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Numerical analysis of an innovative expanding pile under static and dynamic loading

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Abstract. Designing pile foundations subjected to the uplift forces such as buildings, oil platforms, and anchors is becoming increasingly concerned. In this paper, the conceptual design of a new type of driven piles called expanding pile is presented and assessed. Some grooves have been created in the shaft of the novel pile, and some moveable arms have been designed at the pile tip. At first, static analyses using the finite element method were performed to evaluate the effectiveness of the innovative pile on the axial bearing capacity. Then its effect on seismic behavior of moment frame is considered. Results show that the expanding arms were provided an ideal anchorage system because of the soil's noticeable locking-up effect increasing uplift bearing capacity. For example at the end of the static tensile loading procedure, displacement decrement up to 55 percent is observed. In addition, comparing the uplift bearing capacity of the usual and new pile with different lengths in sand and clay layers shows noticeable effect and sharp increase up to about two times especially in longer piles. Besides, a sensible reduction in the seismic response and the stresses in the beam-column connection between 23-36 percent are achieved that ensures better seismic behavior of the structures.

Keywords: asymmetric settlements; expanding pile; static and dynamic analyses; uplift bearing capacity

1. Introduction

Piles are among the most applicable types of foundations to confront great forces, largely symmetric and asymmetric settlement of structures, and to control uplift forces. Successful experiences in using this type of foundation have given rise to their development and further use. The increment of the imposed forces and, consequently, the pile's diameter have caused particular problems in driving piles with high section sizes and the necessity of using heavy pile driving hammers. Moreover, using the group of piles near each other has caused some problems, such as the inflation of previous piles resulting from driving the new piles and reducing the pile's skin resistance. Besides, in tension loading, the situation is worse.

In many cases, such as tall buildings, sea structures exposed to frequent lateral forces (oil platforms and piers), and anchors, piles insufficiency are noticeable and could cause severe damage. In other words, the pile's performance versus tension loading is really important but sometimes neglected. For example, some researches have been done on rock-socketed piles as a common method to transfer heavy loads, especially in a mountainous area (Xing *et al.* 2021, Li *et al*. 2019). However, little attention has been paid to uplift behavior, which governs the overall performance of the foundation system. Park *et al.* (2021) investigated the rock-socketed pile under uplift load. The results showed that the characteristics of rock-socket have a significant influence on the uplift behavior of drilled shafts.

Researches show that the pile skin resistance in the tension force is sensibly less than its resistance in the pressure. Usually, 50 percent of reduction, particularly in the case of cohesionless soils, has been reported. Moreover, in the case of short piles implemented in dense clay and or piles of sea structures under frequent lateral loads, the skin resistance in the tension is not reliable and is better to be neglected (Fakher 1993). Besides, the bearing capacity of pile's tip in tension is only noticeable in the base enlarged cast-in-place piles. Naturally, it is not effective in the case of pile driving with a uniform section. In addition, the effect of the groundwater level rising on the soil pile interaction should be considered. Experimentally results show that increasing in the groundwater level causes main decrease in the uplift capacity of the piles. The variation of the submerged pile length ratio from 0 to 100 percent leads uplift capacity reduction as much as 60 percent of its initial value in dry condition (Basha and Azzam 2018). According to the above mentioned, insufficiency of tension bearing capacity of tip and skin resistance of piles, particularly in driving piles with uniform section, has caused the determination of high safety coefficients in their design (Das 2010).

Lu and Zhang (2018) performed a series of centrifuge model tests under different vertical-horizontal combined loading situations to evaluate the combined loads' mechanism on the piles' response in the sand. In addition, the bearing capacity of deep foundations exposed to tension

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forces was evaluated by Nakai *et al*. (2010). The lab results conformity and finite element analyses indicated the relative insufficiency of these piles type under tension forces and occurring large displacement. In another study, Lin and Jiang (2019) investigated the suitability of the existing methods in design manuals, such as FHWA and API, and their proposed analytical solution for estimating the tension capacity of piles. They compared the methods with the results obtained from the finite element analyses considering different scour conditions. In another study, the uplift capacity of single piles and pile groups embedded in cohesionless soil is evaluated by Gaaver (2013) with experimental tests on steel pile samples. The study shows that single piles' behavior under uplift loading depends deeply on both the pile embedment depth to diameter ratio and the soil properties. Moreover, an empirical equation is suggested to reveal the force-displacement relationships of single piles embedded in sandy soil under uplift loading. Faizi *et al.* (2015) evaluated the deformation model of sand around short piles under pullout test through small-scale physical tests and numerical modeling using ABAQUS software. It was found that the slenderness ratio is the most influential factor on the pile uplift capacity obtained by experiments. In addition, an acceptable error ranged by 0.6%, and 11% is observed between the measured bearing capacities obtained by experiments and the numerical modeling results, which proves that the ABAQUS software can simulate the behavior of the experimental tests with a suitable degree of accuracy. In another study related to the lateral forces' effect on offshore structures, Nazir and Nasr (2013) presented a testing program comprising 62 pullout tests. Results indicate that the pullout capacity of a batter pile constructed in dense or medium-density sand increases with the increase of batter angle attains maximum value on 20° and then decreases. In contrast, the pullout capacity for batter pile constructed in loose sand decreases with the increase of pile inclination. The results also indicated that the circular pile is more resistant to pullout forces than the square and rectangular-shaped pile.

