Studying of the Effect of Soil Settlement under Different Types of Footings on Multistory Buildings

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ABSTRACT

The aim of this paper is to study the effect of soil settlement under different types of footings for multistory Buildings. Soil settlement sometimes occurs under the foundations due to bad soil compaction, water pipe leakage, soil erosion and excavation on neighboring site. Also the similar effect might occur due to columns damages happened by explosion. Settlement effect on the moment and shear in beams and footing was studied. Also the effect of columns load and maximum base pressure under footing was studied. Building with dimensions 16*16 meters with four spans in both ways was assumed for studing in this paper, the building has three stories. Software STAAD.ProV8i was used in the analysis, finite elements are used to represent the slabs and footings. The soil subgrade reaction was used to represent soil in software.

Four types of footings were taken in this study which are spread footing, spread footing with tie beam, contineous footing and raft footing. Two settlement positions in the building was studied, the first one is under the internal footing and the second one is under exterior footings. The effect of tie beam dimension increasement and settlement in part of spread footing were studied also. The study clearly show that, the continuous footing is a very good selection because it shows a very good response against settlement, keep the settlement within allowed values and has lower cost than the raft footing. The study recommends to avoid using spread footing with or without tie beam. Tie beam dimension increasement has little effect to improve spread footing. Also,the study recommends suitable values of additional saftey factors for column and beam design when settlement is expected.

Kewords: soil settlement; footing; multistory building; subgrade reaction

INTRODUCTION

Soil settlement sometimes occurs under footings due to bad soil compaction, water pipe leakage, soil erosion as shown on plate 1, excavation on neighboring site to construct new buildings or retaining wall as shown in plate 2.

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Plate 1: Soil erosion under Spread footing

Plate 2: Excavation on neighbor site.

Also the similar effects might occur due to columns damages happened by explosion as shown in plates 3 and 4.

Plate 3 and 4: Column damage due to explosion.

The settlement position in the building has large effect on the type and magnitude of stresses in structural members, therefore two positions were studied. The first one is under the internal footing B4 (2.4 m* 2.4 m) and the second one is under footings along axis 5 (0.85 m from both sides of axis 5 i.e 1.7 m wide). Four types of footings were taken in this study which are spread footing, spread footing with tie beam, contineous footing and raft foundation as shown in figures 1 throgh 4.

Building Specification and Applied Loads:

Preliminary member sections was selected for analysis, many itrations was done to select suitable sections for columns and beams [1]. Suitable footing dimensions was chosen according to allowable bearing capacity [2] [3]. Table 1(a) and Table 1(b) Show the building specification and structural member dimensions. Figures 1 through 4 gives the dimensions of building:

Table 1(a): Building Specifications

No.	Building Specifications Details	Unit	Amount
1	Dimension in X-axis	meter	16
2	Dimension in Y-axis	meter	16
3	No. of Spans in X-axis	No.	4
4	No. of Spans in Y-axis	No.	4
5	No. of Stories	No.	3
6	Height of each story	meter	3
7	Allowable Bearing Capacity for Soil	kN/m2	150

Table 1(b) Structural members dimensions

Slab Thickness (mm)	Beams Dimensions (mm)		Column Dimension (mm)	
	Width	Height (including slab thickness)	Width	Length
150	300	400	300	300
Footings Dimensions (mm)				
Footing type	Thickness	Footing Dimension	Tie Beam Dimension	
			Width	Height
Spread Footing (SF)	450	middle 2400*2400, exterior 1700*1700, corner 1200*1200		
Spread Footing with Tie Beam (SFT)	450	Same as Spread Footing above	300	400
Continuous Footing (CF)	450	800 as shown in Figure 3		
Raft Footing (RF)	450	As Shown un Figure 4		

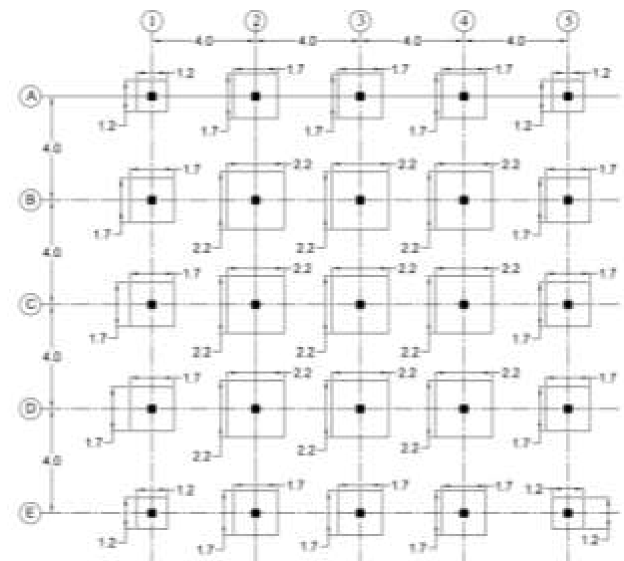


Figure (1): Spread Footing Plan.

Software STAAD.ProV8i[٤] is used in this study with the following load cases [٥]:

1. Dead Load:

1.1. Building self-weight will be automatically calculated by the software.

1.2. Finishing load 2 kN/m^2 on all floors.

1.3. Wall load 10 kN/m on all beams in first and second floors and 3 kN/m in perimeter beams for roof slab.

2. Live Load:

2.1. First and second floors 3 kN/m^2 and 1.5 kN/m^2 for roof [٦].

3. Ultimate Load = 1.2 DL + 1.6 LL

4. Working Load = DL + LL

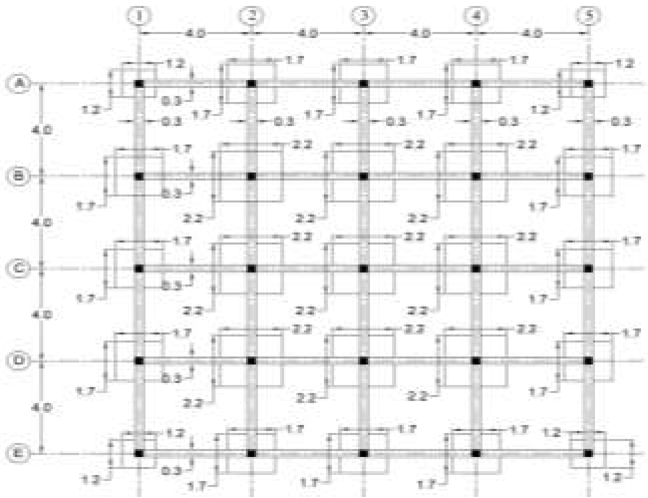


Figure (2): Spread Footing with Tie Beam Plan.

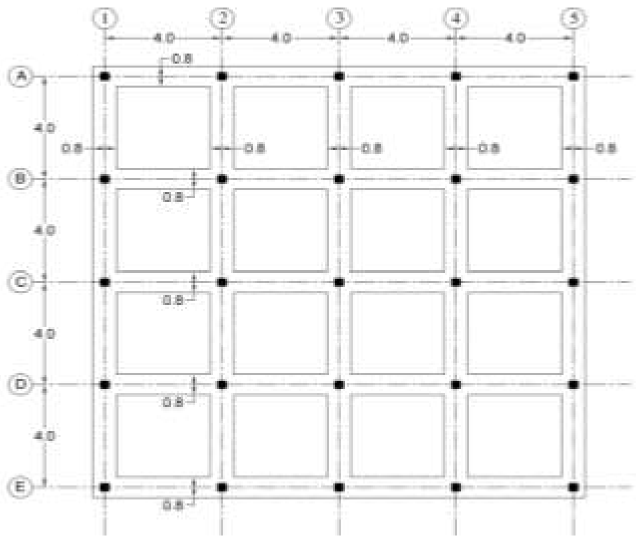


Figure (3): Continuous Footing Plan.

