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Improvement Of Seismic Response Of Multi-Story Buildings Using Jointed Double-Raft Slab.

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Abstract: Achieving the stability of buildings and facilities against any external influence, such as winds and earthquakes, depends mainly on the foundations supporting them, which are responsible for transferring loads to the soil layers beneath them. Accordingly, the design of the foundations to safely withstand these static and dynamic loads without causing dangers or failures on these structures has recently become the focus of the attention of many researchers Raft foundation is one of the most common foundation types in high-rise buildings, but due to the high base shear, it leads to a big value of settlement and soil pressure of the raft to overcome this problem, there are several solutions such as increasing dimensions, soil replacement and use another type of foundation so the main focus of this research is to perform THA to study the effect of joining the raft and basement ceiling slab with shear walls on raft settlement and soil pressure, Three high-rise buildings with different wall distributions were analyzed using ETABS V. 20.3.0 to perform the study. Various parameters were changed, including the modulus of subgrade reaction, earthquake records, raft thickness, basement ceiling slab thickness, and shear walls thickness. Based on the results joining the raft with the basement ceiling slab lead to improving settlement and reducing soil pressure.

Index terms – Buoyant, Compensated, High rise buildings, Settlement.

I. Introduction

Over the past 40 years, considerable progress has been made in understanding the nature of earthquakes and how they could cause structural damage and in improving the seismic performance of the built environment. However, much remains unknown regarding the prevention or mitigation of earthquake damage in worldwide, leaving room for further studies. A common practice of analysis and design of buildings is to assume the base of the building to be fixed, whereas in reality supporting soil influences the structural response by permitting movement to some extent due to its natural ability to deform[1], [2], [3], [4], [5], [6], [7], [8] Based on the depth of embedment (D), foundations are commonly classified as shallow or deep foundations. Raft/Mat foundation is a preferred category of shallow foundation and is preferred when the individual isolated footings provided under the structural columns occupy more than 50% of the entire foundation area (Tomlinson 2001), one of the most common problems in designing high-rise buildings is the large settlement and stress beneath the raft due to static and dynamic loads which may lead to the use of another type of foundation with more cost so many studies were performed to study the capability of improving settlement and stress under raft such as using Compensated raft foundation and buoyant raft which are used to support heavily loaded structures resting on soft and low-permeable soils, and aids in the reduction in settlement due to lowering of the stress transferred to the underlying soil[9],[10]. The objective of this research is to investigate the impact of connecting the raft foundation and basement ceiling slab with shear walls on settlement and soil pressure of the raft. This will be achieved through nonlinear time history analysis using ETABS V. 20.30. Three models with different systems were analyzed, system 1 (original system) without any shear walls, systems 2 and 3 with shear walls connecting raft with basement ceiling slab but with different distribution Each model comprises a basement, ground floor, and 10 typical floors, with five spans in longitudinal and transverse directions and a core at the center of the plan.

A parametric study was conducted to examine the impact of different parameters (modulus of subgrade reaction, raft thickness, basement ceiling slab thickness, and wall thickness) on settlement and soil pressure of the raft for the three systems under three different earthquake records (ELCENTRO, HOLLISTER, and SYLMAR). The goal is to evaluate the effect of connecting the raft with the basement ceiling slab.

II. Research Methodology

The research analyzes a hypothetical case study involving high-rise buildings. The high-rise building consists of 12 floors, with a basement floor that is 5.5m in height and 11 typical floors that are 3m in height. The floor plan incorporates 5 spans in the X-direction and 5 spans in the Y-direction, each spanning 5m. Additionally, there is one core in the middle in the shape of a 'C', a raft included in the model as a shell element, a retaining wall with 30cm thickness, and an area spring to represent the soil. Three different systems were utilized to investigate the effect of wall distribution, as illustrated in Figure 1. The 3D models of the structures were created using ETABS, with a 3D view of the developed model displayed in Figure 2.

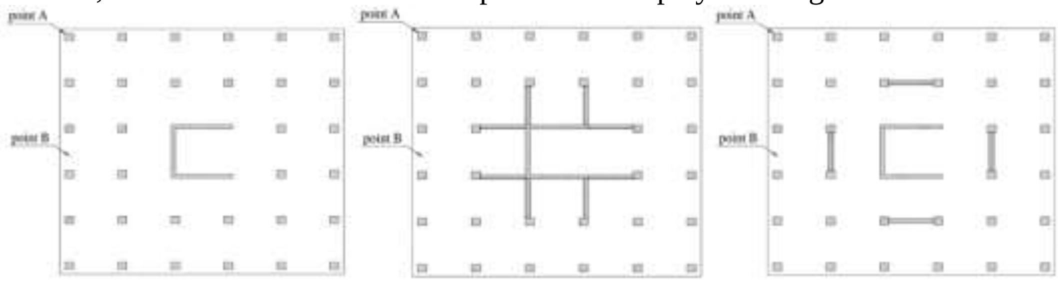

Figure 1: wall distribution

Figure 2: structure 3D model

2.1 Material properties

The concrete properties used in the analysis are shown in **Table 1**.

Table 1: Material properties for structural elements.

properties	value	units
Concrete compressive strength for columns and walls, Fcu	40	Mpa
Concrete compressive strength for beams, slabs, and raft, Fcu	35	Mpa
Modulus of elasticity of concrete for columns and walls, Ec	2782804	Mpa
Modulus of elasticity of concrete for beams, slabs, and raft, Ec	2603075	Mpa

2.2 Stiffness modifiers

Table 2 shows the Stiffness modifiers used to consider actual concrete member stiffness due to cracking according to ECP-201.

Table 1: Property modifiers of sections

Member	**Property Modifier**
columns	0.7
Beams	0.5
slabs	0.25
walls	0.35

2.3 Structure Geometry

Table 3 presents the structure details and section dimensions utilized for the analysis of high-rise buildings. Additionally, the table encompasses the various values of the parameters understudy (modulus of subgrade reaction, basement ceiling slab thickness, raft thickness, and wall thickness).

Table 3: Structure details and section dimensions for parametric study.

Model Configurations	Value and Description	Units
Number of bays along longitudinal And transverse direction	5	
Spacing along the longitudinal and transverse direction	5	m
Columns	80x80	cm
Marginal Beams	30x70	cm
slabs	20,30,40	cm
raft	120,140,160	cm
walls		
Retaining wall thickness	30	cm
Shear walls and core	30,40,50	cm
Spring Modulus of subgrade reaction	350,700,1400	t/m^3

2.4 Gravity loads

Table 2: Gravity loads on the structure

Load type	Value (KN/m^2)
loads on raft	
F.C.	2
L.L	5
WALLS	1.5
Loads on typical slabs	
F.C.	2
L.L	2
WALLS	1.5

2.5 Seismic Loads

Table 5: Characteristics of earthquake ground motion records used in the analysis

earthquake/station	PGA (g)	PGV(cm/sec.)	PGD (cm)
Imperial Valley-02, elcentro array #9	0.1781	8.6123	2.6741
Central Calif-01, Hollister City Hall	0.018	1.4531	0.3791
Whittier Narrows-01, Sylmar-olive view	0.0418	1.8662	0.2519

2.6 Investigated Parameters

A parametric study was conducted, varying several parameters as detailed in **Table 6** These parameters were adjusted within three different wall distribution systems while performing THA for three different TH records. The aim was to study the effect of connecting the raft with the basement ceiling slab on the settlement, soil pressure, and bending moment of the raft.

Table 6: Studied parameters.

Parameter	Variation	Unit
Modulus of subgrade reaction	350-700-1400	t/m³
Raft thickness	120-140-160	cm
Basement ceiling slab thickness	20-30-40	cm
Wall thickness	30-40-50	cm

III. parametric study

This chapter describes the effect of the studied parameters (modulus of subgrade reaction, raft thickness, basement ceiling slab thickness, wall thickness, and number of stories) on the soil pressure and settlement of the raft under A suite of three-ground motion records from three different earthquakes (PEER2012) is selected for the purpose of understanding the input ground motion effect (ELCENTRO, HOLLISTER, AND SYLMARE) at fixed points of the raft (A and B).

Three systems were studied: System 1, the original system without any walls; System 2 (star shape), with walls at the center; and System 3, with wall distribution at the outer perimeter of the raft, as shown in Figure 1.

3.1 Modulus Of Subgrade Reaction

To study the effect of changing the modulus of subgrade reaction on raft settlement and soil pressure, three values of K (350 t/m³,700 t/m³, and 1400 t/m³) were used, raft thickness=120cm, basement ceiling thickness=20cm, walls thickness=30cm and number of stories =12.

3.1.1 Settlement

With changing modulus of subgrade reaction (K), connecting the raft with the basement ceiling slab using shear walls leads to improved settlement. In system 2, the distribution of walls is more efficient than in system 3. Increasing the values of K enhances the efficiency of connecting the raft with the basement ceiling slab. However, in system 2 at point B, the settlement values increase, although not significantly, while system 3 almost matches the settlement values of system 1 (the original system without connecting walls). This effect is consistent across the three different TH records as shown in Figures 3-8.

