International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 03 | Mar 2024 www.irjet.net p-ISSN: 2395-0072

BEHAVIOR OF DOUBLE ROW MICROPILE WITH GROUTED NAIL SYSTEM IN DEEP EXCAVATION

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Abstract - *Deep excavation is a common practice of construction in densely populated areas, uncertainty problems can arise due to the significant settlement at the ground surface and large movements at the facing of the excavation walls. Stabilizing these excavations can be achieved by the most popular methods such as micropile and nailing system. This method has also been widely used to stabilize natural slopes and earth retaining structures. In the present study, numerical modelling and the analysis of an 8m deep excavation supported with different earth retaining systems has been carried out by adopting finite element-based software PLAXIS 2D. A parametric study is conducted using a double row micropile system and a composite system using micropile and nail system. The behavior of the soil body, the forces generated in the micropile, nails, and global safety factors are compared for each case in both static and dynamic conditions. In the case of a double row micropile, the soil body collapse during the final excavation indicating instability condition. To overcome this problem, a composite system has been adopted. The influence of building load on the stability of deep excavation has also been investigated in the present study. The building is placed at different offsets from the excavation line and the behavior of the soil body is compared for all the cases. It is found that when the building is at the edge of the excavation line without any offset, the maximum displacement and bending moment are observed and vice versa.*

***Key Words*: Deep excavation, Composite system, Double row micropile, Grouted nail, PLAXIS 2D**

1.INTRODUCTION

Due to rapid urban developments and growing population in the major cities around the world, the need for underground space has increased. Therefore, deep excavations for development of underground space, such as subway transportation networks, tall buildings basements, underground car parks, and shopping centres have been widely used [2]. However, due to scarcity of land, major developments are increasingly being carried out in peripheral areas of the city. This situation presented unique challenges and opportunities for innovative design as the selling price is not enough for conventional basement excavation technique (e.g. Diaphragm wall) to be economically feasible. However, with larger development area, some flexibility in basement layout and design allow techniques such as soil nail and micropile to be employed even for deep excavation with basement of greater depth. Now a days in Earth retention or Deep excavations stabilization are generally followed by many methods here we followed Micropile and Soil nailing technique.

In this present study a Composite system using double row micropile with and without nailing system is analysed for a deep excavation of 8m using finite element package PLAXIS 2D. The system consist of the Double row micropile with grouted nailing technique is adopted in the way such that the system retains the soil and prevent the soil from cave-in or collapse.

1.1 Micropile

A micropile is a small-diameter (typically less than 300 mm), drilled and grouted replacement pile that is typically reinforced. Generally, micropiles are applicable when there are problems with using conventional deep foundation systems. These problem conditions include: obstructions, adjacent structures, limited access job sites, and other shaky areas like caves, sinkholes, underground rivers. For example, micropiles are commonly the preferred foundation choice in the challenging areas that feature nearby buildings and difficult access [3]. Installation techniques vary depending on the load bearing specifications of the project. The selection of the installation technique depends largely on soil conditions and load transfer requirements.
Generally, micropile consists of two general applications,

a) Structural support
b) In-situ reinforcement

1.2 Soil nailing

Soil nail walls are particularly well suited to excavation applications for ground conditions that require vertical or near-vertical cuts. They have been used successfully in highway cuts; end slope removal under existing bridge abutments during underpass widening; for the repair, stabilization, and reconstruction of existing retaining structures; and tunnel portals [13]. Soil nailing is an economical technique used to stabilize existing slopes and to construct retaining walls from top down. The soil reinforcement process uses steel tendons which are drilled and grouted into the soil to create a composite mass similar to a gravity wall. Soil nails are usually installed at an inclination of 10 to 20 degrees with horizontal and are primarily subjected to tensile stress.

2. PROBLEM STATEMENT

8m vertical deep excavation in a homogeneous soil strata supported by using double row micropile with and without grouted nailing techniques. Taking surcharge of uniformly distributed load 50kPa (building load) along the excavation line.

Table - 1: Soil properties

Parameter	Name	Soil Layer
Material model	Model	M C model
Type of material behaviour	Type	Drained
Soil dry unit weight (kN/m³)	γ_{unsat}	18
Soil saturated unit weight (kN/m³)	γ_{sat}	20
Horizontal permeability (m/day)	Kx	10^{-6}
Vertical permeability (m/day)	Ky	10^{-6}
Young's modulus (kN/m²)	E_{ref}	20000
Poisson's ratio	v	0.3
Cohesion (kN/m²)	C_{ref}	1
Friction angle (degree)	Φ	25
Dilatancy angle (degree)	Ψ	0

Table - 2: Properties of Micropile for Double row micropile (FHWA-SA-97-070)

Parameter	Name	Data
Type of behaviour	-	Elastic
Normal stiffness (kN/m)	EA	$20.75*10^6$
Flexural rigidity (kNm²/m)	EI	$138.4*10^3$
Weight (kN/m/m)	w	0.282
Poisson's ratio	v	0.45

Table - 3: Properties of Grouted nail for Double row micropile (FHWA-NHI-14-007)

Parameter	Name	Data
Normal stiffness (kN/m)	EA	$101.0*10^3$
Flexural rigidity (kNm²/m)	EI	142
Weight (kN/m/m)	w	0.129
Poisson's ratio	v	0.45

Table - 4: Properties of Capping beam and Basement (PLAXIS manual)

Parameter	Name	Data
Normal stiffness (kN/m)	EA	$12*10^6$
Flexural rigidity (kNm²/m)	EI	$160*10^3$
Weight (kN/m/m)	w	0
Poisson's ratio	v	0.499

Table - 5: Properties of Rest of building (PLAXIS manual)

Parameter	Name	Data
Normal stiffness (kN/m)	EA	$9*10^6$
Flexural rigidity (kNm²/m)	EI	$67.50*10^3$
Weight (kN/m/m)	w	10
Poisson's ratio	v	0

The deep excavation is analyzed for various cases by varying the parameters of the Micropile and soil nailing, the parameters for which the analysis is performed are listed below.

a] Properties of Micropile.
b] Length, spacing and properties of soil nailing.
c] Position of building surcharge from excavation line.
d] Static and dynamic analysis.

