Research Article

Characterization displacement of multilayered soils using smoothing seismic data, numerical analysis, and probabilistically statistics analysis

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Abstract

Differential displacement of soil foundation owing to the seismic excitation has received significant attention for evaluation infrastructure seismic resistance. The multilayered soil interaction requires investigation for the prediction and characterization of multilayered soil differential displacement. In this study, the Fast Fourier Transform (FFT) filtering method was applied for smoothing acceleration history. The numerical simulation performed using ABAQUS for soil layers interaction assessment. The statistical analysis was also applied for verification accuracy of numerical analysis and to predict the probability of the multilayered soil differential displacement occurrence. The mechanical properties of the soil, the number of soil layers, the location of soil arrangement, the type of seismic loading, and the accuracy of seismic loading were considered for modeling. The hexahedral mesh with a 500 mm size was selected in the numerical simulation. The results reveal the soil layer's interaction influence on differential displacement and flexibility of the multilayered soil. It was observed the nature of seismic loading has a significant influence on the type of soil in minimizing displacement. The soil layer arrangement controls the displacement magnitude and soil layer vibration magnitude. The conversion of the soil differential displacement to soil linear displacement and enhancement of the soil seismic stability occurred because of multilayered soil interaction and the nature of the seismic loading. This study's finding shows the statistical model verified and predicts differential displacement through a suitable application of the statistical model in geotechnical earthquake engineering. The presented method implies the appropriate design of multilayered soil. It can be alternative solutions to predict the differential displacement of multilayered soil by minimizing the number of the modeling through the applied statistical method. It characterized the conversion of the differential displacement to linear displacement by multilayered soil design occurrence.

Highlights

- The nonlinear displacement mitigation of multilayered soils was numerically investigated.
- The statistical model supports minimization and verification numerical simulation.
- The multilayered soil arrangement has a significant impact to minimize the nonlinear displacement of multilayered soils.

Keywords Multilayered soil interaction · Seismic data · Numerical simulation · Statistics analysis · Displacements

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1 Introduction

The multidirectional differential displacement at the soil occurs because of nonlinear excitation strain energy. The differential displacement accelerates owing to the nonlinear strength of the soil and causes complex damage to the structure through the development of shearing cracks on structural components. It is well known the linear displacement of the subsoil has less damage to the structural components compared to differential displacement. However, change the mechanism of differential displacement to linear displacement through the appropriate technique is meaningfully important in enhancing a structure's seismic stability.

Numerous research articles have published concerning the different concepts for monitoring multilayer soil is subjected to seismic and dynamic loadings under different conditions. For example, research has shown that the advantage of the soft soil layer on the improvement of the site seismic response and tunnel seismic resistance [1]. The soft clay layer has been used in multilayered soil foundation arrangement and soil-structure interaction basis the dynamic response was assessed using the shaking table test [2]. On the other hand, numerical analysis and shaking table test was performed for assessment seismic response of sub-layered soil for liquefaction mitigation [3]. The horizontal displacement behavior of a multilayered soil with circular geometry was investigated using ABAQUS and analytical methods [4]. Also, several types of research investigated were reported on the compressibility and displacement of multilayered soil [5–7]. From the 1995 Kobe earthquake has been realized the seismic response of the ground significantly governs the seismic resistance of a structure [8]. Additionally, some attempts have been made to analyze seismic site amplification in a multilayer soil model and a multilayer soil dynamic response as well [9–12]. There is a report available in the literature that indicates the heavy static vertical surcharge interaction with dynamic horizontal loading on a soil foundation, leads to minimizing soil collapse magnitude. The failure mechanism behavior of soil considerably changes [13]. In contrast, the dense and loose zone of soil interaction has not been discussed for evaluation of single and multidirectional differential displacement at the soil foundation.

The numerical analysis and shaking table were used to examine displacement of embankment rest on soft clay soil for seismic response simulation [14], the investigation was made for evaluation of cement-mixed soil [15], the stress characteristics method was used to calculate the ultimate bearing capacity of footings [16], to integrate experimental results the centrifuge test was used for evaluation impact of the thickness the saturated zone on embankments seismic resistance [17], among these techniques for soil load capacity improvement, the arrangement of the soil arrangement have not been investigated for the seismic response.

For soil deformation monitoring direct shear model test was performed, and strain integration method was introduced to convert measured strain to shear displacement [18], and vertical displacement of slope owing to seismic loading was studied [19], the nonlinear displacement of embedded retaining structure because of applying seismic load was investigated, the method is applicable on several geotechnical structures [20], and numerical simulation was performed to assess deformation behaviors of the embankment rested on liquefiable soil [21], and the laboratory investigation was done for realizing embankments constructed on loose sandy subsoil [22]. On the other hand, the statistical technique was applied to control improvement safe bearing capacity of soil using mixed soil techniques [23]. It requires verifying the results of the research investigation using a suitable statistical method.

Literature suggests that there are several methods for multilayered soil monitoring that are well established. With attention to these existing methods, the most of methods for the evaluation of multilayered soil either analytical, numerical and experimental methods under laboratory conditions or in situ were limited to considering. The specific improvement characteristics of multilayered soils while have not been discussed on mitigation and prediction differential displacement. The multilayer soil through the multilayered soil arrangement design, soil layers interaction of multilayered soil for evaluation conversion of the soil differential displacement to soil linear displacement and enhancement of the soil seismic stability.

From the design point of view, the main goals of the present study examined the conversion of differential displacements of the multilayers soil to linear displacement basis soil layers arrangement and interaction of multilayered soil through analysis quasi-experimental on smoothing seismic data, perform numerical analysis and using statistical analysis during the model is imposed to near-fault ground motion.

2 Modeling and materials

In considering the cost of a finished seismic soil foundation improvement which is one of the key factors in the construction industry. It needs to investigate and introduce a new method to reach soil foundation seismic resistance improvement with a cost-effective process and high-quality results. The assessment of the presented method is needed using a suitable statistical method for validation. Suitable decision analysis for geotechnical earthquake engineering design can be made basis on the combination of quasi-experimental, statistical modeling, and numerical analysis. The assessment of multilayered soil displacement mechanisms is required to investigate with a combined suitable method.

To assess multilayered soil nonlinear displacement and consider the effect of different soil types in multilayered soil arrangement three efficient multilayered soil modeled and numerically subjected to the seismic loading using ABAQUS software. Each soil layer was simulated with equal geometry and different soil layer arrangement is made at all configuration. The multilayered soil has a modeled basis on the interaction between two surfaces which is provided by ABAQUS. In the modeling, for each node, the boundary condition has been introduced and appropriate constraints to all elements and nodes were applied. This kind of boundary condition improves the quality of the numerical analysis. The hexahedral mesh with a 500 mm size was selected in the numerical simulation. The soil foundation's boundary condition included a rigid basis and multilayered soil laterally moveable. The multilayered soil could compressible in the horizontal and vertical directions. The equal seismic loading was applied to the multilayered soil model.

According to Table 1, the mechanical properties of soil have been obtained from those reported in the literature. The mechanical properties for soil "A" are the elastic modulus of 24 MPa, the Poisson's ratio of 0.2, the maximum dry unit weight of 18.5 (kN/m^3), the cohesion of 17 (MPa), highest friction angle of 40 (degree) and dilatancy angle of 2 (degree) [24]. The mechanical properties for soil "B" are the elastic modulus of 80 MPa, the Poisson's ratio of 0.3, the maximum dry unit weight of 17.2 (kN/m^3), the cohesion of 1 (MPa), highest friction angle of 44 (degree) and dilatancy angle of 11 (degree) [25]. The mechanical properties for soil "C" are the elastic modulus of 20 MPa, the Poisson's ratio of 0.3, the maximum dry unit weight of 18.5 (kN/m^3), the cohesion of 3 (MPa), highest friction angle of 30 (degree) and dilatancy angle of zero (degree) [26].

The magnitude of the load has been applied concerning realistic earthquake loading and the Fast Fourier Transform (FFT) filtering method applied to enhancement acceleration history, velocity, and displacement for improving the accuracy of the numerical analysis. The characteristics of near-field ground mention are as flowing.

