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The Impact of Landslides in Reclamation Areas from Stone Crusher Production Residue Materials in the Tsunami Event in the Sulawesi Earthquake on September 28, 2018

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ABSTRACT: Sulawesi earthquake disaster followed by a tsunami on September 28, 2018 still leaves several big questions, namely the type of normal strike slip fault that rarely causes a tsunami, the very short tsunami arrival time of around 2-5 minutes and the bay area that should rarely be hit by a tsunami. Several previous studies have provided several hypotheses that the tsunami was caused by an underwater landslide or vertical deflection of the seabed due to the super shear movement. This study conducted a study of the impact of Stone Crusher factories residual production based on a field survey and supported by secondary data from previous researchers on the tsunami disaster after the strong earthquakes. The results of the field survey showed an area of around 40 Ha that collapsed on the surface, most of which was a pile area of residual Stone Crusher production on the West coast of Palu Bay. This area stretches around 20 km covering the areas of Palu City and Donggala Regency. Based on the data, there are around 240 Stone Crusher factories permits, from 42 companies that have operated on the West coast of Palu Bay, 19 operating in the Donggala Regency area and 23 in the Palu City area. Some of these mines have been operating since 2000. Around 20-30% of the total production is the remaining production in the form of landfill that is transported from the factory location to the coast and stockpiled around the loading area of the Stone Crusher results before being sent to Kalimantan and other islands. One Stone Crusher unit annually produces around 300,000 m^3 of waste in the form of landfill. If the average of 40 Stone Crusher factories that have been producing for 20 years, the waste output is around 200,000,000 m^3. This mass of material if it experiences a landslide after the earthquake is significant enough to move the mass of water to cause a tsunami that spreads to the East side of Palu Bay. Secondary data in the form of photos and videos shortly after the earthquake shows a white whirlpool and the spread of tsunami waves from the coast towards the middle and there is a wave direction parallel to the coastline. This indication shows a landslide from the reclaimed landfill from the remaining stone crusher production that was stockpiled on the West coast of Palu Bay. In addition to the impact on disaster vulnerability, mining activities of Stone Crusher factories in the form of Stone Crusher factories also have an impact on the surrounding natural environment in the form of pollution of settlements, damage to vital infrastructure, marine biota, human health and livestock. Comprehensive and sustainable efforts are needed to overcome the negative impacts of Stone Crusher factories mining activities together from all stakeholders.

KEYWORDS: Sulawesi Earthquake, Tsunami, Underwater Landslide, Residual Stone Crusher Production

1. INTRODUCTION

The tsunami disaster as a secondary impact of the Sulawesi Earthquake on September 28, 2018 has become the center of world attention. The latest data on the number of fatalities due to this disaster is 3879 people, of which 1252 died due to the tsunami [1]. Several hypotheses from several articles try to find out and analyze the tsunami generation process and explain the impacts it causes. The Palu-Koro Fault as one of the most active faults in Indonesia has caused earthquakes accompanied by tsunamis at least 4 (four) times in the last 100 years around Palu Bay, namely in 1927, 1938, 1968 and 1996 [2]. The massive damage impacts in the form of damage to settlements, infrastructures and other vital life facilities (lifelines) including residential buildings, roads, docks and Electricity networks [3]. From several amateur video recordings, it is known that the tsunami arrival time ranges from 2-15 minutes after the main earthquake. Several studies have been carried out starting from bathymetric measurements of Palu Bay, surveys of the impact of tsunamis on infrastructure to modeling the process of the tsunami. However, all of these studies have not been able to conclude with certainty what caused the generator and mechanism of the tsunami. The provisional conclusion states that the tsunami was triggered by an underwater landslide [4]. Based on the simulation of vertical movement, the sinistral movement model of the Palu-Koro fault, the right side experienced a decrease of about 1m and the left side experienced an uplift of about 0.6 m [5]. Another study with tsunami source modeling around the mouth of the bay stated that there was an uplift of 0.8 m and about 1 m in the North and South of Palu Bay [6]. The post-earthquake bathymetry

