



Comprehensive Analysis of Combined Pile Raft Foundation using PLAXIS 3D, SAP 2000, and ELPLA

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ABSTRACT

Considering the growing population and limited land availability, towering buildings with several basements have been built to increase floor area ratios while also meeting storage and parking needs. The design of Combined Pile Raft Foundations (CPRF) is crucial in supporting complex structures. Still, traditional techniques frequently ignore the interplay between pile-to-pile and pile-to-raft, compromising the overall performance and reliability of the foundation system. CPRF analysis is carried out using a variety of software packages, including PLAXIS 3D, SAP 2000, ETABS, and the recently announced ELPLA, each having its own set of capabilities, constraints, and user interfaces. To assess their reliability and applicability, this study offers a thorough comparative analysis of CPRF systems utilizing these techniques in five case studies. The findings indicate that PLAXIS 3D, a Finite Element Method (FEM) program, is the most accurate and dependable instrument for comprehensive analysis. In contrast, ELPLA was shown to underestimate loads, potentially leading to unsafe designs, whereas the Winkler Model for Piled Raft (WMPR) produced contradictory results, rendering both only appropriate for exploratory studies. These findings provide useful information for selecting appropriate software for CPRF analysis based on accuracy, dependability, and design safety factors.



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Introduction

The current population growth and the fast rate at which the world is turning into urban city consequence the call for advancement in architecture and construction to meet adequate housing and infrastructure needed in urban centers. One of the foremost responses to these challenges has been the increase in tall buildings, which helps us use limited space in fashion and maximize vertical space. Such structures tend to have numerous basements to be useful as they serve densely populated places with great roles in having parking spaces and stores. However, due to very large vertical loads in addition to the requirement to restrict the settlement, the traditional foundations are thus unsuitable in many instances. Thus, engineers have resorted to efficient systems of foundations that can handle all these issues. Among these, the Combined Pile Raft Foundation (CPRF) has been designed as one of the most effective solutions [1], [2].

CPRF system then can be defined as a good system or construction method that combines the features of piles in terms of load bearing with the efficiency of raft in supporting the loads. Each pile distributes the structural loads to more stable subsoil or bed, on the other hand, the raft distributes loads to a greater area to reduce differential amount of settlement. Collectively, these two components contribute towards fully effective load sharing, minimal bending moment in piles and optimal control of settlements. In weak or heterogeneous ground conditions, the application of the two stages of the foundation system has been more beneficial than utilizing simple pile or raft foundation at lesser cost. Burj Khalifa in Dubai and the Brooklyn in New York are examples of some of the large projects where CPRF systems have been used in handling loads and difficult soils [3].

Still, establishing a proper CPRF strategy is very challenging even with all the mentioned benefits. For instance, previous design practices involve designing the pile and the raft separately, which ignores the complex interfacial contributions between the piles, raft, and the supporting soil [3], [4] provided basic framework for CPRF design and understanding of load distribution and settlement. These methods do not capture the pile-soil-raft interaction, especially in cases of varying load sharing system or varying soil conditions [5], [6].

The use of computers in CPRF analysis has further enriched the accuracy and detail of analysis possible by this powerful tool. Numerical modeling software based on the Finite Element Method (FEM) like the PLAXIS 3D has become popular for geotechnical engineering

applications due to its efficiency in providing complex three-dimensional analysis of soil structure interaction. Likewise, SAP 2000, which is used in structural engineering, uses the Winkler Model for piled raft (WMPR) where the pile-raft interaction is broken down into springs and plates. ELPLA is a recently developed software, and its main area of operation is the analysis of the interaction between pile and raft foundation with particular attention given to the compressibility of the subsoil and layers of the subsoil [7], [8]. These are rather helpful tools in managing different types of projects, although each of them has its own advantages and disadvantages. For instance, PLAXIS 3D offers a lot of details with a very high complexity and expensive fee as compared to SAP 2000 that is simply developed but loses interaction accuracy. Despite of developed for CPRF only, ELPLA has been raised some concerns for providing less load capacities in some cases causing unsafe design [9].

This has made it easy for simple models such as the plate-on-springs or the strip-on-springs models to be preferred by engineers in solving contact problems. However, these methods are not effective to represent significant interaction effects like pile-pile and pile-raft interactions. For instance, the Winkler model assumes piles and rafts to be isolated springs while in a real system, piles and rafts interact in a way that impacts the performance of CPRF under varying load conditions. Such oversimplifications can call for wrong estimation of settlement as well the bending moments, especially in case of more complex structures where differential settlement is a very crucial point of concern [10].

Nevertheless, much investigation remains scarce regarding the comparison of various software platforms for effective CPRF analysis in the present era of computational tools and advanced analytical techniques. In the current literature, various analyses are performed only by single tools or with straightforward approaches, providing few comparisons between them. For instance, [11] highlighted the significance of interaction effects in CPRF systems but failed to offer a direct analysis of how various software tools address such effects. Similarly, ELPLA, though being the software specially designed for the pile-raft interaction analysis, has not been checked for its accuracy against the real-life examples for its performance appraisal.

Considering these gaps, this research seeks to undertake a comparative analysis of the performances of PLAXIS 3D, SAP 2000, and ELPLA through five case studies. These cases also have a variety of soil conditions and load distributions, to compare and test each software on modeling and simulating CPRF systems. This study aims

to compare accuracy, usability, and limitations by following these questions in a bid to offer insightful recommendations to engineers when choosing proper CPRF design tools. The conclusions will not only shed light on the behavior of CPRF but also contribute to the formation of enhanced dependable and economically efficient perspectives of foundation systems for high-rise structures.

2. Research Methodology

This research focuses on a comprehensive analysis of Combined Pile Raft Foundation (CPRF) systems using three advanced software tools: PLAXIS 3D, SAP 2000, and ELPLA. Five specific case studies were conceptualized to evaluate several factors that affect CPRF performance with a special focus on the settlement pattern of developing region under different geotechnical conditions. The specifications of each case study were made as precise as possible to facilitate recreation of the study and reproducibility of the findings. The subsequent

sections present the research case studies under consideration and the modeling and simulation strategies underpinning them.

2.1 Case Studies

The case studies were intended to encompass a variety of situations and conditions, including parametric changes and practical uses. Each case study was conducted with reference to particular values of the soil, structural loads and foundation type.

2.1.1 Case Study 1: Validation of CPRF System

The first case study intended to assess the CPRF model with the results obtained from the [10]. Raft and piles were used as the foundation system and were made of concrete, and the soil was determined to be clayey sand. The study assessed settlement behavior under different soil modulus ($E_s = 30 \text{ MPa}$, 60 MPa , 80 MPa). The parameters for this case are presented in Table 1.

Table 1. Properties of CPRF for Case Study 1

Component	Type	Density (kN/m^3)	Young's Modulus (MPa)	Poisson's Ratio	Additional Properties
Soil	Clayey Sand	19	30, 60, 80	0.3	Cohesion: 50 kN/m^2
Raft	Concrete	25	30,000	0.2	Thickness: 0.3 m
Piles	Concrete	25	3,000	0.2	Diameter: 0.5 m, Length: 15 m, 9 piles

2.1.2 Case Study 2: Parametric Analysis of Pile Length

The second case study considered a study of the effect of the different pile lengths on settlement response the results obtained from the [12]. The soil properties, raft dimensions, and pile material were kept constant, however, the pile length were chosen at 4m, 10m, 16m,

and 22m. This enabled a close analysis of the way in which pile length influences the level of settlement reduction. The parameters of this case study are provided in Table 2.

Table 2. Properties of CPRF for Case Study 2

Component	Type	Density (kN/m^3)	Young's Modulus (MPa)	Poisson's Ratio	Additional Properties
Soil	Clayey Sand	17	30	0.3	Cohesion: 10 kN/m^2
Raft	Concrete	25	20,000	0.2	Thickness: 0.3 m
Piles	Concrete	25	20,000	0.2	Diameter: 0.5 m, Length: Variable

2.1.3 Case Study 3: Parametric Analysis of Number of Piles

The third case study sought to compare settlement behavior when the number of piles was changed. The number of piles was heightened from four to twenty-five, while the other options were like the basic parameters of

Case Study 2. This study helped in understanding the influence of pile quantity on load distribution and hence minimal settlement.

2.1.4 Case Study 4: Idealized 12-Story Building

The fourth case study is an idealized 12-story building, where the CPRF system is compared to real structural loads of an actual building. The height of each story was 3.353m, and superstructure loads were: $SDL = 2.872$

kN/m² and $LL = 1.91$ kN/m². The mechanical properties of the soil, raft and pile are illustrated in Table 3.

