

Research Article

Shrish Chandrawanshi* and Vivek Garg

Effect of adjacent structures on footing settlement for different multi-building arrangements

<https://doi.org/10.1515/eng-2024-0092>

received May 25, 2024; accepted October 17, 2024

Abstract: Rapid urbanization and land scarcity lead to the construction of multiple structures in proximity, supported on common soil media. This proximity increases soil stress, influencing the deformation characteristics of nearby footings. Hence, there is a need to investigate the effect of structure–soil–structure interaction (SSSI) on the footing settlement. In the present study, the effect of SSSI on the footing settlement of a three-storey building is investigated due to the presence of similar adjacent buildings arranged in various patterns (single adjacent building, side-by-side, L-shape, and inverted T-shape). The various interaction analyses are performed using finite element software ANSYS under gravity loading. The vertical and differential settlement of footings obtained from soil–structure interaction (SSI) and SSSI analyses are compared to evaluate the effect of SSSI under various adjacent building arrangements. The results indicate that in SSI case, inner footings show greater settlement compared to peripheral footings which causes high value of differential settlement between peripheral footings and those immediately adjacent to them. However, the presence of an adjacent structure in SSSI cases provides higher settlement in adjacent footings, which in turn reduces the differential settlement in these footings. Moreover, the SSSI effect on vertical settlement in SSSI (L-shaped) and SSSI (inverted T-shaped) is found to be more in corner footing located near to the adjacent buildings due to overlapping of soil stresses from two sides. The study quantifies the extent of settlement increase in various SSSI cases compared to SSI case, contributing valuable insights to mitigating potential settlement issues in densely developed areas.

Keywords: adjacent building, ANSYS, FEM, footing settlement, structure–soil–structure interaction

1 Introduction

The structure–soil–structure interaction (SSSI) is an interdisciplinary field that deals with the interaction between adjacent structures through the soil media they are built upon. As urbanization continues to expand, structures are being constructed in close vicinity, sharing the same soil media. However, in common design practice, this interaction effect is often neglected to simplify the structural analysis. Previous studies have shown that interaction effects are quite significant, particularly built on highly compressible soils. The flexibility of soil mass causes the differential settlement between footings when loads are applied, which can lead to distress and cracking of structural elements. Therefore, it is essential to understand the behavior of closely spaced structures built on the same soil media under gravity loading to ensure safe and economical design.

Several studies have been conducted to investigate the SSSI between adjacent buildings. To investigate the SSSI, a numerical study using the finite element method (FEM) in buildings was conducted by Bolisetti and Whittaker [1]. The study demonstrated the effects of soil stiffness, building height, and foundation depth on the dynamic response of buildings. The findings revealed that soil stiffness, building height, and foundation depth are significant parameters that affect the response of structures. Aji *et al.* studied the influence of SSSI on the seismic response of 2D and 3D structures in an arbitrary layered half-space using a boundary element method and soil–structure hybrid FEM. The study found that SSSI has a significant impact on the seismic response of structures, and the 3D SSSI model is more accurate than the 1D model [2]. Vicencio *et al.* recently provide a comprehensive overview of the current state of knowledge in the SSSI. It covers the intricate dynamics of SSSI, emphasizing its significance in structural engineering, particularly in

* **Corresponding author: Shrish Chandrawanshi**, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, India, e-mail: shris1893@gmail.com

Vivek Garg: Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal, India, e-mail: vivek_garg5@yahoo.co.in

seismic-prone regions. Additionally, the article investigates the broader aspect of Site-City Interactions, exploring how urban environments interact with the underlying soil and structural elements. The review is likely to encompass recent advancements, challenges, and potential future directions in these critical areas of study, offering valuable insights for researchers, engineers, and professionals in the field [3].

Recent studies have explored various aspects of SSSI, ranging from the dynamic response of closely spaced foundations to the effects of building clusters on soil motion. Mohammadyar and Akhtarpour studied the impact of soil–structure interaction (SSI) on urban buildings using advanced modeling techniques. The study revealed changes in mode shapes, torsional effects, and variations in inter-story drift patterns compared to fixed-base models, underscoring the importance of considering SSI in seismic design and analysis [4]. Wang *et al.* observed that the presence of surface buildings can affect free-field soil motion, with denser structural layouts enhancing interaction effects. This suggests that building arrangement may play a crucial role in settlement patterns. The complexity of SSSI effects is further underscored by studies focusing on specific structural configurations [5]. Chen *et al.* investigated the SSSI of adjacent nuclear power plants, finding that the presence of one structure can influence the seismic response of its neighbor, although to a limited extent. Such findings emphasize the need for detailed examination of various multi-building arrangements and their impact on foundation behavior [6]. Chandrawanshi and Garg investigate the effects of SSSI on adjacent buildings' foundation forces compared to non-interaction analysis (NIA) and SSI. The results show that SSSI effects lead to substantial force redistribution in footings compared to SSI and NIA, with the greatest impact on footings nearest to adjacent structures [7].

Zeolla *et al.* conducted a comprehensive numerical study analyzing the static and dynamic responses of three adjacent shallow foundations. Their findings highlighted the importance of considering SSSI effects, particularly for squat structures, and demonstrated significant increases in spectral acceleration along the ascending branch of the design spectrum. The influence of adjacent structures extends beyond seismic considerations to static settlement behaviors. While extensive research has been conducted on SSI for individual buildings, the effects of multiple building arrangements on footing settlement remain less explored [8]. Chen *et al.* present a discrete modeling approach for analyzing dynamic interactions between structures, soil, and embedded foundations. The study focuses on developing a detailed model that captures the complexities of these interactions, particularly in the context of embedded foundations [9].

Kamal *et al.* demonstrated that SSSI effects can expand displacement demands by up to 30% in mid-rise buildings [10]. Furthermore, when combined with rotational ground motion, these effects can amplify structural responses by as much as 40%, a finding corroborated by Vicencio and Alexander [11]. The influence of site-city interaction on building responses has been quantified to reach up to 24%, depending upon urban configuration and soil characteristics Vicencio and Alexander [12]. Chen *et al.* revealed that soil nonlinearity can have both reducing and amplifying effects on these phenomena [13]. In the context of adjacent structures, Kandemir and Jankowski [14] observed that SSI can intensify pounding forces, while Sanghai and Pawade elucidated its implications for damping requirements and friction damper efficacy [15]. Advancements in SSI modeling techniques have been proposed by Dhehbiya and Salah [16], and Kraus *et al.* underscored the criticality of foundation contact pressure in seismic design considerations [17].

