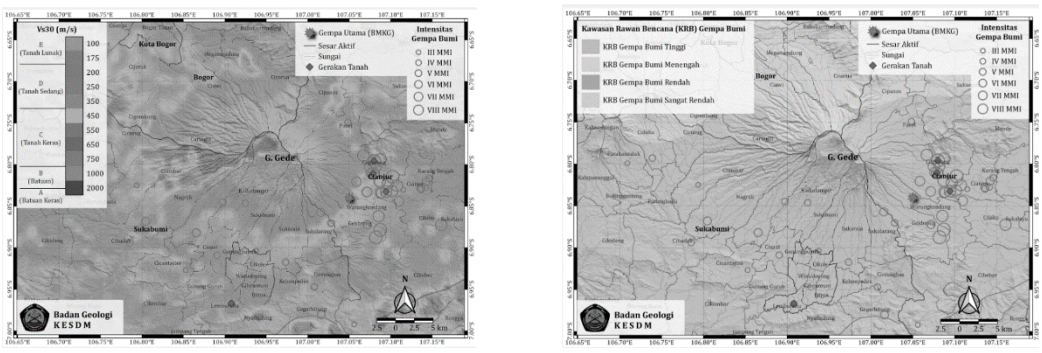

Figure 2. (a) Examines the ground motions that transpired in Cisarua village by analyzing aerial photographs. (b) The present research focuses on the creation of a Surface Rock Hardness Map in the Cianjur Earthquake area, utilizing the Matsuoka Method. - Source (Geology, 2022)

This paper aims to disseminate information among the local communities in disaster zones regarding the regions that may be susceptible to landslides due to the recent seismic event.

METHODS

This community service involved implementing geotechnical surveys and assessments in regions that have encountered significant landslide events (Detikjabar, 2022). Specifically, the

investigations were conducted in Sarampad Village and the horseshoe-shaped region, characterized by intricate topographical features, as depicted in Figure 3.

Figure 3. Location of the Cianjur horseshoe, West Java (source: Google Earth)

The analysis was conducted using field surveys and measurements in areas that have seen significant landslides (Highland & Bobrowsky, 2008b). The measurements were conducted utilizing a Theodolite instrument by a group of students collaborating with lecturers from the Civil Engineering department at UKI (Figure 4). The UKI Civil Engineering Study Program team collaborates with Surya Kencana University, BPBD (Regional et al. Agency), and the Cianjur Municipal Regional Settlement and Infrastructure Service. This collaboration aims to conduct a comprehensive assessment and field measurements in areas where landslides have impacted since the Cianjur earthquake on November 21, 2022.

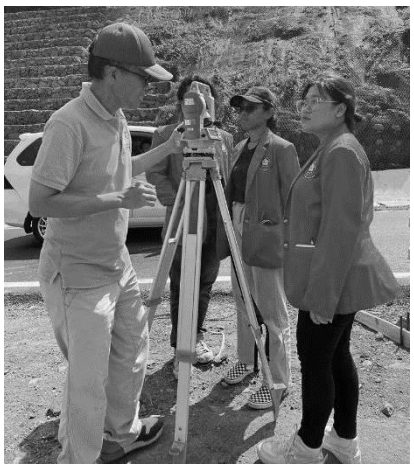

Figure 4. Theodolite Measuring at Field

RESULT AND ACHIEVEMENTS

Red Zone Victims Relocated After Natural Disasters

Initial conversations addressing the temporary mapping of landslide regions that BPBD had carried out at the time of the earthquake were held between the Cianjur Regional Disaster Management Agency (BPBD) and the UKI Civil Engineering Lecturers and Students (Figures 5a, 5b, and 5c). These discussions took place after the earthquake. It was done simultaneously to evacuate any victims or injured people at the landslide site (Sutresna et al., 2021). Compared

to other cities in the West Java region, the area around Cianjur in Indonesia has a relatively high risk of landslides, as shown in Table 2.

