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Load Sharing of Piled-Raft Foundations embedded in soft to medium Clay Subjected to Vertical Loads

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Abstract—Many researches have been performed on pile raft foundation in order to investigate the combined nature of raft and piles that behave as a unit. The load sharing ratio of piled raft has been studied by many researchers and mathematical formulas are achieved to predict the load sharing ratio. In the present study, the closed form equation proposed by Kyujin Choi (2014 which based on tests applied from centrifuge tests on pile raft system) is applied on the case of friction piles embedded in soft/medium clay. The load sharing ratio was calculated in case of different studied parameters and the relationships between the piled raft settlement and load sharing ratio were achieved and plotted. The studied parameters included were cohesion, number of piles, piles length, piles spacing and piles diameter. The study results concluded that the load sharing ration for all studied cases is ranging from 0.73 to 0.96. In addition the load sharing ratio is directly proportional to number of piles, piles length, piles spacing and piles diameter and inversely proportional to piles spacing. Also it can be concluded that the cohesion of soil surrounding the piles has a little effect on the value of load sharing ratio.

Index Terms— Piled Raft System, Numerical Studies, Number Of Piles, Pile Length, Pile Diameter, Pile Spacing, Soil Cohesion.

1. Introduction

In the urban areas pile raft foundation system is commonly used due to many factors such as the limit of areas which lead to using high rise building. High rise water table in case of a basement is located under a given structure and a weak shear modulus of the clay soil or loose sand and using piles as settlement reducers. Pile raft foundation is the system which consists of raft and piles, in this system raft transfer the loads from the superstructure to piles and then the piles transfer their loads to the bearing stratum or to the surrounding soil by friction. Practically many researches proofed that the transmitted load is shared between piles and surrounding soil in the piled raft system**.**

Experimental studies

Experimental studies have discussed the sharing load in pile raft system and also the expected settlement.
Wiesner and Brown (1980) applied an experimental study on models of raft foundations in clay soil to investigate the validity of methods based on elastic continuum theory for predicting the behavior of piled-raft foundation subjected to vertical load. Cooke (1986) presented results of model tests on piled-raft foundations. He compared the behavior of piled-raft foundations with that of un-piled raft and free-standing piled group. Horikoshi and Randolph (1996) conducted centrifuge tests on piled-raft foundation models to observe settlement of piled-raft foundations on clay soil. Also Conte (2003) carried out an experimental study using centrifuge tests to determine the effect of the variation of the raft and pile geometry on the stiffness of piled-raft foundation. Moreover Lee and Chung (2005) conducted tests on piled-raft foundations models to investigate the effect of pile installation and interaction between the raft and the piles on the behavior of piled-raft system.

1.1 Theoretical studies

Many theoretical studies were studied to discuss the sharing load in pile raft system and also the expected settlement.
Wiesner and Brown (1980), Russo (1998), Mendonca and de Paiva (2000), Poulos (2001) and Small and Zhang (2002) developed an approach for analyzing the piled raft system based on elastic continuum theory.
Zhuang and Lee (1994), Prakoso and Kulhawy (2001), El-Mosallamy (2002), Mendonca and da paiva (2003), Kitiyodom and Matsumoto (2003), Reul (2004), Wong and Poulos (2005) and Comodromos (2009) introduced an analysis procedure based on two dimensional and three dimensional finite element analysis.
In the conventional design of pile raft system, piles carried all the loads transferred from the superstructures to the raft and so the pile cap or the raft bearing capacity is neglected. The aim of this study to determine the load sharing of pile raft system and the factors effecting the load sharing value.

2. Present Numerical study

Numerical calculations were applied in the present study to determine the load sharing ratio (δ) in a piled-raft system where the piles are embedded in soft/medium clay soil. This study takes into account the effect of many parameters on the sharing ratio (δ) throughout 1500 case study. The studied parameters included pile diameter (D), pile length (P_L), pile spacing (P_s), number of piles (N_p) and soil cohesion (C). The closed formula was investigated by Junhwan Lee in 2014, which is based on tests carried out by

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centrifuge tests is applied to determine the sharing ratio, which means the percentage of superstructure loads transmitted via the raft and carried by piles only.

Sharing ratio (δ) = $1/((\beta.\zeta).(a_p.\lambda_B+b_p.(S/B_r)/(a_r+b_r.(S/B_r)+1)$

Where β is the load capacity interaction factor, from centrifuge tests applied on different types of clay soil and for single pile, unpiled raft, pile group and piled raft the magnitude of is β= 1.

ζ is the load capacity ratio equal to $Q_{ur,u}$ / $Q_{pg,u}$. $Q_{ur,u}$ (ultimate load capacity of unpiled raft), $Q_{pg,u}$ (ultimate load capacity of pile group).

a_p, b_p, a_r and b_r are model parameters. From centrifuge test applied on different types of clay soil and for single pile, unpiled raft, pile group and piled raft the magnitude of a_p, b_p, a_r and b_r are 0.02, 0.80, 0.01 and 0.90 respectively.

λ_B is the foundation size ratio equal to PS/D (pile spacing / pile diameter).

S is the settlement of piled-raft system.

B_r is the raft width.

This closed formula based on the normalized non-linear load settlement relationship and the normalized non-linear load settlement relationship based on the hyperbolic functions of raft and piles which are investigated from centrifuge tests.

2.1 Parametric study

The following table presents the different values of parameters considered in the parametric study.

No.of piles (N_p)	Pile Diameter (D) m	Pile Spacing (P_s)	Pile Length (P_L)	Soil Cohesion (C) Kn/m²
9	0.40	4D	20D	60
16	0.50	5D	25D	80
25	0.60	6D	30D	100
36	________	7D	35D	________
49	________	8D	40D	________

3. Results of numerical study

3.1. Introduction

The mentioned closed form equation was applied to different studied cases in order to construct the relationship between load sharing ratio (δ) of the piled-raft system and observe the effect of the considered parameters on the ratio (δ) at any desired settlement ratio (S/D).

3.2. Effect of no.of piles (N_p)

To investigate the effect of number of piles (N_p) which varies from 9 piles to 49 piles on the relationship between load sharing ration (δ) and piles raft settlement (S), The parametric study were plotted in figures (1) to (8) . Each graph represents the mentioned relationship at different values of number of piles (N_p) with constant values of the other parameters Pile spacing (P_s), Pile length (P_l), Pile diameter (D), and Soil cohesion (C). Then the same investigation was repeated throughout four series. Series no.1 shows the effect of (N_p) for different studied values of pile spacing (P_s) which varies from 4D to 8D with the constant values of the other parameters (pile diameter, pile spacing, pile length and soil cohesion), By the same way, series no.2 shows the effect of (N_p) at different studied values of pile length (P_l) which varies from 20D to 40D. Whereas series no.3 represents the effect of N_p for different studied values of pile diameter (D) ranging from 0.40 m to 0.60 m, Last series no.4 was performed to observe the effect of (N_p) for different studied values of surrounding soil cohesion (C) ranging from 60KN/m² to 100KN/m². The resulting graphical relationships represent the values of load sharing ratio (δ) versus raft-pile system settlement up to a limit value of (0.1D). on the other hand each graphical relationship was re-plotted specifically up to (0.02D) which is the allowable value of pile group settlement according to Egyptian Code of Practice (E.C.P). That, in turn means that the load sharing ratio (δ) corresponding to the settlement of (0.02D) may be considered the working load sharing ratio.

3.2.1 Effect of no.of piles at different values of pile spacing

Cases studied of series no.1 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of number of piles (N_p) at different values of pile spacing (P_s) varying from 4D to 8D center-line to center-line. Figures (1.a) and (1.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.1, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) increases as the number of piles beneath raft increases. In addition, it is obvious from figure (2) that the load sharing ratio (δ) is inversely proportional to the pile spacing (P_s) for the same number of piles. For all the studied cases through the parameter (N_p), it is noticed that the load sharing ratio (δ) is ranging from 0.734 to 0.957 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

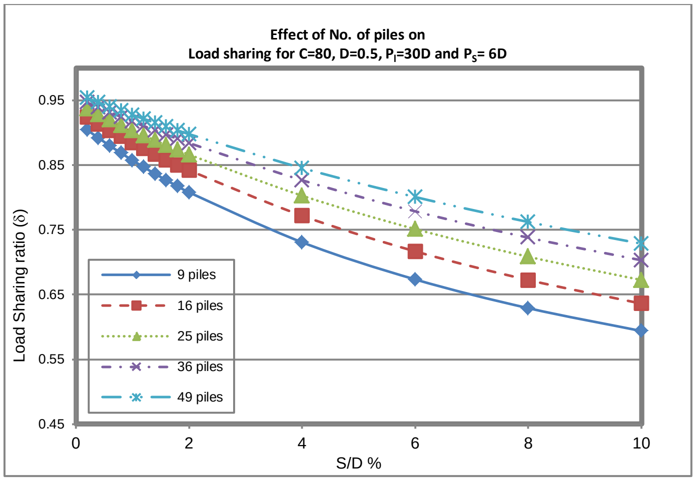

Fig. 1.a

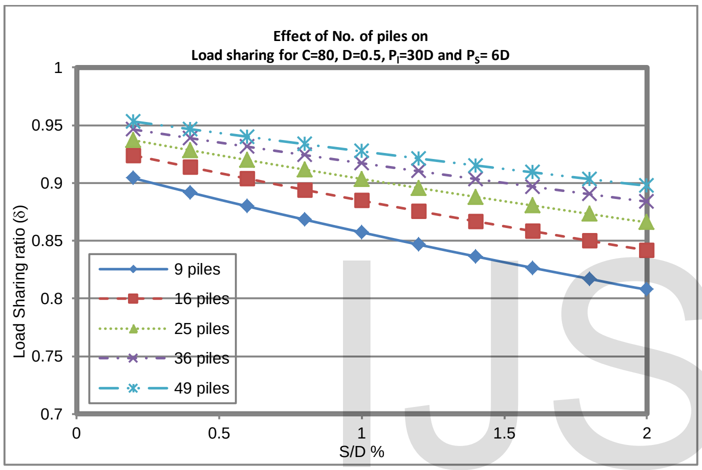

Fig. 1.b

Fig.1. Relationship between (N_p) and (δ) for different values of (P_s)

		P_S				
		4D	5D	6D	7D	8D
N_P	9	0.897	0.850	0.808	0.769	0.734
	16	0.923	0.880	0.842	0.806	0.773
	25	0.939	0.901	0.866	0.833	0.803
	36	0.949	0.916	0.884	0.854	0.826
	49	0.957	0.926	0.898	0.871	0.845

Table.1. Values of (δ) for the relation between (N_p) and (P_s)

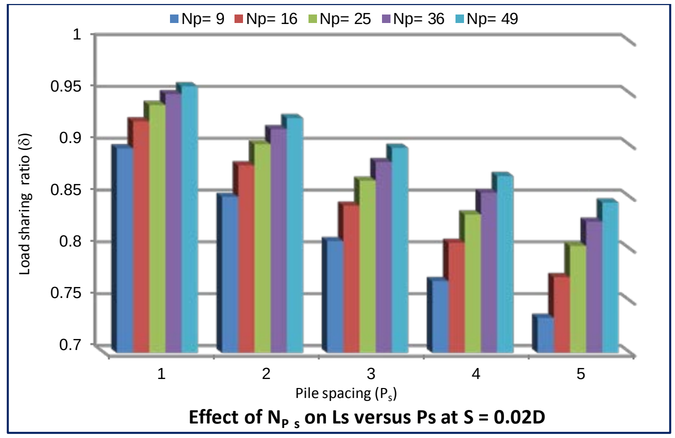

Fig.2. values of (δ) for the relation between (N_p) and (P_s)

3.2.2 Effect of no.of piles at different values of pile length

Cases studied of series no.2 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of number of piles (N_p) at different values of pile length (P_l) varying from 20D to 40D. Figures (3.a) and (3.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.2, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) increases as the pile length increase. In addition, it is obvious from figure (4) that the load sharing ratio (δ) is direct proportional to the pile length (P_l) for the same number of piles. For all the studied cases through the parameter (N_p), it is noticed that the load sharing ratio (δ) is ranging from 0.737 to 0.921 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

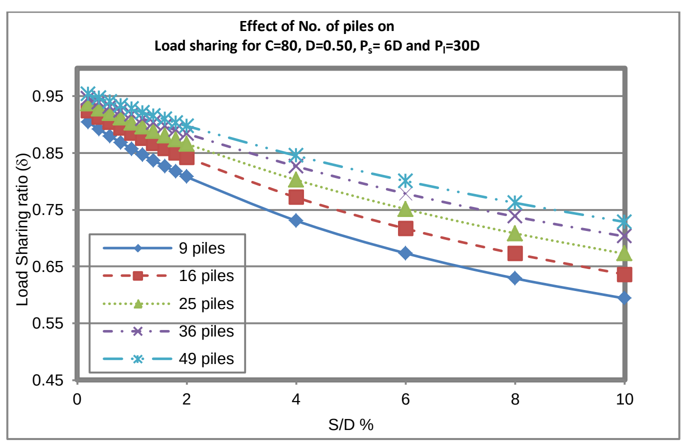

Fig.3.a.

