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Numerical Assessment of Squeezed Branch Pile in Silty Clay Soil

R. P. Bhujade, A. I. Dhatrak, S. W. Thakare

***Abstract:** Squeezed Branch Pile is derived on the basis of caste in place concrete pile. It has one or more branches along the pile shaft at design depth. Squeezed branch piles are often used in high rise building, transmission tower and in other pile foundations where anticipated uplift or vertical load may cause failure. This pile is one of the excellent options of pile foundation for soft soil and silty soil. The behaviour of Squeezed Branch pile is difficult to explain using simple pile-soil theories or two dimensional numerical analyses because of complicated geometry of pile.In the present numerical analysis, a 3D pile-soil model of conventional circular pile and squeezed branch pile foundations are analysed using MIDAS GTS NX finite element software to find out effectiveness of squeezed branch pile over conventional pile. The aim is to study the performance of Squeezed Branch Pile foundation in silty clay with respect to various parameters such as types of loading, branch diameter, branch spacing and number of branches. Analysis shows that the squeezed branch pile has higher vertical, lateral and uplift load capacity as compared to conventional pile.*

Keywords- Squeezed branch pile, ultimate load capacity, MIDAS GTS NX software, Vertical and Uplift loading.

I. INTRODUCTION

Pile foundation is considered as one of the widely used foundation technique when it comes to soft soil, which has huge problem of low bearing capacity, excessive and differential settlement. The squeezed branch pile is developed from conventional circular pile, it has one or more enlarged part (branch) along the pile shaft.Based on conventional intellection, many new techniques of pile foundation have been developed by changing cross section of conventional pile, providing multi-section to pile for more efficient foundation at lower cost. The squeezed branch pile is construction modification ofpile in which cavities for branches is formed by tightly squeezing of surrounding soil laterally without digging the soil. It achieves pile capacities more than that of conventional piles.The branches of pile not only increase the surface area of pile but also utilises the soil present around and under the branches to transmit the load. Squeezed branch pileeffectively decreases the settlement and cost of construction of pile because of unique load sharing mechanism Full scale field load test was carried out on squeezed branch pile to determine the bearing capacity and interaction law between soil and pile.Load shared by branch and plates were greater than that of the straight part and pile toe [1]. Applied bearing force was first shared by first disk. Once it reached to maximum limit the remaining load was shifted to second disk to compensate and balance the actionof load [2]. The three-dimensional numerical analysiswas conducted on squeezed branch pile to evaluate bearing responses of squeezed branch pile[3,4]. From the study it was concluded that as the distance of plate position increased from top, the lateral bearing capacity of pile was reduced.

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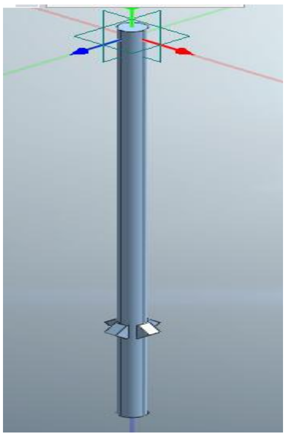
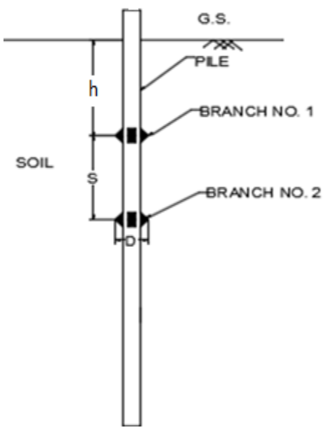
* Correspondence Author
Dr. A. I. Dhatrak*, Associate Professor, Department of Civil Engineering, Government College of Engineering, Amravati, India.
R. P. Bhujade Department of Civil Engineering, Sant Gadge Baba Amravati, University, India.
S. W. Thakare, Associate professor, Department of civil Engineering, Government college of Engineering, Jalgaon, India.