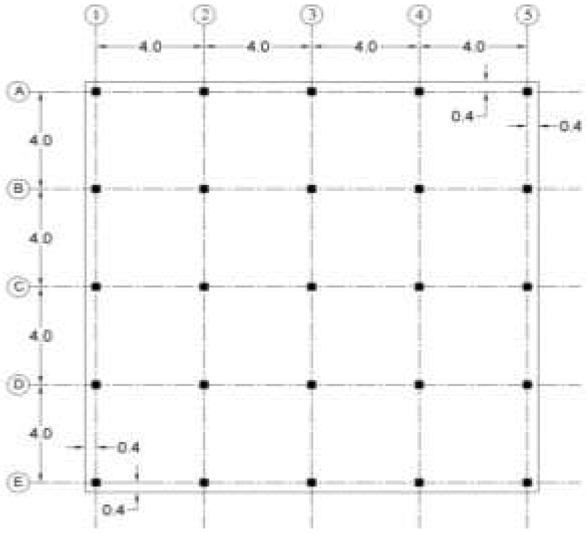


Figure (4): Raft Footing Plan.

Soil Allowable Bearing was assumed 150 kN/m^2. The option (plate mat) in software was used with modulus of subgrade reaction = 18000 kN/m^2/m which found by using equation [٧]:

k_s= 40(S.F.) q_a

where k_s is modulus of subgrade reaction in kN/m^3

q_a is allowable bearing capacity in kN/m^2

S.F. is safety factor =3

Finite elements were used to represent the slabs and footings in the software and the option offset in the software was used to put the slabs in the right position to share carrying loads with the beams.

This study is aim to the following:

- Study of soil settlement risk for different types of footing on multistory building and their effects.
- Helping Engineers for suitable selection of footing type when soil settlement is expected.

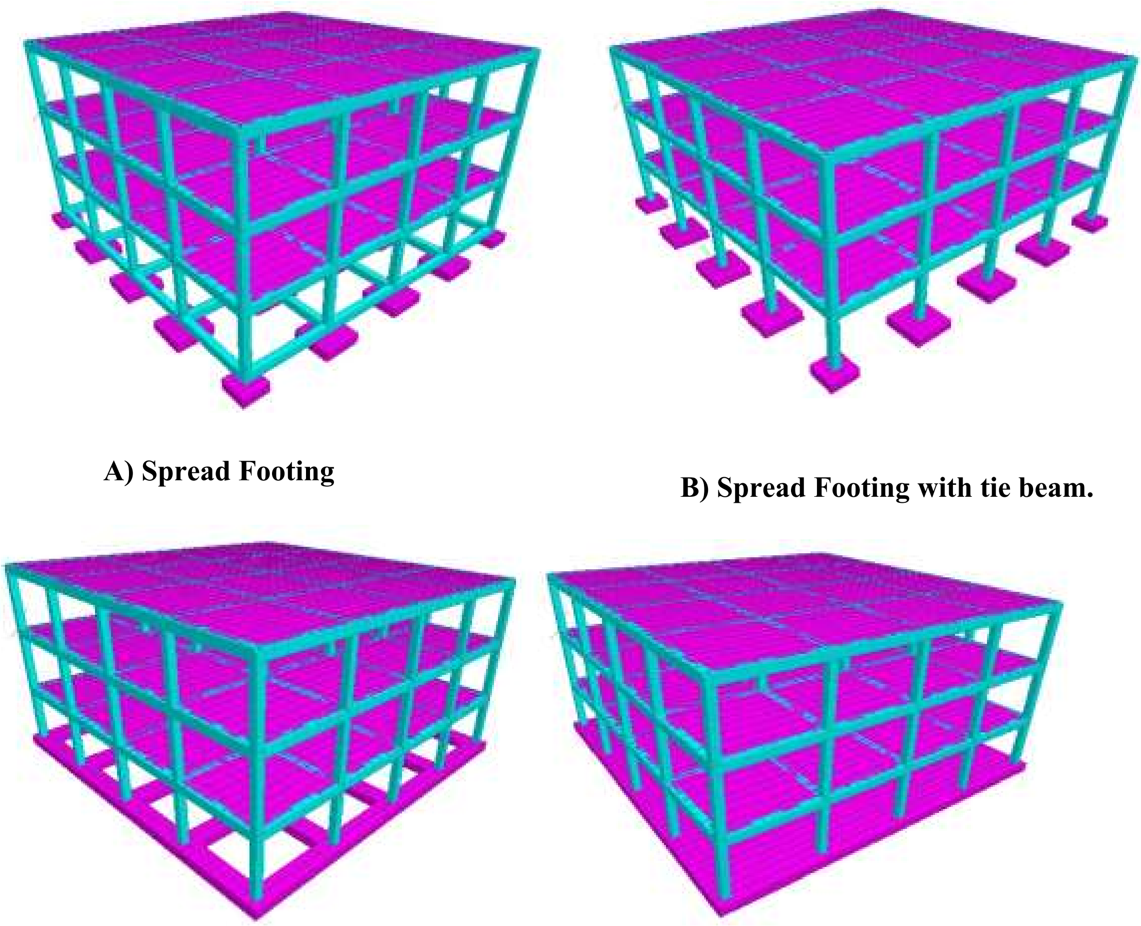
Finite Element Modeling and Meshes:

The STAAD [٤] plate (shell) finite element is based on hybrid finite element formulations is used. An incomplete quadratic stress distribution is assumed. The main distinguishing features of this finite element are:

1. Displacement compatibility between the plane stress component of one element and the plate bending component of an adjacent element which is at an angle to the first is achieved by the elements.
2. The out of plane rotational stiffness from the plane stress portion of each element is usefully incorporated and not treated as a dummy as is usually done in most commonly available commercial software.
3. These elements are the simplest forms of flat shell/plate elements possible with corner nodes only and six degrees of freedom per node. Yet solutions to sample problems converge rapidly to accurate answers even with a large mesh size.
4. These elements may be connected to plane/space frame members with full displacement compatibility. No additional restraints/releases are required.

5. Out of plane shear strain energy is incorporated in the formulation of the plate bending component. As a result, the elements respond to Poisson boundary conditions which are considered to be more accurate than the customary Kirchoff boundary conditions.

Finite element meshes size was taken not more than 0.5Xo.5 m in all structure analysis. Figure 5 shows three dimensional models for multistory buildings with different type of footings



A) Spread Footing **B) Spread Footing with tie beam.**

C) Continuous Footing **D) Raft Footing**

Figures (5): Three Dimensional Models for Multistory Buildings with Different Type of Footings

Analysis, Discussion and Results:

Table 2 shows the positive and negative ultimate moments in ground floor beam along axis B in settlement case 1 (See the notation) eleven cases was studied. In all footings types, it can obviously be notice that the biggest effects are in the negative moments on B4 axis. In continuous footing settlement, negative moment is reduced by about 60% on column B4 while the moment behavior in spread footing with and without tie beam is totally change because the beam span behave as the sum of the two neighboring spans i.e. 8 meters instead of 4 meters, therefore the negative moment of beam above column B4 change to positive moment. In all types of footings the most effects of settlement is gradually reduce in the first next span. Figure 7 shows the effect of increasing tie beam dimensions, two tie beam dimensions were considered, the first is 0.3*.4 m, and the second is 0.3*.8 m. increasing of tie beam dimension shows a little bit reducing of settlement effect.