Table 3. Properties of CPRF for Case Study 4

Component	Type	Density (kN/m ³)	Young's Modulus (MPa)	Poisson's Ratio	Additional Properties
Soil	Sand	19	30	0.3	Cohesion: 50 kN/m ²
Raft	Concrete	25	30,000	0.2	Thickness: 0.5 m
Piles	Concrete	25	30,000	0.2	Diameter: 0.5 m, Length: Variable

2.1.5 Case Study 5: Real-World Analysis of Highrise Building

The last case study was related to the evaluation of the high rise building built by communication & Works Department on Warsak Road in Peshawar. Thus, the

present engineering practice offered a chance to test the CPRF model in a complicated geotechnical environment with a high-water table. The material properties for this case are summarized in Table 4.

Table 4. Properties of CPRF for Case Study 5.

Component	Type	Density (kN/m ³)	Young's Modulus (MPa)	Poisson's Ratio	Additional Properties
Soil	Clay	20	20	0.3	Cohesion: 34.3 kN/m ²
Raft	Concrete	25	30,000	0.2	Thickness: 0.762 m
Piles	Concrete	25	30,000	0.2	Diameter: 0.5 m, Length: 25 m, 132 piles

2.2 Software Modeling and Simulation

PLAXIS 3D was used to analyze the structure and design, SAP 2000 was used to generate the lateral force resistance system, and ELPLA was used for the lateral load demand. Each software tool is special in modeling the interaction of structures with the soils and in analyzing the foundations. The modeling process was adjusted to keep all the tools consistent yet allow for each tool to be utilized in its unique capacity.

The CPRF system was modeled in a three-dimensional domain using finite element method (FEM) software called PLAXIS 3D. The raft was modeled as plate elements, and the piles were modeled as embedded beam elements to account for skin and base resistance. The mechanical properties of the soil were determined by using the Mohr-Coulomb materials model, which offers a correct depiction of nonlinearity. The tetrahedral mesh was deployed to model the geometry of the structures with accuracy, and the loads were uniformly or variably distributed according to the cases under investigation. It also produced comprehensive results such as settlement profiles, load-sharing ratios, and stress distributions.

For the analysis of the CPRF system in SAP 2000, the Winkler Model for Piled Raft (WMPR) was applied. The raft was idealized as a plate element and the piles as spring elements, with the stiffness of the springs determined by soil properties. Superstructure loads were applied to the raft and based on this input the software provided for load settlement and load distribution at the raft pile interface. Essentially, this approach offered a useful approximation of how the CPRF system would function under different load conditions.

ELPLA (Elastic Plate) considered the CPRF system through the modulus of compressibility approach, with the soil treated as a continuum medium and the raft discretized into finite elements. This made it easier for the user to input geotechnical properties, raft, and pile dimensions as well as loading conditions. Due to ELPLA's versatility, rigid, elastic, and flexible foundation models allowed the researchers to capture the CPRF behavior under multiple conditions.

This systematic approach also guarantees that the findings of this study can be replicated or applied in future studies in geotechnical engineering.

3. Results and Discussion

In this section, the results for each case study are discussed in terms of the findings which are determined by the use of PLAXIS 3D, SAP 2000, and ELPLA software. The details of each software output are presented and analyzed for all the case studies, and a comparison of their performance is also made. The numerical results and tabular data are provided in the text and described in detail to enhance the understanding of the study results.

3.1 Case Study 1: Validation of CPRF System

3.1.1 Results from PLAXIS 3D

The analyses of the CPRF system were performed by modeling the structure using PLAXIS 3D and applying different soil modulus values, including $E_s = 30, 60,$ and 80 MPa. Table 5 presents the settlement results of the study and reveals that settlement decreases with an increase in soil stiffness. Such behavior has demonstrated that the software can model the soil-structure interaction correctly and accurately and respond geotechnically to real-world conditions.

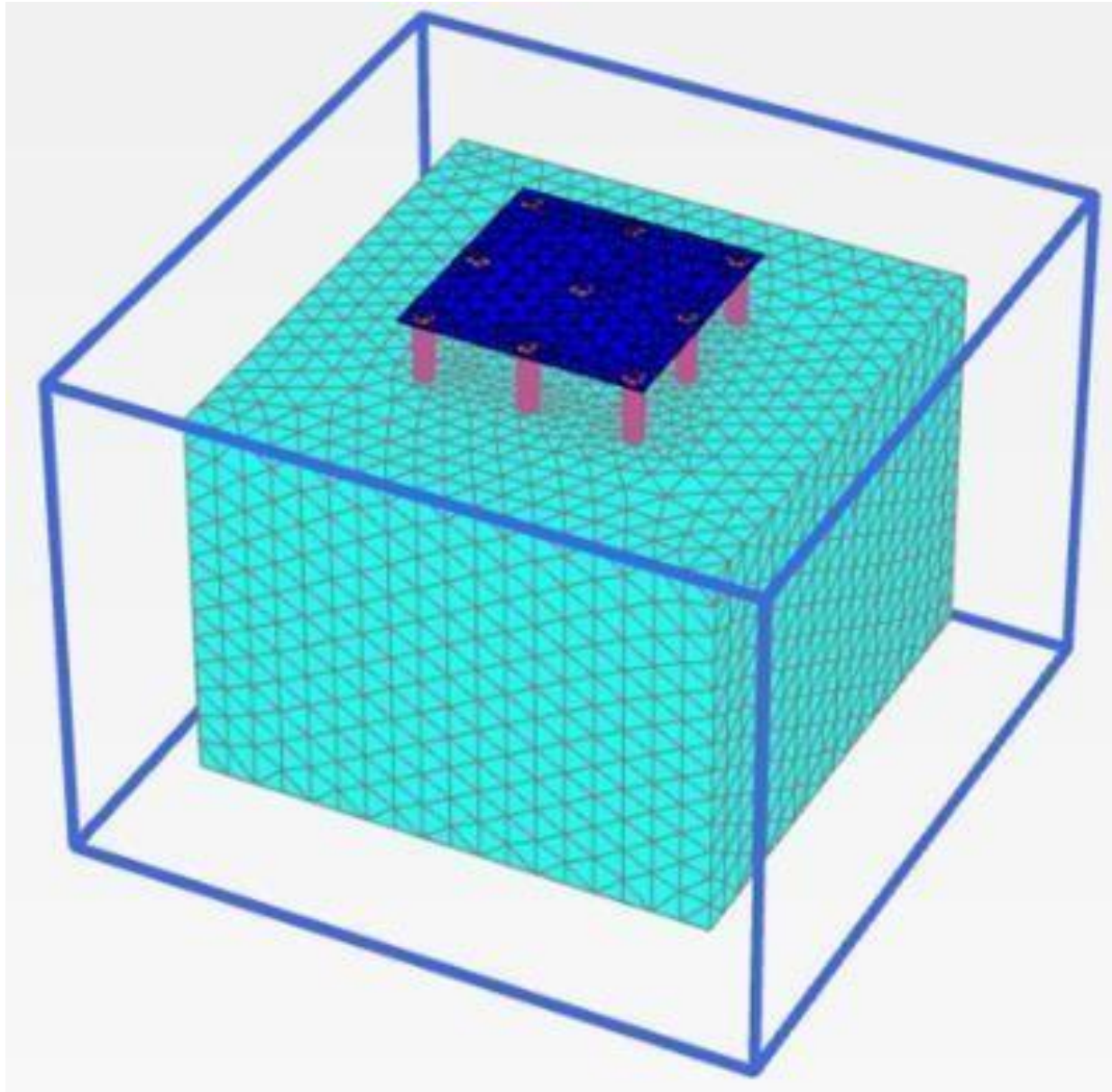


Fig. 1. Finite Element Model of the first case study in Plaxis-3D

Figure 1. just represents the Pile raft model in Plaxis-3D.