The belled and helical piles have been used to resist the tension force for a long time. Based on the experimental tests, Wang *et al.* (2020) proposed a simple theoretical method that calculates the uplift capacity of helical piles installed by torque and compression. Moreover, Sakr *et al.* (2020) proposed a novel recent technique called anchor winged piles to improve the pile's uplift capacity. The results of sixty experimental models showed that such wings at the tip of the mono-pile provided a suitable anchorage system. Also, Azzam and Elwakil (2017) introduced finned pile. Results show that four fins welded at the bottom of a pile provided an appropriate anchorage system because of the considerable locking-up effect of the soils within the fins, resulting enhancement of uplift capacity.

Considering all problems resulting from driving piles with high section level and weakness of pile's tension bearing capacity, finding new methods to confront this deficiency seems necessary.

In this study, an innovative expanding pile is proposed. This pile consists of a grooved main shaft, internal and external expanding telescopic arms, arms' opening mechanical equipment, pile tip, etc. The details of different parts of the pile and the arms' opening mechanism are presented in forthcoming sections. A finite element model of the pile and surrounding soil is developed and the pile performance is evaluated by static and dynamic numerical analyses. The results are compared with those of a usual pile.

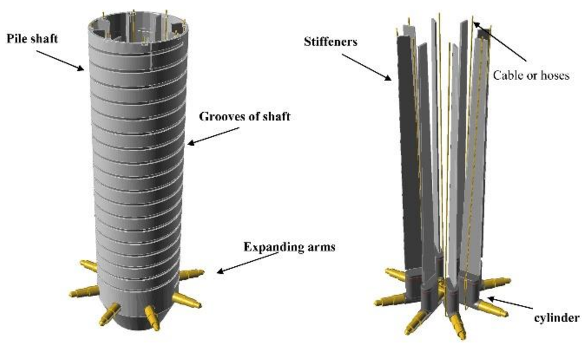


Fig. 1 Inside and outside view of the innovative expanding pile

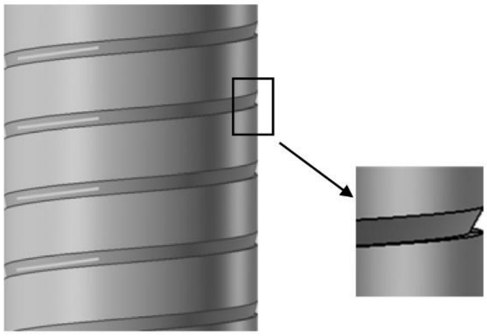


Fig. 2 Pile shaft and design of friction grooves and drain gap

2. Details of the innovative expanding pile

Inside and outside views of the innovative expanding pile are shown in Fig. 1. The details and different parts of the pile and each part's function are described in this section.

2.1 Pile's shaft

As shown in Fig. 2, spiral grooves are designed on the pile shaft whose primary duties are to create further friction with soil and increase the skin resistance and pullout capacity. As shown in the figure, the grooves' shape is such that while creating more friction with soil and increasing the skin resistance against the tension force, they do not make any resistance against penetration of the pile. Besides, creating the drainage property in the pile makes it possible to design specific grooves' gaps. The dimensions of the gap are essential, and decrement of pile stiffness should be considered in their design.

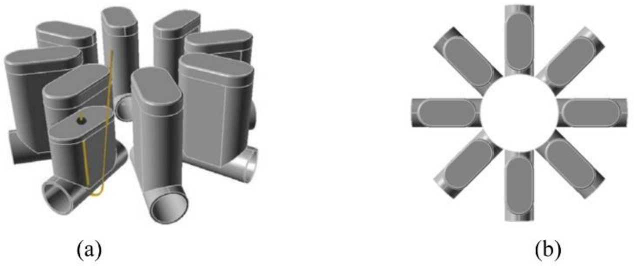


Fig. 3 (a) Perspective and (b) plan of cylinders

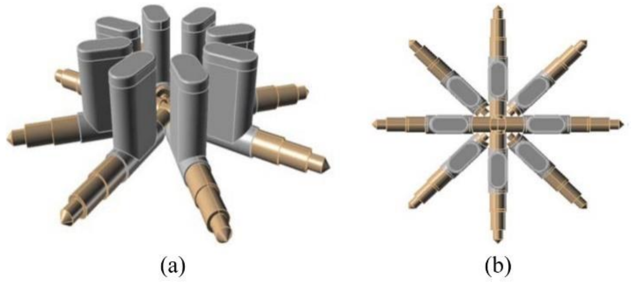


Fig. 4 (a) Perspective and (b) plan of expanding telescopic arms

Considering the possibility of placing the pile in loose saturated sand soils susceptible to liquefaction, reducing the liquefaction potential of these soils type by reducing water pressure and increasing the effective stresses are provided. It is noticeable that the necessity of devising or not devising these grooves and their step and dimension will be specified after performing geotechnical tests and identifying soil type. In the case of loose collapsing soils, it is necessary to consider the effect of the negative skin friction increment resulting from clays' sudden fall under dynamical forces.