Figure 1a is shown the earthquake data that has been used from, United States Geological Survey (USGS) Center for engineering strong motion data (CESMD), which is available at, the Earthquake Engineering Online Archive, NISEE e-Library. The earthquake data is used, from those recorded at Amatrice station and Forca canape stations. The magnitude of Norcia earthquake is 6.2 and 6.6 for Amatrice and Forca canapine stations recorded, respectively [27]. After applied the Fast Fourier Transform (FFT) filtering method on the whole earthquake data and eliminating noise, the earthquake data have been used in numerical simulation. The smoothing earthquake data enhances the results of the numerical simulation accuracy. Figure 1b, c are shown the Fast Fourier Transform (FFT) filtering method applied on some parts of the earthquake data of those recorded at Amatrice station and Forca canapine station. To compare the results of the numerical simulation, two near-field ground mentions are selected. The seismic response of multilayered soil is interpreted using statistical analysis and modeling, based on the results of the numerical simulation. The statistical model and analysis support minimizing using the number of near-field ground mentions in the numerical simulation. On other hand, this study has been modeled based on the ground motion acceleration impact on multilayered soil.

In the present study, the numerical analysis is carried out by the application of a finite element analysis software namely ABAQUS. The rectangular elements are used to discretize the problem domain. Figure 2 shows the single and multilayer soil models. The developed models simulate multilayered soil interaction. The dimensions of models 1, 2, and 3 are 6 (m) thickness * 20 (m) width * 20 (m) length, models 1, 2, and 3 content of one soil layer. The dimensions of models 4 and 5 are 2 (layers) * 3 (m) = 6 (m) thickness * 20 (m) width * 20 (m) length. Models 4 and 5 are the content of two types of soil layers. The dimensions of models 6 and 7 are 3 (layers) * 2 (m) = 6 (m) thickness * 20 (m) width * 20 (m) length. Models 6 and 7 content of three types of soil layers. The geometry of the models illustrated in Table 2

Table 1 Mechanical properties of the materials [24–26]

Type of material	Modulus elasticity, E (MPa)	Poisson's ratio, ν	Unit weight, γ (kN/m^3)	Cohesion, C (MPa)	Friction angle, ϕ (°)	Dilatancy angle, ψ (°)	References
Soil—A	24	0.2	18.5	17	40	2	[24]
Soil—B	80	0.3	17.2	1	44	11	[25]
Soil—C	20	0.3	18.5	3	30	0	[26]

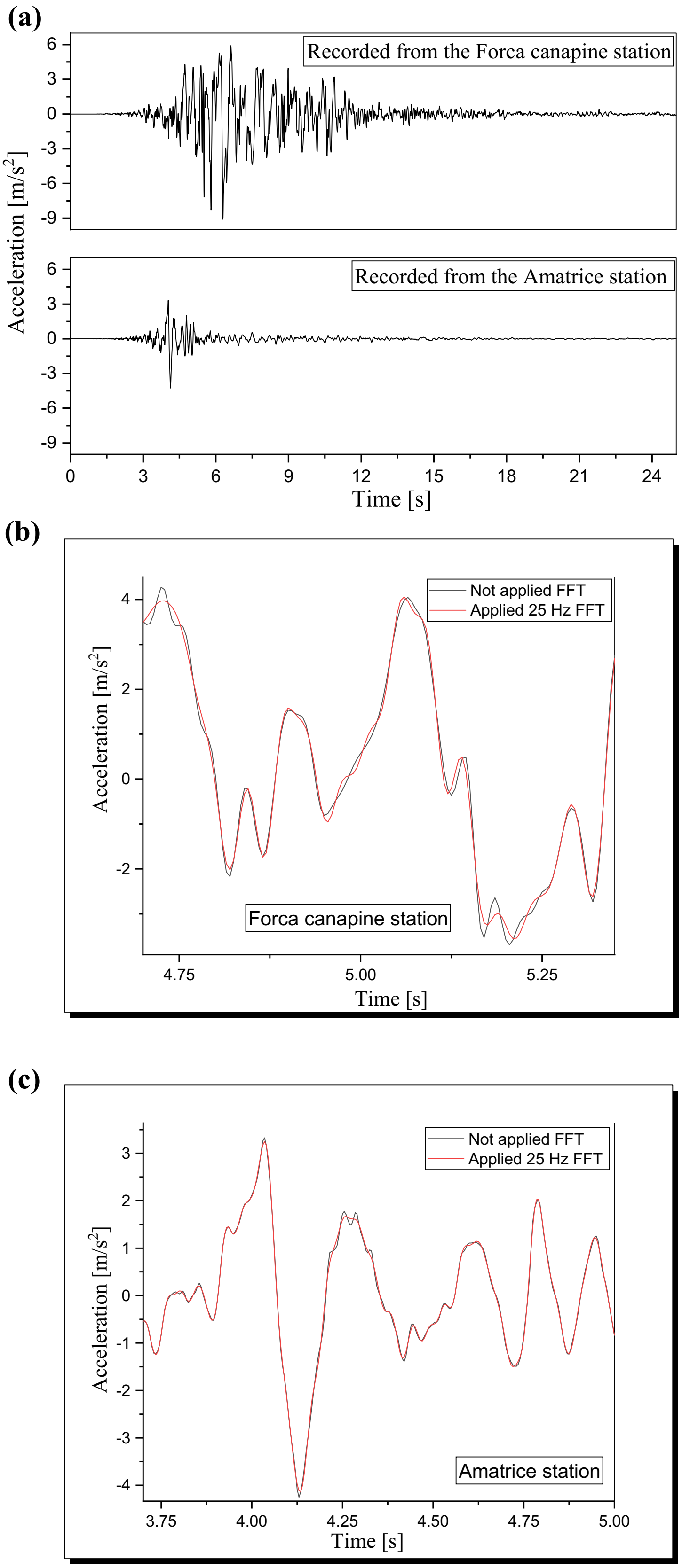

Fig. 1 **a** Acceleration history of Norcia, Italy earthquake [27]. **b** Acceleration history of Norcia, Italy earthquake after applied FFT filtering method. **c** Acceleration history of Norcia, Italy earthquake after applied FFT filtering method