II. METHODOLOGY

The behaviour of conventional circular pile and squeezed branch pile was analysed using MIDAS GTS NX finite element software. To govern the soil behaviour, soil was modelled as Mohr-coulomb model. The pile was modelled as a linearly elastic perfectly plastic model. The dimensions of soil model were 100 m × 100 m × 100 m. The geometry of three-dimensional model of pile and section of squeezed branch pile considered for analysis is shown in Fig 1. The properties assigned to pileand soil are shown in following Table I and II respectively.

(a) (b)

Fig.1: (a) The three-dimensional view of squeezed branch pile, (b) Schematic diagram of squeezed branch pile for proposed analysis

Table I: Properties assigned to the pile

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	**E**	27386127	kN/m^2
2	Poisson's ratio	**υ**	0.2	-
3	Density	**γ**	24	kN/m^3

III. NUMERICAL ANALYSIS

The analysis was conducted on a three-dimensional finite element model pile foundation. Analysis was carried out to evaluate the performance of squeezed branch pile and conventional circular pile embedded in silty clay. The varied parameters were types of loading, branch diameter, branch spacing and number of branches. Shaft diameter and length of pile were kept constant.Details of parameters selected for analysis is given in Table III.

Table II: Properties assigned to the soil [7]

Properties	Unit weight	Young's modulus	Poisson's ratio	Angle of internal friction	Cohesion
Symbol	**γ**	**E**	**Y**	**Ǿ**	**C**
Unit	kN/m^3	kPa	-	Degree	KPa
Silty clay	18	20000	0.4	20	22

Table III: Details of constant and varying parameters

Sr. No.	Details of Parameter	Constant Parameter	Varying Parameter
1	Length of pile (L)	15 m	
2	Diameter of shaft (d)	0.7 m	
3	Length of branch (l)	0.7 m	
4	Width of branch (b)	0.35m	
5	Type of Loading	-	i. Vertical Loading ii. Lateral Loading iii. Uplift Loading
6	Number of Piles (N)	-	i. Single pile ii. Pile group with 3, 4, 5 and 6 piles
7	Branch Position ratio (h / L)	-	0.20, 0.38, 0.56, 0.74, 0.92
8	Branch Spacing ratio (S / D)	-	1.5, 2, 2.5, 3, 3.5
9	Branch Diameter ratio (D/d)	-	1.5, 2, 2.5, 3
10	Branch Number	-	1, 2, 3
11	Spacing between piles (s)	-	3D

IV. RESULTS AND DISCUSSION

The analysis was conducted on single squeezed branch pile and conventional circular pile subjected to vertical load, uplift load and lateral load in silty clay. The load settlement /displacement curves for conventional circular pile, squeezed branch pile with different branch diameter, branch position, branch spacing and number of branches are shown in Fig 1 to Fig 6 respectively. The ultimate load capacity for conventional pile and squeezed branch pile are taken as per provision of IS: 2911 (Part -4) 1985.

The ultimate vertical, lateral and uplift load capacities of conventional circular pile is given in Table IV. A load settlement / displacement curve for conventional circular pile subjected to vertical load isshown in Fig. 2.

Table IV: Ultimate load capacities of conventional pile

Type of Loading	Ultimate load capacity (kN)
Vertical Loading	1481

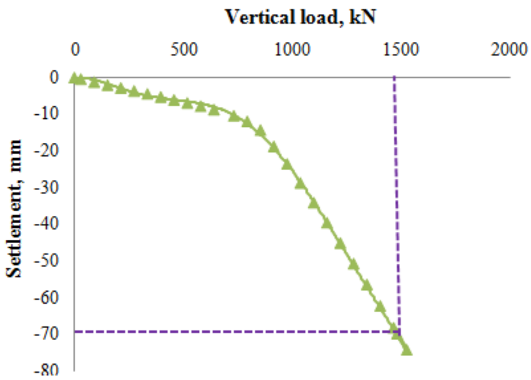


Fig. 2: Load settlement curve for conventional pile subjected to Vertical load

Ultimate vertical load capacities of squeezed branch pile with different branch diameters are shown in Table V.Fig. 3 showsload settlement curves for squeezed branch pile with different branch diameters.