2.2 Cylinder and pistons

There are particular cylinders inside the pile pit that, with the application of tension forces through cables connected to them or the application of pressure by compressor set and condensation of oil inside them, afford the gradual opening of inside and outside expanding arms (Fig. 3). The forces imposed on the walls of cylinders and the rate of forces applied on pistons are among the factors affecting the design of the thickness of cylinders' walls.

2.3 Internal and external expanding telescopic arms

There is no doubt that the arms are the most significant parts of the expanding pile, and their design is so important. It is such that in addition to the possibility of expanding, they should be sufficiently resistant to bear the imposed stresses (Fig. 4).

The arms' primary duty is to increase the effective sectional area of the pile and make the involvement of pile with soil through penetration in the soils around the pile. Besides, internal arms can be designed to increase the tension bearing capacity of the pile.

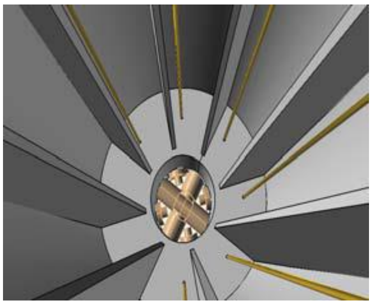


Fig. 5 Using the potential of soil volume inside the pile shaft after closing the internal arms to increase the tension bearing capacity

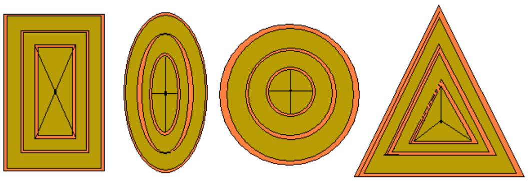


Fig. 6 Different possible sections of expanding telescopic arms concerning the geotechnical conditions and requirement bearing capacity

The expansion of internal arms and confinement of the soil volume inside the pile shaft will be a beneficial factor, especially in large diameter and long piles that inside soil volume is noticeable in reducing the pile's displacement in facing tension forces (Fig. 5). The shape, number, and size of the arms are changeable per the geotechnical situation, calculation of forces imposed on the arms, and their behavior in circular, rectangular, triangular, and elliptical sections (Fig. 6).

2.4 Cables and hoses

In order to transfer forces from tensile jacks into pistons up to the final opening of arms, some cables are devised. Cables pass through cylinders and are connected to their movable pistons inside them (Figs. 7 and 8).

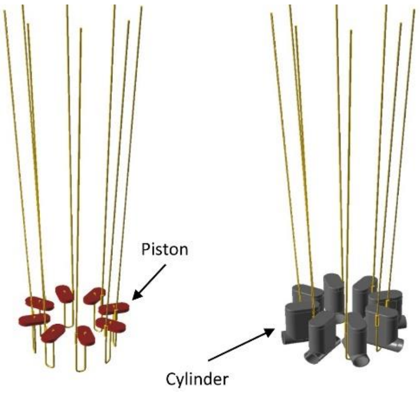


Fig. 7 Passing cables through cylinders and connection to pistons

Fig. 8 Application of tension forces through tensile jacks into cables connected to pistons results in opening the arms

Fig. 9 Application of pressure forces by compressor to expand arms

The down part of the cylinder will be like a support converting cable tension forces into compression imposed on pistons. Imposed forces, soil density, and embedment depth of the pile are among the effective parameters that should be considered in cable size selection. There is a possibility of replacing the cables with resistant hoses connected to a compressor to provide the required compression forces (Fig. 9).

2.5 Stiffeners

In order to provide sufficient stiffness for the pile shaft to prevent damage on cylinders and pile tip while driving, some stiffeners are devised on the internal shaft of the pile (Fig. 10). The concentration of these stiffeners is mainly in the pile tip's internal area and around the cylinders. The rate of applied forces through pile driving hammer and forces imposed by tensile jacks or the compressor is noticed for designing their dimensions and thickness.

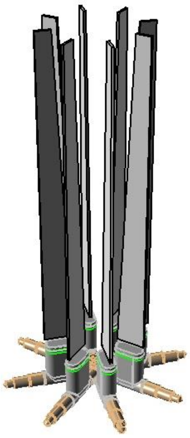
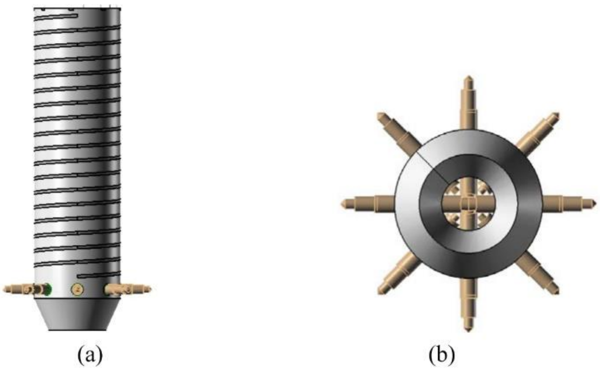


Fig. 10 Internal stiffeners to prevent damage on cylinders



(a) (b)

Fig. 11 (a) Side view and (b) plan of pile tip

Fig. 12 Indicator of the rate of arms expansion

2.6 Pile tip

The proper design of pile tip angle is of great importance since it directly affects the required forces' rate to drive the pile and place it in proper depth and direction. The special sloping design of the pile tip provides the possibility of devising all cylinders and arms in this part. Moreover, it provides proper penetration of the pile, and will be no need to heavier pile driving hammers (Fig. 11).