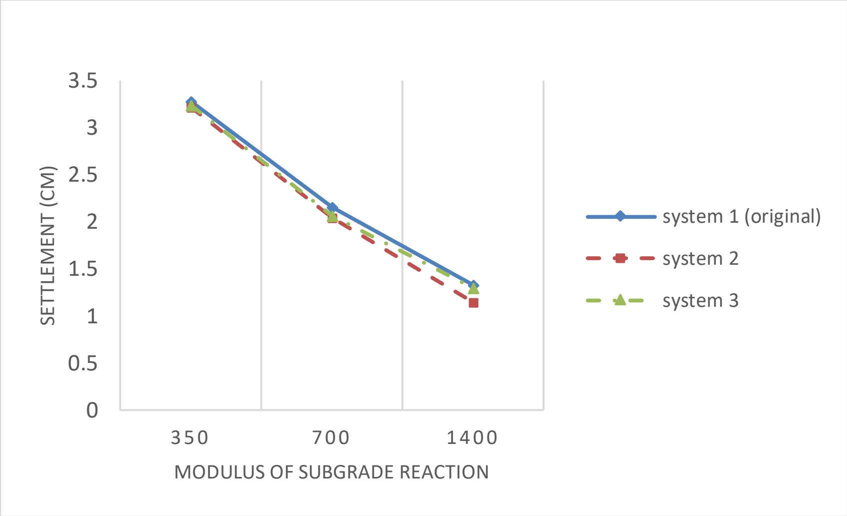

Figure 3: settlement at point A due to ELCENTRO-TH

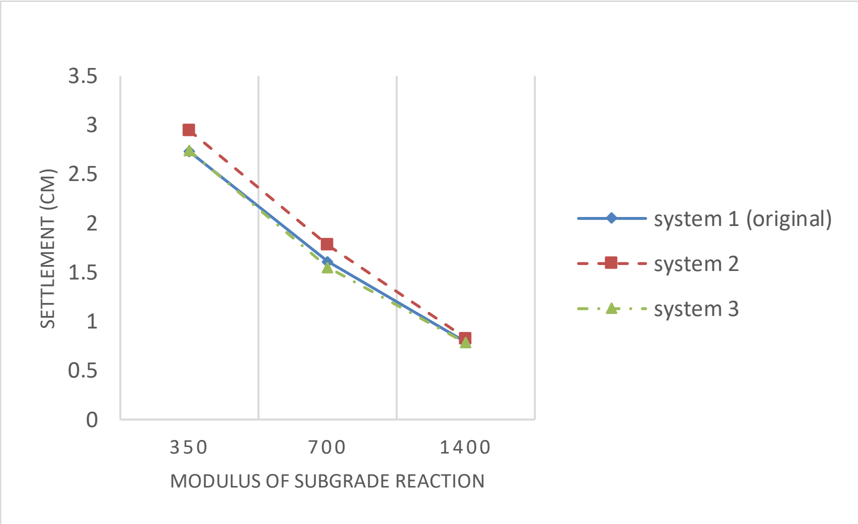

Figure 4: settlement at point B due to ELCENTRO-TH

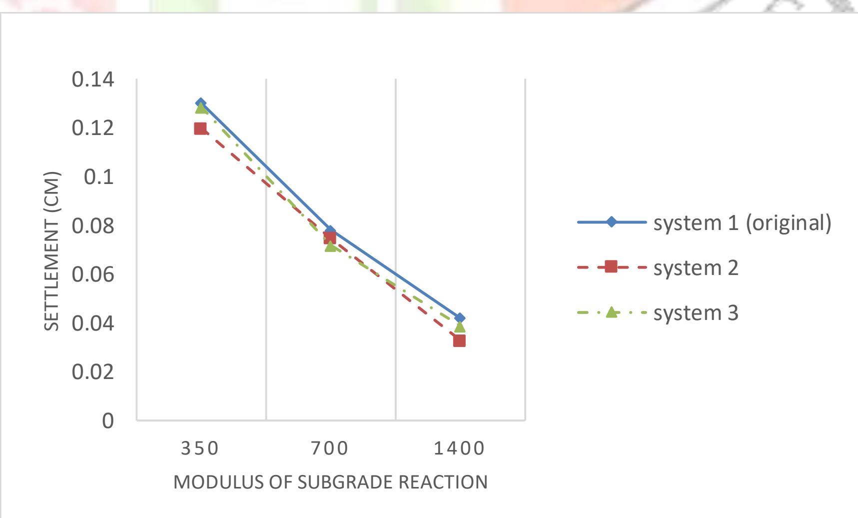

Figure 5: settlement at point A due to HOLLISTER-TH

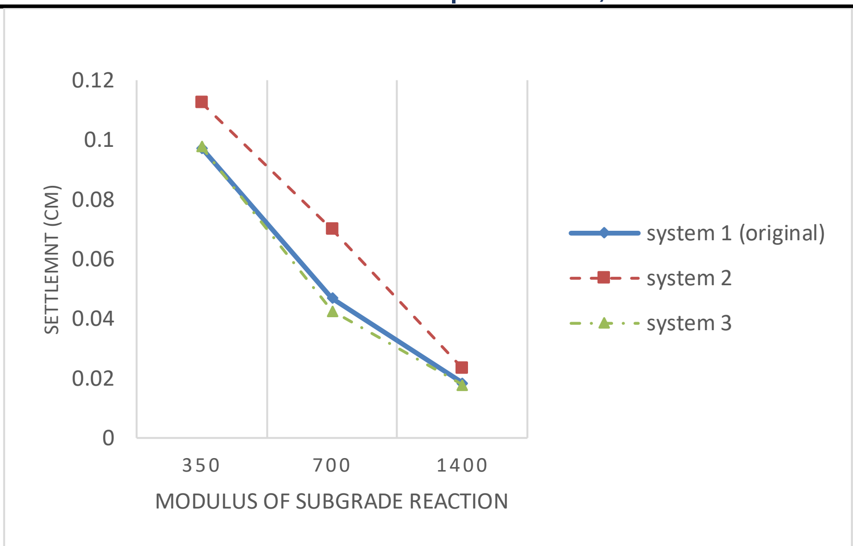

Figure 6: settlement at point B due to HOLLISTER-TH

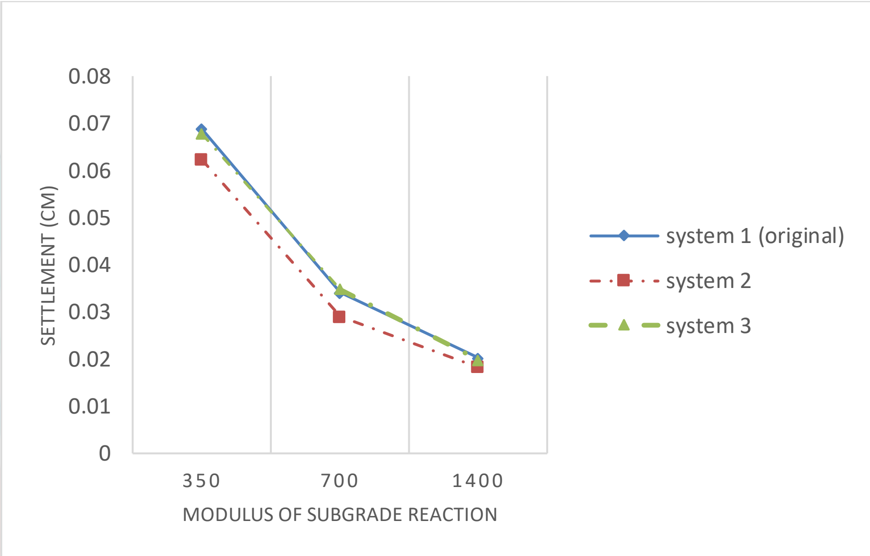

Figure 7: settlement at point A due to SYLMAR-TH

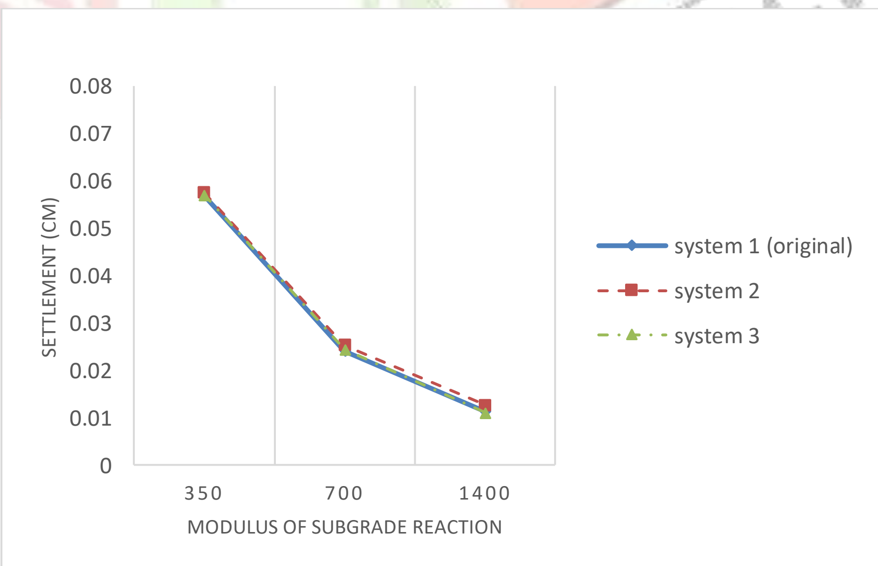

Figure 8: settlement at point B due to SYLMAR-TH

3.1.2 Soil Pressure

By adjusting the modulus of the subgrade reaction (K) and connecting the raft with the basement ceiling slab using shear walls, we can improve soil pressure. In System 2, the distribution of walls is more efficient compared to System 3. However, in System 2 at point B, soil pressure values increase slightly, while in System 3, settlement values almost match those of System 1 (the original system without connecting walls). This effect is consistent across the three different TH records as shown in Figures 9-14.

