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Electrical Resistivity Tomography as a Geotechnical Justification Support in a case Makassar – Pare-Pare Railway Bed Construction KM 68+450 to KM 68+750

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ABSTRACT

This study examined the presence of underground water channels under the Makassar - Pare-pare railway line KM 68+450 – KM 68+750 and the design concept for the technical solution. The potential for underground water channels was identified during construction, based on community information, the location's morphological phenomena, and geological conditions whose base rock was the limestone formation. The problems can cause instability of the railway line, resulting in unsafe train travel. One of the characteristics of limestone rock conditions is its hollow shape, like a cave that can become underground water flow. It was a case study whose solution was based on data obtained from geotechnical investigations. Boring testing can only provide information on soil layers at the test point and cannot describe soil stratigraphy section, including underground water channel. Combination ERT and Boring tests were carried out to examine the presence of underground water channels. This study was conducted in three stages: initial identification, advanced identification, and design concept of Technical Solution. In these three stages, data collection and analysis were carried out. The results of the study indicated that ERT tests could provide a picture of the subsurface to shallow bedrock, thus facilitating the justification of geotechnical design. From the analysis, it was concluded that no channel cavities, such as caves, that function as underground water channels. The existing water flow was estimated to be a confining aquifer where water flows due to the height difference in the surrounding morphological conditions through the media of the broken limestone water shaft. It was confirmed with the results of Boring and ERT tests. The proposed technical solution concept was strengthening the Dolken embankment structure and geogrid, combined with a subdrain layer. The technical solution was prepared based on the results of research on construction contract data and project resource readiness.

1. Introduction

A technical issue has arisen in the construction of the Makassar–Parepare Railway Line at KM 68+450 to KM 68+750 in Mandalle Village, Pangkajene Regency, involving the potential presence of an underground water flow directly beneath the planned railway line. This potential was identified based on several observations: the rice field, which should be dry during the dry season,

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remains consistently wet, forming patterns in various areas. Additionally, a reservoir, believed to be a sinkhole, was also observed, as shown in Figure 1. The geological conditions of karstic/limestone bedrock locations, such as this research area, can result in subsurface flow and sinkholes. A sinkhole disaster occurred previously in Maros, approximately 40 km from the research site. That sink hole suspected to be the result of an underground river's former flow [1] . Limestone often contains cavities that can serve as water channels, commonly known as underground rivers. This is what underlies this researcher's identification of whether there are underground water channels on the Makassar-Parepare railway line at KM 68+450 to 68+750, which can endanger the construction of the railway.

The soil boring method and Standard Penetration Test (SPT) are commonly used for geotechnical investigation. However, these tests can only provide information on soil layers in a 1-dimensional (only at the test point) and cannot describe the soil layer. This is an obstacle for any geotechnical engineer, as it creates uncertainty about subsurface conditions. Especially in this case, there is a potential for problems that are not commonly encountered.

Figure 1. Reservoir at research site that suspected to be a sinkhole

One way to find out the picture of the subsurface soil stratigraphy of KM 68+450 to 68+750 is through Electrical Resistivity Tomography testing or can be abbreviated ERT testing. In addition to identifying the presence of subsurface flow with ERT and geotechnical testing (boring method), this study also aims to propose a design concept of Technical Solution on the Makassar - Pare-Pare KM 68+450 - 68+650 railway by considering the existing project resources.

2. Methods

This study consisted of three main stages: initial identification, advanced identification, and concept design of Technical Solution as Figure 2. At each stage, data collection and data analysis were also carried out. Data was collected through field testing, observation, and literature studies.

a) In the initial identification stage, primary data were collected through field observations, supplemented by secondary data to enhance the analysis.
b) Advanced Identification: In this stage, primary data were collected through ERT testing, followed by geotechnical testing with boring and SPT. Discussions and analysis were then conducted based on the test results.
c) Design Concept of Technical Solution: At this stage, the technical solution for the research location was planned, considering primary data and available project resources, such as construction contracts and applicable technical specifications. The goal was to ensure that the technical solution would be both effective and efficient, incorporating technical risk control measures.

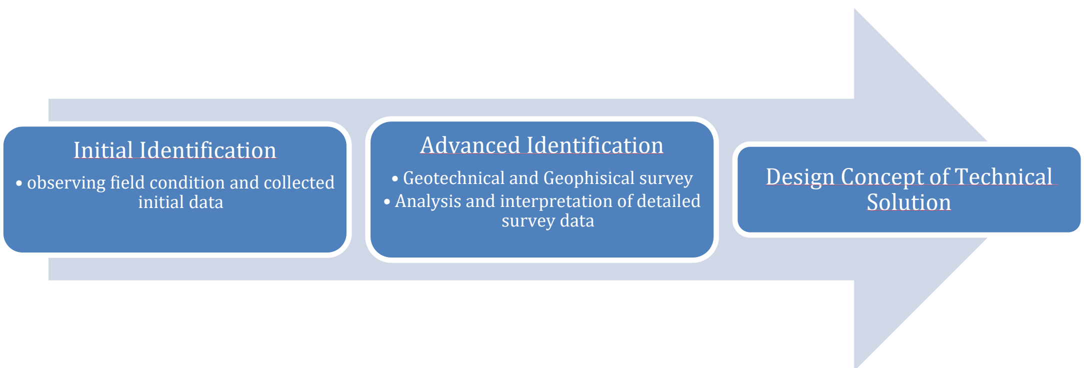

Figure 2. Research Stages

2.1. Literature Review

2.1.1. Geological Conditions

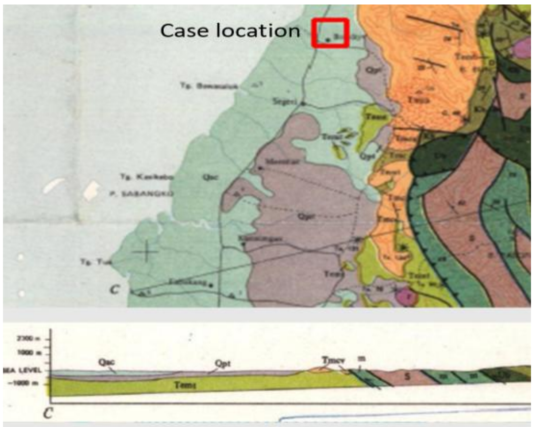

Figure 3. Pangkajene Regional Geological Map [2]

The research location was in an alluvial geological formation, with the base rock in the Tonasa formation [2], as shown in Figure 3. The Tonasa Formation (Temt) is formed as limestone sediments. Some are layered and solid: coral, bioclastic, and calcarenite with globigerina marl inserts. The majority of the formation is white to light gray, though some areas appear dark gray or brown. Fossils from the Tonasa Formation show ages ranging from Eocene to Middle Miocene. The depositional environment is shallow to deep neritic, and some are lagoons. This formation is overlain by the Camba Formation (Tmc); in some places, it is intruded by hacks, sills, and stocks composed of basalt and diorite, well developed around Tonasa in the Lembar Pangkajene and Watampone West areas, to the north [3] . The geological conditions of the research location shown in Figure 3.