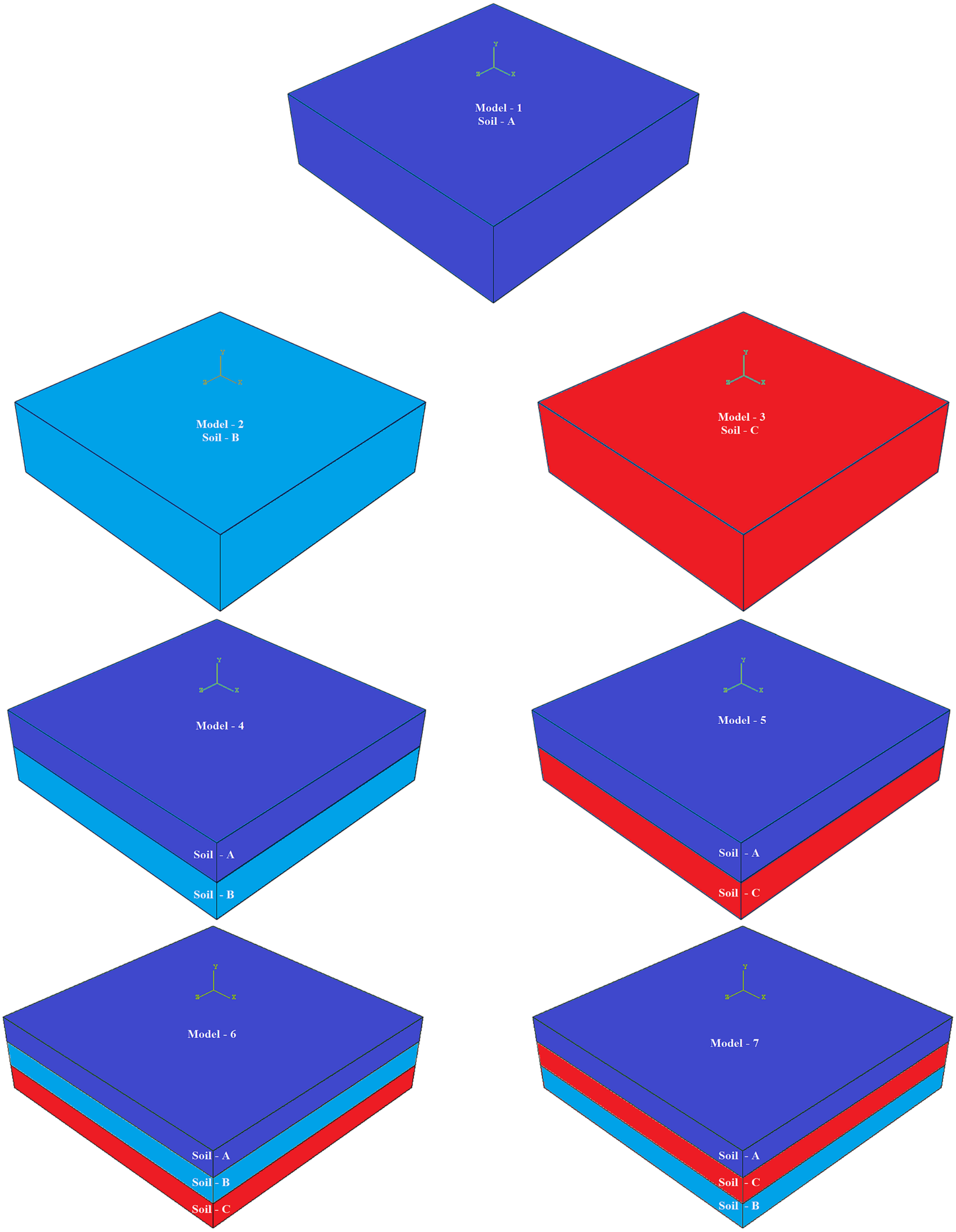

Fig. 2 Models are used in numerical simulation

and Fig. 2. The probability concept, which is a supportive technique from mathematics science, is applied to assessing the precision possibility of differential displacement occurrence through the linear regression model based on the built-up mathematical operational. The mathematical theory of random variation and the conceptual population is applied in the statistical analysis. Figure 3 illustrates the numerical simulation process

Table 2 The models are made from different soils

Model number	Soil layers arrangement	Soil layer thickness	Soil layer width	Soil layer length
Model 1	A	1*6 m	20 m	20 m
Model 2	B	1*6 m	20 m	20 m
Model 3	C	1*6 m	20 m	20 m
Model 4	A+B	2*3=6 m	20 m	20 m
Model 5	A+C	2*3=6 m	20 m	20 m
Model 6	A+B+C	3*2=6 m	20 m	20 m
Model 7	A+C+B	3*2=6 m	20 m	20 m

A=Soil type 1, B=Soil type 2 and C=Soil type 3

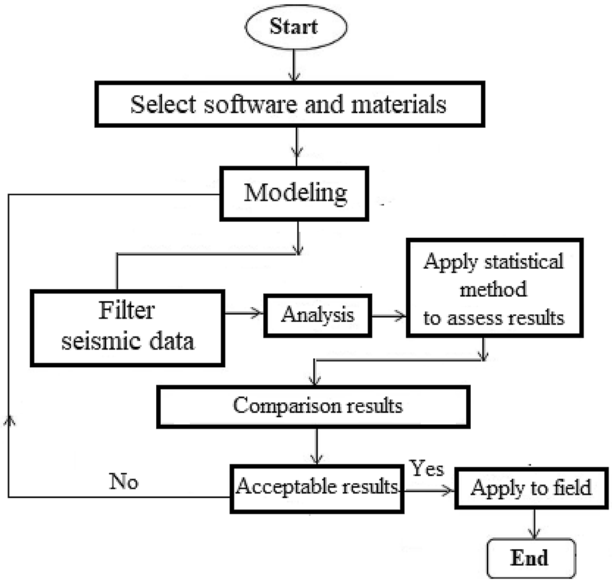

Fig. 3 The flow chart had shown the modeling and results verification

through the flow chart. The investigation on multilayered soil displacement mechanisms is illustrated according to Fig. 3.

2.1 Theoretical concept applied in methodology

In considering principal virtual work for the static problem,

$$\delta' W = 0 \tag{1}$$

Principal virtual work for the dynamical problem,

$$\delta \int_{t_1}^{t_2} T dt + \int_{t_1}^{t_2} \delta' W dt = 0, \tag{2}$$

In small displacement theory the strain-displacement relationship is given as follows [28]:

$$\varepsilon_x = \frac{\partial u}{\partial x}, \tag{3}$$

$$\varepsilon_y = \frac{\partial v}{\partial y}, \tag{4}$$

$$\varepsilon_z = \frac{\partial w}{\partial z} \tag{5}$$

$$\gamma_{yz} = \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z} \tag{6}$$

$$\gamma_{zx} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \tag{7}$$

$$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}. \tag{8}$$

In the present study, the above fundamental theoretical concept is used for the creation of nonlinear displacement from strain energy.

The stress-strain relationship can be written as following equations [28], in this research work, assume the soil is isotropic material.

$$\sigma_x = 2G\left[\varepsilon_x + \frac{v}{1-2v}\left(\varepsilon_x + \varepsilon_y + \varepsilon_z\right)\right] \tag{9}$$

$$\tau_{yz} = G\gamma_{yz} \tag{10}$$

$$\sigma_y = 2G\left[\varepsilon_y + \frac{v}{1-2v}\left(\varepsilon_x + \varepsilon_y + \varepsilon_z\right)\right] \tag{11}$$

$$\tau_{zx} = G\gamma_{zx} \tag{12}$$

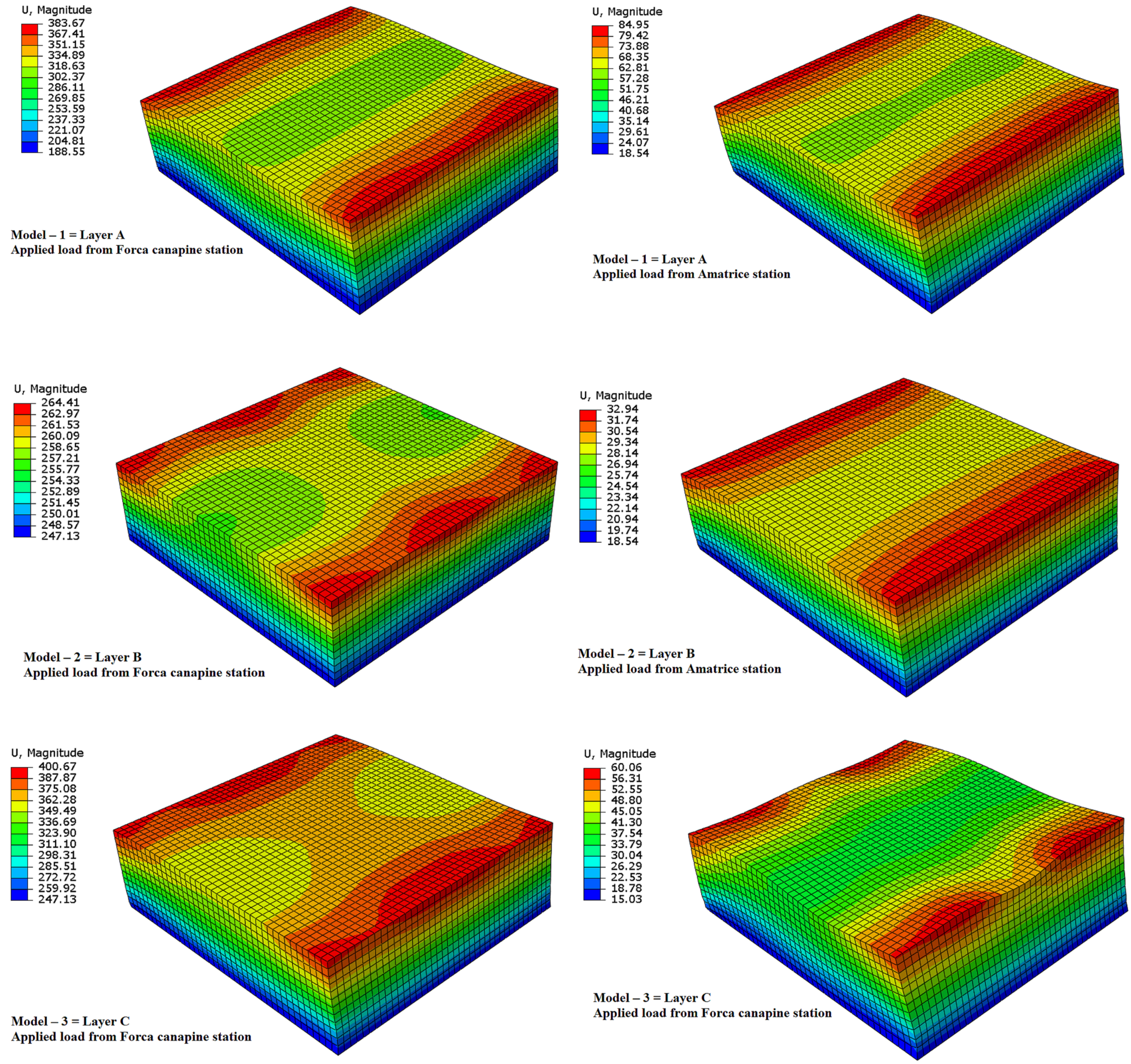

Fig. 4 The displacement of single-layer soil models

$$\sigma_z = 2G\left[\varepsilon_z + \frac{\nu}{1-2\nu}\left(\varepsilon_x + \varepsilon_y + \varepsilon_z\right)\right] \tag{13}$$