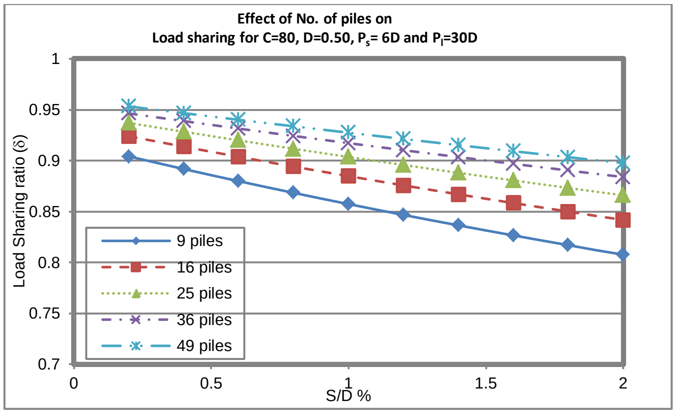

Fig.3.b.

Fig.3. Relationship between (N_p) and (δ) for different values of (P_l)

		P_l				
		20D	25D	30D	35D	40D
N_p	9	0.737	0.778	0.808	0.831	0.849
	16	0.780	0.8168	0.842	0.861	0.877
	25	0.812	0.8438	0.866	0.883	0.896
	36	0.835	0.864	0.884	0.899	0.910
	49	0.854	0.879	0.898	0.911	0.921

Table.2. Values of (δ) for the relation between (N_p) and (P_l)

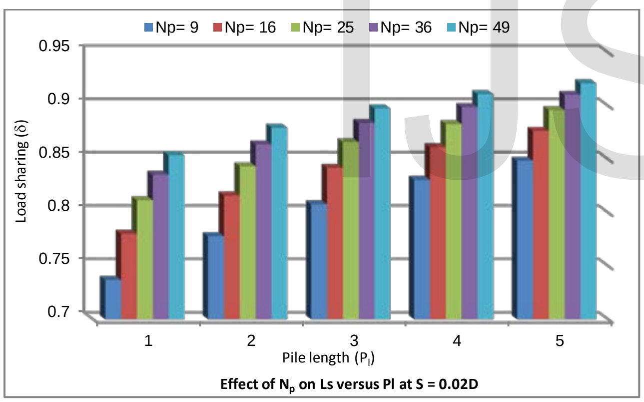

Fig.4. values of (δ) for the relation between (N_p) and (P_l)

3.2.3 Effect of no.of piles at different values of pile diameter

Cases studied of series no.3 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of number of piles (N_p) at different values of pile diameter (D) varying from 0.40m to 0.60m. Figures (5.a) and (5.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.3, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is constant as the pile diameter increase. In addition, it is obvious from figure (6) that the load sharing ratio (δ) is constant to the pile diameter (D) for the same number of piles. For all the studied cases through the parameter (N_p), it is noticed that the load sharing ratio (δ) is ranging from 0.808 to 0.894 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

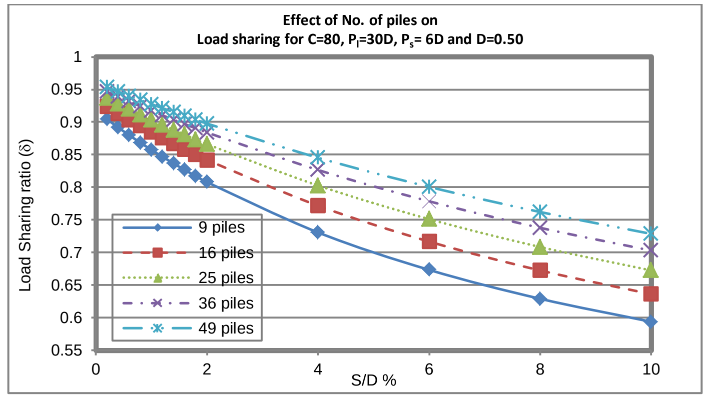

Fig. 5.a

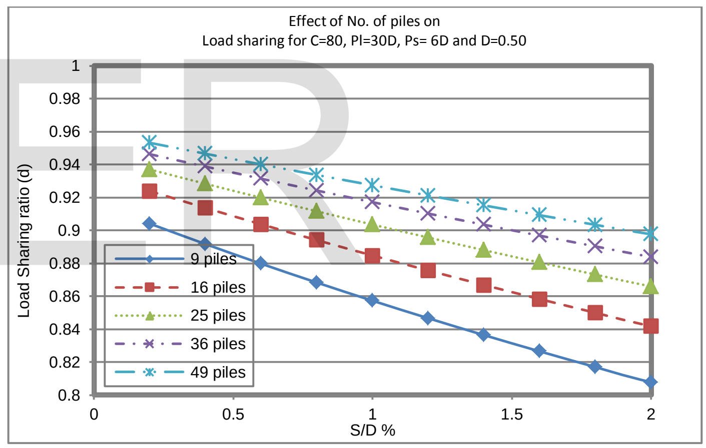

Fig. 5.b

Fig.5. Relationship between (N_p) and (δ) for different values of (D)

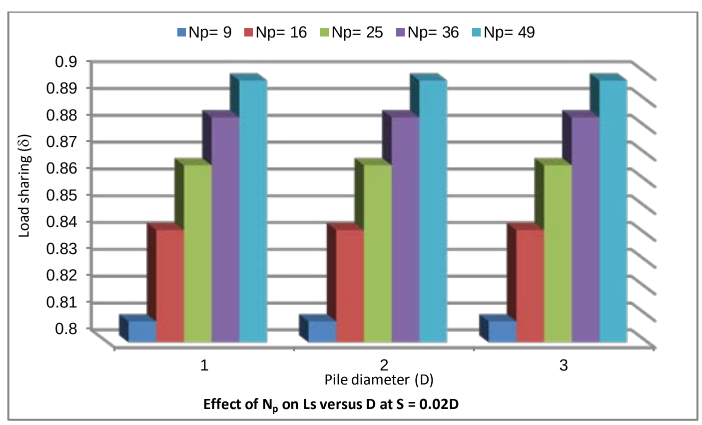

Fig.6. values of (δ) for the relation between (N_p) and (D)

D

		0.40	0.50	0.60
N_p	9	0.808	0.808	0.808
	16	0.842	0.842	0.842
	25	0.866	0.866	0.866
	36	0.884	0.884	0.884
	49	0.898	0.898	0.898

Table.3. Values of (δ) for the relation between (N_p) and (D)

3.2.4 Effect of no.of piles at different values of soil cohesion

Cases studied of series no.4 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of number of piles (N_p) at different values of soil cohesion (C) varying from 60KN/m² to 100KN/m². Figures (7.a) and (7.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.4, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) has a small increases as the soil cohesion increase. In addition, it is obvious from figure (8) that the load sharing ratio (δ) has a neglect able direct proportional to the soil cohesion (C) for the same number of piles. For all the studied cases through the parameter (N_p), it is noticed that the load sharing ratio (δ) is ranging from 0.806 to 0.898 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

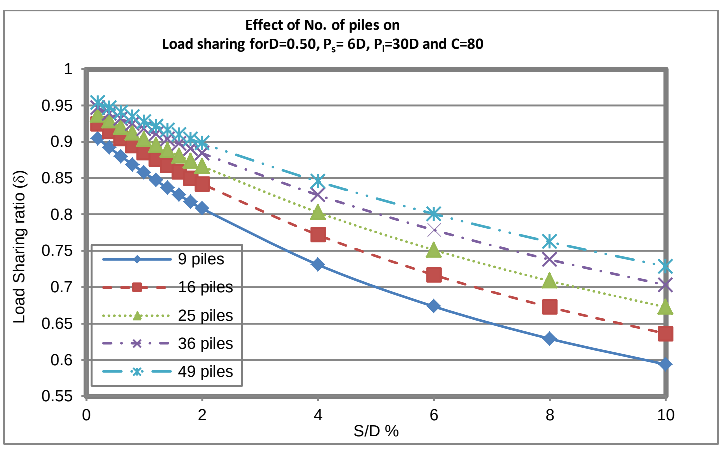

Fig. 7.a

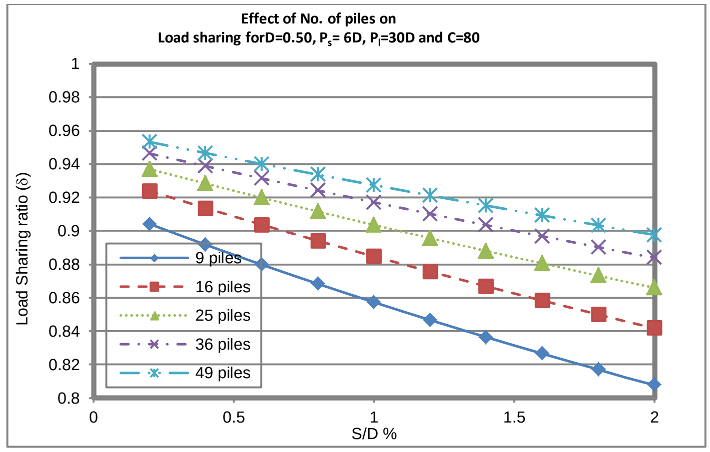

Fig. 7.b

Fig.7. values of (δ) for the relation between (N_p) and (C)

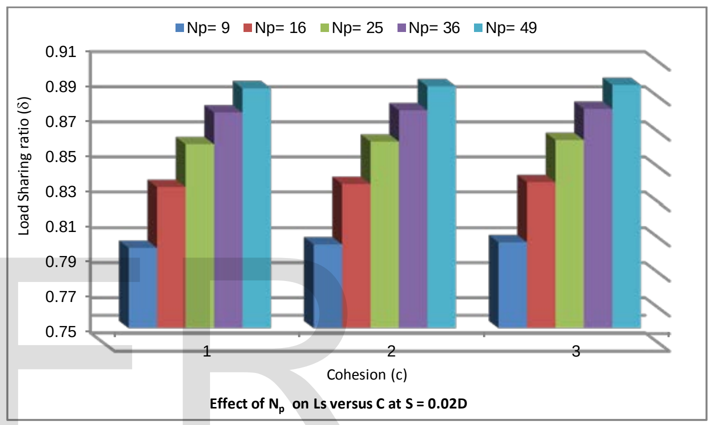

Fig.8. values of (δ) for the relation between (N_p) and (C)

		C		
		60	80	100
NP	9	0.806	0.808	0.809
	16	0.840	0.842	0.843
	25	0.865	0.866	0.867
	36	0.883	0.883	0.885
	49	0.896	0.898	0.898

Table.4. Values of (δ) for the relation between (N_p) and (C)

3.3. Effect of pile length (P_l)

To investigate the effect of pile length (P_l) which varies from 20D to 40D on the relationship between load sharing ration (δ) and piles raft settlement (S), The parametric study were plotted in figures (9) to (16) . Each graph represents the mentioned relationship at different values of pile length (P_l) with constant values of the other parameters Pile spacing (P_s), No.of piles (N_p), Pile diameter (D), and Soil cohesion (C). Then the same investigation was repeated throughout four series. Series no.5 shows the effect of (P_l) for different studied values of pile spacing (P_s) which varies from 4D to 8D with the constant values of the other parameters (pile diameter, pile spacing, no.of piles and soil cohesion), By the same way, series no.6 shows the effect of

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(P_l) at different studied values of no.of piles (N_p) which varies from 9 piles to 49 piles. Whereas series no.7 represents the effect of P_l for different studied values of pile diameter (D) ranging from 0.40 m to 0.60 m, Last series no.8 was performed to observe the effect of (P_l) for different studied values of surrounding soil cohesion (C) ranging from 60KN/m² to 100KN/m². The resulting graphical relationships represent the values of load sharing ratio (δ) versus raft-pile system settlement up to a limit value of (0.1D). on the other hand each graphical relationship was re-plotted specifically up to (0.02D) which is the allowable value of pile group settlement according to Egyptian Code of Practice (E.C.P). That, in turn means that the load sharing ratio (δ) corresponding to the settlement of (0.02D) may be considered the working load sharing ratio.