2.7 Arms expansion Indicator

Among the possible problems during the procedure of arms opening, there is a possibility of being hit with rock or

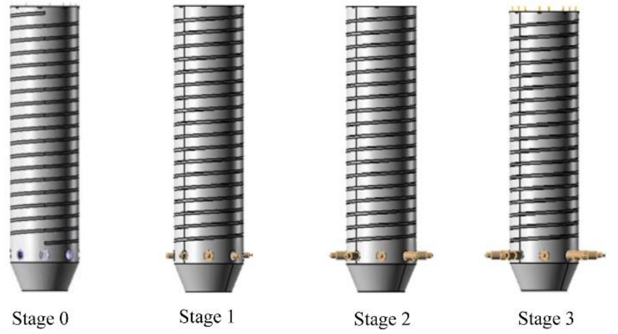


Fig. 13 Different stages of the gradual opening of arms

stone pieces and possible failure of the arms as due to imposed stresses. Therefore, to evaluate the rate of opening of each arm and adapt the authenticity of calculations made in determining the bearing capacity of each pile, several force meters may be connected to each arm. With the gradual expansion of the arms, the rate of applied forces on each of the force meters indicates the rate of expanding each arm (Fig. 12). In addition, there will be a possibility to employ other proper sensors to determine arms' position.

3. Mechanism of expanding pile

As shown in Fig. 13, the design of expanding pile is such that in the beginning, all telescopic arms are inside the container of pile tip and do not make any prevention in pile driving. In order to open the arms, two mechanisms have been considered:

(a) After placement of pile in proper depth, with the application of tension force to the cables by tensile jacks similar to the application of post-tensioning in post-tensioned concrete, the stage of arms opening will start. By devising supports under cylinders, the upward tensile force in cables will afford downward compression force in pistons and the gradual opening of the arms.

(b) The application of pressure on pistons by compressor set. The advantage of the second method is creating a strike in arms due to the increase and decrease of compressor pressure by its operator. Drilling and forward movement of the arms in the soil will be done easier in this mechanism due to performing strike and pressure together. The opening of arms starts from the most inner member, which is the smallest part, and will continue to open all of them.

In the end, by observing the force meter's indicator, the rate of expansion of each arm will be evaluated, and we will be able to make precise control of pile bearing capacity.

4. Developed finite element model and loading specifications

In this section, innovative expanding pile's performance is assessed through the finite element method using ABAQUS software. Since this article's primary purpose is to introduce this new pile, only numerical studies are performed, and experimental studies are not addressed herein and can be considered future work.

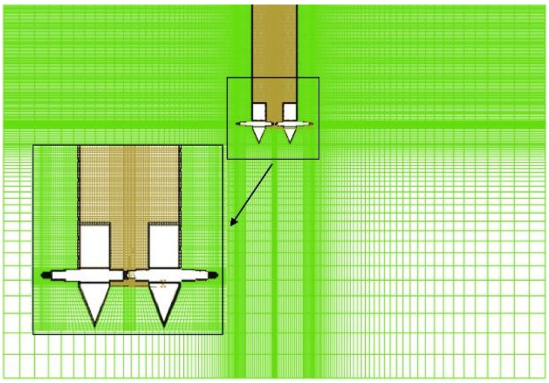


Fig. 14 Mesh used in pile-soil model

The finite element model of pile-soil-structure is developed using 4-node rectangular elements. A rectangular medium of 15 by 20 m is considered, including the pile at the middle. In this medium, the size of elements gradually increases, moving toward the boundaries. The mesh size is optimized to achieve reliable results. The mesh was refined at the high-stress gradient region near the pile and gradually became coarser away from the pile in both directions, as shown in Fig. 14. The size of elements varies from 0.025 m to 0.5 m in horizontal and from 0.025 m to 0.7 m in vertical directions.

Besides, simple two-node wire elements having three degrees of freedom are used to model a one bay 15 story frame on the pile. The frame, together with its elements' specifications and loading, is shown in Fig. 15.

The specifications of the materials and expanding pile used in the analyses are presented in Tables 1 and 2. The soil properties are according to the Das (2010).