$$\tau_{xy} = G\gamma_{xy} \tag{14}$$

2.2 Simulation analysis results

To study the soil's displacement mechanism, the numerical simulation was made in several stages on soil with the configuration of a single layer, two layers, and three layers. Figure 4 shows the highest level of displacement that has occurred in models 1, 2, and 3. At the selected stage of the numerical simulation, these models are made of a single soil layer. The selected stage of the numerical simulation is made based on the maximum occurrence of displacement to the soil model. The Amatrice earthquake and Forca canapine with 6.2 and 6.6 magnitudes are applied to the models, respectively. The earthquake with 6.6 magnitudes and the earthquake with 6.2 magnitudes have two different vibration mechanisms, leading to a specific displacement at each earthquake. Model 2 built up from the single soil layer B, this model shows higher resistance in displacement during seismic load applied to the model, while

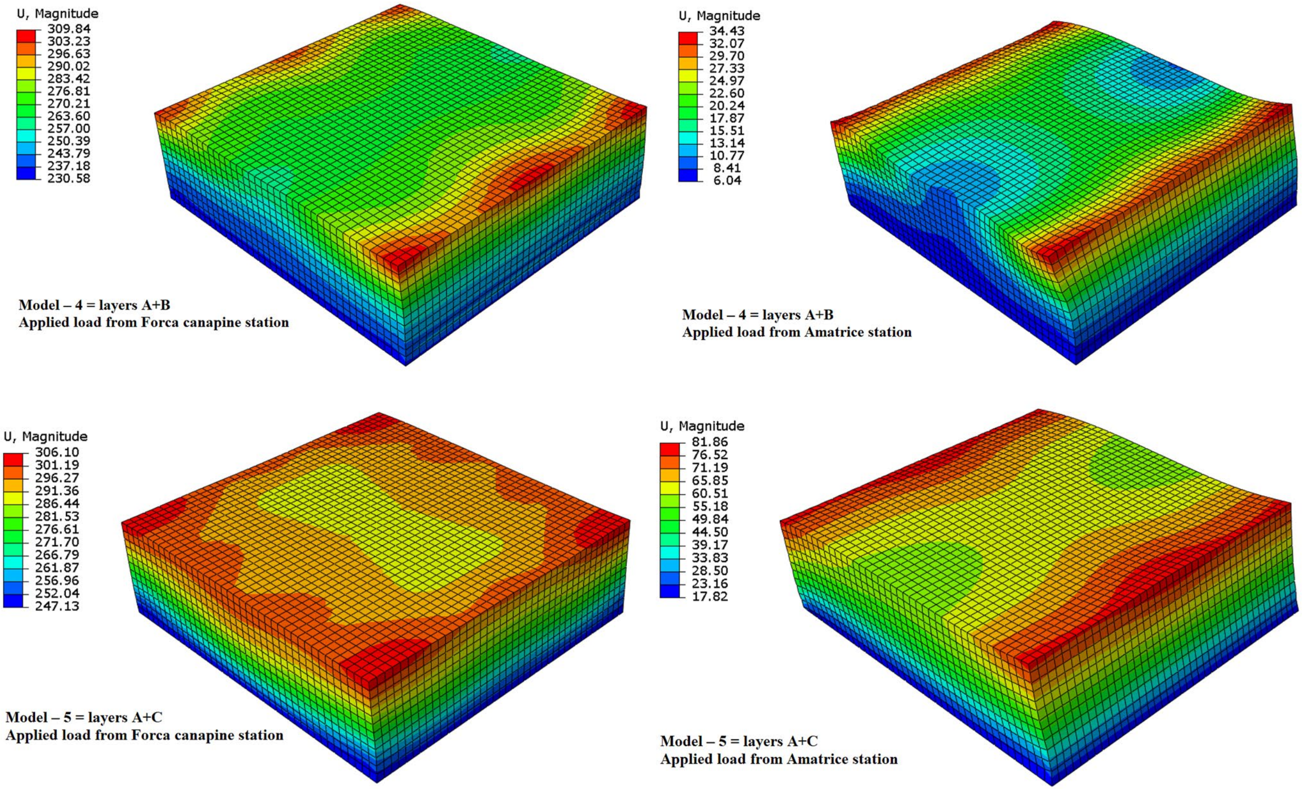

Fig. 5 The displacement for two layered soils models

models 1 and 3 exhibits higher displacement. The maximum differential displacement occurs in models 1 and 3, and lower differential displacement occurs in model 2. The maximum differential displacement and maximum level of displacement in the soil model are associated with the soil's mechanical properties. The modulus elasticity of soil B plays an important role in the displacement mechanism. The internal friction angle of the soil support minimizing displacement in model 2. An earthquake with a stronger magnitude causes a reduction of the differential displacement, and a lower earthquake magnitude develops more differential displacement.

Figure 5 shows the highest-level of displacement that has occurred in models 4 and 5; these models are made of the two soil layers. The Amatrice earthquake and Forca canapine with 6.2 and 6.6 are applied to the models, respectively. The mechanism of soil layers interaction at multilayered soil differential displacement was analyzed. Model 4 was built up from the soil layers A+B, and model 5 built up from the soil layers A+C. In the model, 4 higher differential displacement occurred and compared with model 5, in the higher stage of selecting the numerical simulation. While concerning Fig. 8, it has been understood that in considering all stages of the numerical simulation and using the statistical model in analyzing the differential displacement, the mechanical properties of soil layer B, controlled the differential displacement. However, in the interpretation of the numerical simulation, all stages of the numerical simulation are essential.

Figure 6 shows the highest-level of displacement that was occurred in models 6 and 7; these models are made of the three soil layers. The Amatrice earthquake and Forca canapine with 6.2 and 6.6 are applied to the models, respectively. The presented method supports solving a complex multilayered soil design. It was observed the nature of seismic loading has a significant influence on using the type of soil in minimizing displacement. Model 6 built up from the soil layers A+B+C, and model 7 built up from the soil layers A+C+B. When the seismic data were applied in the numerical simulation, all stage of recorded displacements are require for statistical modeling to interpret differential displacement of the model.

Referring to Fig. 9, it has been realized in analysis the differential displacement of the soil model, considering all numerical simulation stages are required. However, using the statistical model in analysis the differential displacement, enhances engineering judgment quality in the seismic design of the soil foundation. In models 6 and 7 with three soil layers, models 5 and 4 with two soil layers, and models 1, 2, and 3 with a single soil layer, the mechanical

