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Comparative Study on Structural Behaviour of Reinforced Concrete Building for the Effect of Differental Settlement

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***Abstract*—**Nowadays, most of the buildings are constructed by modern architectural designs which focus on the structural elegance. Such kind of buildings has many irregularities through the entire structure. Since the column loads from the structure are not the same from place to place, differential settlement may occur while the footings are on equal bearing capacity. Therefore, the effects of differential settlement on the irregular structure must be considered. This study includes four main parts. First step is modeling a proposed building which is located in seismic zone 4. Then, analysis and design of building is done by ETABS software. Load consideration is based on Uniform Building Code UBC-97 and structural members are designed according to American Concrete Institute ACI-318-99. Different kinds of material strength used in the design are f'_c = 2500 psi and f_y = 40000 psi. In the second place, bearing capacity is calculated by using Braja M. Das method with the soil parameters taken from soil report. From the result of bearing capacity value, the footings are designed with SAFE software. In which isolated footing of six different types are used in accordance with the loading range. In the third portion, the values of settlements are calculated in different load groups by using Joseph E. Bowel's method and Braja M. Das's method. The larger value obtained from the calculation is taken. Then the structure is analyzed and designed again by taking support settlement into consideration. Finally, the effects of differential settlement on irregular building are discussed.

Keywords*—Braja M. Das's method, differential settlement, irregular building, Joseph E. Bowel's method; seismic zone 4*

I. INTRODUCTION

From the engineering point of view, superstructure basically rests on foundation. But no matter how nice is the foundation, if the soil underlying the foundation is not well enough to withstand the transferred load from the superstructure, the structure would fail with no doubt. This fact may not usually include in a building design problem, but it is a symptom of the movement and conditions of the soil around the building. This may be termed as foundation settlement.

Although there are many causes of foundation problems, settlement is the most common one. The term settlement indicates the sinking of a building due to the compression and deformation of the underlying soil. Any structure built on soil is subject to settlement. In designing a structure it is commonly assumed that the foundation will not move. Correspondingly, if cracks appear in the structure it is assumed that the foundation has moved and that this is the sole cause of cracking. Some settlements are inevitable and, depending on the situation, some settlements are tolerable.

If the settlement profile is uniform throughout the entire structure, it would minimize the structure damage. However, if the settlement profile is non-uniform, differential settlement occurs and the entire structure may collapse. The term differential settlement means that one part of a structure more settle down than the rest of the structure and it causes the distortion of a structure. In general, therefore, a structure can be more tolerable if the settlement is uniform or nearly uniform, than if the settlement varies from place to place.

Generally, it can be seen that differential settlement frequently occurs in irregular building. Nowadays, most of the buildings are constructed by modern architectural design which focused on the structural elegance. Therefore, most of the buildings were constructed as an irregular one. Hence, the effects of irregularities on differential settlement must be considered. Differential settlement can have a number of undesirable results. They may impair the structural usefulness and they may even lead to the failure of the entire structure. Therefore, differential settlement for four storey irregular reinforced concrete building which is located in Mandalay will be investigated. The specific objectives of the study are (i) to predict the magnitudes of the settlements under different loading, (ii) to study the irregularities of structure with differential settlement and (iii) to study the difference between with and without differential settlement on structure.

II. STRUCTURAL MODEL

The location of proposed building is in Mandalay, seismic zone 4. Selected model is four storey reinforced concrete structure and rectangular shape. The length and width of the structure is 64 ft and 55 ft. The story height is 12.83 ft in ground floor and 10.83 ft for other storey. It is 45.32 ft above ground level. A building is affected by lateral forces due to wind or earthquake actions and gravity forces due to dead load and live load. In this study, the applied loads are dead loads, live loads, wind loads and earthquake loads Analysis and design of proposed building is according to UBC-97 and ACI-318-99 by using ETABS software.

A. Required Soil Parameters from Soil Report

In order to compute the allowable bearing capacity of the soil, the site soil parameters are needed. These are obtained from Civil Engineering Service Group. From which, the type and size of foundation are designed using the load obtained from analyzing the superstructure. To evaluate the soil properties pertaining to its physical and engineering characteristics, the subsurface investigation is performed. The depth of each bore hole is about 35 feet. Samples were collected at the depth of 5, 10, 15, 20, 25, 30 and 35 feet. Standard Penetration Test was performed wherever the samples were collected. At the site, the ground water table was found at 21 ft below the ground level. It is found that the soil type is mostly low plasticity clay and sandy silt soil and some gravel. Sand is found in 15 and 20ft below the ground level. The depth of foundation is 12 ft below the ground level. The site is located at the corner of $81^{st} \times 21^{st}$ street, Mandalay. The soil parameters of the site are described in Table I.

