

Foundation in Refilled Soil

Sagar Satish Tayade, Mukund M. Mahajan

Student of M-tech, Applied Mechanics Dept., Visvesvaraya National Institute of Technology (V.N.I.T.),
Nagpur, Maharashtra, India. .

Professor, Applied Mechanics Dept., Visvesvaraya National Institute of Technology (V.N.I.T.), Nagpur,
Maharashtra, India.

Abstract: In major cities due to scarcity of the space in prime locations, the construction is even proposed on refilled areas. The refilled areas may be of natural fill or engineering fill. In engineering refill the proper precaution is taken for the selection of the refill material and at most care is taken for the compaction too with the understanding that some construction may be taken in future on such areas. But this type of the filling procedure is rarely adopted. Normally the filling is done by any material including garbage with no importance given to compaction; it is just dumping of the material in to the pits of the ground. It is always beneficial to have foundations on engineering refilled soil. But however it is a matter of great concerned when the foundation will be proposed on such type of natural or man made refills. In this paper an attempt is made to study the raft foundation and raft with pile foundation on refilled man made soil.

Keywords: refilled soil, consolidation settlement, rafts foundation, piled raft foundation, SAFE software.

I. INTRODUCTION

In town planning system a ring road is provided which acts a boundary of a developed area. Out of this boundary of ring road the waste from the city including organic and inorganic material are dumped in to the pits for number of years. With the growth of cities, the area of dumping also becomes part of city and structures have to be constructed over this refill. The properties of this type of refill are unpredictable. Even in case of organic refill (eg. Sanitary landfill) the chances of settlement is more due degradation of organic matter. Foundation over such refill may be dangerous or pile foundation or drilled piers may be provided after detailed investigation of refilled soil.

Whenever a construction has to take place over natural refill, the foundation may fail in one or both i.e. strength and settlement criteria due to insufficient bearing capacity of soil and due to consolidation of refill under structural loading. Same is the condition applicable for the strata which was placed only for levelling purpose and now construction has to be carried out on such non consolidated refilled soil. This paper covers the study on some important aspects required to be considered for provision of foundation; mainly raft and piled raft type foundation over refilled strata. As per IS 2950 [1] the foundation analysis has two main approaches i.e. rigid foundation approach and flexible foundation approach. And for foundation on soft soil, normally consolidated clays, muck (refilled soil) etc. the rigid foundation approach is more justified. Kame [4] has studied both the approaches and stated that modelling of raft does not gives results closer to rigid foundation approach. Hence in this paper for the calculations of consolidation settlement; the analytical formulae considering rigid foundation approach are used. Bowels [3] have briefly given different types of refill and the type of foundations suitable for a particular type of refill strata. Among these foundations, raft foundation and piled raft foundation are common and mostly used for constructions hence these are focused in this paper. The paper mainly highlights the foundation on refilled strata; the topic is divided in to two parts i.e. refilled strata and foundation. To study this, the prime necessity is to study the behaviour of raft foundations on normal soil. The parameters observed in the study of normal soil and raft, are considered for refilled strata and are summarized in this paper. Cho [5] has performed a three dimensional non linear analysis with pile soil slip interface model for different pile configurations and the conclusions made by him are; a) the average settlement can be reduced by widely spacing the piles keeping the number of piles same. b) The differential settlement of the raft can be minimized if piles are provided at central area. c) The loading pattern greatly influences the differential settlement. Hence firstly to concentrate on uniform settlement under consolidation, in rigid approach uniform loading is assumed and in case of piled raft also the uniform and

symmetric pile configuration is adopted and throughout the refill layer the properties of refill material are assumed as same.

In this paper all the possible alternatives of providing foundation on refilled strata are summarized which will serve as a guide to consider the parameters for construction of any structure on refilled strata in safe and economic way. The parametric study carried out on normal raft and piled raft using SAFE software will also be useful for developing and improving recent trends for analysing and designing the foundations of structures on refilled strata.

