Effect of Diameter of Secant Pile Wall in Deep Excavation Analysis

A. Mahesh, B. Sarath Chandra Kumar

Abstract: ***Deep excavations in high groundwater levels, industrial area and large constructions with heavy structures is a challenge, where secant piling techniques are one of the best solutions. The wall which is constructed by series of piles is embedded as a retaining wall. These are constructed by overlapping of reinforced concrete piles and plain concrete piles. In this paper the bending performance and the shear strength of different layers of the soil with a secant pile made of Reinforced Concrete Pile (RCP) and Plain Concrete Piles (PCP) are arranged alternately overlapped with each other for the retaining support to the earth. In this paper, an attempt has been made to study the effect of secant pile wall capacity, lateral displacement and bending moment of wall from elastic and plastic stage by using Time History analysis.***

Index terms: ***Cap Beam, Deep Excavation, Primary and Secondary Piles, Secant Pile, Time History Analysis.***

I. INTRODUCTION

Due to space limitation in the urban areas, and to construct skyscrapers, deep excavation is indeed essential. The secant pile wall is the alternative way of constructing retaining wall like sheet piling, soldier piling and lagging, soil mix wall and diagram walls. Secant pile is shaped by a progression of interlocking overlapping exhausted concrete piles. It consists of primary (un-reinforced) and secondary (reinforced) piles. Primary piles are first driven in certain interval of spacing throughout the perimeter and then secondary piles are driven/overlapped in between the primary piles. These are formed by drilling the piles into the specified diameter and required depth. Fig. 1 shows the different types of secant pile wall.

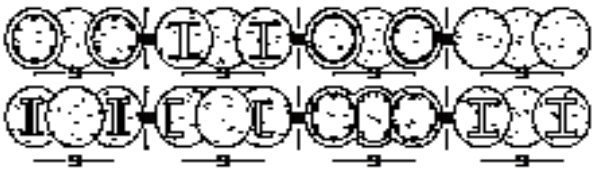

Fig. 1: Different Types of Secant Pile Walls

The both vertical and horizontal movement of diaphragm panel excavation supported by the bentonite slurry material and they showed that total horizontal movement may occurs 1/3rd of depth of panel from the ground level [1]. The Construction sequences of a typical diaphragm wall on a clay and are simulated by using three-dimensional finite element distinction program. Also, it is reported that the settlement happens at a distance 0.2D of behind the influence zone during the diaphragm wall installation. Influence zone nothing but 1/3D beneath from the toe and 1/3L from the edge, then the horizontal stress may of pile reduce behind the center of the panel [2].The finite element method with low shear strength is used to find the base stability of circular excavation in soft clay due the shape effect (N_c) circular excavation is larger stability, then the rectangular excavation. For circular excavation safety factor are: modification factor λ_c=1.2, shape effect N_c and H/B. Reportedly, the nearness of hard stratum and near the base of excavation had significantly increased the N_c value in circular excavation. N_c value increased directly with H/B when H/B≤1 and marginally increment found in H/B when H/B>1 [3]. The design considerations, load testing program, observation, and integrity testing of Drilled Soil Displacement Piles (DSDP) for a gas-fired power plant. DSDP is used successfully to bring loads through the free and delicate soil to the hidden bearing stratum. Finally, the complete project may complete within six months [4]. The design and construction of secant pile wall for a real estate improvement. The wall may be 1.5m away from the adjacent structure. The pile length of 58 m total 96 pile is installed over the entire area, then it will be completed within five months only. Finally, settlement of wall is 3 cm and horizontal movement of 2.5 cm. The utilization of bentonite slurry as penetrating operator to limit the base hurl of borehole and will diminish the effect of nearby structures improvement [5].