Table 1: Required Soil Parameters From Soil Report For Isolated Footing

Depth (ft)	w (%)	G_S	γ (lb /ft³)	L.L (%)	P.L (%)	N blow/ft
5	19.17	2.70	105.68	52.41	19.49	5
10	22.15	2.67	102.93	38.67	18.64	10
15	21.23	2.68	112.65	NL	NP	19
20	23.91	2.70	115.69	NL	NP	20
25	16.09	2.69	107.62	47.78	19.05	30
30	21.69	2.70	108.73	53.24	22.81	38
35	21.91	2.67	108.93	51.74	21.57	41

B. Results of Settlement and Angular Distortion

Table 2: Settlement Under Each Footing

Point	Settlement	Point	Settlement	Point	Settlement
A1	0.552	B5	0.876	D3	0.432
A2	0.78	B6	0.876	D4	0.708
A3	0.709	C1	0.78	D5	0.864
A4	0.864	C2	0.78	D6	0.804
A5	0.912	C3	0.672	E1	0.432
A6	0.672	C4	0.708	E2	0.528
B1	0.768	C5	0.816	E3	0.468
B2	0.9	C6	0.884	E4	0.66
B3	0.828	D1	0.66	E5	0.792
B4	0.66	D2	0.564	E6	0.612

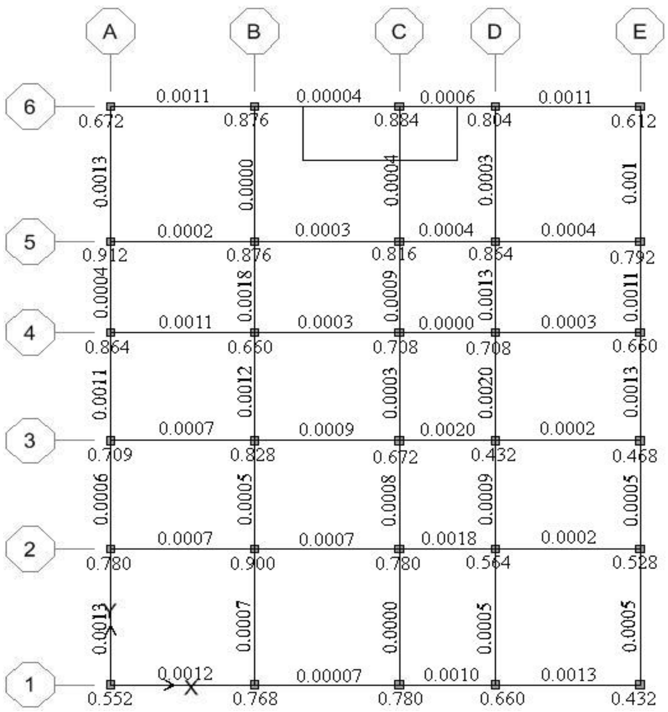


Figure.1: Total Settlement and Angular Distortion

The amount of settlement under different loading is calculated. Joseph E. Bowel's method and Braja M. Das's method are used to calculate settlement. The computations of settlement for different types of footing are presented. The larger value of settlement obtained from the calculation is taken into consideration.

Settlement computation is carried out under each footing. Soil parameters required to use in the computation of settlement is taken from the soil report. Total settlement is calculated by using the larger value obtained from the two different methods.

Calculation of settlement under different footings is carried out by using two methods and the results are presented in Table II. Total settlement and angular distortion are shown in Figure 1. According to Skemptom and Mac Donald, the allowable angular distortion for building is 0.002.

III. COMPARATIVE STUDY ON STRUCTURE WITH AND WITHOUT DIFFERENTIAL SETTLEMEN

After analyzing, changes in stresses from ground floor to roof floor of failed members before and after settlements are shown in Table III to Table VII. Selected beam labels are B9, B18, B26 and B36 which are in the large angular distortion frame. Beam label plan and selected members are shown in Figure 2. Graphical comparisons of selected member stresses are shown in Figure 3 to Figure 12.