Table (2): Settlement case 1-UM in GFB along axis B

Case no.	Settlement Case	Spans											
		1--2			2--3			3--4			4--5		
		-ve	+ve	-ve	-ve	+ve	-ve	-ve	+ve	-ve	-ve	+ve	-ve
Spread Footing													
1	No Soil Settlement	23.2	-24.43	39.2	37.6	-17	38.4	38.4	-17	37.6	39.2	-25.8	23.2
2	Soil Settlement under column B4 Footing	22.7	-23.3	41.2	42	-5.7	55.4	97	-20.7	-51	-50	-35.6	70.6
3	Soil Settlement under half footing of column B4	12.6	-16.3	21.6	22.8	-6	31	43.1	-13.5	-14.4	-13.4	-22.7	27.2
Spread Footing with tie beam													
4	No Soil Settlement	23.4	-24.3	39.4	37.9	-17	38.2	38.2	-17	37.9	39.4	-24.3	23.4
5	Soil Settlement under column B4 Footing	22.9	-23	41.5	43	-8.2	49	88.2	-28	-36.8	-37.8	-32	66.6
6	Soil Settlement under half footing of column B4	22.6	-24.1	40.1	40	-12.7	46.2	59.9	-24	2	16.7	-26.54	41.1
7	Soil Settlement under column B4 Footing (Enlarge tie beam to 0.8*.3 m)	22.8	-22.6	42.7	45.5	-12.2	39.3	66.6	-24.2	-6.2	-3.1	-28.7	51.4
Continuous Footing													
8	No Soil Settlement	25.2	-24.8	36.5	39.9	-18.2	34.8	34.8	-17.9	39.9	36.5	-26	25.2
9	Soil Settlement for 2.2 m*2.2m in footing under column B4	25.1	-24.4	37.3	41.8	-16.5	35.9	44.9	-20.4	24.4	21.3	-27.3	34.8
Raft Footing													
10	No Soil Settlement	17.6	-23.7	45.6	42	-16.7	36.3	36.3	-16.7	42	45.6	-23.7	17.6
11	Soil Settlement for 2.2 m*2.2m in footing under column B4	17.5	-24.3	45.8	42.5	-16.3	36.6	38.9	-17	38	41.8	-26.2	19.9

Figure 8 shows the special case when the settlement cover the half footing of spread footing comparing with whole footing settlement, unbalance moment will happen and smaller change in ground beam moment compared with whole footing settlement was noticed.

Table 3 shows the positive and negative ultimate moments in roof beams along axis B in Settlement -case 1. Figure 9 shows the same behavior of moment due to settlement in ground and roof beams. Bigger change in roof beams moments comparing with the moments in ground beam was found. Figures 10 shows negligible effect of footing type on beams moments.

Table 4 shows the moments on footing for settlement-case 1. Figures 11 and 12 show the moments in raft and continuous footing respectively. Both types of footings give very good response for settlement because of little change in moments with and without settlements. A little effect of connecting spread footing with tie beams was noticed in Figure 13

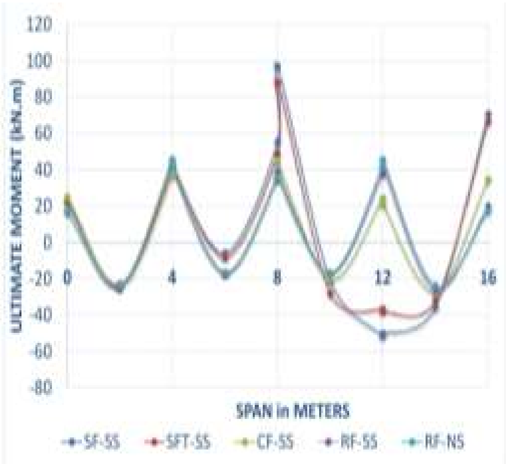
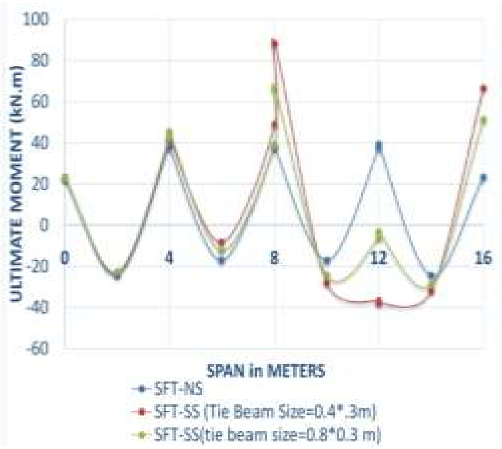


Figure (6): Settlement case 1-UM in GFB along axis B for different type of footings



Figure(7): Settlement case 1-UM in GFB along axis B for spread footings with different dimensions of tie beams.

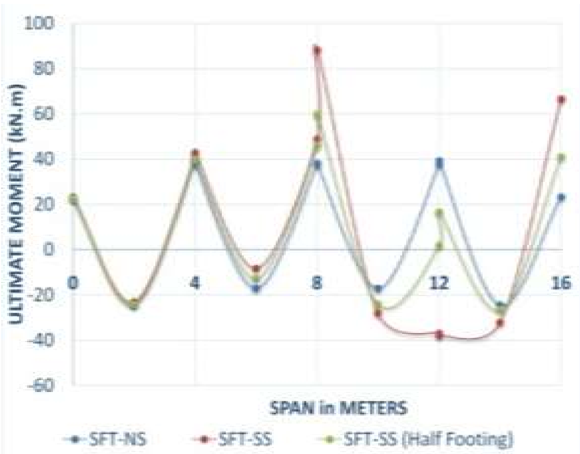


Figure (8): Settlement case 1-UM in GFB along axis B due to whole and half settlement of B4 spread footing with tie beam.

Table (3): Settlement case 1-UM in RB along axis B

Case no.	Settlement Case	Spans											
		1--2			2--3			3--4			4--5		
		-ve	+ve	-ve	-ve	+ve	-ve	-ve	+ve	-ve	-ve	+ve	-ve
Spread Footing													
1	No Soil Settlement	13	-17	19.7	19.6	-11	24	24	-11	19.6	19.7	-18	13
2	Soil Settlement under column B4 Footing	12	-15	23.6	25.6	-0.8	39.2	64.1	-16	-50	-48	-40	41
Spread Footing with tie beam													
3	No Soil Settlement	13	-17	20	19.9	-11	23.9	23.9	-11	19.9	20	-17	13
4	Soil Settlement under column B4 Footing	12	-16	23.6	25.4	-2.6	35.6	56.3	-22	-37	-35	-32	36
Continuous Footing													
5	No Soil Settlement	15	-17	18.1	20.4	-12	21.2	21.2	-12	20.4	18.1	-18	15
6	Soil Settlement for 2.2 m*2.2m in footing under column B4	15	-17	19.1	22	-11	22.9	27.4	-15	8.5	6.5	-20	20
Raft Footing													
7	No Soil Settlement	10	-16	24.2	23	-11	22.7	22.7	-11	23	24.2	-16	10
8	Soil Settlement for 2.2 m*2.2m in footing under column B4	10	-16	24.5	23.4	-10	23.1	24.3	-11	20	21.3	-18	11