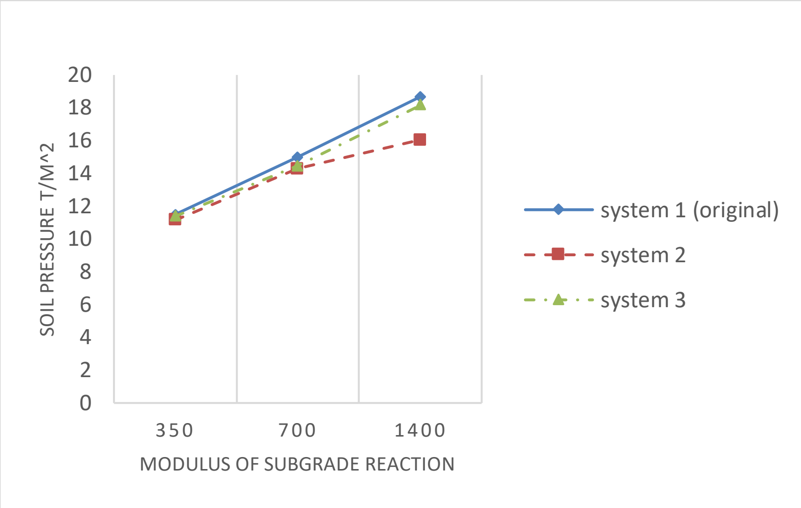

Figure 9: soil pressure at point A due to ELCENTRO-TH

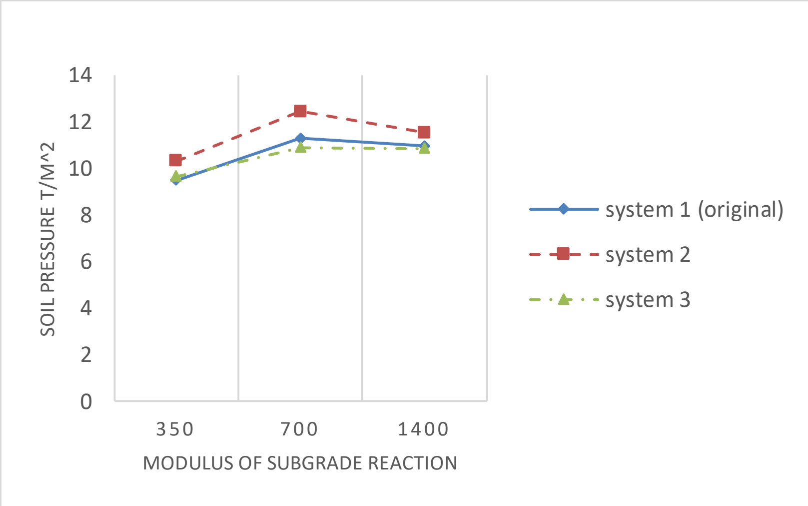

Figure 10: soil pressure at point B due to ELCENTRO-TH

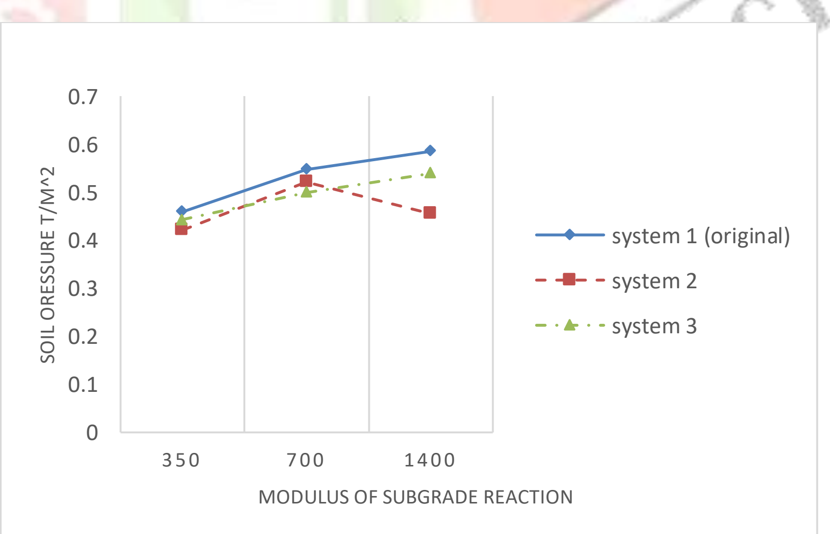

Figure 11: soil pressure at point A due to HOLLISTER-TH

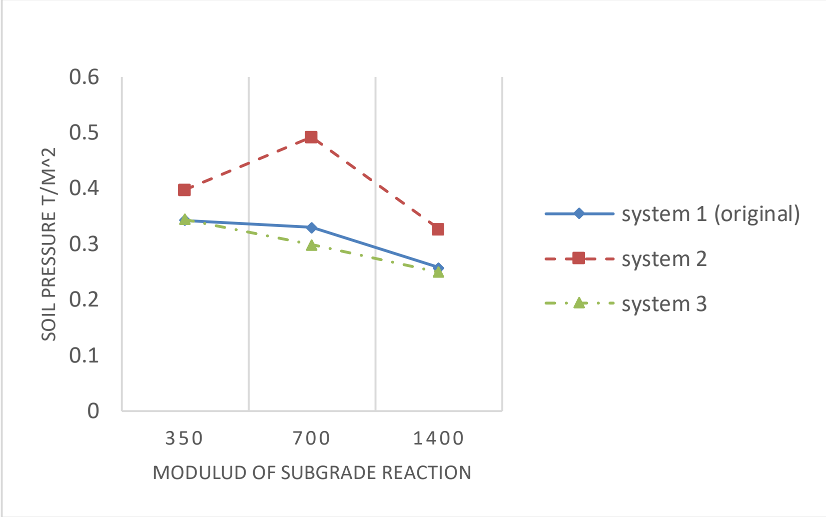

Figure 12: soil pressure at point B due to HOLLISTER-TH

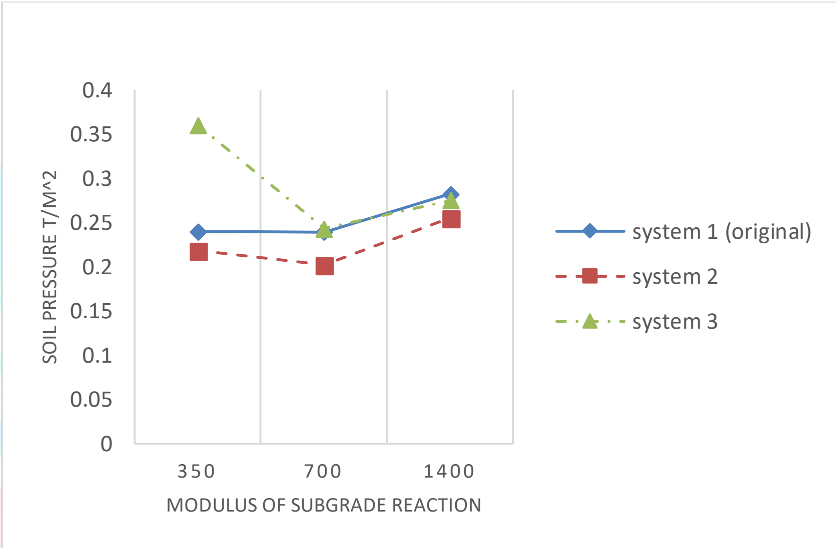

Figure 13: soil pressure at point A due to SYLMAR-TH

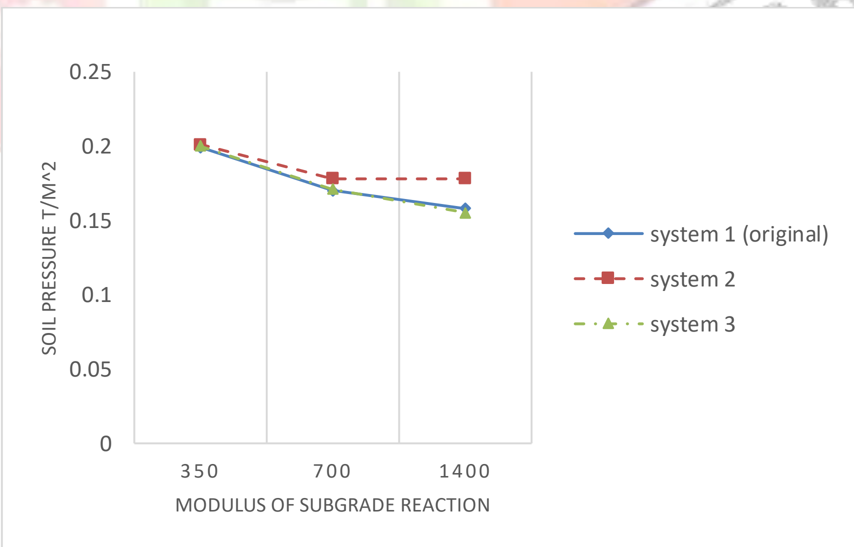

Figure 14: soil pressure at point B due to SYLMAR-TH

The distribution of walls in system 2 leads to a decrease in soil pressure due to working vertical loads with significant values at any value of modulus of subgrade reaction as shown in Figure 15.

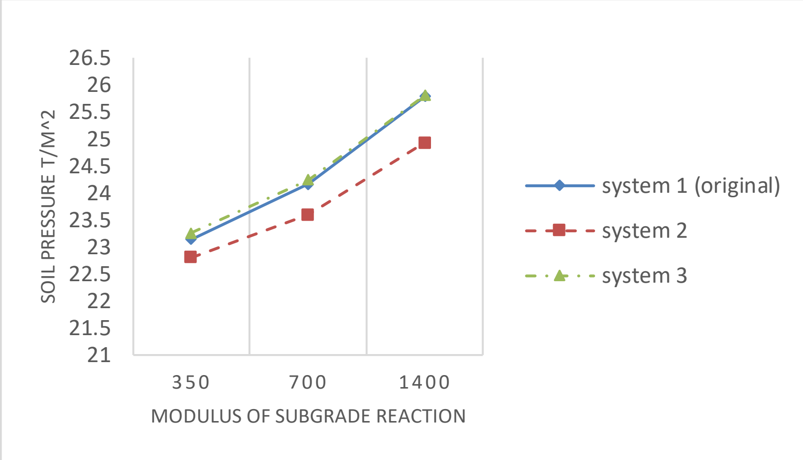

Figure 15: maximum soil pressure due to working vertical loads

3.2 raft thickness

To study the effect of changing raft thickness on raft settlement, soil pressure, and bending moment three values of raft thickness were used (120cm,140cm, and 160cm), k=1400, basement ceiling thickness=20cm, walls thickness=30cm and number of stories =12.

3.2.1 Settlement

With changing raft thickness, connecting the raft with the basement ceiling slab using shear walls leads to improved settlement. In system 2, the distribution of walls is more efficient than in system 3. Increasing the value of raft thickness reduced the decrease in settlement. However, in system 2 at point B, the settlement values increase, although not significantly, while system 3 almost matches the settlement values of system 1 (the original system without connecting walls). This effect is consistent across the three different TH records as shown in Figures 16-21.