measurement data of Palu Bay compared to data in 2014 showed a change in the depth of the bay floor, after the earthquake followed by a tsunami, the bay floor especially around the western coast of Palu Bay experienced shallowing due to landslides [7]. The horizontal shift of the super shear of the Palu-Koro fault was very large based on the results of optical satellite data, an average of 5.4 m. The height of the tsunami on the east-north coast of Palu Bay was measured at 7.3 m in Mamboro and 4.9 m in Pantoloan Port [8]. This earthquake caused extensive liquefaction and liquefaction-induced flow slides inland. Despite a strike-slip fault, which typically displaces land horizontally, being unlikely to produce significant tsunamis, the earthquake in fact caused devastating tsunamis [9]. In the end, the conclusion leads to several simultaneous causes and not a single cause. The topographic conditions of the slopes on the West side of Palu Bay are steeper than the East side which tends to be gentle, causing the potential for landslides on the surface and below the surface to be greater on the West side of Palu Bay [4]. The C-type mining activity in the form of Stone Crusher production along the Palu-Donggala road section which is on the West side of Palu Bay in the last 18 years has also contributed to the potential for landslides on the surface due to the accumulation of residual stone crusher production material on the shoreline [10]. Field surveys conducted by several researchers also show that the area of land that collapsed after the earthquake and tsunami was around 40 hectares around Palu Bay. The condition of the landfill from the remaining stone crusher production that has not been properly consolidated causes this area to easily experience structural changes due to earthquake shocks and tsunami currents, so it has great potential for landslides. Several residential settlements, operational offices for stone crusher production shipments and C-type mining loading docks were built in this embankment area. Most of the areas mentioned above have experienced landslides up to 100 m from the shoreline, leaving no remains after the earthquake and tsunami.

2. DATA, MATERIAL AND METHODS

This research is in the form of direct survey research and support from secondary data from several parties and previous research data. The first thing to do is to conduct a survey of the stone crusher factory along the Palu-Donggala road, this road is about 30 km long. Of that length, 15 km of it is used as a place for crushed stone production. Based on the latest data, there are about 200 permits that have been issued for mining permits for type C. Of the 42 located on the West coast of Palu Bay, which have been operating since 2003, there are 19 mining units in Donggala Regency and 23 mining units in the Palu City area. The operating period of this Stone Crushed factory has been 18 years. The production results in the form of mountain stone, crushed stone, crushed sand and tasirtu (sand and stone soil) are used in the Palu area and its surroundings and are mostly sent to Kalimantan Island. The production results of each crushed stone factory are around 100,000 metric cubic meters per month. Around 25% or around 25,000 metric cubic meters are the remaining production in the form of tasirtu (soil, sand and stone). The remaining waste is usually dumped on the beach below the stone crusher plant location.

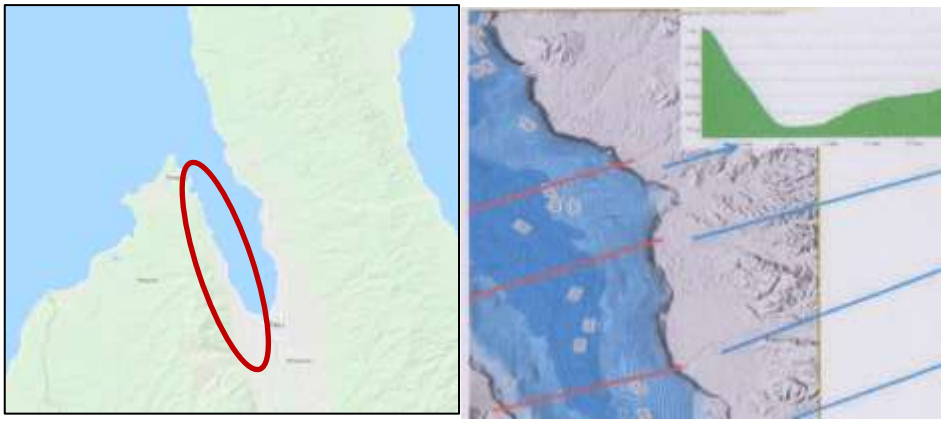

Fig 1. Map of survey locations and slope of coast affected tsunami by fill landslide Palu Bay West Coast [4]

Fig.2 Stone Crusher Factory Activity in Buluri Subdistrict, before (Left) and after (Right) [11]

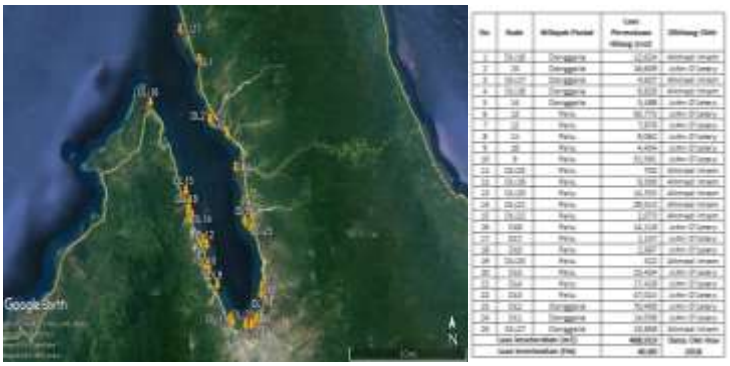

Fig.3 Map and table of land area lost after the Palu-Donggala earthquake on September 28, 2018 [11]

