Slope Analysis for Evaluation of Influence Zone of Road Embankment and Bridge Foundation due to nearby Excavation

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ABSTRACT: In recent years, there have been a large number of underground infrastructure construction projects in right of way areas where the existing roads and pile foundations might have been affected by these construction activities. In order to control or minimize the damage of existing structures, the protection zone for excavation activities should be rationally established with appropriate code of practice. This study examined effects of the cut-and-cover excavation on adjacent existing road embankment and pile foundation to determine the influence distance between them. Two and three dimensional numerical simulations based on a finite element method are employed by using PLAXIS program. A two-stage approach is used to analyze the problems. The first step addresses the determination of required clearance for preventing the existing structures from slope failure zone due to unsupported excavation. The pile/road response to excavation is then determined in the second step to specify the required clearance again with criterions of safety and serviceability aspects. From the results, various influence zones or clearances between excavation and each type of existing structures and subsoil conditions are established.

1 INTRODUCTION

The increase in demand for infrastructures for utility systems in urban area, such as conduits for electricity and telecommunication cables, water supply and natural gas pile lines, results in underground structures being constructed in close proximity to the existing road structures and bridge foundations due to space constraint. Those underground structures are commonly constructed in right of way areas at various distances from the edge of road embankment or bridge abutment depending on the available width of the right of way.

With the current policy of Department of Highways (DOH), such small underground pipes or tunnels are specified to be constructed at a shallow position to avoid the larger tunnels which are constructed at deeper position. The method used for construction is then the cut-and-cover excavation and commonly without retaining structure. With this type of construction method-the excavation without supports, the soils are excavated with slope and at a certain close distance the construction activities might affect the nearby existing structures. Therefore, one of the main design constraints in these projects is to prevent or minimize damage to adjacent structures.

In order to control or minimize the damage of existing structures, the protection zone for excavation activities should be rationally established with appropriate code of practice. As a part to fulfill this goal, the effects of cut-and-cover without support adjacent to existing road embankment and bridge pile foundation are investigated by means of both 2D and 3D analyses using the finite element software (PLAXIS) in this study. The influence zones for underground construction are developed based on the analysis results in conjunction with the concept shown in next part. The entire details on this research can be found in DOH (2009).

2 EVALUATION CONCEPT

It is well known that the lateral soil movements from excavation activities can be detrimental to nearby existing piles (Finno & Lawrence 1991; Poulos & Chen 1997; Leung et al. 2000). Few theoretical methods have been developed (e.g., Poulos & Chen 1997) to evaluate the pile response to these movements. Nevertheless, these methods have been developed for deep excavation with retaining structures. The similarity in the nature of problem as the effect of unsupported lateral soil movements on pile is referred to the case of antislide piles for landslide control (Won et al. 2005). Most researches on this issue have paid attention to either stability of pile-reinforced slope or estimation of lateral force acting on stabilizing piles. There are numerous empirical and numerical methods for designing stabilizing piles which can generally be classified into two different types: (1) pressure/displacement-based methods (Ito & Matsui 1975; Chen & Poulos 1997) and (2) finite element/ finite difference methods (Goh et al. 1997). With the difficulty on estimation of free soil displacements and insufficient consideration of soil– pile interaction of the displacement-based method, the finite element-based methods are more popular in recent year and are chosen in this study. However, in this study, the interest is neither the safety factor of the excavated soil slope nor the lateral force acting on piles, but the induced bending moment in the piles. Therefore, the finite element based method is adapted as described as follows. This method is also used for effect on road embankment.

In all cases in this study, the analyses are performed with consideration of 2 stages. The first stage concerns the slope stability of excavated soils, whereas the stability of pile or serviceability of road is afterwards evaluated in the second stage. The analyses start with excavation with vertical slope and the stability of excavated pit is evaluated. The analyses are repeated with less steep slope if insufficient stability is indicated until the stability is satisfied. By this concept, it is expected that the final slope of excavation obtained from the analyses would be satisfied to natural strength of in-situ soil and the clearance between the existing structure and the edge of excavation pit is of interest for required protection distance. However, it is restricted that the final edge of excavation pit must not cross the existing structure even though the stability of excavation is achieved.

After the stability of excavation is achieved with a certain slope, in the second stage, the stability of pile and serviceability of road is evaluated for nearby pile foundation and road embankment problems, respectively. The stability of pile is determined by comparing the induced maximum bending moment in the pile with its capacity. For road embankment, the change in road surface slope is investigated as serviceability assessment.