II. METHODOLOGY

In most of the cases of refilled strata; uniform or differential settlement of foundation is the major criteria that should be given prime importance for analysis and design. Pile, raft or cassion are the types of foundations which are recommended for the structures resting on loose or refilled strata. Raft is mostly used under these situations if it satisfies both the load and settlement criteria. If the raft alone is able to carry the superstructure's load but it fails in settlement criteria piles are introduced to reduce the settlement of the foundation [7]. Hence it is necessary to analyse raft alone even if we have to provide piled raft foundation.

The common alternatives to provide raft on refilled strata are:

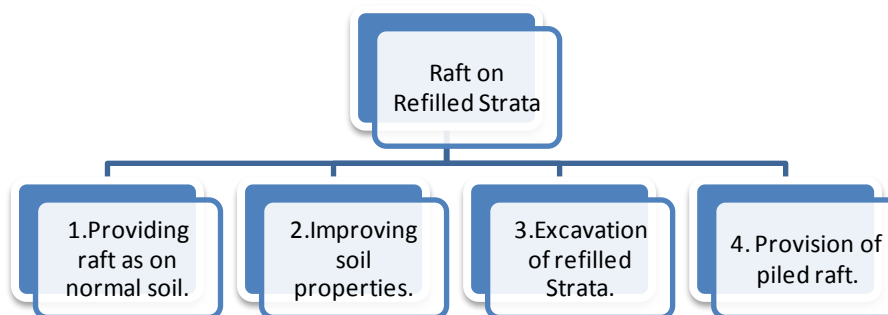


Fig. 1 Alternatives for providing raft on refilled strata.

A. Providing raft as on normal soil.

If the refill has got sufficient strength and has already consolidated under the action of existing overburden pressure; the soil can be treated as normal soil and after investigation of soil properties the foundation can be provided as on normal soil. Also the case may be that the depth of refill is small such as complete excavation of refilled strata is possible; in this case the raft can be provided on underlying normal soil.

B. Improving soil properties.

If the strength of refilled soil could be improved by effective and economic soil improving technique, the raft can be placed on this improved soil as it is provided on normal soil.

C. Excavation of refilled strata.

In most of the practical cases, it is not possible to completely excavate the refilled strata; in these cases partial excavation of the refill strata can be done such as the settlement of the underlying strata is within permissible limit.

A numerical example is considered to know the depth of excavation and the corresponding settlement of the strata. The data for this example is taken from the video lecture of National Programme on Technology Enhanced Training (NPTEL), and based on the analytical formulae for rigid foundation approach an excel program is prepared to find the settlement for various depths of foundations. The refill material is assumed as cohesive, hence Skempton's equation for calculating bearing capacity is used.

Problem statement: To find out depth of excavation for permissible settlement of foundation.

TABLE NO.1
PROPERTIES OF SOIL LAYERS

Properties	Soil Layer			
	Layer 1	Layer 2	Layer 3	Layer4
Saturated unit weight (γ) in KN/m ³	18	18	19	19
Modus of elasticity (E) in KN/m ²	42000	24500	49000	70000
Cohesion (Cu) in KN/m ²	60	35	70	100
$\frac{C_c}{1 + e_0}$	0.05	0.1	0.06	0.03
Total load in KN	7200			
Raft area in m ²	156.25			