The present study aims to address this knowledge gap by examining the vertical and differential settlement of footings due to multi arrangement of adjacent buildings. Building upon the methodologies and insights from recent SSSI research, this article investigates how different multi-building arrangements influence footing settlement patterns. This article is structured as follows: first, is a comprehensive literature review of current knowledge on SSSI, footing settlement, and multi-building interactions. Next, the research methodology will be detailed, including the numerical modeling approach and the parameters considered in the study. Section 3 will present the findings on vertical and differential settlement for various building arrangements. Finally, conclusions will be drawn, highlighting the key insights and recommendations for future research.

2 Problem for investigation

To investigate the SSSI effect on the vertical and differential settlement of footings, various interaction analyses, *i.e.*, SSI and SSSI analyses with various arrangements, were performed under gravity loading using finite element analysis software ANSYS. In SSI and SSSI analyses, the superstructure, its foundation, and underlying soil were considered to act as a single compatible structural unit for more realistic analysis.

In the present study, to investigate the interaction behavior, the interaction analyses were carried out on a three-storey symmetrical RCC building for five cases. Case 1

was the SSI analysis considering the columns supported on isolated footings and resting on soil media under gravity loading. Case 2 to case 5 were the SSSI analysis, considering single adjacent building, side-by-side, L-shaped, and inverted T-shaped arrangements of adjacent buildings, respectively, founded on the isolated footing and resting on soil media.

This study aims to investigate the SSSI effect on footing vertical and differential settlement with various arrangements of adjacent buildings under gravity loading. To observe the SSSI effect, the various models are prepared by different arrangements of adjacent buildings shown in Figure 1. Figure 1 illustrates five different configurations of adjacent buildings to demonstrate various SSSI cases. The arrangements progress from (1) a single building (SSI) to more complex layouts including, (2) two similar adjacent buildings, (3) three buildings side by side in a row, (4) an L-shaped arrangement, and (5) an inverted T-shape. “M” represents the main building under study, while “A” indicates adjacent buildings. This figure shows the range of building arrangements typically encountered in urban settings, which are crucial for analyzing the effects of SSSI on foundation behavior.

2.1 Modeling of structure

A three-storey RCC symmetric building of 4-bay $\times$ 4-bay was considered for interaction analyses in the present problem. It was assumed that the joints between various members are perfectly rigid. The SSI and SSSI analyses were carried out considering that the columns are supported on individual column footings (isolated footings) and resting on

soil media. The RCC building was assumed to behave in a linear elastic manner. It was also assumed that footings of similar adjacent buildings are of the same size and located at the same level. The elevation and plan view of the building structure is shown in Figure 2, whereas material and geometrical properties of the RCC building and footing are given in Table 1.

The footing plan of the SSSI model with a single adjacent building is shown in Figure 3.

2.2 Modeling of soil domain

The soil mass was idealized as isotropic and homogeneous. It was assumed that rocky strata were present at a depth of 13 m; hence, the soil model was considered $130\text{ m} \times 130\text{ m} \times 13\text{ m}$ which is achieved by trial and error by performing linear interaction analysis. The extent of soil mass was decided where horizontal stresses are found to be negligible due to loading on the superstructure. The soil behavior was considered with $25 \times 10^3\text{ kN/m}^2$ of elastic modulus and Poisson's ratio of 0.30.

2.3 Gravity load

The dead load and imposed load have been taken as per Bureau of Indian Standards code IS 875 (Part 1) and (Part 2): 1987, respectively [18,19]. The thickness of the brick wall was considered 230 mm for outer walls and 130 mm for inner walls. The evaluated loads which include dead and imposed loads are shown in Table 2.

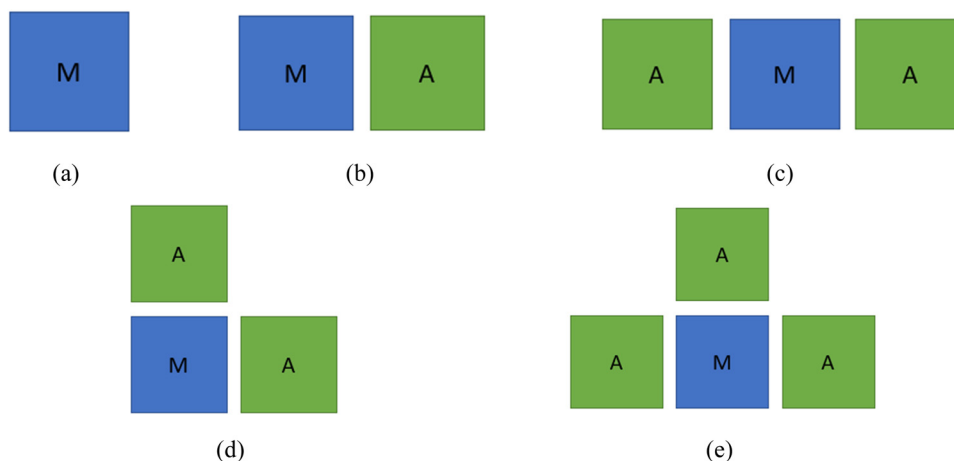


Figure 1: Plan of adjacent buildings with various arrangements: (a) SSI, (b) SSSI (single adjacent building), (c) SSSI (side by side), (d) SSSI (L-shaped), and (e) SSSI (inverted T-shaped).