3 GROUND CONDITIONS AND PROBLEMS TO BE ANALYSED

Two subsoil conditions are chosen in this study, Bangkok subsoil and typical subsoil. The Bangkok subsoil consists of made ground with the thickness of 1.50 lied over the 18.50 m thick soft clay layer. The 7.0 m thick first stiff clay layer is encountered below the soft clay layer at the depth of 27.0 m. Beneath the first stiff clay layer is the 8.0 m thick dense sand layer and the 6.0 m thick second stiff clay layer at the depths of 35.0 m and 41.0 m respectively. The lowest is the 19.0 m thick second dense sand layer at the depth of 60.0 m. For road problem, the 2 m high embankment is considered in the study.

Due to the variety of subsoil conditions in other parts of Thailand, the typical subsoil is assumed to be a single layer with homogeneous properties. For road problem, the 4-m high embankment is considered in the study. Two kinds of piles are considered in this study, bridge foundation piles and bearing unit piles, using the pile dimensions following the standard construction of DOH.

4 METHODS OF NUMERICAL ANALYSES

Evaluations of the effects of excavation adjacent to existing road embankment/pile foundation are accomplished by the finite element program named PLAXIS. Two dimensional plane strain or and three dimensional analysis is employed to model the excavation project depending on the nature of problem and the necessity. The soil element composes of triangular element for 2D and tetrahedral element for 3D problems. The pile is modeled by beam elements with elastic properties. The undrained condition is assumed in the analyses for Bangkok subsoil case whereas the drained analysis is performed for typical subsoil case.

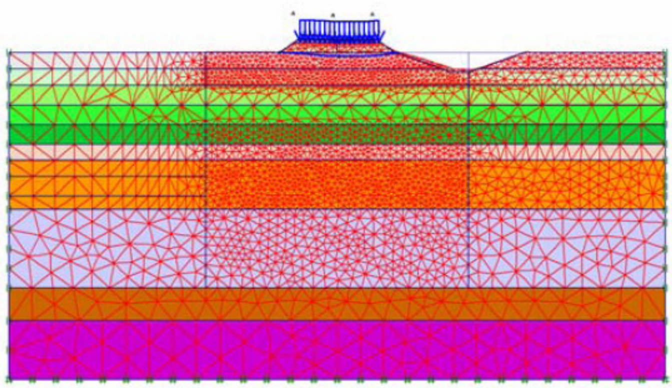
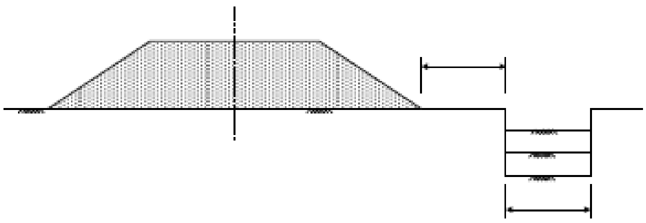


Figure 1: 2D FE mesh for analysis of excavation adjacent to road- repeated analysis with less steep slope case (Bangkok subsoil).

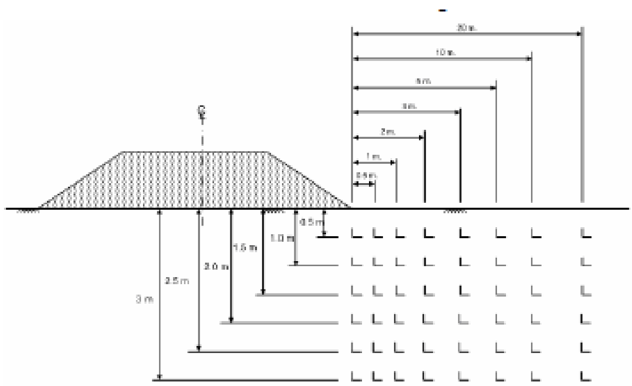
For Bangkok subsoil, the sand layer is modeled with Mohr-Coulomb (MC) model with ν′, φ′, c′ and E′ = 0.3, 36°, 0 and 8×10^4 kPa, respectively. The Hardening Soil model (HS) is used with clay layers. The soil parameters used are adopted from previous research on excavation analysis in Bangkok subsoil (Rukdeechuai et al. 2009). Those parameters are obtained based on the comprehensive site investigation by Prust et al. (2005). The validation of using HS model for clays, MC model for sand layer and the soils parameters in FE analyses of excavation was done by well-documented, high quality excavation case histories in the previous works (i.e., Wonglert et al. 2008 & Rukdeechuai et al. 2009).

