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COMPARISON OF VARIOUS RETROFITTING TECHNIQUES TO ENHANCE THE FOUNDATION CAPACITY OF AN EXISTING MULTI-STOREYED R.C. BUILDING

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Abstract:** Taller buildings are preferably considered so as to accommodate the increasing population. It is a solution to the shortage of land for building construction. Thus, storey extensions are an increase popular way to densify cities. In cases where there is a need to extend the existing building, it poses enormous risk because of the fact that they were constructed without considering the aspect of further extension. Foundation undergoes an increase in settlement due to augmented loads because of the addition of storeys. Generally, retrofitting codes have given little attention to retrofitting of foundations due to its complexity in construction. In this paper different methods to retrofit the foundation are discussed so as to reduce the settlement for the vertical extended structures. Enlarging the area of foundation, underpinning with four end bearing piles of varying dimensions and underpinning with a group of nine end bearing piles. The analysis showed that as the height of the building increased, the settlement of the foundation increased but the percentage increase in the settlement value decreased with each addition of storey. The percentage increase in the settlement values of the existing was more with the addition of one storey than with the addition of two storey. The method of enlarging the foundation reduced the settlement values by 20.23% in case for the addition of one storey and by 19.55% for the addition of two storeys. About 82.21% reduction in differential settlement value was obtained in case of using end bearing piles of size 300mm x 300mm, 85.7% due to piles of size 400mm x 400mm, 89.37% due to piles of size 500mm x 500mm and the maximum reduction of 92.74% in the case of group of nine underpinned piles. As the dimension of the underpinning pile augments, the stiffness of the pile increases therefore the settlement value decreased.

Keywords: foundation, retrofitting, settlement, differential settlement, ANSYS, nonlinear finite element analysis.

I.INTRODUCTION

The new structures are constructed by keeping the situation of shortage of land as an important aspect. But some buildings that are designed without the consideration of the need of further vertical extension, the cost of demolition of the building, destruction of material, creation of solid waste destined for landfills are encouraging to reuse and upgrade the existing building. Thus, to extend an existing building, the substructure part of the building which is the foundation, needs to be strengthen for the upgradation in the building in terms of the addition of floors or additional loadings. Retrofitting modifies the foundation capacity to bear the additional loads and it also reduces the increased settlement values.

Researches have been carried out to analysis the methods of retrofitting the foundation in order to enhance its capacity. [1] studied the effect of additional 200mm sized minipiles into the foundation so as to enhance the foundation capacity in order to bear the additional four storeys on top of existing buildings. [2] discussed various retrofitting methods for existing foundation in seismological active regions. Retrofitting with micropiles and strengthening of existing piles were the most practical found approaches. [3] analysed settlement law during the underpinning process of a framed structure by using the three-dimensional finite element model based on ANSYS program. End bearing piles composed with beam were used to retrofit the existing pile foundation. Settlement value and differential settlement was obtained through adjusting the length, which increased settlement value and differential settlement.

In this paper a comparison between the methods of enlarging the area of foundation, underpinning with four piles of sizes 300mm x 300mm, 400mm x 400mm, 500mm x 500mm at each corner of the foundation and underpinning with group of nine piles was made in order to reduce the increased settlement values due to the addition of storeys in an existing building. A nonlinear finite element analysis was carried out in ANSYS software.

II.METHODOLOGY

In finite element analysis, the existing designed foundation of the building was analysed for the existing support reactions, support reactions due to addition of one storey and support reactions due to addition of two storey. Load settlement results were obtained for these three load cases. Methods were applied with the objective to reduce the settlement of foundation for extended building structure.

2.1 GEOMETRIC MODELLING

In this research, a two storeyed building was modelled in STAAD PRO software. The analysis was carried out in the software for the following data:

Two storeyed building with floor to floor height: 3.2m
Depth of foundation below GL: 1.5m
Thickness of slab at each floor: 0.125m
External wall thickness: 0.23m
Internal wall thickness: 0.11m
Sizes of columns: 450mm x 400mm
500mm x 500mm
600mm x 500mm
600mm x 600mm
Sizes of beams: 500 x 400 mm
500 x 450 mm
Live loads on floors: 3kN/m^2
Live load on roofs: 3kN/m^2
Zone: IV

Support reactions obtained from the analysis of the building were considered in designing the existing foundation. The designed existing foundation of the building was modelled in ANSYS software for its finite element analysis.