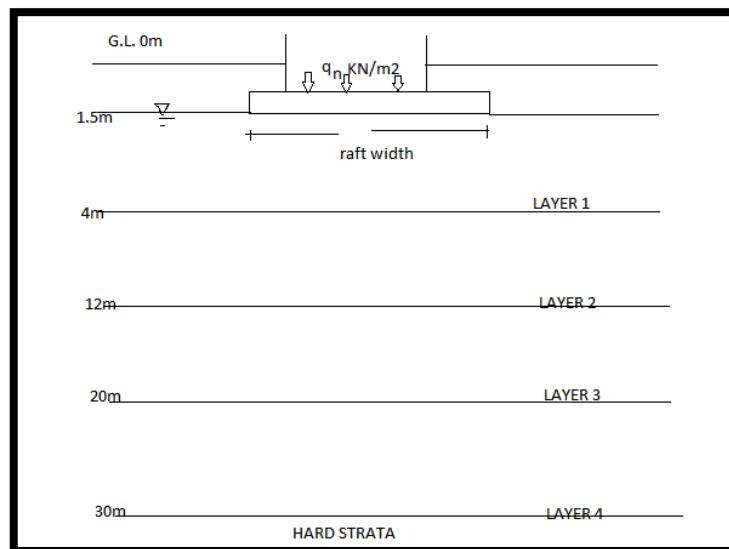


Fig. 2 Thickness of various soil layers

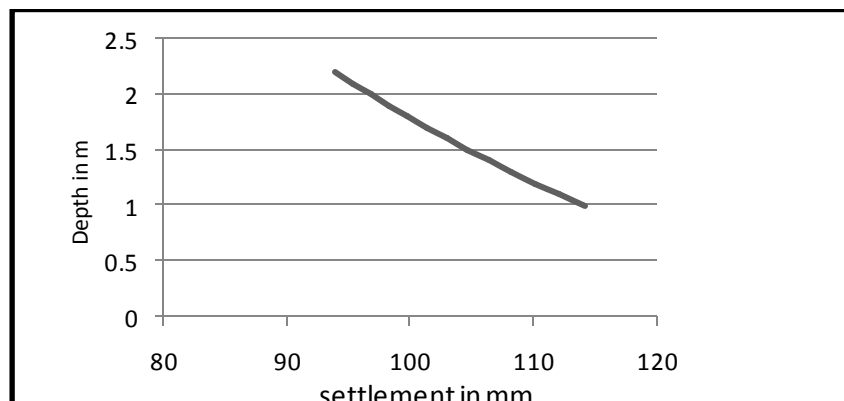


Fig. 3 A line graph for depth of excavation Vs settlement of foundation.

Hence from the results obtained above, the minimum depth at which the foundation should be placed to satisfy settlement criteria can be obtained. Along with these criteria the other criteria influencing the depth of foundation [6]

should be satisfied. To know the amount of consolidation settlement with respect to time for the load of superstructure, the oedometer test is recommended on representative refill soil sample. In the structures of heavy loading or uneven loadings to avoid the risk of uneven settlement, deep foundation can be adopted instead of raft foundation on partially excavated refilled strata.

D. Provision of piled raft.

Piles are added to raft foundation at critical locations so as to satisfy design criteria of foundation. Piles are mainly used as settlement reducers [7]. To study the behaviour of piled raft foundation many researchers have carried out the parametric study on piled raft foundation [8, 11, 12]. As the piles can be terminated at higher elevation the piled raft is considered as economical alternative to pile foundation [8].

The load from superstructure is taken partially by raft and partially by piles. The load from piles is transferred to soil partially by skin friction and partially by end bearing action. This phenomenon holds good for normal soil or consolidated refill soil, but in case of loose soil or unconsolidated refill soil load transfer due to skin friction may not be there; even it may impart negative skin friction. Hence it is important to study load sharing between piles and raft. To study the load sharing, the analytical approach given by Polous [2] is used in the numerical example. The piles are assumed to be terminated at hard strata occurring at significant depth, hence greater is the depth of raft lesser will be the pile length.

Problem statement: To find out the load sharing between raft and piles for the following data.

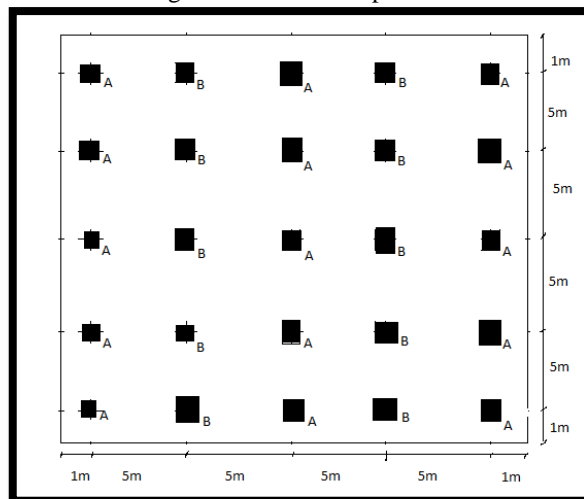


Fig. 4 Plan to show column positions and dimensions of raft

Raft size = 22m x 22 m

Raft thickness = 500mm

E_r = Modulus of raft = $2E+06$ KN/m²

E_p = Modulus of pile = $2E+06$ KN/m²

Soil modulus = $2.5E+04$ kN/m²

Poisson's ratio for raft and pile = 0.3

Poisson's ratio for soil = 0.45.