Fig.4 Map of the location of the C-type mining (Stone Crusher Factory) around Palu Bay [10]

3. RESULTS AND DISCUSSION

Figure 1 shows the research location, which is on the West side of Palu Bay. The slope conditions in Palu Bay are also presented in the figure. The steeper slope of the West side than the East side causes the potential for underwater landslides due to embankments or natural cliff landslides to be more dominant on the West side. Figure 2 shows the loading activity of the stone crusher factory's production in the form of sand and split which will be sent to the Provinces of East Kalimantan and North Kalimantan on the island of Kalimantan. There are at least 11 jetty locations like this. After the earthquake accompanied by a tsunami, the condition of the shipping location like this was damaged and some of the land was lost, collapsing into the seabed. After the earthquake and tsunami, most of the jetty facilities have been repaired and the loading process of stone crusher production materials has resumed. Figure 3 shows a map and table of the area of land lost after the earthquake and tsunami around Palu Bay. At the research location around the C mining factory, there are 7 points with an area of about 7 Ha where the land was lost to the seabed. The total area of land lost around Palu Bay after the earthquake and tsunami is around 40 Ha. Of the vast area of land that has been lost to the seabed, there are residential areas, public facilities such as mosques, tourist attractions and several other infrastructure facilities on top of it. In Figure 4. Also presented are satellite images around the Palu Bay area in the form of conditions before and after the tsunami hit the coast of Palu Bay. The condition of the embankment that has not been properly consolidated causes

the embankment on the coast to be easily lost, either due to the tsunami or landslides to the seabed. At the time of the disaster, temporary loading activities were taking place, so that many people became victims buried along with facilities such as office buildings, loading ships and container ships. Figure 5. shows the condition of the bottom of Palu Bay before and after the earthquake accompanied by a tsunami. The red color on the west side of Palu Bay is an indication of shallowing of the bay floor, which indicates a landslide of material on the edge of the beach. In Figure 6. Shows an aerial photo shortly after the earthquake, the presence of 5-7 whirlpools at several locations indicates that landslides occurred simultaneously at these points. As an area crossed by a fault with weathered rock conditions and also because of the topography which has a high slope and minimal vegetation, it will worsen the impact of this slope condition if at any time there is land movement. This land movement will have an impact on the surrounding environment. The rainy season with high rainfall, although rare in this area, also worsens the condition of settlements, infrastructure and other public facilities. According to the analysis results of the three-dimensional map of the drone team, the average slope of the mountains that have been exploited in the area is 20.6 Ha, with a height of 120 meters from a slope of 70 degrees to 90 degrees.

Fig.5 Coastal conditions in Palu Bay before and after the tsunami and landslide graphics (Reuter Graphic, 2018)

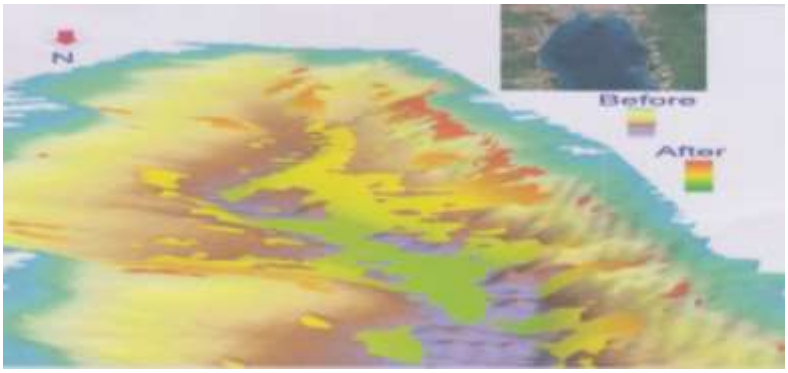

Fig.6 The depth of the bottom of Palu Bay before and after the earthquake (red color is shallowing due to landslides) [7]

Fig.7 Landslide near the coastline after the earthquake marked by a white vortex [4]