2.1 Numerical modeling

PLAXIS version 23 is used for the simulation of 8m deep vertical cut in soil using staged construction of composite system and analyzing the response of micropile and nailing, under static and seismic condition. Numerical modelling is carried out taking the plane strain state of stresses. The 15-node triangular element with finer mesh density are used for the finite element discretization. The in-situ soil is simulated as Mohr-coulomb (MC) material for the static and dynamic analysis. Figure 3 shows the dynamic analysis, strong motion record of upland earthquake respectively is used. Nailing and micropile are simulated as the linear elastic material. Plate element is used to model the micropile and nailing system. The analysis is performed for a 8m deep vertical excavation supported by composite system using double row micropile with and without nailing, considering a surcharge load of 50kPa (building load) starting from the excavation line. The deep excavation is performed as staged excavation, Excavation sequences are simulated as the staged excavation with 2-m excavation lift in each stage. The analysis is carried out in the sequence indicated below.

1. Starting a new project.
2. Creating soil stratigraphy using the geometry line feature.
3. Creating and assigning of material data sets for soil strata (MC model).
4. Assigning the dynamic line load to model.
5. Creating and assigning of properties for double row micropile (plate element).
6. Creating and assigning of properties for grouted nails (plate element).
7. Assigning a distributed load to model the surcharge load.
8. Mesh generation.
9. Calculation of staged excavation.

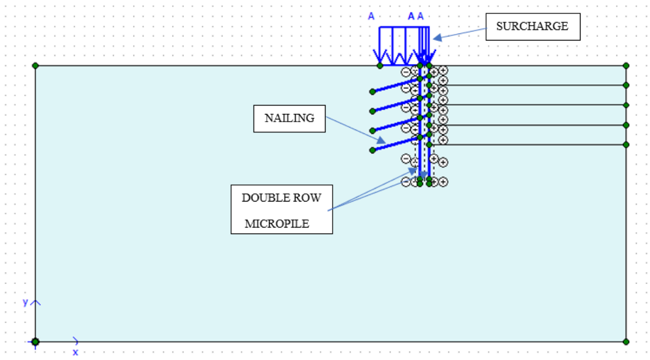


Fig -1: Typical model showing the double row micropile with grouted nailing system

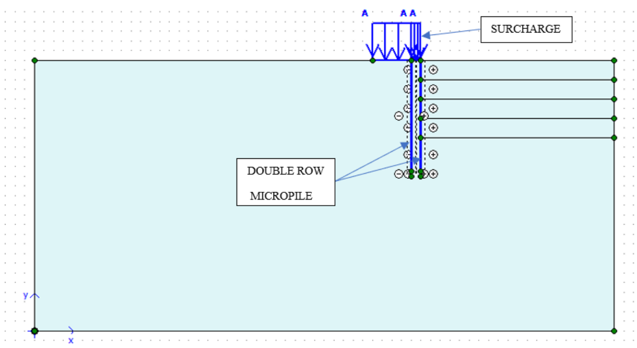


Fig -2: Typical model showing the double row micropile without grouted nailing system

Figure 1 shows typical model of the homogeneous soil strata and the support system provided for the proposed excavation, by adopting double row micropile with grouted nailing system and figure 2 shows the typical model of the double row micropile without nailing system is prepared using numerical modeling tool PLAXIS 2D.

2.2 Output

Figure 3 and 4 shows the deformed mesh, how the soil body deforms after the excavation of 8m deep is made using the double row micropile with grouted nails. The double row micropile with grouted nails deflects due to the earth pressure and the building load, bottom heave is observed at the final excavation level.

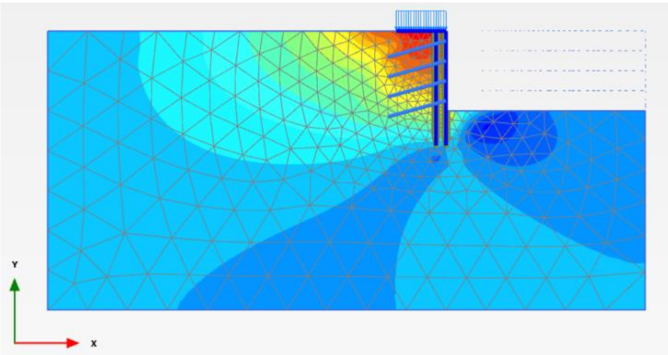


Fig -3: Deformed mesh (static analysis)

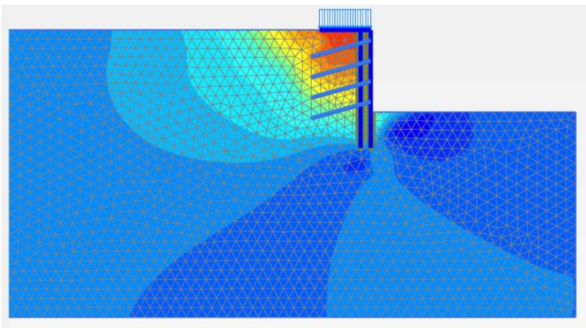


Fig -4: Deformed mesh (dynamic analysis)

2.3 Results and discussion

In this present study a Composite system using micropile and nailing system is analysed for a deep excavation of 8m using finite element package PLAXIS 2D. The system consists of the Double row micropile with and without nailing technique is adopted in the way such that the system retains the soil and prevent the soil from cave-in or collapse. Micropile and nailing system is analysed for different cases, varying the configuration of the system such as the double row micropile with or without Nails and altering the length and spacing of nails. The different cases were also analysed by varying the building load location. These all cases were analysed by both Static and Dynamic conditions. In Static conditions the forces acting on the system such as the lateral earth pressure is calculated and the system is made such that is resist all the forces acting on the system. In dynamic condition the forces generated due to the dynamic loading were calculated and the system is made such that it resists the forces effectively without any failure. The various parameters that were varied during analysis are as follows