2.1.2. Characteristics and Potential of Geological Problems

Limestone, being a sedimentary rock significantly influenced by dissolution, rarely exhibits a smooth morphology. As a result, it often develops a complex structure, such as the formation of water channels or caves as seen in Figure 4. The many fractures (joints) in limestone that make karst topography so that large pores, high secondary permeability, and high degree of rock dissolution cause the occurrence of conduit passages, which are underground rivers, so that the smallest input will be received and percolated through the pores and enter the underground river passages and spread easily [4].

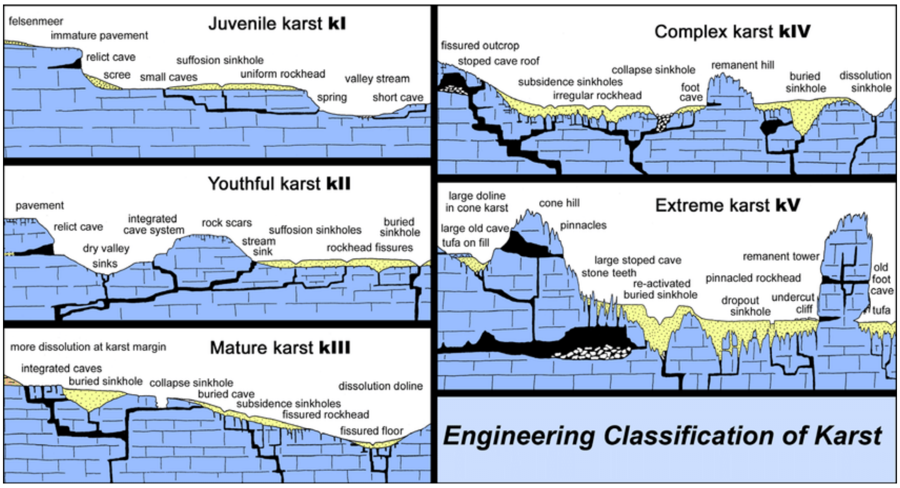

Figure 4. Karst Conditions that May Occur in Underground [5]

Dolines in karst literature are often referred to by various terms, such as sinkholes, sinks, swallow holes, cenotes, and blue holes. Karstification always begins with forming a single doline due to a concentrated dissolution process. Karstification is the process of forming dolines and underground caves, while karst hills are residual formations from the development of dolines [6]. Various problems in limestone areas can technically be handled in various ways. One way is to strengthen the cavities in the limestone with grouting curtain [7].

2.1.3. Geotechnical Investigation

Geotechnical investigation is a crucial stage in the planning and designing construction projects. Its primary purpose is to understand a site's geological and geotechnical characteristics [8]. According to SNI 8460:2017, the types of field investigations include: a) field tests (e.g., CPT, SPT, dynamic penetration tests, WST, pressure meter tests, dilatometer tests, plate loading tests, field vane shear tests, and permeability tests), b) soil and rock sampling for description and laboratory tests, c) groundwater measurements to determine the groundwater level or pore water pressure profile and its fluctuations, d) geophysical investigations (such as seismic tests, radar tests, soil resistance measurements, and wave propagation velocity measurements in the soil), e) large-scale tests, such as determining the bearing capacity or direct behavior of certain structural elements, such as anchors [9].

2.1.4. Electrical Resistivity Tomography (ERT) Test

ERT (Electrical Resistivity Tomography) is a geophysical exploration method used to investigate subsurface conditions by measuring the electrical properties of rocks. These properties include resistivity, conductivity, dielectric constant, the ability to generate self-potential and induction fields, the nature of storing potential, and others. ERT analyzes subsurface materials based on their resistivity values, described in 1D, 2D, and 3D [10] . Table 1 shown that ERT can be used for engineering investigation, hydrogeological investigation needs and detection of sub-survace cavities [11]. The principle of conducting a resistivity survey is to pass a direct electric current into the earth through two current electrodes inserted at two points on the ground surface and then measure the potential difference response that occurs between two other points on the ground surface where two potential electrodes are placed in a specific arrangement [12].

Table 1. Comparison of Types of Geophysical Tests [11]

Geophsical method	Dependant physical property	Aplications (see key below)									
		1	2	3	4	5	6	7	8	9	10
Gravity	Density	p	p	s	s	s	s	!	!	s	!
Magnetic	Susceptibility	p	p	p	s		m	!	p	p	!
Seismic refraction	Elastic modul; density	p	p	m	p	s	s	!	!	!	!
Seismic reflection	Elastic modul; density	p	p	m	s	s	m	!	!	!	!
Resistivity	Resistivity	m	m	p	p	p	p	p	s	p	m
Spontaneous potential	Potential differences	!	!	p	m	p	m	m	m	!	!
Induced polarization	Resistivity, capacitance	m	m	p	m	s	m	m	m	m	m
Electromagnetic	Conductance; inductance	s	p	p	p	p	p	p	p	p	m
EM-VLF	Conductance; inductance	m	m	p	m	s	s	s	m	m	!
EM-ground penetrating radar	Permitivity; conductivity	!	!	m	p	p	p	s	p	p	p
Magneto-telluric	Resistivity	s	p	p	m	!	!	!	!	!	!
Gravity	Density	p	p	s	s	s	s	!	!	s	!

p = primary method; s = secondary method; m = may be used but necessarly the best approach, or has not been developed to this aplication; (!) = unsitable

Aplication

1 Hydrocarbon exploration (coal, gas, oil)
2 Regional geological studies (over areas of 100s of km2)
3 Exploration/ development of mineral deposit
4 engineering site investigation
5 Hydrogeological investigation
6 Detection of sub-surface cavities
7 Maping of leachate and contaminan plumes
8 Location and definition of buried metalic objects
9 Archaegeophysics
10 Forensic geophysics

Resistivity surveys provide an overview of the distribution of subsurface resistivity. To convert the subsurface resistivity profile into a geological representation, knowledge is needed to differentiate the types of subsurface materials and their geological features based on their resistivity values [13]. Telford categorizes the resistivity values of natural materials which are presented in Table 2.