2.2 FINITE ELEMENT MODELLING

2.2.1 Element type

The element type used for this modelling are as follows:

MATERIAL TYPE ELEMENT	ANSYS
CONCRETE	Solid65
STEEL REINFORCEMENT	Link180

To model the concrete a Solid65 element was used which is available in the element library of the ANSYS software. It has eight nodes with three degrees of freedom at each node translations in the nodal x, y and z directions. The element is capable of plastic deformation. Fig 1 shows a schematic diagram of the element.

A Link180 element is used to model steel reinforcement. This element is a 3D element with two nodes and three degrees of freedom translations in the nodal x, y and z directions. This element is capable of plastic deformation. The element is shown in Fig 2.

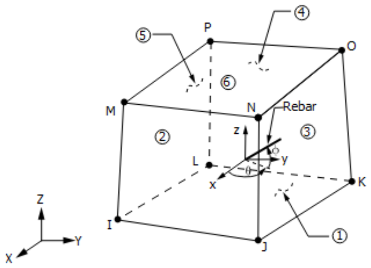

Fig 1 Solid65 element

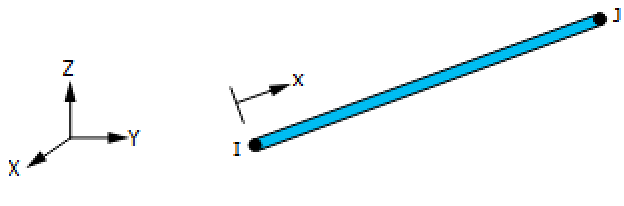

Fig 2 Link180 element

2.2.2 Commands used for the FEM

Commands are used in pre-processing for the analysis. Following are the commands that were used in pre-processing:

Commands for Solid65: ET,matid,65

Commands for Link180: ET,matid,180
SECTYPE,matid,link
secdata,201.6

Commands used pre-processing:
/prep7
ESEL, S, Ename, , 180
ESEL, a, Ename, , 65
NSLE, S, all
CPINTF, all, 0.0001
allsel
/solu

2.2.3 Supports used for the foundation

Elastic Support: This support allows one or more faces (3D) or edges (2D) to move or deform according to a spring behaviour. The Elastic Support refers to Foundation Stiffness which is defined as the pressure required to produce a unit normal deflection of the foundation and is measured in units as N/mm3. This value of pressure is corresponding to the subgrade modulus of reaction which is calculated on the basis on soil properties and the dimensions of foundation.

2.2.4 Material properties

Material properties were assigned through the option of material properties which is inbuilt in the software. Properties of concrete and steel are given as follows:

TABLE I : PROPERTIES OF CONCRETE

S.No.	Properties	Concrete
1.	Grade	M30
2.	Young's Modulus	30000 (N/mm^2)
3.	Density	2500 (kg/m^3)
4.	Bulk modulus	1.56 E+10 (Pa)
5.	Shear modulus	1.27 E+10 (Pa)

TABLE II : PROPERTIES OF STEEL

S.No.	Properties	Steel
1.	Grade	Fe500
2.	Young's Modulus	200000 (N/mm^2)
3.	Density	7850 (kg/m^3)
4.	Bulk modulus	1.66 E+11 (Pa)
5.	Shear modulus	7.69 E+10 (Pa)

TableIII: Properties of Sand

S.No.	Properties	Sand
1.	Bearing capacity	150 (kN/m^2)
2.	Soil modulus	20000 (kN/m^2)
3.	Poisson's ratio	0.3
4.	Subgrade modulus reaction	0.013 (N/mm^3)

2.2.5 Non-linear analysis

In non-linear analysis, the total load applied to a finite element model is divided into a series of load increments called load steps. At the completion of each incremental solution, the stiffness matrix of the model is adjusted to reflect nonlinear changes in structural stiffness before proceeding to the next load increment. The ANSYS program uses Newton Raphson equilibrium iterations for updating the model stiffness. Newton Raphson equilibrium iterations provide convergence at the end of each load increment within tolerance limits.