Table 5. Settlement Results for PLAXIS 3D

Es (MPa)	Settlement (mm)
30	23.9

60	15.0
80	11.0

3.1.2 Results from SAP 2000

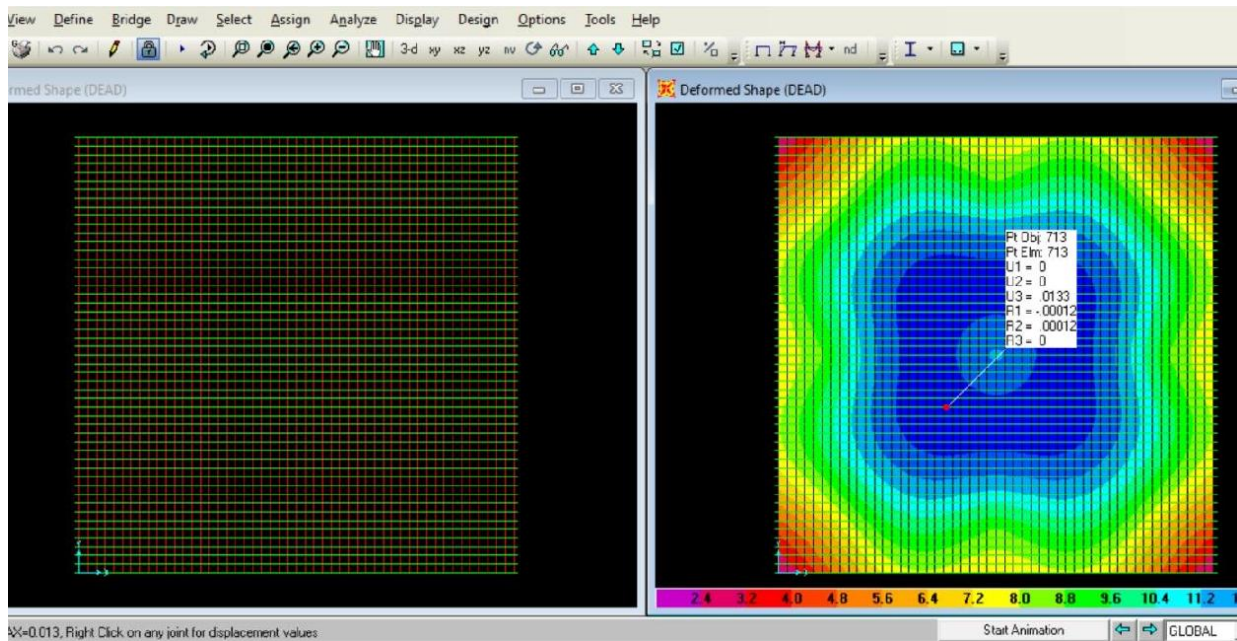


Fig. 2. Model of the first case study in Sap2000

SAP 2000, the CPRF system was modeled with the raft represented as plate elements and the piles as spring elements. It is possible to find the settlement results for different values of E_s is presented in Table 6. The results

Es (MPa)	Settlement (mm)
30	24.2
60	15.3
80	11.4

Figure 3. illustrates the settlement concentration under the applied load which has similar values as those presented in

show a similar pattern to that observed for PLAXIS 3D, but slightly higher settlements due to the simplified modeling of the soil-pile system.

Table 6. Settlement Results for SAP 2000

PLAXIS 3D but slightly higher because of the less accurate modeling of SAP 2000.

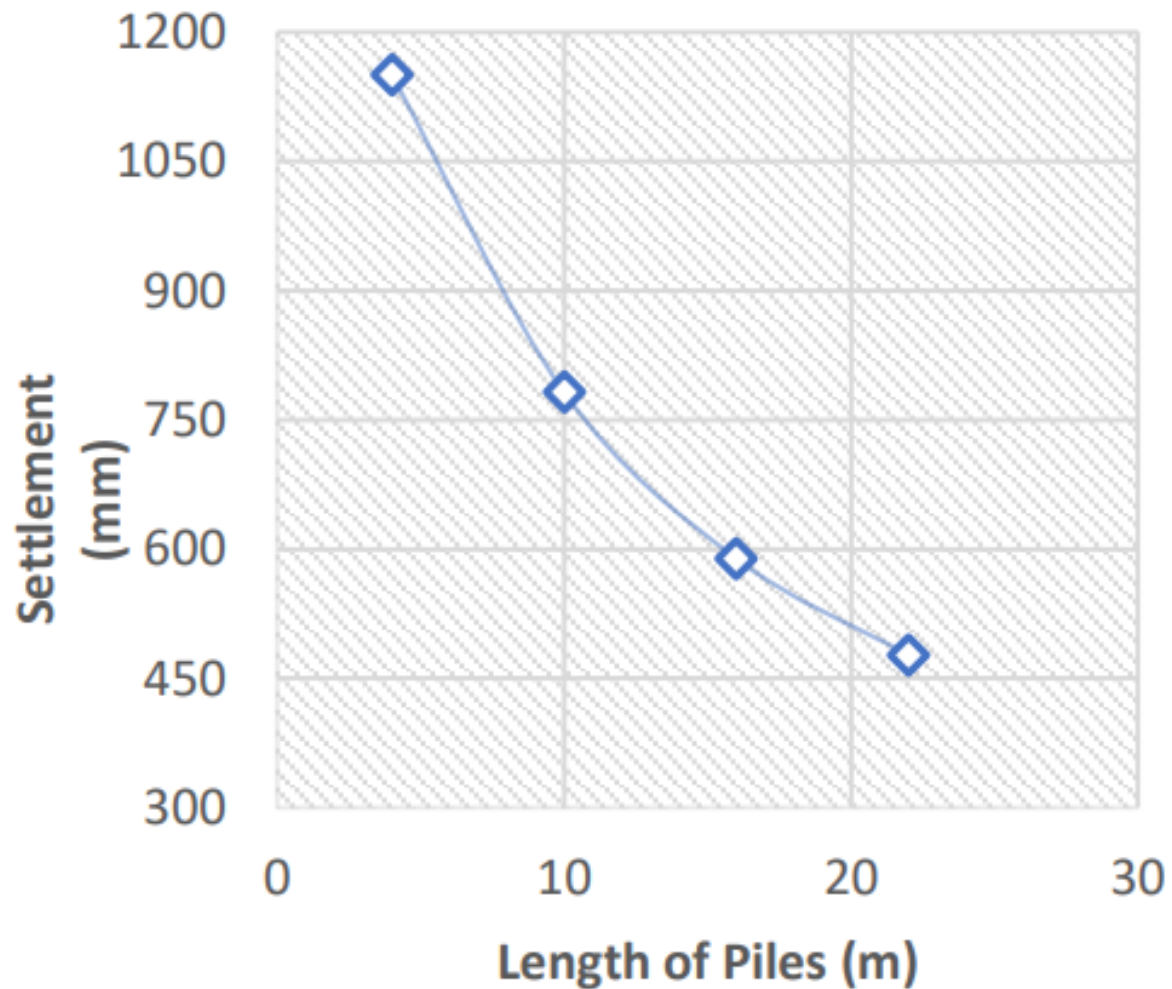


Fig. 3. Settlement versus length of piles for Case Study 1

3.1.3 Results from ELPLA

ELPLA evaluated the CPRF system employing the modulus of compressibility method. Table 7 summarizes the settlement results obtained for different E_s values.

The results are nearly consistent with those of PLAXIS 3D and SAP 2000, showing that ELPLA is effective in modeling CPRF systems.