Table 2. Natural Material Resistivity Value [13]

Material	Resistivity (Ohm-Meter)
Pyrite	0.01 – 100
Quartz	500 - 800.000
Calcite	1×10^{12} - 1×10^{13}
Rock Salt	30 - 1×10^{13}
Granite	200 - 100.000
Andesite	1.7×10^{2} - 45×10^{4}
Basalt	200 - 100.000
Limestone	500 - 10.000
Sandstone	200 - 8.000
Shales	20 - 2.000
and	1 - 1.000
Clay	1 – 100
Ground Water	0.5 – 300
Sea Water	0.2
Magnetite	0.01- 1.000
Dry Gravel	600 - 10.000
Alluvium	10 – 800
Gravel	100 – 600

2.1.5. ERT Test Application to Identify Cavities and Aquifer

ERT testing was conducted by Putisˇka in 2014, proving that ERT testing can effectively describe the presence or absence of cavities in shallow limestone rocks in Komberek, Slovakia [14]. Visualization of ERT Test Results in Putisˇka's Research pointed to Figure 5.

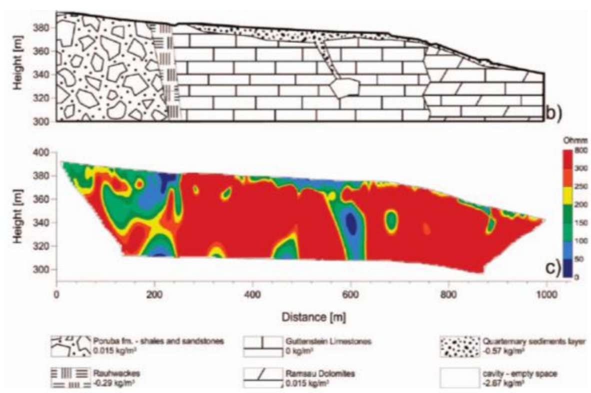

Figure 5. Visualization of ERT Test Results in Putisˇka's Research [14]

ERT testing can also provide an easier interpretation of the size and position of subsurface anomalies in caves, sinkholes, faults, etc., in a case study in Amdoun, Tunisia [15]. ERT testing to identify the karst area on the UNY Gunungkidul campus has also been carried out by Wilopo, who obtained results depicting the subsurface conditions of limestone rocks [16].

As in Nasution's research on aquifers in alluvial deposits, ERT can be used to determine the presence or absence of free water flow in cavities or an aquifer [17]. Aquifer or a permeable layer that carries water in the ground can be in the form of an Unconfined Aquifer, Confined Aquifer, Semiconfined Aquifer, or Perched Aquifer [18].

2.1.6. Bedroad Reinforcement Method of Railway Construction

In Indonesia, the Regulation of the Minister of Transportation called Peraturan Menteri Perhubungan No 60 Tahun 2012 Tentang Persyaratan Teknis Jalur Kereta Api. The regulation governs the design criteria for bedroad railway tracks that must meet stability aspects and meet settlement requirements [[19]. The DJKA Technical Specification 2021 is also a normative reference in railway infrastructure development activities. The Technical Specification also describes various types of soil improvement systems, including dolken, sirtu wrapped in geotextile, and soil stabilization with lime [20]. To carry out soil improvement efforts, mechanical stabilization or chemical stabilization can be employed [21]. The selection of soil improvement methods should be adjusted to the conditions of the construction project and must meet the required technical criteria.

Layers in railway bed formation must be carefully planned to prevent shear failure and accumulated/plastic deformations under repeated axle loads. Because of the static and dynamic impacts of moving wheel loads, the blanket and subgrade layers support the track construction and endure additional strains. The sub-grade and embankment fill layers transfer load to the subsurface or ground level. [22].

In general, the research location is in an area that is quite wet and flooding can occur. When designing embankment segments in floodplains, hydrology and hydraulic studies based on known flood levels must determine the highest water level [23]. As seen in Figure 6, the embankment fill section must be constructed with an underlying "drainage layer" in addition to a surface layer of drainage material and riprap protection to safeguard foreslopes situated inside the highest water level zone.

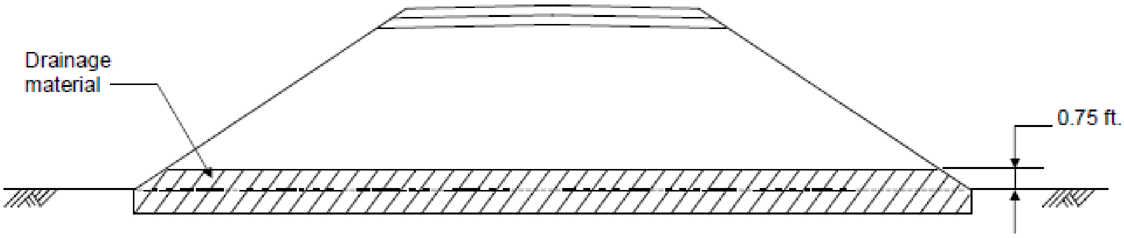

Figure 6. Drainage Layer under Embankments in Wet Locations [23]

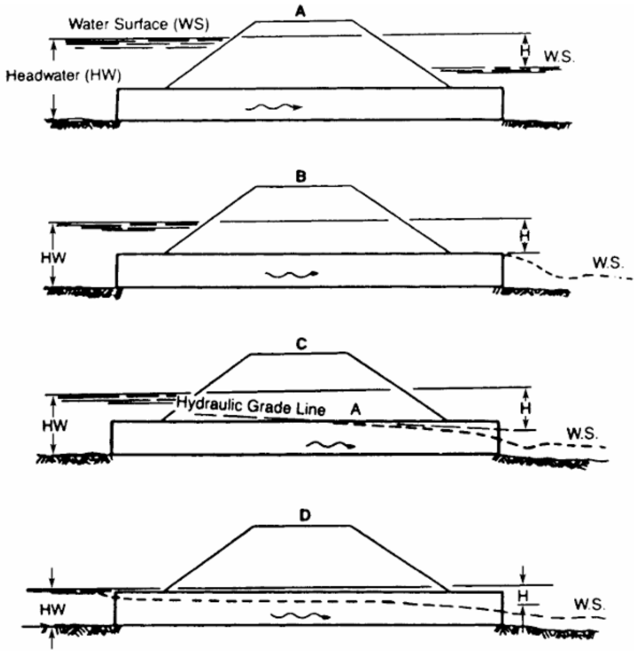

Figure 7. Typical of Crosectional Culvert with outlet control [24]