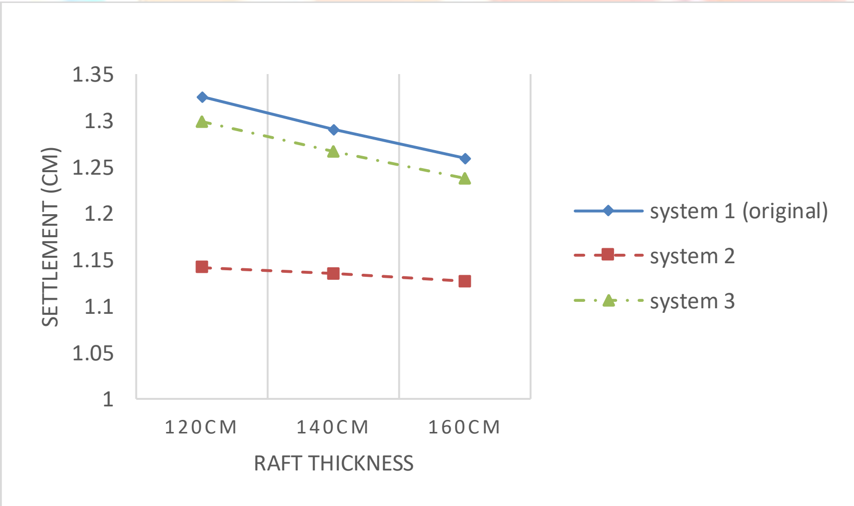

Figure 16: Settlement at point A due to ELCENTRO-TH

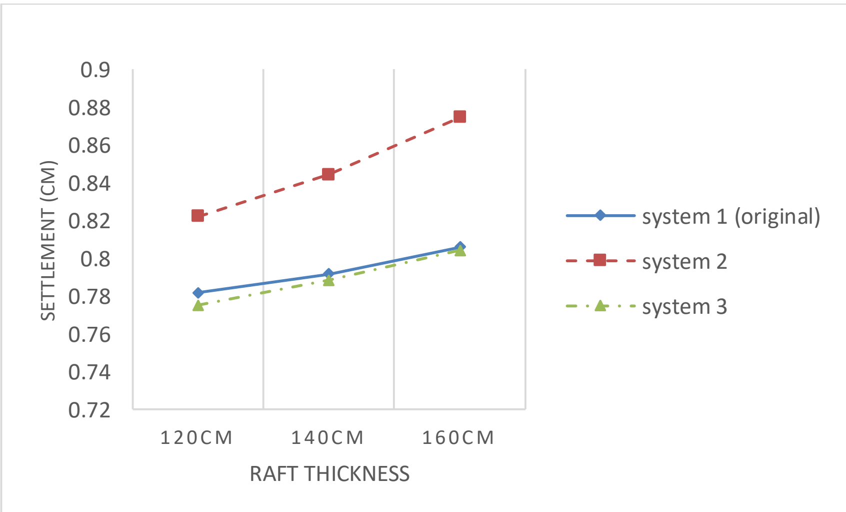

Figure 17: Settlement at point B due to ELCENTRO-TH

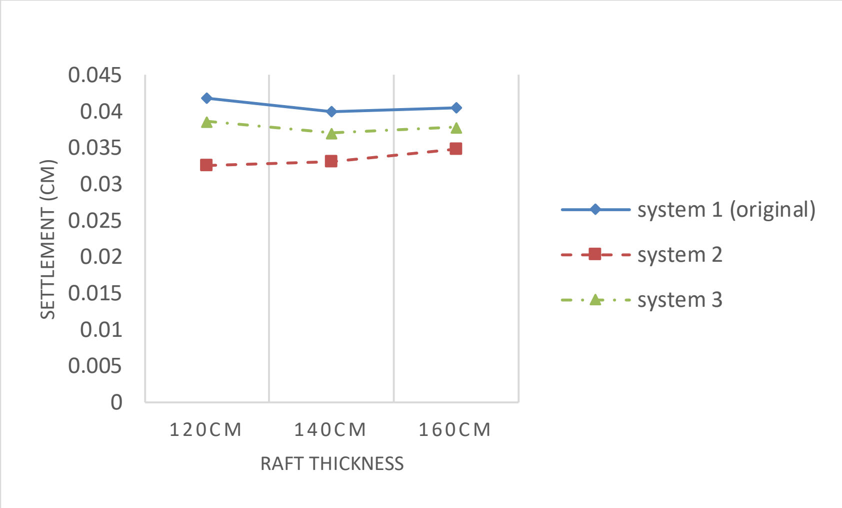

Figure 18: Settlement at point A due to HOLLISTER-TH

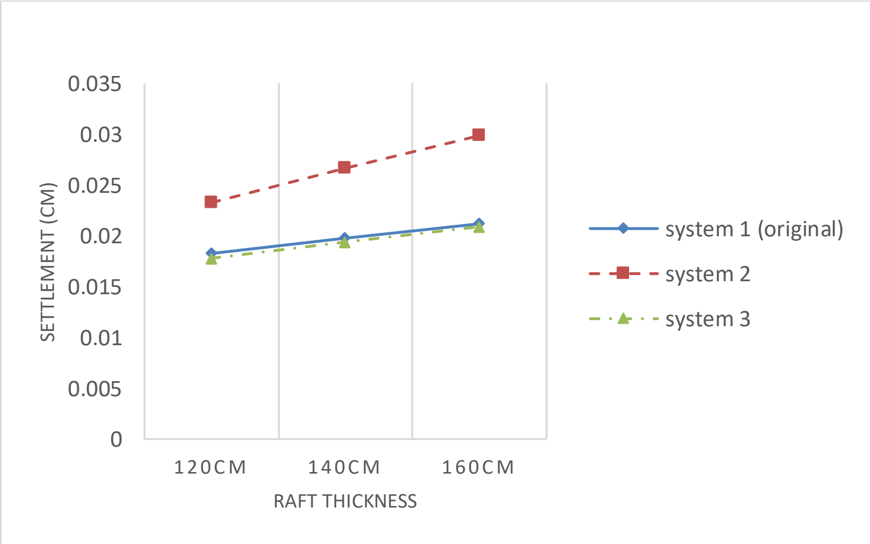

Figure 19: Settlement at point B due to HOLLISTER-TH

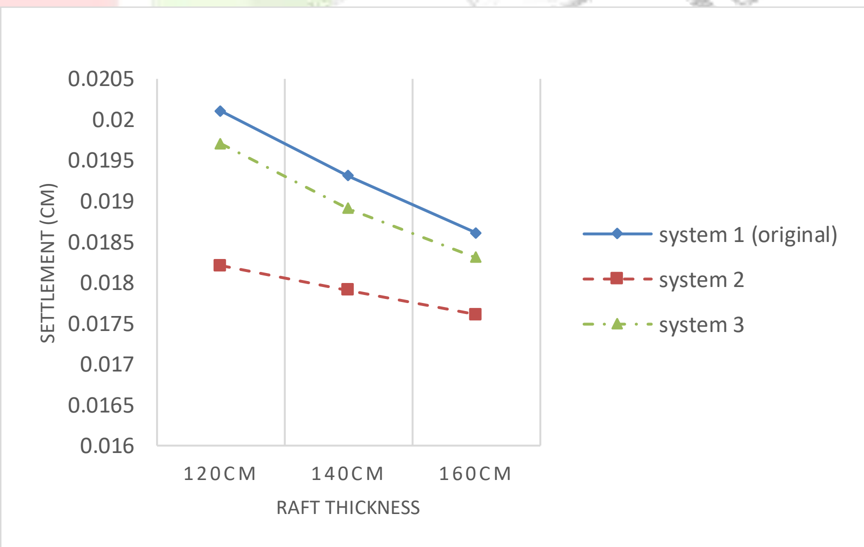

Figure 20: Settlement at point A due to SYLMAR-TH

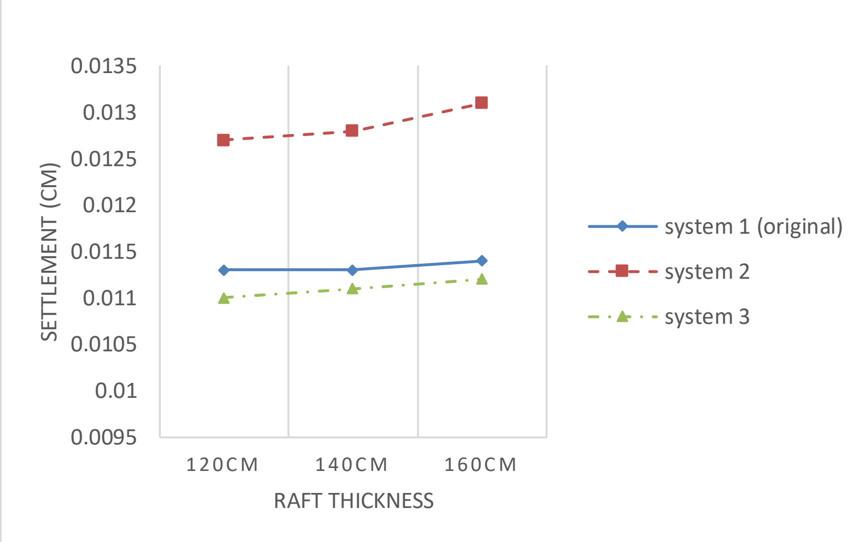

Figure 21: Settlement at point B due to SYLMAR-TH

3.2.2. Soil pressure

Modifying the thickness of the raft and connecting it to the basement ceiling slab using shear walls improves soil pressure. In System 2, the distribution of walls is more efficient compared to System 3. However, in System 2 at point B, there is a slight increase in the soil pressure values, while in System 3, the settlement values closely match those of System 1 (the original system without connecting walls). This pattern is consistent across the three different TH records.as shown in Figures 22-27.