Undrained cohesion of soil = $C_u = 20.83$ KN/m²

Loading A = 3000KN, Loading B = 2000KN.

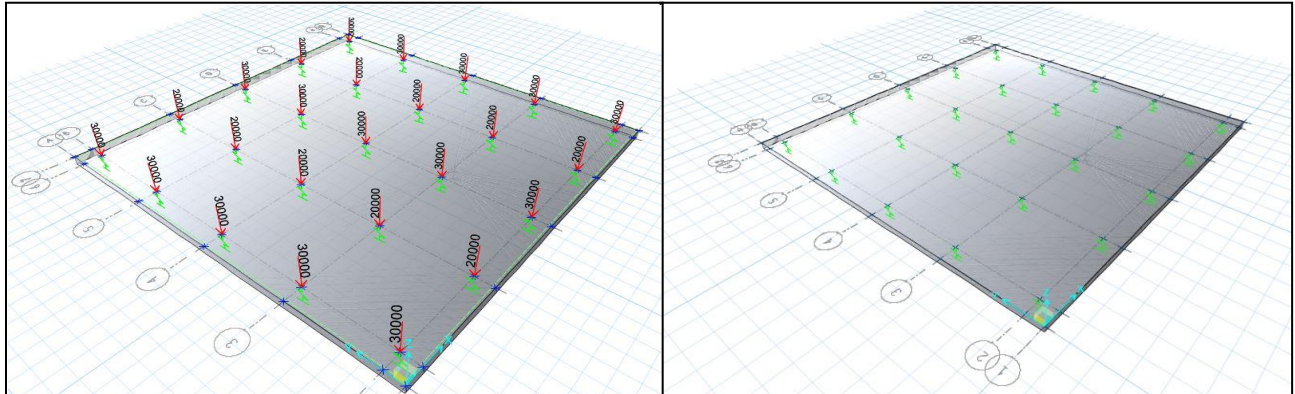


Fig. 4 Raft modelled in SAFE to show loading and pile position (piles are represented as springs)

The load sharing in this method is based on stiffness of raft and piles. The methods to find out stiffness of pile group and raft are given by Poulos [2] and Maharaj D.K. [12]. As the depth of foundation increases the length of piles reduces hence the load sharing is calculated for various lengths of piles.

TABLE NO.2
SHARING OF LOAD BETWEEN PILES AND RAFT OF PILED RAFT FOUNDATION

Sr. no.	Length of pile in meter	Load taken by raft as % of total load	Load taken by piles as % of total load
01	14	8.69	91.3
02	12	9.54	90.46
03	10	10.94	89.06
04	8	15.23	84.77
05	6	58.1	41.89

To check the behaviour of piled raft foundation the parametric study is carried out using SAFE software. The parameters affecting the behaviour of piled raft are:

1. Raft thickness.
2. Length of piles.
3. Pile configuration.

To compare the settlement behaviour of simple raft and piled raft, both the types of foundation are modelled in SAFE software. For the soil properties the data from the soil testing report is useful. Many researchers have given empirical relations to relate the soil parameters such as modulus of elasticity of soil and modulus of subgrade reaction with CBR [9] or with results of standard penetration test [10].

Raft thickness = 500mm.

$E_r = E_p = 25E+03$ MPa.

Soil modulus = $2E+04$ kN/m³

Pile Diameter = 500 mm.

Pile Length = 10 m.