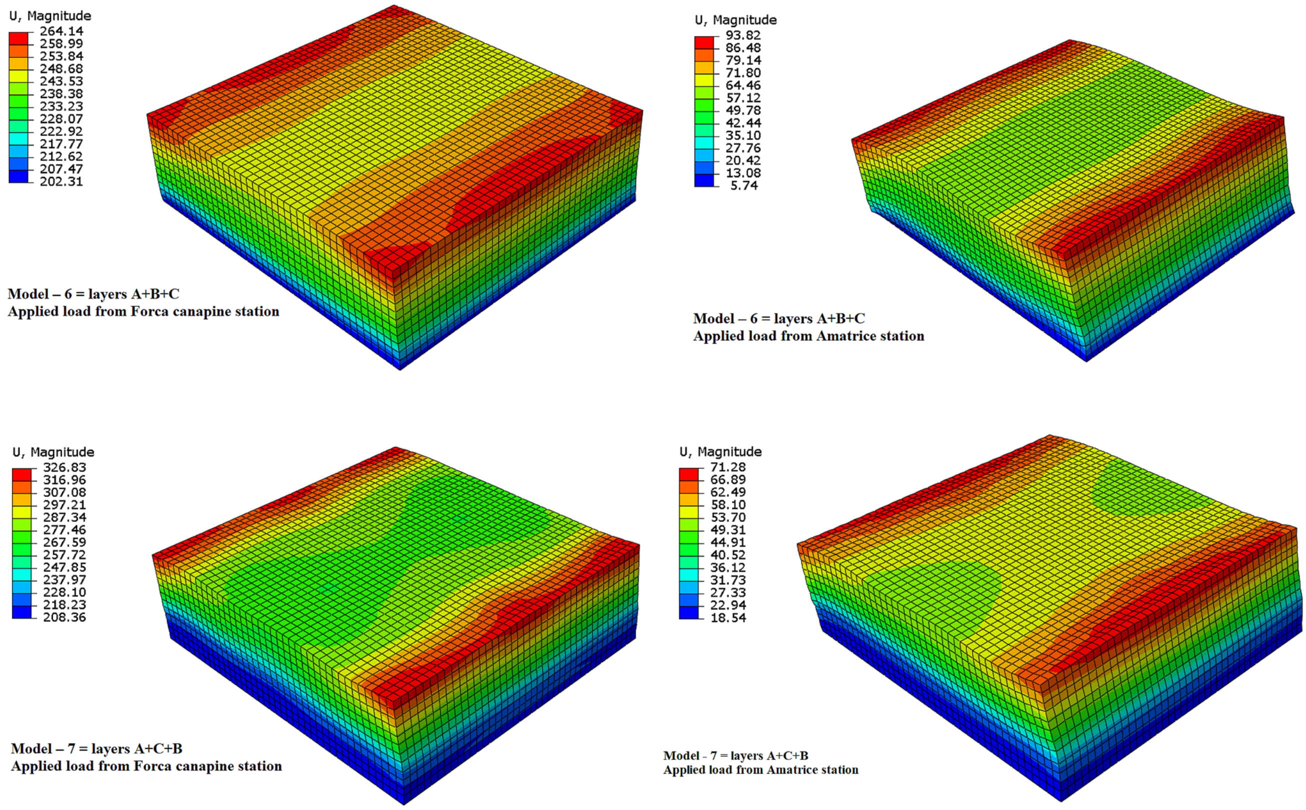

Fig. 6 The displacement for three layered soils models

properties of the soil layer B are associated with the nature of the seismic loading were controlled the differential displacement mechanism. Comparing the numerical simulation results with the results of statistical models, it integrates the engineering judgment for built up a safe and economic soil foundation.

A set of differential displacements were developed due to the nature of the seismic loading during the loading-unloading-reloading process, this phenomenon explains the seismic stability of the soil foundation. However, to explain the entire nonlinear displacements mechanism of the model in the numerical simulation process, the linear regression model was used to illustrate the differential displacement of each model. Figures 4, 5, 6, 7, 8 and 9 show that the maximum differential displacement was reduced in single soil layers and multilayered soil when soil B was used in the model. This phenomenon shows the soil's mechanical properties are important in controlling differential displacement and maximum displacement of the soil model. On the other hand, in the multilayered soil model, the soil's mechanical properties in associate with the nature of the seismic loading that produces the vibration mechanism of the soil model. The mechanical properties of soils, the soil layer arrangement, and soil layer interaction are controlling the excitation strain energy at each archetype. The displacement patterns change associate with the soil's mechanical properties, the number of soil layers, the location of soil arrangement, and the type of seismic loading. The excitation strain energy is associated with a multilayered soil arrangement. According to Figures 4, 5, 6, 7, 8 and 9, it has been found that each model has a specific seismic excitation mechanism. The physiognomies of seismic wave propagation manage the stiffness and strength of the soil mass. The seismic loading reaction accelerates excitation strain energy and leads to develops complex stress paths and results in irregular soil layers interaction at each simulated model. The suitable multilayer soil arrangement design enhances the deformation resistance of the model. The higher excitation strain energy leads to a higher variation of irregular cyclic loading during the reversal of stress. This phenomenon allows the displacement and flexibility of soil to increase. The linear regression model was provided the accuracy of the numerical simulation, and brief results of the statistical model are presented in Table 3.

An explanation of the displacement because of the soil model's 1–7 vibration is presented in Figs. 7, 8 and 9. The R^2 and RMSE are based on the differential displacement

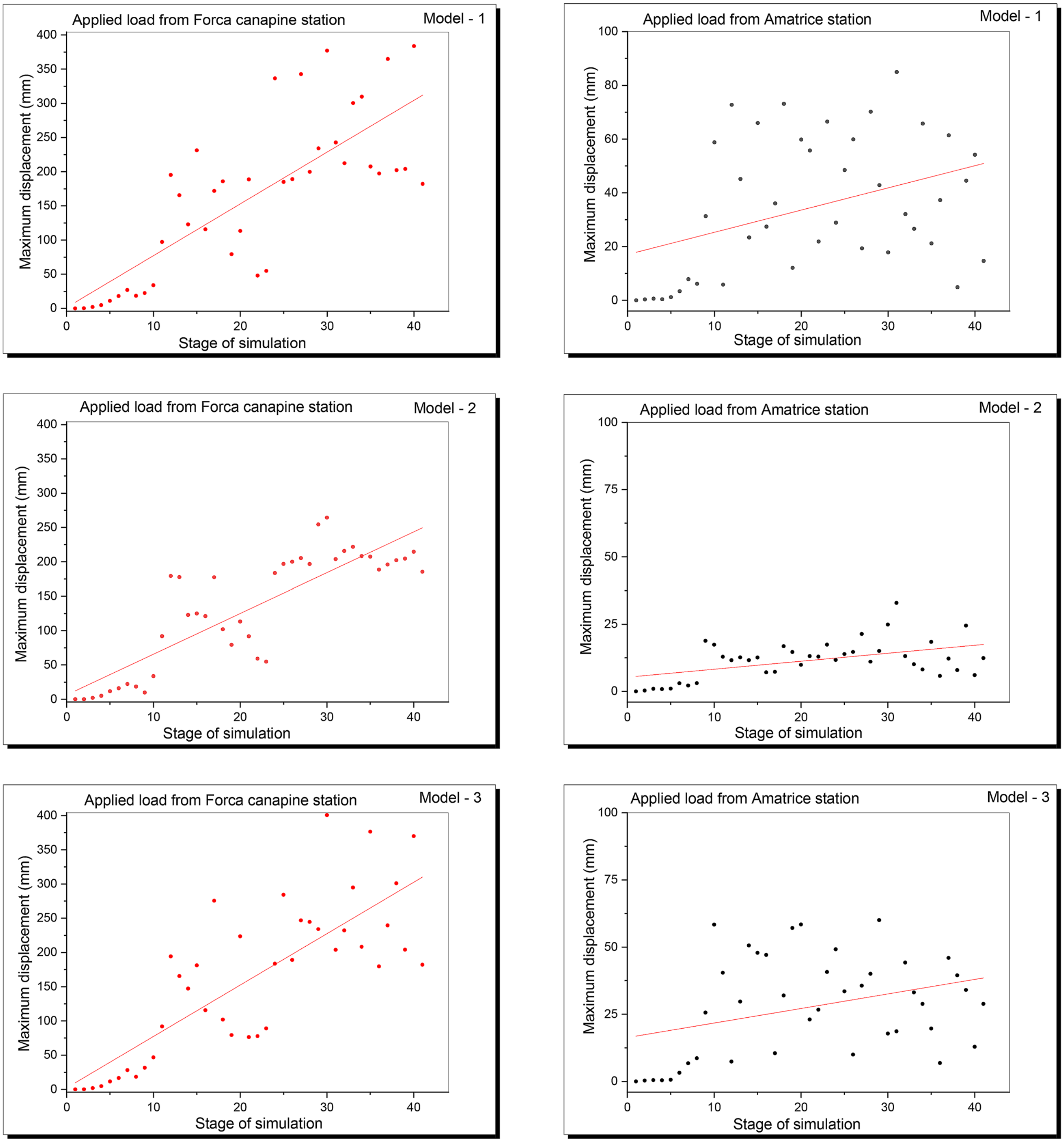

Fig. 7 The all displacement in model with single soil layer

mechanism present in table 3. When the seismic data were recorded by Forca canapine station used in the numerical simulation, it finds the R^2 with a suitable fit. In the single-layer soil model, the R^2 and RMSE of 0.71 and 45.58 are for model 2. And In the two layers of the soil model, the R^2 and RMSE of 0.73 and 53.54 are for model 4. And In the three layers of the soil model, the R^2 and RMSE of 0.70 and 49.35 are for model 6. However, the statistical model shows, using soil B minimizing the differential displacement. When the Amatrice station recorded the seismic data was used in the numerical simulation, it finds the R^2 has a lower fit compared to when the seismic data were recorded by Forca