1. Double row micropile with or without nails.
2. Building load location.
3. Type of Analysis.

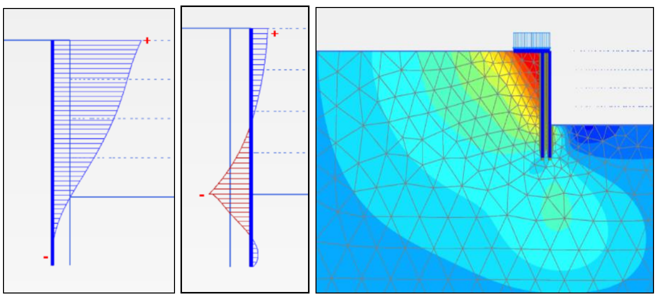
Static analysis

In static analysis the loads which are acting on the system is constant with respect to time. So, at every instance of time the magnitude of the forces acting on the micropile is constant. To perform static analysis in finite element analysis programme the geometry of the problem is defined, the double row micropile with and without grouted nailing system is modelled and the analysis is carried out in stage manner.

1. Double row micropile

In this case, the use of a double row micropile was necessary because the various cases were done with a single row micropile, but the soil was not strong enough to carry the load. The systems are designed based on the FHWA micropile design and construction. Micro-piles in the form of steel pipes of 300mm dia with 16mm thickness, spaced at 50cm and 11.5m length are considered. Horizontal component of shear resistance provides resistance for induced shear forces due to excavating and loading. In addition 6 rods of 32mm diameter of steel rods are provided, in the annular space of micropile to provide additional shear resistance and can be positioned in the central space of the pile. The space in the pile and between the steel rods can be filled up with grouting. And the analysis has been carried out for different offset of building from the line of excavation.

a) Surcharge load at excavation line

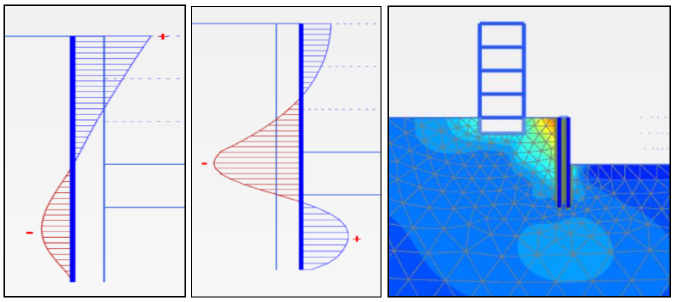


(a) (b) (c)

Fig - 5 : (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

It is seen from the figure 5 that the system is safe, because of the capping beam is provided at the top it will act like a held back system offering fixity at the top. From the figure 6 (c) it shows that the horizontal displacement is maximum at the top of the wall and is found to be 23.76mm (at the stage of excavation 4).

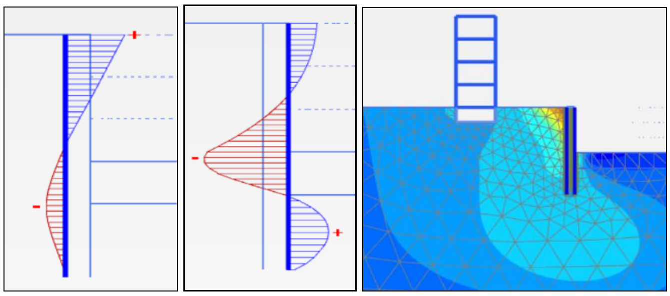
b) Building load is located at 5m distance from excavation line



(a) (b) (c)

Fig - 6: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

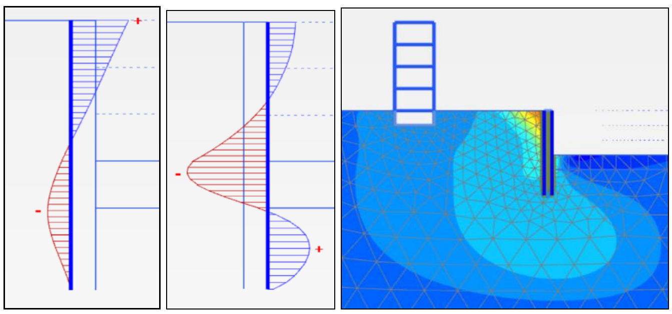
c) Building load is located at 10m distance from excavation line



(a) (b) (c)

Fig - 7: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

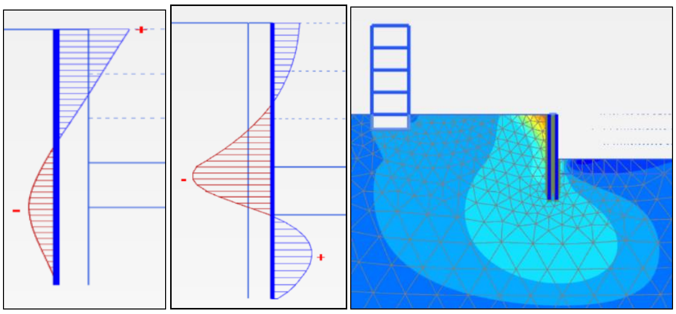
d) Building load is located at 15m distance from excavation line



(a) (b) (c)

Fig - 8: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

e) Building load is located at 20m distance from excavation line



(a) (b) (c)

Fig - 9: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

It is seen from the figure 6 to 9 that the system fails at the excavation of 8m. The reason for the failure is the soil body collapse (at the stage of excavation 4). It shows that the horizontal displacement of the double row micropile is maximum at the top of the wall and that the system so provided for the excavation of 8m is not sufficient to resist the external loads, and the system has to be redefined.