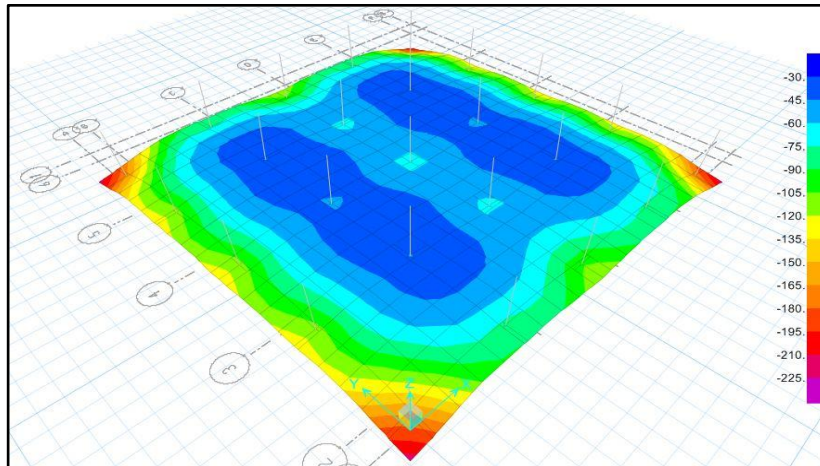


Fig. 5 Raft modelled in SAFE to show deformation pattern and total settlement.

Depending on the pile capacity, number of piles varies. But as in case of piled raft, the piles are supposed to be used as settlement reducers and used to carry some portion of load only, different pile configurations are prepared to study settlement behaviour:

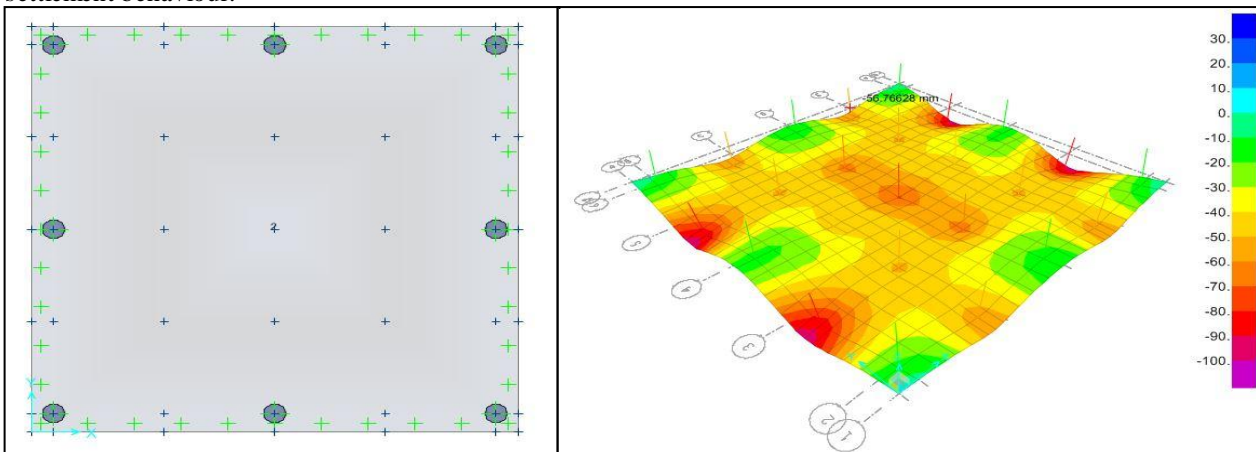


Fig. 6 Pile configuration 1 and corresponding settlement of raft.

