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Article

Geotechnical Analysis and Evaluation of Semarang City, Central Java, Indonesia

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Abstract: This study was conducted in the Geological Investigation Project of the proposed GROBOGAN CEMENT PLANT 6000t/d Clinker Cement Production Line Geological Investigation Project in GROBOGAN Regency located about 60 km east of Semarang City, Central Java Province, Central Java, Republic of Indonesia. We conducted a geotechnical investigation to meet the needs of the requirements for engineering design and construction. The seismic effect of the site and the suitability of foundation soil as a holding layer were evaluated based on the Chinese standard "Code for Seismic Design of Buildings" (GB50011-2010) (2016 edition) and according to the engineering geology analogy method and regional experience. The earthquake intensity in the study site was classified as a 7-degree area, implying the area is stable.

Keywords: Geological Survey, Geotechnical Survey, Engineering Design, Seismic Design

1. Introduction

Integrated design in geotechnical engineering is a key element of civil and geotechnical engineering. The design enables projects with the appropriate understanding of soils and foundations. The city of Semarang where the study site is located is in the Central Java Province, central Java, Republic of Indonesia (110°37'19" E, 07°05'30" S). Java has a tropical rainforest climate, hot and humid all year round. Temperatures are high in the plains along the northern coast while lower in the mountains. The northwest monsoon period lasts from November to March with lots of rain and clouds. From April to October, the southeast monsoon prevails with sunny days and little rain. The average annual temperature in Semarang is about 29 °C. The average precipitation throughout the year is about 2000 mm. In such areas with complex geographic and environmental conditions, complex tools and techniques are needed to identify appropriate construction sites, especially [1,2].

Since the recent demand for new buildings and infrastructures is rapidly increasing, appropriate management and design in geotechnical engineering is extremely important. Evaluation of subsurface conditions and accurate measurement of geotechnical properties are essential to determine the feasibility and safety of construction projects. The topography of the study site is dominated by hills and plains. Java is located on the demise boundary between the Asian-European and Indian Ocean plates and is geologically active with frequent earthquakes and volcanic activities. Regionally, Java Island mainly consists of volcanic rocks distributed in an arc in the center and Tertiary sedimentary rocks in the south and north. The geology of Java is relatively simple, with tectonic lines generally trending east-west, and a small number of normal and reverse faults distributed (Fig. 1–3).

Geotechnical parameters are important in the design and implementation of geotechnical engineering projects [3–5]. There are no major tectonic fractures in the vicinity of the study site, which is affected by volcanic activity. However, the southern area of Java near the sea belongs to the most active seismic zone in the world, the Pacific Rim Seismic Zone, which is prone to frequent earthquakes. Therefore, the study site is inevitably affected by earthquakes. The engineering and physical properties of soils in the study site change significantly horizontally and vertically [6]. Traditionally, geotechnical measurement is a long process. However, recent technological advances enable non-destructive geophysical measurements such as seismic wave velocity measurement [7,8]. The regional geotectonic map and the drilling data of the site present that there are no active fractures as well as fracture fragmentations passing through and within 1 km of the site. No obvious geological structure phenomenon is observed on the surface, and the drilling data does not reveal any sign of fractures and fragmentations. In summary, the geological and tectonic conditions are simple and the regional crust is stable.