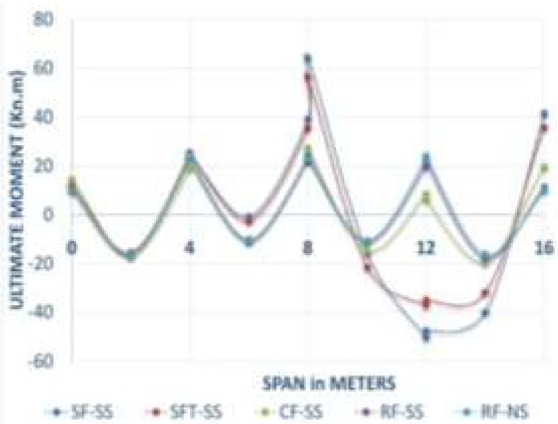
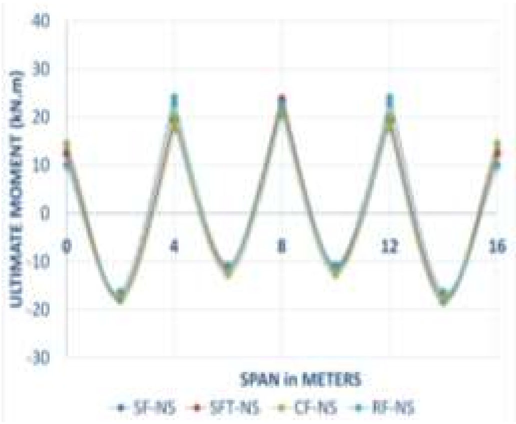


Figure (10): Settlement case 1-UM in RB along axis B for different type of footings



Figure(9): Settlement case 1-UM in RB along axis B for different type of footing with no settlement

Table (4): Settlement case 1-UM in Footing along axis B

Case no.	Settlement Case	Spans											
		1--2			2--3			3--4			4--5		
		+ve	-ve	+ve	+ve	-ve	+ve	+ve	-ve	+ve	+ve	-ve	+ve
Spread Footing													
1	No Soil Settlement	-60		-105	-105		-104	-104		-105	-105		-60
2	Soil Settlement under column B4 Footing	-60		-105	-105		-131	-123		0	0		-74
Spread Footing with tie beam													
3	No Soil Settlement	-62		-104	-104		-104	-104		-104	-104		-62
4	Soil Settlement under column B4 Footing	-61		-103	-107		-110	-141		0	0		-89
Continuous Footing													
5	No Soil Settlement	-18	111	-140	-133	62	-110	-110	62	-133	-140	111	-18
6	Soil Settlement for 2.2 m*2.2m in footing under column B4	-18	115	-140	-140	76	-99	-82	49	-180	-187	111	-17
Raft Footing													
7	No Soil Settlement	-28	75	-107	-107	42	-107	-107	42	-107	-107	75	-28
8	Soil Settlement for 2.2 m*2.2m in footing under column B4	-23	75	-107	-107	42	-103	-103	41	-153	-153	73	-23

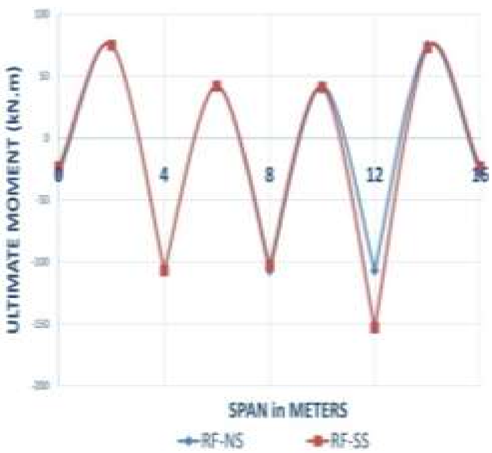


Figure (11): Settlement case 1-UM in raft footing along axis B with and without settlement under B4.

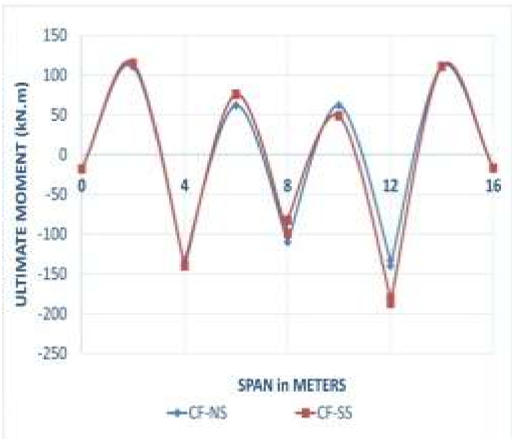


Figure (12): Settlement case 1-UM in continuous footing along axis B with and without settlement under B4.

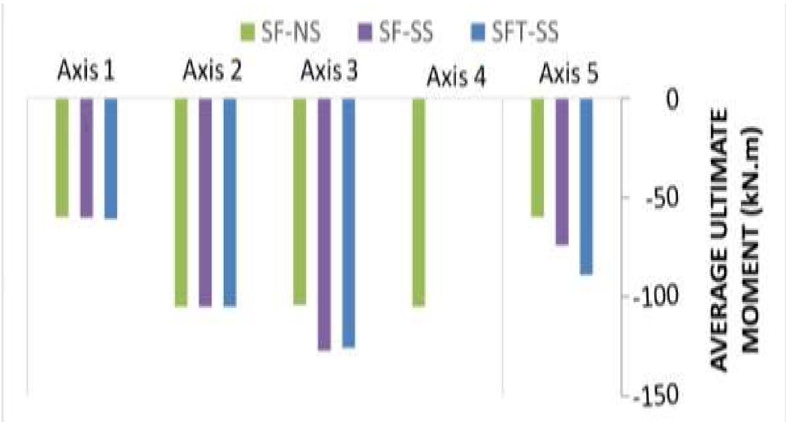


Figure (13): Settlement case 1-UM in spread footing along axis B with and without tie beam

Tables 5, 6 and 7 show the shear force in ground floor beams, roof beam and footing along axis B respectively. Negligible change in continuous footing shear force was noticed in Figure 19. About 80% increasing of raft footing shear value was found in Figure 20, this may not represent the true situation because this shear value located in very small area directly under column and can be neglected comparing with large section of raft.

Table (5): Settlement case 1-US in GFB along axis B

Case no.	Settlement Case	Spans							
		1--2		2--3		3--4		4--5	
	Spread Footing								
1	No Soil Settlement	63	-74	66	-67.2	67.2	-66.4	73.8	-63
2	Soil Settlement under column B4 Footing	62	-75	62	-71.3	116	3.5	9.3	-107
3	Soil Settlement under half footing of column B4	60	-77	61	-72.4	94.7	-19.3	53.8	-82
	Spread Footing with tie beam								
4	No Soil Settlement	63	-74	67	-67	67	-66.7	73.9	-63
5	Soil Settlement under column B4 Footing	62	-75	65	-67.9	108	-7.7	19.7	-101
6	Soil Settlement under half footing of column B4	63	-74	64	-70	85.4	-38.5	56	-78
7	Soil Settlement under column B4 Footing (increasing tie beam size to 0.8*.3 m)	62	-75	69	-63.2	90.9	-32.3	41.2	-87
	Continuous Footing								
8	No Soil Settlement	65	-72	69	-65.4	65.4	-69.2	72	-65
9	Soil Settlement for 2.2 m*2.2m in footing under column B4	65	-72	69	-64.6	73.8	-57	60.3	-73
	Raft Footing								
10	No Soil Settlement	58	-80	70	-66	66	-70.1	79.9	-58
11	Soil Settlement for 2.2 m*2.2m in footing under column B4	59	-79	70	-65.8	68.2	-66.9	76	-61

