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Optimization the Distance between Piles in Supporting Structure Using Soil Arching Effect

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ABSTRACT: High cost value of traditional methods for stabilization of pit, encouraged the engineers to study more about soil characteristics and its application. Arching effect is one of these characteristics, it allows to designers apply non-continuous structural elements to provide safety and economy of project. To investigate arching effect of retained structure with anchorage method, Plaxis 3D Tunnel software is used to model fine-grain (CL-ML) with hardening soil behaviour which simulate soil material. In first model, the distances between piles are 2m and number of anchors are 5. In second model, the distance between piles are 4m and number of anchors are 3. The numerical modeling results show horizontal arching appearance in distance between piles. A comparison between the results gained from the 3D FE analyses and the more or less conventional method shows that the classical method is very much on the safe side.
Keywords: Arching effect; Excavation; Anchorage method; Plaxis 3D Tunnel software.

INTRODUCTION

Statement of problem

Today, while urban constructions progress and value of land are developing, height and weight of buildings are increasing too that it has caused to try to find appropriate soil in high quality and effective excavation, then small and large excavations has been common. Additionally, because of increasing population and lack of available spaces to construct new passages in the cities, it is necessary to develop urban trains and construct underground stations. If excavation is operated in the loose soils, it is necessary to construct stable walls to operate train stations, embedded constructions, urban constructions and tunnels. Meanwhile, Stabilization of soil walls at the time of excavation and making tunnel has been considered by the engineers since a long time ago.

Scientists have studied on soil properties and using them to more efficiency. Soil arching is one of these properties that it can play important role to draw the plane safely and economically. The results from laboratory and theoretic comparisons suggest that embedded discontinued piles in a slope can result in double stability of the slop significantly if there are conditions to make arch. In this case, the piles can be installed at the time of constructing without decreasing stability. If retaining wall is equipped with piles and lagging, all costs of materials, stability and size can be optimized.

Definition and description of soil arching between piles

Soil arching, the transfer of soil pressure from a yielding support to an adjacent non-yielding support, is a phenomena commonly encountered in geotechnical engineering (Terzaghi, 1943; Ladanyi et al., 1969; Vardoulakis et al.,1981; Otani et al.,2010; Sadrekarimi and Abbasnejad, 2010) (Fig.1). Recently soil arching theory has been extended to the study of forces and stresses exerted by a yielding soil mass against discrete piles embedded in a slope and extending into a firm, non-yielding base (Bosscher et al.,1986; vermeer et al., 2001) (Fig. 2).

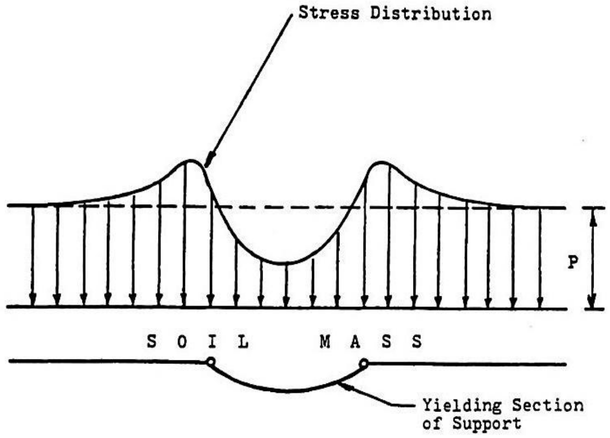

Figure 1. Stress distribution in the soil above a yielding base (Bjerrum et. al., 1972; Revised by Evans, 1984)

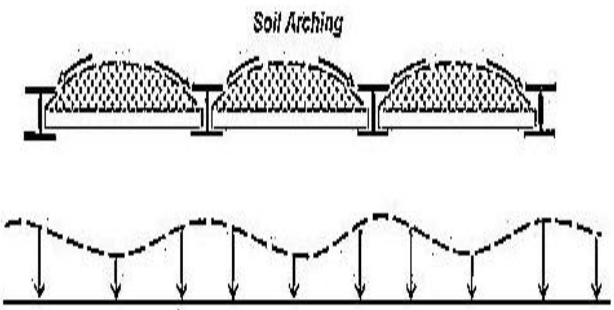

Figure 2. Soil arching between piles

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Numerical results were validated by the finding of Prakash (1962), Cox et al. (1984), Reese et al. (1992), Liang and Zeng (2002), Smethurst and Powrie (2007), Pradel and Carrillo (2008), Kahyaoglu et al. (2009), chang et al. (2010) and Kourkoulis et al. (2011). according to which pile spacing S≤4D is required to generate a group effect and the associated soil arching between the pile. Hence, such an arrangment cannot be applied for slope stabilization and will not be further examined. Therefore, S=4D can be thought of as the most cost-effective arrangment, because it has the largest spacing required to produce soil arching between the piles for the inter-pile soil to be adequately retained. This is consistent with both common engineering practice and numerous research findings.