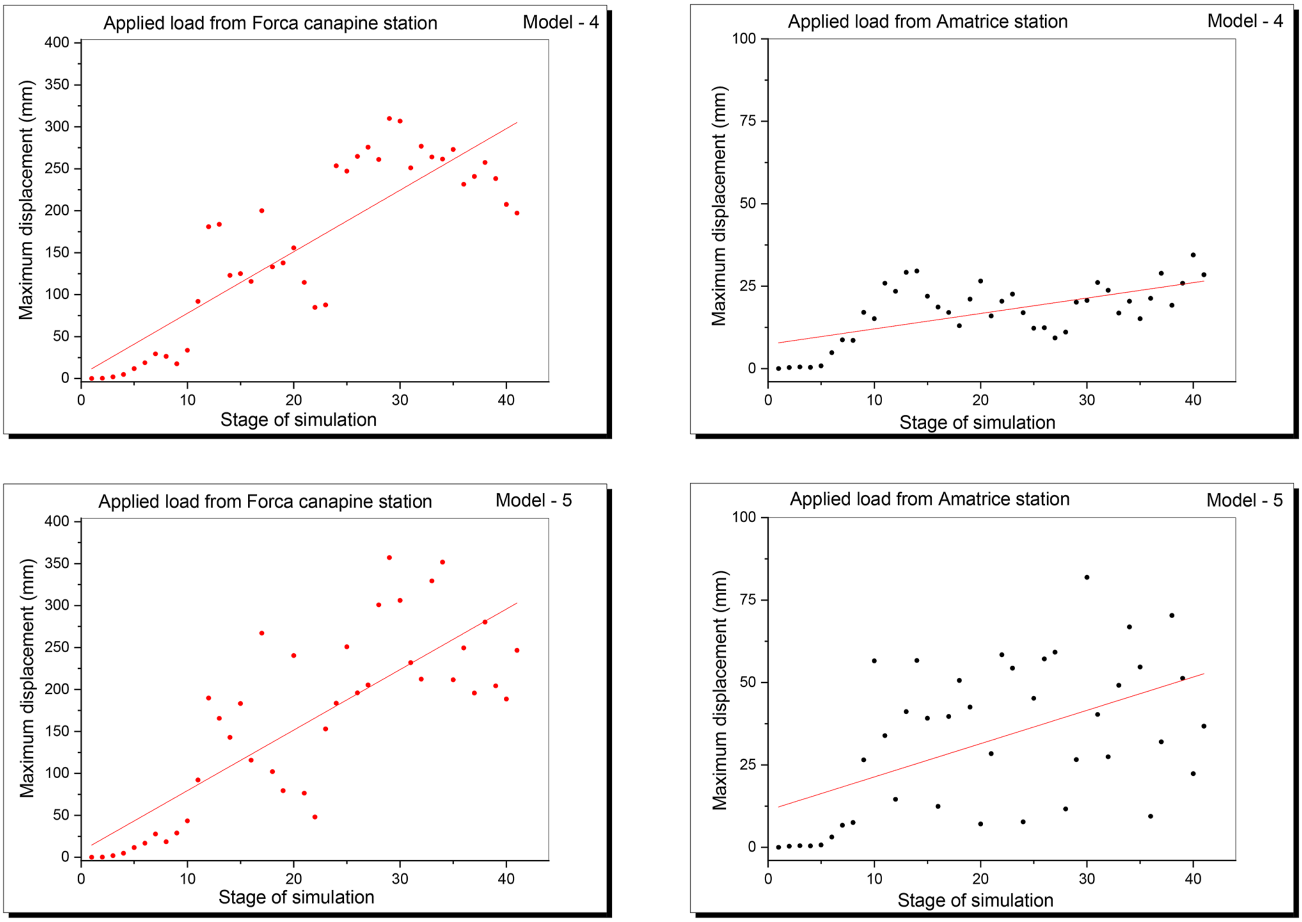

Fig. 8 The all displacement in model with two soil layers

canapine station used in the numerical simulation. In the single-layer soil model, the R^2 and RMSE of 0.24 and 6.4 are for model 2. And In the two layers of the soil model, the R^2 and RMSE of 0.38 and 7.2 are for model 4. And In the three layers of the soil model, the R^2 and RMSE of 0.41 and 22.77 are for model 6. However, the statistical model shows, using soil B minimizing the differential displacement.

Figures 10, 11 and 12 show the prediction of the maximum displacement in the single-layer soil model, two layered soil model, and three layered soil model, based on the results of the numerical simulation and occurrence of the maximum displacement in all stages. According to the calculated value of the displacement by the numerical simulation, the expected displacement is illustrated in Figs. 10, 11 and 12. The mu and sigma were obtained for all models indicate that the R^2 and RMSE were obtained from the statistical model agree with prediction differential displacement. In the single-layer model, model 1 made of soil B has lower differential displacement. In the two layers and three-layered soil models also soil B governs the differential displacement mechanism.

3 Discussion

In the model with the single layer, the maximum differential displacement and displacement are associated with the mechanical properties of the soil. The nature of seismic loading governs the displacement mechanism. In seismic design, it can suggest for prediction of displacement mechanism of soil, it needs to make decisions based on the several seismic loadings were applied on the soil by using statistical analysis. The three-layered soil reacts such as a composite cross-section. The numerical simulation was indicated the suitable model significantly mitigates differential displacement of the model. The soil layer nonlinear seismic load response develops differential displacement and soil multilayered complex interaction influence the soil model's displacement mechanism.

In the statistical model using the linear regression analysis, when the seismic data was recorded by the Amatrice used in the numerical simulation, the R^2 had a lower fit than when the seismic data were recorded Forca canape