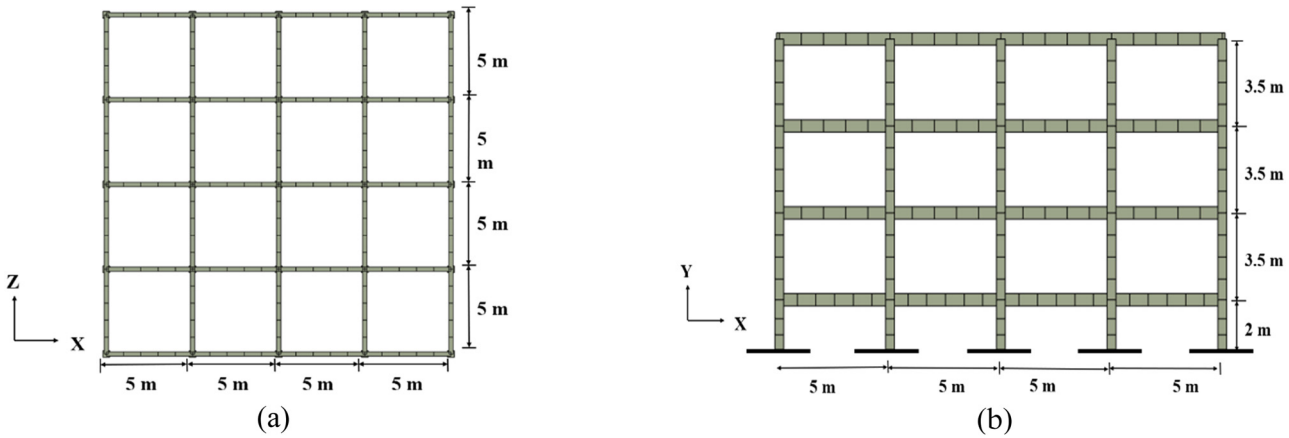


Figure 2: Plan and elevation of the superstructure. (a) Plan and (b) elevation.

Table 1: Material and geometrical properties of the superstructure and its foundation

Sr. no.	Description	Value
1	Elastic modulus of concrete	$2.5 \times 10^7 \text{ kN/m}^2$
2	Poisson's ratio of concrete	0.17
3	Size of column	$0.40 \text{ m} \times 0.40 \text{ m}$
4	Size of beam	$0.25 \text{ m} \times 0.50 \text{ m}$
5	Slabs thickness	0.14 m
6	Size of isolated footing	$2.6 \text{ m} \times 2.6 \text{ m} \times 0.5 \text{ m}$

Table 2: Gravity loads on the superstructure

Sr. no.	Loads	Structural component	Intensity
1	Dead load	Outer walls	13.80 kN/m
		Inner walls	7.80 kN/m
		Parapet wall	6.90 kN/m
		Slab	3.50 kN/m^2
		Slab finish	1.00 kN/m^2
		Column	4.00 kN/m^2
2	Imposed load	1st and 2nd floors	3.0 kN/m^2
		Roof	1.50 kN/m^2

2.4 Boundary condition

In SSI and SSSI models, the soil mass was restricted from vertical displacement at the bottom boundary considering the rock beneath it, while at the horizontal boundaries, the soil mass was restrained for corresponding horizontal displacement.

2.5 Finite element meshing

The finite element discretization of the interaction model was performed by using appropriate elements available in the ANSYS library. The beam and column components

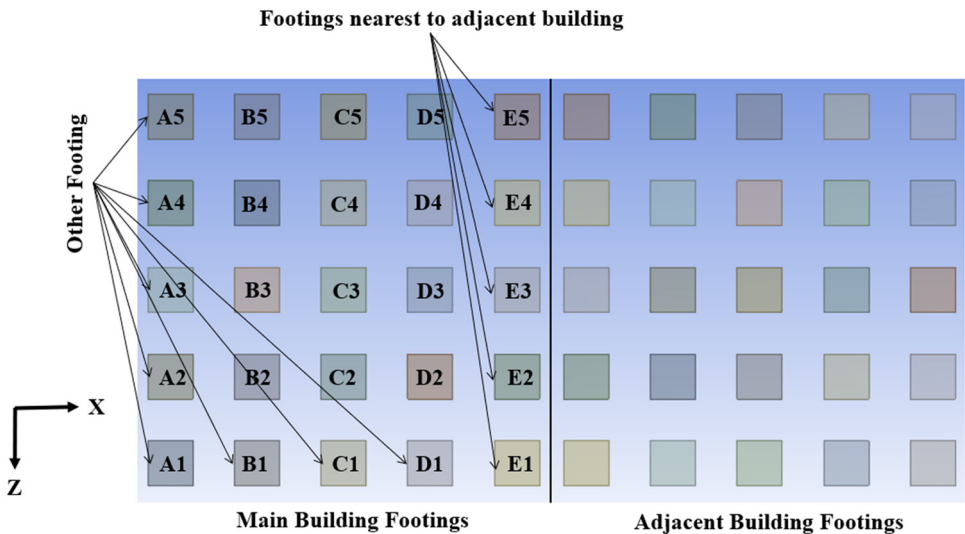


Figure 3: Footing plan.

were modeled by BEAM188 elements, while slab and footings were modeled using SHELL181 elements. The soil domain was discretized by SOLID186 and SOLID187 elements. The surface-to-surface interaction between the footing and the soil was defined by CONTA174 and TARGE170 interface elements. The soil mass was discretized with finer meshes in close vicinity of footing where stresses are of higher order to achieve computational accuracy. The finite element meshing of the problem is shown in Figure 4.

3 Results

3.1 Vertical settlement (U_y) of the footings

The results of the interaction analyses are presented and discussed for the vertical settlement (U_y) of the footings due to gravity loading.

The footings vertical settlement (U_y) of SSI and SSSI analyses with various arrangements of adjacent buildings under gravity loading and their ratios are shown in Figure 5.

The effect of SSSI causes a significant increase in the vertical settlement of footings located near the adjacent buildings in all cases due to overlapping of stress in soil media. However, this effect reduces gradually for the footings located away from the adjacent buildings. SSSI

(L-shaped) and SSSI (inverted T-shaped) provide a maximum increase of 1.80 and 1.76 times in the vertical settlement in corner footing E5, respectively, compared to SSI. Moreover, the SSSI (single adjacent building) and SSSI (side by side) provide a maximum increase of only 1.43 and 1.38 times in the vertical settlement in corner footing E5, respectively, compared to SSI. This increase in SSSI effect in SSSI (L-shaped) and SSSI (inverted T-shaped) is found to be more in corner footing (E5) due to overlapping of soil stresses from two sides compared to SSSI (single adjacent building) and SSSI (side-by-side) case, where overlapping of stresses is only from one side.