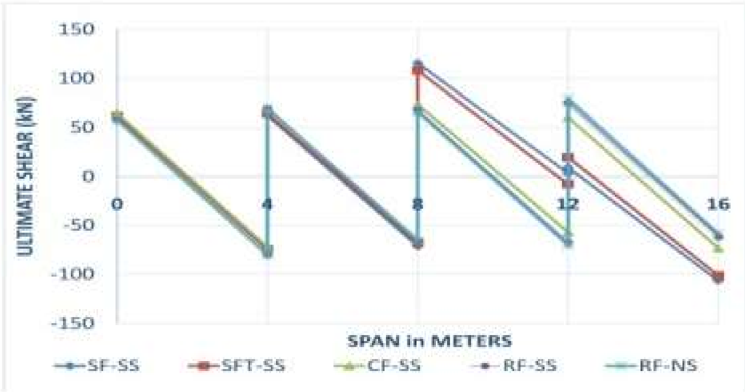


Figure (14): Settlement case 1-US in GFB along axis B for different dimension size of type of footing

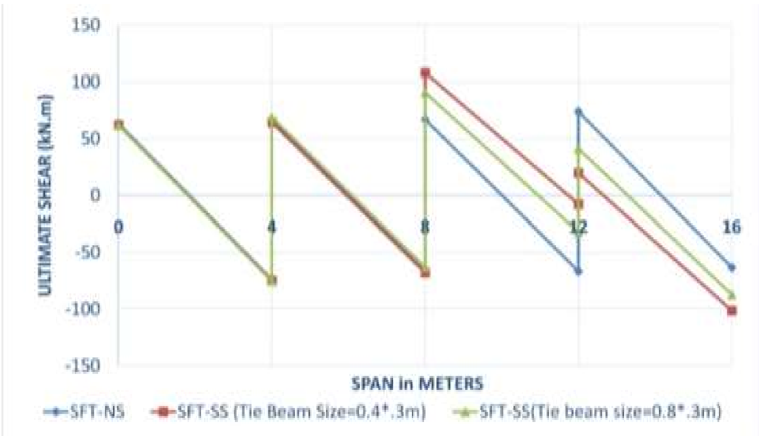


Figure (15): Settlement case 1-US in GFB along axis B for different dimension

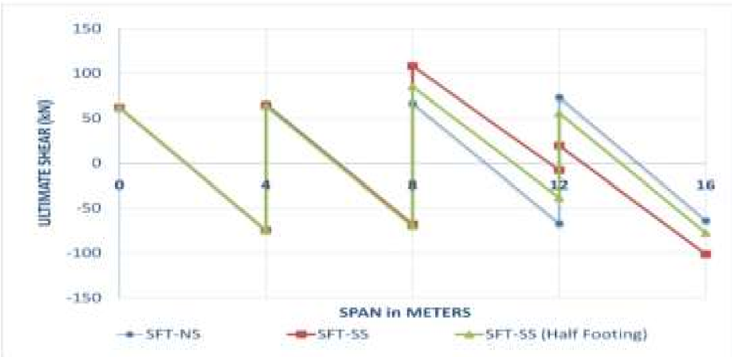


Figure (16): Settlement case 1-US in GFB along axis B due to whole and half settlement of B4spread footing with tie beam.

Table (6): Settlement case 1-US in RB along axis B

Case no.	Settlement Case	Spans							
		1--2		2--3		3--4		4--5	
		1	2	2	3	3	4	4	5
Spread Footing									
1	No Soil Settlement	37	-40	35	-38.6	41.5	-37.7	40.2	-37
2	Soil Settlement under B4 Footing	36	-42	33	-42.1	72.9	17.7	-7.9	-66
Spread Footing with tie beam									
3	No Soil Settlement	37	-40	36	-38.5	38.5	-35.5	40.4	-37
4	Soil Settlement under B4 Footing	35	-42	34	-40.7	66.3	9.3	1.3	-60
Continuous Footing									
5	No Soil Settlement	39	-39	37	-37.4	37.4	-36.9	38.9	-39
6	Soil Settlement for 2.2 m*2.2m in footing under column B4	38	-39	37	-37.3	43	-28	30.6	-44
Raft Footing									
7	No Soil Settlement	34	-44	38	-37.7	37.7	-38	43.9	-34
8	Soil Settlement for 2.2 m*2.2m in footing under column B4	35	-44	38	-37.7	39.1	-35.6	41.3	-36

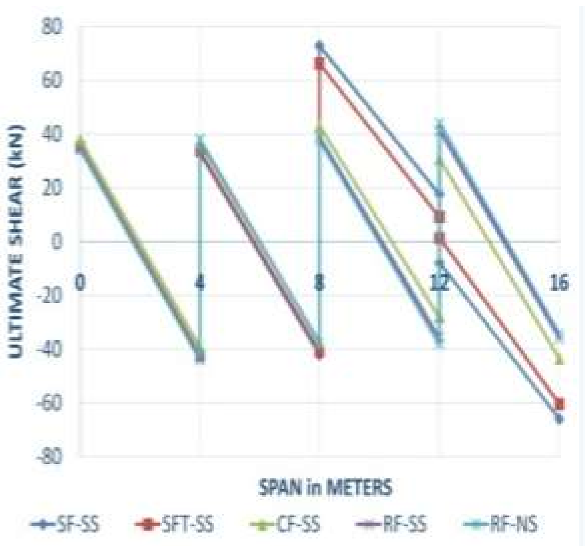


Figure (17): Settlement case 1-US in RB along axis B for different type of footings

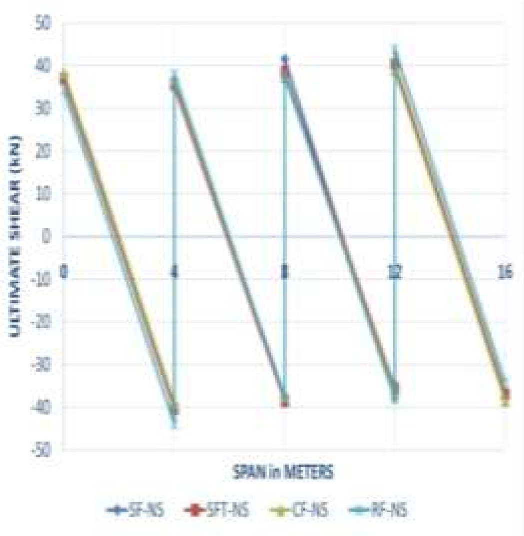


Figure (18): Settlement case 1-US in RB along axis B for different type of footing with no settlement.

Table (7): Settlement case 1-US in Footing along axis B

Case no.	Settlement Case	Spans							
		1--2		2--3		3--4		4--5	
		1	2	2	3	3	4	4	5
	Spread Footing								
1	No Soil Settlement	-711	958	-959	948	-948	959	-958	711
2	Soil Settlement under B4 Footing	-702	959	-957	1175	-1134	0	0	900
	Spread Footing with tie beam								
3	No Soil Settlement	-720	950	-955	950	-955	950	-950	720
4	Soil Settlement under B4 Footing	-715	947	-969	1061	-1220	0	0	991
	Contineous Footing								
5	No Soil Settlement	-655	891	-864	857	-857	864	-891	655
6	Soil Settlement for 2.2 m*2.2m in footing under column B4	-653	892	-875	886	-894	737	-770	700
	Raft Footing								
7	No Soil Settlement	-632	975	-945	900	-900	945	-975	632
8	Soil Settlement for 2.2 m*2.2m in footing under column B4	-627	968	-924	909	-895	1721	-1746	628

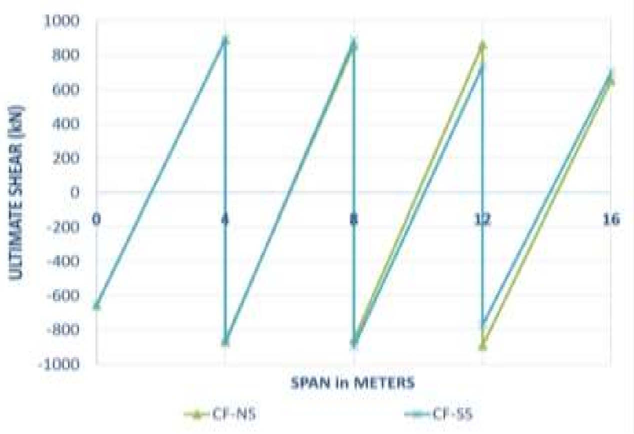


Figure (19): Settlement case 1-US in continuous footing along axis B with and without settlement under B4.