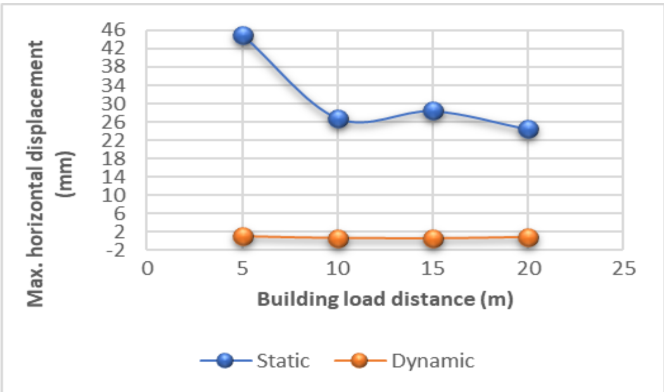


Chart – 1: Building load distance vs Maximum Horizontal displacement

Chart 1 shows that the building load distance from excavation line and the corresponding maximum horizontal displacement in the wall after the final stage of excavation. From the graph we can see that the displacement is not maximum when the Surcharge load is placed at the excavation line but it is maximum when the surcharge is placed at 5m from the excavation line in the case of static analysis and is maximum when the load is placed at excavation line in the case of dynamic analysis. When the surcharge placed further away from the excavation line the displacement keeps decreasing and almost become constant (i.e., at 8m).

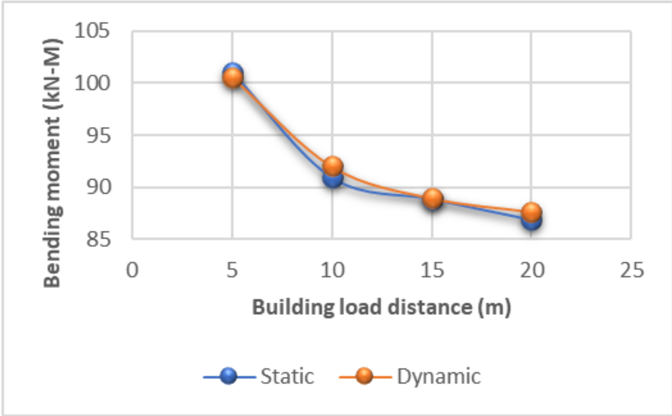


Chart – 2: Building load distance vs Maximum Bending moment (Front pile)

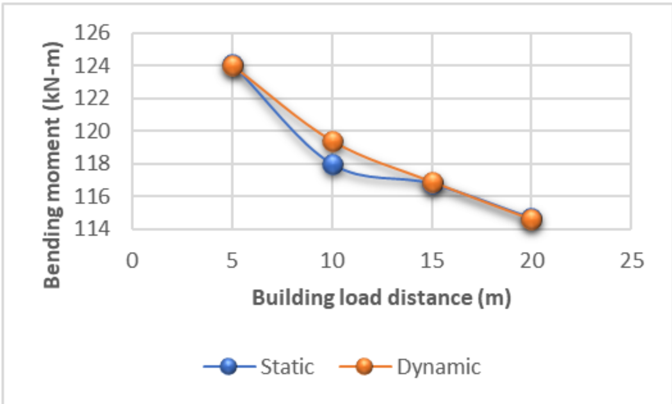


Chart – 3: Building load distance vs Maximum Bending moment (Back pile)

Chart 2 and 3 shows that the building load distance from excavation line and the corresponding maximum bending moment in the wall after the final stage of excavation. From the graph we can see that the bending moment is maximum when the Surcharge load is placed at the excavation line (i.e., at 0m) and it will goes on decreasing as the surcharge load is placed away from the excavation line (for static and dynamic condition). As we keep on moving the surcharge away from the excavation line the variation of bending moment will almost become constant (i.e., at 20m). The bending moment in the back pile is maximum when compared to front pile in case of double row micropile.

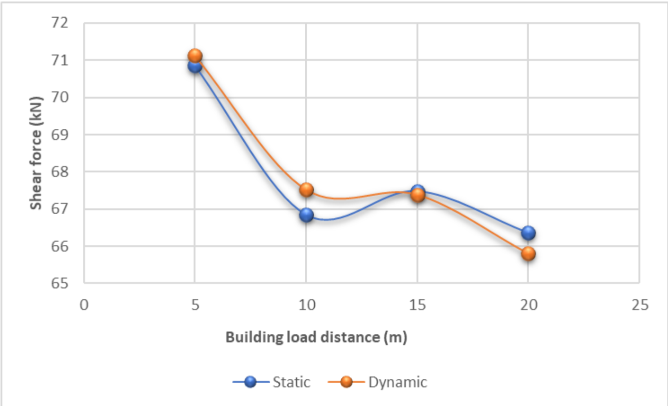


Chart – 4: Building load distance vs Maximum Shear force (Front pile)

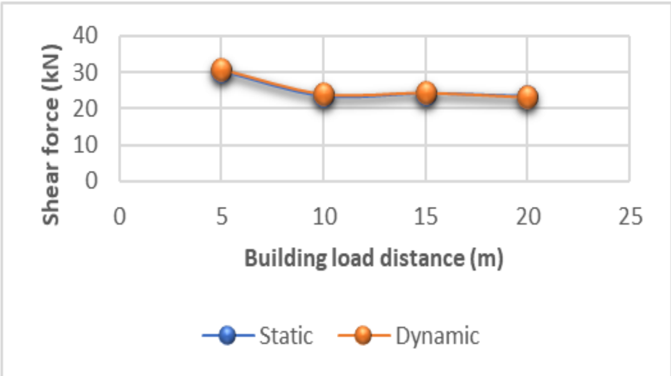


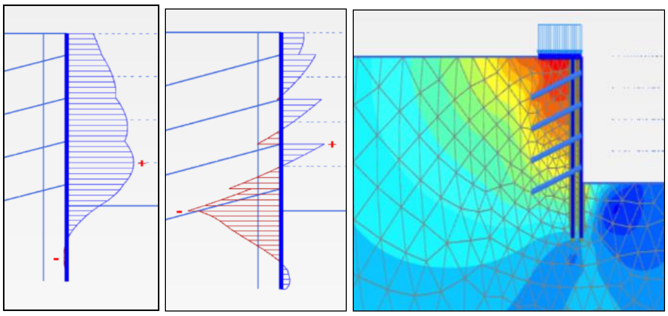
Chart – 5: Building load distance vs Maximum Shear force (Back pile)

Chart 4 and 5 shows that the building load distance from excavation line and the corresponding Maximum shear force in the wall after the final stage of excavation. From the graph we can see that the shear force is maximum when the Surcharge load is placed at the excavation line (i.e., at 0m) and it will goes on decreasing as the surcharge load is placed away from the excavation line (for both static and dynamic condition). As we keep on moving the surcharge away from the excavation line the variation of shear force will almost become constant (i.e., at 8m). The shear force in the front pile is maximum when compared to back pile in case of double row micropile.

