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Monopile design applied in the Panama Metro Line 2

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ABSTRACT

There are 3 lines in The Panama Metro. Line 1 was opened in 2014, Line 2 will be open in 2019, and Line 3 is currently in the design stage. The metro Line 2 will include 16 stations and 21 kilometers of elevated railway lines, connected the stations from district of San Miguelito to Nuevo Tocumen. The metro Line 2 are an elevated line with all of its viaduct portion supported by the single pier and the station supported by two-column bent and three-column bent. Regard to the foundation system, Earthquake Resistant Monopile foundation system is used in the metro Line 2. Monopile could reduce land needed and speed up work compared to multiple piles. It is the best advantage to use monopile for infrastructure construction with limited working space and heavy traffic. This study aimed to introduce monopile design and construction in The Panama Metro Line 2.

Keywords: Monopile, Panama Metro, pile design

1 INTRODUCTION

There are 3 lines in The Panama Metro. Line 1 was opened in 2014; Line 2 will be open in 2019; and Line 3 is currently in the design stage. The metro Line 2 will include 16 stations and 21 kilometers of elevated railway lines, connected the stations from the district of San Miguelito to Nuevo Tocumen.

2 GEOLOGICAL CONDITION

The Republic of Panama is constituted by a narrow territorial belt that stretches from East to West in a sinuous way and ended at the Central America Isthmus. The territory of the Republic of Panama has three terrain configuration: a) the mountain regions, b) the regions of low hills and hills, and c) the low regions and coastal plains. According to its geological history, the lithology and tectonics information is shown in Figure 1. The geology of Panama includes the complex tectonic interplay between the Pacific, Cocos, and Nazca plates, the Caribbean Plate and the Panama Microplate.

According to the geological profile, the formation can be roughly divided into 4 layers, a) fill material, b) fine-grained soil, c) weathered rock, and d) sound rock.

Fill material was encountered from ground surface and extends until 0.5~5m deep, continued by fine-grained soil with thickness ranged 1.5~9m. Beneath the fine-grained layer is weathered rock layer with thickness is in range 0.5~25.5m.

The shear wave velocity measurements were used to define the site class in project area. In accordance with AASHTO, the site class along the route of The Panama Metro Line 2 has been determined to be class C or D.

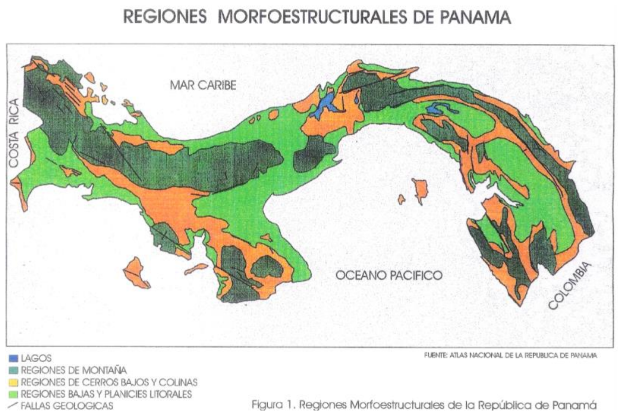


Figure 1 Geological map in The Republic of Panama

3 DESIGN SPECIFICATION AND DESIGN METHOD

Regulations for monopile design are quite comparative and can be found in the design specifications of each region, AASHTO, or CalTrans. And AASHTO LRFD was chosen for the design of this project.

Line 2 are an elevated line with all of its viaduct portion supported by the single pier and the station supported by two-column bent and three-column bent. Earthquake Resistant Monopile foundation systems are applied to the foundation design in the metro Line 2. The schematic of substructure in the viaduct and in the station are shown in Figure 2(a) and 2(b), respectively.