Table 7. Settlement Results for ELPLA

Es (MPa)	Settlement (mm)
30	23.8
60	14.9
80	10.8

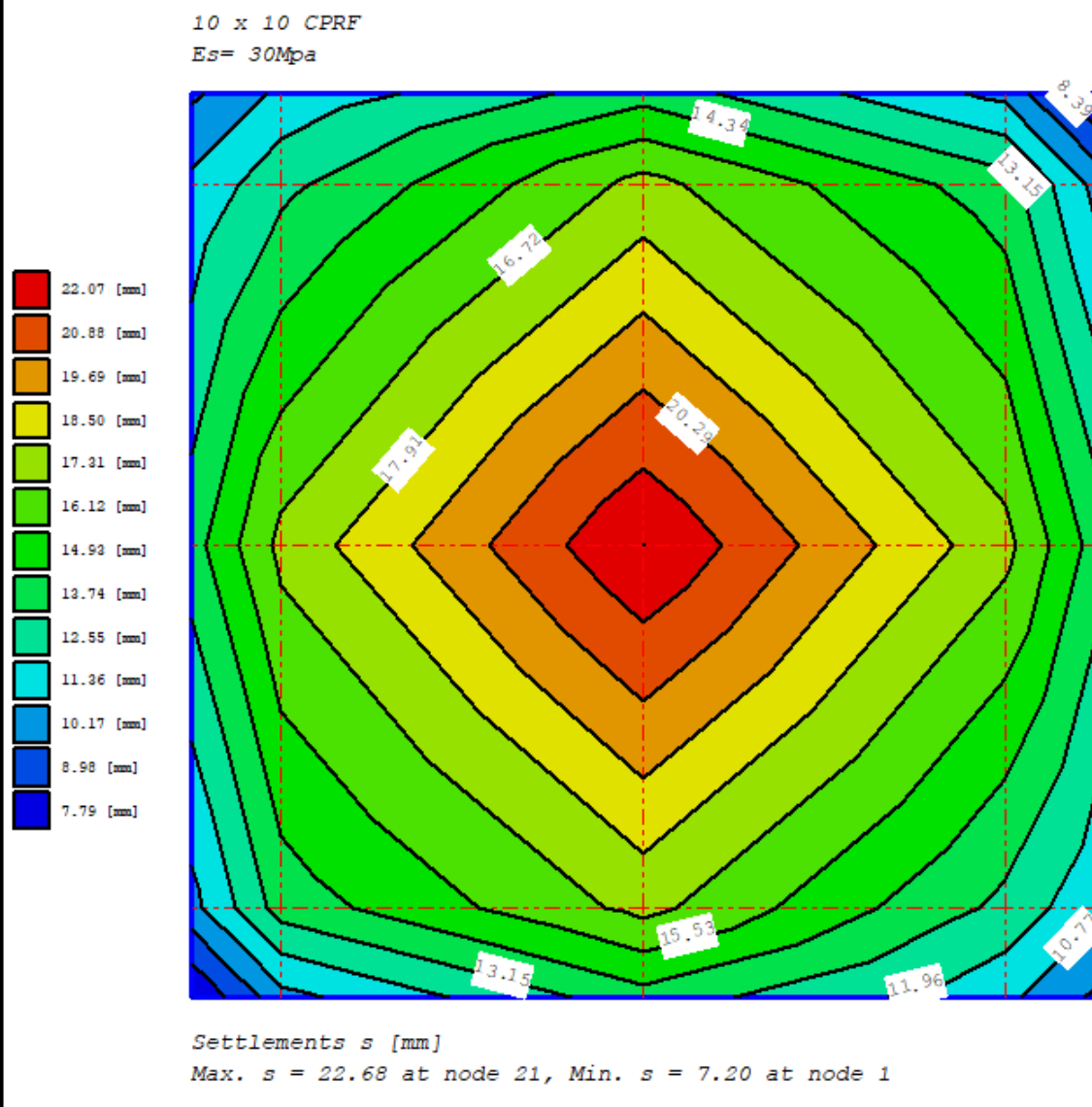


Fig.4. Settlement Results of ELPLA

Figure 4. just shows the actual and simulated settlement profile of ELPLA.

3.1.4 Comparative Analysis

A summary of the comparative settlement results for all three tools is presented in Table 8 & Figure 5. The results show that there is a reduction in the settlement as the soil stiffness increases for all the tools employed. Some

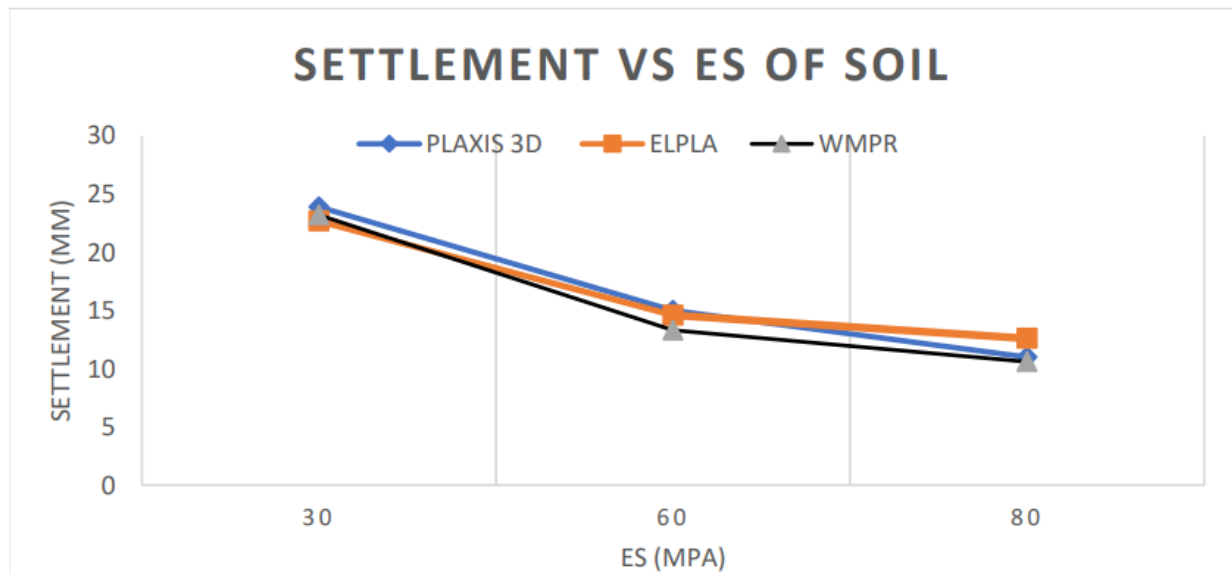
variation in the settlement values can be explained by the conceptual differences in the modeling done in the two software. As it can be seen from the illustrations, PLAXIS 3D has given the best result as compared to the other two software SAP 2000 and ELPLA which give slightly different results due to some assumptions made and different ways of computing by the software.

Table 8. Comparative Settlement Results for Case Study 1

Es (MPa)	PLAXIS 3D (mm)	SAP 2000 (mm)	ELPLA (mm)
30	23.9	24.2	23.8
60	15.0	15.3	14.9
80	11.0	11.4	10.8

SAP 2000 outcome is slightly greater since it assumed grounded piles to have a simpler approach to the soil-pile

interaction. ELPLA results are lower because they can characterize the state of compressibility in soil.



3.2 Case Study 2: Parametric Analysis of Pile Length

3.2.1 Results from PLAXIS 3D

PLAXIS 3D determined the impact of pile length on settlement by comparing pile lengths of 4m, 10m, 16m, and 22m. The settlement outcomes are illustrated in

Table 9 specifying that regardless of the SCMs, settlement decreases significantly with pile length. This suggests that there is potential for an increase in pile lengths to facilitate enhanced load transfer, hence lesser overall settlement.

Table 9. Settlement Results for PLAXIS 3D

Pile Length (m)	Settlement (mm)
4	1,197
10	910
16	702
22	501

3.2.2 Results from SAP 2000

As for the modeling of the CPRF system, the raft was modeled using plate elements while the piles were modeled as spring elements. The effects of the difference in pile lengths are given in the settlement results as presented in Table 10. The performance of the software was like that of the PLAXIS 3D with a marginal increase

in settlements due to its basic modeling method. The settlement values are significantly reduced showing enhanced load transfer and distribution benefits associated with longer piles. Hence, the closeness in the data with PLAXIS 3D strengthens the strength of SAP 2000 in simulating CPRF.

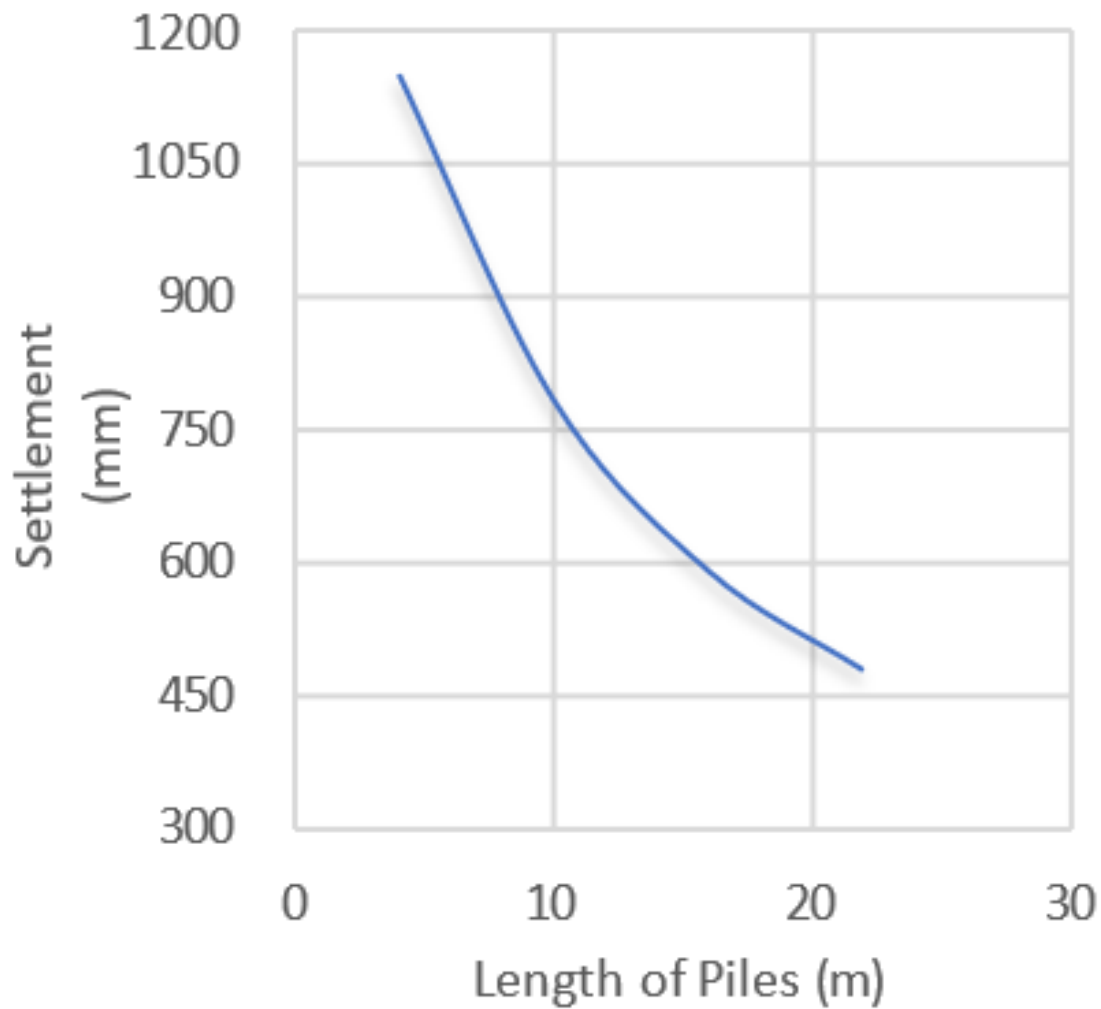
Table 10. Settlement Results for SAP 2000

Pile Length (m)	Settlement (mm)
4	1,190
10	920
16	710
22	500

3.2.3 Results from ELPLA

Using the modulus of compressibility method, ELPLA determined the response of the CPRF system and was

found to correlate with PLAXIS 3D and SAP 2000. The settlement results of the piles of different lengths are presented in Table 11 and Figure 6.

