Liquefaction disaster mitigation on railway corridors in Padang City, West Sumatra

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Abstract. Earthquake-induced liquefaction, which turns the soil to liquid from solid, can cause substantial lateral movement to the ground surface. It has detected the potential liquefaction due to earthquakes in West Sumatra is very high. The most problems due to liquefaction are loss of stability and significant settlements. For particular infrastructure such as railway, liquefaction has a considerable influence on the railway embankments. Then, it needs to be investigated whether the railway corridors are built in areas with a high potential of liquefaction. The analysis method used in this research is by comparing railway corridors against the Map of West Sumatra liquefaction potential. This study presents the most railway corridors in West Sumatra that were built in areas with having the liquefaction potential. For the corridors which may be potentially destroyed by liquefaction, special treatment must be applied to them.

1. Introduction

The definition of Liquidity is the transformation of granular material from solid to liquid. Liquefaction event occurs due to air pressure and effective stress increase which is caused by cyclic stresses during an earthquake, [1,2,3]. This process occurs because of the loss of sediment strength as a result of the pore pressure excess, so that pore pressure replace almost all of the total sediment pressure [4].

More detail, [5], mentioned that when a cyclic motion occurred at the semi-impermeable sandy soil, pore pressure increase sorter than the time required for transferring the stress into the soil particles. If pore pressure grows higher than its effective stress, then the soil behaves like a liquid. This phenomenon refers to a liquefaction condition. [4] describe the phenomenon of liquefaction mathematically as follows:

\[ \sigma' = \sigma - u \leq 0.0 \text{ or } \sigma' \leq u \] (1)

where and \( \sigma' \) are total and effective stresses in the soil, \( 'u' \) is the pore pressure in the liquefied soil element, and \( 'u' \) is the growth pore pressure due to the motion.

Liquidity generally occurs on poorly graded soils such as SP (Sandy Poor) or so-called loose sand, because of this soil stores more water than well-graded soils, [6]. The occurrence of liquefaction must meet several criteria, namely; sedimentary layer in the form of sand (not cohesive), rot or loose (not solid), if under ground water or saturated water, shallow ground water level, the earthquake must be strong and long time occurrence [7]. The liquefaction potential of a land deposit will be determined by
a combination of several components, including the soil properties index, environmental factors, earthquake characteristics [3].

Numbers of studies to evaluate the liquefaction potential in a soil deposit have been done in the past. The liquefaction analysis can be based on the soil parameters from the laboratory as well as field tests [8,9,10]. Comprehensively, Tohari et al. conducted studies of the liquefaction potential in Padang city in 2006; 2008 and 2011 [11,12,13].

There were several things that could be done to determine the potential liquefaction, namely determining the number of cyclic stresses arising from ground movements during an earthquake; determine the amount of cyclic stress through a loading test in a laboratory represented by an undisturbed sample and comparing the shear stresses caused by an earthquake with things that can cause liquefaction [3]. Related to the last point in determining liquefaction potential can be illustrated in Figure 1. The study of liquefaction potential is essential to do to plan liquidation disaster mitigation

![Figure 1. Metode Evaluasi Potensi Likuifaksi. Source : [3]](image)

2. Liquefaction phenomenon in West Sumatra
The liquefaction phenomena have occurred in some areas of Padang during the earthquake of 30 September 2009. Soil liquefaction due to the 7.6 SR of Padang Earthquake has contributed to the damage of houses, water facilities, and roadways. The liquefactions on sites of Padang are indicated by sand boils right after the earthquake. The soil liquefaction was observed on several sites, including road, riverbank, sport court, and playground (Figure 2), [5]. The results of their research are in the form of liquefaction maps as a result of the 30 September 2009 earthquake, as shown in Figure 2.
Figure 2. Liquefaction map due to earthquakes 30 S 2009. Source: [4]

Figure 3 shows the location of ground settlement, sand boiling, and lateral spreading due to the earthquake. This phenomenon generally occurred in the populated areas up to 5 km from the coastal line, with significant damage to the infrastructures (roads and bridges), residential housing, and buildings. Many buildings, located near the riverfront experienced foundation movement due to ground settlement. Tohari et al., in 2011, created a micro zonation map by using the liquefaction potential analyses and indexes data.

In 2014, [14] conducted a study of the facies and physical properties of Quaternary sediments regarding the liquefaction potential in the Coastal Areas of Padang City and surrounding areas. The method used was drill core observation and CPTu curve pattern to determine the developed facies, laboratory analysis. Liquefaction potential analysis was conducted to study the physical characteristics of each facies. Data collection activities include primary data that contains maps of drilling locations, core drill data, N-SPT data, CPTu data, and advanced groundwater data (MAT). As shown in Figure 4, based on the liquefaction potential analysis, the research area has relatively high potential.

Examined the level of potential liquefaction based on sondir data (Cone Penetration Test) in the city of Padang [6]. The location of the investigation consists of 9 sites scattered in the city of Padang. As shown in Figure 5, the results of the analysis show that at the point of the investigation with the location of the GOR Haji Agus Salim at a depth of 5-6 meters, potential liquefaction with a liquefaction index value > 5. Koto land at a depth of 3.8 m - 4.4 m has a potential of the liquefaction index 12.69, and wean River has potential liquefaction at a depth of 4.8 m with a liquefaction index value 5.2. Hos Cokroaminoto, Purus, and Siteba have minimal potential for liquefaction to occur. Whereas Ujung Gurun, potentially liquefaction at a depth of 3.5 m - 6m, Lolong has potential liquefaction at a depth of 1.4 m - 2m, Chatib Sulaiman has potential liquefaction at a depth of 1.2m - 4.8m.
Figure 3. Locations of the sub-surface geotechnical investigation of liquefaction potential in Padang city. Source: [11]
3. The liquefactions potential of railway embankments

In this research, a superimposing of 4 liquefaction events and liquefaction potential in Padang City (Figure 2- Figure 5), then the result combined with the railway corridor in Padang City. As seen in Figure 6, there are four segments of the railroad corridor in Padang City, which are in areas with potential for liquefaction, namely in Air Tawar water areas (Basko Mall), Alai area, Simpang Haru and Sungai Air, Kota Tua.