Foundation for node 444	Storey height (m)	Settlement (mm)	% increase	Differential settlement (mm)	% increase
Existing foundation (2 m x 1.8 m)	7.9	21.9	-	16.4	-
	11.1	34.1	55.7	24.02	46.4
	14.3	44.5	30.4	28.45	18.44

TABLE IV SETTLEMENT OF THE EXISTING FOUNDATION

III.LOADINGS

Three FEM models were analysed for a foundation of size 2m x 1.8m with a rectangular column of size 600mm x 500mm. All the three models (1) existing foundation with the support reactions for two storeyed building as: vertical force F_Y = 600kN, M_X = +124 kNm, M_Z = -10 kNm (2) existing foundation with the support reactions for the three storeyed building as: vertical force F_Y = 965kN, M_X = +180 kNm, M_Z = -11 kNm (3) existing foundation with the support reactions for the four storeyed building as: vertical force F_Y = 1325kN, M_X = +215 kNm, M_Z = -11 kNm are analysed and load settlement results were obtained. Fig 3, Fig 4 and Fig 5 shows the load settlement values for the existing foundation. Table 4 refers to the obtained settlement and differential settlement values of existing foundation due to the cases mentioned above.

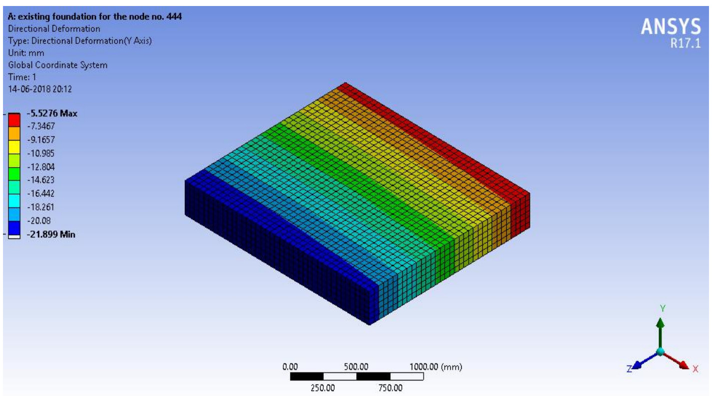

FIG.3 LOAD SETTLEMENT RESULTS OF EXISTING FOUNDATION DUE TO THE EXISTED BUILDING

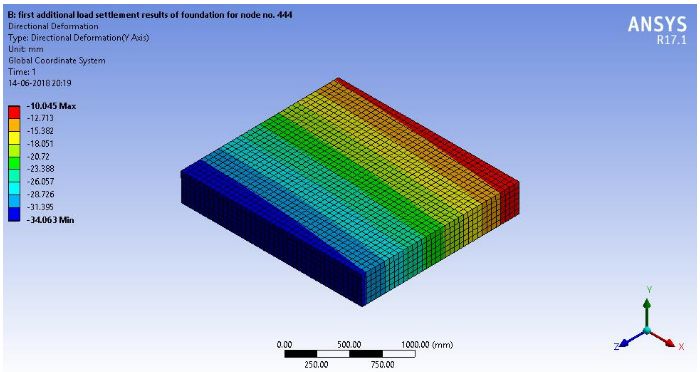

FIG.4 LOAD SETTLEMENT RESULTS OF EXISTING FOUNDATION DUE TO ADDITION OF ONE STOREY

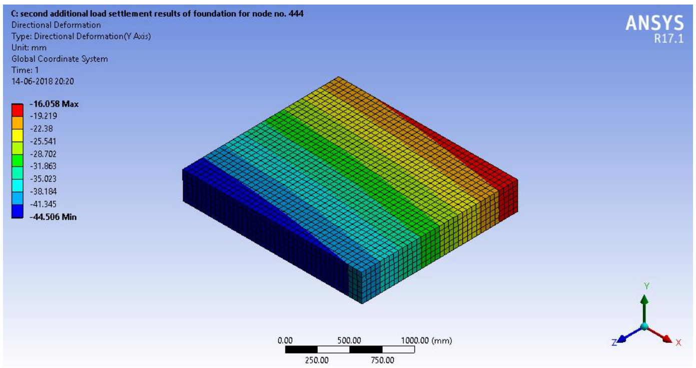

FIG.5 LOAD SETTLEMENT RESULTS OF EXISTING FOUNDATION DUE TO ADDITION OF TWO STOREY