2. Double row micropile with grouted nail

Double row micropile option has been tried and failed at the final excavation stage, to overcome this case, adopt composite system using double row micropile with nailing and the analysis has been done by inserting 6m nail at an angle of 15° inclination and the construction is carried out. Initially 2 m excavation is carried and followed by insertion of nails at an interval of 2m. if stability is less, then the nail length is increased to achieve the factor of safety more than 1.5. Further another 2 m excavation is carried and the process is repeated until a depth of 8m. Design of nailing system done by using FHWA soil nail reference manual. And the analysis has been carried out for different offset of building from the line of excavation.

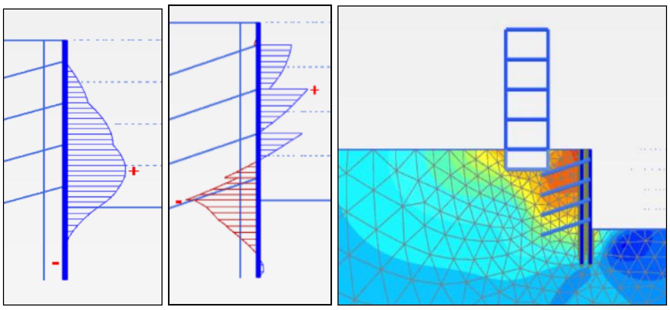
a) Surcharge load at excavation line



(a) (b) (c)

Fig -10: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

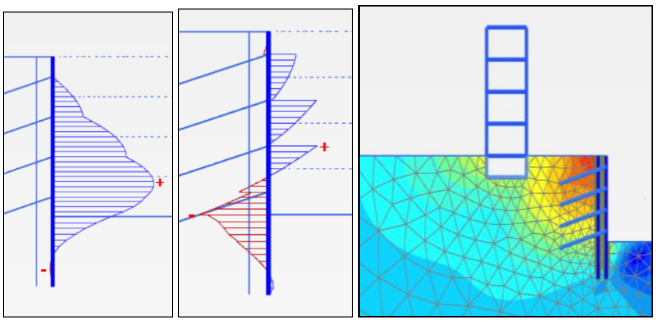
b) Building load is located at 5m distance from excavation line



(a) (b) (c)

Fig -11: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

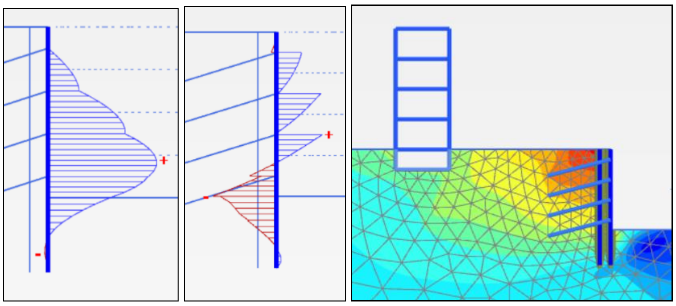
c) Building load is located at 10m distance from excavation line



(a) (b) (c)

Fig -12: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

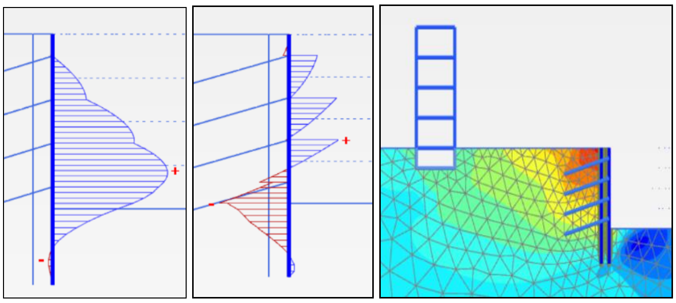
d) Building load is located at 15m distance from excavation line



(a) (b) (c)

Fig -13: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

e) Building load is located at 20m distance from excavation line



(a) (b) (c)

Fig - 14: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

From the above figures 10 to 14, it seen that the horizontal displacement of the double row micropile is maximum at the top of the wall. From the analysis results that the system so provided for the excavation of 8m is sufficient to resist the external loads, and the system is safe.

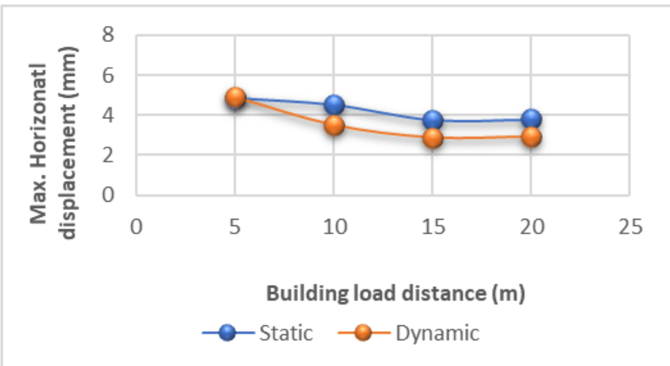


Chart – 6: Building load distance vs Maximum Horizontal displacement

Chart 6 shows that the building load distance from excavation line and the corresponding maximum horizontal displacement in the wall after the final stage of excavation. From the graph we can see that the displacement is not maximum when the building load is placed at the excavation line but it is maximum when the building load is placed at 5m from the excavation line in the case of dynamic analysis. When the building load placed further away from the excavation line the displacement keeps decreasing and almost become constant (i.e., at 8m).