Static and dynamic analyses are performed to evaluate the pile's behavior. In each case, an expanding pile and its corresponding usual pile with the same length and diameter without expanding arms are considered. The static analyses were performed in two parts. At first, tensile and compressive load of 100 tons is applied to the piles and the displacements of the piles are obtained. After ensuring positive performance of expanding arms versus tension & compression loading in the next part, the uplift bearing capacities of the new and usual pile with different lengths in sand and clay layers are compared with each other. In the dynamic case, time history analyses are performed by using the longitudinal components of the 1971 San Fernando earthquake, 2003 Bam earthquake, and 2002 Zarand earthquake with PGAs equal to 0.3 g, 0.35 g, and 0.43 g, respectively, applied at the bottom boundary. The selected records have various peak ground accelerations, magnitudes and frequency contents that result comprehensive research on seismic behavior of new pile. In the dynamic analyses, the pile is first statically loaded to simulate the reaction from the weight of the structure and the resulting settlements obtained. Then, with the application of the

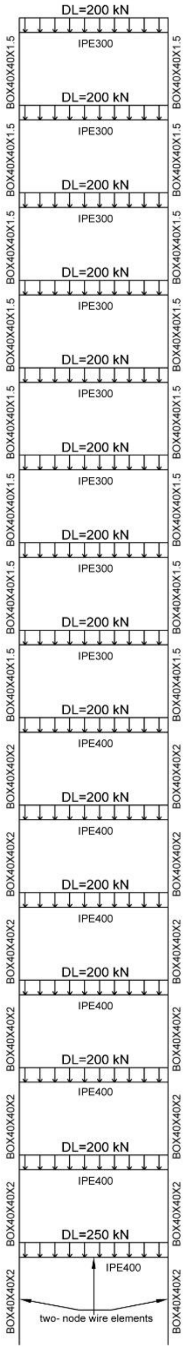


Fig. 15 Specifications of the 15 stories building model

mentioned accelerograms, the maximum stresses in the frame's connections and horizontal displacements are calculated.

The normal and tangential interaction between contacting soil-pile surfaces are considered. The surface to surface contact method is used at the soil-pile interface to permit separation between them in compression and tension forces near the pile. These surfaces are called master-slave surfaces and contact pair that is well discussed in ABAQUS manual (2010). The bottom boundary of the model is taken 10 m below the tip of the pile to ensure that the free field behavior of the pile is not influenced by the boundaries.

Table 1 Specifications of the materials used

Material	Elasticity modulus (MPa)	Density (kg/m3)	Poisson coefficient	Cohesion of soil (MPa)	Friction angle ϕ (º)
Soil	11.4	1700	0.3	0.08	35
Steel	2.06×10^5	7850	0.3	-	-

Table 2 Specifications of expanding pile

Pile length (m)	Pile diameter (m)	Number of arms	Length of arms (cm)	Arms diameter (cm) (External to internal)
5	1.5	8	70	20-15-10

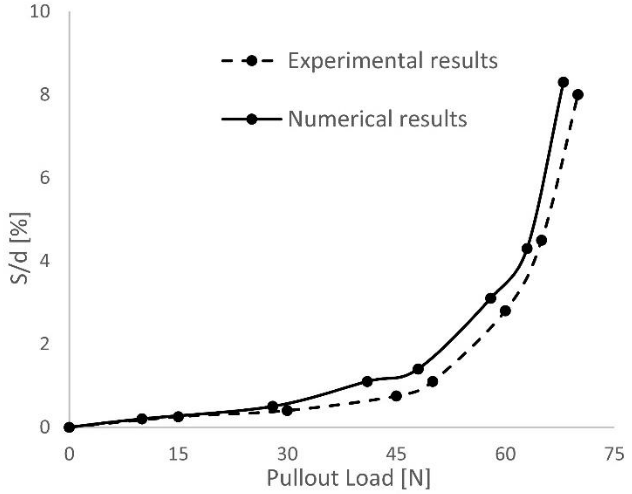


Fig. 16 Load displacement curve

Moreover, a nodal damping coefficient is used at lateral exterior nodes to prevent seismic waves' reflections back to the system from the boundaries. The side boundaries are constrained against horizontal displacement, and the bottom boundary is constrained vertically. The soil is modeled with the well-known Drucker-Prager elasto-plasticity constitutive model, and the pile is treated as an elastic material. As a comparison, all conditions in both usual and expanding pile models are the same.

5. Verification with experimental results

A simple circular hollow pile is modeled according to Nazir and Nasr (2013) tests under axial pullout loading to verify the modeling. The sample is considered to be made of mild steel hollow pipes with 25, 375, and 1.5 mm for outside diameter, length, and thickness, respectively. Also, the pile is modelled in medium-sized dried and washed loose sand with a dry unit weight of 14.15 kN/m3 and loaded in vertical direction. As shown in Fig. 16, a suitable agreement between the experimental and numerical results is observable. (s and d are the displacement and the diameter of the pile, respectively).

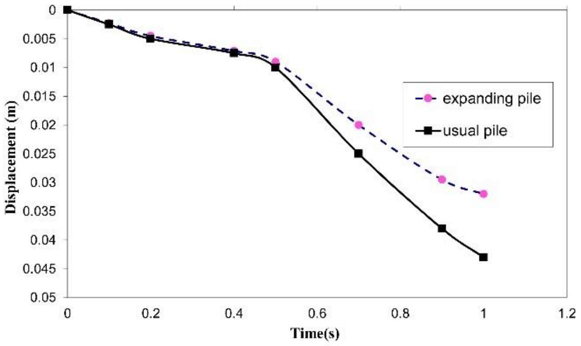


Fig. 17 Structure settlement under static compressive loading

6. Numerical results

6-1 Static tensile and compressive loading

The settlements of the structures under static loads are obtained. As shown in Fig. 17, the expanding pile has an ideal influence on reducing the rate of structure's settlement under static loads. For instance, at the end of the loading procedure, a settlement decrement of about 26 percent can be observed. This is especially much more desirable in structures sensitive to asymmetric settlements, e.g., petrochemical reservoirs with moveable ceilings and moment frame structures. As a result, secondary stresses caused by asymmetric settlement could be considerably reduced.