MATERIALS AND METHODS

Anchorage method

If we consider an excavation, we can determine an failure plane in low safety factor. We can increase safety factor of stability in excavation by reinforcing this plane with using special elements. Anchorage method has been suggested on the basis of stabilization of slope and prevention of wall slide of excavation by using reinforcing soil. In this method, some anchors are entered in the ground and they play reinforcing role as the same as armature in reinforced concrete.

In this method, the anchors will be pre-stressed in the soil and their performance is as the same as available cables in the pre-stressed concrete. Then, pre-stressing in the soil causes to increase stabilization of soil and decrease deformation of adjacent buildings significantly.

In this method, anchor is anchored to the excavation wall on one side and its end on the other side and tensioned that this tension causes to lateral and vertical pressure and prevent to move the wall. The soil is stressed in the place of probable failure wedge by stretching the anchor. It is clear that load transfer will transfer to the soil only at the back of failure wedge where called load transfer area (load zone) and load transfer at this place that called unload area (no load zone) cause to fail (fig.3).

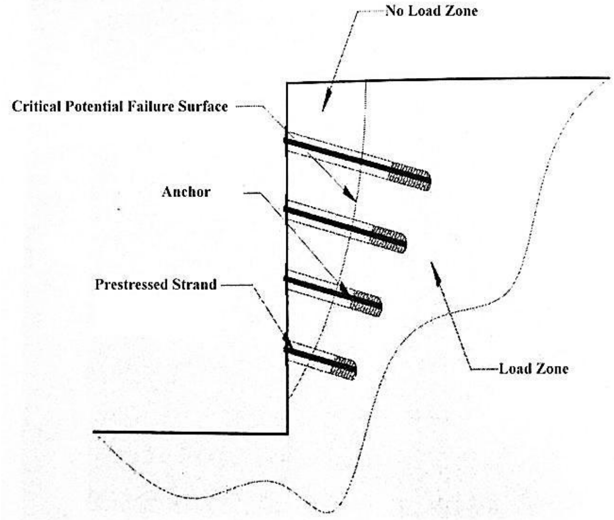

Figure 3. Load zone and no load zone in anchorage method

Then, it is necessary to consider transferring load only in load transfer area and there isn't any stress between soil and anchor in unload area. It is clear that if load transfer performs in unload area, failure wedge will be pulled towards excavation and the anchor not only prevent to fall but the available force in the anchor causes to pull failure wedge towards excavation and to fall excavation. Generally, stages of anchorage system are operated as follow as:

At first, several wells are drilled close to excavation. Then, steel profiles in the forms of H or I will be installed in these wells vertically. Sometimes, two profiles are placed side by side to able to fasten the anchors on the piles. Depth of wells should be considered 1.25 -1.35 in height. Broms and Wang- Reese methods (they are used in FHWA standard) can be used to determine effective depth of piles. In the next stage, excavation is performed in considered depth that it depends on soil conditions, stable depth and interval of piles that it is 2-4m. Then concrete around steel columns is shaved to facilitate. The boring is drilled to place anchors in considered depth, slope and diameter. The anchors are placed in the boring and end of boring will be filled with grout. After that, an anchor will be pulled and this force is transferred to the soil. After placing anchor and armatures on the walls of excavation and performing concrete cover in shotcrete method, a surface in high stiffness is made on the excavation wall. This surface can transfer all forces and changes of excavation wall to the anchor place. Then, the first stage of safe excavation is finished and the next stage of excavation will be the same. This operation will continued in the next stages to finish the excavation.

Numerical modelling

Finite element method is used to analysis the patterns applied in this research. Soil arching phenomenon is applied for three dimensional process (3D) since 2D has different difficulties. Plaxis 3D Tunnel is utilized regard to special characteristics and abilities.