Due to flood condition, apart from using a drainage layer, flood control can also be done by building transverse water channels. This is to stabilize the flow of water from one side of the embankment to the other side of the embankment. Conventional Culverts considered here are circular and oval pipes and pipe arches, with uniform barrel cross-section throughout. There are two major types of culvert flow – with inlet control or outlet control [24], as seen in Figure 7.

3. Result and Discussion

In the initial identification stage, primary data and secondary data were collected. The primary data were from the community based on field observations, while secondary data included regional Geological maps of the Pangkajene and Watampone. The information obtained from field observations and the community were as follows:

a) Geologically, the research location is limestone formation bedrock which has the potential to contain natural cavities, but cannot be seen because it has been covered by alluvial deposits.
b) The research location was a rainfed rice field area where the rice field land was dry during the dry season, while in several areas, there was a wet ground surface.
c) Around the research location, there was a hole/reservoir that was always filled with water as seen in Figure 8, which was estimated to be a sinkhole.
d) The research location was at an elevation of ± 2 meters above sea level, and the plains were almost always saturated with water.
e) The distance between the research location and the beach was approximately ± 2 km.
f) There was a pattern of 10 spring gaps (estimated to be sinkholes) running from east to west or from the mountain towards the sea.

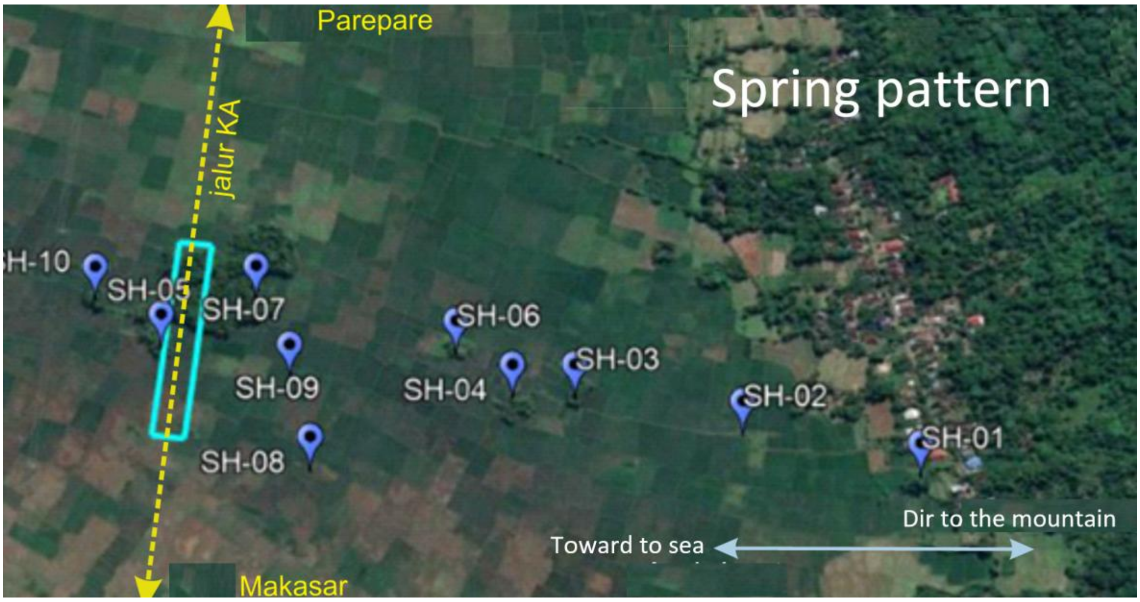

Figure 8. Reservoir Patterns around the Research Location

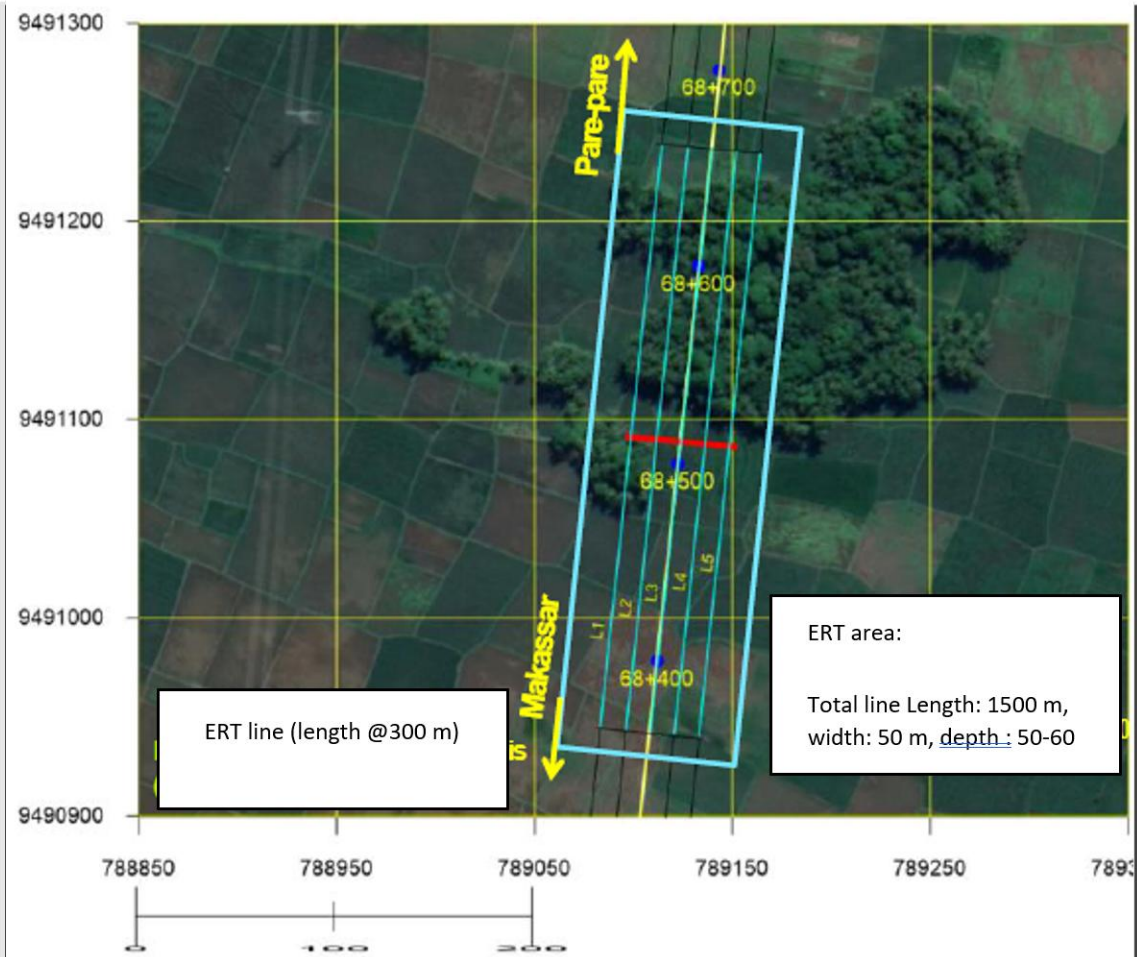

Figure 9. ERT Test Implementation Map

At the advanced identification stage, primary data collection was carried out by Boring and ERT testing, with the results: ERT tests were carried out on five longitudinal lines parallel to the planned railway line, from KM 68+350 to 68+650. The investigation lines were carried out on two lines on the left side of the As-Track, 1 line on the As-Track, and two lines on the right side of the As-Track. Each line was installed lengthwise from KM