Table 4 Shows that with the addition of one storey the settlement value increased by 55.7% and differential value increased by 30.4% than the settlement and differential value due to the existing building. With the addition of two storeys, the settlement and differential settlement value increased by 46.4% and 18.44% respectively than the values corresponding to the addition of one storey. This showed that with the addition of one storey to two storeys in the building, the percentage increase in the settlement and differential settlement values of the foundation decreases.

IV.RETROFITTING METHODS

Three methods were used to retrofit the foundation so as to bring down the increased settlement values of existing foundation, within the limits of 25mm and to get the increased differential settlement values within 20mm.

Method 1. Enlarging the area of foundation

The area of the foundation is enlarged by inserting reinforced bars into the foundation and extending the faces of existing foundation up to 250mm in each direction to enlarge the area. Fig.6 shows foundation retrofitted to enlarge its area.

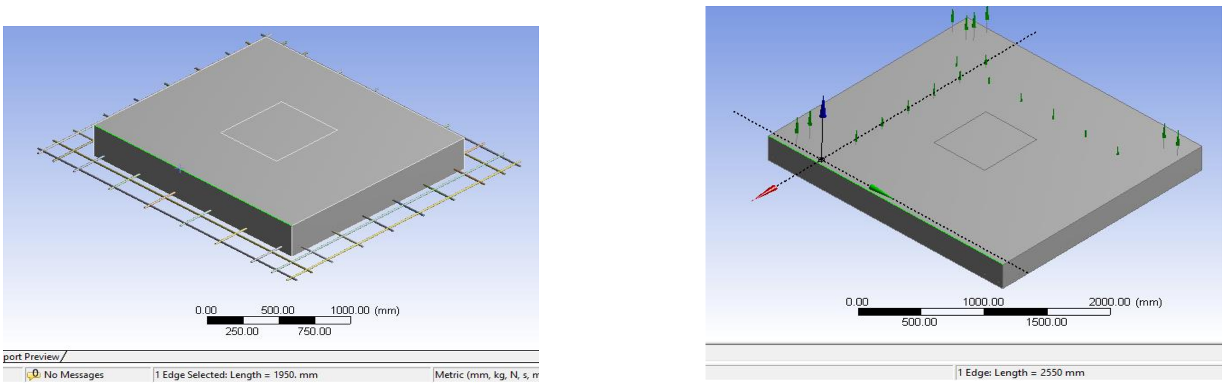

FIG.6 ENLARGING THE FOUNDATIONAL AREA FROM 2M X 1.8M TO 2.5M X 2.3M

Method2. Underpinning with the end bearing piles of varying dimensions

When increasing the area of a footing is not sufficient, it becomes necessary to underpin the foundation. This is achieved by transferring the load of the existing structure to a deeper level after installing additional piles. The piles are connected to the existing footing. Existing foundation was retrofitted with four piles at each corner of the foundation of sizes (1) 300mm x 300mm (2) 400mm x 400mm (3) 500mm x 500mm. Fig 7, Fig 8 and Fig 9 shows underpinned piles of mentioned sizes.

