

## Geotechnical assessment for the rehabilitation of the north-south Philippine railway system

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### ABSTRACT

A strategic transport system in the Philippines is essential to support the country's economic growth and growing population, and in line with the government's vision to promote inclusive growth and spur economic development in the underserved areas.

Currently, the railway system serving the National Capital Region (NCR) has only four (4) lines: LRT Line 1 (Baclaran to Roosevelt), LRT Line 2 (Recto to Santolan), MRT Line 3 (Taft to North Avenue), and the Philippine National Railway (PNR) South Commuter Line (Tutuban to Alabang). This study focuses on the rehabilitation and development of the existing PNR mainline track.

The PNR North-South Commuter Rail Project will entail the construction of a 37.9-km rail system for the Solis to Malolos alignment, a 68.7-km rail for the North alignment from Malolos to Clark, and a 68.5-km rail for the South alignment from Solis to Los Baños. The project shall include construction viaducts, elevated embankments, bridge crossings, depots, a workshop and operations control center, and a total of 41 stations for the whole alignment.

Detailed geotechnical investigation and evaluation play a critical role in the cost-effective implementation of the project, more particularly in the foundation design of the railway considering several geotechnical issues. Some of these issues include regional seismicity and active faults, liquefaction potential, soft ground conditions, high groundwater level, expansive soils, and susceptibility to flooding (necessitating high embankments).

This paper presents the geotechnical assessment undertaken for the proposed rehabilitation of the PNR North-South Commuter Project, in the context of the revival of the Philippine railway system. The general characterization of the alignment, assessment, and recommendation for mitigation of various geotechnical hazards are discussed.

**Keywords:** Philippine railway system; geotechnical hazards; railway construction

### 1 INTRODUCTION

Part of the Philippine government's vision is to promote inclusive growth and spur economic development in the underserved areas. One way to fulfill this objective is to develop a strategic transport system in the Philippines.

Currently, there are only four (4) lines serving the National Capital Region (NCR): LRT Line 1 (from Baclaran to Roosevelt), LRT Line 2 (from Recto to Santolan), MRT Line 3 (from Taft to North Avenue), and the Philippine National Railway (PNR) South Commuter Line (from Tutuban to Alabang). This study focuses on the rehabilitation and development of the existing PNR mainline track.

The PNR North-South Commuter Rail Project will entail the construction of a 37.9-km rail system for the Solis station to Malolos station alignment, and another 68.7-km and 68.5-km rails for the North alignment

(from Malolos to Clark stations) and South alignment (from Solis to Los Baños stations), respectively.

The project, whose objective is to link Metro Manila to the north and south areas of Luzon, shall include construction viaducts, elevated embankments, bridge crossings, depots, a workshop and operations control center, ten (10) initial stations (Solis to Malolos), eight (8) north line stations (Malolos to Clark), and twenty-three (23) south line stations (Solis to Los Baños).

Figure 1 shows the proposed alignment of the project.

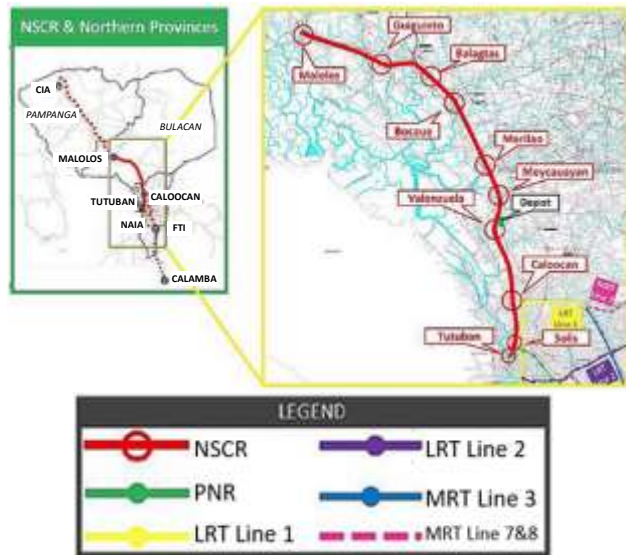


Fig. 1. Alignment of the proposed alignment.