Table 2. Five-Year Landslide Risk Index Averages for Multiple West Java Cities

Year	Regency/City in West Java							
	Cianjur	Sukabumi	Tasikmalaya	Garut	Karawang	Subang	Cirebon	Bandung
2018	207.13	190.75	203.01	208.63	175.20	175.20	170.79	174.00
2019	207.13	190.75	203.01	208.63	175.20	175.20	160.63	174.00
2020	215.08	190.75	203.01	205.52	174.43	171.91	160.63	174.00
2021	197.08	192.40	186.51	185.00	165.58	168.78	147.51	161.89
2022	207.62	186.61	174.11	164.91	157.81	157.25	156.58	145.94

Souce: (Nugroho et al., 2018)

(a)

(b)

(c)

Figure 5. (a) Discussion at BPBD office; (b) BPBD Cianjur; (c) BPBD Mapping for Mitigation

As a result, the disaster industry must prioritize identifying and preparing for landslide-prone locations in Cianjur (Hutabarat et al., 2021). The PKM team consulted with the Cianjur district's Housing, Settlement, and Land Service (PKPP) before conducting the survey and field measurements (Figure 6).

Figure 6. Further Discussion at PKPP Cianjur Regency

Initial reports indicate that some areas in the Red Zone (Figure 9) that sustained the most severe earthquake damage need relocation. Table 3 displays the total number of phase I relocatable residents, while Table 4 shows the significant damage circumstances for a subset of the 496 required homes (Dinas PKPP Cianjur, 2023).

Table 3. Resettled during the initial phase of the Cianjur Earthquake Red Zone

Village	Number of families
Nagrak	115
Mangunkerta	29
Cijedil	1
Benjot	18
Sarampad	27

Source: (Dinas PKPP Cianjur, 2023)

Table 4. The number of families that were relocated from the Red Zone was determined

Subdistrict	Village	Number of families
Cugenang	Nagrak	18
	Cibulakan	78
	Cijedil	110
	Gasol	10
	Mangunkerta	38
	Sarampad	121
Cianjur	Cijedil	110
	Nagrak	125
	Total	496

Source: (Dinas PKPP Cianjur, 2023)

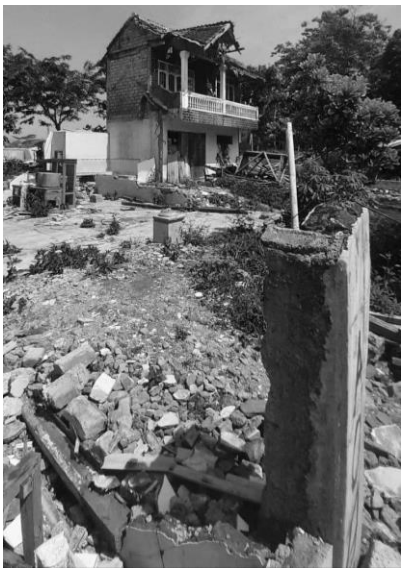

Figure 7. The Red Zone region incurred significant damage, specifically in Sarampad Village

New Residential Location in Sirnagalih Village, Cilaku Distrik

The study was conducted within the residential area designated for relocation in Sirnagalih Village, located in the Cilaku District of Cianjur, West Java. The regional government selected Sirnagalih Village as the newly constructed relocation dwelling within the Bumi Sirnagalih Damai area, spanning 2.5 hectares (Figure 8). Sirnagalih Village is one of the ten villages encompassed within the Cilaku District region, with an elevation of 450-500 meters below sea level. Consequently, it is situated in a low-lying terrain that is reasonably shielded from the potential repercussions of seismic activities. Figure 8 illustrates the occupancy of 200 residential units by individuals affected by the earthquake, whose home structures have been rendered uninhabitable. Two additional sites have been designated for resetting individuals affected by earthquakes and landslides. These sites include Murnisari Village, located in the Mande District, which spans an area of 1.5 hectares and comprises 151 units. The second site is Batulawang Village, situated in the Pacet District, covering an area of 2.6 hectares and accommodating 150 units (Dinas PKPP Cianjur, 2023). The construction of a house involves the utilization of an applicator (Heston, 2015) to expedite the process while ensuring compliance with the Earthquake Resistant Building standards set forth by the Ministry of Public Works (Peraturan Menteri PUPR No. 29/PRT/M/2006 Tentang Pedoman Persyaratan Teknis Bangunan Gedung, 2006; Rizky, A. & Tuhuteru, 2020). Table 5 displays a variety of housing types.