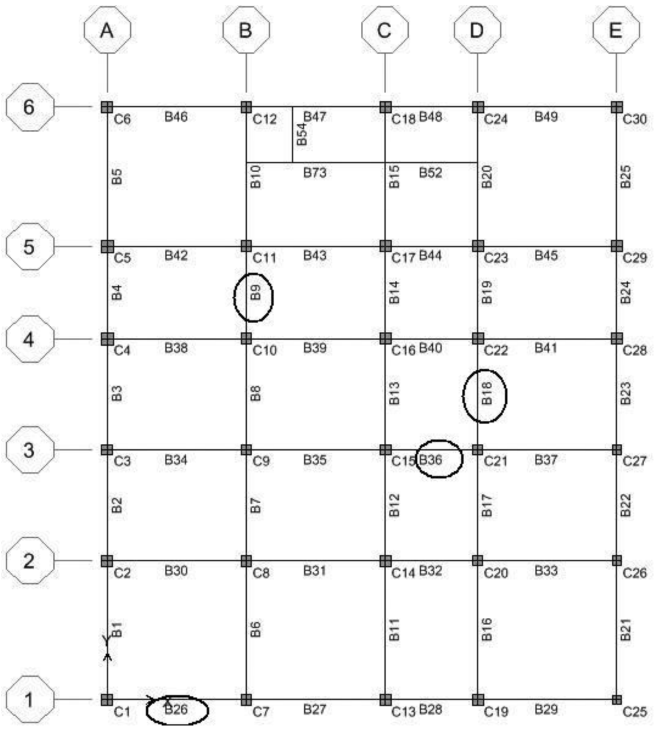


Figure.2. Beam Label Plan and Selected Members

Table 3: Magnitude Of Stresses In Selected Members Before and After Assiging Settlement(Ground Floor)

Beam Label	Shear (kips)	Bending Moment (kips)	Angular Distortion	Remark
B9	-12.45	-721.265	0.0000	Before settlement
	-21.58	- 1310.807	0.0018	After settlement
B18	-8.56	-530.426	0.0000	Before settlement

	-14.76	-1041.833	0.0020	After settlement
B26	-12.12	-829.799	0.0000	Before settlement
	-15.95	-1174.119	0.0012	After settlement
B36	11.89	686.207	0.0000	Before settlement
	19.52	1118.031	0.0020	After settlement

Table 4: Magnitude Of Shear And Bending Moment Before And After Assiging Settlement (First Floor)

Beam Label	Shear (kips)	Bending Moment (kips)	Angular Distortion	Remark
B9	-7.32	-399.942	0.0000	Before settlement
	-12.53	-720.897	0.0018	After settlement
B18	-8.82	-430.716	0.0000	Before settlement
	-12.79	-735.452	0.0020	After settlement
B26	-10.91	-498.346	0.0000	Before settlement
	-13.71	-753.123	0.0012	After settlement
B36	10.15	-506.960	0.0000	Before settlement
	15.13	-812.407	0.0020	After settlement

Table 5: Magnitude Of Shear And Bending Moment Before And After Assiging Settlement (Second Floor)

Beam Label	Shear (kips)	Bending Moment (kips)	Angular Distortion	Remark
B9	-6.32	-342.193	0.0000	Before settlement
	-10.88	-630.367	0.0018	After settlement
B18	-8.65	-326.360	0.0000	Before settlement
	-12.04	-589.266	0.0020	After settlement
B26	-14.82	-601.068	0.0000	Before settlement
	-17.00	-798.268	0.0012	After settlement
B36	9.13	-399.352	0.0000	Before settlement
	13.17	-637.716	0.0020	After settlement

Table 6: Magnitude Of Shear And Bending Moment Before And After Assiging Settlement (Third Floor)

Beam Label	Shear (kips)	Bending Moment (kips)	Angular Distortion	Remark
B9	-5.35	-287.495	0.0000	Before settlement
	-9.63	-556.828	0.0018	After settlement
B26	-14.91	-554.090	0.0000	Before settlement
	-16.52	-695.204	0.0012	After settlement

Table 7: Magnitude Of Shear And Bending Moment Before And After Assiging Settlement (Roof Floor)

Beam Label	Shear (kips)	Bending Moment (kips)	Angular Distortion	Remark
B9	-2.88	-177.830	0.0000	Before settlement
	-6.61	-411.304	0.0018	After settlement
26	-5.42	-227.900	0.0000	Before settlement
	-6.57	-321.942	0.0012	After settlement

