Behavior of pile embedded in different soil types under the effect of earthquake

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Abstract. In the seismic areas, piles are often passed through shallow loose or soft soil deposits and rest on end bearing soils. Damages due to earthquakes in piles built in layered soils occurred close to interfaces separating layers with very different shear moduli. In this study 3D finite element analyses are performed to simulate a soil-pile system under earthquake excitation in different soil types. As an example, the soil profiles of active seismic zones in Iraq will be used. For this a data base was prepared for static and dynamic parameters of different Iraq soils which were gathered and typical profiles for north, middle and south of Iraq were established. The properties of soils were then used as input dynamic data for finite element program PLAXIS 3D 2013 to study the response of single pile foundation. As earthquake input data the recording one obtained from the April 20, 2012 earthquake which hit Ali Al-Gharbi in Missan Province in Iraq was used, because this was one of the influential earthquakes. As a result the maximum bending moment occurs at the influence of different soil layers, also according to the soil-pile interaction, the deflected shape have the same behavior of pile embedded in sand and clayey soil as well as the pile that embedded in two clayey soil layers with thin sandy layers in between.

Key words
pile behavior, earthquake, dynamic properties, and seismic zones.

1. Introduction
Many Post-earthquake reconnaissance works has shown that the settlement and tilting of piles-supported buildings in several cases causes pile damages. Pile damage had mostly happened where the soil conditions consisted of multi layers having different shear moduli. It is widely observed that piles are affected by both the kinematic bending moments induced by the surrounding soil and the movement of the superstructure (inertial forces). The building codes [1] and [2] describe pile design provisions that take in to account the combined effect of both mechanisms. One of the engineering challenges lies in the prediction of the maximum bending moment in the pile at an interface with a sharp stiffness contrast [3]. Predicting the behavior of piles and pile groups during earthquakes still remains a challenging task to geotechnical engineers. Therefore in the last decade it became very necessary to study the seismic behavior of piles in different active seismic zones around the world and also in Iraq. Therefore a database for all the soil parameters of Iraqi soils was collected. The geotechnical site investigations which had all the data required for Mohr- Coulomb model were chosen to be included into the above mentioned database. In addition the record for one of the strongest earthquake which hit Iraq in the latest years was chosen. For the analysis PLAXIS 3D 2013 program was used. Twenty models are simulated for five different seismic zones ('N' North, 'M' Middle, 'WS' Western south, 'ES' Eastern south and 'S' South) in Iraq. The variation of the bending moment and pile horizontal displacements, for the whole pile length is evaluated.
1.1 Aim of Study
In the present study, the geophysical investigations data for different seismic active zones in Iraq are collected to provide a database for the dynamic parameters of soils used together with actual earthquake data from the Iraq Seismological Network (ISN) records to simulate a typical model of soil-pile system to be analyzed by PLAXIS 3D 2013 program.

1.2 Literature Review
The available previous studies investigated the behavior of piles under earthquake action considering liquefaction of cohesionless soils or evaluating the kinematic bending moment for piles. Mokhtar et. al. (2014) investigated one of the most important causes of bridge failures due to the instability of pile accured by liquefaction of loose sand during earthquakes using the 3D finite element program DIANA 9.3[4]. Maiorano et. al., (2009) evaluated kinematic bending moments in single piles and pile groups. In order to perform dynamic analyses in the time domain Quasi 3D FE computer program had been used [5].

Some Iraqi researchers studied the dynamic soil-structure interaction behavior due to seismic activity considering acceleration-time data for earthquakes of other countries rather than Iraq. Al-Damluji and Al-Ani (2005) analyzed Baghdad tower for communications when subjected to earthquake excitation using an elasto-viscoplastic material modeling and (3D FEM) to examine the displacement response under (El-Centro, California, USA, May 1940) earthquake excitation. Other researchers simulate physical models of piles and studied the behavior of piles under the action of vibrating machine [6]. Dihoru et. al., (2010) studied the kinematic behavior of flexible piles in layered soil deposits under seismic excitation by applying a series of shaking table tests [7].