Deep excavation supporting systems like conventional wall, tangent pile wall, diaphragm wall, braced wall etc. are the stability analysis of ground. And various stability analysis of ground includes push-in failure analysis, sand boiling analysis, upheaval analysis and their formulas for clayey and sandy soil. And also, a detailed analysis and design of contiguous pile wall is explained in a case study for excavation supporting retaining wall [6]. The non-linear moment-curvature response of a load bearing wall and numerical simulations are performed using Mohr-coulomb approach with tension cutoff to model a concrete material and an elastoplastic model for steel reinforcement under lateral loading. Load-deformation and stress-strain behavior of secant pile is performed using PLAXIS 2D and program response-2000 software's. Finally, when cracking moment of secant pile exceeded, then it's significantly influence the non-linearity of concrete [7]. The critical design consideration for secant pile shoring system, details of installation procedure and verification techniques for secant pile excavation support. Latest drill rigs and tolling allow the cost-effective installation of secant pile in geotechnical

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ground condition and excavation depth up to 30m. Down-hole survey techniques allow the verticality tolerance of circular piles [8]. The construction of a foundation perimeter (i.e. secant pile) to mitigate the effect of the liquefaction in a 64 m large water tank. He has considered as Chile earthquake in 2010 with magnitude of 8.8. Due to relative settlement of tank and secant pile there should no shear connector between the tank and the connecting top beam of pile. And all non-linear structural elements have neglected because of fluid-structural interaction [9].The experimental data on shear strength of circular concrete beams with sand coated glass fiber- reinforced polymer bars and spirals using different codes (ACI 440 IR-15, CSA S806-12, CSA S6-14, JSCE-1997). Circular RC members are provided equal strength characteristics in all directions subjected to wind and earthquake load. Finally conclude that the tests are conducted up to failure, and the GFRP RC beams of shear strength behavior counteract to the steel reinforcement. Higher GFRP spiral reinforcement ratio, which controls the shear cracks and aggregate interlocking [10].

II. RESEARCH SIGNIFICANCE

Considerable research has investigated on the design and construction of secant pile of circular reinforced concrete piles (RCP) and plain concrete piles (PCP). This paper examines that the deep excavation analysis of secant pile wall for different diameters of circular vertical beam subjected to the lateral earth pressure, hydrostatic pressure, seismic loads for with and without cap beam. Additionally time history analysis of secant pile wall from the EL CENTRO earthquake 2010 with magnitude of 7.3, which is happened in short period of 89 seconds throughout the Western United States.

III. EFFECT OF INFLUENCING PARAMETERS

A. Guide Trench

Resistance is assessed as far as both design control and boring verticality, by utilizing a guide trench and layouts with the end goal to guarantee the heap area is controlled at the ground surface. Verticality resistances of 0.5% (1 in 200) are typically necessary for secant piling projects, compared with standard requirements of 1% to 1.5% (ACI 336.1) for bored piles. Typically, the construction of guide trench at the ground surface with pouring of cement mortar throughout the perimeter.

B. Lateral Earth Pressure

The lateral earth pressure, which is acting on the secant pile wall throughout the perimeter. As the depth of excavation increases, then unwanted forces also increases (like lateral earth pressure and hydrostatic pressure) According to the Rankin's theory the apparent earth pressure is calculated using the following formulas:

For the soil exhibiting both cohesion c', and angle of internal friction, ϕ

Active case:

$$\sigma_a' = \sigma_v' k_a - 2c'\sqrt{k_a} \qquad [1]$$

where:

$$k_a = tan^2(45° - \frac{\emptyset}{2})$$

Passive case:

$$\sigma_p' = \sigma_v' k_p + 2c'\sqrt{k_p} \qquad [2]$$

where:

$$k_p = tan^2(45° + \frac{\emptyset}{2})$$

k_a=coefficient of active earth pressure

k_p =coefficient of passive earth pressure

c' =0; for sandy soil

C. Drilling of the Piles

Secant heaps were penetrated with a Bauer BG 24H twofold turning drive bore fix with a Kelly bar augmentation. The twofold rotating framework comprised of two free engine drives, an upper rotational drive associated with a wood screw, and a lower revolving drive associated with the packaging. The two drives turned inverse each other and allowed expulsion of the twist drill and soil in a constant pass while leaving a cased opening. Continuous flight auger (CFA) also used for drilling of piles. While drilling the piles its mandatory to check the verticality of pile at certain interval of time and distance.