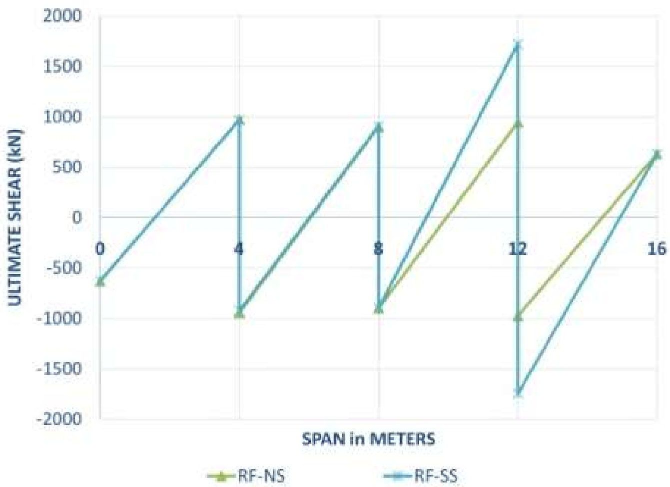


Figure (20): Settlement case 1-US in raft footing along axis B with and without settlement under B4.

The ultimate axial load and moment in ground columns shows in Table 8. Figure 21 for spread footing shows that, the column B4 carrying no loads after settlement and the load transferred to B4 neighbored columns. Good reaction in continuous footing was found in figure 22. Best results was obviously noticed in Figure 23 for raft footing which shown little change in column load, that's mean the footing carry the effect of settlement.

Table 8: Settlement case 1- UAL and UM in ground columns B3, B4 & B5

Case no.	Settlement Case	Columns					
		B3		B4		B5	
		Pu	Mu	Pu	Mu	Pu	Mu
Spread Footing							
1	**No Soil Settlement**	-827	0	-836	0	-485	13
2	**Soil Settlement under B4 Footing**	-1009	-23	0	0	-631	40
Spread Footing with tie beam							
3	**No Soil Settlement**	-827	0	-839	0	-485	14
4	**Soil Settlement under B4 Footing**	-968.4	-29	-145	-3	-601	48.4
Continuous Footing							
5	**No Soil Settlement**	-814	-4.5	-838	3.6	-492	12.7
6	**Soil Settlement for 2.2 m*2.2m in footing under column B4**	-835.6	-7.2	-693	3.9	-514	20.8
Raft Footing							
7	**No Soil Settlement**	-837	2	-892	0	-478	6
8	**Soil Settlement for 2.2 m*2.2m in footing under column B4**	-840.3	2	-850	2	-483	8.8

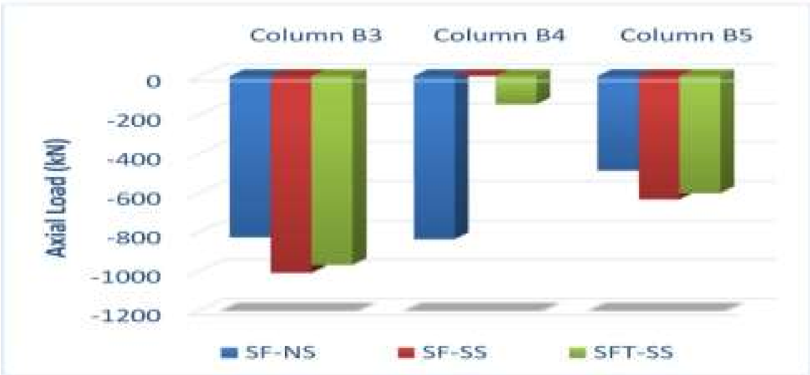


Figure (21): Settlement case 1-UAL in Ground Floor Column B3, B4 & B5 for Spread footing with and without tie beam

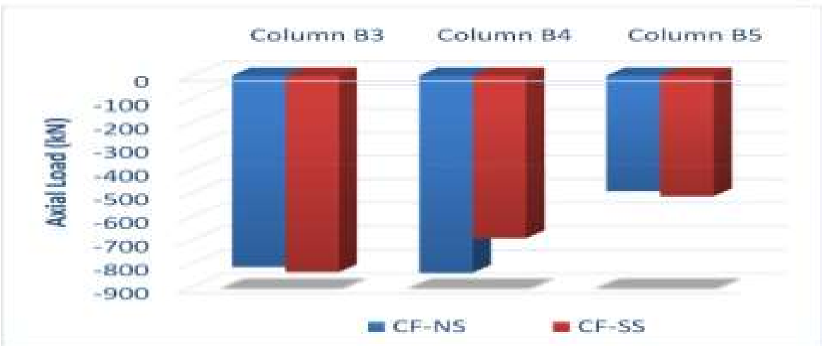


Figure (22): Settlement case 1-UAL in Ground Floor Column B3, B4 and B5 for continuous footing

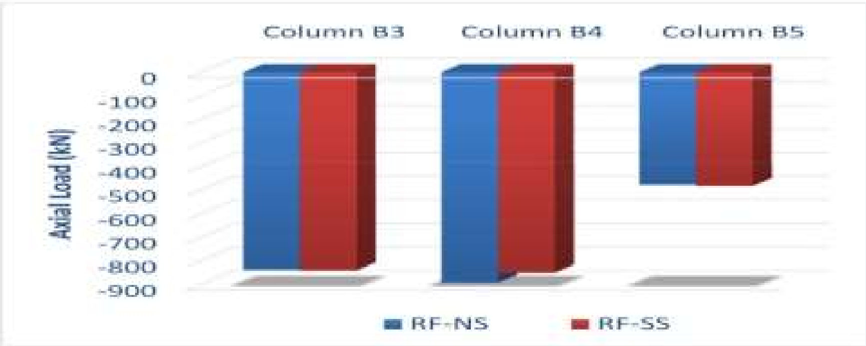


Figure (23): Settlement case 1-UAL in Ground Floor Column B3, B4 and B5 for raft footing

Table 9 shows the settlement in settlement case 1 for different types of footings. Table 10 shows the maximum base pressure for different types of footings of Columns B3, B4 & B5 in Settlement case 1. Figures 24 and 25 shows that the settlement happened in half footing make increasing about 40% in maximum base pressure. In figures 26 and 27 show that negligible change (about 5%) was recorded in maximum base pressure in neighbored footing. It can be notice that all types of footings give homogeneous base pressure under footings.