68+350 to 68+650 (300 m) with a distance between lines of 12.5 m. Figure 9 shows the location of the lines from the ERT test. The results of the ERT test presented in Figure 10 to Figure 14.

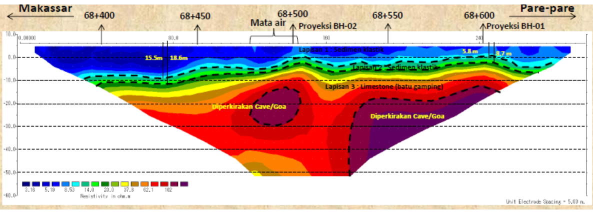

Figure 10. Resistivity Visualization Line 1

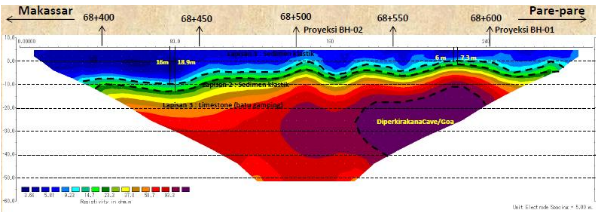

Figure 11. Resistivity Visualization Line 2

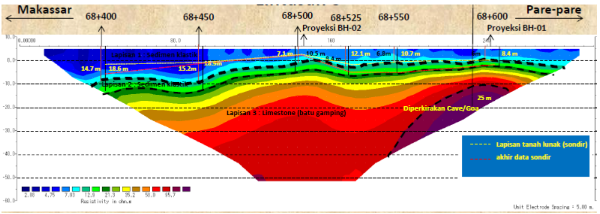

Figure 12. Resistivity Visualization Line 3

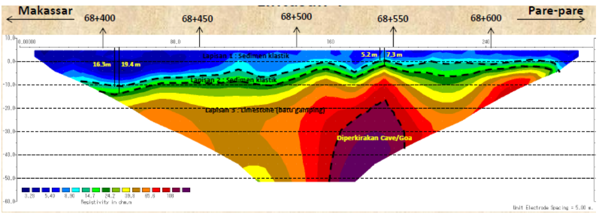

Figure 131. Resistivity Visualization Line 4

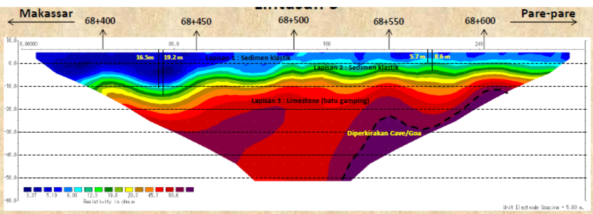

Figure 14. Resistivity Visualization Line 5

The ERT test in Line 1 results that the first layer had a resistivity value of 2.89 - 11 Ωm with a depth varying from 5.2 - 16.3 meters from the surface. The second layer had a resistivity value of 11 - 18 Ωm with a depth of 7.3 - 19.4 meters from the surface (thickness of 2.1 - 3.1 meters). The third layer had a resistivity value of 18 - 201.93 Ωm.

The ERT test in Line 2 results that the first layer had a resistivity value of 3.26 – 11 Ωm with a depth varying from 6 – 16 meters from the surface. The second layer had a resistivity value of 11 – 18 Ωm with a depth of 7.3 – 18.9 meters from the surface (thickness 1.3 – 2.9 meters). The third layer has a resistivity value of 18 – 166.34 Ωm.

The ERT test in Line 3 results that the first layer had a resistivity value of 2.54 - 10 Ωm with a depth varying from 6 - 16 meters from the surface. The second layer had a resistivity value of 10 - 17 Ωm with a depth of 8 - 20 meters from the surface (thickness 2 - 4 meters). The third layer had a resistivity value of 17 - 179 Ωm.

The ERT test in Line 4 results that the first layer had a resistivity value of 2.89 – 11 Ωm with a depth varying from 5.2 – 16.3 meters from the surface. The second layer had a resistivity value of 11 – 18 Ωm with a depth of 7.3 – 19.4 meters from the surface (thickness 2.1 – 3.1 meters). The third layer had a resistivity value of 18 – 201.93 Ωm.

The ERT test in Line 5 results that the first layer had a resistivity value of 3.02 – 10 Ωm with a depth varying from 5.7 – 16.5 meters from the surface. The second layer had a resistivity value of 10 – 14 Ωm with a depth of 8.6 – 19.2 meters from the surface (thickness 2.7 – 2.9 meters). The third layer had a resistivity value of 14 – 119.08 Ωm.