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Table V: Ultimate Vertical Load Capacities of squeezed branch pile with different branch diameter ratio

Branch diameter ratio	D/d = 1.5	D/d = 2	D/d = 2.5
Ultimate Vertical load capacity (kN)	2577	2814	3193

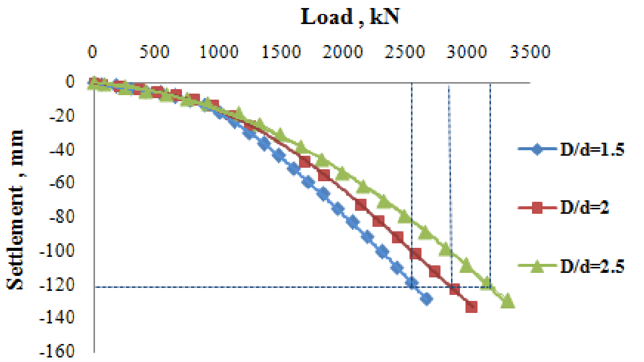


Fig. 3: Load settlement curve for squeezed branch pile with different branch diameters

From the above results, it was observed that the ultimate load capacity of squeezed branch pile increased with the increase in branch diameter. The maximum ultimate load capacity of squeezed branch pile was obtained at the branch diameter ratio equal to (D / d) = 2.5.

Ultimate vertical load capacities of squeezed branch pile with different branch positions are shown in Table VI.Fig. 4 showsload settlement curves for squeezed branch pile with different branch positions.

Table VI: Ultimate Vertical Load Capacities of squeezed branch pile with different branch positions

Position ratio	Ultimate Vertical load capacity (kN)
h / L = 0.20	3195
h / L =0.37	3198
h / L = 0.54	3307
h / L = 0.70	3400
h / L =0.87	2888

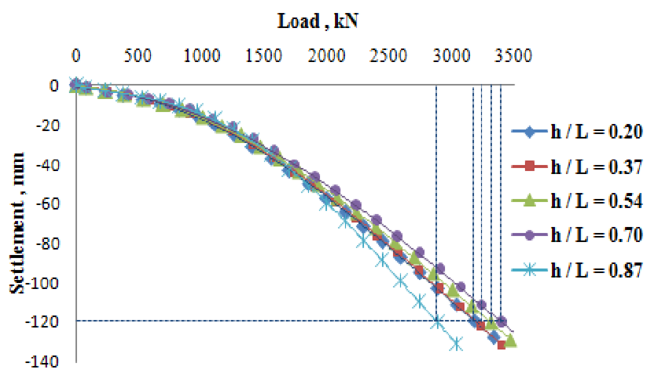


Fig. 4:Load settlement curve for squeezed branch pile with different branch positions

From the above results, it was observed that the ultimate load capacity of squeezed branch pile increased with the depth of branch position up to a certain point and decreases further. Therefore the maximum ultimate load capacity of squeezed branch pile was obtained at the branch position ratio equal to h/L= 0.70.

Ultimate vertical load capacities of squeezed branch pile with different branch spacing are shown in Table VII.Fig. 5 showsload settlement curves for squeezed branch pile with different branch spacing.

Table VII:Ultimate vertical Load Capacities of squeezed branch pile with different branch spacing ratio

Branch spacing ratio	Ultimate Vertical load capacity (kN)
S / D = 2.0	3386
S / D = 2.5	3430
S / D = 3.0	4157
S / D = 3.5	3647

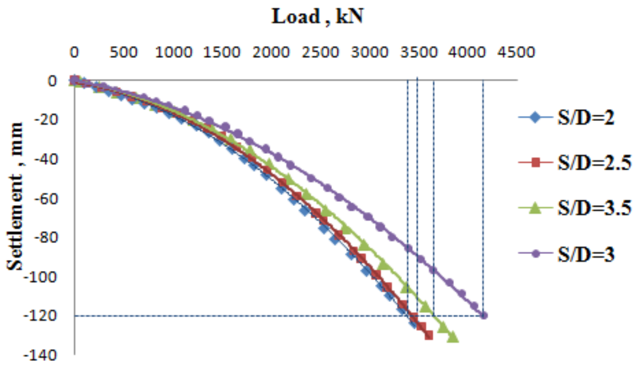


Fig. 5:Load settlement curve for squeezed branch pile with different branch spacing

From the above results, it was observed that the vertical load capacity of squeezed branch pile increased with increase in branch spacing between two branches up to branch spacing ratio S/D = 3, after that ultimate load capacity reduced with further increase in branch spacing. Therefore, analysis of group of double branch squeezed branch piles for ultimate load capacities, pullout capacities and lateral capacities were carried out by keeping spacing ratio S / D = 3 constant. Ultimate vertical load capacities of squeezed branch pile with different branch spacing shown in table VIII.Fig. 6 showsload settlement curves for squeezed branch pile with different number of branch.