**Fig. 6.** Settlement versus length of the pile for case study 2**Table 11.** Settlement Results for ELPLA

Pile Length (m)	Settlement (mm)
4	1,185
10	915
16	705
22	495

3.2.4 Comparative Analysis

the decreasing settlement with the increase in pile length across all the tools.

Table 12. and Figure 7 show the comparative settlement results of all three tools. The results provide consistent observations of

Table 12. Comparative Settlement Results for Case Study 2

Pile Length (m)	PLAXIS 3D (mm)	SAP 2000 (mm)	ELPLA (mm)
4	1,197	1,190	1,185
10	910	920	915
16	702	710	705
22	501	500	495

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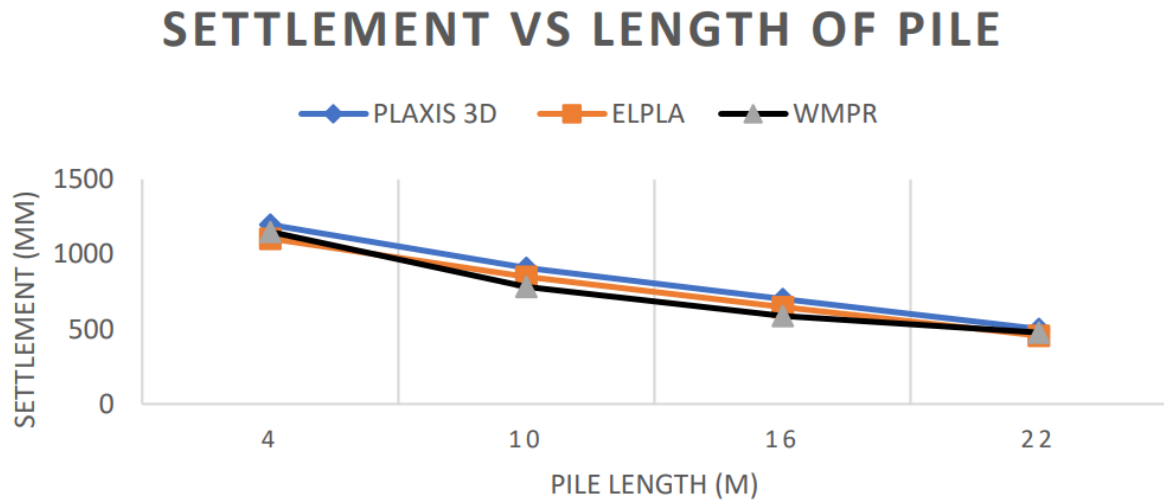


Fig. 7. Comparative Settlement vs length graph for PLAXIS 3D, ELPLA, and WMPR method

The outcome shows that all three tools behave similarly, whereby settlement decreases with an increase in pile length. Small discrepancies can be attributed to differences in the underlying model specifications. The results indicate that PLAXIS 3D gives the most detailed analysis of settlement while SAP 2000 predicted slightly higher settlement probably due to neglected interactions, though it gave the least result compared to the other two programs; ELPLA gives slightly fewer settlement results compared to the other two programs because its major concentration is towards the compressibility feature of soils. Thus, the given results prove that longer piles enhance CPRF performance.

3.3 Case Study 3: Parametric Analysis of Number of Piles

3.3.1 Results from PLAXIS 3D

The analysis aimed at determining the effects of differences in the number of piles (4, 9, 17, 25) on the settlement and was done using PLAXIS 3D. These results are presented in Table 13 which indicates that the settlement decreases with increasing piles. Such behavior demonstrates how an increase in the number of piles results in load distribution and a consequent decrease in the overall settlement.

Table 13. Settlement Results for PLAXIS 3D

Number of Piles	Settlement (mm)
4	936
9	690
17	672
25	643

Figure 8. illustrates the trend of settlement on the number of piles, in which, as the pile’s number increases, the settlement decreases gradually. The settlement, however, has reached the maximum of 936 mm with 4 piles which decreases to 690 mm for 9 piles. Higher values of 17 and 25 piles lead to settlements of 672mm, and 643mm respectively; however, the rate of decrease

in settlement values is declining as the number of piles elevates. This trend illustrates that the degree of improvement in settlement reduction decreases for each additional pile to be established. Figure 8 also emphasizes the need to balance the number of piles to achieve a cost-effective and efficient foundation.

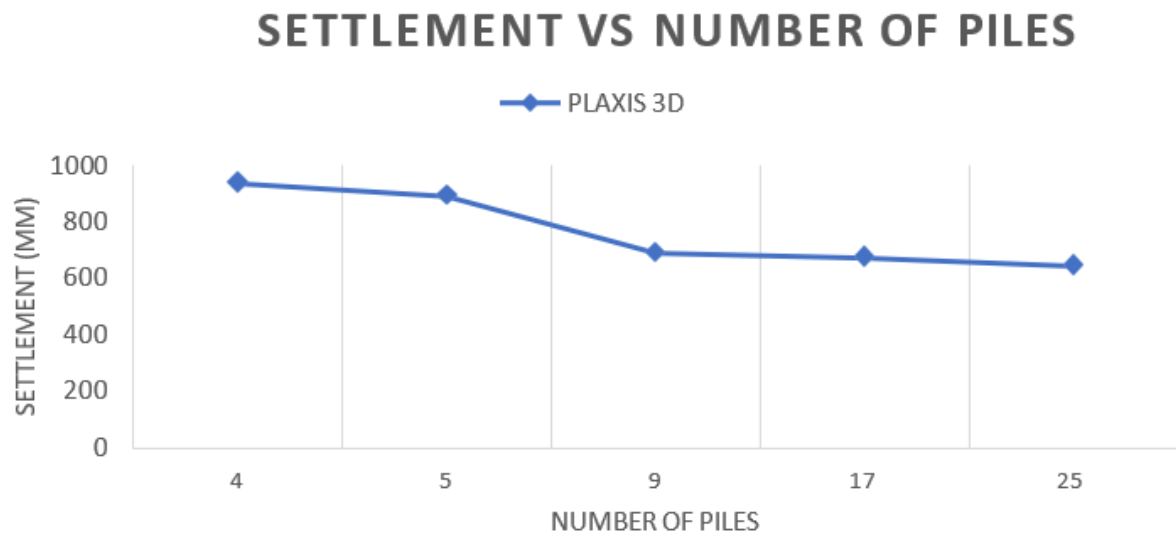


Fig. 8. Settlement vs number of piles graph

3.3.2 Results from SAP 2000

In SAP 2000, the CPRF system was modeled with plate elements on the raft and spring elements on piles. Pile numbers and their corresponding settlement results are presented in Table 14. The trends are like those observed in PLAXIS 3D and the settlements are slightly higher in SAP 2000 because of stemming and a slightly more simplified approach to modeling the soil-pile interaction.

Figure 9 illustrates the analysis carried out in SAP 2000, which is a graph of settlement versus the number of piles that shows the relationship between the number of piles and settlement. When only 4 piles are used, the settlement is at a maximum of 940 mm and then decreases to approximately 695 mm when 9 piles are used. Subsequent increases to 17 and 25 piles yield 675- and 645-mm settlements, respectively.

Table 14. Settlement Results for SAP 2000

Number of Piles	Settlement (mm)
4	940
9	695
17	675
25	645

This behavior emphasizes the need to achieve the right number of piles when seeking to minimize settlement

while keeping the cost of the foundation designs within reasonable limits.