In general, the results of ERT tests showed three types of layers based on resistivity values. The first layer had a resistivity value of 3.02 - 10 Ωm with varying depths. This layer was relatively soft (not compact). Water easily saturated this layer because it had relatively large porosity and permeability compared to the layers below. The second layer had a resistivity value of 10 - 14 Ωm. This layer was a transition layer to the base layer/bedrock, relatively more compact than the layer above. The third layer, with a resistivity value of 14 - 119.08 Ωm, was the lowest and acts as bedrock.

Next, geotechnical testing was carried out to confirm the results of the ERT test. Geotechnical testing involves soil investigation with a drill and SPT test accompanied by taking soil and rock samples. Boring activities are carried out at two investigation points can be seen in Figure 15: BH 2 around KM 68+425 on line 2 of the ERT test (around the reservoir area) and BH 1 around KM 68+600 on line 3. The Boring test was carried out to a depth of 30 m. The Boring activities were carried out by taking samples and SPT tests. SPT testing will provide an overview of the density level of the soil layer in each test layer. This test point is carried out based on the type of rock layer depicted in an area with high resistivity from the ERT image.

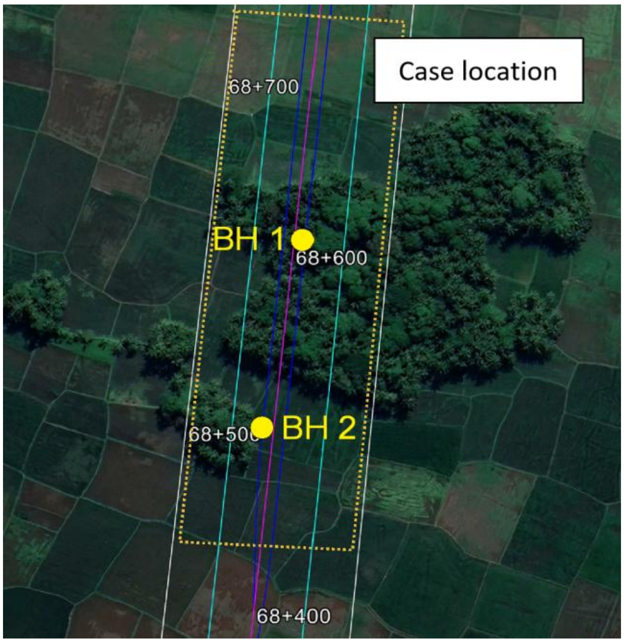

Figure 15. Boring test location

The results of the BH 1 test as shown in Figure 16 were that a new bedrock was found in limestone at a depth of 7.4 m from the original soil. For a soil layer of 7.4 m, most of it consists of clay with a little fine sand. In the soil layer in BH 1, the N-SPT value was relatively low, ranging from 3-10, indicating that the soil layer is quite soft. In the investigation >7 m, limestone rock structures were obtained with varying conditions.

In BH 2 can be seen in Figure 16, limestone bedrock was found at a depth of 5 m from the original soil. In this surface layer of soil, most of the material is clay mixed with fine sand with SPT values of 2 and 3. For BH 1 and BH 2, the rock layers obtained SPT values >60. Figure 17 and Figure 18 show the Borehole Log of BH1 and BH2.

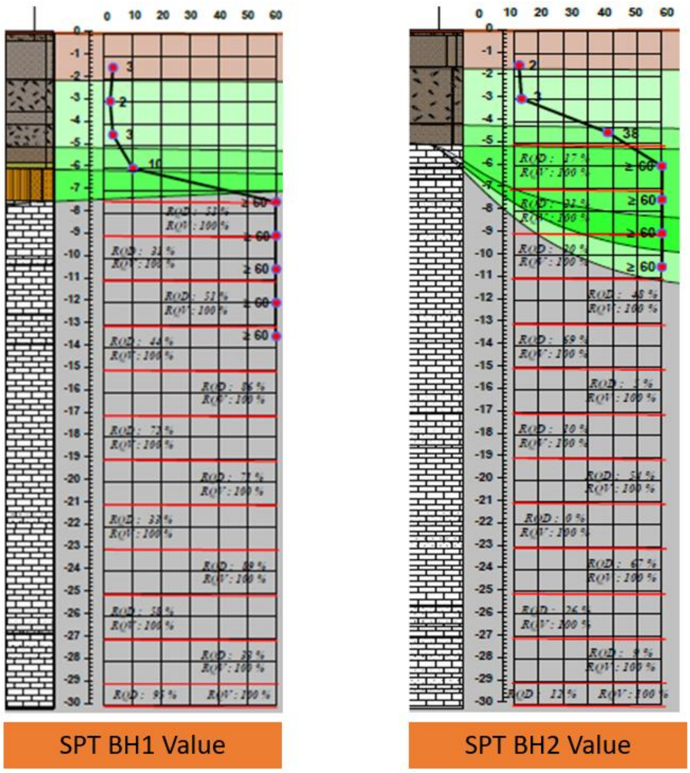

Figure 16. Sketch of Soil Layer based on Boring and SPT Testing.

Figure 17. BH1 Borehole log

Figure18. BH2 Borehole log

Table 1. Data on Contract Activities

Available Project Resources	Data Collection Results
Time	Remaining work time 30 day
Existing Contract Work Items related to land improvement	- Excavation - Sirtu - Selected soil embankment - Geotextile - Geogrid - Dolken - Bamboo - 2x2 m precast box
Construction Equipment	- Escavator 3 unit PC 200 - Dump truck - Vibrocompactor 12 ton 2 unit - Bulldozer 1 unit
Problematic segment	- 250 m’

At the stage of designing the technical solution concept, data collection related to construction work was collected from parties involved in the project, including Table 3.

ERT Interpretation and Regional Geology

Based on the existing geological map, the research area was in an alluvial geological area, where the base was in the form of limestone rocks of the Tonasa formation. Approximately 2 km from the research location, there was a camba rock formation.

Volcanic Camba formation (Tmcv): volcanic breccia, conglomerate lava, and fine-grained tuff to lapilli interspersed with marine sedimentary rocks in the form of tuffaceous sandstone, calcareous sandstone and mudstone containing plant remains. The paleontological and radiometric data indicated a Middle Miocene to Late Miocene age. The layers are mostly weakly folded, with a slope of less than 20, unconformably overlapping the Tonasa Formation limestone (Temt) and older rocks. Alluvial, Swamp, and Beach Deposits (Qac): gravel, sand, clay, mud and coral limestone. They were formed in river, swamp, beach, and delta environments.