3.3.1 Effect of pile length at different values of pile spacing

Cases studied of series no.5 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile length (P_l) at different values of pile spacing (P_s) varying from 4D to 8D center-line to center-line. Figures (9.a) and (9.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.5, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) increases as the pile length beneath raft increases. In addition, it is obvious from figure (10) that the load sharing ratio (δ) is inversely proportional to the pile spacing (P_s) for the same pile length. For all the studied cases through the parameter (P_l), it is noticed that the load sharing ratio (δ) is ranging from 0.731 to 0.954 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

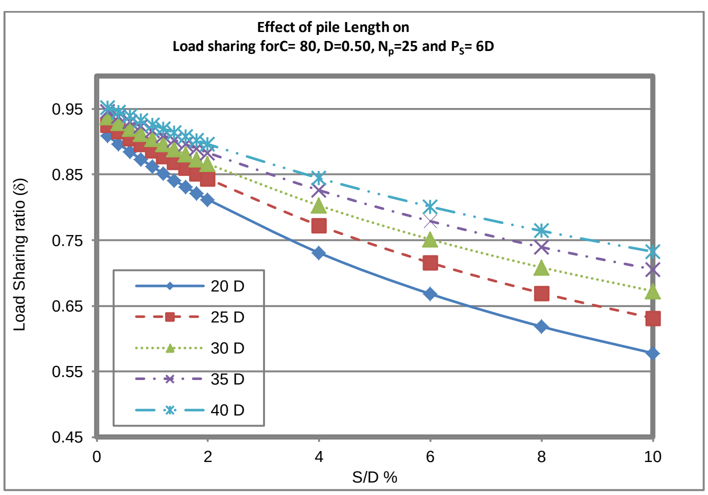

Fig. 9.a

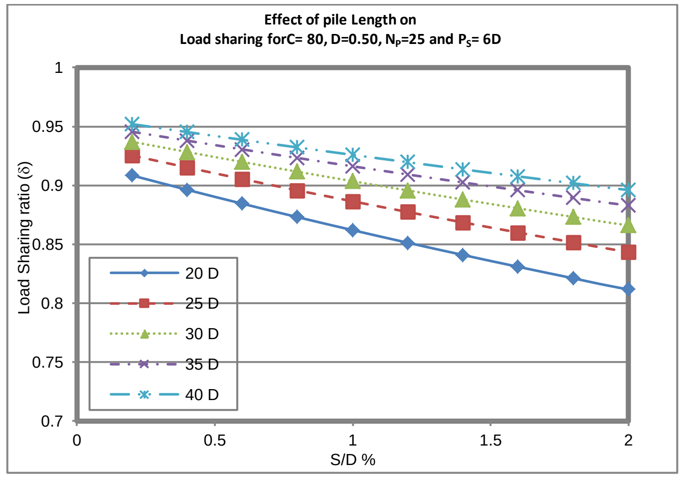

Fig. 9.b

Fig.9. Relationship between (P_l) and (δ) for different values of (P_s)

		P_s				
		4D	5D	6D	7D	8D
P_l	20D	0.911	0.859	0.812	0.769	0.731
	25D	0.928	0.884	0.843	0.807	0.773
	30D	0.939	0.901	0.8665	0.833	0.803
	35D	0.947	0.914	0.883	0.854	0.826
	40D	0.954	0.924	0.896	0.869	0.845

Table.5. Values of (δ) for the relation between (P_l) and (P_s)

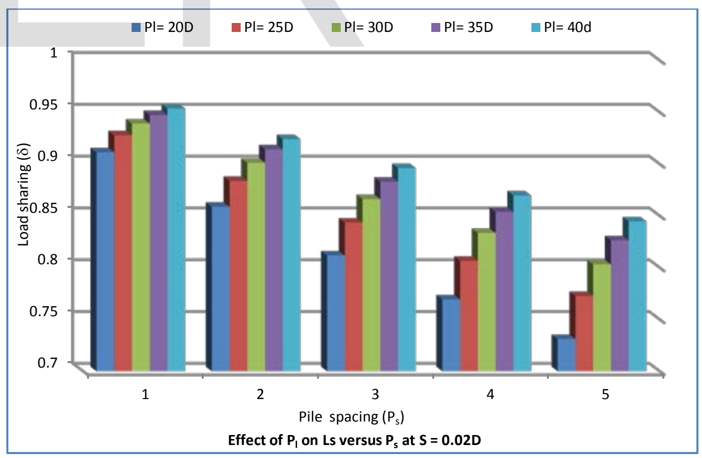

Fig.10. values of (δ) for the relation between (P_l) and (P_s)

3.3.2 Effect of pile length at different values of no.of piles

Cases studied of series no.6 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile length (P_l) at different values of no.of piles (N_p) varying from 9 piles to 49 piles. Figures (11.a) and (11.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.6, the (δ) versus (S) relationships are similar in shape

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and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) increases as the pile length increase. In addition, it is obvious from figure (12) that the load sharing ratio (δ) is direct proportional to the no.of piles (N_p) for the same pile length. For all the studied cases through the parameter (P_l), it is noticed that the load sharing ratio (δ) is ranging from 0.737 to 0.921 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

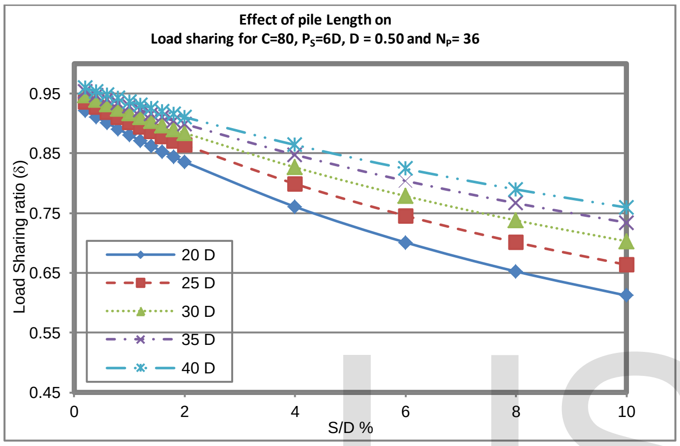

Fig.11.a

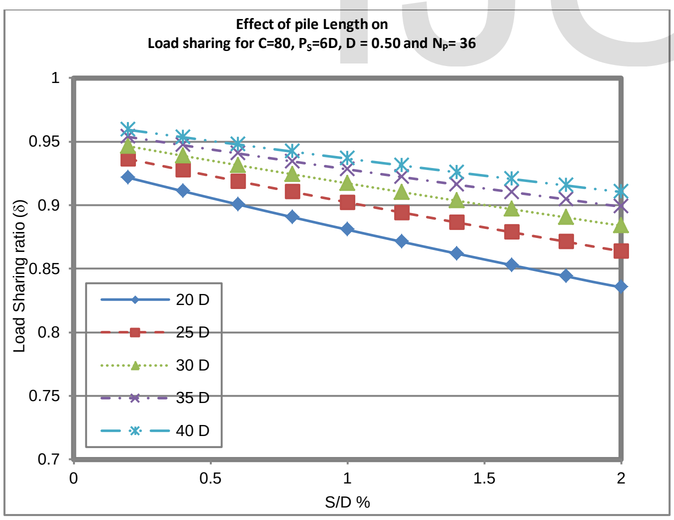

Fig.11.b

Fig.11. Relationship between (P_l) and (δ) for different values of (N_p)

Table.6. Values of (δ) for the relation between (P_l) and (N_p)

		N_p				
		9	16	25	36	49
P_l	20D	0.737	0.780	0.812	0.835	0.854
	25D	0.778	0.816	0.843	0.864	0.879
	30D	0.808	0.842	0.866	0.884	0.898
	35D	0.831	0.861	0.883	0.899	0.911
	40D	0.849	0.877	0.896	0.910	0.921

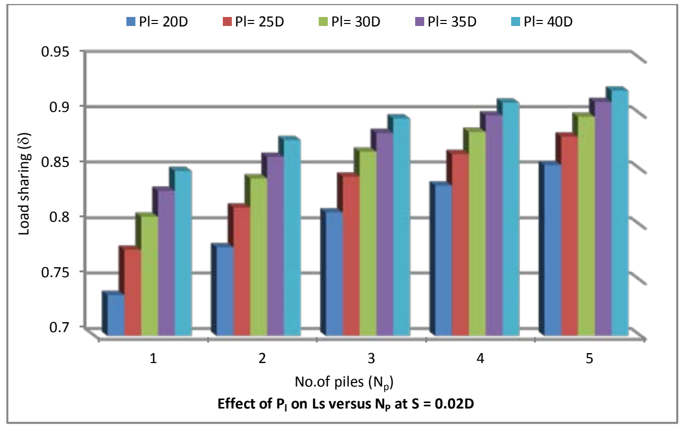

Fig.12. values of (δ) for the relation between (P_l) and (N_p)

3.3.3 Effect of pile length at different values of pile diameter

Cases studied of series no.6 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile length (P_l) at different values of pile diameter (D) varying from 0.40m to 0.60m. Figures (13.a) and (13.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.7, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is constant as the pile diameter increase. In addition, it is obvious from figure (14) that the load sharing ratio (δ) is constant to the pile diameter (D) for the same pile length. For all the studied cases through the parameter (P_l), it is noticed that the load sharing ratio (δ) is ranging from 0.812 to 0.896 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

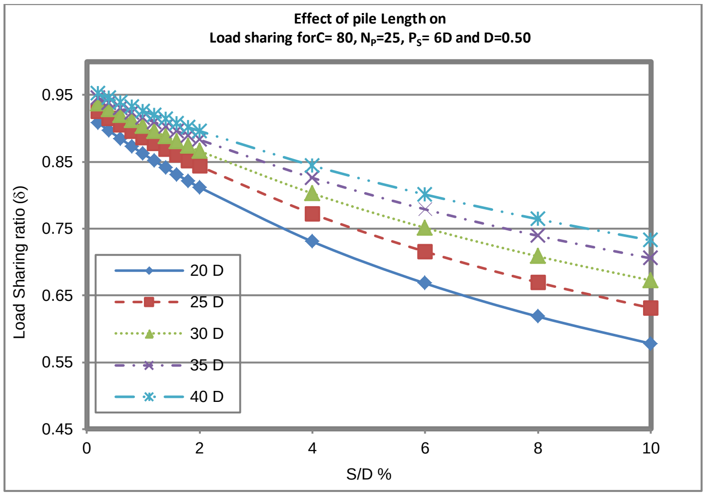

Fig. 13.a

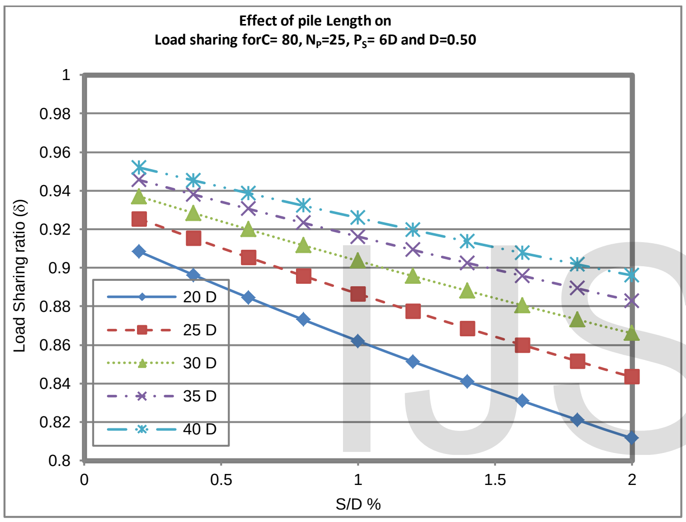

Fig. 13.b

Fig.13. Relationship between (P_l) and (δ) for different values of (D)

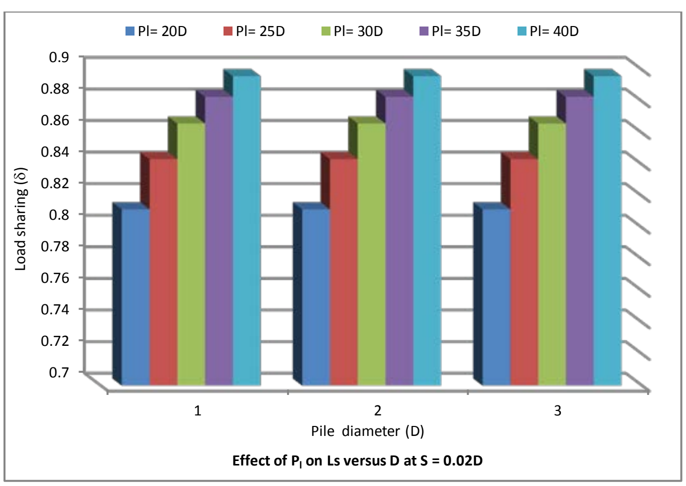

Fig.14. values of (δ) for the relation between (P_l) and (D)

		D		
		0.40	0.50	0.60
P_l	20D	0.812	0.812	0.812
	25D	0.843	0.843	0.843
	30D	0.866	0.866	0.866
	35D	0.883	0.883	0.883
	40D	0.896	0.896	0.896

Table.7. Values of (δ) sharing for the relation between (P_l) and (D)