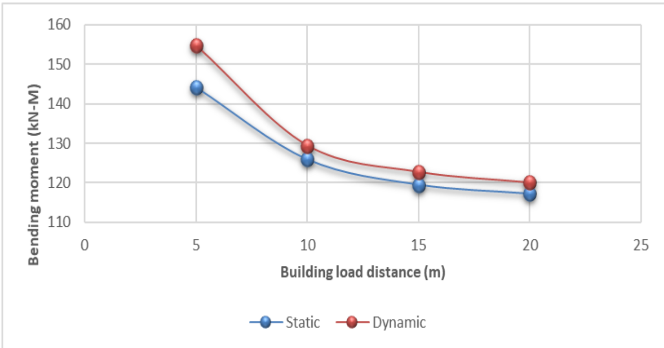


Chart – 7: Building load distance vs Bending moment (front pile)

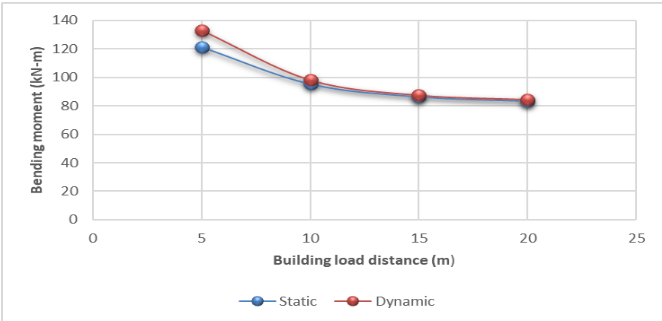


Chart – 8: Building load distance vs Bending moment (back pile)

Chart 7 and 8 shows that the building load distance from excavation line and the corresponding maximum bending moment in the wall after the final stage of excavation. From the graph we can see that the bending moment is maximum when the building load is placed at the excavation line (i.e., at 0m) and it will goes on decreasing as the building load is placed away from the excavation line (for both static and dynamic condition). As we keep on moving the building load away from the excavation line the variation of bending moment will almost become constant (i.e., at 8m). The bending moment in the front pile is maximum when compared to back pile in case of double row micropile with nailing.

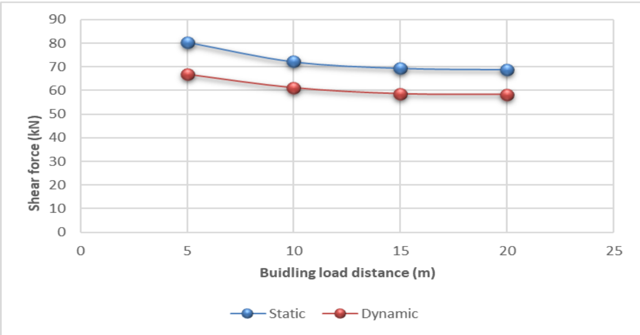


Chart – 9: Building load distance vs Shear force (front pile)

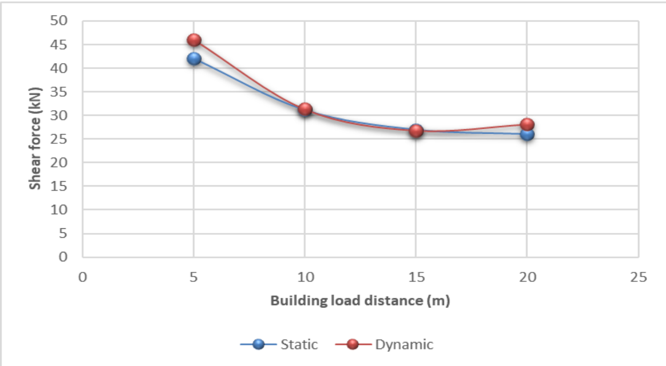


Chart – 10: Building load distance vs Shear force (back pile)

Chart 9 and 10 shows that the building load distance from excavation line and the corresponding maximum shear force in the wall after the final stage of excavation. From the graph we can see that the shear force is not maximum when the building load is placed at the excavation line but it is maximum when the building load is placed at 5m from the excavation line in the case of static analysis. When the building placed further away from the excavation line the shear force keeps decreasing and almost become constant (i.e., at 8m). The shear force in the front pile is maximum when compared to back pile in case of double row micropile with nailing.

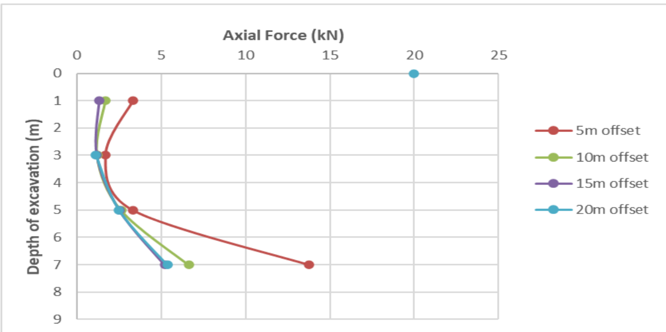


Chart – 11: (a) Depth of Excavation vs Axial Force (static)

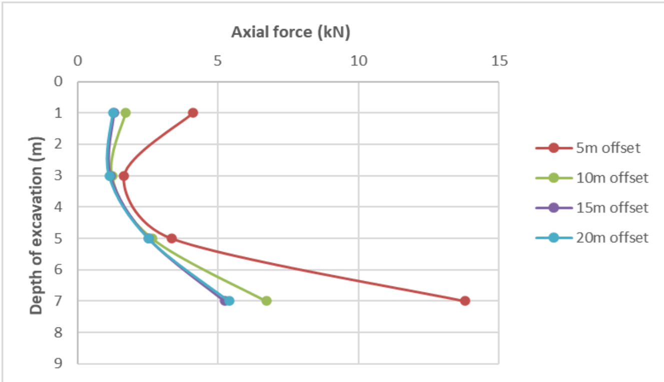


Chart – 12: Depth of Excavation vs Axial Force (dynamic)

Chart 11 and 12 shows that comparison of the axial force in the wall at every stage of excavation (i.e., at 2m intervals) and for all the cases of building load at different locations from the excavation line (static and dynamic condition). From graph it is seen that the axial force initially will be minimum and goes on increasing as the depth of excavation increases and it will be maximum at the final stage of excavation i.e., at 8m. The axial force will be maximum when the surcharge load is at the excavation line i.e., at 0m and it will be least when the surcharge is at 20m from the excavation line

Dynamic analysis

In dynamic analysis the loads which are acting on the system are not constant but they vary with respect to time. So, at every instance of time the magnitude of the forces acting on the composite system is not constant. Dynamic analysis is studied to assess whether the structural system so provided is save in natural calamities such as earthquake. To perform the dynamic analysis in finite element analysis programme the geometry of the problem is defined, and the time-history analysis is done using the strong ground motion data file which is available in the PLAXIS 2D programme files.