2. Database for Dynamic Soil Properties
The soil data used in this study is based on the collected geotechnical site investigation reports from engineering consulting bureaus of Baghdad, Al-Nahrain and Technology universities, also from National Center of Construction Laboratories and Research (NCCLR), and from many projects in Iraq. The reports were for projects of multi-story buildings, water treatment plants and pumping stations, electrical substations, oil refinery, stadiums and other projects from different locations in Iraq. The data has been grouped into five regions, based on the governorate, namely ('N' North, 'M' Middle, 'WS' Western south, 'ES' Eastern south and 'S' South). These zones are shown in figure (1). The various projects in each zone are listed in table (1).

Since in the Finite Element Analysis the Mohr-Coulomb model was considered to be used, care was taken that all the data necessary for the Mohr-Coulomb model in addition to the dynamic parameters used as input data in PLAXIS 3D 2013 program were available. All the parameters symbols with their standard units are listed in table (2). The complete data set of soils parameters are shown in table (3).
Figure 1. Seismic zones and projects locations in Iraq

| No. | Zone     | Site       | Project                                      | Site Symbol |
|-----|----------|------------|----------------------------------------------|-------------|
| 1   | North    | Kirkuk     | Kirkuk North Gas Company 1 June Depot        | N1          |
| 2   | Kirkuk   | Kirkuk     | Kirkuk Cement Factory                        | N2          |
| 3   | Kirkuk   | Kirkuk     | Kirkuk North Gas Company                     | N3          |
| 4   | Middle   | Baghdad    | Al Karkh Pumping Station                     | M1          |
| 5   | Baghdad  | Baghdad    | Al Zawra Stadium                             | M2          |
| 6   | Baghdad  | Baghdad    | Eiwa'n Al Madain                             | M3          |
| 7   | Baghdad  | Baghdad    | Al Taji Stadium                              | M4          |
| 8   | Baghdad  | Baghdad    | Al Qudus Gas Turbine Power Plant             | M5          |
| 9   | Babylon  | Babylon    | Hilla Power Plant                            | M6          |
| 10  | Western  | Karbala    | Karbala Cultural                             | WS1         |
| 11  | South    | Karbala    | Karbala Al Abbasia Sacred Shrine             | WS2         |
| 12  | Al Najaf | Al Najaf   | Al Najaf Al Salam Housing Complex            | WS3         |
| 13  | Eastern  | Missan     | Al Amarah Water Intake Depot                 | ES1         |
| 14  | South    | Missan     | Halfaya Oil Field                            | ES2         |
| 15  | Missan   | Missan     | Missan Oil Export Pipe Line                  | ES3         |
| 16  | South    | Al Dewaniya| Al Dewaniya Pumping Station                  | S1          |
| 17  | Al Nasiriya | Al Nasiriya| Al Nasiriya Oil Depot                        | S2          |
| 18  | Al Nasiriya | Al Nasiriya| Al Nasiriya Water Intake Refinery            | S3          |
| 19  | Al Basrah| Al Basrah  | Faw Depot Turbine                            | S4          |
| 20  | Al Basrah| Al Basrah  | Al Sheiba Oil Refinery                       | S5          |
Table 2. Parameters symbols and standard units

| Symbol | Meaning | Unit | Symbol | Meaning | Unit |
|--------|---------|------|--------|---------|------|
| E      | Young’s modulus | kN/m² | E_d   | Dynamic modulus of elasticity | kN/m² |
| v      | Poisson’s ratio | - | G_d   | Dynamic shear modulus | kN/m² |
| c      | Cohesion | kN/m² | V_s   | Shear wave velocity | m/s |
| φ      | Friction angle | ° | V_p   | Compression wave velocity | m/s |
| ψ      | Dilatancy angle | ° | γ_unsat | Unsaturated unit weight | kN/m³ |
| γ_sat  | Saturated unit weight | kN/m³ |