3.3.4 Effect of pile length at different values of soil cohesion

Cases studied of series no.8 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile length (P_l) at different values of soil cohesion (C) varying from 60KN/m² to 100KN/m². Figures (15.a) and (15.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.8, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) has a small increases as the soil cohesion increase. In addition, it is obvious from figure (16) that the load sharing ratio (δ) has a neglect able direct proportional to the soil cohesion (C) for the same pile length. For all the studied cases through the parameter (P_l), it is noticed that the load sharing ratio (δ) is ranging from 0.809 to 0.896 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

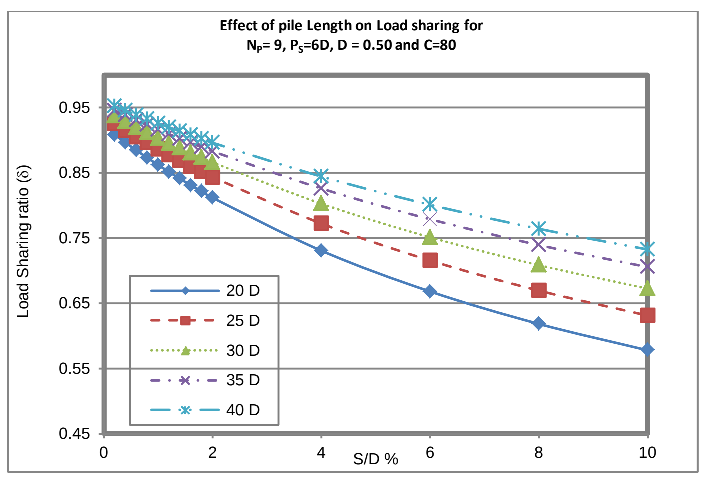

Fig. 15.a

ISSN 2229-5518

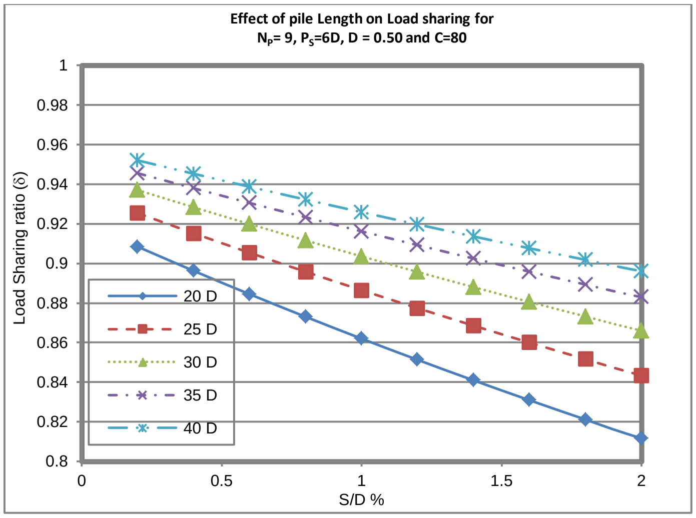

Fig. 15.b

Fig.15. values of (δ) for the relation between (P_l) and (C)

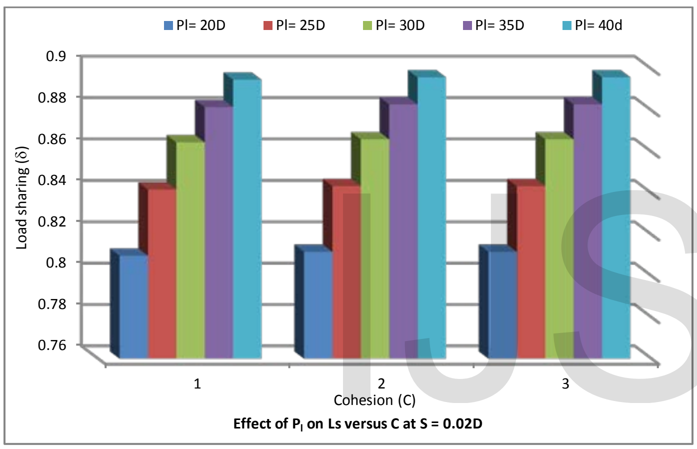

Fig.16. values of (δ) for the relation between (P_l) and (C)

		C		
		60	80	100
P_l	20D	0.806	0.808	0.809
	25D	0.840	0.842	0.843
	30D	0.865	0.866	0.867
	35D	0.883	0.883	0.885
	40D	0.896	0.898	0.898

Table.8. Values of (δ) sharing for the relation between (P_l) and (C)

3.4. Effect of pile spacing (P_s)

To investigate the effect of pile spacing (P_s) which varies from 4D to 8D on the relationship between load sharing ration (δ) and piles raft settlement (S), The parametric study were plotted in figures (17) to (24) . Each graph represents the mentioned relationship at different values of pile spacing (P_s) with constant values of the other parameters Pile length (P_l), No.of piles (N_p), Pile diameter (D), and Soil cohesion (C). Then the same investigation was repeated throughout four series. Series no.9 shows the effect of (P_s) for different studied values of pile length (P_l) which varies from 20D to 40D with the constant values of the other parameters (pile diameter, pile length, no.of piles and soil cohesion), By the same way, series no.10 shows the effect of (P_s) at different studied values of no.of piles (N_p) which varies from 9 piles to 49 piles. Whereas series no.11 represents the effect of P_s for different studied values of pile diameter (D) ranging from 4D to 8D, Last series no.12 was performed to observe the effect of (P_s) for different studied values of surrounding soil cohesion (C) ranging from 60KN/m² to 100KN/m². The resulting graphical relationships represent the values of load sharing ratio (δ) versus raft-pile system settlement up to a limit value of (0.1D). on the other hand each graphical relationship was re-plotted specifically up to (0.02D) which is the allowable value of pile group settlement according to Egyptian Code of Practice (E.C.P). That, in turn means that the load sharing ratio (δ) corresponding to the settlement of (0.02D) may be considered the working load sharing ratio.

3.4.1 Effect of pile spacing at different values of pile length

Cases studied of series no.9 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile spacing (P_s) at different values of pile length (P_l) varying from 20D to 40D. Figures (17.a) and (17.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.9, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) increases as the pile length beneath raft increases. In addition, it is obvious from figure (18) that the load sharing ratio (δ) is inversely proportional to the pile spacing (P_s) for the same pile spacing. For all the studied cases through the parameter (P_s), it is noticed that the load sharing ratio (δ) is ranging from 0.731 to 0.954 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

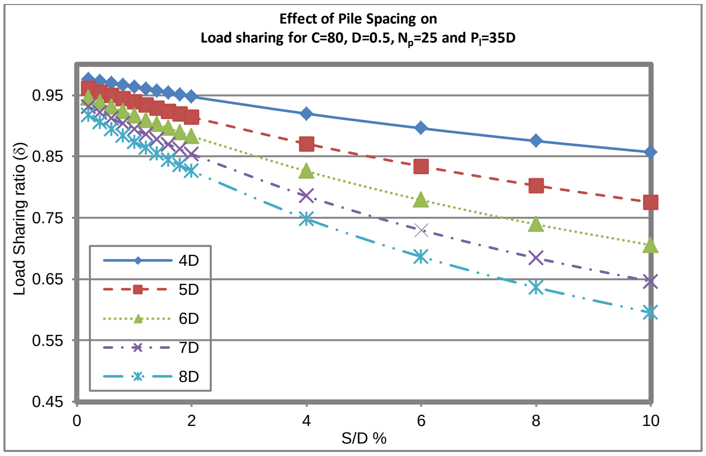

Fig. 17.a

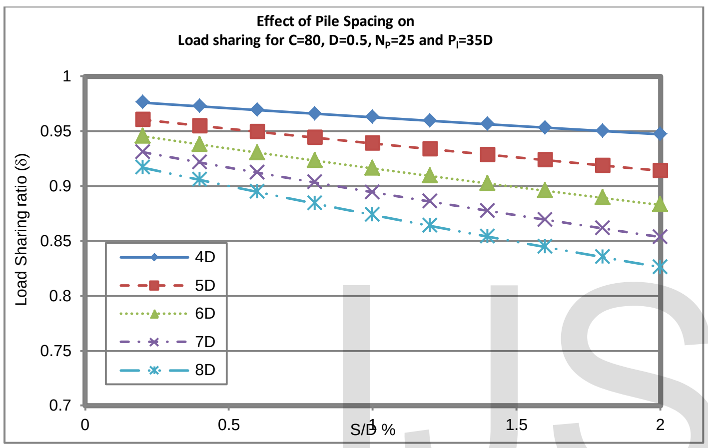

Fig. 17.b

Fig.17. Relationship between (P_s) and (δ) for different values of (P_l)

		P_l				
		20D	25D	30D	35D	40D
P_s	4D	0.911	0.928	0.939	0.947	0.954
	5D	0.859	0.884	0.9012	0.914	0.924
	6D	0.812	0.843	0.866	0.883	0.896
	7D	0.769	0.807	0.833	0.854	0.869
	8D	0.731	0.773	0.803	0.826	0.845

Table.9. Values of (δ) for the relation between (P_s) and (P_l)

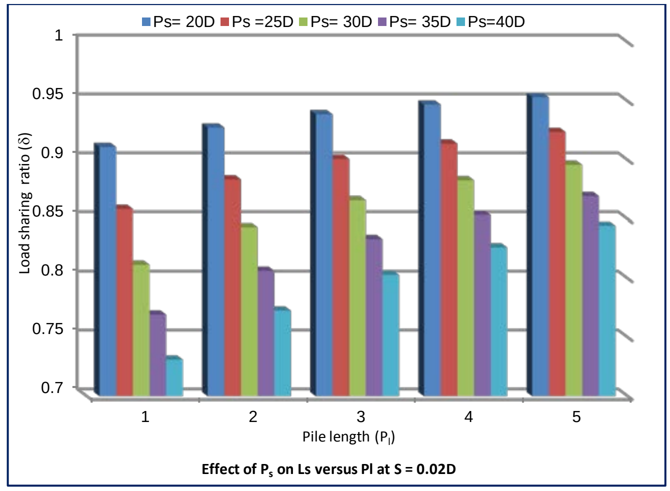

Fig.18. values of (δ) for the relation between (P_s) and (P_l)

3.4.2 Effect of pile spacing at different values of no.of piles

Cases studied of series no.10 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile spacing (P_s) at different values of no.of piles (N_p) varying from 9 piles to 49 piles. Figures (19.a) and (19.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.10, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) decreases as the pile spacing increase. In addition, it is obvious from figure (20) that the load sharing ratio (δ) is inverse proportional to the no. of piles (N_p) for the same pile spacing. For all the studied cases through the parameter (P_s), it is noticed that the load sharing ratio (δ) is ranging from 0.734 to 0.957 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

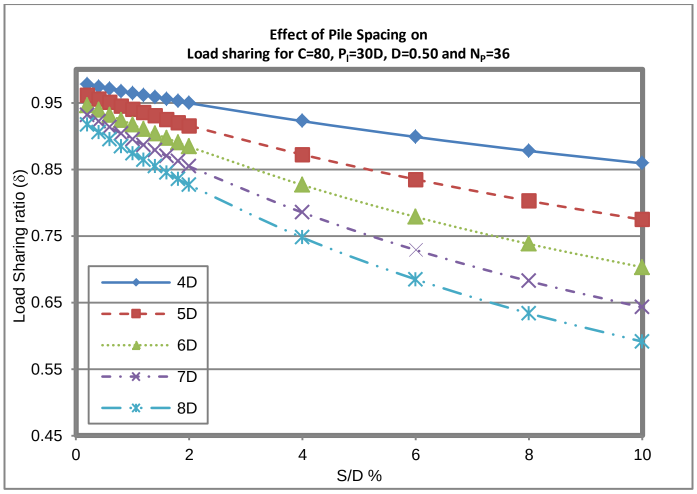

Fig.19.a

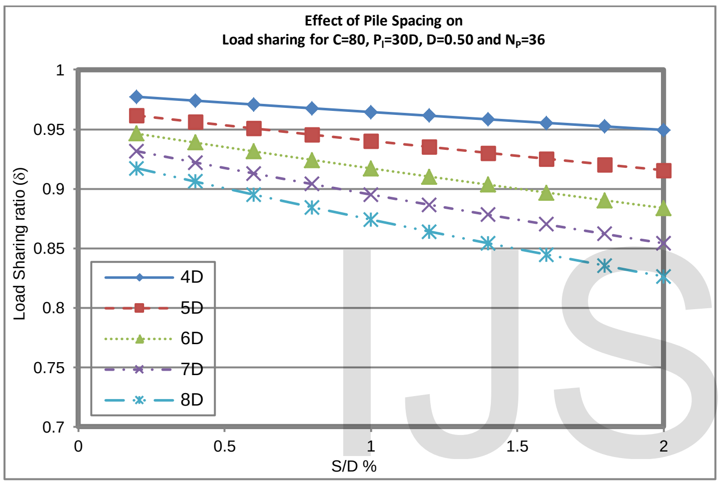

Fig.19.b

Fig.19. Relationship between (P_s) and (δ) for different values of (N_p)