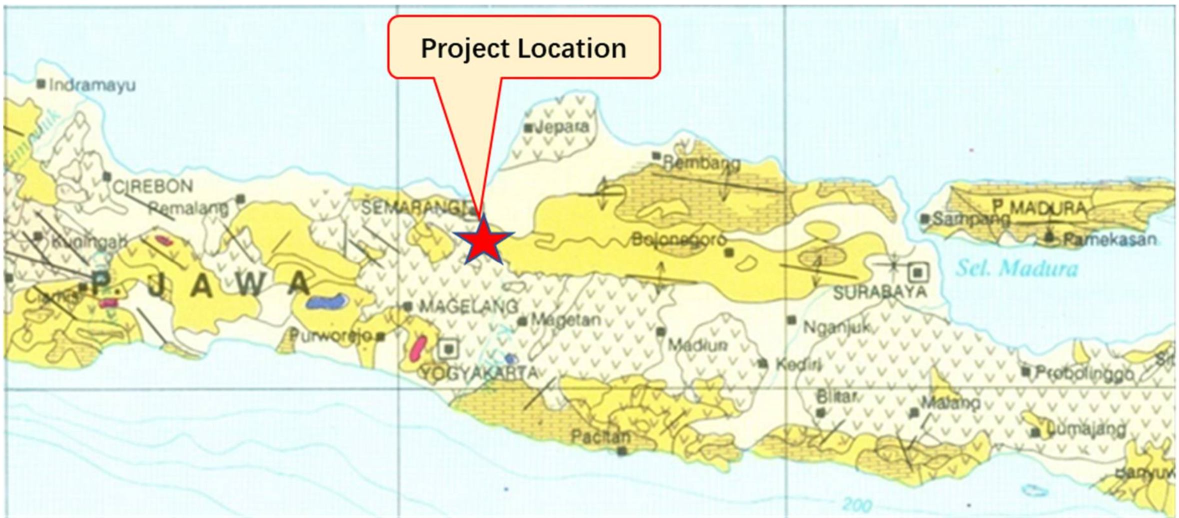


Fig. 1. Geologic map of central Java in Indonesia in 1 : 5 million scale.

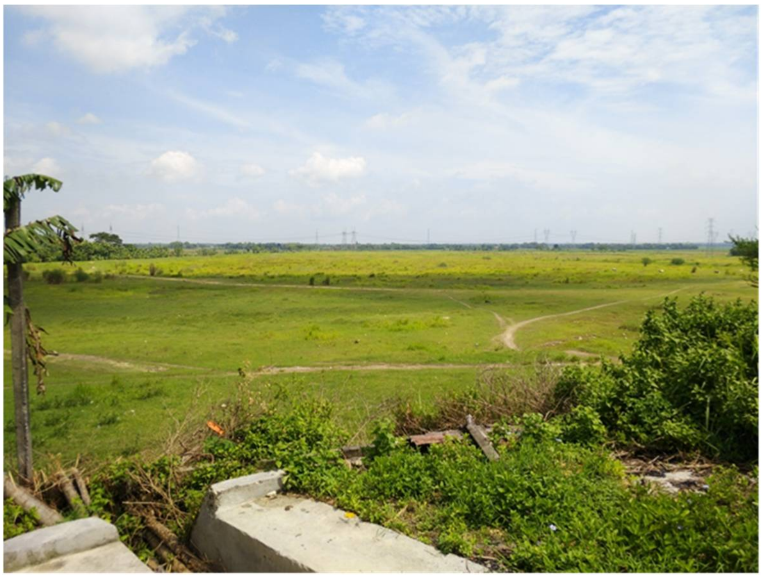
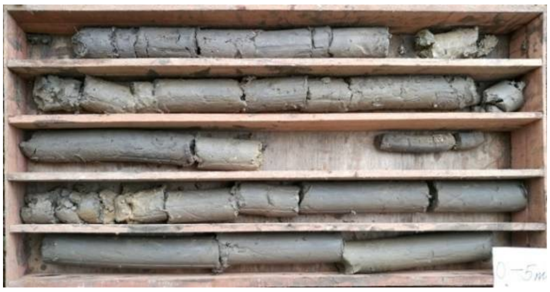


Fig. 2. Photograph of study site.

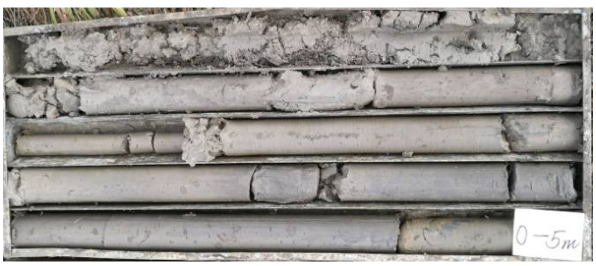
Fig. 3. Topography and geomorphology of study site (Google Earth).

The stratigraphy exposed at this site consists of artificial fill (Q4ml): Quaternary slope with chalky clay layer, silty clay deposited by flood, silt-bearing clay, chalky clay, medium-coarse sand layer, and residual deposited chalky clay layer from top to bottom. The underlying bedrock is Tertiary (R) limestone and marl (Fig. 4).