Settlement Vs Number of Piles

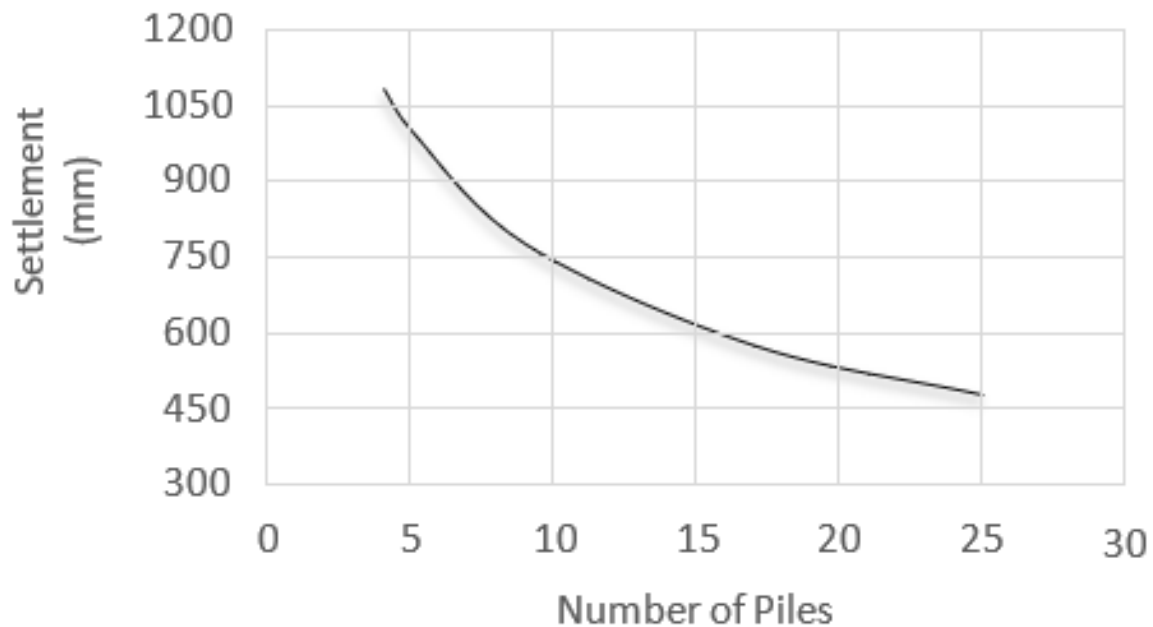


Fig. 9. Settlement versus Number of piles for Case 3

Table 15. Settlement Results for ELPLA

3.3.3 Results from ELPLA

Number of Piles	Settlement (mm)
4	935
9	685
17	670
25	640

ELPLA also mimicked the parametric study of pile numbers as well. The settlement results obtained are illustrated in Table 15 where the average settlement values are slightly smaller as compared to PLAXIS 3D and SAP 2000. This is due to the assumption made by ELPLA while using the modulus of compressibility method.

3.3.4 Comparative Analysis:

The comparison of the settlement results for all three tools is presented in Table 16 and Figure 10. These observations indicate the pattern where the settlement reduces gradually as the number of piles rises with all the tools.

Table 16. Comparative Settlement Results for Case Study 3

Number of Piles	PLAXIS 3D (mm)	SAP 2000 (mm)	ELPLA (mm)
4	936	940	935
9	690	695	685
17	672	675	670

25	643	645	640
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All three tools establish that with an increase in pile numbers; the settlement significantly decreases as revealed by the results obtained. Some small variations in the settlement values are attributed to the various modeling methodologies. Among the three software,

PLAXIS 3D offered the highest accuracy in the analysis, even though SAP 2000 and ELPLA offer a little variation in the result due to their assumptions. This overall trend therefore further emphasizes the importance of pile numbers to the performance of CPRF systems.

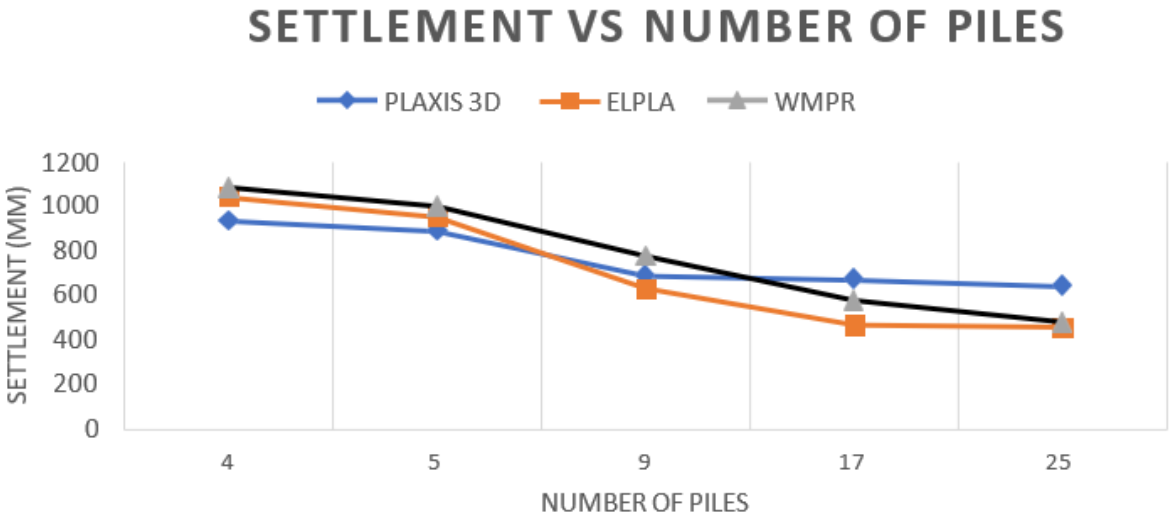


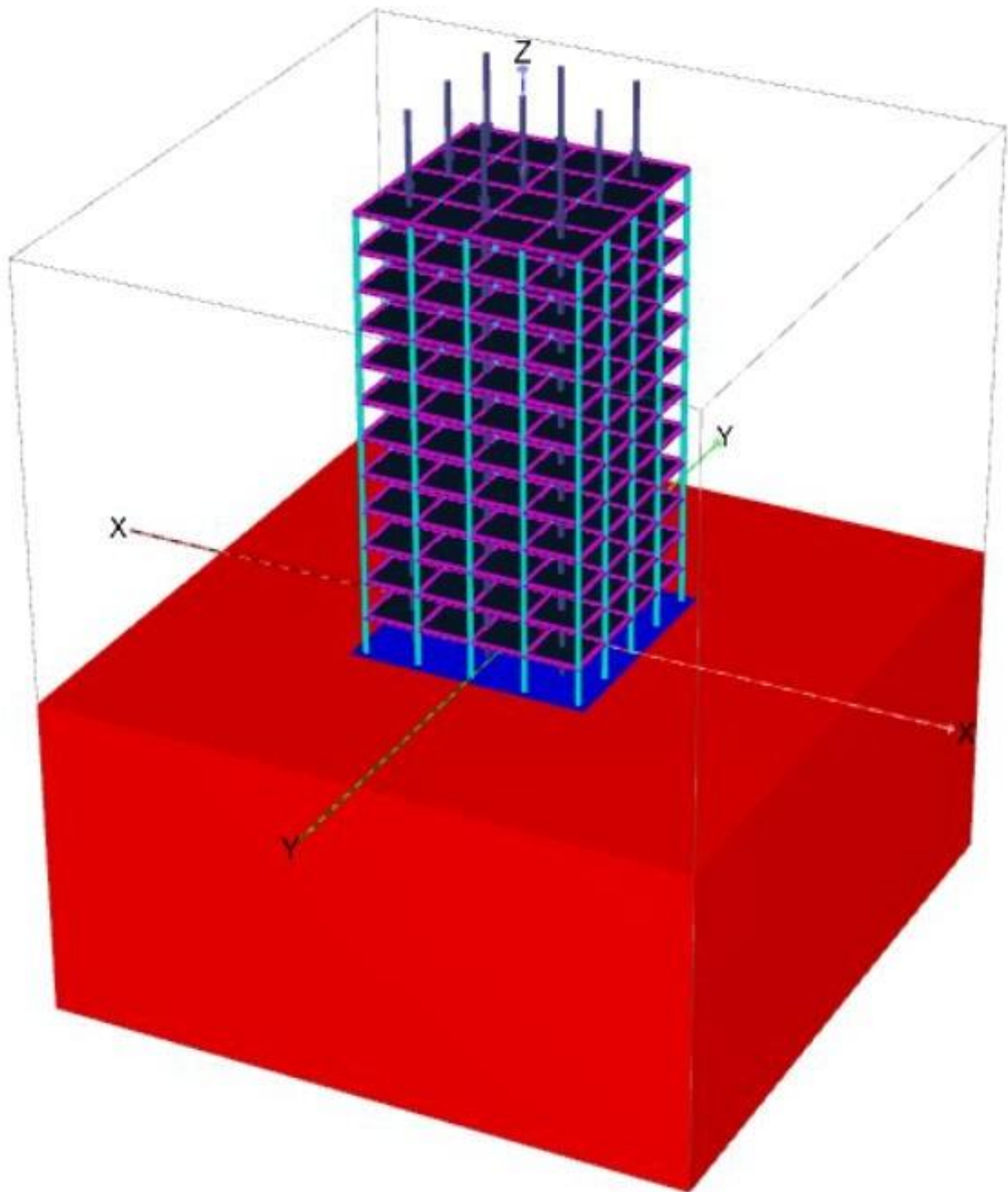
Fig. 10. Combined Settlement Graph for Case Study 3

All three tools establish that with an increase in piles; the settlement significantly decreases as revealed by the results obtained. Some small variations in the settlement values are attributed to the various modeling methodologies. Among the three software, PLAXIS 3D offered the highest accuracy in the analysis, even though SAP 2000 and ELPLA offer a little variation in the result due to their assumptions. This overall trend therefore further emphasizes the importance of pile numbers to the performance of CPRF systems.

