

SEISMIC SITE AMPLIFICATION MAPS AND DESIGN SPECTRA FOR RECLAMATION ISLANDS IN HONG KONG CONSIDERING SPATIAL VARIATION OF SITE CONDITIONS

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In alignment with the 2030+ vision for Hong Kong, the development of artificial islands through reclamation around Kau Yi Chau, Peng Chau, and Sunshine Island aims to create approximately one thousand hectares of land. Given Hong Kong's moderate earthquake risk, the absence of a seismic design code and limited guidelines, it is greatly needed to conduct comprehensive seismic hazard assessments of these new development areas.

This study investigates seismic site amplification at the new proposed artificial island at the reclamation site in Hong Kong considering spatial variation of subsurface conditions. Data from over 100 boreholes facilitated the characterization of subsurface soil layers, with dynamic properties derived from laboratory and field tests, which account for confining pressures in granular soils and plasticity indices in cohesive soils. The representative boreholes were selected for one-dimensional site response analyses utilizing nonlinear method.

The analyses incorporated eleven earthquake records as outcrop motions, matching the rock Uniform Hazard Spectrum (UHS) of 2% probability of exceedance over 50 years, representing the Maximum Considered Earthquakes (MCE) level. The influence of the spatial variation of the marine deposit layer and the depth of rockhead on seismic site amplification were assessed for ground conditions before and after the reclamation process.

Site amplification maps of peak ground acceleration (PGA) have been created for before and after reclamation cases and comparison of surface spectral accelerations with design spectra from Hong Kong was conducted. Findings indicate that variations in the soil profiles significantly affect spectral accelerations and site periods, necessitating the development of new design response spectrum models for these specific locations. Finally, based on all these site-specific analyses, new design spectral acceleration curves for MCE level are proposed for these reclamation islands.

Keywords: Site Conditions Spatial Variation, Marine Deposit, Site Response Analysis, Site Amplifications Maps, Design Spectral Acceleration.

1. Introduction

The Hong Kong government recently conducted an extensive study on the feasibility and implications of constructing around 1,000 hectares of artificial islands near Kau Yi Chau in Hong Kong's central waters. Site response analysis (SRA) plays a pivotal role in seismic hazard assessment and structural design, guiding site-specific designs and effective risk mitigation strategies.

The current study investigates the impact of marine deposit thickness at Kau Yi Chau Artificial *Island C* on seismic site response analysis due to Maximum Considered Earthquakes (MCE) rock outcrop scenarios in Hong Kong, considering the temporal evolution of dynamic soil properties in pre- and post-reclamation scenarios. This research used nonlinear methodology using DEEPSOIL (Hashash, 2020) for creating seismic site amplification maps for before and after reclamation cases considering the spatial variation of complex geological conditions. Also, computing surface spectral acceleration against established design codes, thereby proposing new design spectra that consider the diverse effects of land reclamation on seismic response characteristics.

2. Spatial Variation of Geological Conditions at Reclamation Artificial Islands in Hong Kong

As shown in Fig. 1(a), the topographic level of the existing islands ranges from 0.00 to +62.00 mPD (mean datum at Hong Kong) and the seabed level at the proposed artificial islands and the neighbouring central water, ranges from -5.00 to -15.00 mPD.

The geological conditions at artificial islands comprise five types of soils: Fill, MARINE DEPOSIT, Eustrian Deposit (ED), ALLUVIUM (Sand, Silt and Clay) and RESIDUAL SOIL respectively, underlying by granite and rhyolite of varying weathering grades, ranging from grade V (completed decomposed, CDG_V and CD RHYOLITE_V), grade IV (highly decomposed, HDG_IV and HD RHYOLITE_IV), moderately decomposed

(MDG_III and MD RHYOLITE_III) and slightly decomposed (SDG_II and SD RHYOLITE_II) as shown in some of boreholes' profiles in Fig. 1(b) for artificial Island C.