ZK15 (0–3.2 m) plain fill layer (1 layer)

ZK1 (0–0.6 m) chalky clay (2 layers)



ZK62 (0–4.6 m) silty clay loam (layer 3-1)

ZK80 (1.2–0.5 m) pulverized clay layer (3-2 layers, plastic)

ZK95 (11.6–13.4 m) medium-coarse sand layer (3-3 layers)

ZK70 (5–10 m) Silt-bearing clay layer (3-4 layers, plastic)

ZK110 (25–30 m) pulverized clay layer (3-5 layers, hard plastic)

ZK97 (10–15 m) pulverized clay layer (layer 4-1, plastic)

ZK176 (40-45m) pulverized clay layer (4-2 layers, hard plastic)

ZK1 fully weathered limestone layer (5-1 layers)

ZK87 Strongly weathered limestone layer (layer 5-2)

ZK26 Moderately weathered limestone (layer 5-3)

ZK75 Strongly weathered marl layer (layer 6-1)

ZK41 Moderately weathered marl layer (layer 6-2)

Fig. 4. Typical stratigraphic layers of drilled cores in study site.

2. Materials and Methods

2.1 Site Stability and Suitability

There are no adverse geologic effects and geologic hazards such as landslides, dangerous rocks, avalanches, debris flows, active fractures, hollowing out areas, and ground subsidence except for local karst development, liquefaction of sand and soil, and a potentially unstable slope in the site. Adverse geologic effects and geologic hazards are not strong. No buried streams, ditches, caves, graves, bomb shelters, isolated rocks, or other buried objects detrimental to the project are observed on the site.

2.*2. Seismic Effects*

According to Article 9.1.6 of the Chinese Standard Design Code for Cement Plants (GB50295-2016), the proposed project's main step-down transformer substation and central control room in the study site are classified into Category B (key protection category); the seismic protection of the loader shed, bulldozer shed, winch room, trigger room, various small material stacking sheds, material storage, and toilet belongs to Category D (moderate protection category); the remaining sub-items are classified into Category C (standard protection category); and the seismic protection category of the remaining sub-items belongs to Category C (standard protection category). The seismic protection category of the remaining sub-buildings is Category C (standard defense category).

According to Article 4.1.3 of the Chinese national standard “Code for Seismic Design of Buildings” GB 50011-2010 (2016 edition), the wave velocity test results are shown in Table 1. The stratum characteristics exposed by drilling and the shear wave velocity test results of each rock and soil layer are used to determine the soil type using the equivalent shear wave velocity. 23 representative boreholes were selected to measure the shear wave velocity and its equivalent. The results of the calculations and the building site categories are presented in Table 1.

Table 1. Calculation results of equivalent shear wave velocity values for each hole and determination of building site category.

Hole number	Equivalent wave Speed (m/s)	Overburden thickness (m)	Categories of construction sites	Item
ZK4	266.9	<5	**I_1**	Limestone crushing
ZK28	171.4	3–50	**II**	Limestone prehomogenizing & storing
ZK59	172.8	3–50	**II**	Marl prehomogenizing & storing
ZK71	213.0	3–50	**II**	Conveying
ZK89	395.3	<5	**I_1**	Raw material proportion station
ZK100	162.6	3–50	**II**	Cyclone preheater
ZK101	152.1	3–50	**II**	Pyroprocess(kiln)
ZK129	170.0	3–50	**II**	Cooler(Kiln hood)
ZK132	165.0	3–50	**II**	Other common workshop
ZK133	183.0	>50	**III**	Raw coal crusher
ZK134	179.1	>50	**III**	Silica ,iron & gypsum crusher

Hole number	Equivalent wave Speed (m/s)	Overburden thickness (m)	Categories of construction sites	Item
ZK139	179.6	3–50	**II**	Clinker storing & conveying
ZK141	167.6	3–50	**II**	Raw meal homogenizing silo
ZK144	175.5	3–50	**II**	Coal grinding
ZK145	179.7	>50	**III**	Cement grinding
ZK148	173.1	3–50	**II**	Laboratory management system
ZK164	215.2	3–50	**II**	Main power station
ZK182	182.3	>50	**III**	Cement mill proprotioning station
ZK184	154.3	>50	**III**	Cement silos
ZK188	155.7	>50	**III**	Cement packing and lodaing
ZK220	160.7	3–50	**II**	Raw material grinding & exhaust-gas treatment
ZK226	171.1	>50	**III**	Raw coal prehomogenizing & storing
ZK230	172.3	>50	**III**	Auxiliary materials prehomogenizing & storing