Fig. 18 shows the contour of the total displacement of the soil around the vertically loaded compression pile. As seen, the sediment displacement is continuous along the pile, and the displacement zone gets enlarged with increasing the pile-top displacement.

The undeniable role of external expanding arms in increasing pile's effective section to confront structure settlements and excessive displacement under lateral forces and the establishment of sufficient restraint of pile with surrounding soil is very noticeable. Moreover, soil weight inside the pile after closing the internal arms can be considered a factor to increase the pile's tension bearing capacity. The considerable displacement reduction of the structure under static tensile loading up to 55 percent reveals this favorable capability. (Fig. 19).

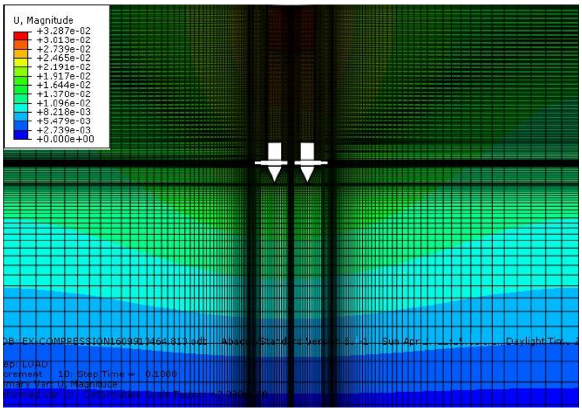


Fig. 18 Displacement contour of the model around the vertically loaded compression pile

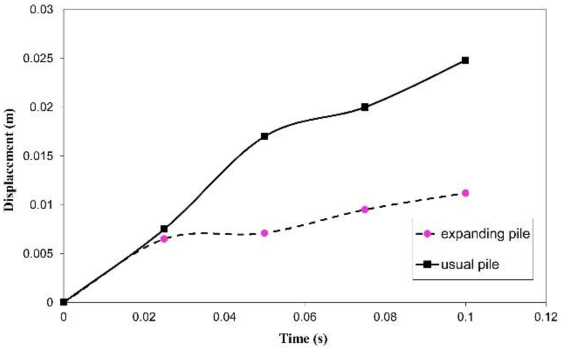


Fig. 19 Displacement of the base of the structure under static tensile loading

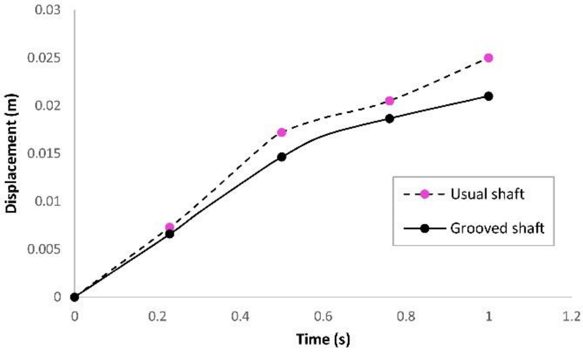


Fig. 20 Displacement of the usual and grooved shaft under tensile loading

Table 3 Maximum displacements of the pile in static loading

Load	Maximum displacement (cm)		Displacement decrement (%)
	Expanding pile	Usual pile	
Compressive	3.2	4.3	26
Tensile	1.12	2.48	55

Considering the sensible reduction of skin resistance of ordinary piles against tension, it seems that the grooved shaft of the expanding pile affords the increase of soil and pile friction coefficient and uplift load capacity without resisting against the penetration of the pile while pile driving. So, hollow pile with usaual shaft and grooved shaft (without expanding arms) modeled and their performance under static tensile loading compared with each others. As shown in Fig. 20, the grooved shaft in tension loading increased the skin resistance, and the displacement is decreased about 15 percent. Of course, the parameters such as soil specifications, pile length, groove size, and step affect the impact.

Regarding the soil type, geotechnical studies, and the possibility of liquefaction in saturated loose sand soils, by devising specific gaps inside the grooves, the drainage capability of these types of soils and the reduction of their liquefaction potential can be provided.