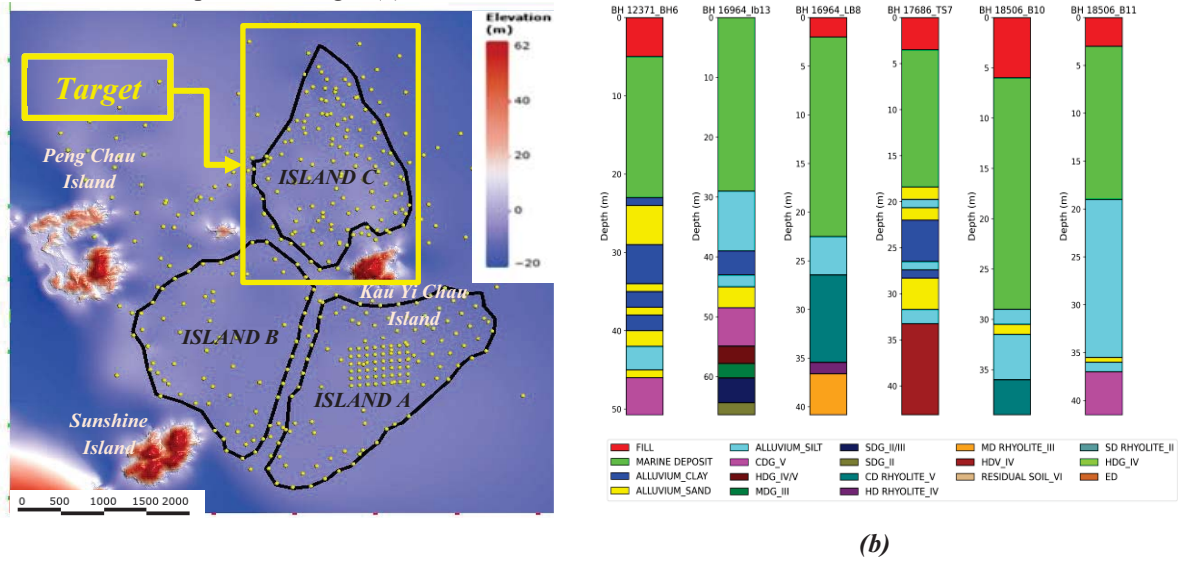


Fig. 1. (a) Topographic and Seabed levels map, (b) Spatial variation of geological conditions of samples of boreholes profiles at reclamation Island C.

3. Shear Wave Velocity (V_s) Profiles

Based on the SPT-N values of different soil and weathering rock types, there are empirical equations proposed by Pappin et al. (2012) in Hong Kong (see Table 1). These relations used for our reclamation site except for Marine and Estuarine Deposits, whose relations will be related to undrained shear strength S_u , which is more reliable than SPT-N. The relation proposed by Taboada et al. (2022) to estimate the shear wave velocity for the Bay of Campeche at the southern portion of the Gulf of Mexico has been used in our study. Thus, knowing S_u , water content and effective vertical stress for each soil type, the shear wave velocity (V_s) can be estimated (see Eq. (1)).

$$V_s = 26S_u^{0.184} \left(\frac{\sigma'_{vo}}{w} \right)^{0.195} \quad (1)$$

Table 1. Relations between V_s and SPT N

Soil Type	$V_s = f(\text{SPT-N})$
Completely Decomposed Granite (CDG)	$90.043 * N^{0.304}$
Completely Decomposed Soil (CDS)	$138.17 * N^{0.2244}$
Alluvium	$198.04 * N^{0.0643}$
Fill	$111.07 * N^{0.2082}$

The sandy soil assumed to be the reclamation soil, so the unit weight and shear wave velocity V_s for dry sandy fill and saturated sandy fill are chosen as (16 and 19.6 kN/m³) and (190 and 170 m/s) respectively, referring to the reclamation sandy soil used in Tsuen Kwan O in Hong Kong by Wong et al. (2010). Finally, the shear wave velocity V_s profiles before and after reclamation process have been estimated for each representative borehole at ISLAND C as shown in Fig. 2 (a).

4. Selected Ground Motions for 1D Site Response Analysis

Based on the uniform hazard spectrum (UHS) 2% probability of exceedance in 50 years proposed by Pappin, et.al. 2015, eleven earthquakes' motions have been selected for the Maximum Considered Earthquakes (MCE) (2475yrs return period) whose median response spectral acceleration matching with the target UHS rock outcrop as presented in Fig. 2 (b).