Method3. Underpinning with a group of nine end bearing piles

Existing foundation is retrofitted by underpinning with nine end bearing piles of size (1) 350mm x 300mm. Fig 10 shows underpinned group of piles

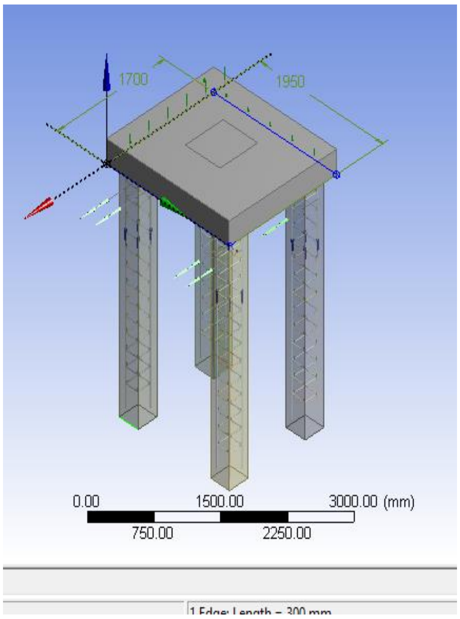

FIG.7 RETROFITTING OF EXISTING FOUNDATION WITH END BEARING REINFORCED CONCRETE PILES OF SIZE 300MM X 300MM

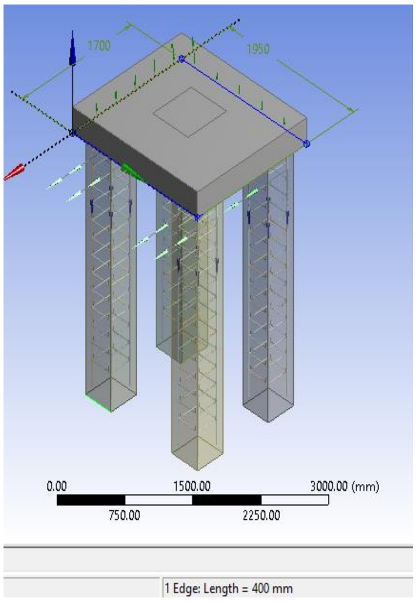

FIG.8 RETROFITTING OF EXISTING FOUNDATION WITH END BEARING REINFORCED CONCRETE PILES OF SIZE 400MM X 400MM

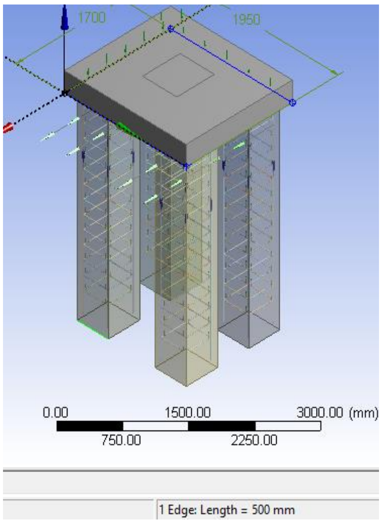

FIG.9 RETROFITTING OF EXISTING FOUNDATION WITH END BEARING REINFORCED CONCRETE PILES OF SIZE 500MM X 500MM

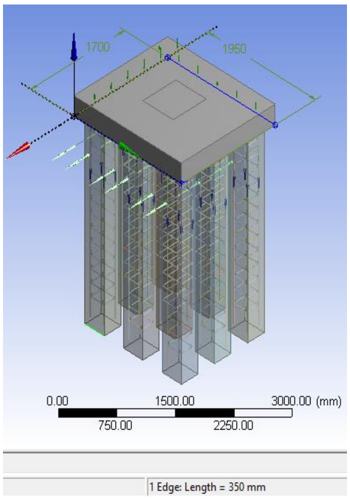

FIG.10 RETROFITTING OF EXISTING FOUNDATION WITH END BEARING REINFORCED CONCRETE PILES OF SIZE 350MM X 300MM

V.RESULTS AND COMPARISONS

Settlement and differential settlement results were obtained for the existing foundation and retrofitted foundations. The comparison was made on the basis of obtained values of settlement and differential settlement. Table V shows different settlement values obtained and percentage decrease from the existing foundation settlement values.