		N_p				
		9	16	25	36	49
P_s	4D	0.897	0.923	0.939	0.949	0.957
	5D	0.850	0.881	0.901	0.916	0.926
	6D	0.80	0.842	0.866	0.884	0.898
	7D	0.769	0.806	0.833	0.854	0.871
	8D	0.734	0.773	0.803	0.826	0.845

Table.10. Values of (δ) for the relation between (P_s) and (N_p)

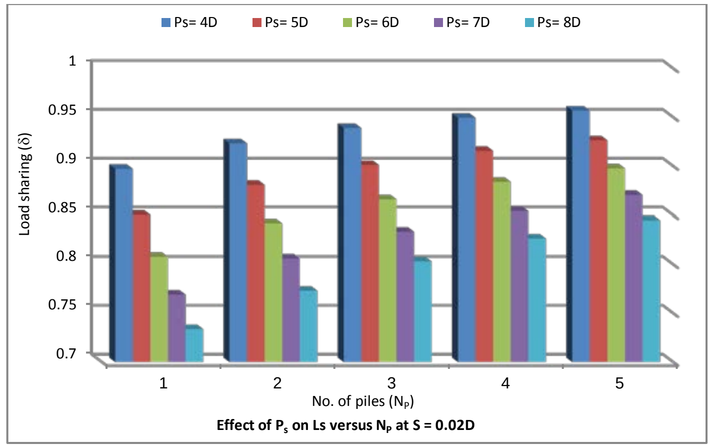

Fig.20. values of (δ) for the relation between (P_s) and (N_p)

3.4.3 Effect of pile spacing at different values of pile diameter

Cases studied of series no.11 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile spacing (P_s) at different values of pile diameter (D) varying from 0.40m to 0.60m. Figures (21.a) and (22.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.11, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is decrease as the pile spacing increase. In addition, it is obvious from figure (22) that the load sharing ratio (δ) is constant to the pile diameter (D) for the same pile spacing. For all the studied cases through the parameter (P_s), it is noticed that the load sharing ratio (δ) is ranging from 0.803 to 0.939 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

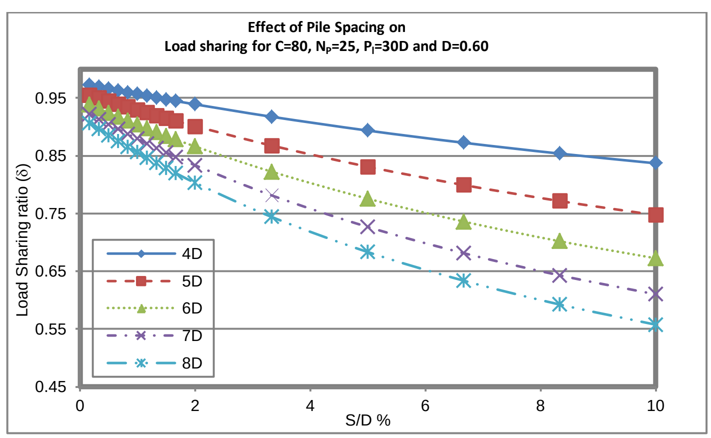

Fig. 21.a

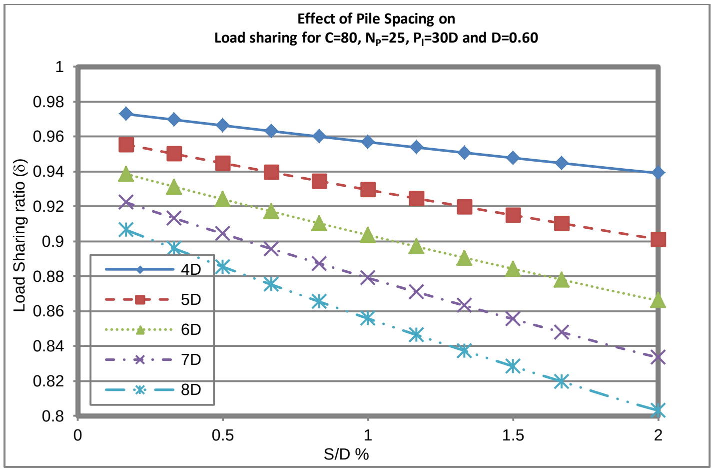

Fig. 21.b

Fig.21. Relationship between (P_s) and (δ) for different values of (D)

		D		
		0.40	0.50	0.60
P_s	4D	0.939	0.939	0.939
	5D	0.901	0.901	0.90
	6D	0.866	0.866	0.866
	7D	0.833	0.833	0.833
	8D	0.803	0.803	0.803

Table.11. Values of (δ) for the relation between (P_s) and (D)

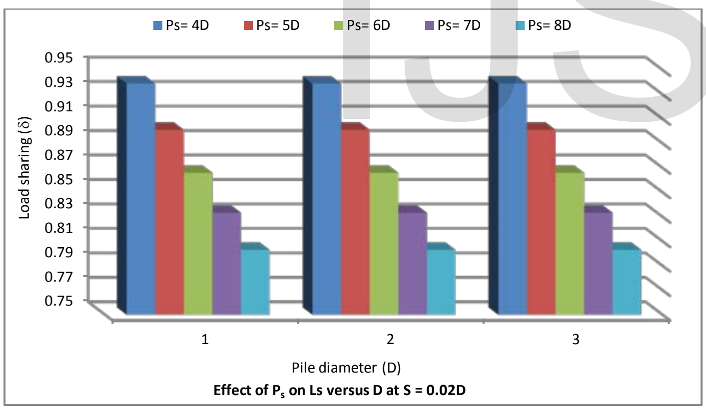

Fig.22. values of (δ) for the relation between (P_s) and (D)

3.4.4 Effect of pile spacing at different values of soil cohesion

Cases studied of series no.12 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile spacing (P_s) at different values of soil cohesion (C) varying from 60KN/m² to 100KN/m². Figures (23.a) and (23.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.12, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) has a small increases as the soil cohesion increase. In addition, it is obvious from figure (24) that the load sharing ratio (δ) has a neglect able direct proportional to the soil cohesion (C) for the same pile length. For all the studied cases through the parameter (P_l), it is noticed that the load sharing ratio (δ) is ranging from 0.809 to 0.896 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

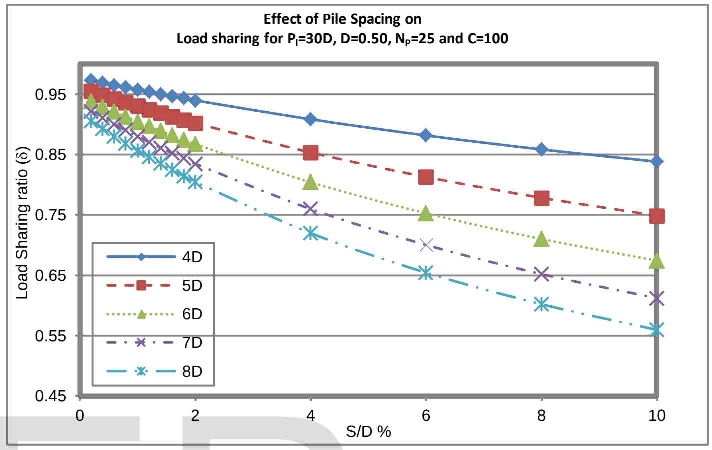

Fig. 23.a

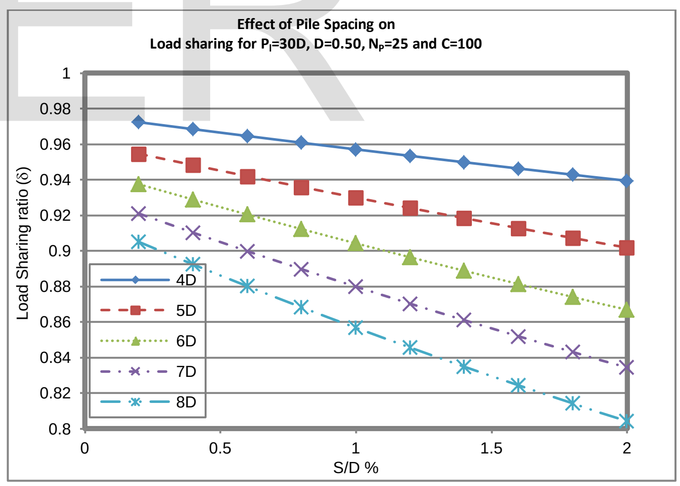

Fig. 23.b

Fig.23. Relationship between (P_s) and (δ) for different values of (C)

		C		
		60	80	100
P_s	4D	0.938	0.939	0.939
	5D	0.900	0.902	0.902
	6D	0.865	0.866	0.867
	7D	0.832	0.833	0.834
	8D	0.801	0.803	0.804

Table.12. Values of (δ) for the relation between (P_s) and (C)

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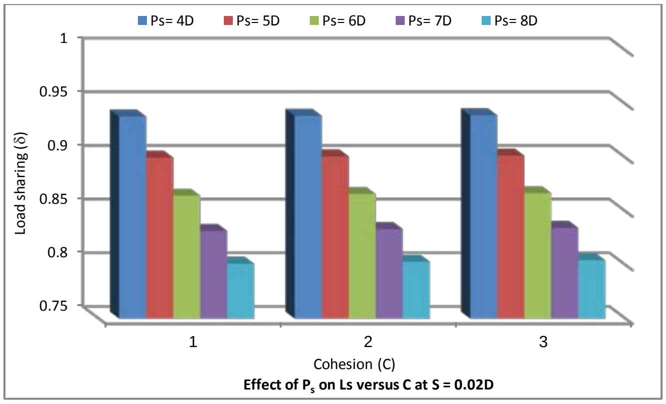

Fig.24. values of (δ) for the relation between (P_s) and (C)

3.5. Effect of soil cohesion (C)

To investigate the effect of soil cohesion (C) which varies from 60KN/m² to 100KN/m² on the relationship between load sharing ration (δ) and piles raft settlement (S), The parametric study were plotted in figures (25) to (32) . Each graph represents the mentioned relationship at different values of soil cohesion (C) with constant values of the other parameters Pile length (P_l), No.of piles (N_p), Pile diameter (D), and pile spacing (P_s). Then the same investigation was repeated throughout four series. Series no.13 shows the effect of (C) for different studied values of pile length (P_l) which varies from 20D to 40D with the constant values of the other parameters (pile diameter, pile spacing, no.of piles and soil cohesion), By the same way, series no.14 shows the effect of (C) at different studied values of no.of piles (N_p) which varies from 9 piles to 49 piles. Whereas series no.15 represents the effect of C for different studied values of pile diameter (D) ranging from 0.40 m to 0.60 m, Last series no.16 was performed to observe the effect of (C) for different studied values of pile spacing (P_s) ranging from 4D to 8D. The resulting graphical relationships represent the values of load sharing ratio (δ) versus raft-pile system settlement up to a limit value of (0.1D). on the other hand each graphical relationship was re-plotted specifically up to (0.02D) which is the allowable value of pile group settlement according to Egyptian Code of Practice (E.C.P). That, in turn means that the load sharing ratio (δ) corresponding to the settlement of (0.02D) may be considered the working load sharing ratio.