5. Dynamic Soil Properties (G/G_{max} and Damping versus Shear Strain (γ))

The Modulus Reduction (MR) G/G_{max} and Damping Ratio (DR) versus shear strain γ are required to perform one-dimensional site response analysis. Therefore, the Marine Deposit G/G_{max} and D versus shear strain γ model proposed by (Wong et al., 2000) for a reclamation site (Tsuen Kwan O) in Hong Kong used as shown in Fig. 3. For the other soil and weather rock types, the MR and DR proposed by Pappin et al. (2012)

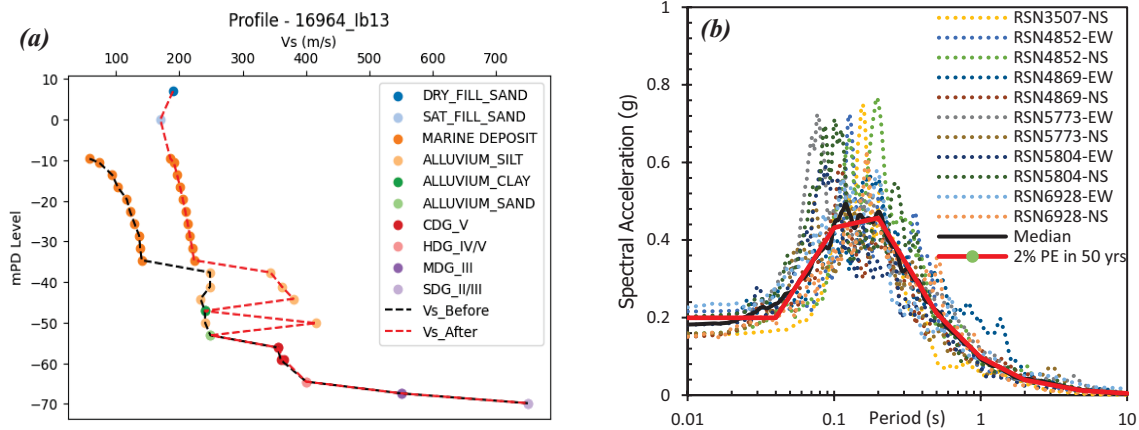


Fig. 2. (a) Samples of boreholes profiles at artificial Island C in central water of Hong Kong, (b) Selected earthquakes matching with UHS 2% probability of exceedance in 50 years (MCE scenarios rock outcrop)

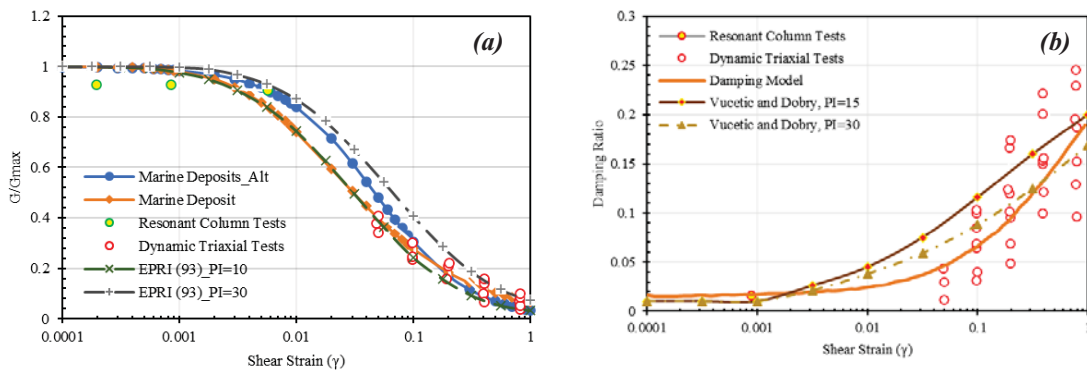


Fig. 3. Modulus Reduction G/G_{max} (a) and D (b) V_s Shear Strain (γ) of Marine Deposit in Hong Kong (Wong et al., 2000)