3.4 Case Study 4: Idealized 12-Story Building

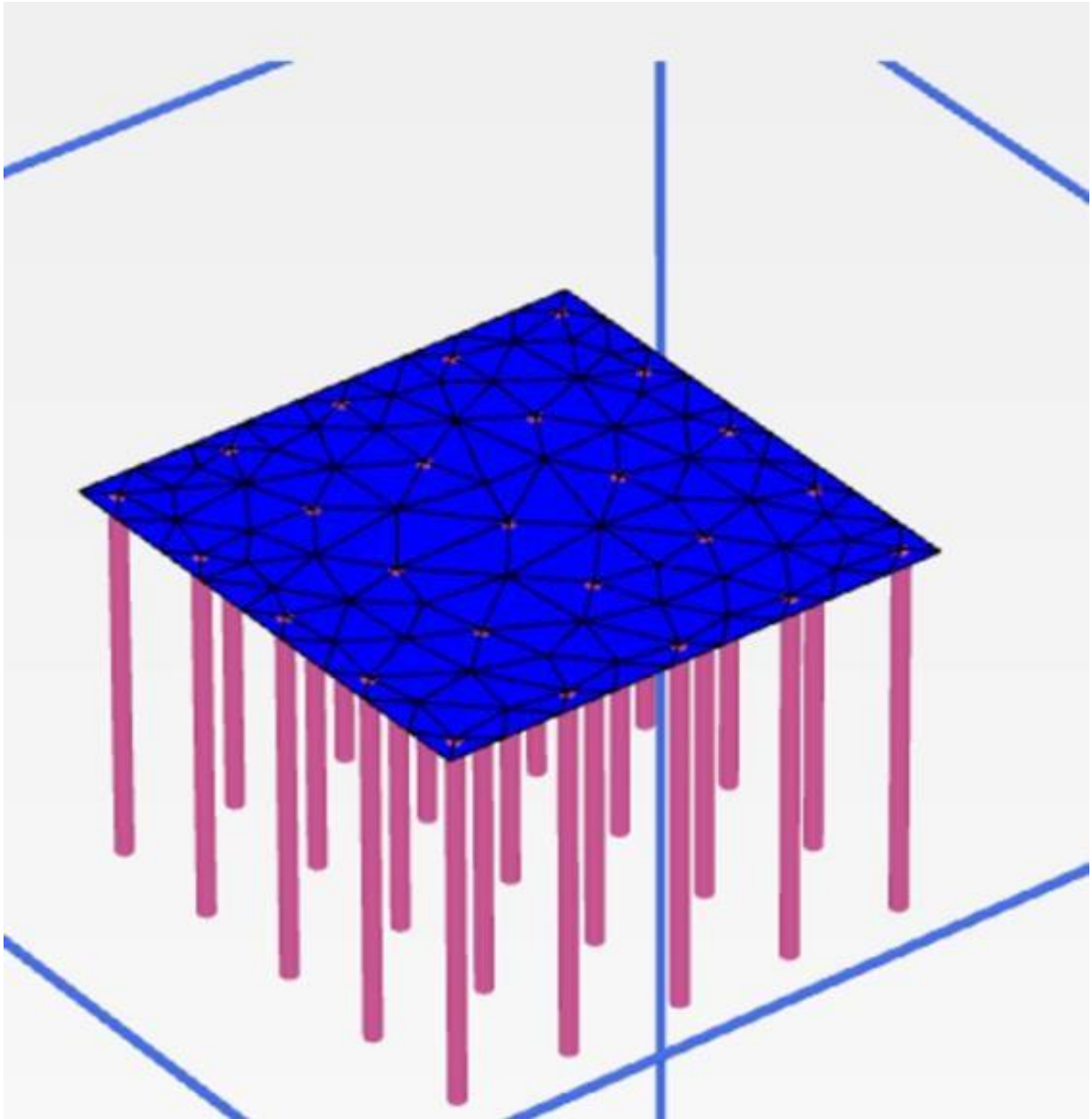
3.4.1 Results from PLAXIS 3D

To investigate the total settlement of the 12-storey building supported by the CPRF system, computational modeling was done with the help of PLAXIS 3D. Proved and obtained in the analysis the settlement of 18.38 mm, and homogenous settlement under the given load carrying conditions. This emphasizes the capability of the software in simulating the soil structure interactions as well as indicates how optimal CPRF would mitigate complete settlement. Figures 11 and 12 illustrate further understanding of the settlement behavior of 12-story buildings consistent with the known properties of the CPRF system.



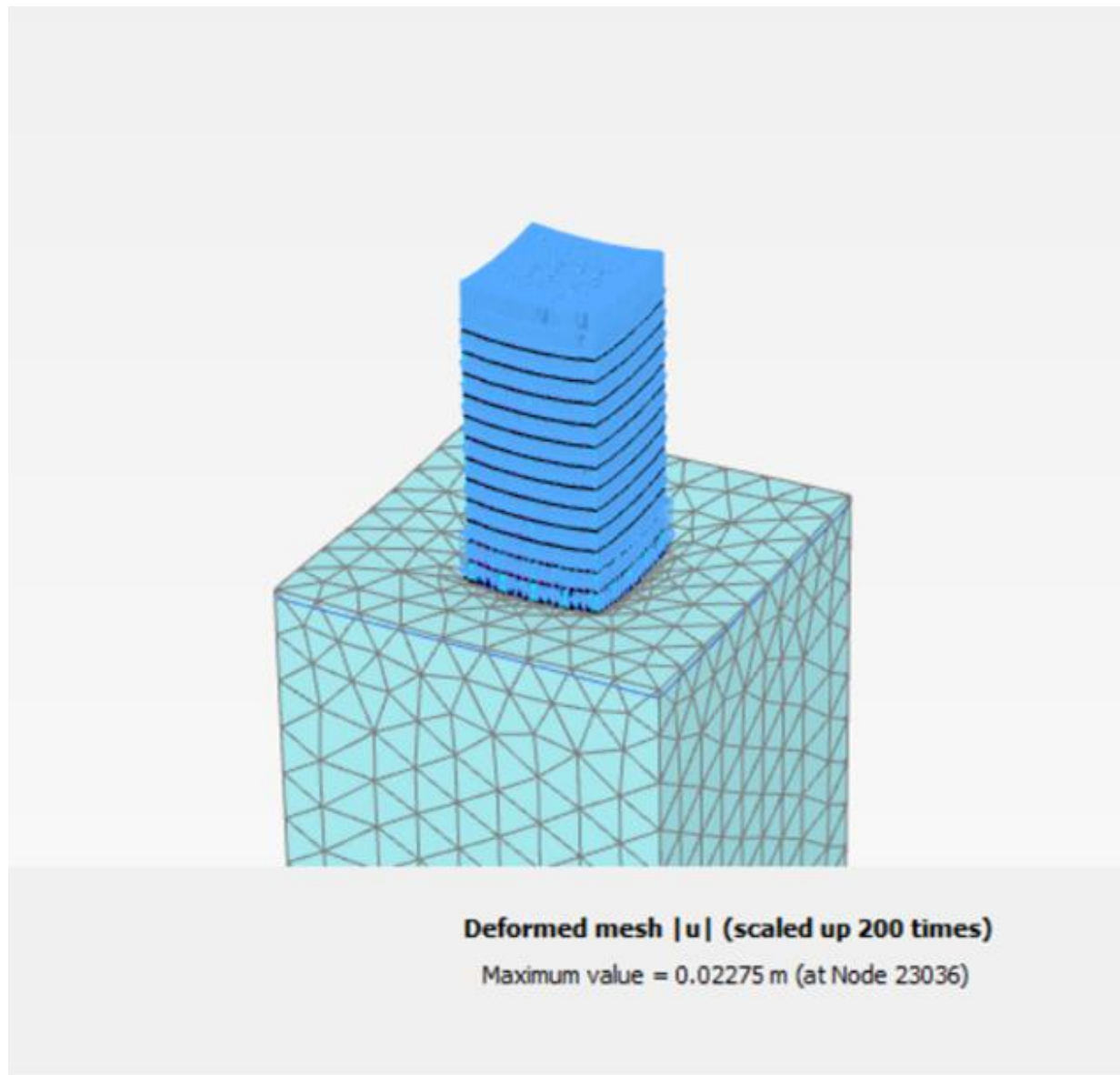
a) 12 Story building with soil b) building with piles and raft

Fig.11. Ideal case study in Plaxis-3D



a) Piles settlement b) Raft total settlement

Fig. 12. Settlement in Plaxis-3D



a) soil meshing b) whole building meshing

Fig. 13. Finite Element Models in Plaxis-3D

The structural configuration which reveals the physical relationship between the building, soil, and pile-raft systems is shown in Figure 13. This visualization reveals details of the system layout and the organization of the structure concerning the surrounding soil. Also illustrates the settlement profiles showing the balance load distribution provided by the CPRF system. The profiles focus on the effectiveness of the system to prevent differential settlement and structural stability.