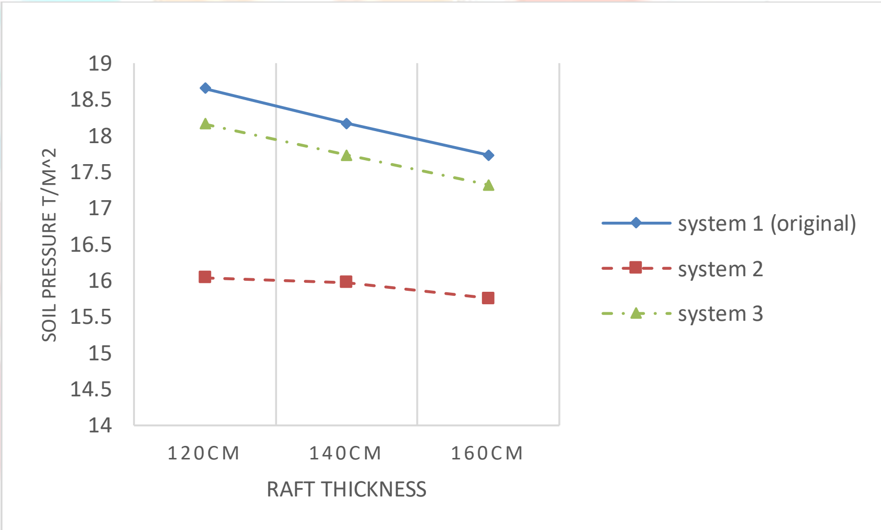

Figure 22: Soil pressure at point A due to ELCENTRO-TH

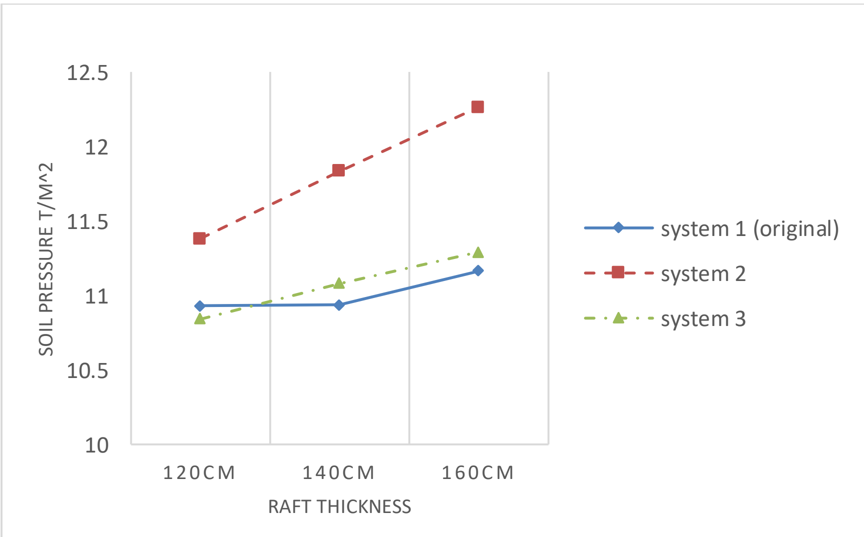

Figure 23: Soil pressure at point B due to ELCENTRO-TH

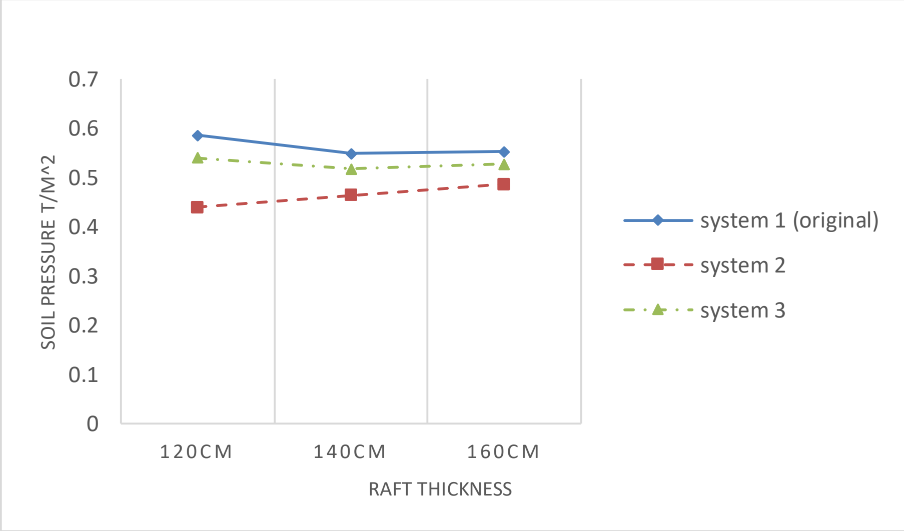

Figure 24: Soil pressure at point A due to HOLLISTER-TH

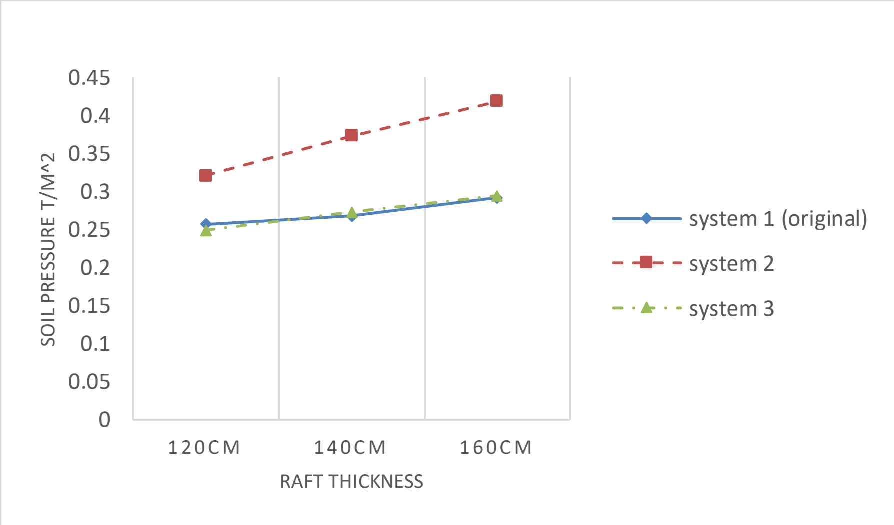

Figure 25: Soil pressure at point B due to HOLLISTER-TH

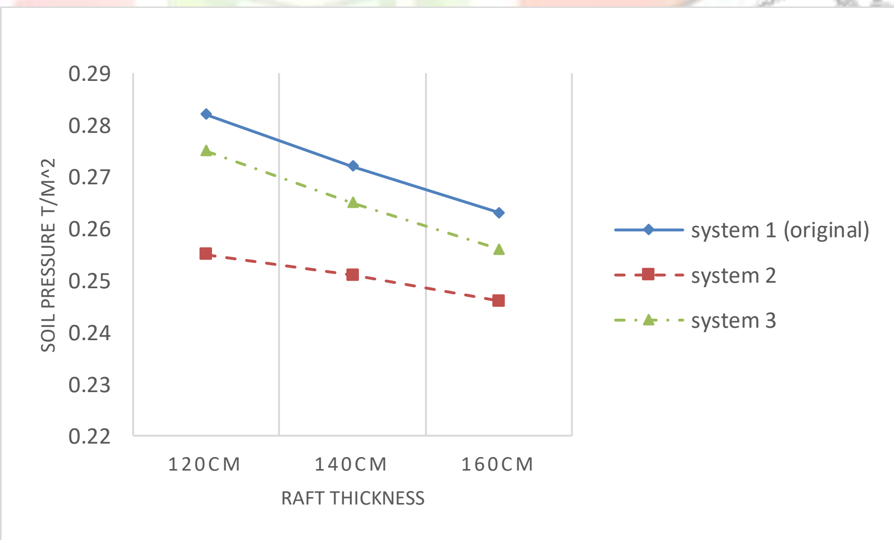

Figure 26: Soil pressure at point A due to SYLMAR-TH

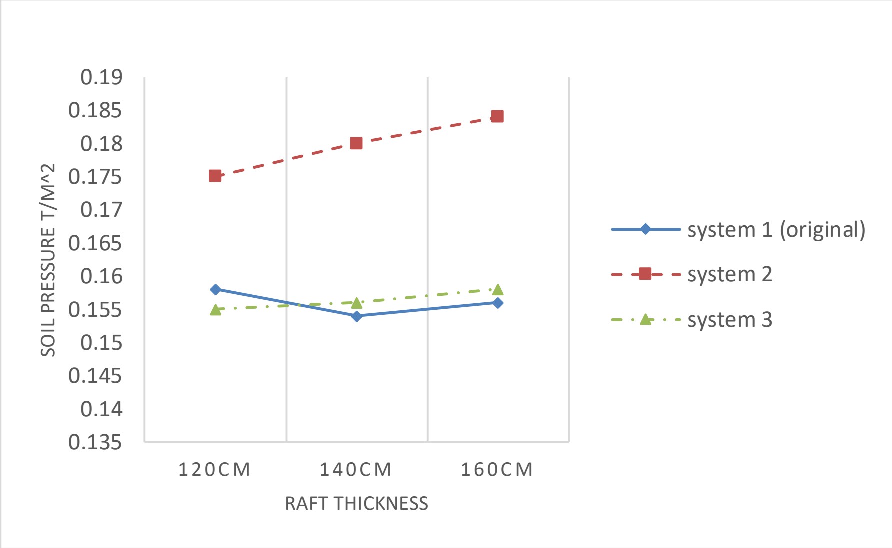

Figure 27: Soil pressure at point B due to SYLMAR-TH

The arrangement of walls in system 2 results in a decrease in soil pressure when handling vertical loads of significant magnitude, regardless of the thickness of the raft as shown in Figure 28.

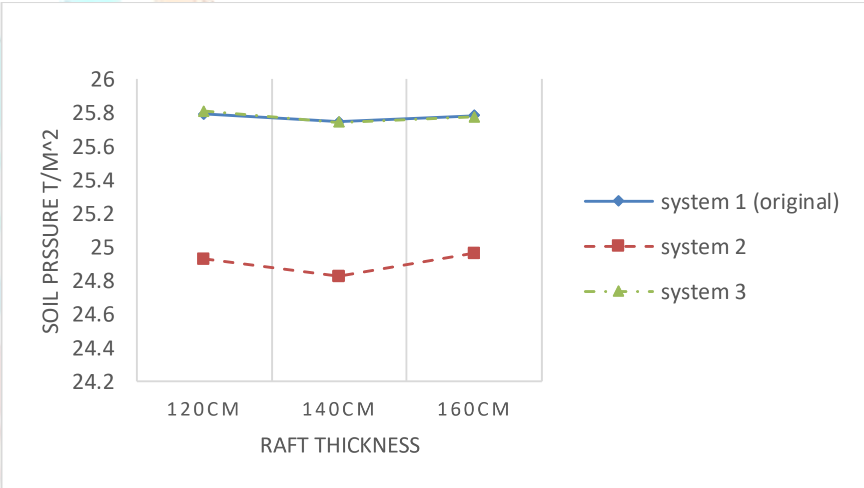

Figure 28: Maximum soil pressure due to working vertical loads

3.3 Basement Ceiling Slab Thickness

in order to analyze the impact of varying basement ceiling slab thickness on raft settlement, soil pressure, and bending moment, three different thickness values were considered for the basement ceiling slab (20cm, 30cm, and 40cm). Other relevant parameters include k=1400, wall thickness=30cm, raft thickness=120cm, and number of stories=12.

3.3.1 Settlement

With changing basement ceiling slab thickness, connecting the raft with the basement ceiling slab using shear walls leads to improved settlement. In system 2, the distribution of walls is more efficient than in system 3. Increasing the value of basement ceiling slab thickness reduced the decrease in settlement. However, in system 2 at point B, the settlement values increase, although not significantly, while system 3 almost matches the settlement values of system 1 (the original system without connecting walls). This effect is consistent across the three different TH records as shown in Figures 29-34.