3.5.1 Effect of soil cohesion (C) at different values of pile length

Cases studied of series no.13 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of soil cohesion (C) at different values of pile length (P_l) varying from 20D to 40D. Figures (25.a) and (25.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.13, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) increases as the soil cohesion increases with small values. In addition, it is obvious from figure (26) that the load sharing ratio (δ) is directly proportional to the soil cohesion (C) for the same pile length. For all the studied cases through the parameter (C), it is noticed that the load sharing ratio (δ) is ranging from 0.801 to 0.939 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

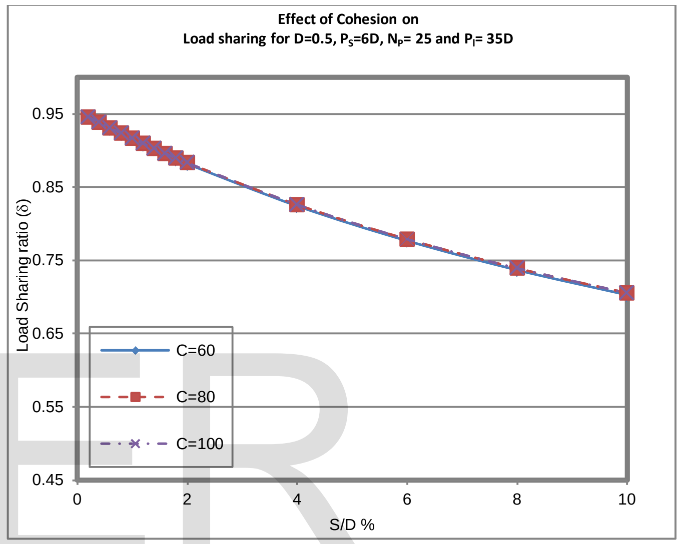

Fig. 25.a

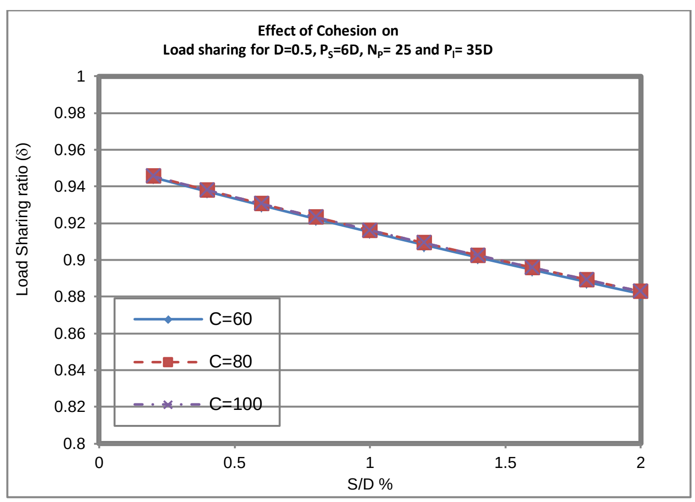

Fig. 25.b

Fig.25. Relationship between (C) and (δ) for different values of (P_l)

		P_l				
		20D	25D	30D	35D	40D
C	60	0.938	0.900	0.865	0.832	0.801
	80	0.939	0.901	0.866	0.833	0.803

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	100	0.939	0.902	0.867	0.8345	0.804

Table.13. Values of (δ) for the relation between (C) and (P_l)

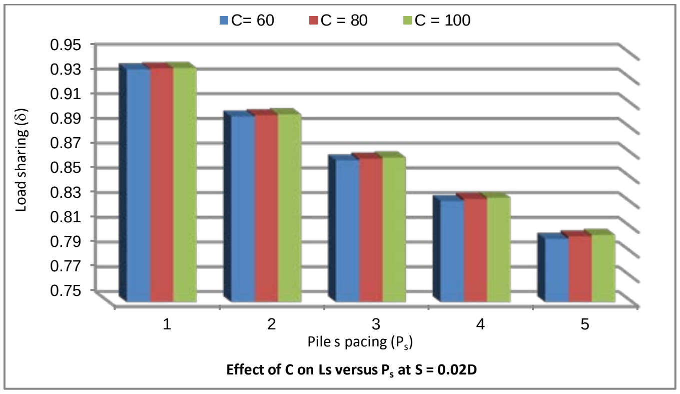

Fig.26. values of (δ) for the relation between (C) and (P_l)

3.5.2 Effect of soil cohesion at different values of no.of piles

Cases studied of series no.14 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of soil cohesion (C) at different values of no.of piles (N_p) varying from 9 piles to 49 piles. Figures (27.a) and (27.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.14, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) increases as the soil cohesion increase with small values. In addition, it is obvious from figure (28) that the load sharing ratio (δ) is directly proportional to the no. of piles (N_p) for the same soil cohesion. For all the studied cases through the parameter (C), it is noticed that the load sharing ratio (δ) is ranging from 0.734 to 0.957 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

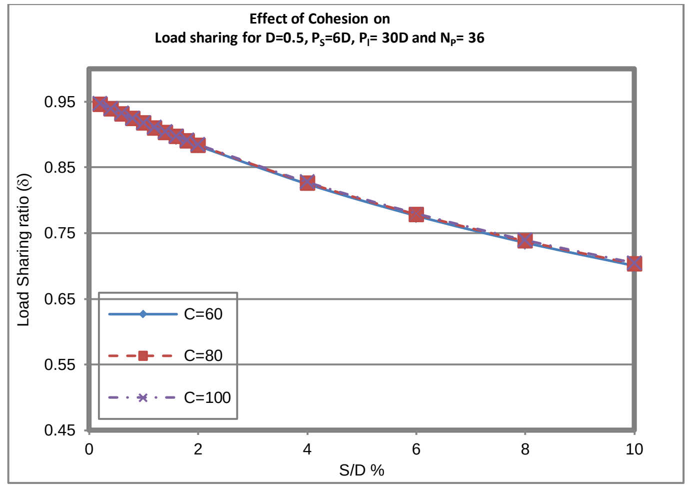

Fig.27.a

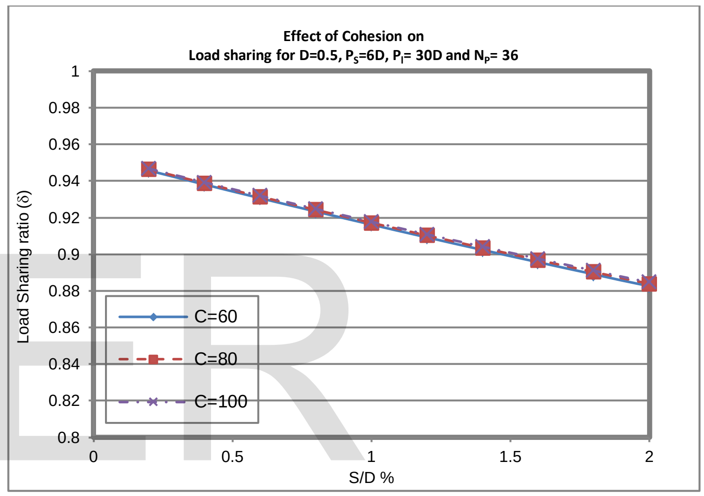

Fig.27.b

Fig.27. Relationship between (C) and (δ) for different values of (N_p)

		N_p				
		9	16	25	36	49
C	60	0.806	0.840	0.865	0.883	0.896
	80	0.808	0.842	0.866	0.884	0.898
	100	0.809	0.843	0.867	0.885	0.898

Table.14. Values of (δ)for the relation between (C) and (N_p)

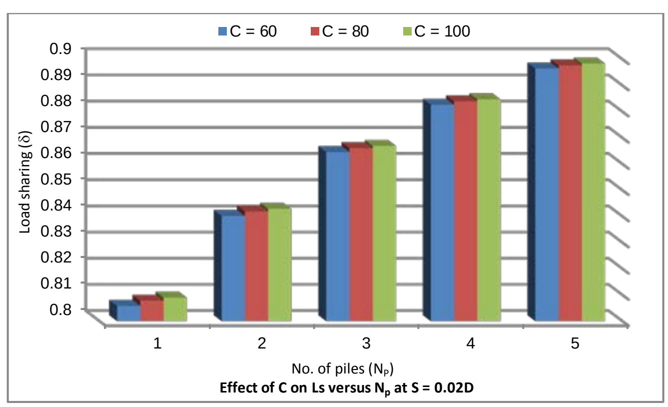

Fig.28. values of (δ) for the relation between (C) and (N_p)

ISSN 2229-5518

3.5.3 Effect of soil cohesion at different values of pile diameter

Cases studied of series no.15 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of soil cohesion (C) at different values of pile diameter (D) varying from 0.40m to 0.60m. Figures (29.a) and (29.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.15, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportional between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is constant as the pile diameter increase. In addition, it is obvious from figure (30) that the load sharing ratio (δ) is constant to the pile diameter (D) for the same soil cohesion. For all the studied cases through the parameter (C), it is noticed that the load sharing ratio (δ) is ranging from 0.865 to 0.867 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

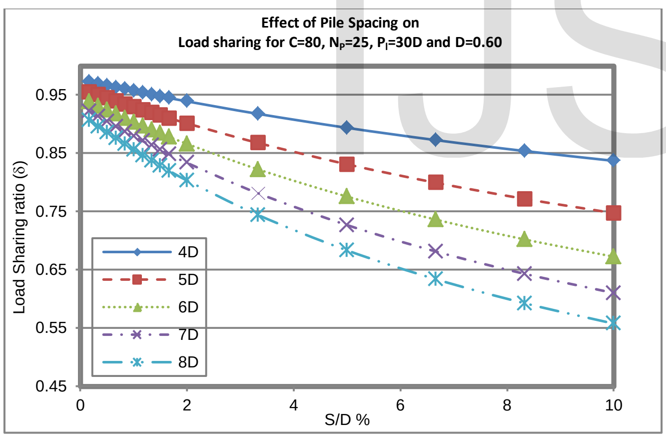

Fig. 29.a

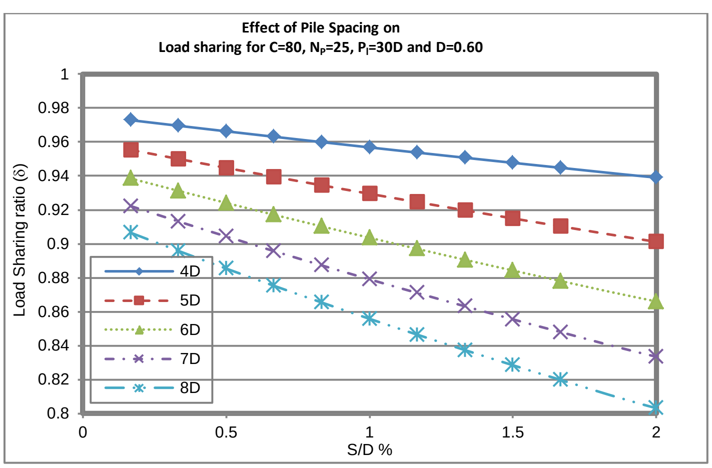

Fig. 29.b

Fig.29. Relationship between (P_s) and (δ) for different values of (D)

		D		
		0.40	0.50	0.60
C	60	0.865	0.865	0.865
	80	0.866	0.866	0.866
	100	0.867	0.867	0.867

Table.15. Values of (δ) for the relation between (C) and (D)

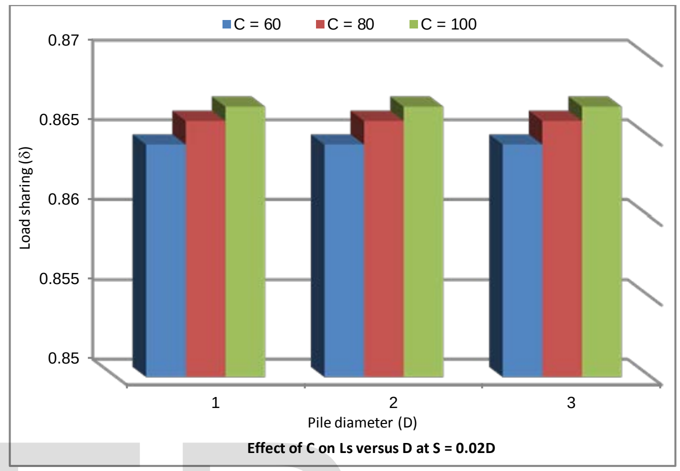

Fig.30. values of (δ) for the relation between (C) and (D)

3.5.4 Effect of soil cohesion at different values of pile spacing

Cases studied of series no.16 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of soil cohesion (C) at different values of pile spacing (P_s) varying from 4D to 8D center to center. Figures (31.a) and (31.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.16, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ)increases as the soil cohesion increase with small value. In addition, it is obvious from figure (32) that the load sharing ratio (δ) has an inverse proportional to the soil cohesion (C) for the same pile spacing. For all the studied cases through the parameter (C), it is noticed that the load sharing ratio (δ) is ranging from 0.809 to 0.896 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

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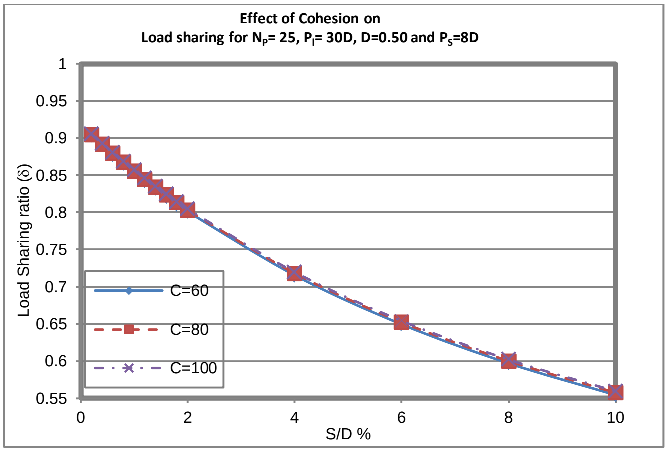

Fig. 31.a

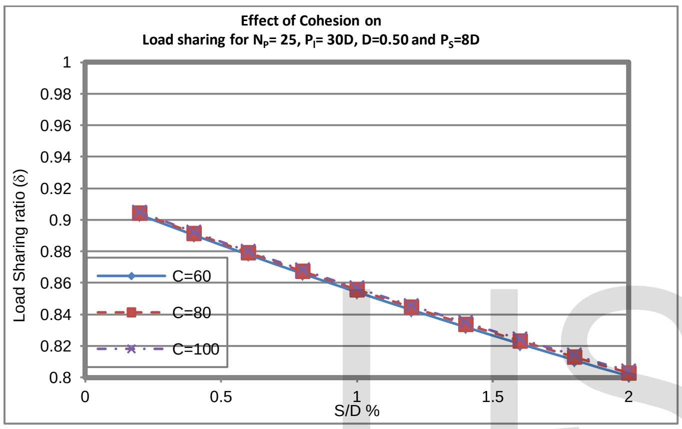

Fig. 31.b

Fig.31. Relationship between (C) and (δ) for different values of (P_s)