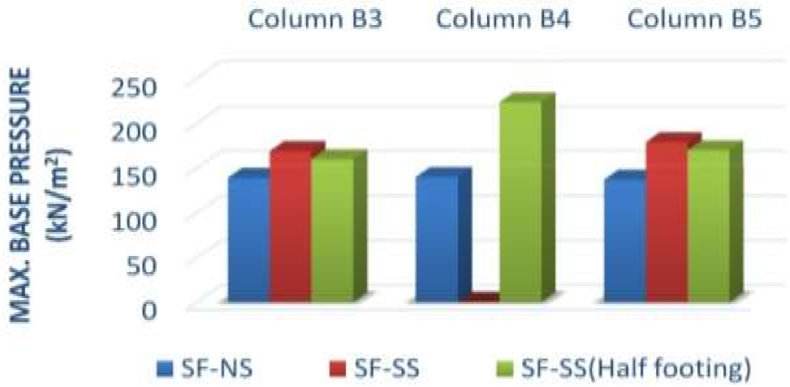


Figure (24): Settlement case 1- Maximum base pressure (kN/m^2) for spread footings of Columns B3, B4 & B5)

Table (9): Settlement case 1- Settlement on Columns B3, B4 & B5 (mm) in Footing & Roof

Case no.	Settlement Case	Columns					
		B3		B4		B5	
		Footing	Roof	Footing	Roof	Footing	Roof
Spread Footing							
1	No Soil Settlement	-9.8	-12.2	-10	-12.3	-9.6	-11
2	Soil Settlement under column B4 Footing	-12	-14.8	-22	-22	-12.4	-14
3	Soil Settlement under half footing of column B4	-11	-13.5	-15.9	-17	-10.9	-13
Spread Footing with tie beam							
4	No Soil Settlement	-9.8	-12.1	-10	-12.2	-9.6	-11
5	Soil Settlement under column B4 Footing	-11.8	-14.6	-20.1	-20.4	-12.4	-14
6	Soil Settlement under half footing of column B4	-10.4	-13	-14	-15.5	-11	-13

7	**Soil Settlement under column B4 Footing (Increase tie beam size to 0.8*.3 m)**	-11.8	-14.3	-16.7	-17.9	-12.2	-14
	Continuous Footing						
8	**No Soil Settlement**	-8	-10.3	-7.7	-10	-6.7	-8.1
9	**Soil Settlement for 2.2 m*2.2m in footing under column B4**	-8.6	-10.9	-9.9	-11.8	-7.2	-8.6
	Raft Footing						
10	**No Soil Settlement**	-3.1	-5.5	-3	-5.5	-3.6	-4.9
11	**Soil Settlement for 2.2 m*2.2m in footing under column B4**	-3.2	-5.6	-3.6	-6	-3.7	-5

Table (10): Settlement case 1- Maximum base pressure (KN/m2)for different type of footings of Columns B3, B4 & B5

Case no.	**Settlement Case**	**Columns**		
		B3	B4	B5
	Spread Footing			
1	No Soil Settlement	139	140	137
2	Soil Settlement under column B4 Footing	169	0	179
3	Soil Settlement under half footing of column B4	160	224	170
	Spread Footing with tie beam			
4	No Soil Settlement	139	140	136
5	Soil Settlement under column B4 Footing	176	0	187
6	Soil Settlement under half footing of column B4	145	198	168
	Continuous Footing			
7	No Soil Settlement	113	108	99
8	Soil Settlement for 2.2 m*2.2m in footing under column B4	119	0	104
	Raft Footing			
10	No Soil Settlement	42	42	52
11	**Soil Settlement for 2.2 m*2.2m in footing under column B4**	45	0	55

Figure (25): Settlement case 1- Maximum base pressure (kN/m^2) for spread footings with tie beamof Columns B3, B4 & B5

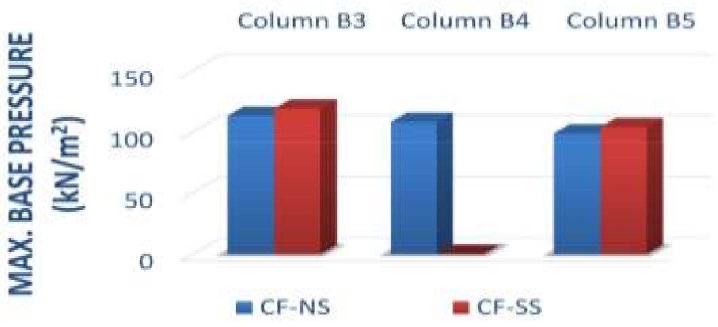


Figure (26): Settlement case 1- Maximum base pressure (kN/m^2) for continuous footing of Columns B3, B4 & B5)

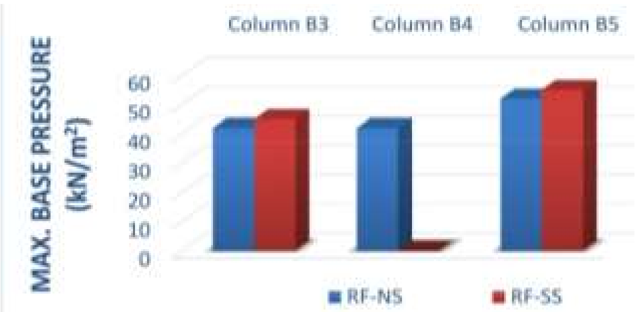


Figure (27): Settlement case 1- Maximum base pressure (kN/m^2) for raft footing of Columns B3, B4 & B5)

Table 11 shows the moment in ground floor along axis A in settlement case 2. Figure 28 shows clearly the effect of line 5 settlement extend to all adjacent spans in spread footings with and without tie beam. While continuous and raft footings, the effeteness disappeared in the first adjacent span. With no settlement no change was found in moments for different type of footing as in Figure 29.

Table (11): Settlement case 2- UM in GFB along axis A

Case no.	Settlement Case	Spans											
		1--2			2--3			3--4			4--5		
		-Ve	+Ve	-Ve	-Ve	+Ve	-Ve	-Ve	+Ve	-Ve	-Ve	+Ve	-Ve
Spread Footing													
		0	2	4	4	6	8	8	10	12	12	14	16
1	No Soil Settlement	14	-18	33	28	-12	29	29	-12	28	33	-18	13.6
2	Settlement under footings axis 5	-35	-23	60	-17	-6.6	78	15	30	103	186	52	-88
Spread Footing with tie beam													
3	No Soil Settlement	14	-18	33	28	-12	28	28	-12	28	33	-18	13.9
4	Settlement under footings axis 5	-35	-23	68	-21	-6.7	81	10	33	93	161	-12	-105

Continuous Footing													
5	**No Soil Settlement**	16	-18	29	30	-14	25	25	-14	30	29	-18	16.1
6	**Settlement under footings axis 5**	-7.6	-21	46	7.6	-12	48	11	1.7	65	86	-18	-39
Raft Footing													
7	**No Soil Settlement**	12	-18	34	31	-12	25	25	-12	31	34	-18	11.5
8	**Settlement under footings axis 5**	5.4	-18	38	24	-12	32	21	-7.4	42	53	-19	-6.6

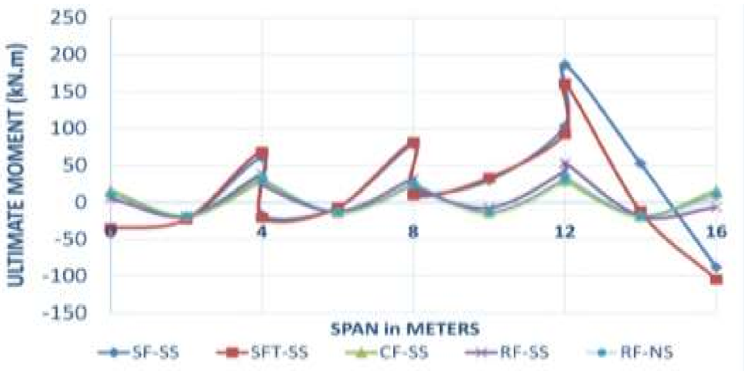


Figure (28): Settlement case 2-UM in GFB along axis A for different type of footings