Geometry of the method and support conditions

To achieve specified aim, soil arching phenomenon is investigated between steel piles. A 10m deep excavation with vertical depth and horizontal surface behind the wall is selected to utilize anchorage method for stabilization. It should choose boundary conditions sufficient far from excavation or zone of influence under stress states, as there is no difference between stress states and displacements before and after applied changes. Without consideration of this, the modeling result is mistake and provides less safety factor. To define and investigate the required dimensions for modeling, Plaxis 2D version 8.5 is used in addition to suggested dimension to suggested dimensions with different researchers including Briaud and Lim (1999).

With the use of try and error method, different geometry dimensions specially width of excavation is simulated with this software and the desired distance is obtained from model boundaries.

Therefore, according to specified dimensions of excavation and considered documents, the geometry of the model is illustrated in fig 4 with 2D dimensional condition.

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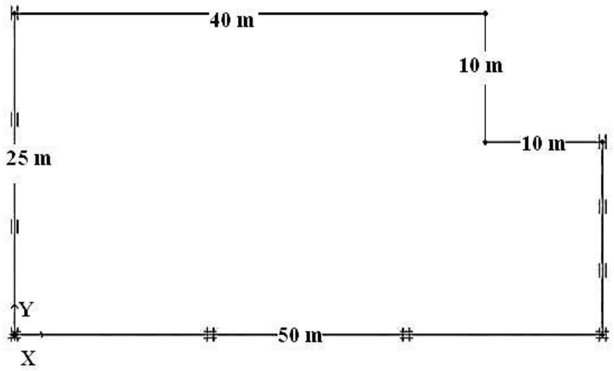

Figure 4. Dimensions of the model

As it shows in fig.4, support conditions of vertical boundaries in both sides with vertical rollers which movement of boundary points is restricted in horizontal direction (U_x=fixed, U_y=free). Horizontal and lower displacements are considered closed in lower horizontal boundary (complete anchoring conditions). Width of the model is variable depending on distance between piles (2m and 4m). the modeling of water flow is not considered in this research.

Soil materials and suitable behavioral model

In numerical modeling, behavioral model definition and related input parameters are most effective principal parameters to obtain output of analysis. In essence, the behavioral models present a mathematical description in mechanical behavior of materials which considers important aspects of material behavior. In this research, homogenous fine-grain soil (CL-ML type) with hardening soil model is used to simulate soil materials according to their advantages and its applications. Hardening soil model is an advanced model for simulation, and stiffness of soil describes very accurate with three different input stiffness. In hardening soil model, the stiffness is function of stress, on the other hand, the whole stiffness increase with pressure. According to lack of laboratory facilities, the hardening soil characteristics are derived from valuable documents (Rechea et al., 2008). Therefore, the considered soil characteristics are presented for modeling in Table 1.

Table 1. Parameters for soils

Parameter	Symbol	CL-ML	Unit
Material model	-	Hardening soil	-
Type of behavior	-	Drained	-
Moist unit weight	γ	18	kN/m^3
Secant stiffness in standard drained triaxial test	E_{50}^{ref}	1.8 ×10^4	kN/m^2
Tangant stiffness for primary oedometer loading	E_{oed}^{ref}	1.44×10^4	kN/m^2
Unloading / reloading stiffness	E_{ur}^{ref}	5.4×10^4	kN/m^2
Power for stress-level dependency of stiffness	M	0.85	-
Effective cohesion	c'	35	kN/m^2
Friction angle	φ'	25	°
Dilatancy angle	Ψ	0	°

Steel piles and anchors characteristics

In Y direction of the models, structural elements of steel piles are selected as 2IPE300 construction profile. The piles characteristics are illustrated in fig 5 as shown schematically. Number of piles is 4 in Z direction of models from centre to centre 2m and 4m. These piles are simulated with plate element. Then, with combination of node to node anchor and geogrid, the simulation is made for anchor and cement grouts. Cable anchors are performed to have 18600 kg/cm^2 failure strength. Each cable consists of 7 string twisted together and diameter of cable is 0.6 inch. To perform cables, 116 mm drilling diameter with 10 degrees relative to horizon is used. The length of the grouts for all the cables are considered 8 m. the location of anchors are considered as FHWA standard method (consists of the distance for the first row of anchors to surface and the vertical, horizontal distance between anchors). In all models, the distance of first anchor from surface is 1.2 m, and the distance from end of first row anchors to surface is 4.5 m. Therefore, free length of first row anchor in all models is 15 m which considers the length of the other anchors relative to the length of first row anchors.

In order to investigate arching phenomenon in numerical modeling, it was not used any lining or structural support between steel piles (lagging or shotcrete) is not utilized. Physical characteristics of assumed elements are illustrated in table 2.