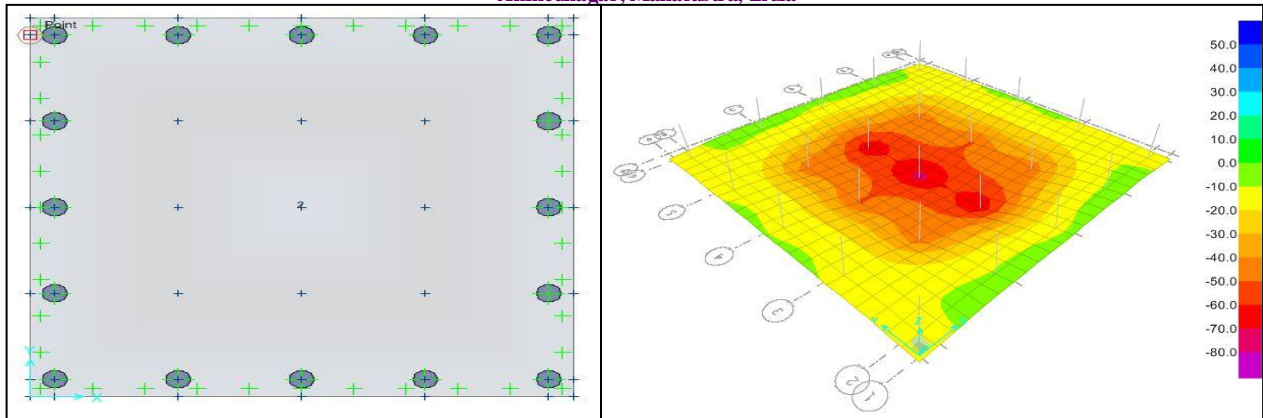


Fig. 7 Pile configuration 2 and corresponding settlement of raft.

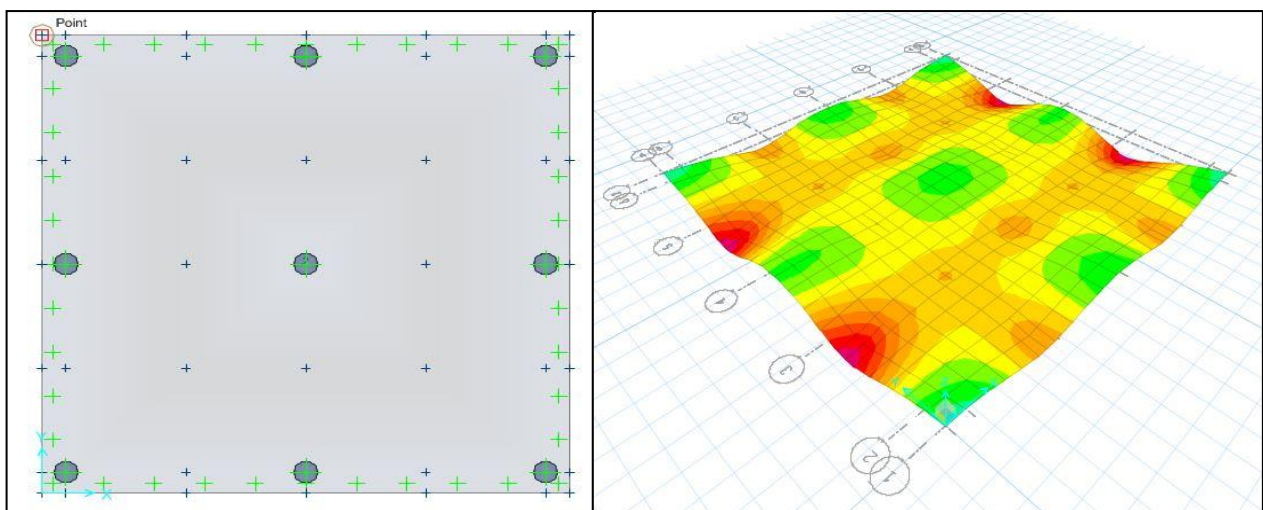


Fig. 8 Pile configuration 3 and corresponding raft settlement.