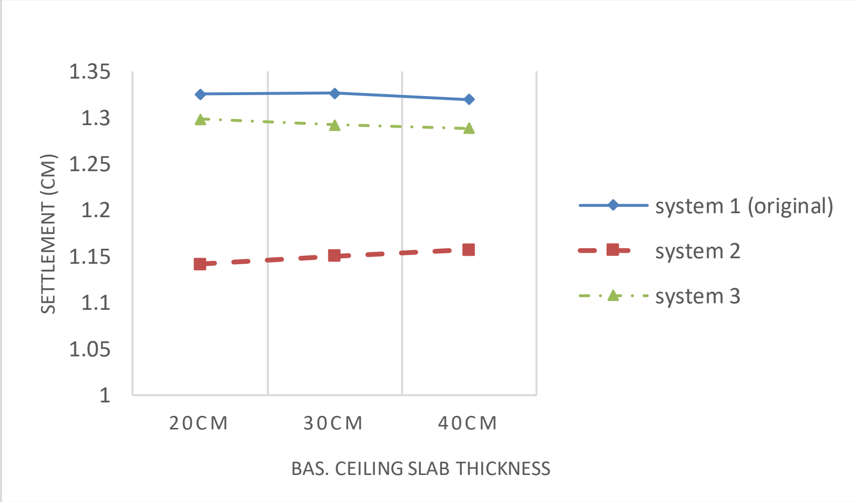

Figure 29: Settlement at point A due to ELCENTRO-TH

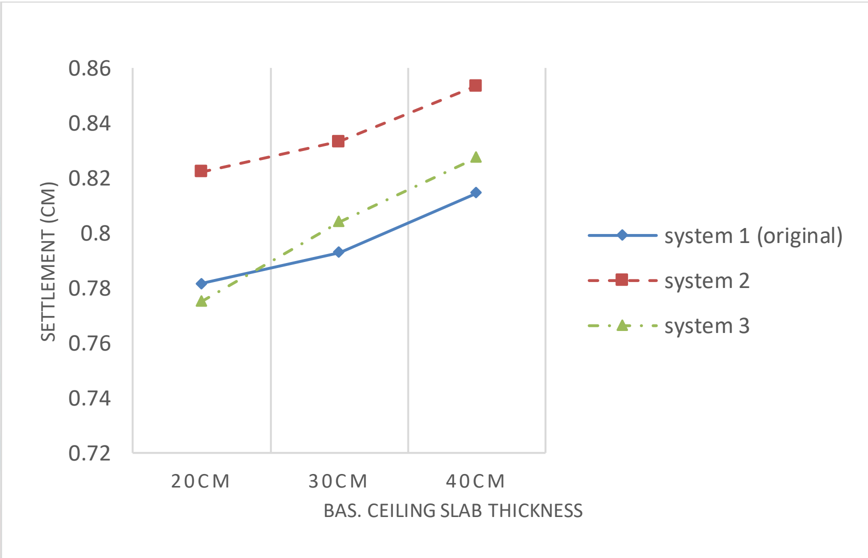

Figure 30: Settlement at point B due to ELCENTRO-TH

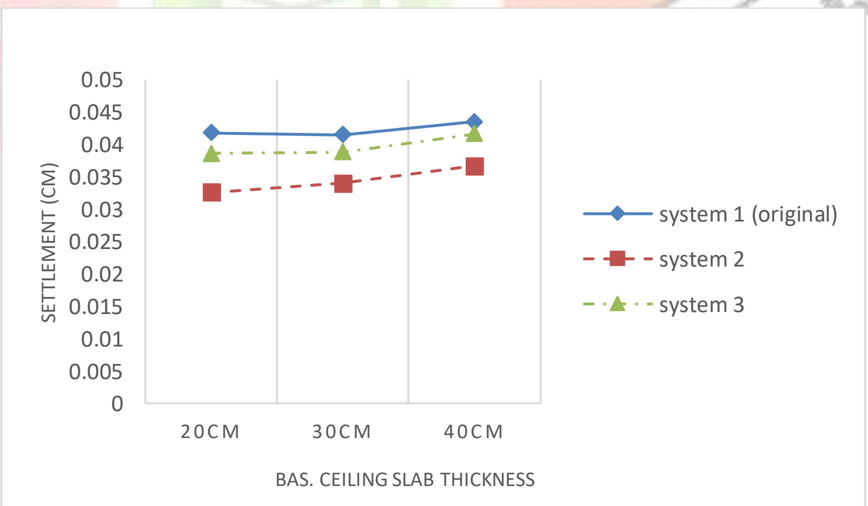

Figure 31: Settlement at point A due to HOLLISTER-TH

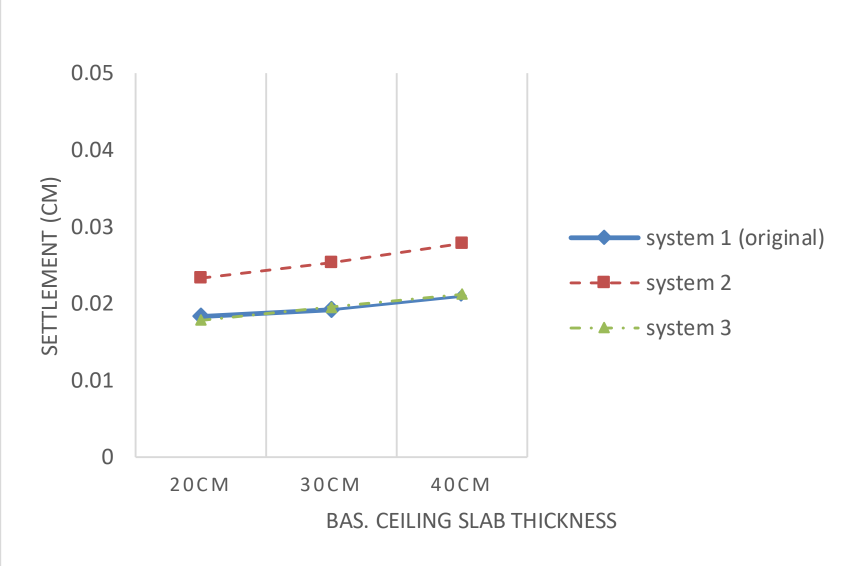

Figure 32: Settlement at point B due to HOLLISTER-TH

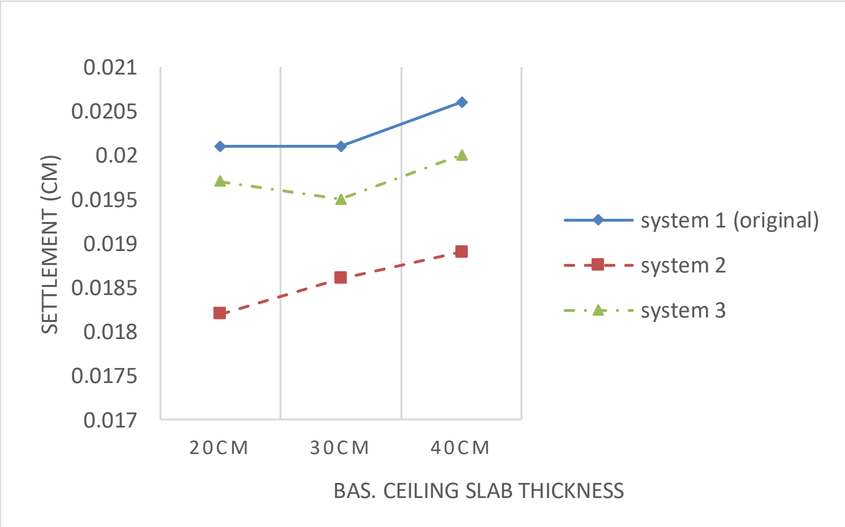

Figure 33: Settlement at point A due to SYLMAR-TH

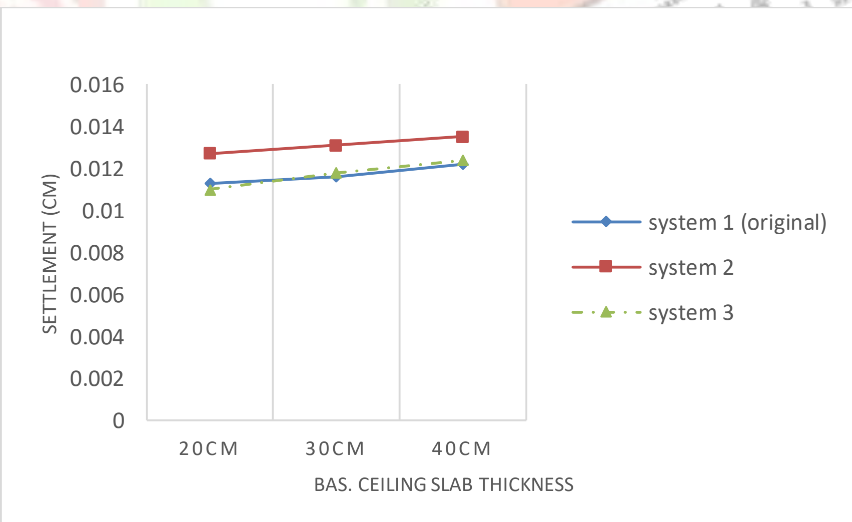

Figure 34: Settlement at point B due to SYLMAR-TH

3.3.2 Soil pressure

With changing basement ceiling slab thickness, connecting the raft with the basement ceiling slab using shear walls leads to improved Soil pressure. In System 2, the distribution of walls is more efficient than in System 3. However, in System 2 at point B, the soil pressure values increase, although not significantly, while System 3 almost matches the settlement values of System 1 (the original system without connecting walls). This effect is consistent across the three different TH records as shown in Figures 35-40.

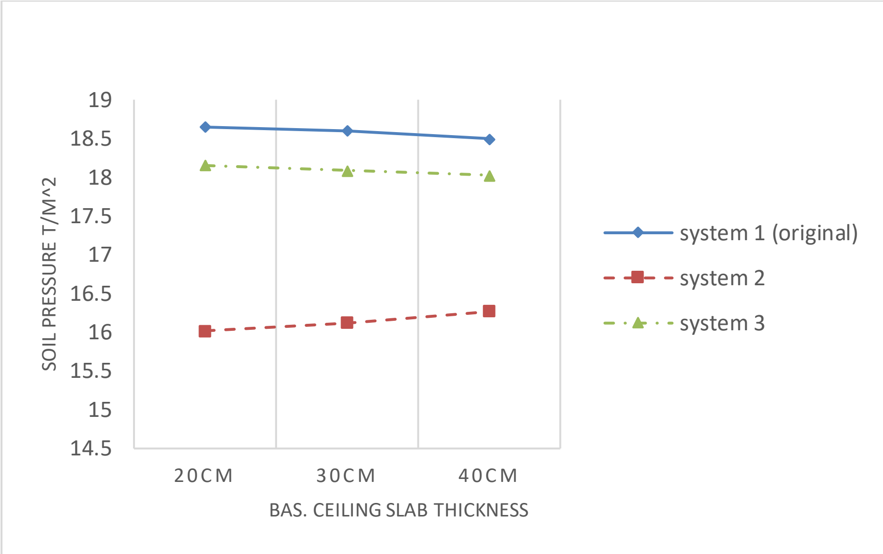

Figure 35: Soil pressure at point A due to ELCENTRO-TH

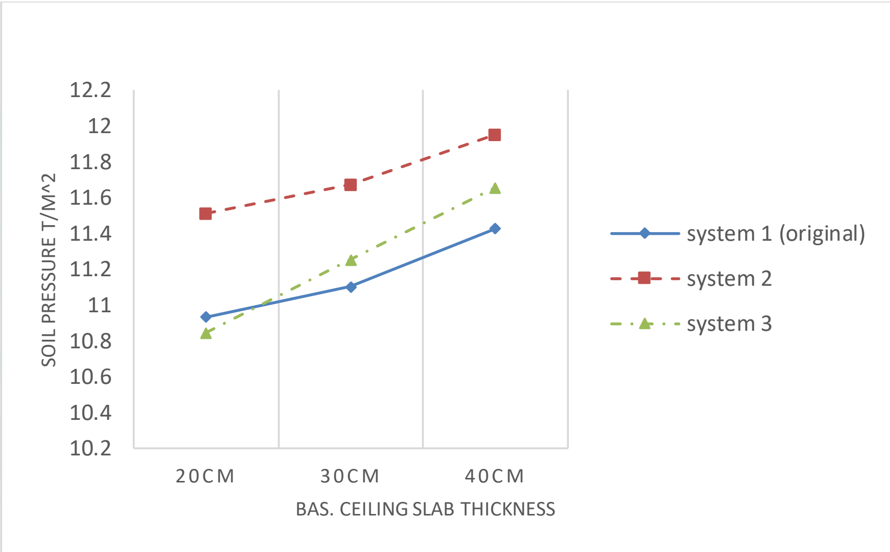

Figure 36: Soil pressure at point B due to ELCENTRO-TH

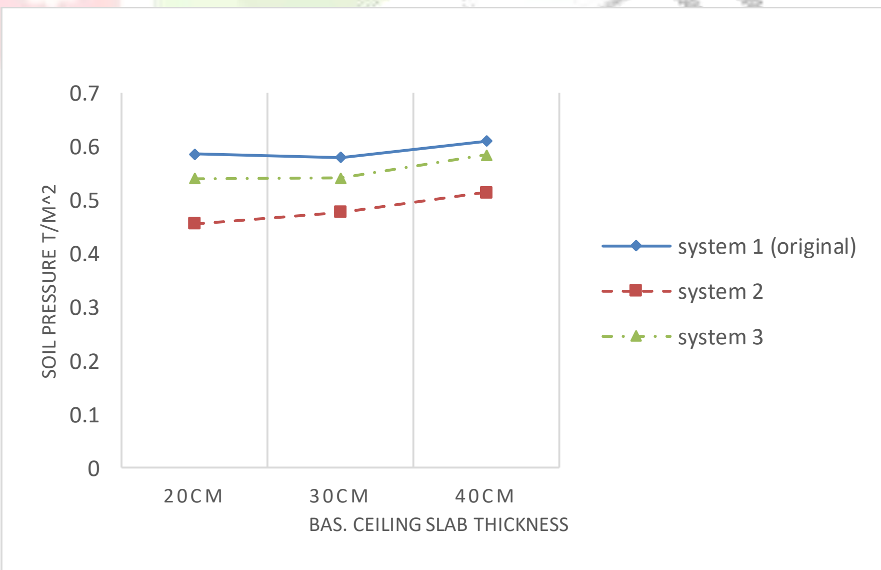

Figure 37: Soil pressure at point A due to HOLLISTER-TH

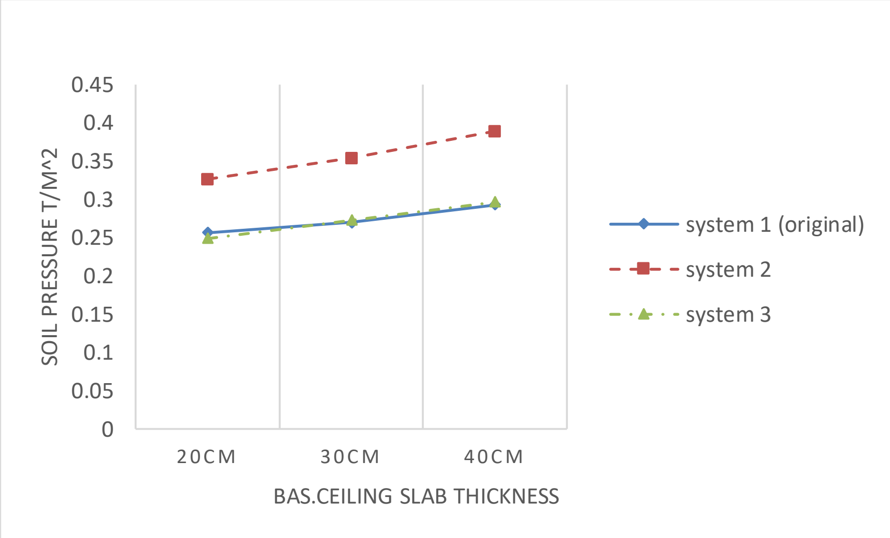

Figure 38: Soil pressure at point B due to HOLLISTER-TH

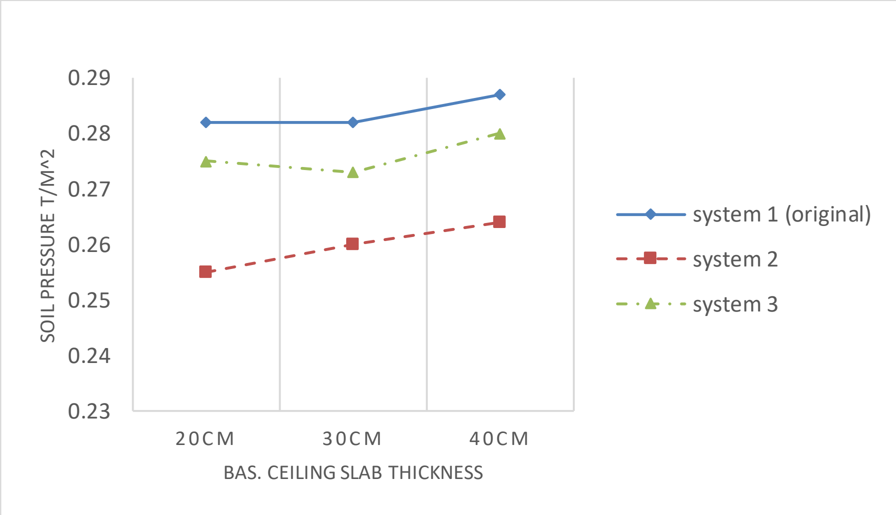

Figure 39: Soil pressure at point A due to SYLMAR-TH

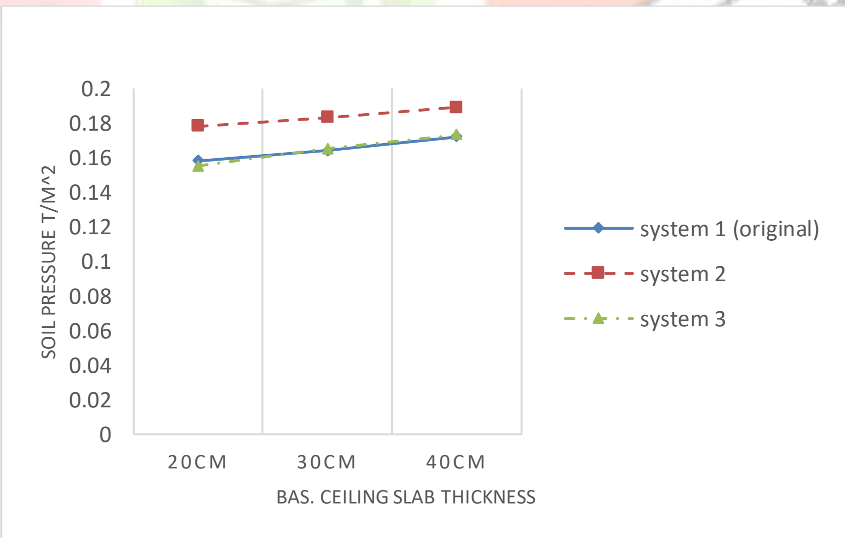

Figure 40: Soil pressure at point B due to SYLMAR-TH

The distribution of walls in system 2 leads to a decrease in soil pressure due to working vertical loads with significant values at any value of basement ceiling slab thickness, as shown in Figure 41.