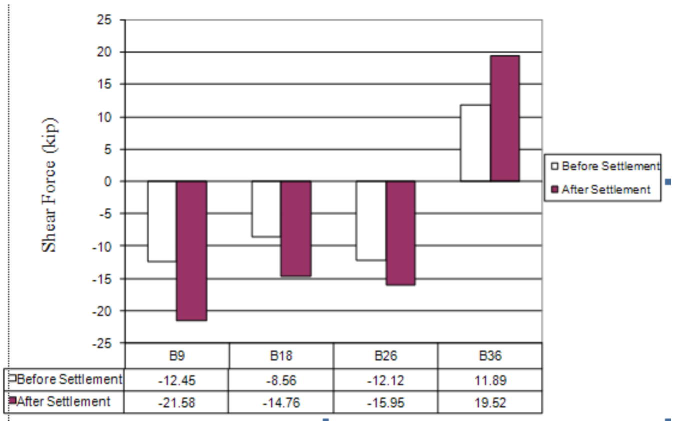


Figure.3: Comparison of Shear Force for Beam at Ground Floor

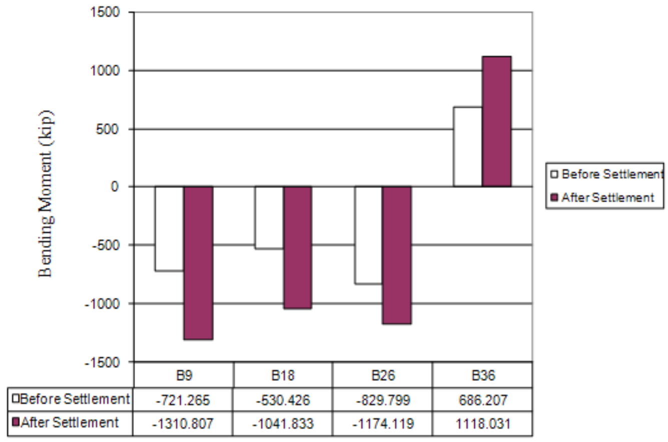


Figure.4. Comparison of Bending Moment for Beam at Ground Floor

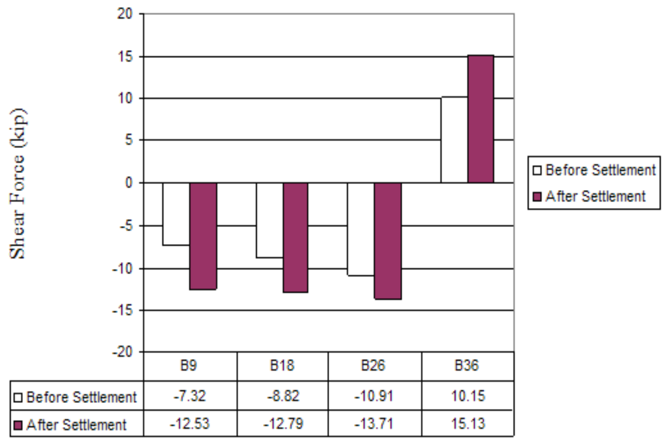
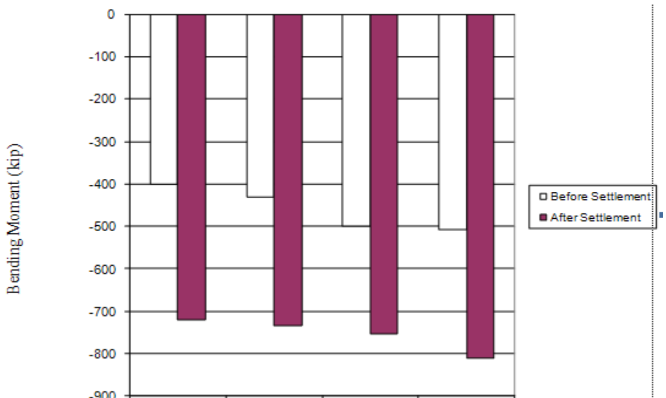
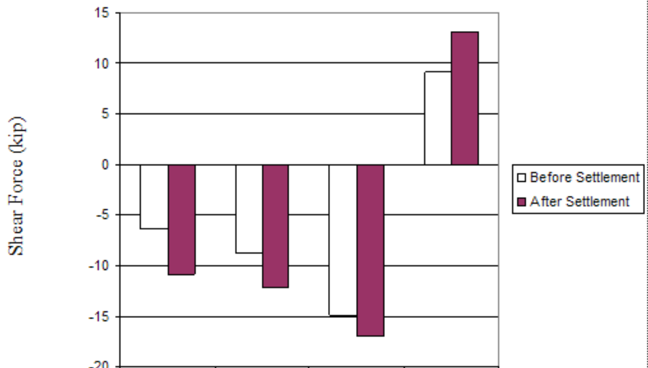