Based on the interpretation of the five ERT test results, there were three layers based on resistivity values. The first layer had a resistivity value of 3.02 - 10 Ωm with varying depths. This layer was relatively soft (not compact). Water easily saturated this layer because it had relatively large porosity and permeability compared to the layers below. This layer was estimated to be sediment originating from rocks at high altitudes, namely the terraced sediment formation and volcanic rocks of the Camba formation, and it was interspersed with deposits originating from the sea in the form of swamp and beach deposits (Qac).

The second layer had a resistivity value of 10 - 14 Ωm. This layer was a transition layer to the base layer/bedrock based on the Cone Penetration Test (CPT) data information and was relatively more compact than the layer above. Based on the Boring data, this layer was estimated to be predominantly clastic sediments, primarily silty clay with a little sand. The third layer, with a resistivity value of 14 - 119.08 Ωm, was the lowest and acts as a bedrock. This layer was estimated to be compact based on the Boring data information and was estimated to be limestone originating from the Tonasa formation (Temt).

Seeing the large resistivity value interval in the third layer indicated that the condition of this layer was irregular due to secondary porosity produced after this rock was formed through the dissolution process and tectonic forces that can create fractures and cavities of various sizes ranging from small channels to caves. It appears that in several lines, there were also areas with resistivity above 170 Ωm (purple) in (limestone) that formed cave geometry or interconnected fractures and could act as what was known by the general public as an underground river, but this must also be seen as another possibility where in the Tonasa formation there are intrusive rocks composed of basalt and diorite so that further investigation is required.

Interpretation of Geotechnical Investigation

The results of the BH 1 test at a depth of 7.4 m from the original soil only found limestone as the base rock. A soil layer as thick as 7.4 m mainly consists of clay with a little fine sand, following alluvial deposits' characteristics. The N-SPT value was obtained relatively low in the soil layer in BH 1, ranging from 3-10. This indicated that the soil layer was quite soft. In the investigation> 7 m, limestone rock structures were obtained with varying conditions. In the core box samples obtained, white rocks (limestone) were crushed into powder; some were intact and weathered, and some were hard. This follows the characteristics of the type of limestone rock where the surrounding physical and chemical processes influence the hardness and integrity. In general, the results of the BH 1 test are in line with the results of the ERT test, where the surface layer is dominated by a fine-grained layer of clay and fine sand. The second layer transitions between sedimentary soil and rocks; the third layer is limestone.

Similar to the test results on BH 2 at a depth of 5 m from the original soil, limestone bedrock has been found. On the surface layer of this soil, most of the material was clay mixed with fine sand with SPT values of 2 and 3. The small SPT value indicated that the density of this soil layer was quite soft. The rock layer was the same as the results of the investigation on BH 1, where the bedrock is limestone with varying levels of weathering and hardness. For BH 1 and BH 2, the rock layer obtained an SPT value of >60, which means that the layer is indeed rock. If referring to the SPT value, the rock will get an SPT value of >60. One method to determine the rock mass quality from this Boring test is by reading the RQD value. Rocks with an RQD value <20% are often defined as rocks with inferior rock mass quality, and an RQD value of >50% is only considered good. In general, the results of the BH 2 test were in line with the results of the ERT test, where the surface layer was dominated by fine-grained layers of clay and fine sand. The second layer transitions between sedimentary soil and rocks; the third layer was limestone.

ERT Review and Geotechnical Investigation

The high resistivity value in part of layer 3 (purple) from the BH 1 and BH 2 Boring results did not indicate any materials in the rock other than limestone. As previously discussed, there was an area in layer 3 with a high resistivity value. This could occur because a cavity was not filled with an electrical conductor or rock with a higher density than limestone.

When the soil investigation was conducted, there was no drop of the drill stick at all during Boring, which means there were no cavities in the Boring field. So, the initial suspicion that cavities were below the ground surface was not proven. In addition, if you look at the elevation of the base soil, where it is only at an elevation of ±2 m, and the MAT is not deep, it is almost certain that if there are cavities, it will describe low resistivity.

In principle, ERT tests describe the difference in resistivity levels in soil or rocks. One of the uses of ERT tests is to detect the presence of underground caves, as in the Putisˇka’s research and Redhaunia’s research where from a case example of ERT test results where there is a high difference in resistivity values (dark purple) indicates the presence of a cave that is not submerged. Generally, these caves occur in limestone rock formations in non-submerged areas, as in Wilopo's research. This is different from the investigation results at the research location in this study, where the rock has the same high resistivity value (purple). However, it is located in a submerged area. If there is a cave in submerged rock, it will show a low resistivity value because the nature of water will easily conduct electricity.

Suppose the geophysical and Boring tests are to be evaluated. In that case, it can be concluded that the area with high resistivity (in purple) in the submerged area does not have cavities or caves. High resistivity is possible due to the irregular condition of this layer, which is associated with the degree of compaction of the limestone. From the Boring data (BH01 and BH02), the large resistivity value in the third layer is on the right side of the non-compact limestone cross-section. It is associated with the low RQD (Rock Quality Designing) value and indicates the presence of secondary porosity developing in the layer.

A reservoir always filled with water can be caused by the confining aquifer event or subsurface flow due to a soil layer with high permeability and water head energy in the aquifer path. Morphologically, this event is possible because not far from the reservoir on the side of the mountain (to the east ± 1 KM), there is a spring on the plateau in the form of sedimentary rocks of the Camba formation. With a fairly large head difference and the characteristics of the soil and rocks in the research area that are possibly water axis media, there is indeed a flow below the ground surface. The flow is not in a cavity or cave but in a water axis media.

Design Concept of the Technical Solution

In this condition, the Technical Solution of the structure in this area will focus on the stability of the construction and not disrupt the flow of underground water. In Peraturan Menteri Perhubungan No 60 Tahun 2012 Tentang Persyaratan Teknis Jalur Kereta Api, the technical requirements of railways for embankment structures must meet the stability of 3 things: stability to the soil bearing capacity, settlement, and slope stability. The safety factor and settlement tolerance on embankments were regulated in these regulations. Because the case location is a wet area and has the potential for flooding, the concept of handling methods is also planned in accordance with the technical provisions for embankments.