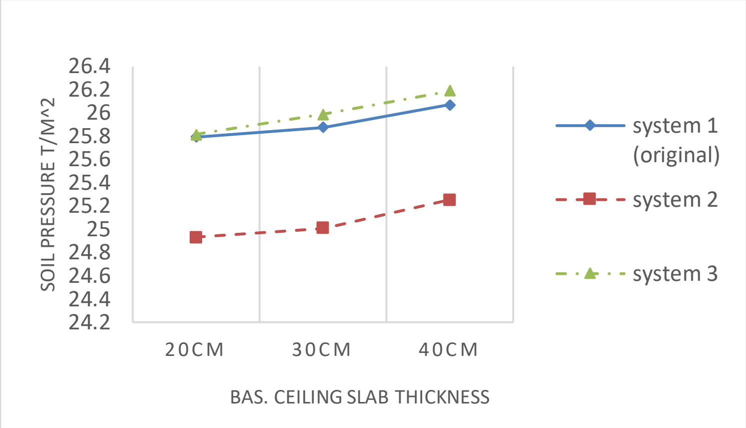

Figure 41: Maximum soil pressure due to working vertical loads

3.4 Walls thickness

To study the effect of changing wall thickness on raft settlement, soil pressure, and bending moment, three values of wall thickness were used (30cm,40cm, and 50cm), k=1400, basement ceiling slab thickness=20cm, raft thickness=120cm, and number of stories =12.

3.4.1 Settlement

With changing shear walls thickness, connecting the raft with the basement ceiling slab using shear walls leads to improved settlement. In system 2, the distribution of walls is more efficient than in system 3. Increasing the value of shear walls thickness improves settlement. However, in system 2 at point B, the settlement values increase, although not significantly, while system 3 almost matches the settlement values of system 1 (the original system without connecting walls). This effect is consistent across the three different TH records as shown in Figures 42-47.

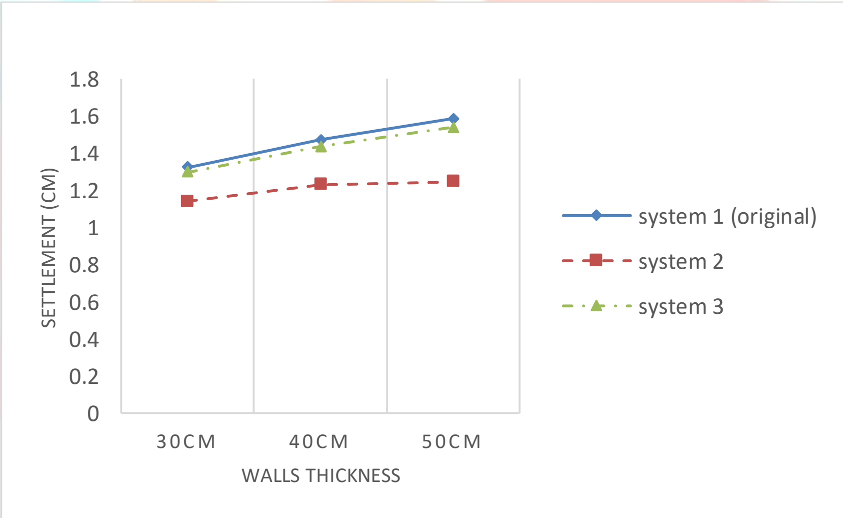

Figure 42: Settlement at point A due to ELCENTRO-TH

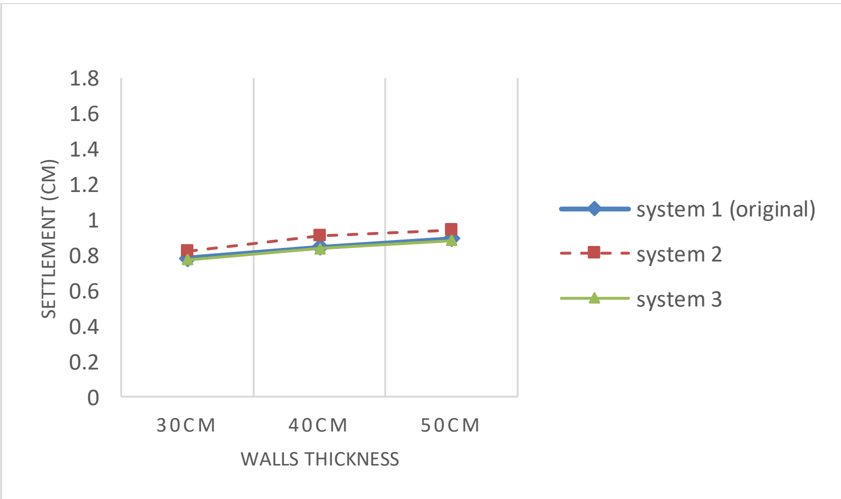

Figure 43: Settlement at point B due to ELCENTRO-TH

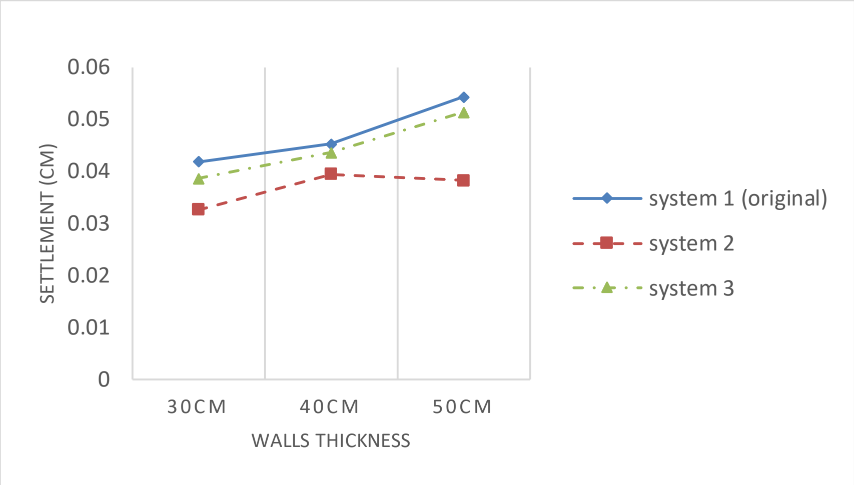

Figure 44: Settlement at point A due to HOLLISTER-TH

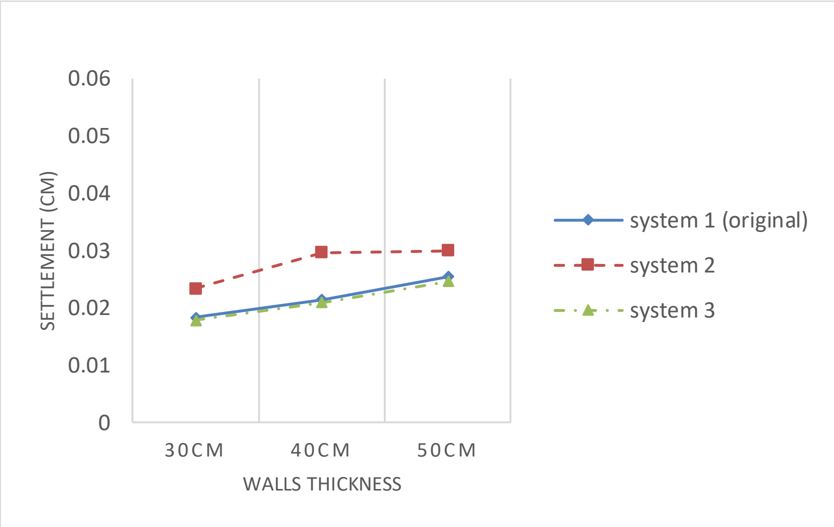

Figure 45: Settlement at point B due to HOLLISTER-TH

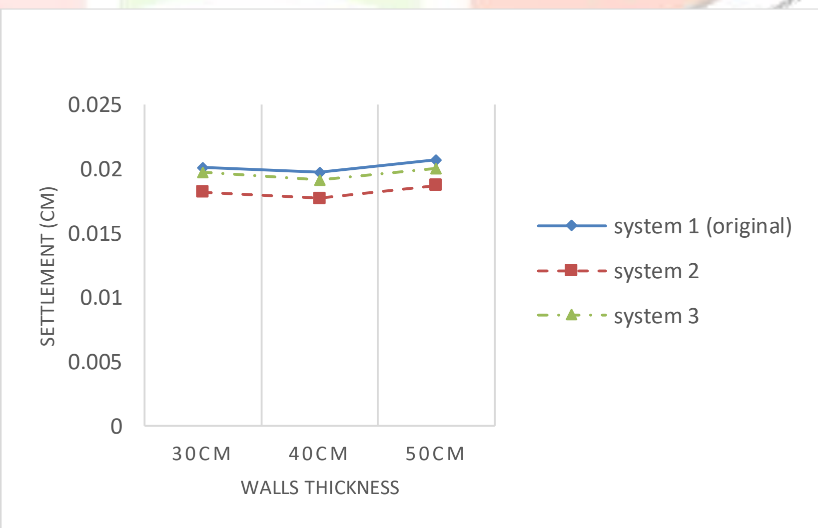

Figure 46: Settlement at point A due to SYLMAR-TH

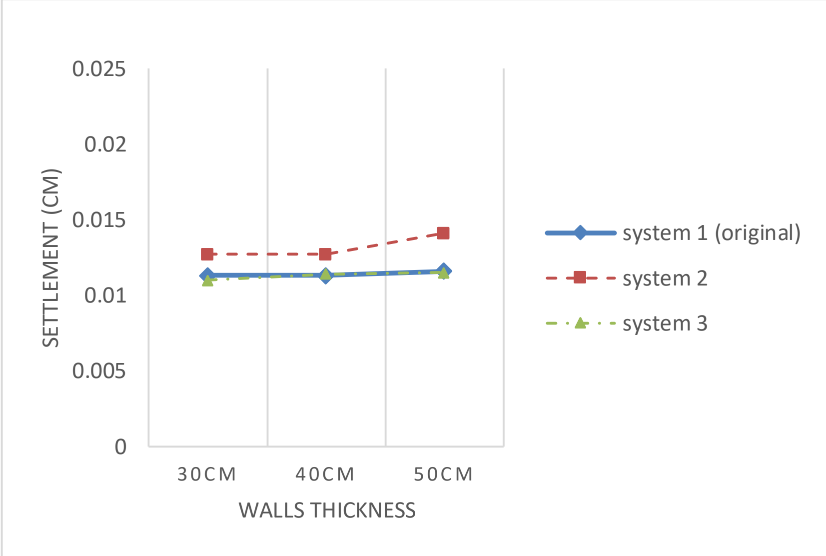

Figure 47: Settlement at point B due to SYLMAR-TH

3.4.2 Soil pressure

With changing shear walls thickness, connecting the raft with the basement ceiling slab using shear walls leads to improved Soil pressure. In System 2, the distribution of walls is more efficient than in System 3. However, in System 2 at point B, the soil pressure values increase, although not significantly, while System 3 almost matches the settlement values of System 1 (the original system without connecting walls). This effect is consistent across the three different TH records as shown in Figures 48-53.