The dynamic analysis is performed for those cases where the soil body is safe in the static analysis, and for those cases in which soil body is collapsing during the excavation stage itself, which is while performing the static analysis the dynamic analysis is not performed.

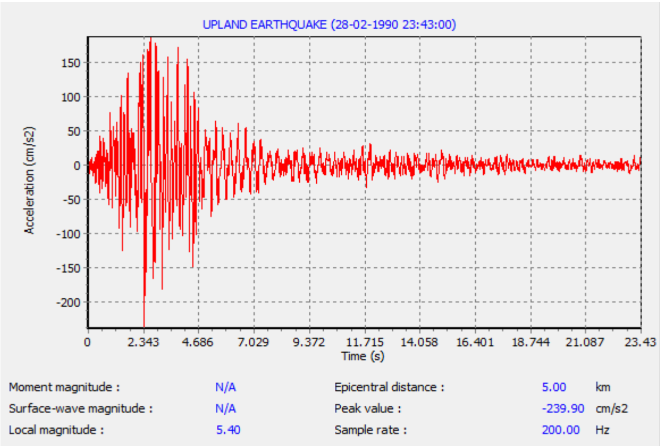
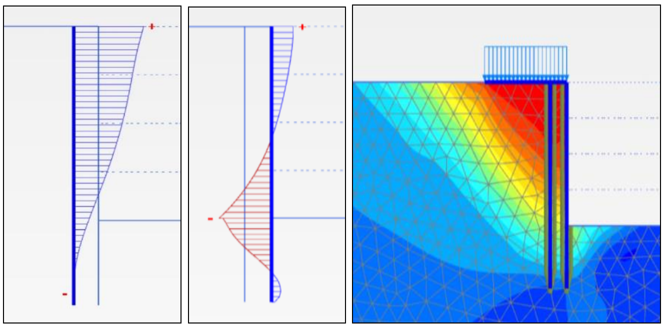


Fig -15: Strong ground motion record of Upland earthquake.

Dynamic analysis is performed using Upland earthquake (occurred during 20th Feb 1990 at 3.44 pm in South California) of peak acceleration of 0.245g (0.24 m/s2).

1. Double row micropile

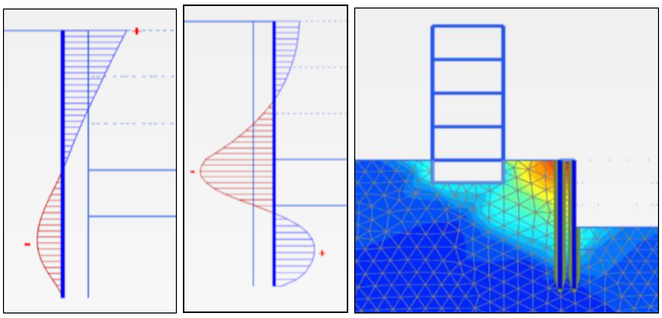
a) Surcharge load at excavation line



(a) (b) (c)

Fig -16: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

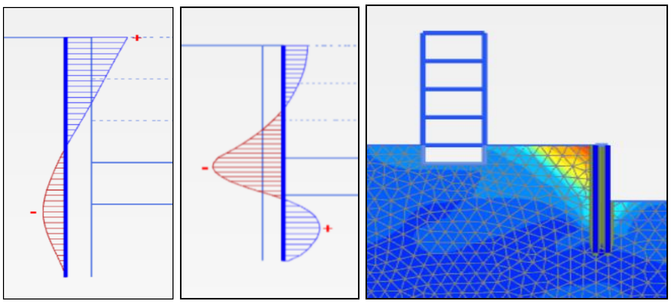
b) Building load is located at 5m distance from excavation line



(a) (b) (c)

Fig -17: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

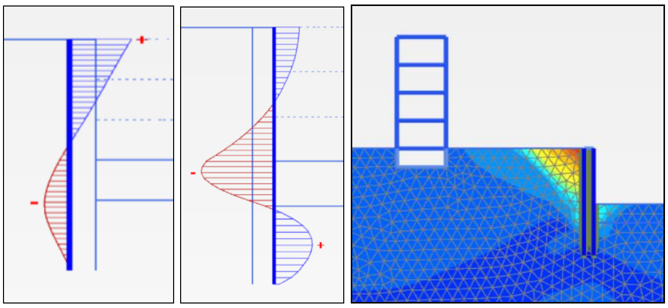
c) Building load is located at 10m distance from excavation line



(a) (b) (c)

Fig - 18: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

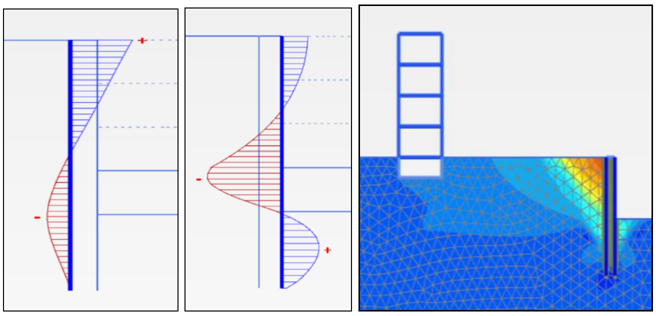
d) Building load is located at 15m distance from excavation line