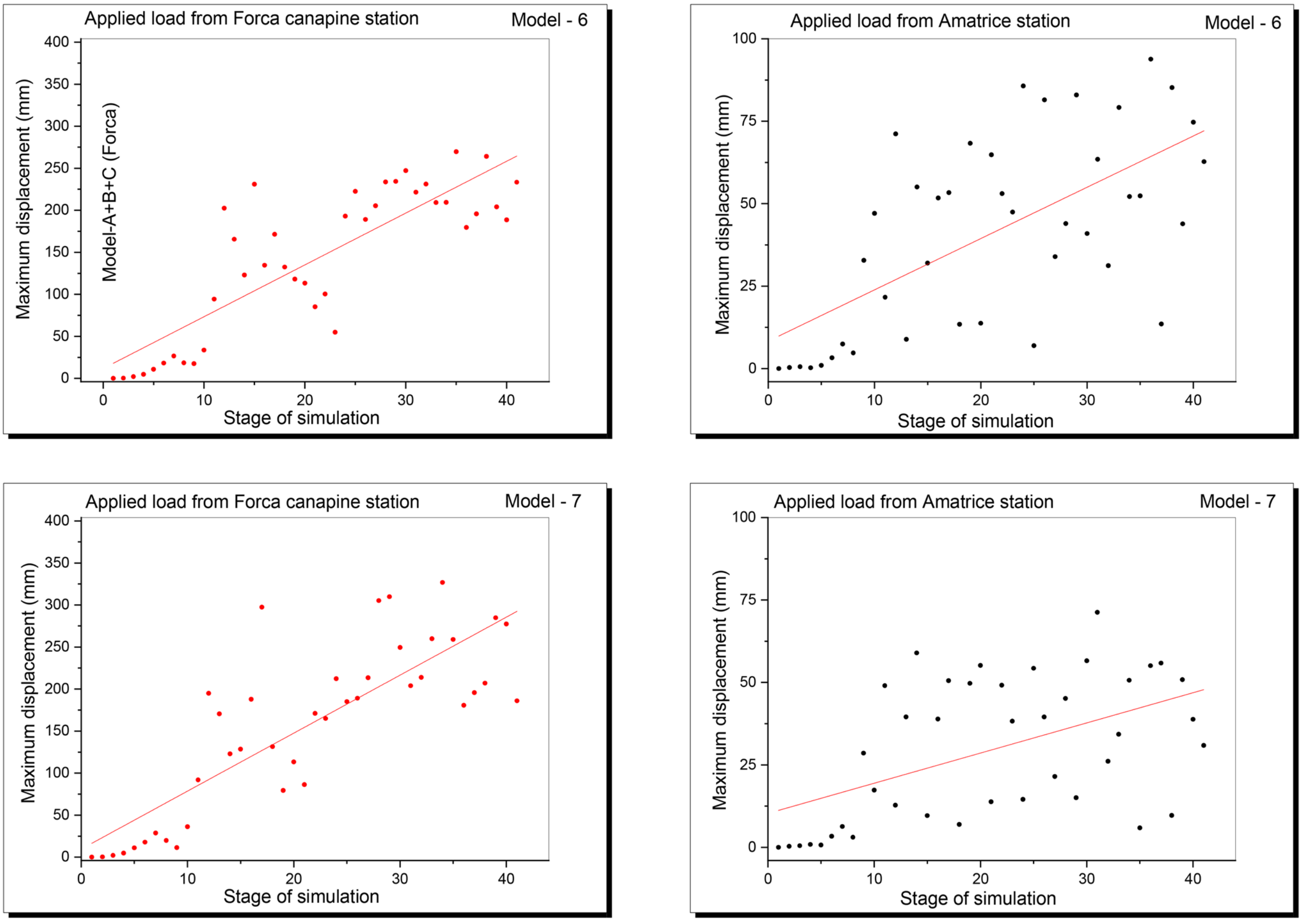

Fig. 9 The all displacement in the model with three soil layers

Table 3 The R^2 and RMSE for displacement analysis

Stations	Statistical results	Model—1 Soil A	Model—2 Soil B	Model—3 Soil C	Model—4 Soil A+B	Model -5 Soil A+C	Model—6 Soil A+B+C	Model—7 Soil A+C+B
Forca canapine	R^2	0.62	0.71	0.64	0.73	0.64	0.70	0.68
	RMSE	72.48	45.58	68.49	53.54	66.11	49.35	57.83
Amatrice	R^2	0.15	0.24	0.12	0.38	0.28	0.41	0.26
	RMSE	23.62	6.4	17.83	7.2	19.78	22.77	18.66

station used in the numerical simulation. It can understand, the higher fit in R^2 in the statistical model means the reduction of differential displacement. The R^2 fit in this study is presented the nonlinear displacement seismic response of the multilayered soil. The higher fit represented lower nonlinear displacement, this is a novelty concept in apply statistical modeling based on the ground motion acceleration impact on multilayered soil. However, the statistical model verified, using soil B minimizing the differential displacement. The verification of reduction of differential displacement by the statistical model is new achievement support using the numerical simulation in geotechnical earthquake design with a high level of accuracy and also the statistical model used in the present study enhances differential displacement prediction.

A realistic ground motion for a soil layered design is required to simulate a complex nonlinear displacement mechanism related to the strength and stiffness of the model. From the displacement mechanism, the potential level of earthquake damage is predictable. The displacement mechanism behavior of each model is associated with soil layer interaction. However, displacement

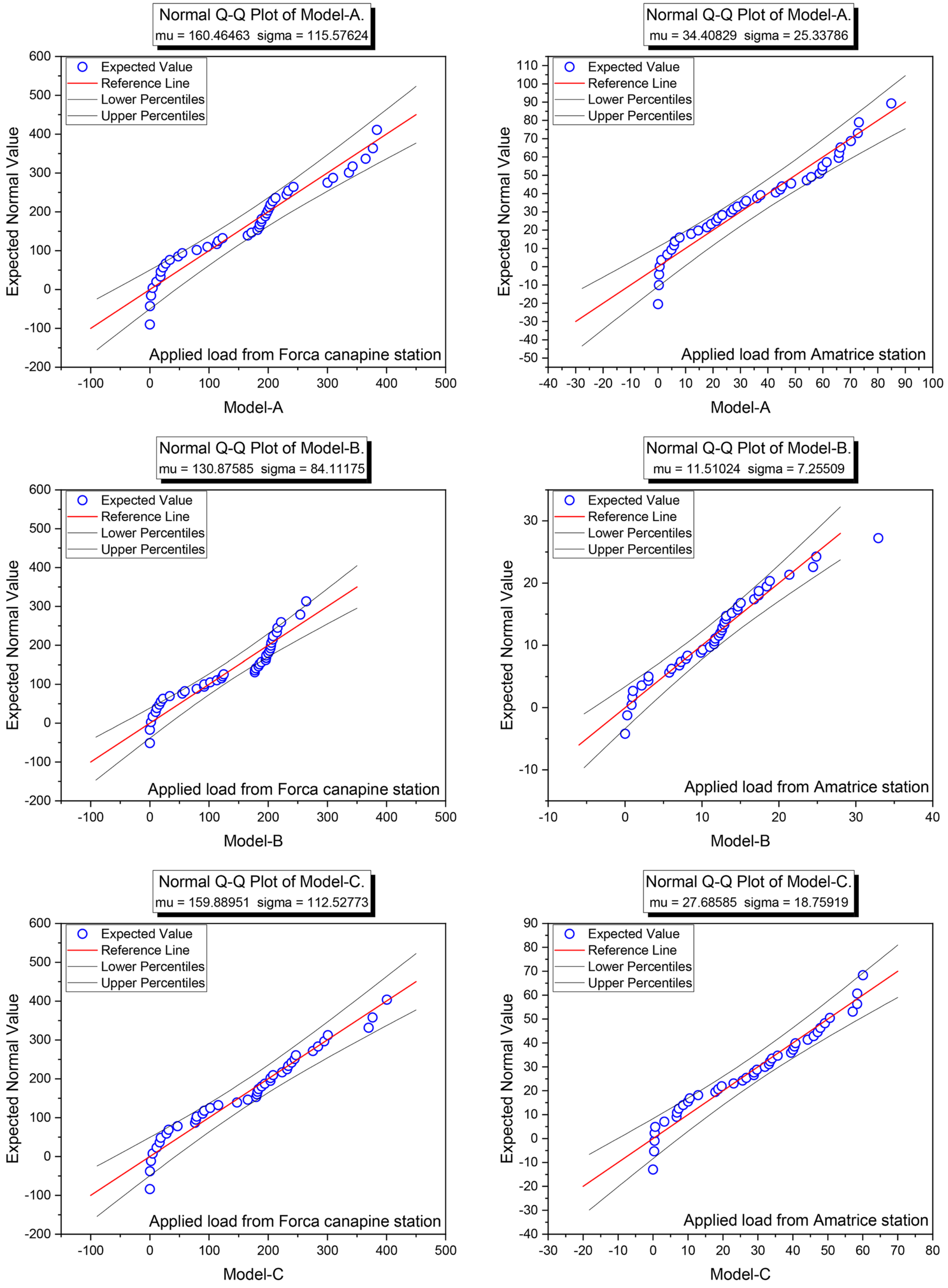

Fig. 10 Prediction displacement in the single-layer soil model, models 1, 2 and 3