		P_s				
		4D	5D	6D	7D	8D
C	60	0.93	0.900	0.865	0.832	0.801
	80	0.939	0.901	0.866	0.833	0.803
	100	0.939	0.902	0.867	0.834	0.804

Table.16. Values of (δ) for the relation between (C) and (P_s)

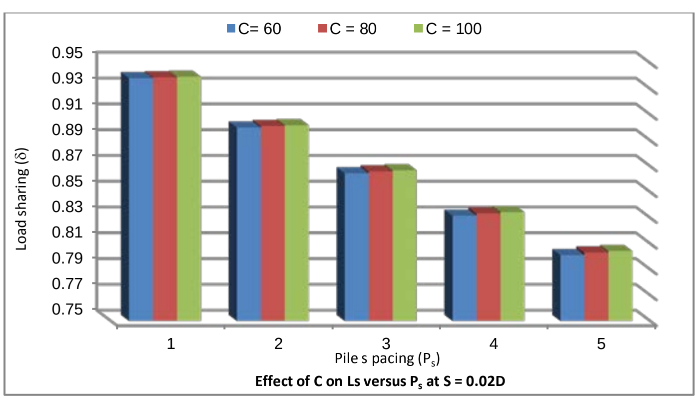

Fig.32. values of (δ) for the relation between (C) and (P_s)

3.6. Effect of pile diameter (D)

To investigate the effect of pile diameter (D) which varies from 0.40 m to 0.60 m on the relationship between load sharing ration (δ) and piles raft settlement (S), the parametric study were plotted in figures (33) to (40). Each graph represents the mentioned relationship at different values of pile diameter (D) with constant values of the other parameters Pile length (P_l), No.of piles (N_p), Soil cohesion (C), and pile spacing (P_s). Then the same investigation was repeated throughout four series. Series no.17 shows the effect of (D) for different studied values of pile length (P_l) which varies from 20D to 40D with the constant values of the other parameters (pile spacing, no.of piles and soil cohesion), By the same way, series no.18 shows the effect of (D) at different studied values of no.of piles (N_p) which varies from 9 piles to 49 piles. Whereas series no.19 represents the effect of D for different studied values of soil cohesion (C) ranging from 60KN/m² to 100KN/m² , Last series no.20 was performed to observe the effect of (D) for different studied values of pile spacing (P_s) ranging from 4D to 8D. The resulting graphical relationships represent the values of load sharing ratio (δ) versus raft-pile system settlement up to a limit value of (0.1D). on the other hand each graphical relationship was re-plotted specifically up to (0.02D) which is the allowable value of pile group settlement according to Egyptian Code of Practice (E.C.P). That, in turn means that the load sharing ratio (δ) corresponding to the settlement of (0.02D) may be considered the working load sharing ratio.

3.6.1 Effect of pile diameter (D) at different values of pile length

Cases studied of series no.17 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile diameter (D) at different values of pile length (P_l) varying from 20D to 40D. Figures (33.a) and (33.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.17, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is constant with the increase of pile diameter. In addition, it is obvious from figure (34) that the load sharing ratio (δ) is directly proportional to the pile diameter (D) for the same pile length. For all the studied cases through the parameter (D), it is noticed that the load sharing ratio (δ) is ranging from 0.812 to 0.896 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

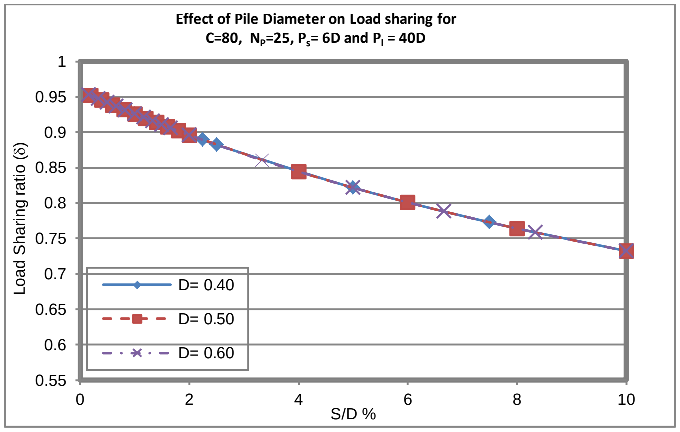

Fig. 33.a

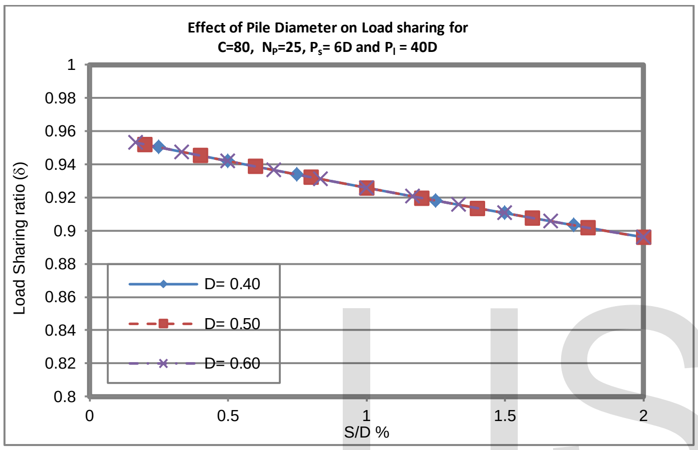

Fig. 33.b

Fig.33. Relationship between (D) and (δ) for different values of (P_l)

		P_l				
		20D	25D	30D	35D	40D
D	0.40	0.812	0.843	0.866	0.883	0.896
	0.50	0.812	0.843	0.866	0.883	0.896
	0.60	0.812	0.843	0.866	0.883	0.896

Table.17. Values of (δ) for the relation between (D) and (P_l)

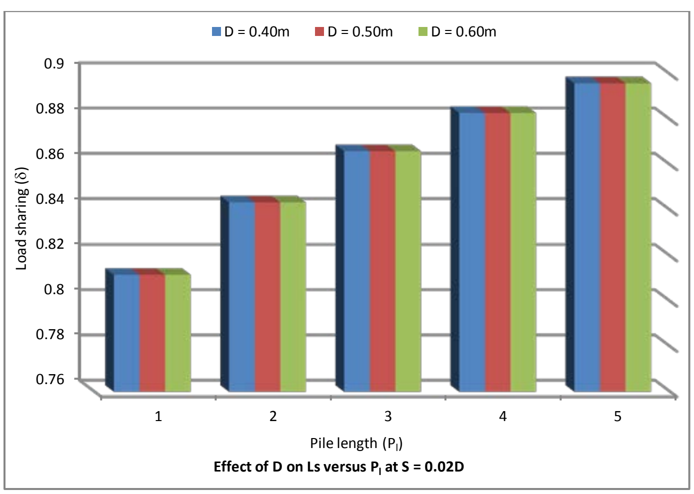

Fig.34. Relationship between (D) and (δ) for different values of (P_l)

3.6.2 Effect of pile diameter at different values of no.of piles

Cases studied of series no.18 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile diameter (D) at different values of no.of piles (N_p) varying from 9 piles to 49 piles. Figures (35.a) and (35.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.18, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is constant with the increase of pile diameter. In addition, it is obvious from figure (36) that the load sharing ratio (δ) is directly proportional to the no. of piles (N_p) for the same pile diameter. For all the studied cases through the parameter (D), it is noticed that the load sharing ratio (δ) is ranging from 0.734 to 0.957 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

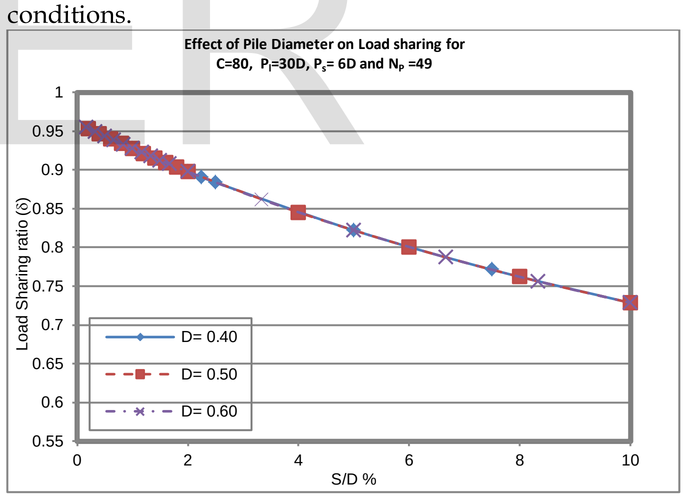

Fig.35.a

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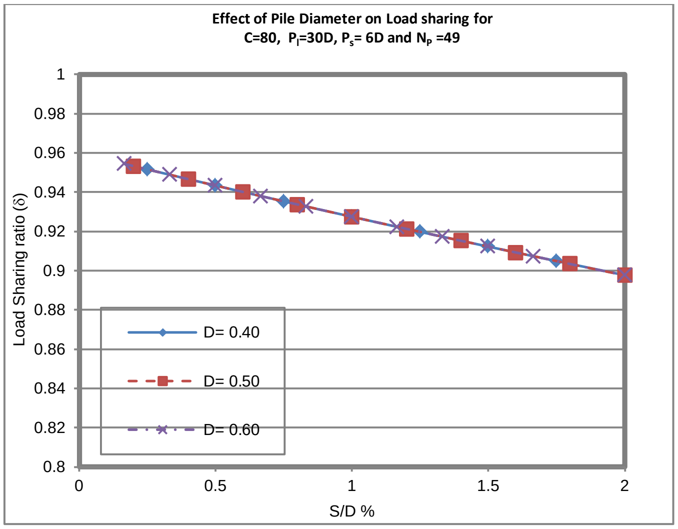

Fig.35.b

Fig.35. Relationship between (D) and (δ) for different values of (N_p)

		N_p				
		9	16	25	36	49
D	0.40	0.808	0.842	0.866	0.884	0.898
	0.50	0.808	0.842	0.866	0.884	0.898
	0.60	0.808	0.842	0.866	0.884	0.898

Table.18. Values of (δ) for the relation between (D) and (N_p)

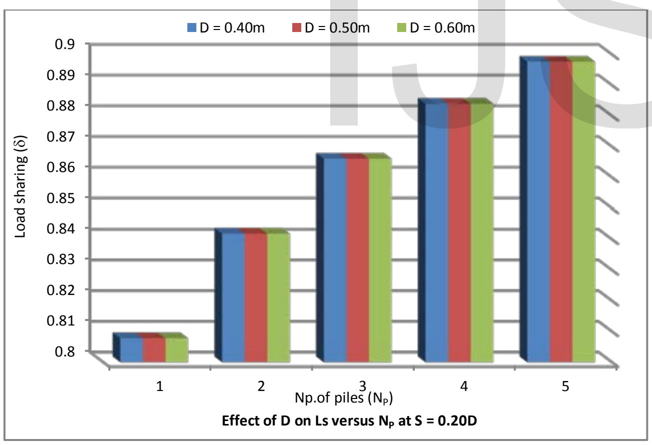

Fig.36. values of (δ) for the relation between (D) and (N_p)

3.6.3 Effect of pile diameter at different values of soil cohesion

Cases studied of series no.19 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile diameter (D) at different values of soil cohesion (C) varying from 60KN/m² to 100KN/m² . Figures (37.a) and (37.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.19, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportional between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is constant as the pile diameter increase. In addition, it is obvious from figure (38) that the load sharing ratio (δ) is increase with the increase of soil cohesion. For all the studied cases through the parameter (D), it is noticed that the load sharing ratio (δ) is ranging from 0.865 to 0.867 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