Figure 8. Relocation Location for Earthquake and Landslide Victims in Bumi Sinagalih Permai

Table 5. Home Construction with Applicator

Type	Description	Quantity
RUMBAKO	Banua Tadulako Home	210
DOMUS	Permanent Instant Home	56
RISHA	Instant Simple Healthy Home	20
RUSPIN	Superior Home Instant Panel System	12

Source: (Dinas PKPP Cianjur, 2023)

Preventing Landslides in the Sarampad Village and Tapal Kuda Region

Landslides are a geological occurrence characterized by the displacement of substantial rock, soil, or soil fragments. Various patterns of landslides have been documented in the literature (Highland & Bobrowsky, 2008a; Salimah et al., 2019; Sri Naryanto et al., 2020). In most instances, landslides may be attributed to two primary factors: the driving force and the triggering mechanism. The state of the slope material directly impacts the driving parameters, sometimes referred to as internal variables. According to previous findings (Sugianti et al., 2014), the landslide occurrence can be attributed to external forces affecting the slope. The primary catalyst for this calamity is the gravitational forces exerted on steep inclines, although other additional elements contribute to its occurrence, as presented in Table 5.

Table 5. Factors Influencing Landslides

Factors	Slide-inducing Mechanism
Erosion	Rainwater, rivers, and ocean waves facilitate progressively steeper slope erosion, effectively removing soil from the base.
Saturated	Slopes are weakened as a result of water-saturated layers of rock and soil induced by intense precipitation.
Earthquake	Landslides on slopes are induced by the occurrence of vibrations, which result in an elevation in pore water pressure within the soil. Consequently, this elevation in pore water pressure reduces the shear strength of both soil and rocks.
Volcano	causing dust storms, heavy rain, and dust flows
Machine vibration	The auditory disturbances are caused by motor traffic, detonations of explosives, and lightning discharges.
Excess weight	The precipitation accumulation contributes to the increase in mass on the slopes.

A high susceptibility to natural disasters characterizes Cianjur district, which holds the top position regarding catastrophe occurrence within the West Java province. The catastrophic event in Cianjur had the most significant impact on the region's western area. Individuals congregate at a designated location during a disaster, while road accessibility becomes challenging. Consequently, communication becomes arduous, and the supply of electricity is disrupted. The onset of the calamity transpired in the region of Horseshoe and concluded in the vicinity of Swamp China. Fractures are extending in an east-west direction. The relocation of the Rawa Cina community to the Murnisari and Batulawang villages is planned, whereby around 300 housing units will be constructed.

The seismic event that transpired along the eastern fault line in Sarampad Village involved a substantial displacement of the land (Natawidjaja, 2021; PUSGEN, 2017; Supartoyo et al., 2014; Supendi et al., 2022). Land displacement resulting from fault activity is evident in Sarampad Village, where the huts located in the fields have undergone significant displacement relative to their initial positions. Similarly, landslides were observed in the horseshoe region along the national road connecting Cianjur City and Puncak. The topography of the surrounding area exhibited a significant incline, with the upper slope of the highway experiencing a steep gradient. This downward slope extended towards the side of the highway, ultimately leading to the river beneath the road's surface. A river suggests a shallow water layer near the property, a vital resource for the nearby town and military barracks. This phenomenon results in the soil becoming fully saturated with water, rendering it susceptible to triggering landslides in an earthquake. The ridge above the highway has been fortified against landslides with stone gabion reinforcements, strategically positioned using a terracing technique. In contrast, the reinforcement of the landslides beneath the highway has not yet been undertaken. In addition, it is imperative to address the faults that arise on road sections that traverse the road body close to the horseshoe-shaped curves with curved contours.