Essential heaps are intended to go about as slacking between the basic auxiliary heaps, and it will take care of compression capacity because of un-reinforcement under soil, groundwater and surcharge loads. The plan of pressure quality of the un-fortified ring can be figured utilizing ACI 318, albeit once in a while basic, the clasping limit of the ring ought to be assessed.

Secondary piles are designed to have adequate flexural and shear strength as beams in vertical direction. The main failure mechanism occurs in the wall is the minimum overlap between the adjacent piles will trade off the structure's ability to execute as planned. The discharge of concrete by using tremie pipe of 0.3 to 0.4 meters above the pile pile-tip elevation, with hopper at top and plug inside the tremie pipe. The fitting was utilized as a plug to keep soil and water from getting into the tremie pipe amid cement pouring.

D. Cap Beam

Core beam or capping beam which is placed top of the secant pile wall, then the piles subjected to fixed condition. The main purpose of core beam is to prevent the deflection of the wall, due to lateral earth pressure, hydrostatic pressure surcharge loads. The installation of core beam after concreting of borehole, then removal of casing and concrete may pour into the beam, before that the reinforcement may be welded at the junction of the core beam and secondary pile rebar cage.

E. Lateral Bracing System

There are two types of bracings systems are as following: Temporary lateral bracing system of secant pile walls was provided by a rigid internal bracing system consists of wales, corner bracing and cross lots struts. Permanent lateral bracing system was provided by the vent floor slabs. These bracing systems are provided in certain internal along the

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depth of the excavation to support the circular secant piles. Basically, the struts are compression members, the design of secant pile wall and lateral bracing system, estimation of wall movement's and performed by using conventional and soil-structural analytical methods.

IV. MODELING AND INFLUENCING PARAMETERS

The model has adopted to characterize the behavior of excavation, deformation of the wall and material properties. In order to make realistic prediction of the stability and deformation of the excavation and the adjacent building.

A. Parameters and Material Modeling of Sandy Soil

The excavation soil properties as shown in below Table I.

Table I. Input physical and mechanical properties of soil

Parameters	Depth of excavation (m)	Clayey Sand	Silty Sand	Clayey Sand	Clayey Sand	Rock
Unsaturated unit weight, (γ_{unsat}) (kN/m^3)	0- 2	17	-	-	-	-
Submerged unit weight (γ_{sub}) (kN/m^3)	2 - 6	-	16	12	10	10
Poisson's ratio, ϑ	6 - 10	0.3	0.25	0.2	0.2	0.2
Undrained cohesion (C_u) (kN/m^2)	10-16	0	0	0	0	0
Friction angle ($\emptyset$)	16-21	28	30	32	36	42
Dilatancy angle (φ)	-	4.76	4.92	5.2	5.64	6
Type of material behavior	-	Undrained	Drained	Drained	Drained	Drained

B. Excavation Supporting System

There are two types of piles were used for the earth supporting system. They are Reinforced concrete pile (RCP) and plain concrete pile (PCP). Two diameter of piles were considered in this analysis, pile (A) of diameter =0.8m and pile (B) of diameter =0.6m.The pile was modeled by a circular vertical beam element, the pile parameters are presented in the below table II.

Table II. Material properties of pile (circular)

Parameters	Pile A (0.8m)	Pile B (0.6m)
Type of behavior	Linear elastic	Linear elastic
Pile young's modulus E (kPa)	25 x 10^3	25 x 10^3
Moment of inertia (I) m^4	0.020107	0.000636
Unit Weight (γ) (kN/m^3)	25	25
Poisson's ratio (ϑ)	0.2	0.2
Interface	Rigid	Rigid

C. Time History Analysis

Time history analysis is a dynamic non-linear inelastic method. This method shows that the structural response of a specified interval of time. The present study was taken as post earthquake data of 2010Elcentro earthquake, its magnitude of 7.3 with the intense shaking lasting of about 80seconds.so-that an attempt on secant pile subjected to earth pressure, water pressure, and earthquake load and along with time history analysis by using Elcentro earthquake 2010.