For typical subsoil, it is modeled with MC model. The strength parameters are selected as to be able to support 4-m high road embankment and the soil stiffness is interpreted from strength property values using the empirical equations from previous research records (NAASRA 1987). The MC model is used for road embankment and structure as well using the soil parameters from correlation by empirical equations of CBR value (Gregory & Cross 2007). The minimum required CBR from DOH standard is used for each road structure layers.

The analyses begin with modeling the initial condition of soil following with road construction or pile installation. The distributed pressure of 10 kPa and working load is applied to the road surface and pile head, respectively. The excavation is thus simulated by removing the soil elements in intended excavation area. With the soil models in the family of elasto-plasticity used in this study, the computational would be terminated with incomplete analysis if excessive yielding of soil happens. The excavation analysis is then re-performed with less steep slope. By repeating the analysis with gradually adjusting the slope of excavation until the complete computation is achieved, the response of pile or road is then investigated.



a) Variation of excavation depths



b) Variation of excavation locations

Figure 2: Identification of excavation depths and locations from road embankment in the analyses.

5 ANALYSES OF EXCAVATION ADJACENT TO ROAD EMBANKMENT

By the analysis method previously described, some additional analysis details for analysis of excavation adjacent to road embankment is presented in this section together with the results, which then lead to the development of influence zone latter. Two dimensional plane strain analysis is employed to model the excavation project as shown in Figure 1. The figure illustrates the FE mesh for re-analysis of excavation with the slope that the excavation can be completely accomplished in Bangkok subsoil. Various analysis cases have been performed by varying the depth of excavation and the clearance between the edge of road embankment and the edge of initially vertical slope of excavation pit as shown in Figure 2.

For each analysis cases, the computation capability is checked together with the strain distribution in soil mass (as shown in Figure 3) to adjust the excavation slope in the next-step of re-analysis until the complete analysis is obtained. Then, the road surface settlements are investigated in order to check if the changes of road surface slope exceed the criterion as shown in Figure 4.

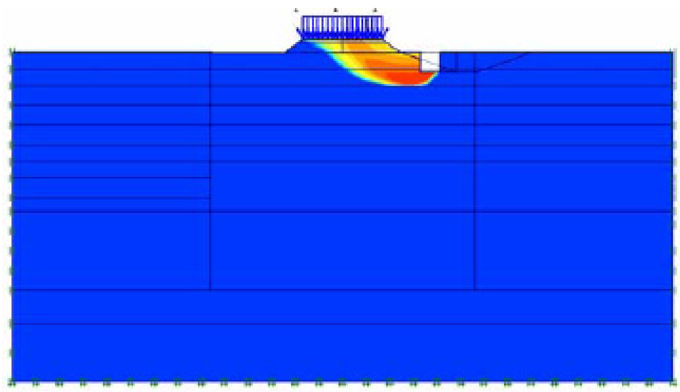


Figure 3: Contour of strain showing the yield zone of soils due to excavation with vertical slope.

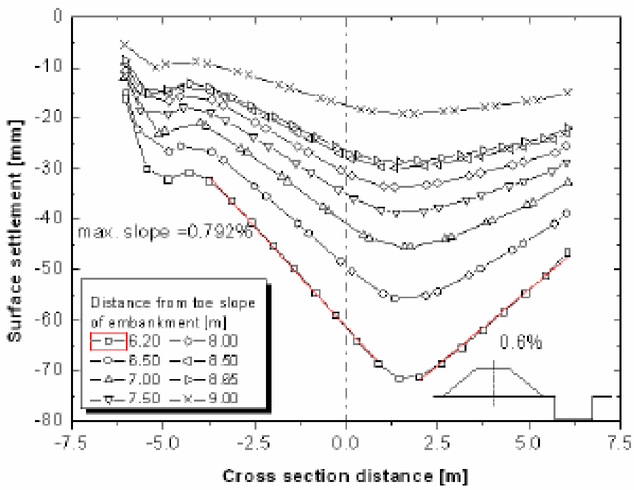


Figure 4: Road surface settlement profile after completion of 3m deep excavation at various distances from edge of road embankment (Bangkok subsoil case).