6. Seismic Site Amplification Hazard Maps of Island C for MCE (Before and After Reclamation Cases)

Site amplification factor of PGA is determined by comparing surface and rock outcrop response spectra (Fig.2 (b)) for before and after reclamation cases. As shown in Fig. 4(a) before reclamation case, the site amplification factor (SAF) map based on NL method shows that the maximum SAF is 1.3 at the zones of low and medium small-strain fundamental site period of Island C. However, the de-amplification for $SAF < 1$ at the zones of longer small-strain fundamental site period with minimum SAF 0.4. For after reclamation case, SAF has maximum value of 1.4 at short site periods 0.4-0.6sec (high frequencies), however de-amplification SAF at longer periods (1-1.3sec) with minimum SAF of 0.60 as shown in Fig. 4(b).

7. Development of Design Spectral Accelerations for MCE Design Level at Artificial Island C

For the soil profiles classified as “Group 4 ($T_{site}=0.5-1sec$)” by Arup (2015), the median S_a results in this study have higher values than the “Group 4 (Arup 2015)” so it has been modified at periods (0.1 to 1.2sec) to capture the response as presented in Fig. 5(a). Finally, most soil profiles at artificial Island C have T_{site} longer than 1sec, so a new site class, named as “RS_Group 5” has been created for $T_{site} > 1.0sec$. The design spectrum for “RS_Group 5” can envelope the median surface spectral acceleration for this site class, as shown in Fig. 5(b).

8. Conclusion

Although the seismic hazard in Hong Kong has been classified as moderate to low, it is very important to study the effect of seismic site amplification at locations that have a deep soft material deposit (e.g. Marine Deposit) at the reclamation islands area. The results of the amplification factor in terms of spectral ratio confirm the importance of the full nonlinear analysis for the amplification factor at longer period due to the deep soft marine deposit and the influence of small strain stie period on the site amplification.

Finally, the surface spectral acceleration of NL after reclamation case for MCEs category has been compared with local (Arup 2012) design S_a curves. As a result, the previous design SA Group 4 has been modified to RS_Group

4 to envelop the response for this site class. In addition, a new design SA group (RS_Group 5) for very soft soil profile has been proposed for such reclamation of artificial island sites. These two new proposed design SA curves can help geotechnical and structural engineers to design more resilient and robust infrastructure and buildings.

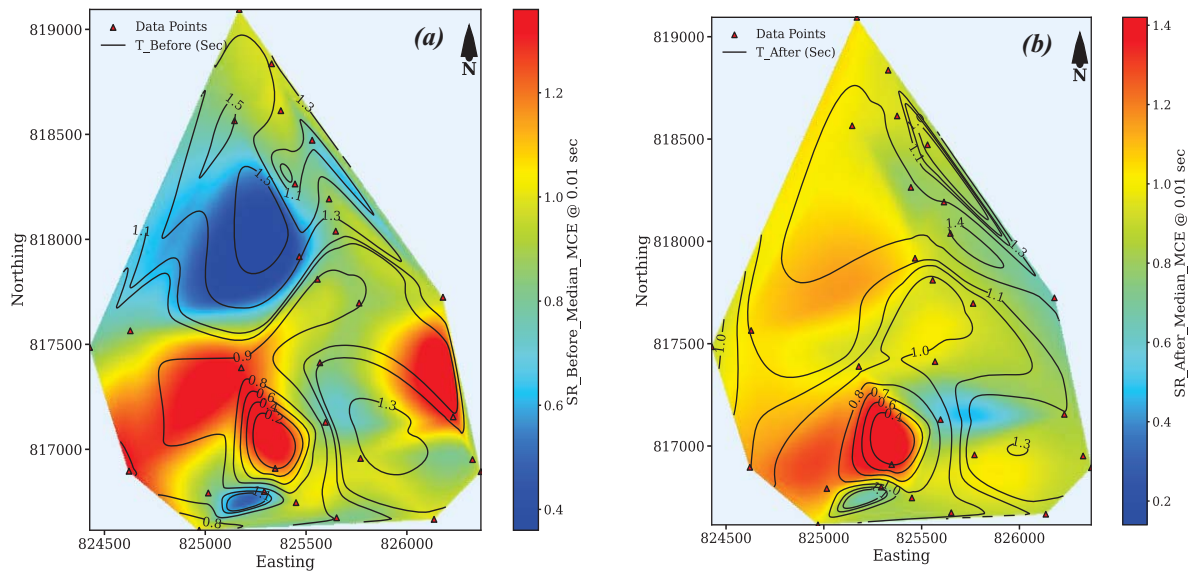


Fig. 4. Site amplification factor maps of PGA for MCE: (a) Before Reclamation, (b) After Reclamation (Contour lines: small-strain site period before and after reclamation cases)