Figure.5. Comparison of Shear Force for Beam at First Floor



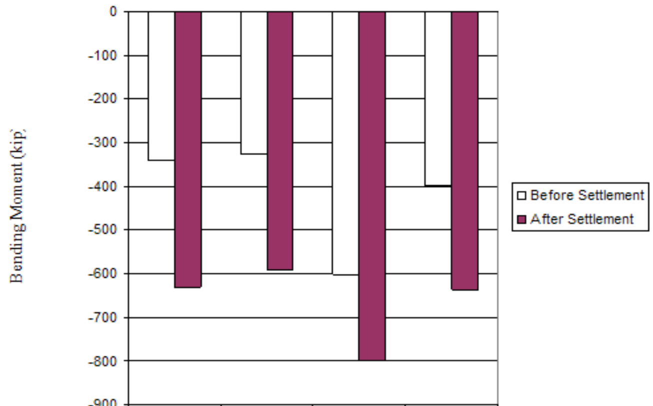
	B9	B18	B26	B36
Before Settlement	-399.942	-430.716	-498.346	-506.96
After Settlement	-720.897	-735.452	-753.123	-812.407

Figure.6. Comparison of Bending Moment for Beam at First Floor



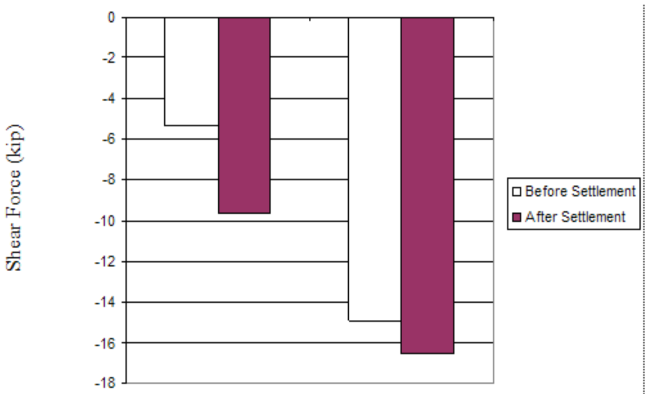
	B9	B18	B26	B36
Before Settlement	-6.32	-8.65	-14.82	9.13
After Settlement	-10.88	-12.04	-17	13.17

Figure.7. Comparison of Shear Force for Beam at Second Floor



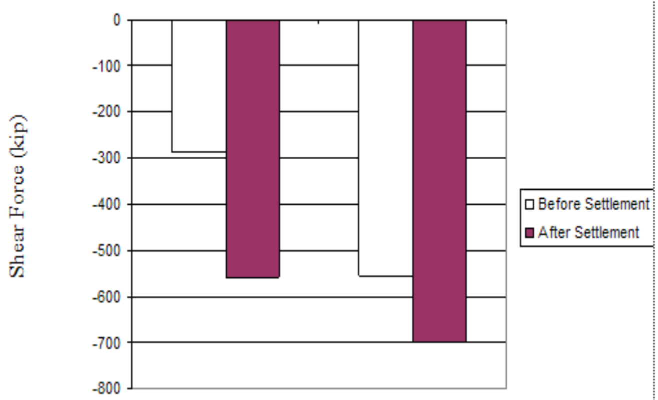
	B9	B18	B26	B36
Before Settlement	-342.193	-326.36	-601.068	-399.352
After Settlement	-630.367	-589.266	-798.268	-637.716

Figure.8. Comparison of Bending Moment for Beam at Second Floor



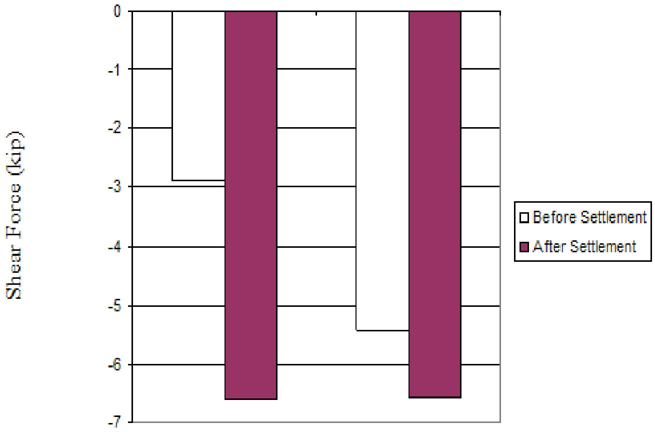
Before Settlement	-5.35	-14.91
After Settlement	-9.63	-16.52