By the processes previously described, the necessary clearances between the initial edge of excavation and the edge of existing road embankment are obtained for each case leading to the development of protection zone (described later).

The analysis results for excavation in typical subsoil using the same methodology are illustrated in figures 5 and 6. The results reveal that, in typical subsoil condition, the unsupported excavation can be done with nearer initial clearance to the road compared to that in Bangkok subsoil. Moreover, the changes in the road surface slope are also smaller than those of excavation in Bangkok subsoil condition.

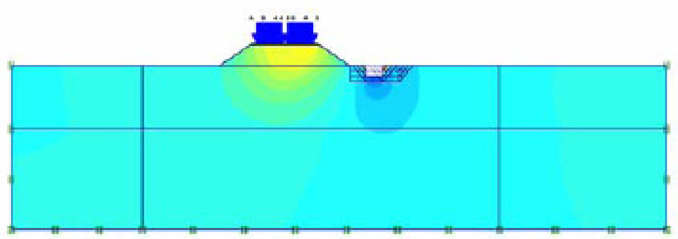


Figure 5: Geometry of problem and contour of strain showing the yielding zone of soils due to excavation with vertical slope (Typical subsoil case).

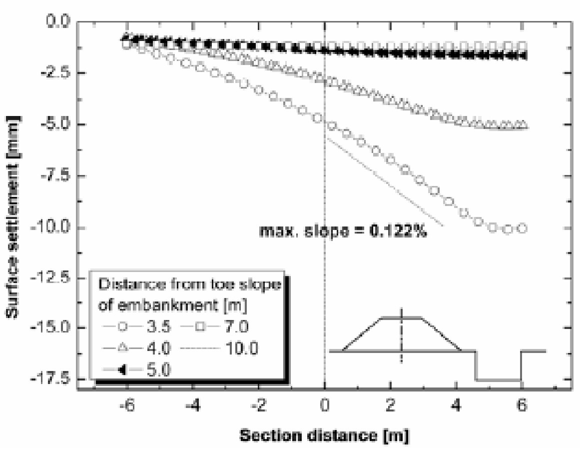


Figure 6: Road surface settlement profile after completion of 3 m deep excavation at various distances from edge of road embankment (Typical subsoil case).

6 ANALYSES OF EXCAVATION ADJACENT TO BRIDGE FOUNDATION

Three dimensional analysis is employed for excavation adjacent to pile foundation. The previous researches indicated that most effect of the excavation would be induced to nearest piles (front pile) in the pile group whereas the induced effect to those located behind (rear pile) is comparatively small (Chae et al. 2004). Therefore, for the sake of simplicity, only single pile is considered in this study. The example of FE mesh used for analyses is depicted in figure 7.

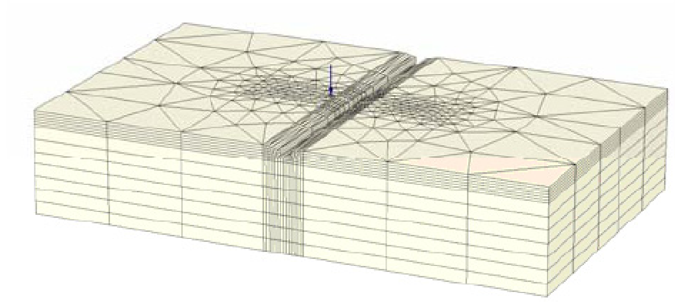


Figure 7: 3D FE mesh for analysis of excavation nearby pile foundation (Bangkok subsoil case).

Using the previously described method, the example of analysis results showing the bending moment distribution in 0.22×0.22@6 m pile along its length after completion of nearby 3-m deep excavation at various distances between pile and edge of initial excavation pit are presented in figure 8.