3.4.2 Results from SAP 2000

Sap 2000 software has given the settlement results of the idealized 12-storey building as 18.75mm. This value is quite like the PLAXIS 3D result and therefore it gives good evidence of the ability of SAP 2000 to model the behavior of CPRF systems. The slightly higher settlement value is attributed to the assumption of the software when it

comes to modeling the interaction between soil and pile. The case studies reveal that SAP 2000 can accurately predict the settlement of multi-story buildings on CPRF systems.

3.4.3 Results from ELPLA

For the idealized 12-storey building, ELPLA yielded a settlement value of 17.95mm. Still, ELPLA's slightly lower settlement compared to those obtained from PLAXIS 3D and SAP 2000 can be due to the differences in the modeling assumptions, especially in the modulus of compressibility method. The results demonstrate the effectiveness of the proposed ELPLA in predicting accurate CPRF system settlements and minor deviations resulting from the different computation methods.

3.4.4 Comparative Analysis

Table 17. compares the settlement outcome from all three tools. The general settlement values are quite similar; some disparity is

attributed to the differences in modeling assumptions and calculations.

The comparative results also show that all three tools give similar values for the predicted settlement of the idealized 12-storey building. Settlement values predicted by PLAXIS 3D and SAP 2000 were slightly higher compared to the values obtained in ELPLA. These minor

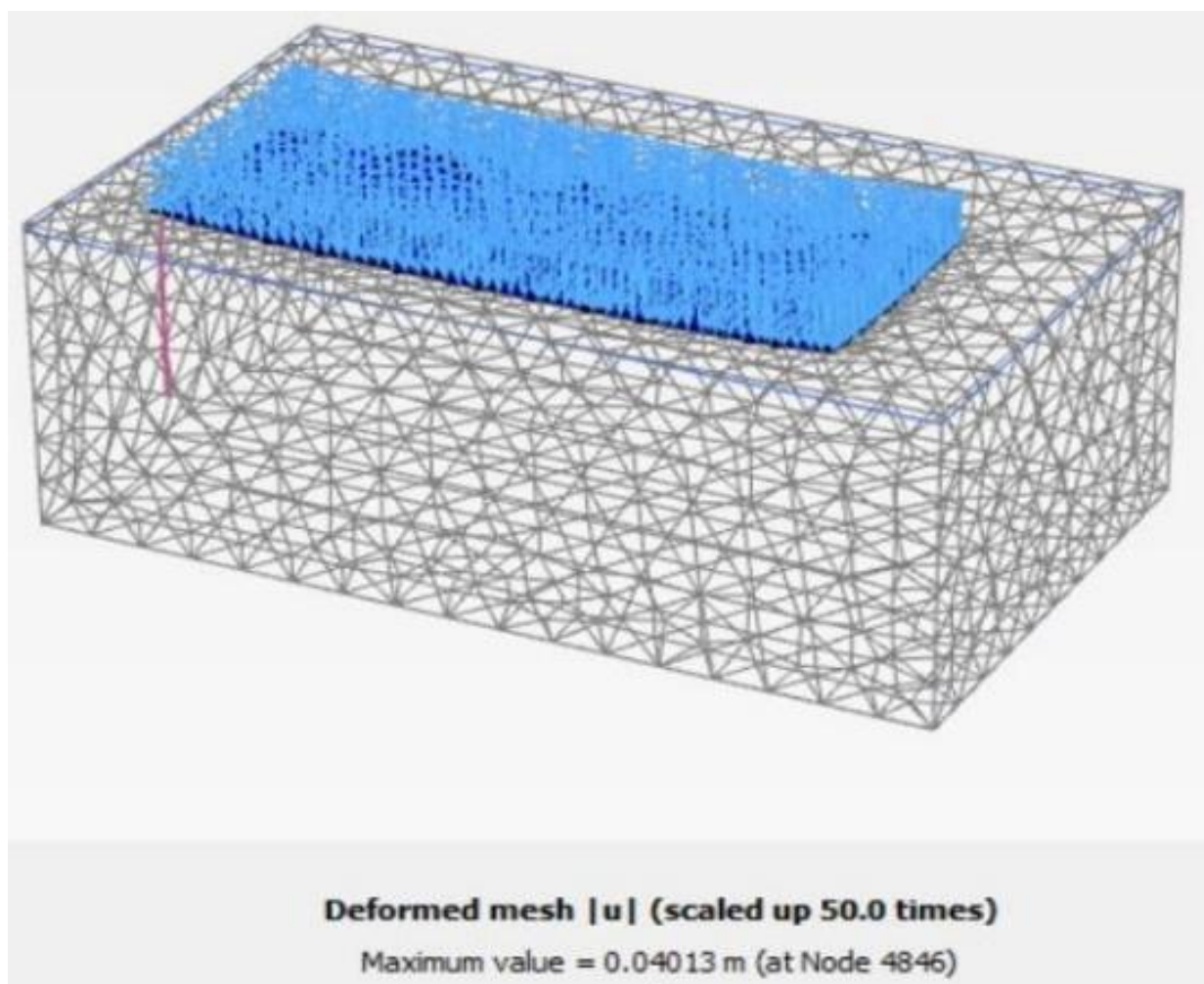
differences can be explained by the differences in methods and assumptions used in each of the programs. In summary, the findings of this study support the use of CPRF systems as an effective technique for reducing settlement on high-rise structures.

Table 17. Comparative Settlement Results for Case Study 4

Software	Settlement (mm)
PLAXIS 3D	18.38
SAP 2000	18.75
ELPLA	17.95

3.5 Case Study 5: Real-World Analysis of a Highrise Building

3.5.1 Results from PLAXIS 3D



a. Highrise Building model in PLAXIS 3D b. Total settlement results of raft and

Fig. 14.

PLAXIS 3D replicated the settlement characteristics of the high rise building constructed by the Communication and Works Department on main Warsak Road within the city of Peshawar. The settlement obtained was 40.13 mm. Figures 14 illustrate the 3D model and settlement

contours created using PLAXIS 3D software. As this shows, the software is capable of modeling real-life situations and offering adequate predicting of settlement behavior. Also presents a 3D model of the C&W Tower foundation which was simulated in PLAXIS 3D.

3.5.2 Results from SAP 2000

SAP 2000 worked out the same foundation system and got a settlement of 41.25mm. The result agrees with

PLAXIS 3D but is slightly higher because the assumption made about the soil-pile interaction is less complex. This demonstrates the capacity of SAP 2000 to mimic real-life conditions and, at the same time, preserve accurate computational modeling.

3.5.3 Results from ELPLA

According to the settlement calculations of ELPLA, the settlement value for above Tower was estimated to be 39.84 mm. This is the lowest settlement among the three tools, and as expected considering that ELPLA tools marked a great value on compressibility and layered soil behavior during the computations. This result is close to PLAXIS 3D and SAP 2000, which also proves the

applicability of ELPLA for modeling CPRF in real situations.

3.5.4 Comparative Analysis

The results comparing the foundation settlement of high rise building from PLAXIS 3D, SAP 2000, and ELPLA are summarized in Table 18. These results clearly show the similarities between all three software tools with slight differences between the various computational techniques and modeling assumptions.

Table 18. Comparative Settlement Results for Case Study 5

Software	Settlement (mm)
PLAXIS 3D	40.13
SAP 2000	41.25
ELPLA	39.84

4. Conclusion

This study thoroughly examined the Combined Pile Raft Foundation (CPRF) system, employing PLAXIS 3D, SAP 2000, ELPLA, and the Winkler Model for Piled Raft. The results show that, while WMPR and ELPLA yield equivalent settlement values, they tend to underestimate settlement when compared to PLAXIS 3D, potentially leading to unconservative designs. In real-world cases, however, WMPR can provide higher settlements, leading to uneconomical designs. As a relatively new software, ELPLA shows potential but requires more development to line more closely with PLAXIS 3D, which remains the most dependable tool for deep geotechnical investigation due to its powerful finite element modeling capabilities. Both ELPLA and WMPR are appropriate for basic assessments, while PLAXIS 3D is preferred for advanced and precise design considerations in CPRF systems.

Data availability

Data will be made available on request.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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