D. Modelling Information

The below Fig. (2) Shows that the total excavation of rectangular area is 10.8x20.4 m^2. This model dimensionswas selected so the limits are far and don't cause any limitation or strain confinement to the examination of the entire perimeter is covered with combination of overlapped RCP and PCP piles total of 154 piles, the overlapping distance of 0.4m and then After driven of piles the excavation will be takes place by supporting the temporary I-shaped strut systems at certain interval of spacing as shown in Fig. (2).

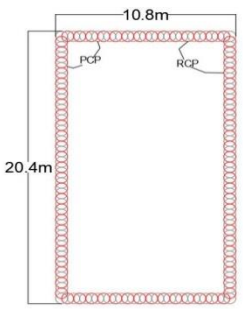

Fig. 2a: Top View (Plan)

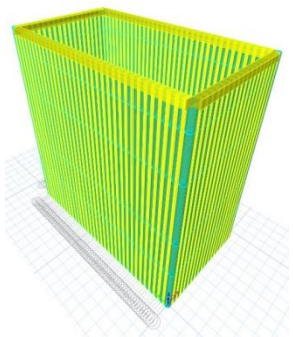

Fig. 2b: 3D View of secant pile wall

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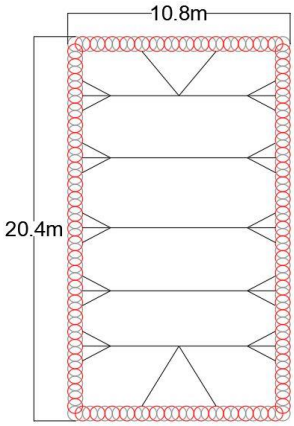

Fig. 2c: Top View

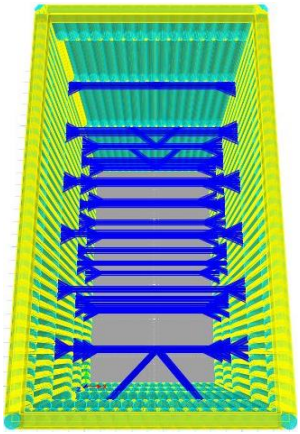

Fig. 2d: 3D View of strut system

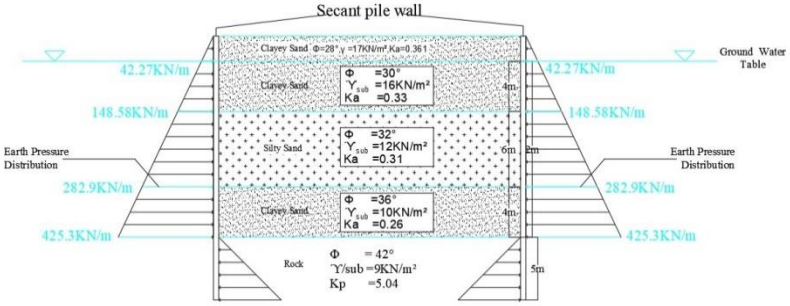

Fig. 2e: Pressure distribution diagram on secant pile wall

Fig. 2: Geometrical representation of secant pile wall

V. RESULTS AND DISCUSSION

This research presents the analysis results of lateral displacement (U_x) and bending moment (M) of secant pile wall height of 21m, pile spacing of 0.4 m for reinforced concrete pile (RCP) and 0.3 m for plain concrete pile (PCP) and the pile diameter was Pile A (0.8 m) and Pile B (0.6 m) respectively, in different layers of sand. The time history analysis by using ELCENTRO earthquake, earth pressure, water pressure and earthquake load on the model of with and without cap beam. The effect of this parameter as lateral displacement (U_x) and bending moment (M) of the secant pile wall were studied.