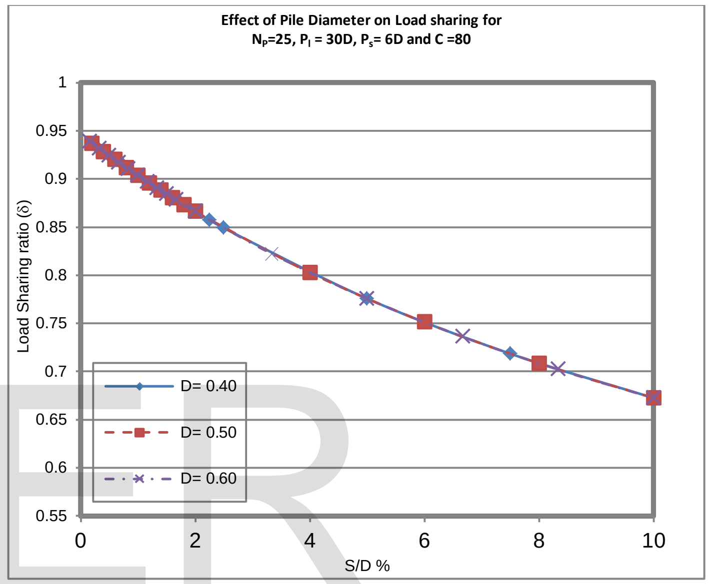

Fig. 37.a

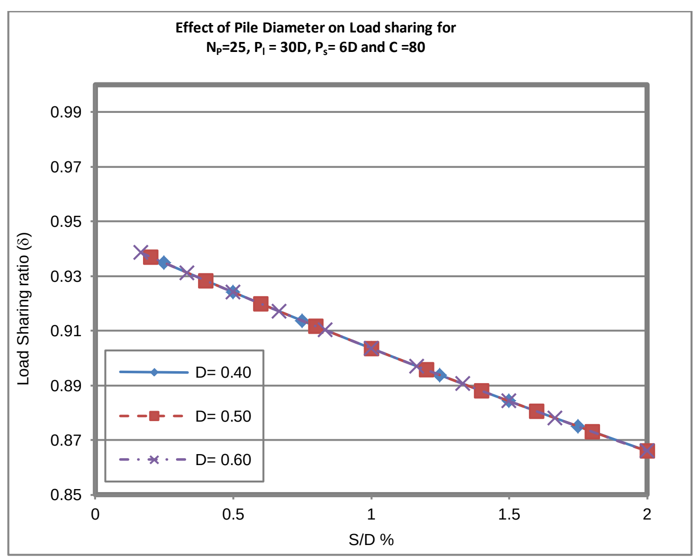

Fig. 37.b

Fig.37. Relationship between (D) and (δ) for different values of (C)

	C		
	60	80	100

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D	0.40	0.865	0.866	0.867
	0.50	0.865	0.866	0.867
	0.60	0.865	0.866	0.867

Table.19. Values of (δ) for the relation between (D) and (C)

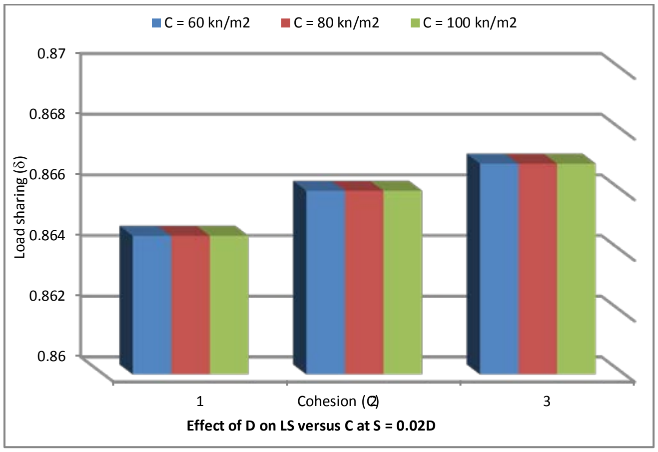

Fig.38. values of (δ) for the relation between (D) and (C)

3.6.4 Effect of pile diameter at different values of pile spacing

Cases studied of series no.20 were numerically studied by applying the closed form equation suggested by (Junhwan Lee in 2014) to calculate the load sharing ratio (δ) taking into account the variation of pile diameter (D) at different values of pile spacing (P_s) varying from 4D to 8D. Figures (39.a) and (39.b) illustrate an example of the resulting relationships between load sharing ratios (δ) and pile raft settlement (S). for all studied cases in case series no.20, the (δ) versus (S) relationships are similar in shape and behavior. Many observations can be observed from these relationships. There is an inverse proportion between the load sharing ratio (δ) and piled-raft settlement (S), and the first portion of any relationship (up to S/D = 0.02) is approximately linear. At the same settlement ratio (S/D), the load sharing ratio (δ) is constant with the increase of pile diameter. In addition, it is obvious from figure (40) that the load sharing ratio (δ) has a direct proportional to the pile diameter (C) for the same pile spacing. For all the studied cases through the parameter (D), it is noticed that the load sharing ratio (δ) is ranging from 0.803 to 0.939 at a settlement ratio (S/D) of 0.02, i.e. at the working load conditions.

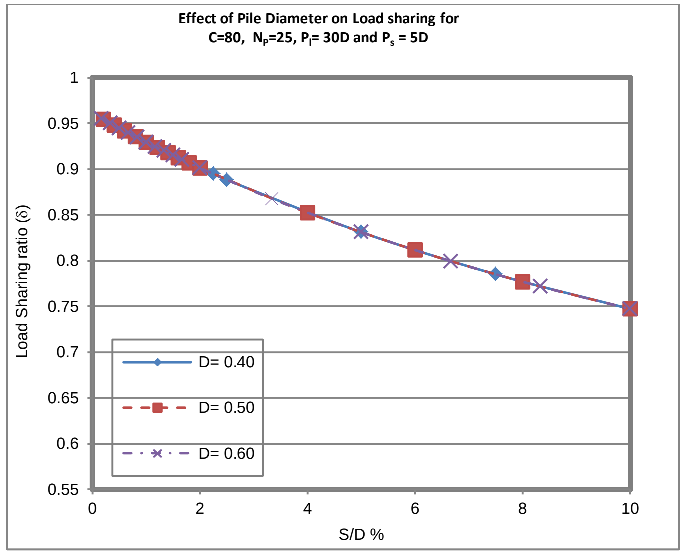

Fig. 39.a

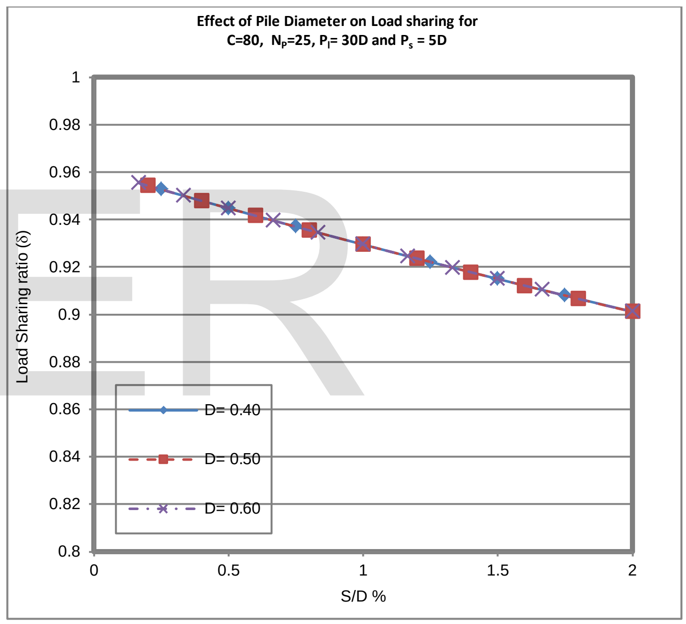

Fig. 39.b

Fig.39. Relationship between (D) and (δ) for different values of (P_s)

		P_s				
		4D	5D	6D	7D	8D
D	0.40	0.939	0.901	0.866	0.833	0.803
	0.50	0.939	0.901	0.866	0.833	0.803
	0.60	0.939	0.901	0.866	0.833	0.803

Table.20. Values of (δ) for the relation between (D) and (P_s)

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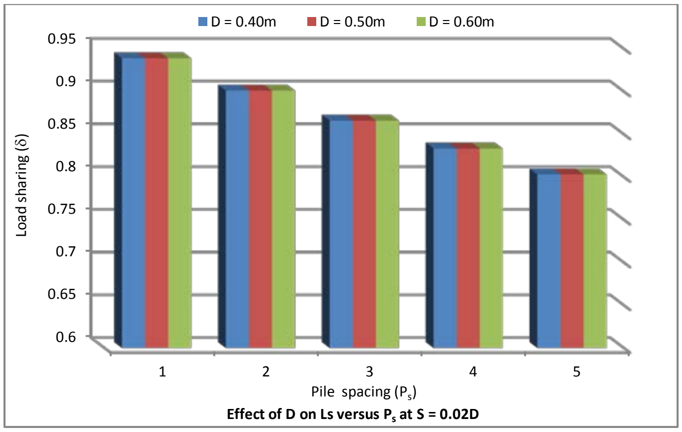

Fig.40. values of (δ) for the relation between (D) and (P_s)

4. Conclusion

- The relation between load sharing and pile diameter, pile length, number of piles, cohesion and pile spacing is non-linear, but the first portion of the graph between load sharing and piled raft system settlement is linear with maximum value of settlement equal to 0.02D.
- Some parameters have no effect on the load sharing such as pile diameter.
- Some parameters have small effect on load sharing such as soil cohesion.
- Some parameters have significant effect on load sharing such as pile length, number of piles and pile spacing.
- The relation between load sharing and pile length, pile diameter, number of piles and cohesion is direct proportion.
- The relation between load sharing and pile spacing is inverse proportion.
- The range of load sharing values can be summarized as follows:

parameters	Ranging values	Variable parameters
N_p versus P_l	0.737 to 0.921	At N_p= 9 piles and P_l= 20D to N_p= 49 piles and P_l= 40D
N_p versus P_s	0.734 to 0.957	At N_p= 9 piles and P_s= 8D to N_p= 49 piles and P_s= 4D
N_p versus C	0.806 to 0.898	At N_p= 9 piles and C= 60KN/ m² to N_p= 49 piles and C= 100KN/ m²
N_p versus D	0.808 to 0.898	At N_p= 9 piles and D= 0.40m to N_p= 49 piles and D= 0.60m
P_l versus N_p	0.737 to 0.921	At P_l = 20D and N_p= 9 piles to P_l = 40D and N_p= 49 piles
P_l versus P_s	0.731 to 0.953	At P_l = 20D and P_s= 8D to P_l = 40D and P_s= 4D
P_l versus C	0.809 to 0.896	At P_l = 20D and C= 60KN/ m² to P_l = 40D and C= 100KN/ m²
P_l versus D	0.812 to 0.896	At P_l = 20D and D= 0.40m to P_l = 40D and D= 0.60m
P_s versus N_p	0.734 to 0.957	At P_s = 8D and N_p= 9 piles to P_s = 4D and N_p= 49 piles
P_s versus P_l	0.731 to 0.954	At P_s = 8D and P_l= 20D to P_s = 4D and P_l= 40D
P_s versus C	0.801 to 0.939	At P_s = 8D and C= 60KN/ m² to P_s = 4D and C= 100KN/ m²
P_s versus D	0.803 to 0.939	At P_s = 8D and D= 0.40m to P_s = 4D and D= 0.60m
D versus N_p	0.808 to 0.898	At D = 0.40m and N_p= 9 piles to D = 0.60m and N_p= 49 piles
D versus P_s	0.812 to 0.896	At D = 0.40m and P_s= 8D to D = 0.60m and P_s= 4D
D versus C	0.803 to 0.939	At D = 0.40m and C= 60KN/ m² to D = 0.60m and C= 100KN/ m²
D versus P_l	0.865 to 0.867	At D = 0.40m and P_l= 20D to D = 0.60m and P_l= 40D
C versus N_p	0.808 to 0.898	At C= 60KN/ m² and N_p= 9 piles to C= 100KN/ m² and N_p= 49 piles
C versus P_s	0.812 to 0.896	At C= 60KN/ m² and P_s= 8D to C= 100KN/ m²and P_s= 4D
C versus D	0.803 to 0.939	At C= 60KN/ m² and D= 0.40m to C= 100KN/ m² and D= 0.60m
C versus P_l	0.865 to 0.867	At C= 60KN/ m² and P_l= 20D to C= 100KN/ m²and P_l= 40D

From 1500 case study applied on piled raft foundation the value of load sharing equal to (1E-5X + 0 .7926).
Where X = ($D.C.N_p.P_l/P_s$)

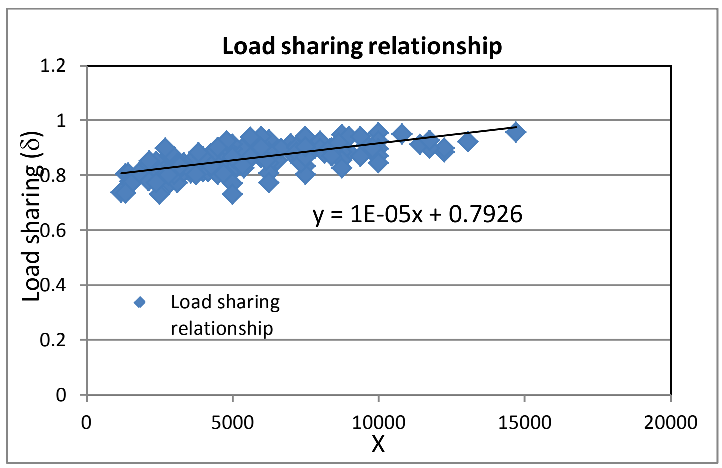

Fig.41. Load sharing relationship

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