3. Results

The project in the study site is the construction of a 6000 t/d cement clinker production line, and its sub-projects include the following structures: firing kiln head, firing kiln middle, kiln tail, kiln tail exhaust gas treatment, pulverized coal preparation, raw coal crushing, raw material homogenization warehouse, clinker warehouse, raw coal pre-homogenization yard, limestone pre-homogenization yard, limestone pre-homogenization yard, auxiliary raw material pre-homogenization yard, raw material dosing station, auxiliary material crushing, limestone crushing, general bucking station, cement warehouse, cement mill, fly ash warehouse, cement dosing station, refractory material warehouse, cement packaging, central control building, and belt conveying. In the project, cement storage, a cement mill, fly ash storage, a cement batching station, refractory material storage, cement packing, a central control building, and a belt conveyor are constructed. According to the geological and geotechnical properties revealed in this study, the foundation program is analyzed with the structural characteristics of the building. The appropriate foundation form in this site requires a natural shallow foundation with treatment and piles.

3.1. Evaluation of Shallow Foundation as Natural Foundation

For buildings (structures) with small loads and insensitive settlement, a raw material batching plant, a raw material mill and waste treatment, limestone crushing, marl crushing, conveying, and control room, the shallow foundation scheme with natural foundation is necessary, and the (4-1) layer of pulverized clay, (4-2) layer of pulverized clay, (5-1) layer of fully-weathered limestone, (5-2) layer of strongly-weathered limestone, (6-1) layer of strongly-weathered limestone need to be used as the foundation bearing layer. The layers of (5-2) strongly weathered limestone and (6-1) strongly weathered limestone are foundation-bearing layers. Foundation depth must be determined according to the depth of each building lot holding layer, and the general foundation bottom must not be higher than 0.50 m into the holding layer.

3.2 Evaluation of Foundation Treatment Programs

The upper part of the proposed site has the (3-1) layer of silty clay, (3-2) layer of pulverized clay, (3-3) layers of medium-coarse sand, and (3-4) layer of silt-containing clay with average mechanical properties and low bearing capacity. For buildings (structures) with little load and insensitive to settlement requirements, such as limestone pre-homogenization yard, marl pre-homogenization yard, pulverized coal preparation, cement packing, auxiliary raw material pre-homogenization shed, raw coal pre-homogenization shed, belt gallery, raw coal crushing, auxiliary material crushing, total pressure-relief station, central control room, and other common workshops and other sub-projects, an adaptive foundation treatment program is required if the deformation calculation of the natural foundations fails to satisfy the specification requirements. Appropriate foundation treatment methods on this site are replacement treatment, cement-fly ash-gravel (CFG) pile-composite foundation, and cement mixing pile review foundation. The depth of treatment is appropriate to enter the (4-1) layer of powdery clay or the 4-2 layer of powdery clay at a certain depth. Foundation treatment design, construction, and quality inspection need to be strictly implemented under the provisions of the Chinese standard “Technical Specification for Foundation Treatment” (JGJ 79-2012).

3.3 Pile Foundation Program Evaluation

A pile foundation also can be considered if the natural foundation does not meet the design requirements, and the piling process can be either drilled (punched) piles or pre-stressed tubular piles. According to the loading conditions of different subsections, the (4-2) layer of powdery clay, (5-1) layer of fully weathered limestone, (5-2) layer of strongly weathered limestone, (5-3) layer of moderately weathered limestone, (6-1) layer of strongly weathered marl, and (6-2) layer of moderately weathered marl can be considered as the pile end bearing layer. According to the in-situ test and geotechnical test, according to the Chinese national standard “Design Code for Building Foundation” (GB 50007-2011) and “Technical Specification for Building Pile Foundation” (JGJ 94-2008).