The effect of SSI and SSSI on footing settlement under gravity loading with various arrangements of adjacent buildings is shown in Figures 6–10. The figure illustrates the variation in the vertical settlement of footings with different arrangements of adjacent buildings.

3.2 Differential settlement between the footings

The results of interaction analyses are presented and discussed for the differential settlement between the footings due to gravity loading. For a better understanding of the SSSI effect, results are shown as per the footing pattern described in Figure 3.

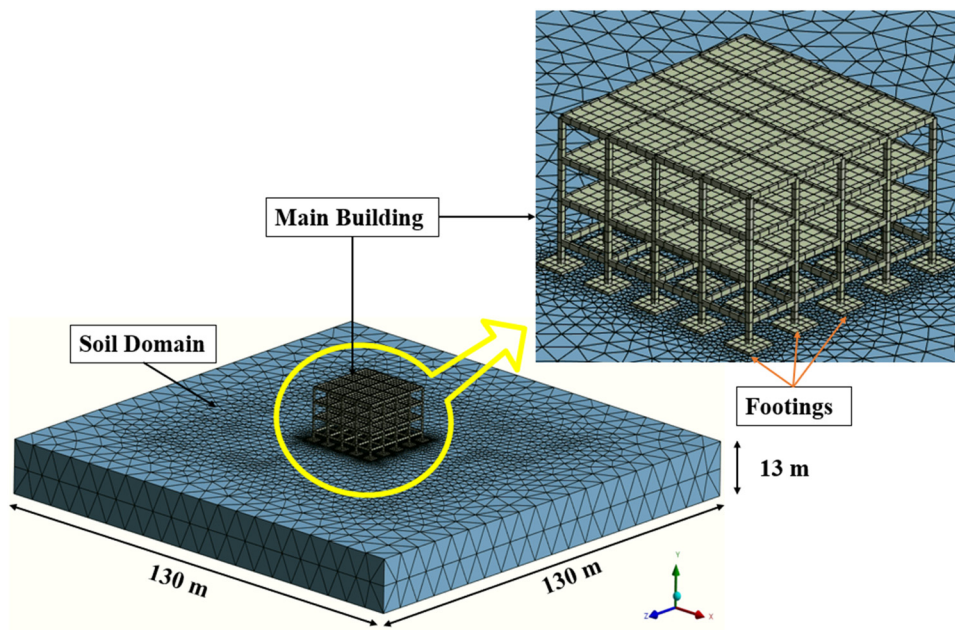


Figure 4: Finite element meshing of SSI model.

	A5	B5	C5	D5	E5				
	-9.88	-13.26	-14.08	-13.26	-9.88				
	A4	B4	C4	D4	E4				
	-13.26	-17.16	-18.14	-17.16	-13.26				
	A3	B3	C3	D3	E3				
	-14.08	-18.14	-19.18	-18.14	-14.08				
	A2	B2	C2	D2	E2				
	-13.26	-17.16	-18.14	-17.16	-13.26				
	A1	B1	C1	D1	E1				
	-9.88	-13.26	-14.08	-13.26	-9.88				
SSI									
A5	B5	C5	D5	E5	A5	B5	C5	D5	E5
-9.43	-13.10	-14.32	-14.64	-14.08	0.95	0.99	1.02	1.10	1.43
A4	B4	C4	D4	E4	A4	B4	C4	D4	E4
-12.80	-17.06	-18.55	-19.01	-18.55	0.97	0.99	1.02	1.11	1.40
A3	B3	C3	D3	E3	A3	B3	C3	D3	E3
-13.62	-18.06	-19.65	-20.17	-19.76	0.97	1.00	1.02	1.11	1.40
A2	B2	C2	D2	E2	A2	B2	C2	D2	E2
-12.80	-17.06	-18.55	-19.01	-18.55	0.97	0.99	1.02	1.11	1.40
A1	B1	C1	D1	E1	A1	B1	C1	D1	E1
-9.43	-13.10	-14.32	-14.64	-14.08	0.95	0.99	1.02	1.10	1.43
SSSI (Single adjacent building)					SSSI (Single adjacent building)/SSI				
A5	B5	C5	D5	E5	A5	B5	C5	D5	E5
-13.65	-14.45	-14.52	-14.45	-13.65	1.38	1.09	1.03	1.09	1.38
A4	B4	C4	D4	E4	A4	B4	C4	D4	E4
-18.01	-18.78	-18.83	-18.78	-18.01	1.36	1.09	1.04	1.09	1.36
A3	B3	C3	D3	E3	A3	B3	C3	D3	E3
-19.24	-19.95	-19.98	-19.95	-19.24	1.37	1.10	1.04	1.10	1.37
A2	B2	C2	D2	E2	A2	B2	C2	D2	E2
-18.01	-18.78	-18.83	-18.78	-18.01	1.36	1.09	1.04	1.09	1.36
A1	B1	C1	D1	E1	A1	B1	C1	D1	E1
-13.65	-14.45	-14.52	-14.45	-13.65	1.38	1.09	1.03	1.09	1.38
SSSI (Side-by-side)					SSSI (Side-by-side)/SSI				
A5	B5	C5	D5	E5	A5	B5	C5	D5	E5
-13.58	-18.23	-19.84	-19.68	-17.75	1.37	1.37	1.41	1.48	1.80
A4	B4	C4	D4	E4	A4	B4	C4	D4	E4
-14.05	-18.68	-20.34	-20.61	-19.68	1.06	1.09	1.12	1.20	1.48
A3	B3	C3	D3	E3	A3	B3	C3	D3	E3
-13.72	-18.23	-19.88	-20.34	-19.84	0.97	1.00	1.04	1.12	1.41
A2	B2	C2	D2	E2	A2	B2	C2	D2	E2
-12.54	-16.72	-18.22	-18.68	-18.23	0.95	0.97	1.00	1.09	1.37
A1	B1	C1	D1	E1	A1	B1	C1	D1	E1
-8.91	-12.54	-13.73	-14.05	-13.58	0.90	0.95	0.98	1.06	1.37
SSSI (L-shaped)					SSSI (L-shaped)/SSI				
A5	B5	C5	D5	E5	A5	B5	C5	D5	E5
-17.35	-19.58	-20.13	-19.58	-17.35	1.76	1.48	1.43	1.48	1.76
A4	B4	C4	D4	E4	A4	B4	C4	D4	E4
-19.30	-20.59	-20.83	-20.59	-19.30	1.46	1.20	1.15	1.20	1.46
A3	B3	C3	D3	E3	A3	B3	C3	D3	E3
-19.47	-20.34	-20.44	-20.34	-19.47	1.38	1.12	1.07	1.12	1.38
A2	B2	C2	D2	E2	A2	B2	C2	D2	E2
-17.85	-18.68	-18.73	-18.68	-17.85	1.35	1.09	1.03	1.09	1.35
A1	B1	C1	D1	E1	A1	B1	C1	D1	E1
-13.18	-13.97	-14.05	-13.97	-13.18	1.33	1.05	1.00	1.05	1.33
SSSI (Inverted T-shaped)					SSSI (Inverted T-shaped)/SSI				
	Maximum settlement					Maximum influence			
	Medium settlement					Medium influence			
	Minimum settlement					Less influence			
						Opposite influence			