A. Lateral Displacement and Bending Moment of Secant Pile Wall (Without Cap Beam) Under Various Loading Conditions

Fig. (3) Shows lateral displacement and bending moment of secant pile wall for various load cases. Fig. 3 (a) and (b) shows that as the depth of excavation increases, the displacement decreases and the maximum displacement of wall occurs at top of the pile for different diameter of the piles. Fig. 3 (c) and 3 (d) shows the maximum displacement occurs at top of pile subjected to the envelope (load combinations) loading. Fig. 3 (e) shows as the maximum negative bending moment occurs at Z=2.96 m for pile A and the maximum positive bending moment occurs at distance of Z=15 m.

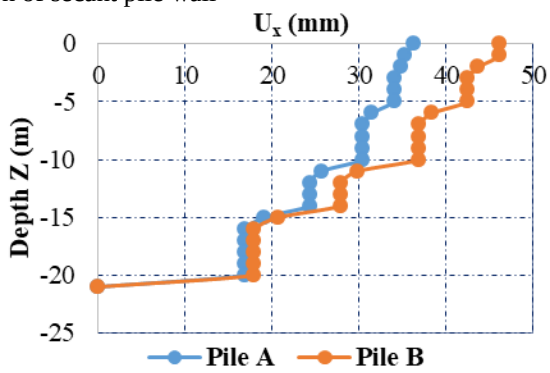

Fig. 3a: Lateral displacement profile for EQX

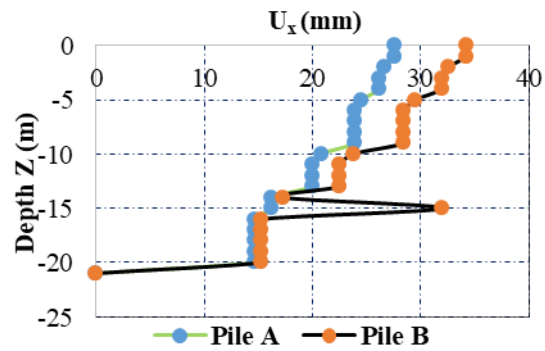

Fig. 3b: Lateral displacement profile for EQY

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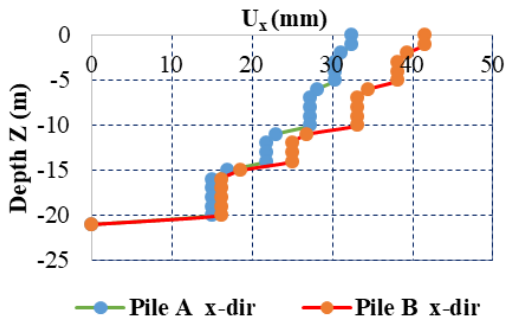

Fig. 3c: Lateral displacement profile for envelope

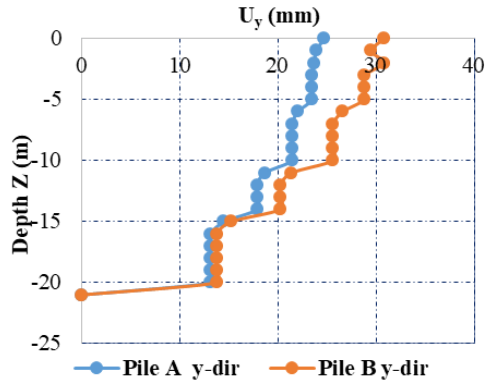

Fig. 3d: Lateral displacement profile for envelope

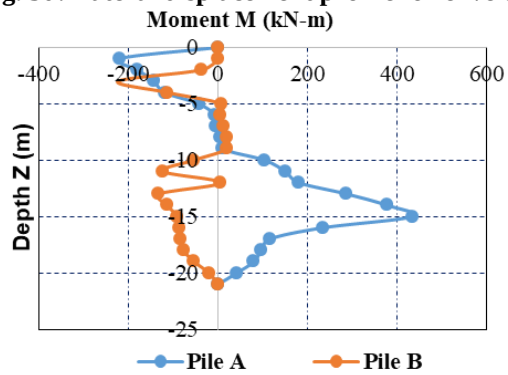

Fig. 3e: Bending Moment Diagram

B. Lateral displacement and Bending Moment of Secant Pile Wall (withcap beam) under Various Loading Conditions

From the previous study, values of lateral displacement and bending moment of secant pile wall was very high. So, proposed of concrete cap beam was studied with width ($b=d_{pile}$) to improve the pile behavior. Fig.(4) showed the decreasing of the lateral displacement (U_x) and bending moment (M), due to using of cap beam, it converted the secant pile support system from free to fixed at the ground surface.