Taking into account the geotechnical conditions below the surface and the not-too-high embankment in this area (2 meters from the original ground level), the basic concept of the design, in this case, is an embankment structure that is safe against soil bearing capacity, slope stability, settlement, embankment deformation and does not interfere with previously predicted subsurface flow.

The availability of project resources, including time, existing contract work items, and related to land improvement and construction equipment, is one of the primary considerations in determining Technical Solution. The existence of a Technical Solution solution that considers existing resources is expected to be an effective and efficient solution because it can speed up the construction process and primarily facilitate material procurement.

The material to be used as a Technical Solution concept refers to the existing material in the contract and the existing technical specifications. In this case, the technical specifications used are the DJKA 2021 technical specifications. The work items that can be applied immediately because they are in the contract and the technical specifications include: dolken, geotextile, geogrid, sirtu, selected fill soil, and 2x2 m precast box.

The initial concept design presents the Technical Solution in this area, and the design is based on existing project resources. Based on Figure 19, embankment reinforcement is carried out by mechanical stabilization of the embankment structure using geogrid. Meanwhile, to handle the problem of subsurface flow, sub-drain and cross-drain channels are used in several locations.

Techinal solution concept is presented in Table 4, which provides a matrix for controlling the risks of existing technical issues with construction.

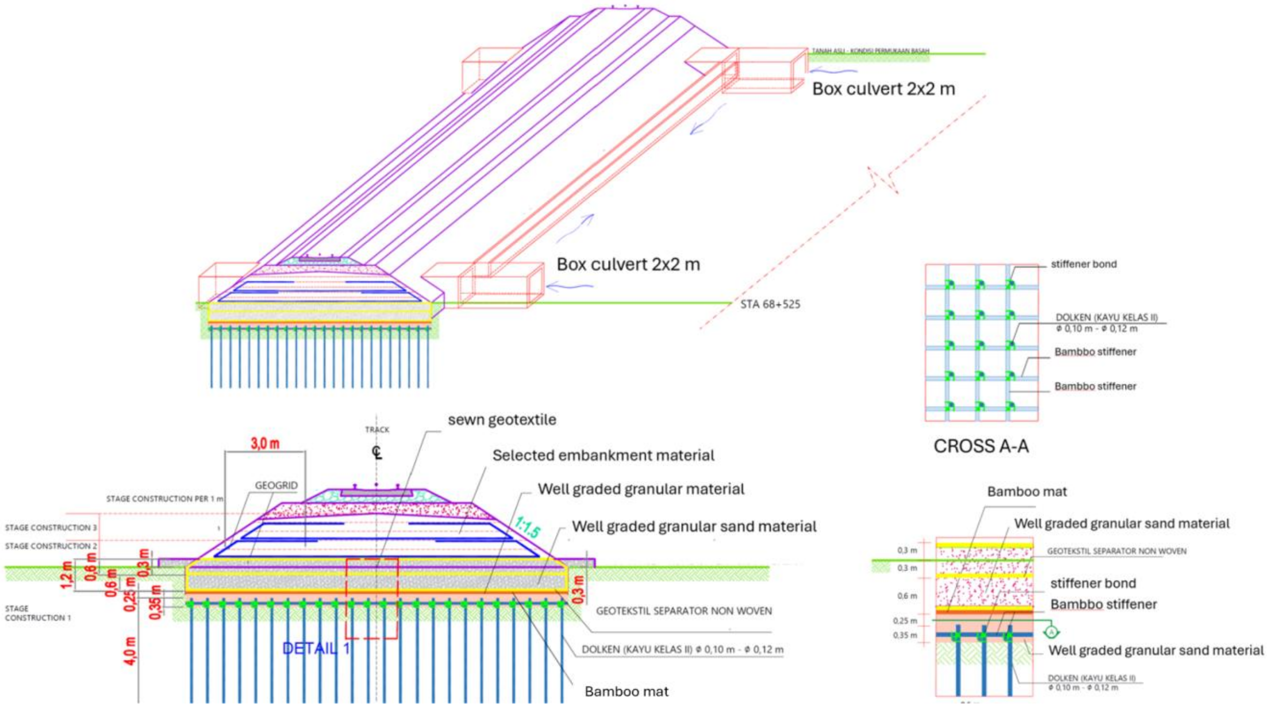

Figure 19. Technical Solution Concept

Table 2. Identification Issues and Risk Control

Identification of technical issues	**Technical Risk Control**
Limited resources and time	Utilizing the availability of local materials already included in the contract. such as: utilization of existing heavy equipment, use of materials that are already in the contract
High embankments are unstable and add weight to the construction.	Changing the embankment design to be not high
Land subsidence due to thick soft soil	Soil reinforcement with pile foundation
Concrete pile foundation requires a long procurement time	Using cerucuk kayu as a pile foundation
Cerucuk pile foundation works individually.	Unifying the foundation of the pillars with a bamboo woven frame
Unstable embankment due to deformation caused by load and soil conditions	Reinforcing embankments with geogrid as a system
Area of water-saturated soil, deep excavation is difficult to perform.	Excavation depth maximum 1 m
Ordinary fill soil cannot compact when it gets wet.	Granular material is used as the base layer for embankment construction.
Under the embankment still has the potential to become an active aquifer, and the impermeable embankment soil has the potential to disrupt the stability of the embankment due to pore water pressure.	The bottom part of the embankment uses well-graded granular material as a subdrain layer and pore water pressure relief, which can disrupt the shear stability of the embankment.
Granular materials are easily carried by water flow.	Separation geotextiles are used to maintain the integrity of granular materials underground.
Floods and the rise of groundwater levels on the side of the embankment can potentially disrupt the stability of the embankment.	Using a 2x2 m box culvert channel for water drainage and balancing

5. Conclusion

ERT can effectively determine the soil condition below the surface so that it is not too deep. The description of the ERT results provides sufficient information to provide supporting information for geotechnical analysis. From the research results, there was no underground cavity with water flow that was initially thought to be an underground water channel cave. The subsurface flow was identified as subsurface flow due to soil layers with high permeability and water head energy in the aquifer path. Due to the fairly low height of the planned bedroad, the Technical Solution that is conceptualized to be applied s in the form of soil reinforcement with dolken pile foundations and supported by the creation of surface water channels and sub drains under the embankment to drain water that has flowed naturally before. It also accommodated the availability of project resources.

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