In construction, the railroad is divided into two forms of structure, namely: 1) Railroad in embankment construction, 2) Railroad in excavated structure. Railroad structure is divided into two parts of the structure consisting of a collection of railroad components, namely:

1. The upper structure is also known as a superstructure comprised of components such as rails, fastening and sleepers, ties,
2. The lower structure, or known as a substructure, consisting of parts of ballasts, subballasts, improve subgrade and natural ground. The subgrade is a layer of soil under the subballast originating from the original native land or the land that was imported (if the condition of the original soil is not good), and has received compaction treatment or given special treatment (treatment). Under certain conditions, ballasts can also be arranged in two layers, namely: top ballast (top ballast) and bottom ballast (bottom ballast).

Below are some of the damage to the railroad due to earthquakes. Figure 8 and Figure 9 shows the ruin that occurred on the railway road in New Zealand. The earthquake occurred on November 14, 2016. The earthquake ruined The Main North line of railway in New Zealand. This is the main link of railway in New Zealand’s National rail network which runs north from Christchurch in New Zealand up the east coast of the South Island through Kaikoura and Blenheim to Picton. It was the most extended railway construction project in New Zealand's history. The first stages built in the 1870s and completed in 1945.
During the earthquake, more than 150 kilometers of broken lines on the November earthquake, which twisted the railroad, sent slip over the route and caused structural damage to bridges and tunnels.

**Figure 6.** The potential liquefaction on the railway corridors in Padang city

**Figure 7.** Railroad Structure
Figure 8. A massive magnitude 7.8 earthquake struck the Kaikoura area: Train tracks bent and buckled

Figure 9 shows the excessive settlements of an embankment along the JR Tohoku Line, located at 200k400m between Izumizaki and Yabuki Stations [15]. The boring survey was conducted after the earthquake, which has revealed that the groundwater level was located within the filled soil layer above the subsoil layers, suggesting that the saturated part of the fill, consisting of sandy soil, may have liquefied and induced a large deformation.

Figure 9. The excessive settlements of an embankment along the JR Tohoku Line. Source: [15]

4. Railway hadlings and Budgeting at Divre II West Sumatra
The level of performance of the railroad tracks is very influential in realizing safety during the trip. The level of performance of the railroad tracks is very prominent in achieving safety during the trip. As
stated in PM 32 of 2011 concerning Standards and Procedures for Maintenance of Railway Infrastructure, maintenance of railway infrastructure must be done to create a reliable railroad track.

The Directorate General of Railways as the infrastructure operator routinely allocates funds for maintenance of railway infrastructure, especially specifically for disaster management. Funds originating from this APBN should be allocated annually, based on information obtained from the Work Unit of the Directorate of Railway Infrastructure. The allocation of funding for disaster management in 2018 was around 15 billion. In 2019 this fund was not allocated, and in 2020 it was allocated as much as 2 billion which subsequently made budget savings so that the available funds in 2020 amounted to 1.4 billion.

The handling process is carried out using the IMO (Infrastructure Maintenance and Operation) scheme, in this case, the Directorate General of Railways delegates this maintenance obligation back to a third party. The process of procuring activities or implementing disaster management on this railway line is divided into 2 (two) types:

1. Carry out a procurement scheme for goods/services by conducting a quick tender as regulated in Perpres 16 of 2018 concerning Procurement of Government Goods / Services;
2. Conducting an IMO scheme implemented by PT. KAI, where in this scheme, PT. KAI (Persero) takes care first, and then the funds that come out of the handling are reimbursed to the Directorate General of Railways through the State Budget.

In terms of handling natural disasters on the railroad track, the Railway Engineering Center as the regulator and PT. KAI (Persero) as the operator has a very important role. Especially in the West Sumatra Region, which is the working area of the Class II Railway Engineering Center for the West Sumatra Region and PT. KAI (Persero) Divre 2 West Sumatra, has jointly carried out a mapping of disaster-prone areas. Mapping is done in areas prone to landslides and prone to flooding (Figure 10).

![Map of landslide and flood prone areas](image-url)

As can be seen on the map of the prone areas above, the railway line in West Sumatra has the potential to be affected by landslide prone areas and flood prone areas. Divre 2 West Sumatra, as the organizer of...
the facility that has the obligation to ensure that train travel runs safely, routinely checks existing vulnerable areas by assigning JPJ (Road Inspector) officers to monitor the geometric of the railroad track in order.

Figure 11. Checking existing vulnerable areas by assigning JPJ officers (road inspectors)

In addition, Divre II West Sumatra also routinely checks the overall geometrical railroad tracks using the KA Ukur. The results of this geometric check will then be processed so that a TQI (Track Quality Index) can be obtained which can be used as a reference for carrying out a railway infrastructure maintenance program on a regular basis. This measurement activity is usually carried out once a year.

Figure 12. Overall geometric measurements of railroad tracks using the Measure Train

5. Conclusion
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