Figure 5: Effect of SSSI on vertical settlement (mm) of footings with various arrangements of adjacent buildings.

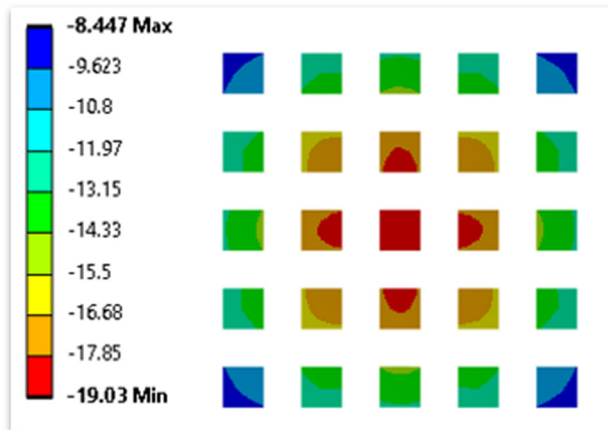


Figure 6: Vertical settlement (mm) of footings for SSI case.

3.2.1 Differential settlement between the footings due to single adjacent building

The differential settlement between the footings for SSI and SSSI analyses due to a single adjacent building is shown in Figure 11.

The SSSI effect causes a significant increase in differential settlement between footings that are nearest to adjacent buildings. However, a significant decrease is found between the footings nearest to the adjacent building and next to the nearest footings. The SSSI effect significantly altered the differential settlement between most of the footings due to a single adjacent building compared to SSI.

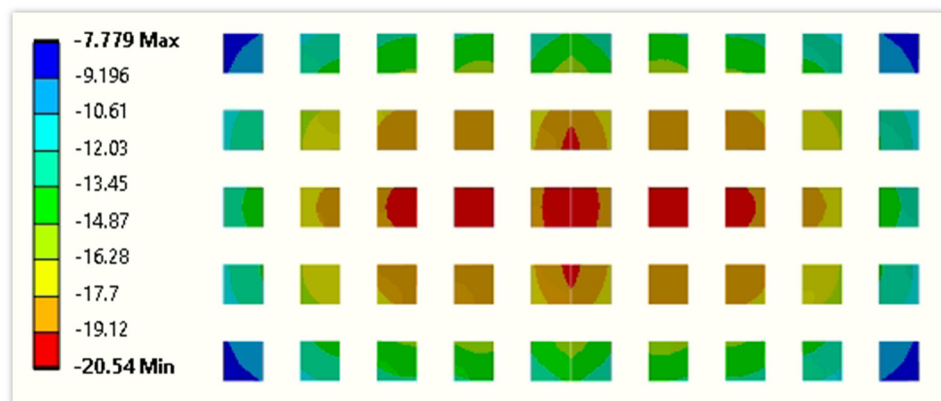


Figure 7: Vertical settlement (mm) of footings for SSSI (single adjacent building) case.

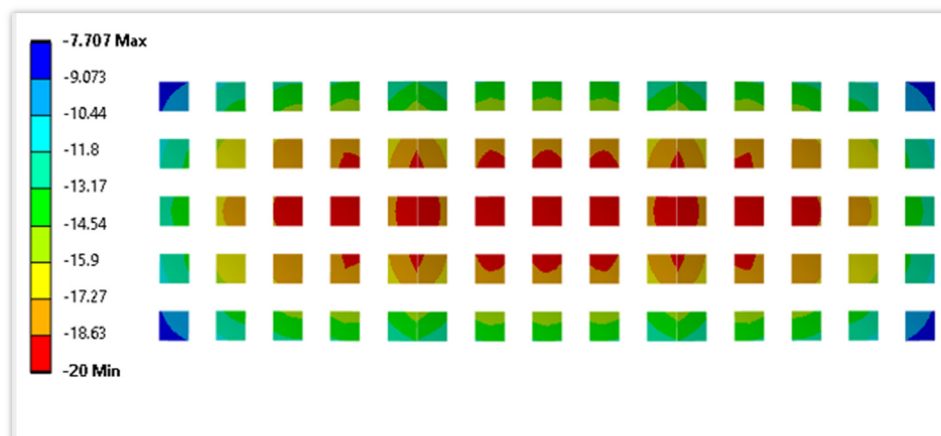


Figure 8: Vertical settlement (mm) of footings for SSSI (side-by-side) case.