4. Discussion

Raw material grinding, kiln tail, kiln, kiln head, homogenization warehouse, raw coal crushing, auxiliary materials crushing, limestone crushing, and other structures form a temporary slope when excavated. As the construction period is relatively short, the excavation pit depth of 2 to 8 m is necessary. According to the drilling situation, the pit sidewall soil layers from top to bottom comprise one layer of vegetal fill, two layers of powdery clay, the (3-1) layer of silty clay, (3-2) layer of powdery clay, (3-4) layer of silty clay and (4-1) layer of powdery clay layer’ the local subsection consists of the (5-2) layer of strong clay, (3-4) layer of silty clay, (4-1) layer of powdery clay, the bottom of the pit is mostly (3-2) layer of powdery clay, (3-4) layer of silt clay, (4-1) layer of powdery clay, local subsection of (5-2) layer of strong clay. In the layer of powdery clay; the pit bottom consists of the (3-2) layer of powdery clay, (3-4) layer of silty clay, (4-1) layer of powdery clay; the local subsection comprises (5-2) layer of strongly weathered limestone. Combined with the surrounding environment, engineering characteristics, consequences and severity of damage, pit depth, engineering geology, and groundwater conditions, the safety level of pit works on this site is Grade III. Considering the characteristics of the pit on this site, the following is recommended.

1. The site is an open area and there is no building nearby, it is recommended to use sloping excavation + anchor spray support, for the depth of the site to be excavated needs to be more than 4.00 m with a grading slope.
2. Due to the shallow bedrock burial and shallow groundwater level of the site, it is unfavorable to use a curtain water-stopping program, and it is recommended to use a well-point precipitation program. In the process of excavation of the foundation pit and underground engineering construction, various observation and analysis works are carried out based on the geotechnical properties of the foundation pit, supporting structure, and surrounding environmental conditions. Drainage and interception open ditches are installed at the periphery of the foundation pit to prevent rainwater from entering the foundation pit. If the groundwater level is too high, precipitation wells are installed in the foundation pit.
3. Considering the depth of groundwater level within the site and annual amplitude changes, the outdoor floor elevation of the building, and the highest local flood level, the groundwater defense level must be determined. For anti-floating, counterweights need to be used to increase the strength of beams and plates, anti-drag pile, and anchor anti-floating.
4. It is recommended to adopt information-based construction, strengthen the monitoring of the pit, keep abreast of the safety of the pit enclosure structure, understand the impact of pit excavation on the surrounding environment, and feedback on the information to the design and construction promptly. Then, the construction program and progress can be appropriately adjusted according to the monitoring results to ensure the safety of pit construction. Drainage facilities must be implemented around the pit, and drainage facilities at the bottom of the pit.
5. The design and monitoring of foundation pit support must be entrusted to an experienced unit with corresponding qualifications, and the program can be implemented only after passing the expert review.
6. Environmental hygiene is important so mud and sludge must be cleaned up in time, and must not flow into the surrounding surface water bodies to prevent pollution of the surrounding environment.

5. Conclusions

The topography of the construction site of this project is relatively flat, and the geomorphology is relatively simple. The drilling data shows a complicated stratum structure with many kinds of rock and soil, undulating strongly weathered rock surface, and ununiform soil quality. The impact of groundwater on engineering construction is relatively limited while the surface drainage conditions are acceptable. In addition to ZK61, ZK66, ZK85, ZK147, ZK108, and other five holes in the scope and depth of exploration holes, other sections of the site are not developed in karst. There are artificial slopes below the belt corridor of the site, which are in the basic stabilization stage, and there are no other adverse engineering geological effects and buried objects unfavorable to the project after the slope management. There is no Holocene active fracture passing through the site and its vicinity, and no sign of fracture structure is found within the depth range of this investigation.

As there is no active fault in this site which belongs to a seismic unfavorable lot, the development degree of adverse geological effects and geological hazards is weak. The complexity of geological conditions is medium, and the difficulty of site management is easy. According to Article 8.3.3 and 8.3.4 of the Chinese standard "Geotechnical Investigation Specification for Cement Plants" (GB 51014-2014), the stability of the site and the suitability of engineering construction are not strong. The site is appropriate for the construction of this project with reclamation, foundation treatment, and pile foundation.

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