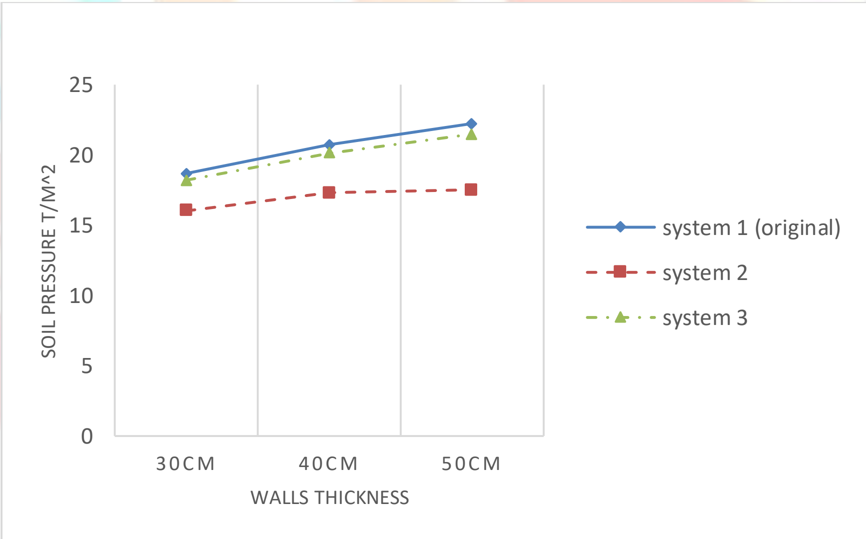

Figure 48: Soil pressure at point A due to ELCENTRO-TH

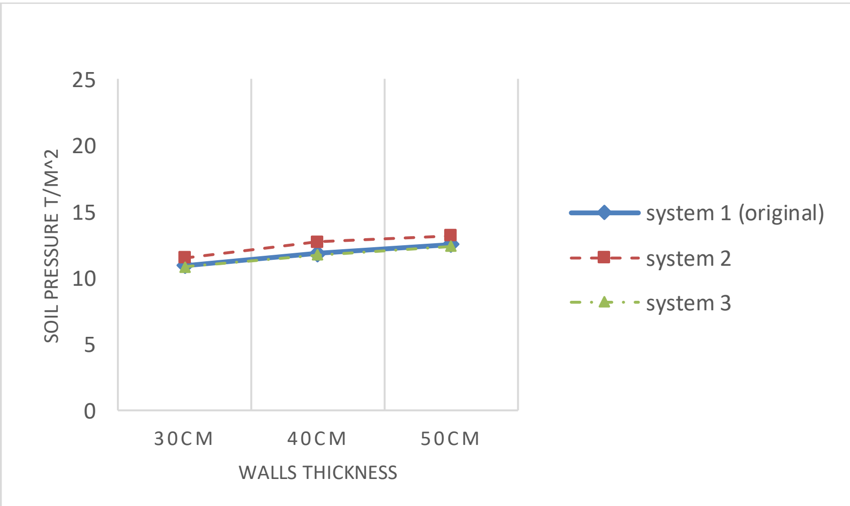

Figure 49: Soil pressure at point B due to ELCENTRO-TH

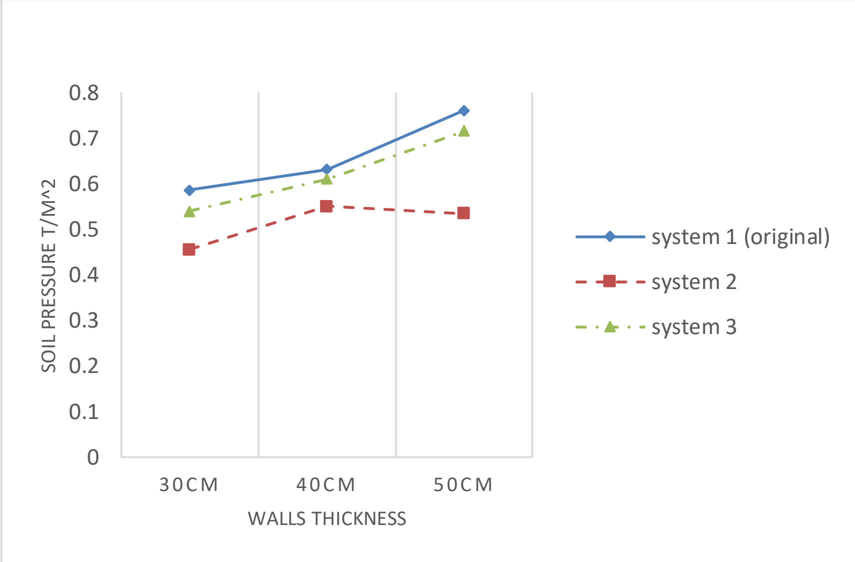

Figure 50: Soil pressure at point A due to HOLLISTER-TH

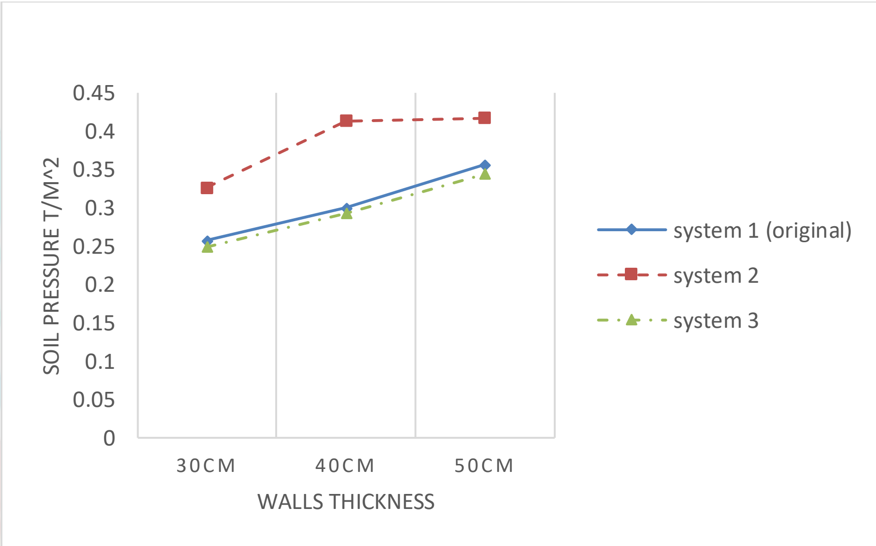

Figure 51: Soil pressure at point B due to HOLLISTER-TH

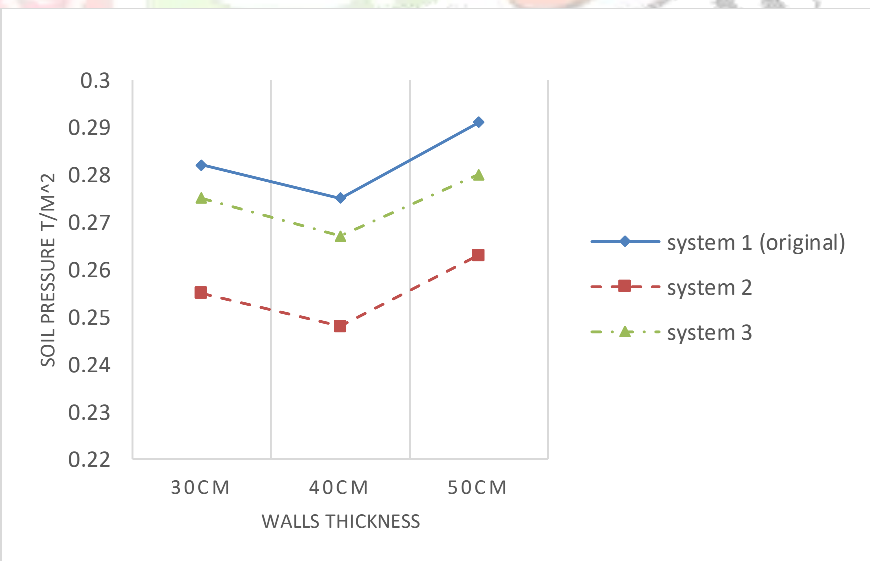

Figure 52: Soil pressure at point A due to SYLMAR-TH

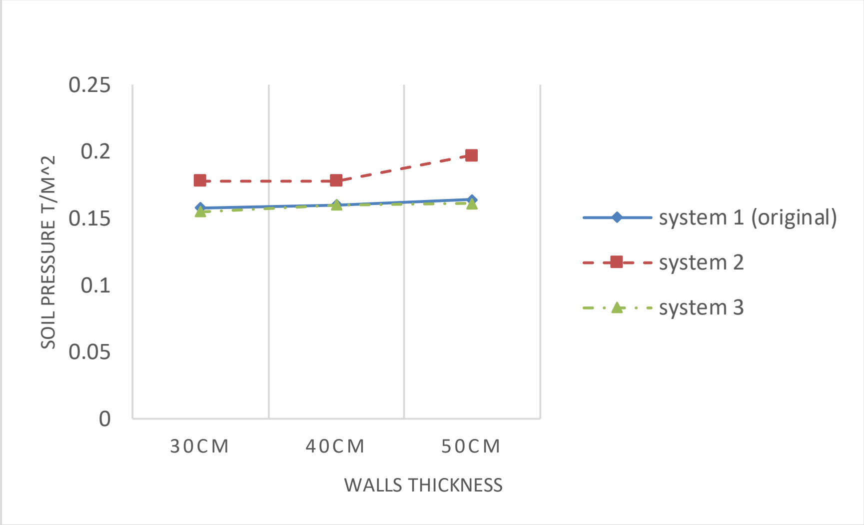

Figure 53: Soil pressure at point B due to SYLMAR-TH

The distribution of walls in system 2 leads to a decrease in soil pressure due to working vertical loads with significant values at any value of basement ceiling slab thickness, as shown in Figure 54.

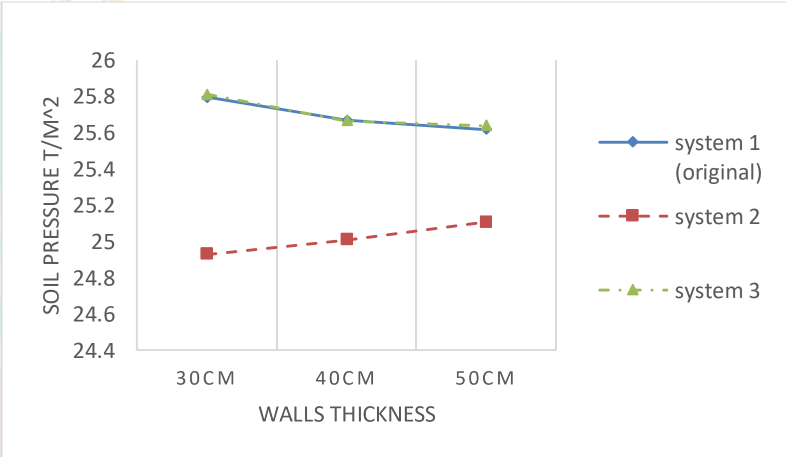

Figure 54: Maximum soil pressure due to working vertical loads

IV. Conclusions

This study investigates the impact of connecting the raft to the basement ceiling slab with shear walls on settlement and soil pressure. Based on the THA investigation involving several parameters, the following conclusions were extracted.

Connecting the raft with basement ceiling slabs leads to a reduction in settlement at the corners of the raft (point A). The reduction increases while using connecting shear walls near the center of the raft (system 2) than at the outer perimeter. However, using connecting shear walls at the outer perimeter (system 3) is more efficient in reducing the settlement at (point B) than (system 2).

The distribution of connecting walls at (system 2) is more efficient in soil pressure reduction than in (system 3) at the corner of the raft (point A), while (system 3) almost matches the soil pressure of the original system without shear walls at (point B).

Under working vertical loads (system2) shows a significant reduction in soil pressure.

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