TABLE:V COMPARISON OF SETTLEMENT AND DIFFERENTIAL SETTLEMENT VALUES FOR DIFFERENT RETROFITTED METHODS

Method	Storey height (m)	Settlement (mm)	% decrease	Differential settlement (mm)	% decrease
Enlarging the area	7.9	17.6	20.4	13.08	22.3
	11.1	27.2	20.23	18.9	21.31
	14.3	35.8	19.55	22.57	20.66
Underpinning with four piles of size 300mm x 300mm	7.9	13.1	40.18	2.91	82.25
	11.1	20.7	39.29	4.26	82.26
	14.3	27.9	37.3	5.08	82.14
Underpinning with four piles of size 400mm x 400mm	7.9	11.9	45.66	2.35	85.67
	11.1	19	44.28	3.39	85.88
	14.3	25.8	42.02	4.11	85.55
Underpinning with four piles of size 500mm x 500mm	7.9	10.7	51.14	1.7	89.63
	11.1	17.1	49.85	2.57	89.3
	14.3	23.3	47.64	2.99	89.2
underpinning with nine piles of size 350mm x 300mm	7.9	10.5	52.05	0.96	94.14
	11.1	17	50.14	1.9	92.08
	14.3	23.1	48.08	2.25	92.01

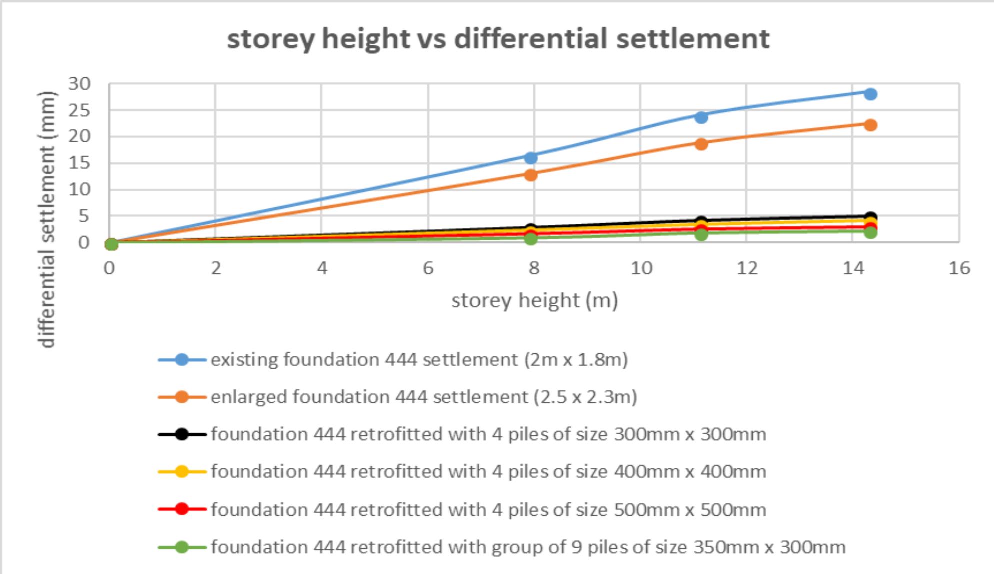

FIG.11: COMPARISON OF VARIOUS RETROFITTING TECHNIQUES ON THE BASIS OF SETTLEMENT VS STOREY HEIGHT

From Table V it was evident that by retrofitting the existing foundation with the mentioned methods there is a decrease in the settlement and differential settlement values. Out of the four methods the optimum method is underpinning the foundation with group of nine piles by which the value of settlement is reduced by 50.14% (for addition of one storey), 48.08% (for addition of two storey) and differential settlement value is reduced by 92.08% (for addition of one storey), 92.01% (for addition of two storey). It was seen that the settlement values are reduced more with the increase in the size of the underpinned piles. Underpinning with the piles gave the minimum value of differential settlement for the foundation. Fig.11 and Fig.12 gives the graphical comparison among the various methods applied.