Table 4 Properties of the pile and soil layers

Soil	Thickness (m)	Pile length (m)	Pile diameter (m)				Cohesion (MPa)	Friction angle ϕ (°)
			Expanding		Usual			
			D_s	D_b	D_s	D_b		
clay	15	4~12	1	1.4	1	1	0.08	0
sand	15	4~12					0	35

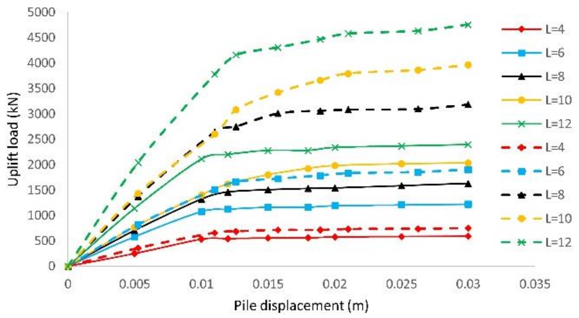


Fig. 21 Comparison of new pile (dotted) and usual pile (solid) uplift load-displacement curves in sand

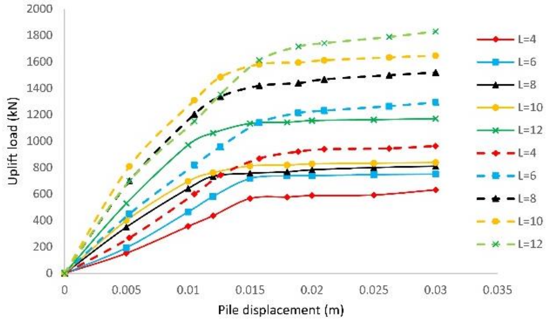


Fig. 22 Comparison of the novel pile (dotted) and usual pile (solid) uplift load-displacement curves in clay

According to the results presented in Table 3, settlement decrements are achieved about 26 and 55 percent due to static compressive and tensile loading, respectively.

6.2 Uplift bearing capacity

Soil properties, pile length, and length to diameter ratio have the main effects on uplift capacity. In this part, the uplift bearing capacity of the usual and new pile with different lengths from 4 to 12 m in sand and clay layers under vertical loading is compared. The model specifications are presented in Table 4, while Ds and Db are the shaft diameter and enlarged base diameter (by expanding arms) of the pile, respectively.

Figs. 21 and 22 show the variation of single tension piles' uplift bearing capacity for various values of pile length in sand and clay, respectively. As can be seen, expanding pile has a noticeable effect on increasing the uplift bearing capacity in both sand and clay material in all samples. For example, uplift bearing capacity of new 12 m pile increased sharply about 1.99 times of usual pile in sand layer, while this amount reached to 1.83 in clay soil.

Table 5 Uplift load in the sand layer

Pile length (m)	Uplift load (kN)		Uplift ratio Expanding/Normal
	Expanding pile	Usual pile	
4	752	591	1.27
6	1911	1215	1.57
8	3175	1650	1.92
10	3970	2025	1.96
12	4463	2241	1.99

Table 6 Uplift load in clay layer

Pile length (m)	Uplift load (kN)		Uplift ratio Expanding/Usual
	Expanding pile	Usual pile	
4	963	632	1.52
6	1292	751	1.72
8	1524	813	1.87
10	1646	890	1.85
12	1715	935	1.83

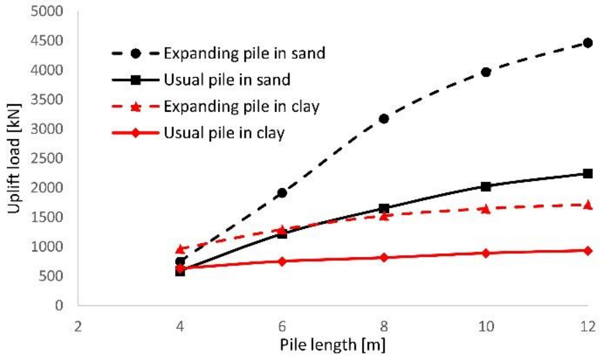


Fig. 23 Variation of uplift load for different pile length

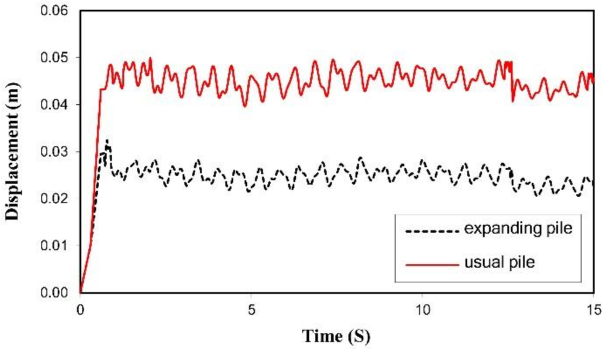


Fig. 24 Vertical column displacement in the 15-storey structure under San Fernando accelerogram

As presented in Tables 5 and 6, in longer piles, the effect of the new pile is much more noticeable, and the uplift capacity increases sharply up to about two times. On the other hand, as shown in Fig. 23, increasing the length of the pile in shorter lengths has a steep slope and increases rapidly, while at long samples the trend is much smoother. For example, from 4 to 6 m length change in the sand layer, the loading capacity of expanding pile increases about 61%,

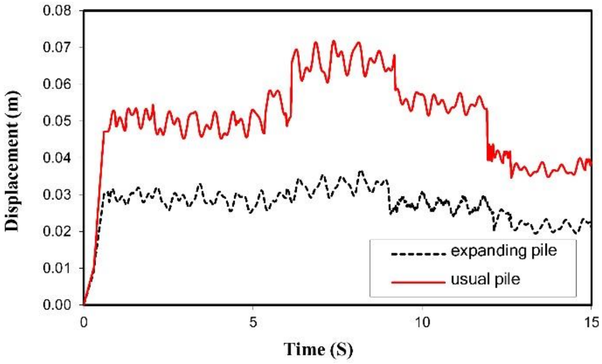


Fig. 25 Vertical column displacement in 15-storey structure under Bam accelerogram