Mining activities in the Palu city area to Donggala Regency, including Tipo, Buluri and Watu Sampu Sub-districts in the Palu City area and Loli Oge, Loli Dondo, Loli Tasiburi, Loli Saluran and Kabonga Besar Sub-district in the Donggala Regency area, are suspected of damaging the condition of the Palu-Donggala national road. Many landslide materials and carried by rainwater from the C-type mining location to the road body. As a result, the national road body is buried in material, sand, gravel and rocks. The Palu-Donggala road section is increasingly badly damaged due to the traffic activities of the C-type mining company. The back and forth of heavy vehicles from the mining location to the jetty has damaged a road of about 10 km. The current Transportation that crosses the area from Palu City towards Donggala Regency is quite disrupted by the presence of mining activities. Material that falls onto the road when being transported by trucks can endanger road users crossing the area. The existence of mining companies that damage national roads, in addition to damaging national roads, these mining companies also operate not in accordance with existing procedures and regulations. A number of these mining companies do not use loading conveyors. A loading conveyor is a tool consisting of many rolls on which there are rotating tires/rubber or a kind of bridge to load materials such as sand, stone and gravel when crossing the Trans Palu-Donggala Route. The most severe C excavation damages provincial roads, one of which is one is in Loli Oge Village, Banawa District, Donggala. Every time it rains, the conditions here are flooded and dusty when the sun is hot. Road damage also occurs from Watusampu Village, Tatanga District, Palu City to Loli Oge Village, Banawa, Donggala. This condition is the impact of operating C mining activities. In addition, C mining rocks and gravel scattered on the highway add to the damage to the asphalt of the national road connecting Palu-Donggala and Mamuju, West Sulawesi. On that route, the asphalt is wavy and difficult for road users to pass. If this condition occurs continuously, it will cause environmental conditions to decline in quality. For this reason, cooperation is needed from all stakeholders so that road conditions on this section do not get worse. Some things that can be done are regulating mining activities, making conveyors for loading directly to loading ships (barges). In addition to worsening environmental conditions, mining activities also have an impact on the environment around the coast. Fishermen's activities have also decreased drastically because of the habitat of fish and other marine animals. In addition to living things on the coast and bay, the environmental impact is also very much felt by humans and pets. Although the company provides assistance to the community in the form of CSR funds and pays taxes to the government, the impact of mining in the form of environmental damage is not comparable to the impact it causes. The most detrimental and disruptive thing is the obstruction of transportation facilities in the form of light vehicles, namely motorbikes and cars when mining material debris is washed into the road. In conditions without good drainage and The topography of the road body is quite sloping, the mud material as a result of mining will enter the road body with a fairly large current speed so that it can sweep away light vehicles that are passing by. Controlling mining activities including how to accommodate the remaining production from the C-type mining is a shared responsibility between the government, companies and the surrounding community. Figures 7 and 8 show the condition of the Palu-Donggala road section during heavy rain. Although the rain is short in duration, the high intensity can cause debris flooding. Figure 8 shows the condition of the coast of Palu Bay on the west side. The increasing intensity of mining, with the increasing number of mining companies, has caused land clearing to become faster The area of land prone to landslides and residual production materials will certainly increase. This will have an impact not only on the area around Palu Bay but also the surrounding areas. The need for building materials in the form of sand, embankments and crushed stone and foundation stones will accelerate the process of environmental damage. In the rehabilitation and reconstruction process after the Palu-Donggala earthquake and the discourse on moving the capital city of Indonesia from Jakarta to East Kalimantan, of course, building materials from this C mining area are needed. For this, early anticipation is needed so that environmental impacts and secondary disasters in the form of landslides, debris floods and tsunamis due to landslides of residual production material from the stone crusher factory can be anticipated

Fig.7 Condition of the Palu-Donggala road during the rainy season

Fig.8 Aerial photo of the condition of the C-type mining area on the west side of Palu Bay on the Palu-Donggala road section [10]

Table 1 Estimated Remaining Production Volume of Stone Crusher Factory on the West Coast of Palu Bay (until 2019)

Number	Sites	Stone Crusher (Unit)	Residual Material (m^3)
1	Kabonga Besar, Donggala	3	15.000.000
2	Loli Dondo, Donggala	7	35.000.000
3	Loli Tasiburi, Donggala	2	10.000.000
4	Loli Saluran, Donggala	2	10.000.000
5	Loli Oge, Donggala	6	30.000.000
6	Watu Sampu, Kota Palu	10	45.000.000
7	Buluri, Kota Palu	10	45.000.000
8	Tipo, Kota Palu	2	10.000.000
	Total Volume	42	200.000.000

Table 2 Stone Crusher Factory That Has Been Producing on the West Coast of Palu Bay [10]