Figure.9. Comparison of Shear Force for Beam at Third Floor



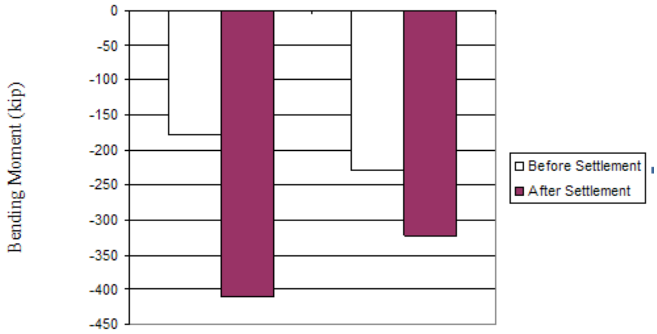
Before Settlement	-287.495	-554.09
After Settlement	-556.828	-695.204

Figure.10. Comparison of Bending Moment for Beam at Third Floor



Before Settlement	-2.88	-5.42
After Settlement	-6.61	-6.57

Figure.11. Comparison of Shear Force for Beam at Roof Floor



Before Settlement	-177.83	-227.9
After Settlement	-411.304	-321.942

Figure.12. Comparison of Bending Moment for Beam at Roof Floor

From above comparison results, it is found that B9 at ground floor fails after assigning settlement. The magnitude of shear force before and after settlement is -12.45 kip and -21.58 kip. The magnitude of bending moment before and after settlement is -721.265 kip and -1310.807 kip. Therefore, additional stresses are 73% for shear force and 81% for bending moment. At B26, the magnitude of shear force before and after settlement is -12.12 kip and -15.95 kip. The shear force before settlement is nearly equal in these beams. However, B9 fails under settlement because of the additional stresses which are greater than those of B26. It occurs because of the magnitude of the angular distortion of these beams. The magnitude of angular distortion of B9 is 0.0018 whereas that of B26 is only 0.0012. At the first floor of the structure, all the selected beams fail because the additional shear force and bending exceeds those of designed beam before assigning settlement. At the second floor of the structure, B26 fails under additional stresses of 15% for shear force and 33% for bending moment.. Therefore, it is noted that small amount of additional stresses can cause the failures of beam if the designed beams before settlement originally have large magnitude of shear force and bending moment

CONCLUSION

In this study, a four storey irregular reinforced concrete building is analyzed and designed by using ETABS software. Structural elements are designed according to ACI 318-99. Wind and earthquake loads are based on UBC-97. Structural system is special moment-resisting frame and the design is considered for residential building in high seismic zone, Mandalay area.

To calculate settlement, unfactored gravity column loads which are obtained from ETABS software are required. From soil report, allowable bearing capacity is calculated by using Braja M. Das's method. Then, the footings are designed with SAFE software. There are six types of footing class accordance with loading range. The total settlement under each footing is calculated by using Joseph E. Bowel's method and Braja M. Das's method. The larger value obtained from the calculation is taken. Generally, the allowable settlement is about 1.0 inch for all types of shallow foundation. Then, the structure is analyzed and designed again by assigning settlement in the ETABS software. When the structure is analyzed with support settlement, the size of beam and column are required to change to resist additional stresses. The stress changes in structure before and after settlement are compared by choosing failed beams of each storey.

As a result of comparison, it is found that the magnitude of shear force is directly proportional to angular distortion. Larger amount of angular distortion may result higher magnitude of additional stresses. Moreover, it is noted that small amount of additional stresses may lead to the failures of beam if the designed beams before settlement originally have large magnitude of shear force and bending moment. According to the study, it can be seen that the amount of settlement under the footing is generally controlled by two factors: loading and footing size. The differential settlement between adjacent footings can be minimized by proportioning footing size or by redesigning the superstructure so that it can resist larger amount of differential settlement. Generally, most of the engineers seem to have the misconception that any footing designed with an adequate factor of safety against a bearing capacity failure would not settle excessively. Therefore, for structural safety, it is important to note that not only bearing capacity checking but also settlement checking plays a key role.

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