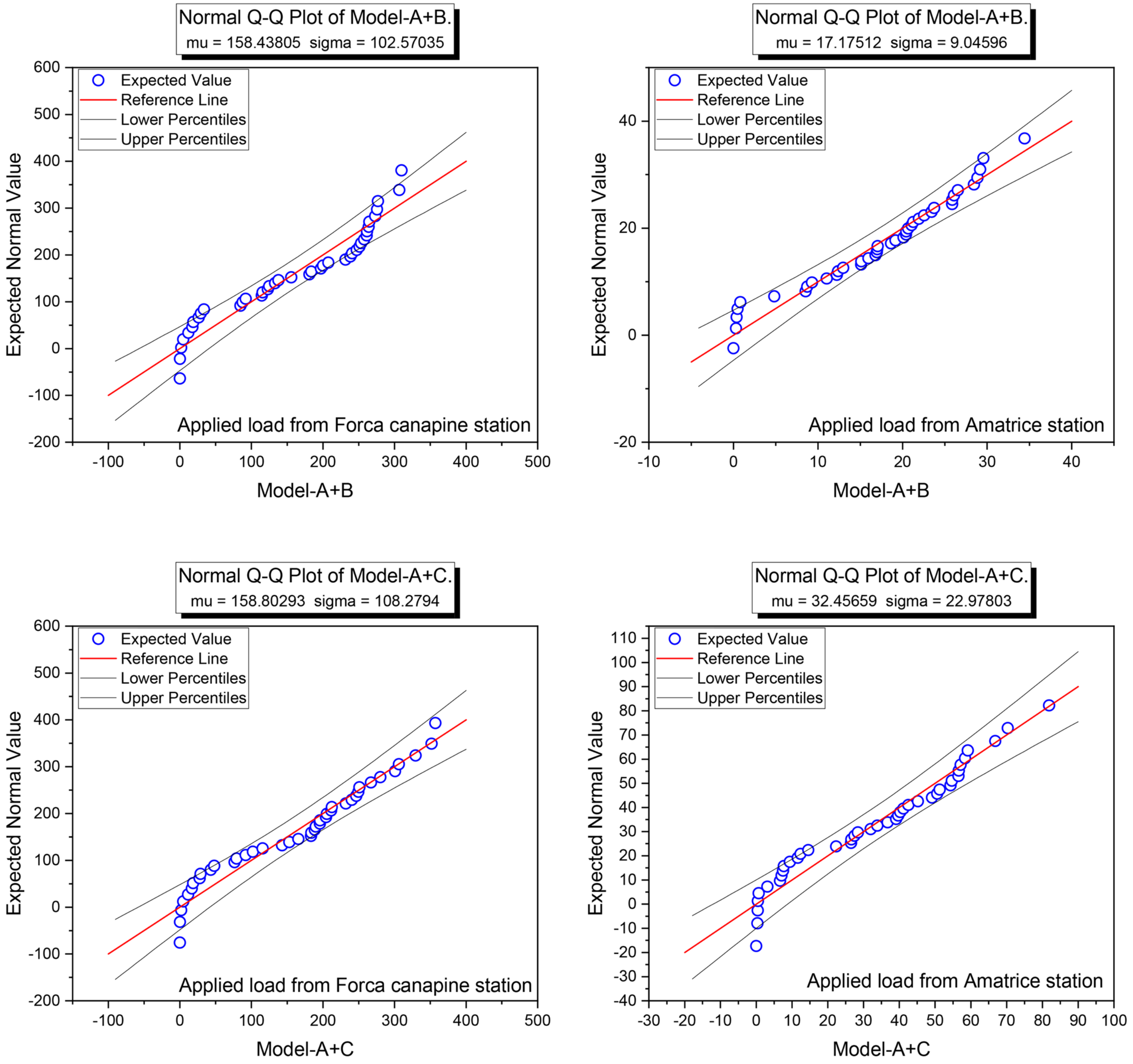

Fig. 11 Prediction displacement in two layers of the soil model models 4 and 5

mitigation is possible with a suitable layer arrangement. The soil exhibits complex nonlinear and inelastic under cyclic loading of the strong ground motion, and it causes failure, and failure defines in terms of critical displacement, and it associates with the cyclic strength and stiffness of the soil model.

The mechanical properties of soil can control dynamic wave propagation. And mechanical properties of the soil in any depth of the subsoil is responsible for natural hazard such as liquefaction [13]. The following research outcome support geotechnical engineering design. And present research work was integrated previous research outcomes. Which was used numerical simulation in displacement simulation of soil, using ABAQUS software [29].

4 Conclusion and research requirement

The numerical simulation was performed to study the nonlinear displacement and maximum displacement of the single and multilayered soil models. The Fast Fourier

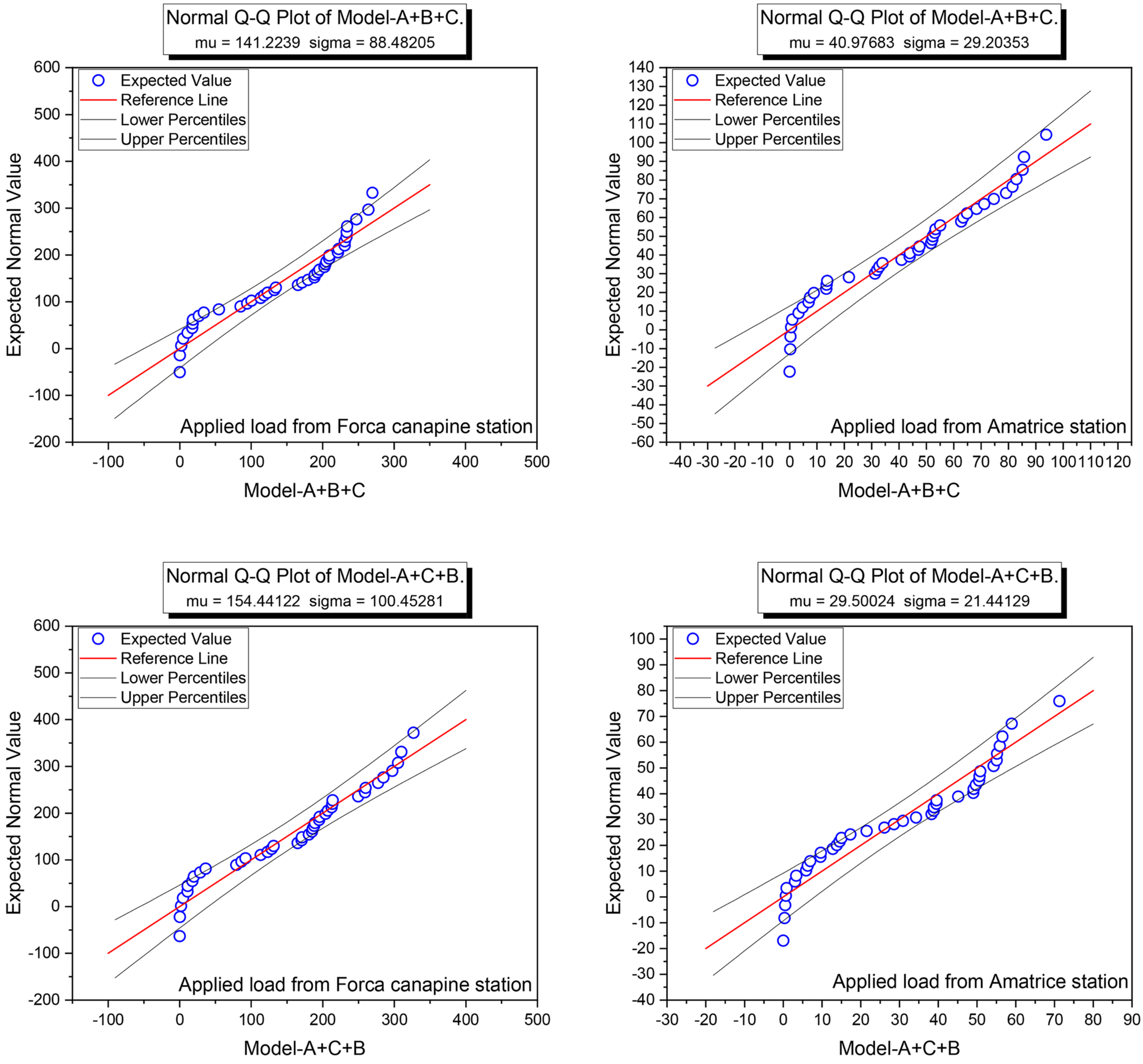

Fig. 12 Prediction displacement in three layers of the soil model models 6 and 7

Transform (FFT) filtering was applied on ground acceleration to improve the quality of numerical simulation results. The statistical model was applied to verify the results of the numerical simulation. The soil's mechanical properties, the number of soil layers, the location of soil arrangement, the type of seismic loading, and seismic loading accuracy become model parameters.

The soil layer arrangement controls the nonlinear displacement mechanism. The multilayered soil interaction results in minimization nonlinear displacement. The soil layer interaction minimizes the intensity of seismic loading. To reduce damage was caused by an earthquake, the presented method is cost-effective. This investigation appropriately was simulated soil layers' design to enhance the cyclic shear strength of a soil foundation. To predict nonlinear displacement in geotechnical earthquake engineering, statistical models support engineering decision-making. The novelty of the work included the construction method for improving seismic stability of the multilayered soil through soil layers interaction mechanism. The higher fit represented lower nonlinear displacement, this is a novelty concept in apply statistical modeling based on the ground motion acceleration impact on multilayered soil.

Future research will focus on applying the presented method for the earthquake-resistant design of various infrastructures and using various seismic data and statistical models.

The limitation of this work is the same as many seismic research works, ground acceleration of horizontal direction was applied on the model, while in the reality needs to apply multidirectional ground acceleration on the model.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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