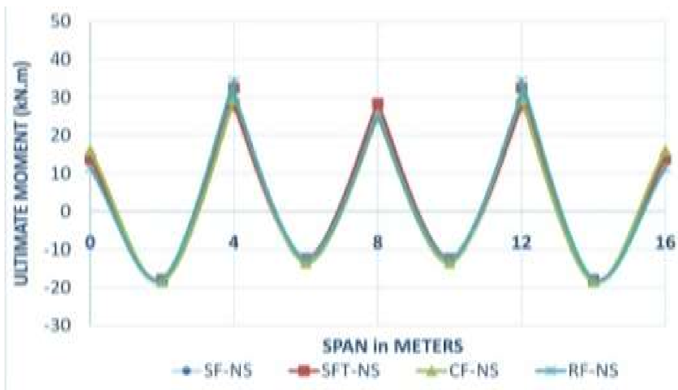


Figure (29): Settlement case 2-UM in GFB along axis A for different type of footing with no settlement.

Table 12 shows shears in ground floor beam along axis B.

Table (12): Settlement case 2-US in GFB along axis A

Case no.	Settlement Case		Spans							
			1--2		2--3		3--4		4--5	
			1	2	2	3	3	4	4	5
Spread Footing										
1	**No Soil Settlement**		40.8	-54	45.3	-46	46	-45	53.7	-41
2	**Settlement under footings axis 5**		19.2	-76	12.2	-78	8.4	-68	134	48.5
Spread Footing with tie beam										

3	**No Soil Settlement**		40.8	-54	45.3	-46	45.9	-45	53.6	-41
4	**Settlement under footings axis 5**		13.3	-82	9.7	-80	11.4	-66	131	47.3
Continuous Footing										
5	**No Soil Settlement**		42.6	-52	47.6	-44	44	-48	51.6	-43
6	**Settlement under footings axis 5**		29.2	-65	31.4	-60	24.4	-61	85.9	-2.5
Raft Footing										
7	**No Soil Settlement**		39.4	-55	47.3	-44	43.9	-47	54.7	-39
8	**Settlement under footings axis 5**		36.1	-58	42.6	-49	37.5	-52	66.3	-26

Table 13 shows the load in axes B5 transferred to axes B4 after settlement. Again the continuous and raft footing have better response than of spread footings.

Table (13): Settlement case 2- UAL and UM in Ground Columns A4, A5, C4 & C5

Case no.	Settlement Case	Columns							
		A4		A5		C4		C5	
		Axial Load	Max M	Axial Load	Max M	Axial Load	Max M	Axial Load	Max M
Spread Footing									
1	**No Soil Settlement**	-486	-1.8	-249	7.3	-827	0	-438	13.6
2	**Settlement under footings axis 5**	-911	-60	7.6	0	-1494	-73	7.6	0
Spread Footing with tie beam									
3	**No Soil Settlement**	-485	-2.2	-250	7.5	-817	0	-472	14.9
4	**Settlement under footings axis 5**	-822	-44	-41	-82	-1375	-49	-80	-103
Continuous Footing									
5	**No Soil Settlement**	-491	4	-263	-6	-814	7	-467	13
6	**Settlement under footings axis 5**	-660	-8.6	-187	-41	-1065	-17	-276	-55
Raft Footing									
7	**No Soil Settlement**	-478	-1	-243	3	-837	-2	-440	6
8	**Settlement under footings axis 5**	-535	-5	-209	-13	-909	-6.8	-394	-12

Table 14 shows the settlement in axes A. The settlements in spread footing with and without tie beam exceed the permissible settlement which is 25 mm [٧] while the continuous and raft footing still within acceptable range of settlements.

Table (14): Settlement case 2 – Settlements (mm) in axis A footings

Case no.	Settlement Case	Columns				
		A1	**A2**	**A3**	**A4**	**A5**
Spread Footing						
1	**No Soil Settlement**	-9.95	-9.6	-9.4	-9.6	-9.95
2	**Settlement under footings axis 5**	-7.2	-8.9	-8.9	-17.9	-56.8
Spread Footing with tie beam						
3	**No Soil Settlement**	-9.96	-9.6	-9.4	-9.6	-9.96
4	**Settlement under footings axis 5**	-7.1	-9	-9.4	-17.5	-48.2
Continuous Footing						
5	**No Soil Settlement**	-6.3	-6.7	-7	-6.7	-6.3
6	**Settlement under footings axis 5**	-5.3	-6.4	-6.6	-8.9	-21.3
Raft Footing						
7	**No Soil Settlement**	-6	-5.5	-5.5	-5.5	-6
8	Settlement under footings axis 5	-3.8	-3.5	-3.5	-4	-8.4

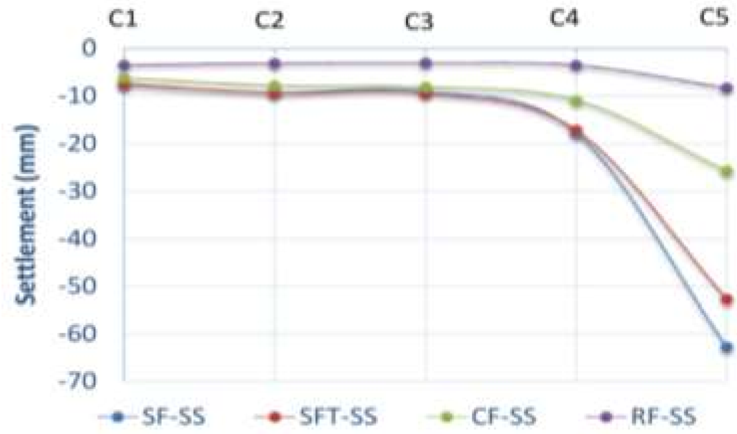


Figure (30): Settlement case 2- Settlements (mm) in axis A footings

CONCLUSION:

This study proves that serious damages may happen due to soil settlements under footings. Exterior footing settlement is more critical than interior settlement. When soil settlement is expected to occur, the following are recommended:

1. Avoid using spread footing absolutely. Using of a tie beam with spread footing still not good solution even if a big dimension of tie beam is used.
2. If the applied base pressure can be kept not to exceed allowable bearing capacity, continuous footing is a very good selection because it shows a very good response against settlement, keep the settlement within allowed values and lower cost than raft footing.
3. Design the columns with additional safety, the results shows the additional safety factors around the following values.

a. For continuous footing: 20% for ground floor columns and 35% for other stories columns.

b. For raft footings: 5% for ground floor columns and 10% for other stories columns.

4. Additional safety factor 10% can be used for moments and shears in beams design or may be considered already included in original code ultimate safety factors.

NOTATIONS

Settlement case 1	Results happened due to specified settlement of Axis B4 Footing
Settlement case 2	Results happened due to specified settlement under Axis 5 Footing
SF	Spread Footing
SFT	Spread Footing with tie beam
CF	Continuous Footing
RF	Raft Footing
NS	No soil Settlement
SS	Soil Settlement
GFB	Ground Floor Beams
RB	Roof Beams
UM	Ultimate Moment (kN.m)
US	Ultimate Shear (kN)
UAL	Ultimate Axial Load (kN)

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