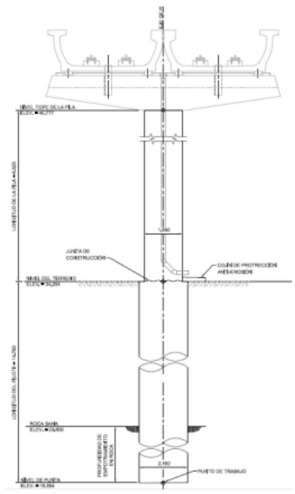


Figure 2(a) Schematic of substructure in the viaduct

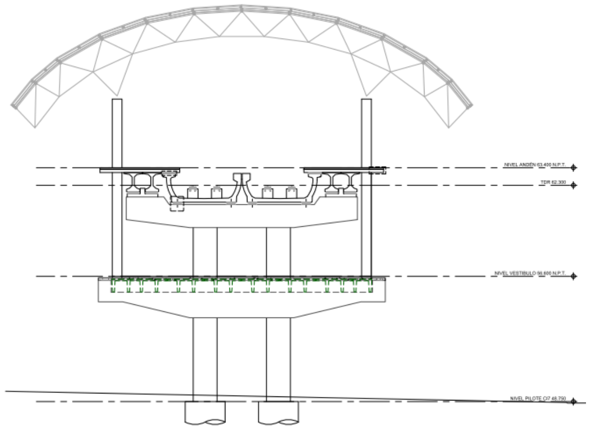


Figure 2(b) Schematic of substructure in the station

The analysis of substructure are separated into three parts: spectral response analysis, nonlinear static analysis (pushover), and foundation analysis. The monopile which subjected to the loading from the bottom of columns and input to LPile software program to be analyzed and produce the demand forces for piles. The loading for strength limit states is obtained from RSA global model and the loading for extreme event is obtained from pushover analysis model. Figure 3 is the monopile Design flowchart.

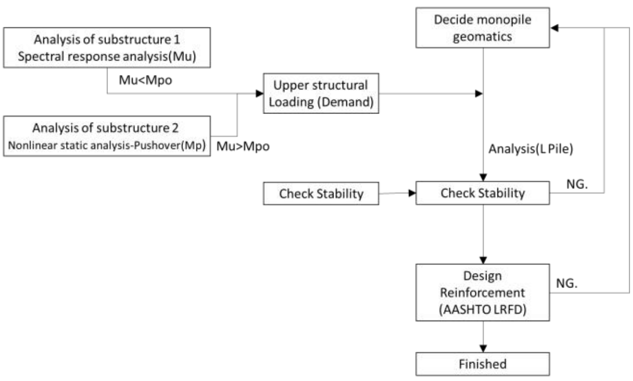


Figure 3 The monopile design flowchart

Under extreme event with Maximum Considered Earthquake (MCE), the structure of foundation is designed to remain essential elastic. Because the mechanism of column allows inelastic behavior which means occurrence of plastic hinges in columns, the foundation is designed to withstand the minimum forces caused by columns' hinge over strength capacity or extreme event with MCE.

Entire monopile for station and viaduct are designed in the same type, which was circular bored piles and cast in site. Diameters of the pile are equal to 2.25 m and pile length (L) is 15~25 m. Pile capacity estimation is based on "AASHTO LRFD bridge design specifications, 2012". Figure 4 shows the result of the pile lateral analysis. Structural demands (moment and shear force) increase significantly at the interface of silt and rock which control the design of monopile.