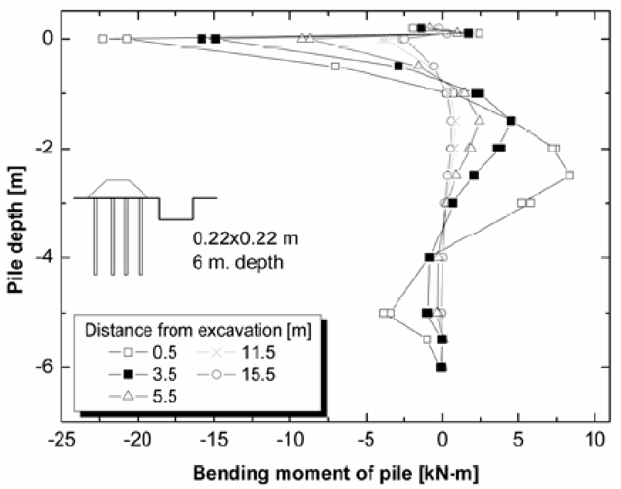


Figure 8: Distributions of bending moment in 0.22×0.22@6 m pile along its length after completion of nearby 3-m deep excavation at various distances.

By varying the pile dimensions, the relationship between the maximum bending moment induced in piles and the clearance can be obtained as illustrated in figure 9. The figure also shows the moment capacity of each pile size. It is seen in the figure that the induced bending moment in only bearing unit piles that exceed their capacities if the soil is excavated nearer than a specific clearance. In contrast, for structural piles of DOH bridge foundation, the maximum induced moments are under the capacity even for close clearance excavation. By varying the excavation depth, the allowable clearance of initial excavation required for each case can be obtained.

The results of analyses for typical subsoil case are illustrated in figures 10 and 11 as examples, respectively, for bending moment distribution along pile length and maximum induced pile moment against the clearance.

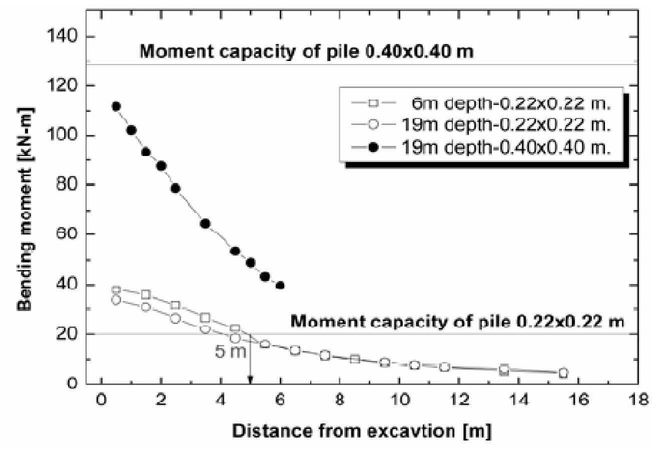


Figure 9: Maximum bending moment induced in bridge approach pile against distance from 3-m deep excavation for various pile dimensions.

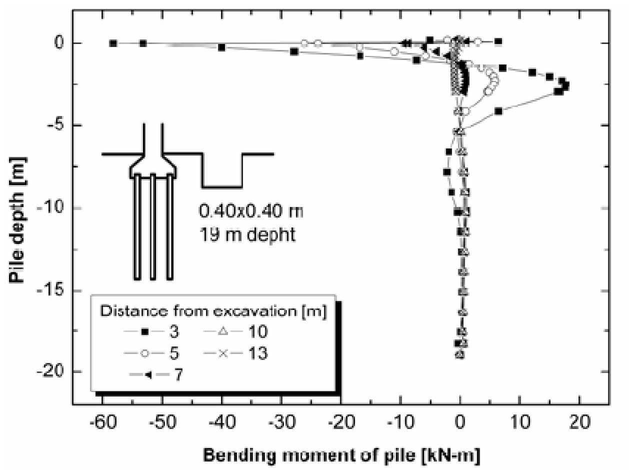


Figure 10: Distributions of bending moment in 0.40×0.40@19m pile along its length after completion of nearby 3-m deep excavation at various distances.

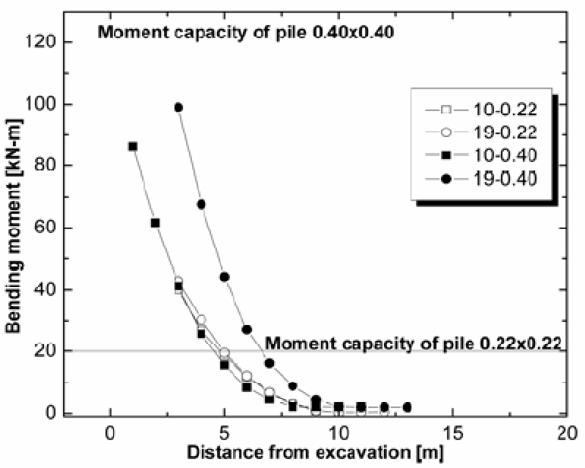


Figure 11: Maximum bending moment induced in bridge pile-foundation against distance from 3-m deep excavation for various pile dimensions.