Table 2. Structural elements characteristics

piles				anchors		geogrid
EA (kN)	EI (kN.m^2)	W (kN/m)	ϑ	EA (kN)	Prestess force (kN)	EA (kN)
3.5028×10^6	6.4602×10^4	0.828	0.3	1.149×10^5	200	5.28×10^4

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Calculation phases

After making geometry of the model, soil characteristics definition, structural elements and underground water condition, the calculation of phases is considered in next section.

In calculation section, it is possible to simulate loading condition and excavation steps according to reality. The type of analysis can be selected in relation to consolidation, dynamic, staged construction, Phi-c reduction analysis and simulate the real conditions. As the time-dependant parameters and dynamic analysis are not concerned in this research, thus with selection of stage construction analysis, the excavation stages and environment condition are simulated with reality and FHWA standard method. Fig.5 shows final calculation phase for distances 2 m and 4 m between piles.

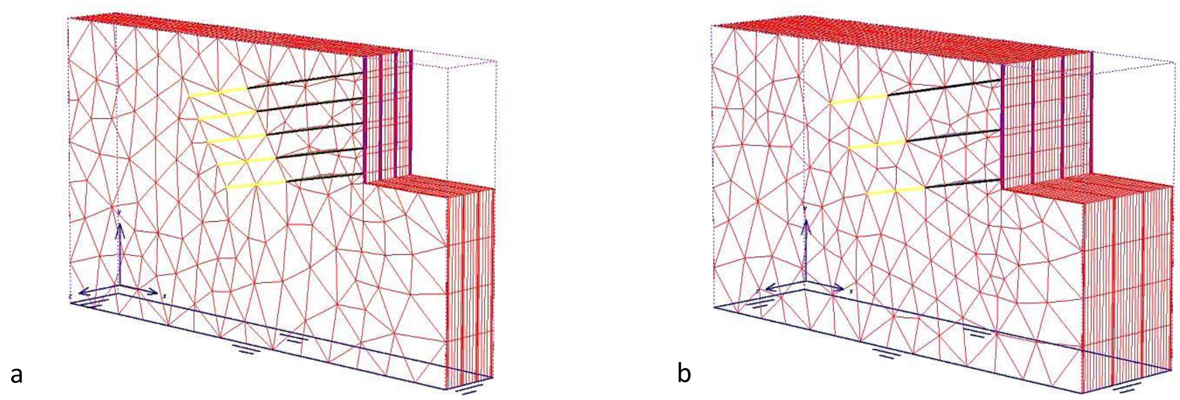

Figure 5. Final excavation phase: a) 2m distance between piles; b) 4m distance between piles

RESULTS AND DISCUSSION

Horizontal stress distribution (σ_{xx}) between two piles from center to center 2 m and 4 m are illustrated alternatively in fig.6 and fig.7. The results from horizontal sections in plane X-Y direction are obtained with the considered depths (Y). As it is observed the horizontal stress pattern showing the same trend for all the depths in 2 and 4 m distances. Stress concentration around piles directly contact with soil is shown clearly.

On the other hand, horizontal stresses in the direction of distance between two piles (Z direction) are reduced to very little amount at the middle of two piles. This means that arching effect is recognized clearly in soil behind the wall.