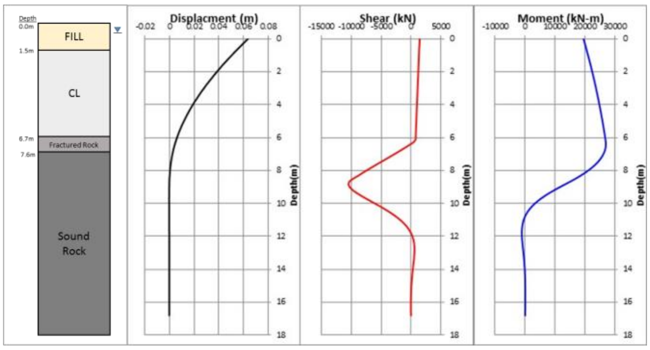


Figure 4 Example of the monopile lateral analysis result

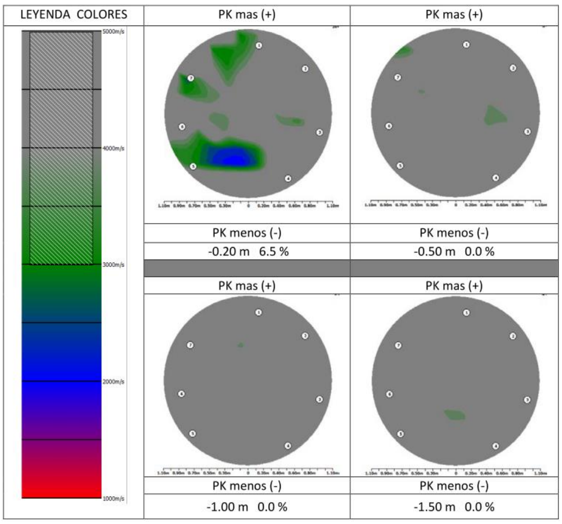
4 MONOPILE CONSTRUCTION

To save the construction time, the reinforcement assembly was completed at the factory by using machine. The reinforce template is a fixed frame as shown in Figure 5, hence this must be taken into account at the design stage because the monopile will have typical reinforcement arrangement and same pile diameter. Then the steel rebar cage transported to the site.

Figure 5 Template of monopile reinforcement

Cross-hole sonic logging (CSL) and low strain integrity testing (PIT) were performed to verify the pile integrity. The test results classified the damage into four categories, Category 1 is both CSL and PIT tests showed that the pile is not damaged. Category 2 to 4 is a different level of damage and required additional analysis, soundings (tomography), or test to determine pile final capacity and recommendations for repairment if necessary. The additional analysis and evaluation of pile capacity will be based on the result from tomography test. Figure 6 shows the example of the record test of the Tomography.

Figure 6 Site photo



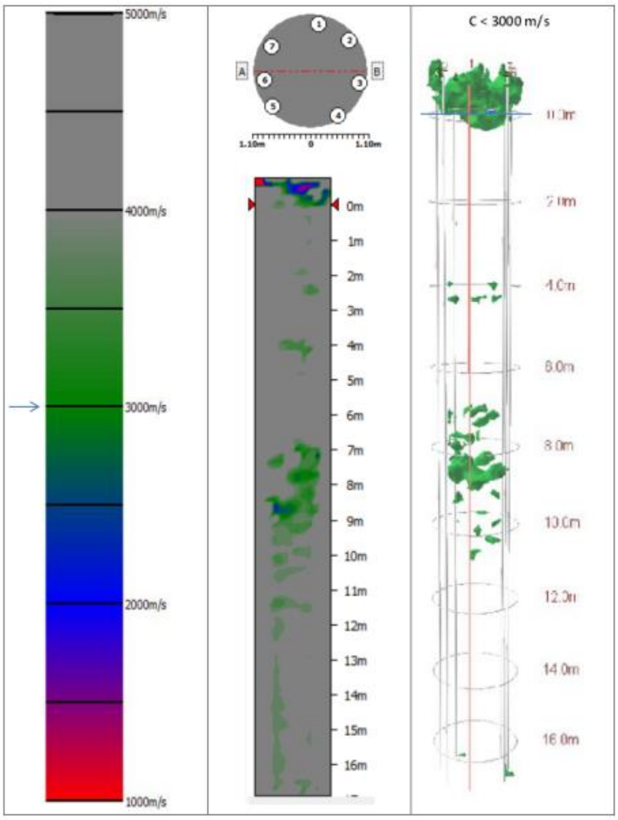


Figure 7 sample of the Record test of the Tomography

5 CONCLUSION

Monopile design was similar to the pile design. The special is that the upper structural analysis should consider the monopile stiffness and behavior in the spectral response analysis, nonlinear static analysis. The benefit of monopile as a foundation does not only reduce the working space at the site during the process of assembling the reinforcement but also speed up the construction time compared to the pile group. Monopile is the best choice for infrastructure construction in a city with heavy traffic.

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