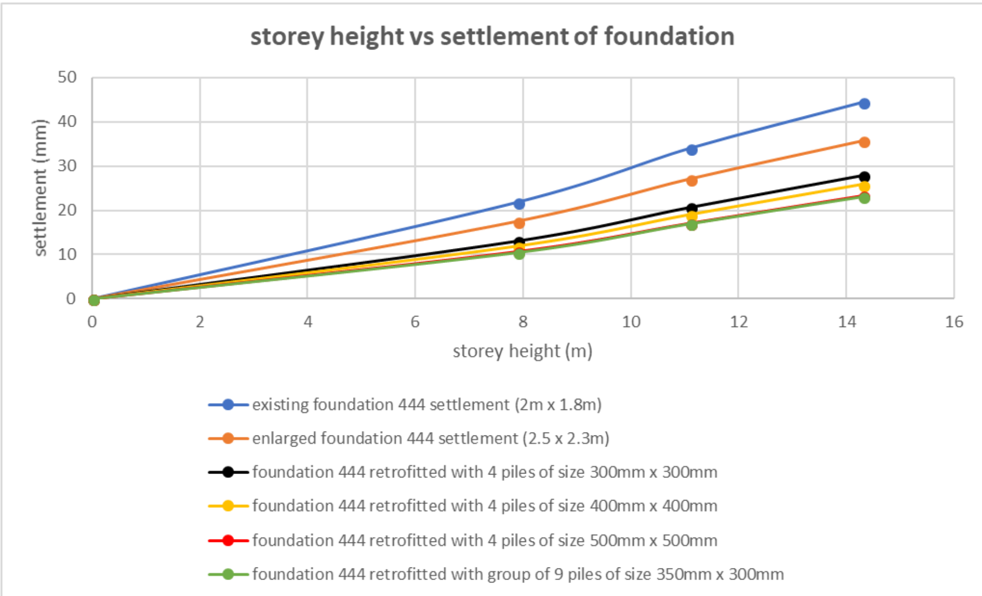

FIG.12: COMPARISON OF VARIOUS RETROFITTING TECHNIQUES ON THE BASIS OF DIFFERENTIAL SETTLEMENT VS STOREY HEIGHT

VI.CONCLUSIONS

The conclusions that emerged from the non-linear finite element analysis are as follows:

1. As the height of the building increased the percentage increase in the settlement values decrease. The percentage increase in the settlement values of the existing was more with the addition of one storey than with the addition of two storey.

2.The increased settlement and differential settlement values of the existing foundation were 55.7% and 46.4% respectively for the addition of one storey.

3.The increased settlement and differential settlement values of the existing foundation lies in the range of 30.4% and 18.44% respectively for the addition of two storeys.

4. The method of enlarging the foundation reduced the settlement values by 20.23% in case for the addition of one storey and 19.55% for the addition of two storeys. Thus, it can be concluded that in case of sand foundation the increase in size of footing improves the bearing capacity and reduces the settlement values.

5. Percentage reduction in settlement value due to underpinning with piles of size 300mm x 300mm was 39.29% (for addition of one storey) and 37.3% (for addition of two storeys).

6. Percentage reduction in settlement value due to underpinning with piles of size 400mm x 400mm was 44.28% (for addition of one storey) and 42.02% (for addition of two storeys).

7. Using piles of size 500mm x 500mm reduced the settlement values of the existing foundation by 49.85% (for addition of one storey) and 47.64% (for addition of two storeys).

8. As the dimension of the underpinning pile augments, the stiffness of the pile increases therefore the settlement value decreases.

9. The method of underpinning with group of nine piles showed the maximum reduction in settlement values by 50.14% (for addition of one storey) and 48.08% (for addition of two storeys).

10. Foundation retrofitted with underpinned piles considerably reduced the differential settlement value. About 82.21% reduction in differential settlement value was obtained in case of using end bearing piles of size 300mm x 300mm, 85.7% due to piles of size 400mm x 400mm, 89.37% due to piles of size 500mm x 500mm and the maximum reduction of 92.74% in the case of group of nine underpinned piles.

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