No	Companies	Locations	No	Companies	Locations
1	PT. Dhea Arum Perkasa	Kabonga Besar	24	PT. Indako Bangun Perkasa	Watusampu
2	PT. Batu Indah Mulia	Kabonga Besar	25	PT. Putra Puti Winata	Watusampu
3	PT. Kaltim Khatulistiwa	Kabonga Besar	26	PT. Sumber Alam Gemilang	Watusampu
4	PT. Batu Alam S. Sejahtera	Loli Dondo	27	PT. Putra Elan Balindo	Watusampu
5	PT. Wiyaya Karya Beton Tbk.	Loli Dondo	28	PT. Aces Selaras	Watusampu
6	CV. Baru Terbit	Loli Dondo	29	PT. Risgun Perkasa Abadi I	Watusampu
7	CV. Murind Persada	Loli Dondo	30	PT. Utama Sirtu Abadi	Watusampu
8	PT. Bakat Maju	Loli Dondo	31	PT. Watu Sinai Abadi	Watusampu
9	PT. Berkah Batu Persada	Loli Dondo	32	PT. Bintang Manunggal P.	Watusampu
10	PT. Prima Bumi Pratama M.	Loli Dondo	33	PT. Watu Bariba Jaya	Buluri
11	PT. Palu Rigton Condev	Loli Tasiburi	34	PT. Yasin Eferin Jaya	Buluri
12	PT. Harapan Perkasa	Loli Saluran	35	PT. Hasal Logam Utama	Buluri
13	PT. Palu Batu Madu	Loli Saluran	36	PT. Risgun Perkasa Abadi II	Buluri
14	PT. Balikpapan Ready Mix	Loli Oge	37	PT. Farhan Batu Palu	Buluri
15	PT.Bosowa Tambang Indonesia	Loli Oge	38	PT. Putra Sausu	Buluri
16	PT. Multisari Bumi Tama	Loli Oge	39	PT. Kawan Kita Abadi	Buluri
17	PT. Marades Jaya Sentosa	Loli Oge	40	PT. Veromas Vatu Kaili	Buluri
18	PT. Palu Indah Teknik	Loli Oge	41	PT. Sirtu Karya Utama	Buluri
19	PT. Sinar Mutiara Megalithindo	Loli Oge	42	PT. Agung Jaya Kencana	Buluri
20	PT. AML	Watusampu	43	PT. Ratu Tambang Mandiri	Tipo
21	PT. Davindo Jaya Mandiri	Watusampu	44	PT. Radar Stone	Tipo

In table 2. Companies from No. 1 to No. 19 are located in Donggala Regency and 23 companies are located in the Palu City area. Mining activities in the West Coast of Palu Bay which includes the Palu City area and Donggala Regency have left a complex environmental impact. In relation to the tsunami incident after the Palu Donggala M7.5 Earthquake, it is indicated that the waste of the remaining production of the stone crusher factory which was piled up on the coast around the factory contributed to the generation of tsunami waves due to the landslide of this material which had not been properly consolidated. When the earthquake accompanied by a tsunami occurred in the Palu Bay area, the appearance of the initial tsunami incident was marked by the appearance of white vortices at several points near the coast of the West Coast of Palu Bay. Palu marks the hypothesis that the tsunami was generated by landslides on the coast. A number of landslide masses of around 200 million metric cubic which are waste products from stone crusher factories including land reclamation embankments that were deliberately made for settlements, loading docks, container docks, cargo ship docks and other coastal facilities are able to push the mass of water as a trigger for the tsunami. It is possible that landslides on the West and East sides of Palu Bay also contributed to worsening the impact of the tsunami in the Palu and Donggala areas. Environmental impacts on settlements, coastal biota and infrastructure need to be anticipated due to the increasing need for post-disaster rehabilitation and reconstruction activities and the discourse on moving the Indonesian city from Jakarta to East Kalimantan. Good cooperation between all stakeholders and a commitment to enforce regulations, especially in the mining process and processing of waste or residual materials from mining activities C will contribute to disaster risk reduction in this highly disaster-prone area.

4. CONCLUSSION

Mining activities in the West Coast of Palu Bay covering the Palu City and Donggala Regency areas have left complex environmental impacts. In relation to the tsunami incident after the Palu Donggala M7.5 Earthquake, it is indicated that the waste from the stone crusher factory that was dumped on the beach around the factory contributed to the generation of tsunami waves due to landslides of waste material from the stone crusher factory amounting to around 200 million metric cubic meters. Handling of the waste from the crushed stone factory in the form of stockpiled material should not be dumped on the beach as reclaimed land. All stakeholders concerned must find a solution to this waste material so that it is handled properly and does not cause impacts and increase vulnerability to disasters in the future.

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