Table VIII: Ultimate vertical Load Capacities of squeezed branch pile with different number of branch

Number of branches	Ultimate Vertical load capacity (kN)
Single branch	3400
Double branch	4157
Triple branch	3427

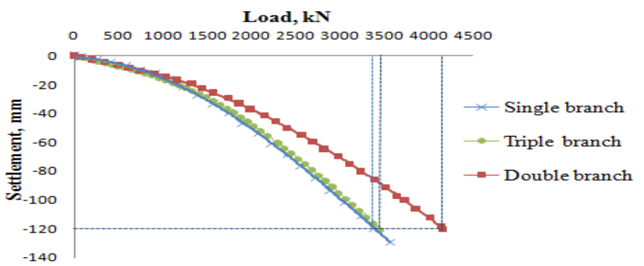
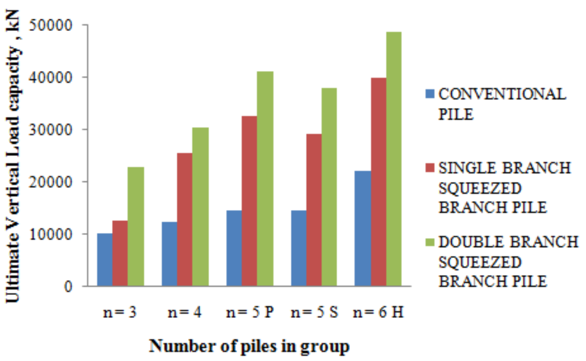


Fig. 6:Load settlement curve for squeezed branch pile with different number of branches

The ultimate load carrying capacity of double branch pile was more than that of single branch pile and triple branch pile when compared to conventional circular pile of same surface area. Vertical, lateral and uplift load analysis were also carried out on squeezed branch pile and conventional circular pile with number of piles equal to 3 (in triangular arrangement), 4 (in square arrangement), 5 (in pentagonal arrangement and square arrangement with one pile at centre), 6 (in hexagonal arrangement and two row arrangement). Table IX shows the ultimate load capacities of group of conventional circular pile and squeezed branch pile.

Ultimate capacities of group of conventional circular pile and squeezed branch pile are represented in the form of bar charts as shown in Fig. 7.



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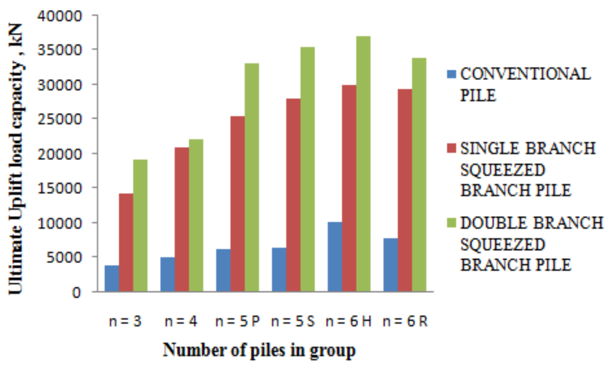

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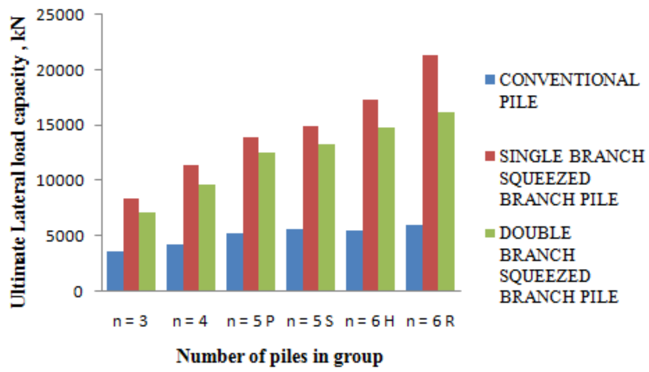