(a) (b) (c)

Fig - 19: (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

e) Building load is located at 20m distance from excavation line



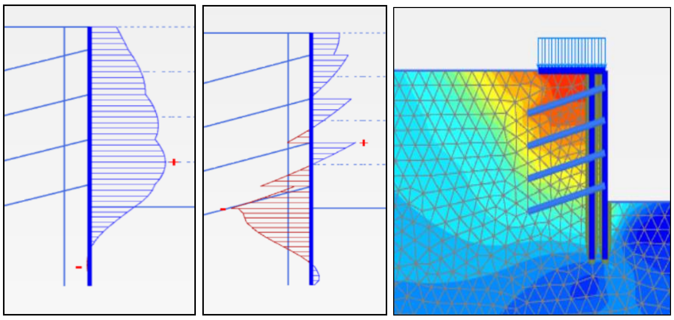
(a) (b) (c)

Fig - 20 : (a) Bending moment diagram (back pile) (b) Shear force diagram (front pile) (c) Horizontal displacement

From the analysis results it is seen that the system is not safe for dynamic analysis as well. From the figure 16 to 20 it seen that when the dynamic loads are applied the complete soil body displaces horizontally along with the double row micropile system. The maximum horizontal displacement recorded is at the stage of excavation 3, and the system is not sufficient to resist the external load.

2. Double row micropile with grouted nail

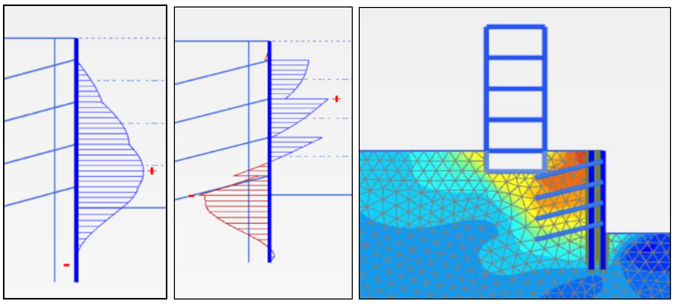
a) Surcharge load at excavation line



(a) (b) (c)

Fig - 21: (a) Bending moment diagram (b) Shear force diagram (c) Horizontal displacement

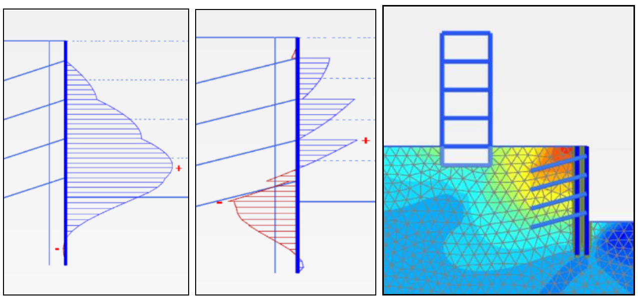
b) Building load is located at 5m distance from excavation line



(a) (b) (c)

Fig - 22: (a) Bending moment diagram (b) Shear force diagram (c) Horizontal displacement

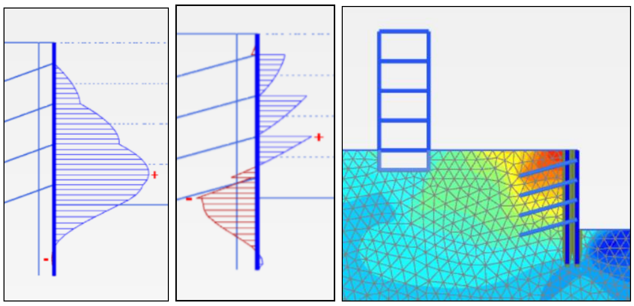
c) Building load is located at 10m distance from excavation line



(a) (b) (c)

Fig - 23: (a) Bending moment diagram (b) Shear force diagram (c) Horizontal displacement

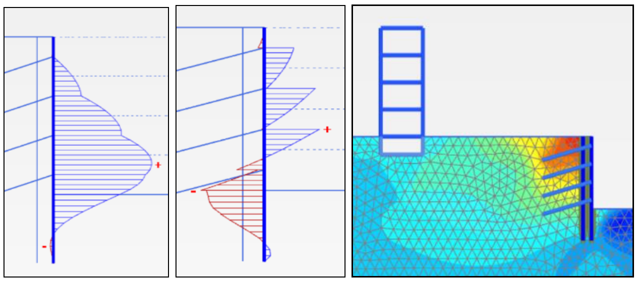
d) Building load is located at 15m distance from excavation line



(a) (b) (c)

Fig - 24 : (a) Bending moment diagram (b) Shear force diagram (c) Horizontal displacement

e) Building load is located at 20m distance from excavation line



(a) (b) (c)

Fig - 25 : (a) Bending moment diagram (b) Shear force diagram (c) Horizontal displacement

From the Figure 21 to 25 it seen that when the dynamic loads are applied the complete soil body displaces horizontally along with the double row micropile with nails. The maximum horizontal displacement is recorded. From the analysis that the system so provided for the excavation of 8m is sufficient to resist the external loads, and the system is safe.

3. CONCLUSIONS

1. In a double row micropile, the capping beam will act like a held back system offering fixity at the top.
2. The minimum bending moments in the micropile are observed in the case of the front pile with the maximum shear force and maximum bending moments are observed in the case of a back pile with minimum shear force and the system found to be not safe to retain a 8m deep excavation.
3. Due to the enhanced strength of double row micropile with nailing, the maximum horizontal displacement is almost nearer in both static and dynamic conditions. It was observed that the maximum bending moment and shear force occur at the front pile, while the minimum bending moment and shear force take place at the back pile.

4. The effect of building load on the excavation is studied by varying the building load offset from the excavation line, and it is found that closer the building load to the excavation area greater will be the displacements caused and vice-versa. It was found that, the maximum axial force is developed at the bottom and minimum at the top.
5. In dynamic condition, the displacements and the forces in the micropile are more when compared to static condition.

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