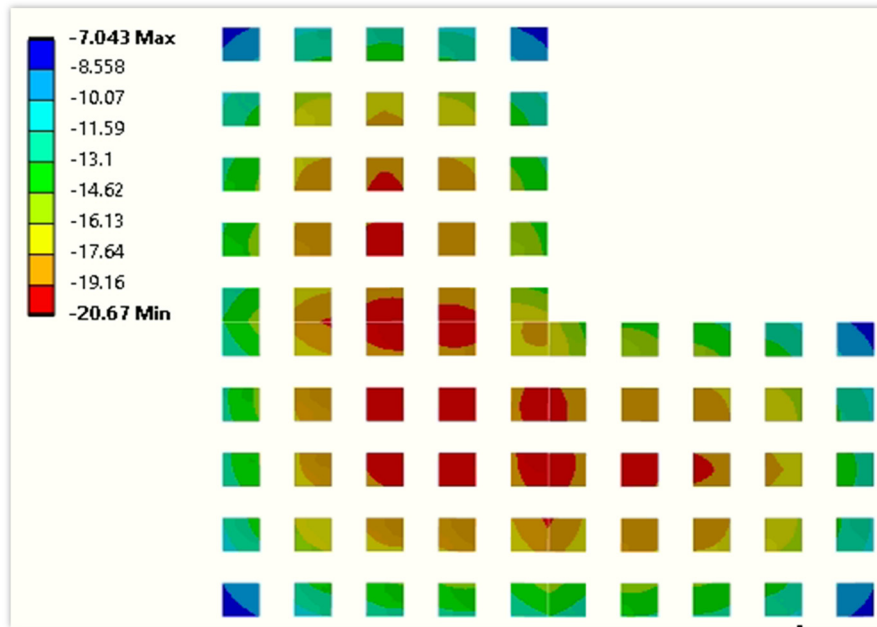


Figure 9: Vertical settlement (mm) of footings for SSSI (L-shaped) case.

3.2.1.1 Comparison between SSI and SSSI along X-direction

In SSSI analysis, the presence of adjacent buildings causes an increase in stress in soil media which results in more settlement in nearby footings (E1–E5). This in turn reduces the differential settlement between footings E1–D1 to E5–D5, which varies from 0.12 to 0.17 times compared to SSI analysis. SSSI provides a significant variation of -0.50 to 1.53 times in the differential settlement compared to SSI. The maximum

increase in differential settlement is found nearly 1.53 times between footings B3–C3 whereas the maximum decrease of nearly -0.50 times is found between footings C3–D3.

3.2.1.2 Comparison between SSI and SSSI along z-direction

The SSSI causes a maximum increase in differential settlement in footings nearest to adjacent buildings (E1–E5) which varies from 1.32 to 1.48 times compared to SSI

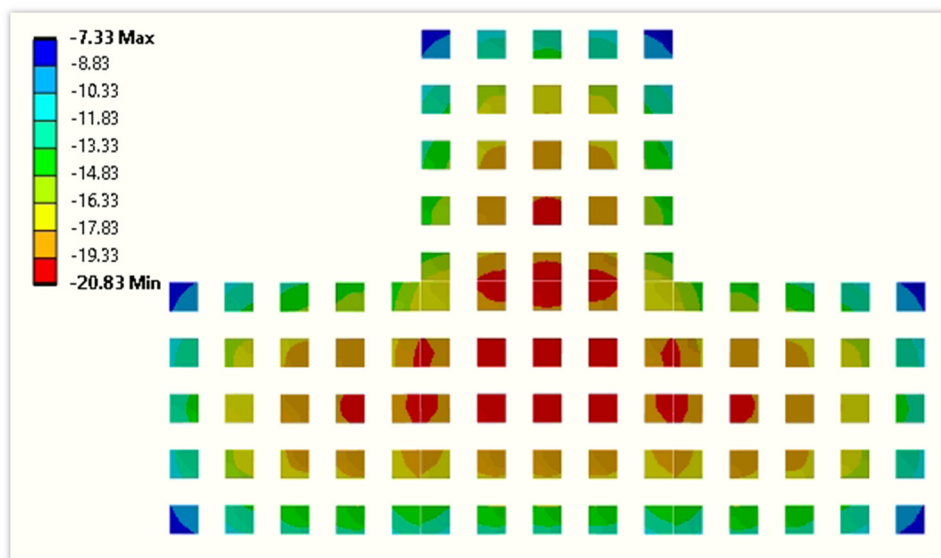


Figure 10: Vertical settlement (mm) of footings for SSSI (inverted T-shaped) case.

A5	-3.38	B5	-0.82	C5	0.82	D5	3.38	E5
3.38		3.90		4.06		3.90		3.38
A4	-3.90	B4	-0.98	C4	0.98	D4	3.90	E4
0.82		0.98		1.04		0.98		0.82
A3	-4.06	B3	-1.04	C3	1.04	D3	4.06	E3
-0.82		-0.98		-1.04		-0.98		-0.82
A2	-3.90	B2	-0.98	C2	0.98	D2	3.90	E2
-3.38		-3.90		-4.06		-3.90		-3.38
A1	-3.38	B1	-0.82	C1	0.82	D1	3.38	E1
SSI								
A5	-3.67	B5	-1.22	C5	-0.32	D5	0.56	E5
3.37		3.96		4.23		4.37		4.47
A4	-4.26	B4	-1.49	C4	-0.46	D4	0.46	E4
0.82		1.00		1.10		1.16		1.21
A3	-4.44	B3	-1.59	C3	-0.52	D3	0.41	E3
-0.82		-1.00		-1.10		-1.16		-1.21
A2	-4.26	B2	-1.49	C2	-0.46	D2	0.46	E2
-3.37		-3.96		-4.23		-4.37		-4.47
A1	-3.67	B1	-1.22	C1	-0.32	D1	0.56	E1
SSSI (Single adjacent building)								
A5	1.09	B5	1.49	C5	-0.39	D5	0.17	E5
1.00		1.02		1.04		1.12		1.32
A4	1.09	B4	1.52	C4	-0.47	D4	0.12	E4
1.00		1.02		1.06		1.18		1.48
A3	1.09	B3	1.53	C3	-0.50	D3	0.10	E3
1.00		1.02		1.06		1.18		1.48
A2	1.09	B2	1.52	C2	-0.47	D2	0.12	E2
1.00		1.02		1.04		1.12		1.32
A1	1.09	B1	1.49	C1	-0.39	D1	0.17	E1
SSSI (Single adjacent building)/SSI								

Figure 11: Effect of SSSI on differential settlement (mm) due to single adjacent building.

analysis. However, this effect diminishes gradually for the footings which are located far from the adjacent building. Overall, SSSI provides a significant variation of 1.00–1.48 times in the differential settlement compared to SSI.