(c)

Fig.7: Ultimate load capacities of squeezed branch pile groups with different numbers of piles in group (a) Ultimate vertical load capacities, (b) Ultimate uplift load capacities, and (c) Ultimate lateral load capacities

Table IX: Ultimate load capacities of group of conventional circular pile and squeezed branch pile under different conditions

Types of pile group	Ultimate load capacity (kN)			Ultimate uplift load capacity (kN)			Ultimate lateral load capacity (kN)		
	Circular pile	Single branch squeezed branch pile	Double branch squeezed branch pile	Circular pile	Single branch squeezed branch pile	Double branch squeezed branch pile	Circular pile	Single branch squeezed branch pile	Double branch squeezed branch pile
n=3 (triangular arrangement)	10257	12051	22950	3994	14262	19312	3475	8323	7090
n=4 (square arrangement)	12386	25416	30343	5180	20939	22215	4210	11391	9597
n=5 (4 at corner and 1 at centre)	14511	32473	41159	6397	28109	35465	5524	14879	13254
n=5 (pentagonal arrangement)	14443	29191	37965	6248	25447	33170	5174	13834	12526
n=6 (hexagonal arrangement)	22055	39792	48565	10222	30005	37111	5455	17311	14783
n=6 (in 2 row arrangement)	16810	36543	43135	7919	29408	33924	5935	21369	16131

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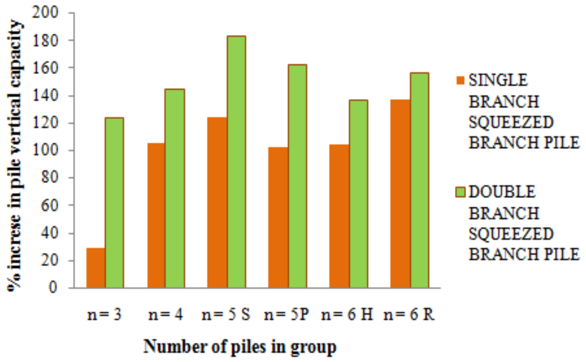
From the results, it was observed that the ultimate vertical load capacity increased with increase in number of piles in group. Vertical and uplift load carrying capacity of double branch squeezed branch pile groups were more as compared to the single branch squeezed branch pile groups. Lateral load carrying capacity of single branch squeezed branch pile groups were more as compared to the double branch squeezed branch pile groups.

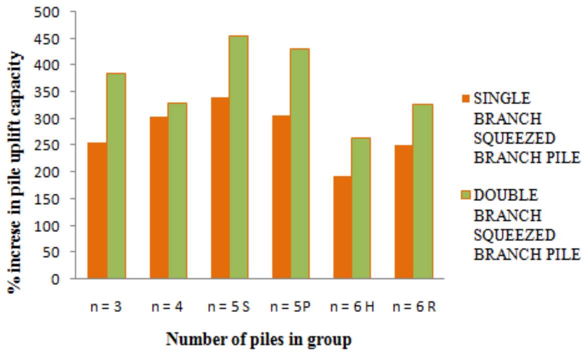
Table X: Percentage increase in pile capacity compared with conventional circular pile

Types of pile groups	% increase in ultimate load capacity		% increase in ultimate uplift load capacity		% increase in ultimate lateral load capacity	
	Single branch squeezed branch pile	Double branch squeezed branch pile	Single branch squeezed branch pile	Double branch squeezed branch pile	Single branch squeezed branch pile	Double branch squeezed branch pile
n=3 (triangular arrangement)	23	123	257	384	139	104
n=4 (square arrangement)	105	145	304	329	170	128
n=5 (pentagonal arrangement)	102	163	307	431	167	142
n=5 (4 at corner and 1 at centre)	124	184	339	454	169	142
n=6 (hexagonal arrangement)	104	137	194	263	217	146
n=6 (in 2 row arrangement)	137	157	271	320	260	172

Table X shows the percentage increase in ultimate load capacities of group of squeezed branch pile compared with groups of conventional circular pile. Percentage increase in ultimate capacities of group of squeezed branch pile compared with conventional circular pile groups are represented in the form of bar charts as shown in Fig 8.