## 2 GEOLOGY AND SEISMICITY

The entire alignment can be subcategorized regionally and geologically into three (3) areas: National Capital Region, Central Luzon, and Southwest Luzon.

### 2.1 Geology

The alignment traversing NCR is characterized by quaternary alluvial deposits of variable thickness, consisting of clays, silts, and sands. These deposits are underlain by the Guadalupe Tuff Formation (GTF), the regional bedrock of Metro Manila. GTF, also commonly referred to as “adobe”, has a thickness of 1,300 to 2,000 meters and is of Pleistocene age. It consists of well laid rock formation of tuffaceous sandstone, tuffaceous siltstone, and shale being the weakest the member. GTF basically falls in the category of very soft rock to hard or very dense soil.

The North alignment, which runs from Malolos to Clark, is part of the Central Luzon Basin. It consists of 8,000-m thick sedimentary sequence. Its western and eastern flanks are stratigraphically distinguished from each other. Sediments on the western side, which cover areas from Pampanga to Tarlac, are Neogene sediments dominated by Middle Miocene turbidites, that overlie directly the Eocene ophiolites of Zambales. The eastern side covers the Bulacan area and are characterized by a significant number of volcanic sources (such as volcanic sandstones and shales, tuffs, and by a shallow marine depositional environment).

The South alignment, which runs from Solis to Los Baños, is divided between National Capital Region and Southwest Luzon. As mentioned, the National Capital region is underlain by GTF. Meanwhile, Laguna area regionally falls at the Southwest Luzon Uplands. The stratigraphy of the area generally consists of alluvium, fluvial, lacustrine, paludal, beach deposits, raised coral reefs, atolls, and beach rocks.

### 2.2 Seismicity

The Philippines accounts for 3.2% of the world’s seismicity. It is situated in the Circum-Pacific Belt or “Ring of Fire”, where 80% of the world’s earthquakes occur. Philippine seismicity is mainly related to plate subduction and in part to strike-slip motions along transcurrent faults.

Based on the seismic map by PHIVOLCS shown in Figure 2, the nearest seismic sources to the project alignment are East Zambales Fault (for the northern segment) and Valley Fault System (for the southern segments).

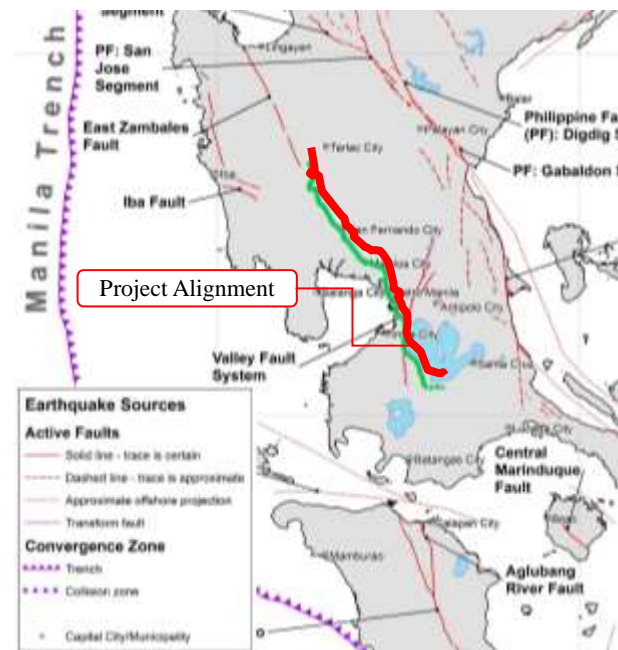


Fig 2. Distribution of active faults and trenches in the Philippines. (Source: PHIVOLCS)

## 3 SUBSURFACE CONDITIONS AND GEOTECHNICAL ASSESSMENT

Stated in the previous sections, the project alignment can be subdivided into three (3) regions, namely: National Capital Region, Central Luzon, and Southwest Luzon. Subsurface conditions and geotechnical assessment of these three (3) regions are discussed in the succeeding subsections.

### 3.1 Liquefaction

Soil liquefaction is a phenomenon that occurs mostly in saturated and loose, medium to fine-grained sands, wherein a mass of soil loses a large percentage of its shear resistance when subjected to monotonic, cyclic, or shock loading, and flows in a manner resembling a liquid. Much of the damage on substructures and foundation during earthquake is attributed to this phenomenon.