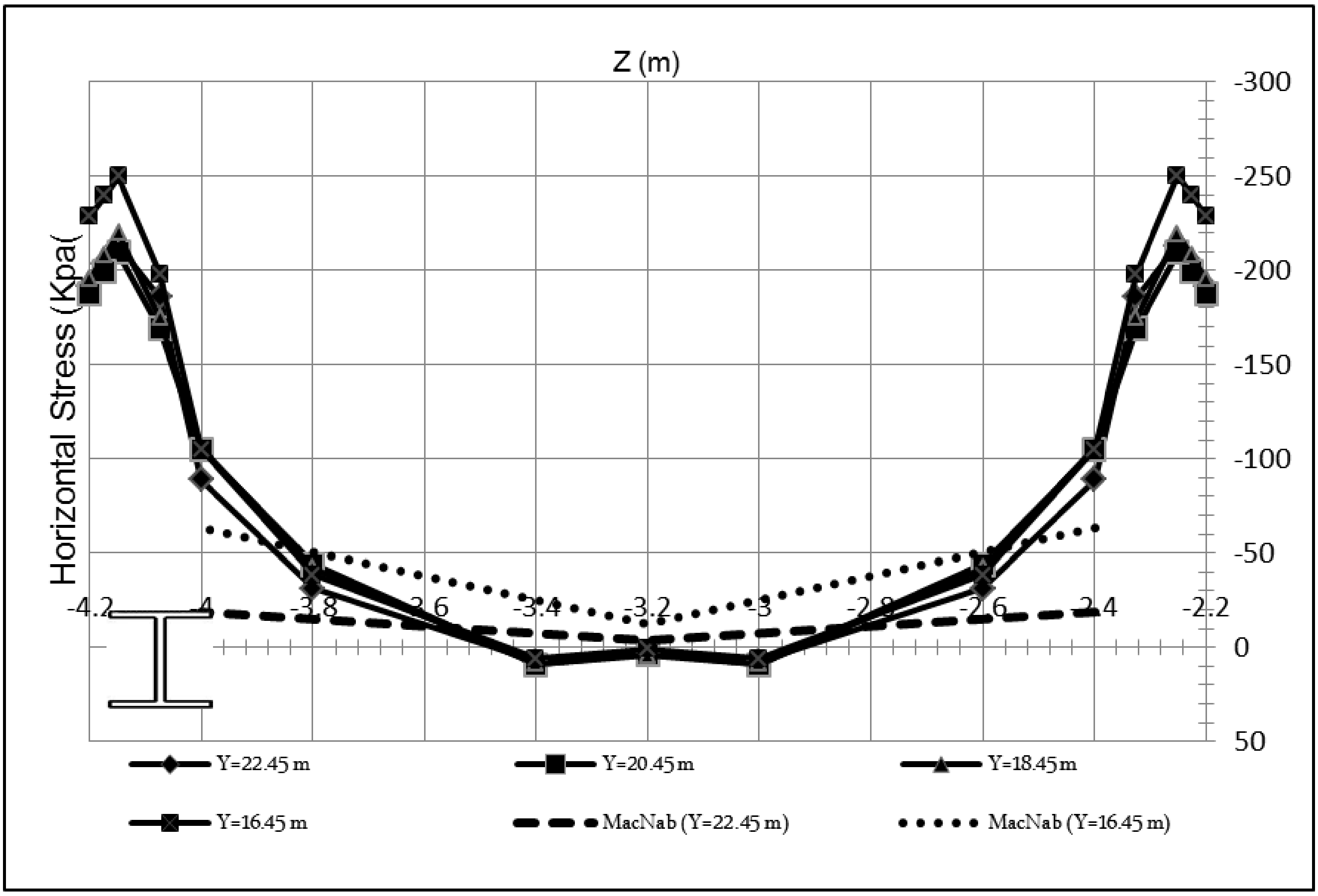

Figure 6. Horizontal stress distribution (σ_{xx}) in different depths between two piles with axial distance 2 m