7 DEVELOPMENT OF PROTECTION ZONE

From the numerical analysis results obtained in previous section, together with the evaluation concept described in section 2, protection zones against nearby unsupported excavation for each existing structures and ground conditions can be suggested as shown in figures 12 to 15. Zone I represents for the clearance to which the initial vertical slope excavation might not affect (or only insignificant level) the stability or serviceability of existing structures. When constructing in Zone II, consideration and monitoring plan should be prepared to assure that the induced effects would not exceed the expected level. Zone III depicts for restriction clearance within that the construction should not be taken place and the retaining system should be employed if the construction can not be avoided.

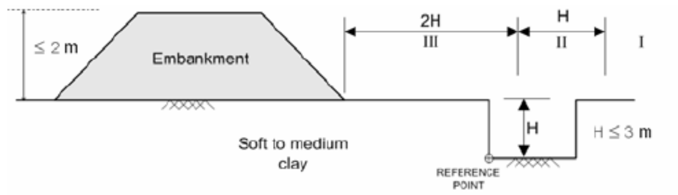


Figure 12: Protection zone of road embankment from nearby excavation suggested from results of analyses in this study (Soft subsoil condition).

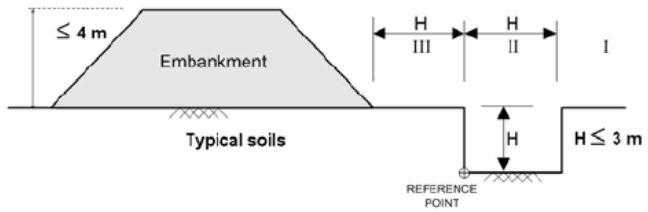


Figure 13: Protection zone of road embankment from nearby excavation suggested from results of analyses in this study (Typical subsoil condition).

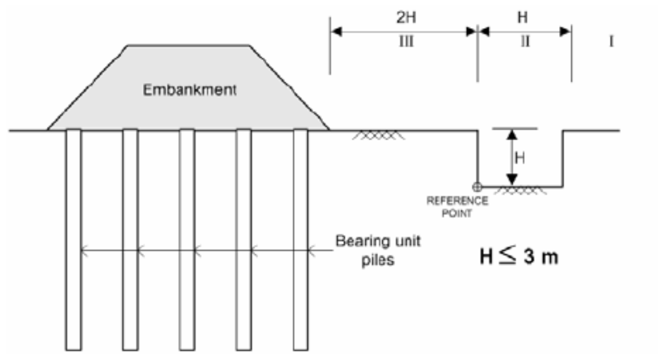


Figure 14: Protection zone of bridge approach piles from nearby excavation suggested from results of analyses in this study.

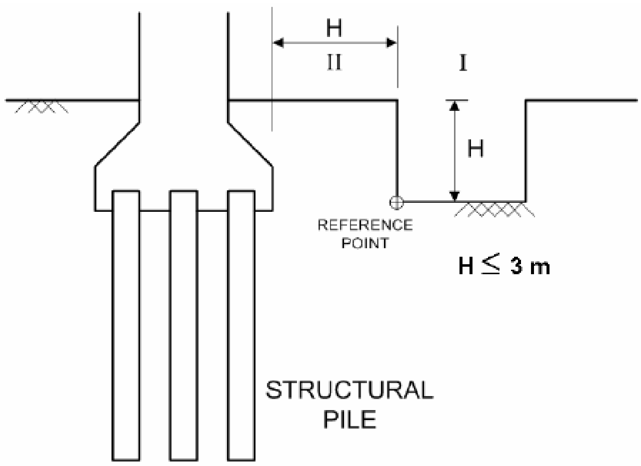


Figure 15: Protection zone of bridge pile foundation from nearby excavation suggested from results of analyses in this study.

8 CONCLUSION

By FEM-based analysis with reasonable evaluation concepts, a two-stage approach is used to analyze the effects of unsupported excavation on nearby existing road embankment and bridge foundation and protection zones are developed. By different subsoil conditions and types of existing structure, different protection zones are obtained in terms of multiplication of the depth of excavation.

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