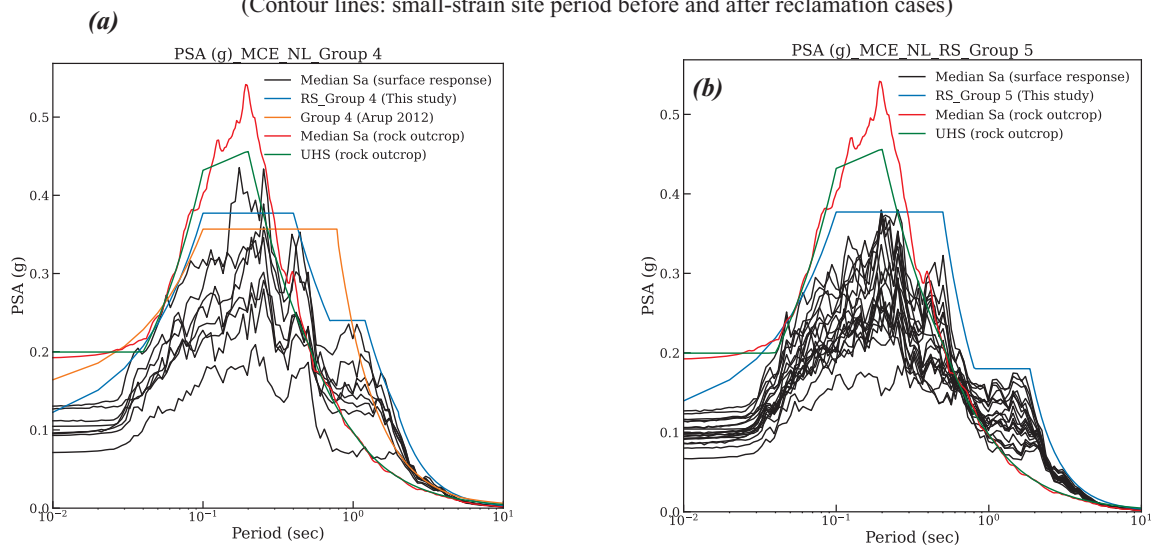


Fig. 5. Median surface $S_a(g)$, UHS- rock outcrop, HK design S_a group and proposed design spectral acceleration curve at design different site classes for MCE design level (a: Group 4, b: RS_Group 5)

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References

- Hashash, Y. M. A. and P. D. (2020). DEEPSOIL 7.0, User Manual.
- Arup (2015). Seismic Hazard Analysis of the Hong Kong Region, GEO Report No. 311, CEDD Government of Hong Kong
- Arup (2018). Report on the Seismic Microzonation Assessment of the North-west New Territories, GEO Report No. 338, CEDD Government of Hong Kong
- Taboada Urtuzuástegui, V. M., Cindy Cao, S., Cruz Roque, D., Flores-López, F. A., Barrera, P., Gan, K. C., Dantal, V., Espinosa Samudio, E. E., Renovato Carrión, S. D., & Hernández Durón, J. M. (2022). DYNAMIC PROPERTIES OF CLAY FOR EARTHQUAKE RESPONSE ANALYSIS IN THE BAY OF CAMPECHE. *Revista de Ingeniería Sísmica*, 109, 47–68.
- Wong, Y., Guo, X., Lui, J. Y. H., Yuan, Y., Zhao, J. X., & Yin, J. (2000). Investigation of Seismic Response of Soil Sites in Hong Kong: Part I-Preliminary Dynamic Test Results. *HKIE Transactions*, 7(3), 19–27.