Fig.4 (a) and (b) shows the maximum lateral displacement which is occurred at top in case of EQX and EQY for different types of piles. Fig. 4 (c) and (d) shows the secant pile wall subjected to the envelope (all the load combinations, i.e. earth pressure, water pressure and earthquake in X direction and Y direction) loadings. As the depth of excavation increases moment, as the diameter of the pile increases the bending moment of the wall decreases.

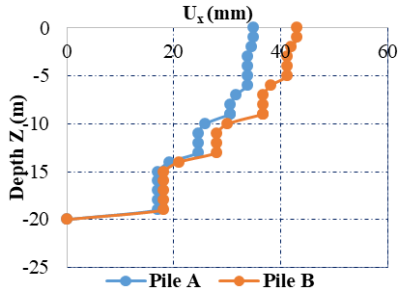

Fig. 4a: Lateral displacement profile for EQX

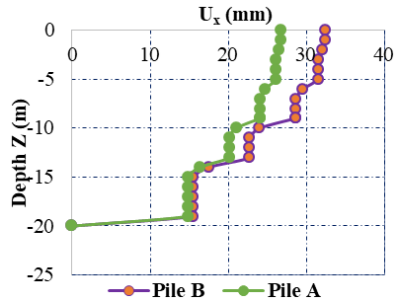

Fig. 4b: Lateral displacement profile for EQY

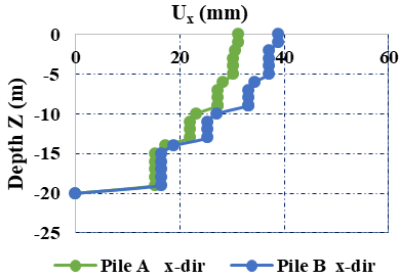

Fig. 4c: Lateral displacement profile for envelope

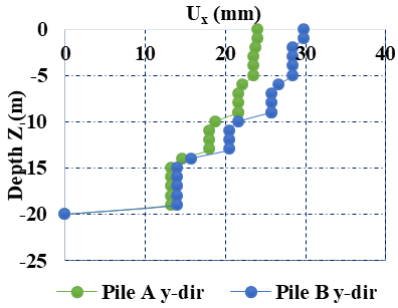

Fig. 4d: Lateral displacement profile for envelope

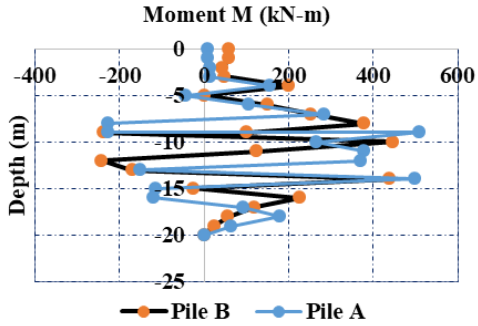

Fig. 4e: Bending moment diagram

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VI. CONCLUSION

The following conclusions have been drawn from the deep excavation analysis using secant pile wall:

1) Increasing the spacing between the secant pile wall results in increase both lateral displacement and bending moment.
2) While increasing the pile diameter (d) from 0.6 m to 0.8 m, the lateral displacement decreased and the magnitude of bending moment increased in the secant pile wall.
3) Using cap beam, reduction the values of both lateral displacement and bending moment of wall is observed, due to change in end condition of secant pile wall supporting system free to fixed at ground surface.
4) As the depth of the cap beam increases, both lateral displacement and bending moment of secant pile wall were reduced at the ground surface.
5) The analysis of excavation showed that the deformation increases as the depth of the excavation increases due to the magnitude of unbalanced force as results in the increasing stresses and deformation of secant pile wall.
6) Secant pile wall supporting system is more effective in case of sandy soil than other systems.

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