(a)



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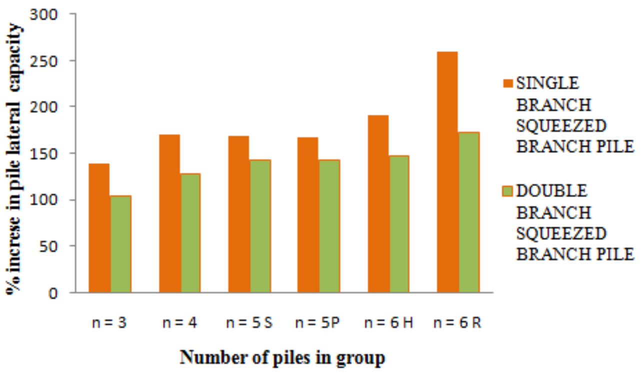

(c)

Figure 8: Percentage Increment in (a) Ultimate load capacities of squeezed branch pile group with number of piles in the group, (b) Ultimate uplift load capacities of squeezed branch pile group with number of piles in the group, and (c) Ultimate lateral load capacities of squeezed branch pile group with number of piles in the group

V. CONCLUSIONS

Based on the results of the present study, the following conclusions are drawn:

1. The ultimate load carrying capacity of squeezed branch increases with increase in diameter of branch of pile.

2. In case of single branch pile, as the branch depth from the top of soil increases its ultimate load capacity also increases.
3. The vertical load carrying capacity of double branch squeezed branch pile is much higher as compared to those of single branch squeezed branch pile and triple branch squeezed branch pile (up to181 %).
4. Ultimate vertical load and Uplift load carrying capacity of double branch squeezed branch pile groups are more as compared to the single branch squeezed branch pile groups.
5. In case of double branch pile, as the spacing between pile increases the ultimate load carrying capacity increases up to the branch spacing ratio S/ D = 3, after that with further increase in the branch spacing ultimate load carrying capacity reduces. The optimum S / D = 3 may be adopted.
6. The percentage increase in ultimate load capacity of single branch squeezed branch pile group of six piles in 2 row arrangement is more as compared to conventional circular pile group (up to137%).
7. The percentage increase in ultimate load capacity of double branch squeezed branch pile group of five piles in square arrangement with one pile at centre is more as compared to conventional circular pile group (up to184 %).
8. The percentage increase in ultimate uplift capacity of single branch squeezed branch pile and double branch squeezed branch pile group of 5 piles in square arrangement with one pile at centre is more as compared to the conventional circular pile.
9. The percentage increase in ultimate lateral load capacity of single branch squeezed branch pile and double branch squeezed branch pile group of six piles in 2 row arrangements is more as compared to the conventional circular pile.

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AUTHOURS PROFILE

Dr. A. I. Dhatrak is working as Associate Professor in Civil Engineering Department, and Dean Academics at Government College of Engineering, Amravati, India. With thirty-one year of experience, he has completed his Ph.D. in 2014. He has more than 90 publications in national and international journal and conferences. He has guided more than 40 students in their Post-Graduation dissertation in geotechnical Engineering. Currently he is guiding six Ph.D. student and thirteen master students in geotechnical engineering.

R. P. Bhujade has completed her Bachelor's degree in Civil Engineering from Sant Gadge Baba Amravati, University, India. Currently she is pursuing her Master Degree in Geotechnical Engineering at Government College of Engineering, Amravati, India.

S. W. Thakare is working as Associate professor in Department of civil Engineering, Government college of Engineering, Jalgaon, India. Currently with thirty-two years of experience, he is pursuing his Ph.D. in "Evaluation of capacities of Barrette Pile Foundation in Sandy soil" at Government college of Engineering, Amravati, India. He has published 40 research paper in various national and international journals and conferences. He has guided about 40 students for their Post-Graduation dissertation in Geotechnical Engineering.