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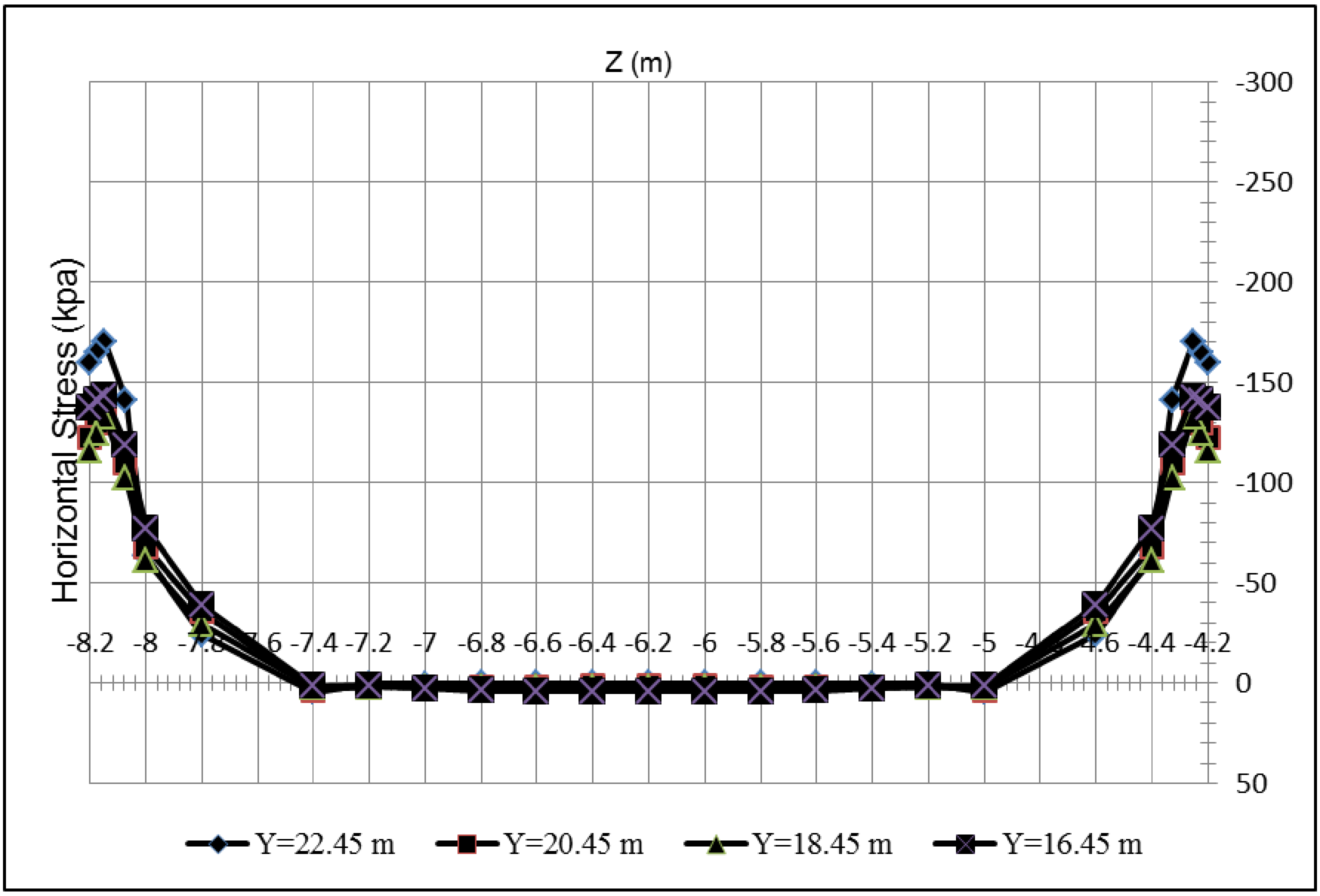

Figure 7. Horizontal stress distribution (σ_{xx}) in different depths between two piles with axial distance 4 m

Generally, horizontal pressure diagrams are used to design supports between piles such lagging or shotcrete, which often ignore arching effect in them or it is associated with simplified assumptions in calculation of this phenomenon. The diagrams shown in fig.8 are suggested by MacNab (2002).

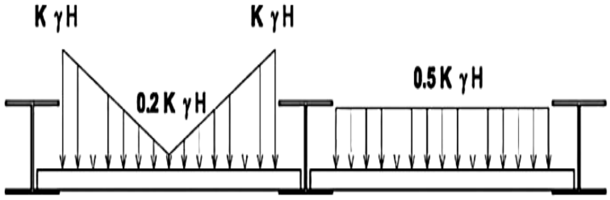

Figure 8. Diagrams reduced pressure on board between two piles

As shown in left side of fig.8, horizontal pressure ground in piles is maximum and less in the distance between piles. In right side of fig.9, pressure between two piles is half of the horizontal pressure in ground. According to both diagrams, applied pressure increases with depth without limitation in distance between two piles.

The left side of the diagram is used to adapt classic and numerical method in depths Y=22.45 m and Y=16.25 m. As it is seen in fig, 6, the calculated horizontal pressure amounts between two piles in different depths using numerical methods are very close to each others, whereas in classic methods the pressure between piles increases with depths which are against each other. In comparison with results of 3D finite element and MacNab method, it can conclude traditional methods and classic design of supports in piles are conservative. In addition, in classic method the span width between piles do not considered in calculations, i.e., pressure diagram is identical for spans 2 m, and 4 m which is shown in figs.7 and 8 for comparison.

CONCLUSION

Arching effect causes reduction of horizontal stress in distance between piles and concentration of horizontal stress behind the piles. Classic methods of horizontal pressure distribution in distance between piles result in conservative design. The width of span between piles in horizontal stress distribution is effective by comparison with classic and numerical methods in this research. As the span between the piles increased, the forces transferred to piles are reduced according to arching effect. This results in increase soil displacement between the piles. The amount of calculated horizontal pressure between two piles in different depths using numerical methods is very close to each other. Whereas in classic methods the pressure between two piles increases with depth which is against finite element results.

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