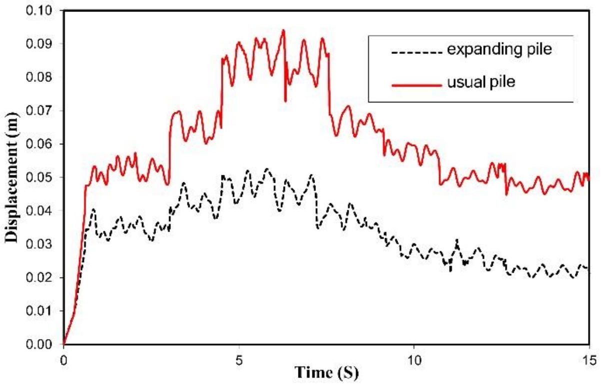


Fig. 26 Vertical column displacement in the 15 storey structure under Zarand accelerogram

Table 7 Comparing maximum stresses in the connections under seismic loading

Accelerogram	Maximum stresses (MPa)		Stress decrement (%)
	Expanding pile	Usual pile	
San Fernando	36.2	126	71
Bam	96.5	288.7	67
Zarand	211.5	365.8	42

but in length change from 10 to 12 m, only 11% increase is visible. For the same usual pile, the amount of 51% and 10% is calculated, respectively.

6.3 Dynamic analyses

As shown in Figs. 24 to 26, the results of time history analyses under seismic excitation indicate the proper influence of expanding pile in reducing the structure displacement under seismic loading. Settlement decrements are achieved about 23, 36 and 34 percent respectively for san fernando, bam and zarand earthquakes.

Besides, comparing the amount of maximum stresses at the beam to column connections in the whole model shows the expanding pile's positive effect in reducing stresses in beam-column connection between 42-71 percent depending on the earthquake specifications (Table 7). This noticeable stress reduction in the connections, particularly in the moment frames, reduces the probability of crack occurrence and results in better behavior of the structure in intensive earthquakes. Besides, maximum pile settlements or, in other words, maximum vertical displacement of the structures in dynamic loading are presented in Table 8.

Table 8 Maximum displacements of the structure in dynamic loading

Accelerogram	Maximum settlement (cm)		Settlement decrement (%)
	Expanding pile	Usual pile	
San Fernando	3.84	5.01	23
Bam	4.67	7.3	36
Zarand	6.05	9.2	34

In all models especially in tension static loading and seismic analyses, stress concentration on the arms to pile connections is visible. So, arms excessive deformation or rupture are possible failure modes of the pile that should be noted in designing process.

7. Conclusions

In this paper, the design of an innovative expanding pile is presented. The effects of implementing the pile on the structural responses under static and dynamic forces are evaluated. The results of this research summarized as:

- Reduction of structural displacement under static loading resulting from driving these kinds of piles indicates new pile's capability in confronting structures settlements. For instance, a settlement decrement of about 26 percent can be observed in the model.
- The increase of the effective pile tip section increases the bearing capability of the pile tip under tension forces as well as increasing the lateral bearing capacity of the pile. Especially in longer piles, the effect of the new pile is much more noticeable, and the uplift capacity increases sharply up to about two times.
- 42-71 percent reduction of Von Mises stresses in the moment frame structure built on the new pile and reducing 23-34 percent asymmetrical settlements guarantees a greater ductile behavior of the structure under severe earthquakes and improves the seismic performance of the structures.
- Due to the proper performance of the new pile, it can be used as a suitable option along with other methods like belled, helical and finned piles. Designing the length and diameter of the arms according to the required resistance and providing an ideal anchorage system because of the soil's noticeable locking-up effect to increase uplift bearing capacity are the advantages of new pile. Although, it seems more expensive especially in case of short piles.
- The drainage capability of loose saturated sandy soils and susceptible to liquefaction, concerning the possibility of creating gaps inside the grooves of the pile's shaft, will increase the efficiency of these types of piles and simultaneous usage of them as drain piles.

- Regarding the similarity of using the cable and tensile jacks in the first arms' opening mechanism with the stage of post-tensioning in the post-tensioned concrete, the parameters such as required tension forces and cables diameter can be calculated by a similar method. In the second arms' opening mechanism, using a compressor set to apply pressure on pistons to open arms is another suitable approach. It provides the possibility of applying pressure and strike simultaneously. Therefore, considering the more advantages and reliability of the latter mechanism, using a compressor is preferred and recommended compared with the first method, i.e., the use of cables.

At the end it should be mentioned that the main purpose of this article is introducing this new pile, different parts and it's possible performance. So, authors believe of course supplimentary analyses considering different soil properties, sensitivity analyses to achieve optimum dimension of arms, length to diameter ratio, groove specification and more experimental studies can be considered as future works. even full scale laboratory test to delete the small-scale factor because of the differences in stress level between the prototype tests and field tests to recognize the real performance of new pile in different soil is necessary.

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