Considering the subsoil condition and the relatively shallow groundwater level, there are areas along the project alignment that are deemed susceptible to liquefaction. These areas are mostly found in Central

Luzon and Metro Manila. This is consistent with the liquefaction hazard map published by Philippine Institute of Volcanology and Seismology or PHIVOLCS, as shown in Figure 3.

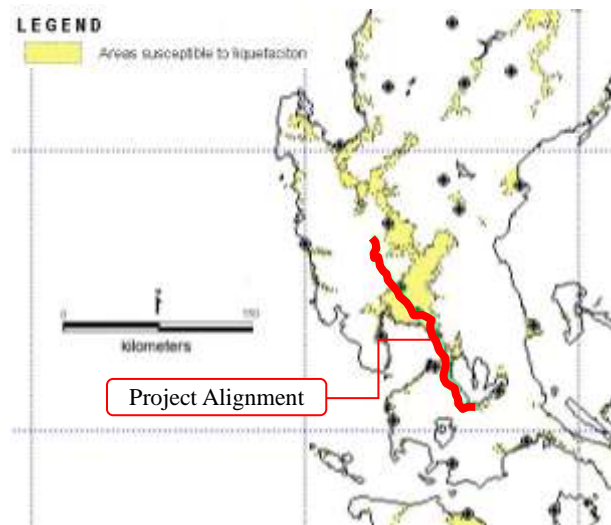


Fig. 3. Liquefaction susceptibility map. (Source: PHIVOLCS)

### 3.2 Settlements

Settlement analyses were carried out to estimate settlements, specifically for sections along the proposed alignment wherein the railway may be constructed on top of embankments. These embankments will induce surcharge loads to the underlying soft/loose soils which may cause consolidation/settlement.

Excessive settlements were estimated for most of the sections analyzed. This was anticipated due to the presence of thick soft clay layers in these sections.

In the design of foundation systems for the proposed railway project, settlements due to consolidation of soft cohesive layers must be accounted for. Ground improvement measures, as well as deep foundations, are commonly explored to mitigate excessive consolidation settlement. Ground improvement will also improve the bearing capacity of the underlying soil, while deep foundation will bypass the loose/soft layers and mobilize strength of the hard strata.

### 3.3 Stability of excavations

Stability of excavations or cuts should be the primary concern for cut-and-cover method of tunneling and similar excavation or underground works. If necessary, excavations for construction of foundation or underground structures shall be adequately braced. Staged construction analysis for stability can check the safety factors at different levels of excavation and corresponding bracings.

In the stability analysis and design of excavation support or retaining walls, the parameters presented in Table 1 may be used. These parameters generally assume the properties of medium dense soils ( $\sim N_v=20$ ), which predominantly constitute the area where the proposed underground structures will be situated.

Table 1. Geotechnical parameters for lateral earth pressure analysis

Geotechnical Parameters	Values
Angle of friction, $\Phi$	32°
Cohesion, $c$	2 kPa
Unit Weight, $\gamma$	18 kN/m <sup>3</sup>
Active Earth Pressure Coefficient, $k_a$	0.307
Passive Earth Pressure Coefficient, $k_p$	3.255
At-rest Earth Pressure Coefficient, $k_0$	0.470

Lateral pressures due to surcharge loads (e.g. vehicular surcharge or loads from adjoining structures), as well as the dynamic thrust in the occurrence of an earthquake must also be included in the analysis.

## 4 NATURAL HAZARDS AND MITIGATION AND RISK REDUCTION

Natural hazards, such as flood, landslide, and tsunamis, are present in some areas of the project alignment. These hazards are further discussed in the subsections below.

To mitigate and to reduce the risks of these hazards, ensure that the geotechnical, geodetic, hydrologic, and seismicity studies are considered in the design and construction of appropriate foundation system and other structures.

### 4.1 Flood and Landslide

Based on the Mines and Geosciences Bureau (MGB) flood inundation map, most parts of Bulacan area and some parts of Pampanga area in the North Line have high susceptibility to flooding. Areas outside Bulacan have none to moderate susceptibility to flooding.