3.2.2 Differential settlement between the footings due to adjacent buildings in side-by-side arrangement

The differential settlement between the footings for SSI and SSSI analyses due to adjacent buildings in a side-by-side arrangement under gravity loading is shown in Figure 12.

The SSSI effect causes a significant increase in differential settlement between footings that are nearest to adjacent buildings. However, a significant decrease is found between the footings nearest to the adjacent building and next to the nearest footings. The SSSI effect significantly altered the differential settlement between most of the footings for side-by-side arrangements of adjacent buildings compared to SSI.

3.2.2.1 Comparison between SSI and SSSI along x-direction

The effect of SSSI causes a significant decrease in the differential settlement between footings due to adjacent buildings on both sides. However, this effect keeps reducing gradually for the footings located away from the adjacent buildings. Additionally, SSSI provides a significant variation of 0.03–0.24 times in the differential settlement compared to SSI.

3.2.2.2 Comparison between SSI and SSSI along z-direction

The SSSI causes a maximum increase in differential settlement in footings nearest to adjacent buildings (A1–A5 and E1–E5) which varies from 1.29 to 1.50 times compared to SSI analysis. However, this effect reduces gradually for the footings that are located far from the adjacent buildings. Overall, SSSI provides a significant variation of 1.06–1.50 times in the differential settlement compared to SSI.

A5	-3.38	B5	-0.82	C5	0.82	D5	3.38	E5
3.38		3.90		4.06		3.90		3.38
A4	-3.90	B4	-0.98	C4	0.98	D4	3.90	E4
0.82		0.98		1.04		0.98		0.82
A3	-4.06	B3	-1.04	C3	1.04	D3	4.06	E3
-0.82		-0.98		-1.04		-0.98		-0.82
A2	-3.90	B2	-0.98	C2	0.98	D2	3.90	E2
-3.38		-3.90		-4.06		-3.90		-3.38
A1	-3.38	B1	-0.82	C1	0.82	D1	3.38	E1
SSI								
A5	-0.80	B5	-0.07	C5	0.07	D5	0.80	E5
4.36		4.33		4.31		4.33		4.36
A4	-0.77	B4	-0.05	C4	0.05	D4	0.77	E4
1.23		1.17		1.15		1.17		1.23
A3	-0.71	B3	-0.03	C3	0.03	D3	0.71	E3
-1.23		-1.17		-1.15		-1.17		-1.23
A2	-0.77	B2	-0.05	C2	0.05	D2	0.77	E2
-4.36		-4.33		-4.31		-4.33		-4.36
A1	-0.80	B1	-0.07	C1	0.07	D1	0.80	E1
SSSI (side-by-side)								
A5	0.24	B5	0.09	C5	0.09	D5	0.24	E5
1.29		1.11		1.06		1.11		1.29
A4	0.20	B4	0.05	C4	0.05	D4	0.20	E4
1.50		1.19		1.11		1.19		1.50
A3	0.17	B3	0.03	C3	0.03	D3	0.17	E3
1.50		1.19		1.11		1.19		1.50
A2	0.20	B2	0.05	C2	0.05	D2	0.20	E2
1.29		1.11		1.06		1.11		1.29
A1	0.24	B1	0.09	C1	0.09	D1	0.24	E1
SSSI (side-by-side)/SSI								

Figure 12: Effect of SSSI on differential settlement (mm) due to side-by-side adjacent buildings arrangement.

3.2.3 Differential settlement between the footings due to adjacent buildings in L-shaped arrangement

The differential settlement between the footings for SSI and SSSI analyses due to adjacent buildings in an L-shaped arrangement under gravity loading is shown in Figure 13.

The SSSI effect significantly altered the differential settlement between most of the footings for L-shaped arrangements of adjacent buildings compared to SSI.

3.2.3.1 Comparison between SSI and SSSI along x-direction

SSSI provides a significant variation of -0.47 to 1.96 times in the differential settlement compared to SSI. The maximum increase in differential settlement is found nearly 1.96 times between footings B5–C5 whereas the maximum decrease of nearly 0.12 times is found between footings D2–E2 and D3–E3.

3.2.3.2 Comparison between SSI and SSSI along z-direction

The SSSI causes a maximum increase in differential settlement between footings A2–A3 to E2–E3 that varies from 1.44 to 1.96 times compared to SSI analysis. Overall, SSSI provides a significant variation of -0.46 to 1.96 times in the differential settlement compared to SSI.

3.2.4 Differential settlement between the footings due to adjacent buildings in inverted T-shaped arrangement

The differential settlement between the footings for SSI and SSSI analyses due to adjacent buildings in an inverted T-shaped arrangement under gravity loading is shown in Figure 14. The SSSI effect significantly altered the differential settlement between most of the footings for inverted T-shaped arrangements of adjacent buildings compared to SSI.

A5	-3.38	B5	-0.82	C5	0.82	D5	3.38	E5
3.38		3.90		4.06		3.90		3.38
A4	-3.90	B4	-0.98	C4	0.98	D4	3.90	E4
0.82		0.98		1.04		0.98		0.82
A3	-4.06	B3	-1.04	C3	1.04	D3	4.06	E3
-0.82		-0.98		-1.04		-0.98		-0.82
A2	-3.90	B2	-0.98	C2	0.98	D2	3.90	E2
-3.38		-3.90		-4.06		-3.90		-3.38
A1	-3.38	B1	-0.82	C1	0.82	D1	3.38	E1
SSI								
A5	-4.65	B5	-1.61	C5	0.16	D5	1.93	E5
0.47		0.45		0.50		0.93		1.93
A4	-4.63	B4	-1.66	C4	-0.27	D4	0.93	E4
-0.33		-0.45		-0.46		-0.27		0.16
A3	-4.51	B3	-1.65	C3	-0.46	D3	0.50	E3
-1.18		-1.51		-1.66		-1.66		-1.61
A2	-4.18	B2	-1.50	C2	-0.46	D2	0.45	E2
-3.63		-4.18		-4.49		-4.63		-4.65
A1	-3.63	B1	-1.19	C1	-0.32	D1	0.47	E1
SSSI (L-shaped)								
A5	1.38	B5	1.96	C5	0.20	D5	0.57	E5
0.14		0.12		0.12		0.24		0.57
A4	1.19	B4	1.69	C4	-0.28	D4	0.24	E4
-0.40		-0.46		-0.44		-0.28		0.20
A3	1.11	B3	1.59	C3	-0.44	D3	0.12	E3
1.44		1.54		1.60		1.69		1.96
A2	1.07	B2	1.53	C2	-0.47	D2	0.12	E2
1.07		1.07		1.11		1.19		1.38
A1	1.07	B1	1.45	C1	-0.39	D1	0.14	E1
SSSI (L-shaped)/SSI								

Figure 13: Effect of SSSI on differential settlement (mm) due to L-shaped adjacent building arrangement.