The occurrence of landslides during the earthquake resulted in significant damage to numerous residential structures, either through being carried away or directly impacted. It emphasizes reassessing spatial and regional planning for this area in subsequent endeavors. Properly implementing residential housing placement in disaster-prone areas, per the Indonesian National Standard (SNI) for housing construction, is crucial. Hence, a significant imperative exists to enhance public awareness regarding the significance of adhering to safety protocols in residential building projects. In addition, it is imperative to establish a comprehensive recovery and reconstruction initiative that encompasses the collaboration of governmental entities, Non-Governmental Organizations (NGOs), and local communities. The implementation of spatial planning that incorporates considerations of earthquake risk factors in regional development is imperative and should be promptly undertaken. In addition, it is recommended to enhance the structural integrity of residential buildings following the guidelines provided by the Indonesian National Standard (SNI 03-1726, 2002; SNI 1726, 2019). Furthermore, the establishment of a dedicated team for structural inspections can effectively contribute to the prevention of similar damage in future occurrences.

Comprehensive disaster mitigation measures are necessary both prior to, during, and after the occurrence of a landslide disaster (Muhammad & Deasy, 2017; Somantri, 2014; Syamsul & Nurjannah, 2022; Waluya & Kautsar, 2021). Other factors necessitate consideration prior to a landslide, including the influence of intense precipitation or seismic activity resulting from tectonic earthquakes. There are some crucial things for locals. The primary factor that people living in landslide-prone locations should be aware of before a landslide disaster occurs is that

high rainfall should not be avoided. Logistic preparations, particularly drinks and ready-to-eat food, medicines, lighting equipment such as flashlights, and sufficient money should be made for anticipation. Rain intensity information from related institutions such as the BMKG should be followed regularly via radio or television (Gustari et al., 2012). Complying with authorities' evacuation instructions as an early warning system is another crucial thing to deploy to locals regularly. In the event of a landslide disaster, it is imperative for the community to promptly evacuate their homes upon hearing an audible roar and expeditiously relocate to an accessible open area or field situated at a safe distance from the descending slope.

Subsequently, in the aftermath of the catastrophic landslide event, the community must direct its focus towards the ensuing matters:

1. It is advisable to exercise caution and refrain from promptly reoccupying the residence until the slope conditions have been deemed entirely secure to preempt any subsequent landslides.
2. Employ specialized footwear and equipment in conjunction with the necessary tools required for aiding in the evacuation of individuals affected by landslides.
3. Ensure that one is traversing on stable terrain while walking. d. When evacuating individuals trapped beneath the debris of structures, exercise prudence in refraining from hasty actions that may exacerbate the situation. Instead, consider deferring to the authorities to evacuate landslide victims safely.

CONCLUSION

Based on the findings derived from the community service activities (PKM) conducted in Cianjur, West Java, it can be inferred that the earthquake that transpired on November 21, 2022, resulted in not only the destruction of residential structures but also triggered landslides in very critical and densely inhabited regions. Hence, a pressing need exists to enhance public awareness of the need to adhere to safety protocols in residential building construction, particularly in regions characterized by a heightened susceptibility to landslides. In addition, it is imperative to establish a comprehensive recovery and reconstruction initiative that encompasses the collaboration of governmental entities, Non-Governmental Organizations (NGOs), and local communities. It is imperative to promptly undertake spatial planning that incorporates considerations of earthquake risk factors in regional growth. Additionally, it is recommended to enhance the structural integrity of residential buildings following the relevant national standards (SNI). Comprehensive disaster mitigation measures must be implemented before, during, and after a landslide disaster. Multiple factors necessitate consideration prior to a landslide, whether triggered by intense precipitation or seismic activity resulting from tectonic earthquakes. In addition, significant and essential structures designed to house large populations must adhere to the guidelines outlined in SNI 1726:2019. This standard pertains to the construction of earthquake-resistant buildings and serves as a revised version of SNI 03-1726-2002. It is particularly crucial for buildings in regions susceptible to disasters, commonly called disaster-prone areas. The enforcement of this standard is officially carried out by referring to the relevant rules outlined in the PUPR Ministerial Regulation No. 29/PRT/M/2006, which pertains to the Guidelines for Technical Requirements for Buildings in 2006.

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