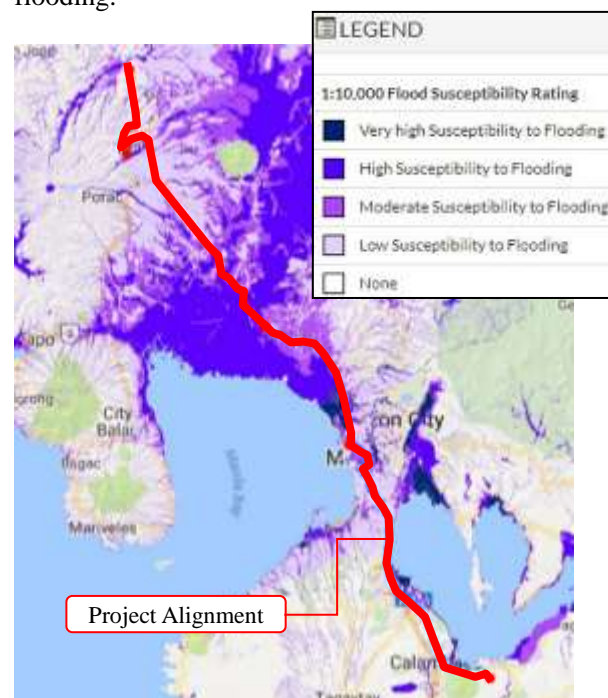


Fig. 4. Flood susceptibility map. (Source: MGB)



Meanwhile, the landslide hazard map shows that the entire alignment is not susceptible to landslides except for some areas in the north and south, which have low susceptibility to landslides.



Fig. 5. Landslide susceptibility map. (Source: MGB)

#### 4.2 Tsunami

According to the United States Geological Survey or USGS, a tsunami is a sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or exploding volcanic islands.

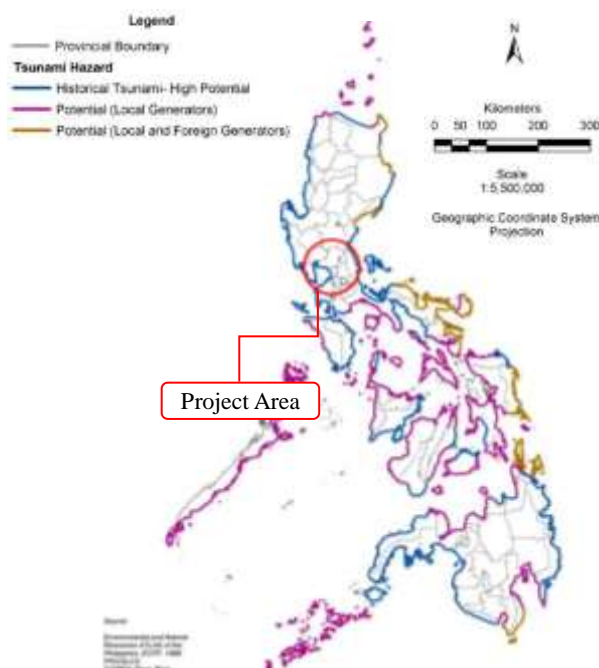


Fig. 6. Tsunami vulnerability map of the Philippines (Source: Manila Observatory and DENR)

Due to the proximity of Manila Bay to the project alignment, especially the segment situated in Metro Manila, the susceptibility to tsunami is potentially high. This is supported by Figure 6, which is published by Manila Observatory and Department of Environmental and Natural Resources (DENR).

## 5 SUMMARY AND CONCLUSION

One objective of the Philippine government is to promote inclusive growth and spur economic development in the underserved areas. The development of a strategic transport system in the Philippines will positively fulfill this objective.

In line with the government's vision, the PNR North-South Commuter Rail Project, which connects Metro Manila to the north and south areas of Luzon, aims to revitalize the PNR mainline track. The project will not only offer convenience to passengers, but will also improve the economic activity in the areas.

Philippines, through its projects, continues to advance its economy and public infrastructures, particularly, the transportation system. These projects open a lot of opportunities to engineers, geologists, and other professionals in the sector. Also, these projects provide sustainable infrastructure solutions that are necessary in a growing world.

## ACKNOWLEDGEMENTS

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