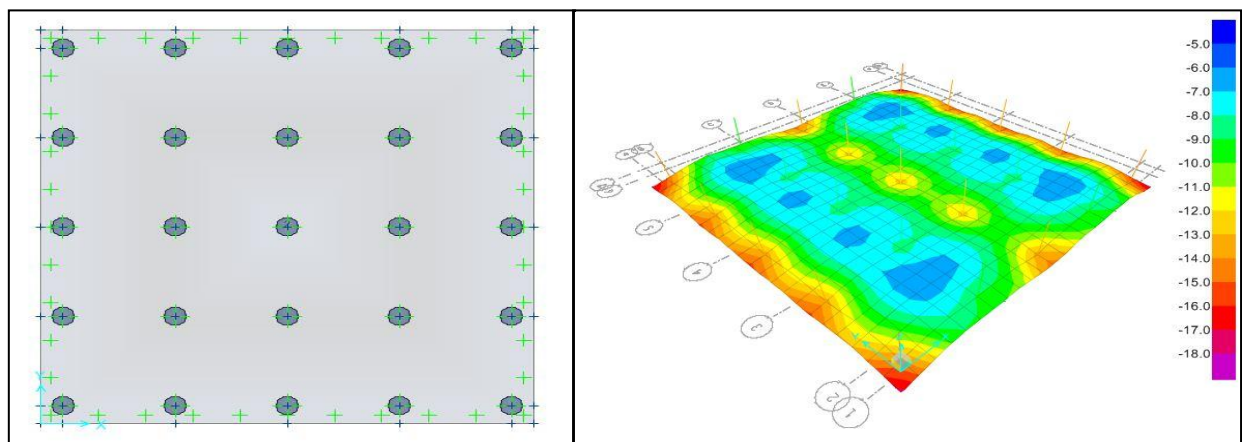


Fig. 9 Pile configuration 4 and corresponding raft settlement.

To compare the settlement of different points on a raft for different configurations of pile, some arbitrary points on raft selected and their total settlement and differential settlement with respect to each other are observed.

TABLE NO.3

COMPARISON BETWEEN SETTLEMENT OF RAFT AND PILED RAFT FOUNDATION

Raft without piles				Configuration 1				Configuration 2				Configuration 3				Configuration 4			
X direction		Y direction		X direction		Y direction		X direction		Y direction		X direction		Y direction		X direction		Y direction	
T.S	D.S	T.S	D.S	T.S	D.S	T.S	D.S	T.S	D.S	T.S	D.S	T.S	D.S	T.S	D.S	T.S	D.S	T.S	D.S
111	-	104	-	28	-	26	-	21	-	23	-	28	-	26	-	23	-	23	-
47	64	65	39	46	18	64	38	50	29	68	45	41	13	59	33	14	9	20	3
67	20	67	2	71	25	71	7	74	24	74	6	25	16	25	34	21	7	21	1
47	20	65	2	46	25	64	7	50	24	68	6	41	16	59	34	14	7	20	1
111	64	104	39	28	18	26	38	23	27	23	45	28	13	26	33	23	9	23	3

** T.S= Total settlement in 'mm' at the point of observation.

D.S= Differential settlement in 'mm' between two points of observation.

III. DISCUSSION AND CONCLUSION

Among the various alternatives to provide foundation on refilled soil, the raft foundation and piled raft foundation are mainly focused in this paper. Depending on the various factors such as age of refill, loading on refill, material used as refill etc. the strength and other physical properties of refill may change, hence if the refill is placed at site before soil testing, the refilled soil is also tested as normal soil and its properties are found out, and if needed ground improvement or partial or complete excavation of the refill is done. If the refill is required to fill at the time of construction, the quality of refill material and compaction method should be maintained. After conforming the satisfactory properties of refilled soil, the type of foundation i.e. raft foundation, deep foundation, or piled raft foundation are adopted. As settlement is one of the major criteria to decide type of foundation and piles can be used as settlement reducers, the settlement of the piled raft is studied. If the soil is under consolidated it may impart negative skin friction on piles as some part of load coming on piles, hence for providing raft at various depths for piles extending up to significant level up to hard strata, (greater will be depth lesser will be length of piles) the load sharing between raft and piles is studied and it is found that the part of total load shared by raft goes on decreasing with increase in length of pile hence depending on the depth of refill the proper depth selection for piled raft foundation is necessary. In the next part for different pile configuration settlement is observed in SAFE software and the utility of piles as settlement reducers as compared to simple raft is verified. For the larger number of piles of same diameter the total and differential settlements both are found to be decreasing for the same loading and same raft and soil properties. The paper has covered the study of most of the parameters which are important to provide foundation on refilled strata which can be useful to guide construction of any structure on refilled strata.

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International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization

Volume 3, Special Issue 4, April 2014

Two days National Conference – VISHWATECH 2014

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