3.2.4.1 Comparison between SSI and SSSI along x-direction

The SSSI effect causes a significant decrease in differential settlement between all footings. SSSI provides a significant variation of 0.02–0.67 times in the differential settlement compared to SSI. The maximum decrease in differential settlement is found nearly 0.02 times between footings B1–C1 and C1–D1, whereas the minimum decrease of nearly 0.67 times is found between footings B5–C5 and C5–D5.

3.2.4.2 Comparison between SSI and SSSI along z-direction

The SSSI causes a significant increase in differential settlement between footings A2–A3 to E2–E3, which varies from 1.64 to 1.96 times compared to SSI analysis. Overall, the differential settlement between footings varies from –0.37 to 1.96 times compared to SSI analysis.

4 Conclusions

The study investigates the effect of SSSI on the footing settlement of a three-storey symmetrical RCC building due to the presence of a similar adjacent building with different arrangements. The various SSSI analyses are conducted to evaluate the vertical and differential settlement of footings under gravity loading compared to SSI analysis. Based on the findings of the present study, the following conclusions are made:

- The effect of SSSI causes a significant increase in the vertical settlement of footings located near the adjacent buildings due to the overlapping of stress in soil media. However, this effect reduces gradually for the footings located away from the adjacent buildings.
- The SSSI effect on vertical settlement in SSSI (L-shaped) and SSSI (inverted T-shaped) is found to be more in corner footing located near the adjacent buildings due to overlapping of soil stresses from two sides compared to

A5	-3.38	B5	-0.82	C5	0.82	D5	3.38	E5
3.38		3.90		4.06		3.90		3.38
A4	-3.90	B4	-0.98	C4	0.98	D4	3.90	E4
0.82		0.98		1.04		0.98		0.82
A3	-4.06	B3	-1.04	C3	1.04	D3	4.06	E3
-0.82		-0.98		-1.04		-0.98		-0.82
A2	-3.90	B2	-0.98	C2	0.98	D2	3.90	E2
-3.38		-3.90		-4.06		-3.90		-3.38
A1	-3.38	B1	-0.82	C1	0.82	D1	3.38	E1
SSI								
A5	-2.23	B5	-0.55	C5	0.55	D5	2.23	E5
1.95		1.01		0.70		1.01		1.95
A4	-1.29	B4	-0.24	C4	0.24	D4	1.29	E4
0.17		-0.25		-0.39		-0.25		0.17
A3	-0.87	B3	-0.10	C3	0.10	D3	0.87	E3
-1.62		-1.66		-1.71		-1.66		-1.62
A2	-0.83	B2	-0.05	C2	0.05	D2	0.83	E2
-4.67		-4.71		-4.68		-4.71		-4.67
A1	-0.79	B1	-0.08	C1	0.08	D1	0.79	E1
SSSI (Inverted T-shaped)								
A5	0.66	B5	0.67	C5	0.67	D5	0.66	E5
0.58		0.26		0.17		0.26		0.58
A4	0.33	B4	0.24	C4	0.24	D4	0.33	E4
0.21		-0.26		-0.37		-0.26		0.21
A3	0.21	B3	0.10	C3	0.10	D3	0.21	E3
1.98		1.69		1.64		1.69		1.98
A2	0.21	B2	0.05	C2	0.05	D2	0.21	E2
1.38		1.21		1.15		1.21		1.38
A1	0.23	B1	0.10	C1	0.10	D1	0.23	E1
SSSI (Inverted T-shaped)/SSI								

Figure 14: Effect of SSSI on differential settlement (mm) due to inverted T-shaped adjacent buildings arrangement.

- SSSI (single adjacent building) and SSSI (side-by-side) cases, where overlapping of stresses is only from one side.
- SSSI (L-shaped) and SSSI (inverted T-shaped) provide a maximum increase of 1.80 and 1.76 times in the vertical settlement in corner footing, respectively. However, the SSSI (single adjacent building) and SSSI (side by side) provide a maximum increase of only 1.43 and 1.38 times in the vertical settlement, respectively.
 - The SSSI effect significantly altered the differential settlement between most of the footings for different arrangements of adjacent buildings compared to SSI.
 - In the SSI case, inner footings show greater settlement compared to peripheral footings which causes a high value of differential settlement between peripheral footings and those immediately adjacent to them. However, the presence of an adjacent structure in SSSI cases provides higher settlement in adjacent footings, which in turn reduces the differential settlement in these footings.

Future research in the field of SSSI can focus on a wider range of building configurations and arrangements to capture the full spectrum of SSSI effects in densely built

environments. Long-term studies are crucial to assess the cumulative impact of SSSI on settlement patterns over time, considering factors such as soil consolidation and creep. Additionally, investigating the combined effects of SSSI and dynamic loading, particularly seismic activities, would provide valuable insights into foundation behavior and overall building performance under various stress conditions. The influence of different foundation types, including deep foundations and mat foundations, on SSSI effects and settlement patterns should also be explored to inform more robust design practices. To validate numerical findings and bridge the gap between theoretical models and real-world applications, it is imperative to conduct field studies or full-scale experiments. These empirical investigations would not only provide crucial data on SSSI effects but also help refine existing models and develop more accurate predictive tools for urban planning and structural design.

Funding information: Authors state no funding involved.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and

consented to its submission to the journal, reviewed all the results, and approved the final version of the manuscript. Methodology, formal analysis, validation, writing – original draft, visualization, conceptualization, investigation, data curation, writing – SC; visualization, data curation, supervision, writing – review and editing – VG.

Conflict of interest: Authors state no conflict of interest.

Data availability statement: Data generated or analyzed during this study are provided in full within the published article.

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