Table 3. Soil properties for different locations in Iraq

| No. | Site | Depth (m) | Soil Type | WT (m) | γ_wet (kN/m³) | γ_dry (kN/m³) | c (kN/m²) | φ (°) | V_p (m/s) | V_s (m/s) | E_d*10⁶ (kN/m²) | G_d*10⁶ (kN/m²) | ν |
|-----|------|-----------|-----------|--------|---------------|---------------|-----------|-------|-----------|-----------|----------------|----------------|----|
| 1   | N₁   | 0-10      | Very stiff to hard brown CLAY (CL) | 3.8    | 20.1          | 17             | 130       | 0     | 1250      | 312       | 585.43         | 199.53         | 0.467|
| 2   | N₂   | 0-2.5     | Stiff brown sandy SILT (ML) | >25    | 19            | 16.8           | 0         | 32    | 1125      | 225       | 290.15         | 98.09          | 0.479|
|     |      | 2.5-15    | Very stiff to hard brown lean to fatty CLAY (CL,CH) | 20.6   | 18.2          | 227            | 0         | 1250  | 321       | 634.86    | 216.38         | 0.467          |    |
|     |      | 15-20     | Very dense silty GRAVEL with SAND (GM) | 20.6   | 18.2          | 0              | 42        | 2500  | 476       | 1409.8    | 475.98         | 0.481          |    |
| 3   | N₃   | 0-10      | Stiff to very stiff brown lean or fat CLAY (CL,CH) | 2.58   | 21.0          | 18.1           | 120       | 0     | 1541      | 304       | 585.82         | 197.91         | 0.48 |
|     | 0-6  | Medium stiff to stiff brown fat CLAY (CH) | 0.63   | 19.8          | 15.8           | 50         | 0      | 641     | 189       | 209.16         | 72.13          | 0.45 |
|     | 6-12 | Very stiff brown lean CLAY (CL) | 19.0   | 14.5          | 100            | 0         | 675    | 248     | 338.44    | 119.17      | 0.42          |    |
|     | 12-15| Medium dense to dense clayey SAND to silty SAND with gravel | 19.0   | 15.0          | 0              | 37         | 750    | 225    | 284.46    | 98.09       | 0.45          |    |
| 5   | M₂   | 0-7       | Medium to hard brown lean to fat CLAY (CL,CH) | 2.3    | 19.6          | 15.8           | 60        | 3     | 914       | 276       | 441.56         | 152.26         | 0.45 |
|     | 7-9  | Very stiff grey sandy SILT (ML) | 20.6   | 17.1          | 0              | 34         | 687    | 195    | 233.25    | 79.88       | 0.46          |    |
|     | 9-14 | Stiff to Hard brown lean CLAY (CL) | 20.0   | 18.0          | 200            | 0         | 945    | 221    | 292.87    | 99.61       | 0.47          |    |
|     | 14-15| Medium to dense grey sandy SILT | 20.0   | 18.1          | 0              | 41         | 1014   | 327    | 628.09    | 218.09      | 0.44          |    |
| 6   | M₃   | 0-8.5     | Medium to hard brown lean to fat CLAY (CL, CH) | 3.86   | 20            | 16.3           | 35        | 0     | 454       | 161       | 151.00         | 52.8           | 0.428|
|     | 8.5-11| Very stiff brown SILT (ML) | 19.6   | 17            | 200            | 0         | 625    | 232    | 305.41    | 107.54      | 0.42          |    |
|     | 11-12| Very stiff brown CLAY (CH) | 19.6   | 17.2          | 240            | 0         | 1000   | 227    | 303.29    | 102.95      | 0.473         |    |
| 7   | M₄   | 0-7.5     | Stiff to very stiff brown lean to fat CLAY (CL-CH) | 2.2    | 19.8          | 17.1           | 65        | 10    | 841       | 165       | 162.7          | 54.97          | 0.48 |
|     | 7.5-12| Medium to very dense grey silty SAND (SM) | 19.0   | 16.5          | 0              | 38         | 1025   | 279    | 440.3     | 150.8       | 0.46          |    |
| 8   | M₅   | 0-1       | Brown to grey clayey silt to sandy silt with filling materials, organic to salts (ML) | 1.3    | 19.00         | 15.8           | 28.7     | 0     | 322       | 140       | 105           | 37.96          | 0.383|
|     | 1-15 | Brown to Grey Silty CLAY to Clayey Silt (ML,CL,CH) | 18.88  | 14.7          | 31.5           | 0         | 776    | 219    | 268.9     | 92.34       | 0.456         |    |
|     | 15-20| Grey Sand to silty or clayey SAND to Gravily SAND | 22.31  | 17.04         | 0              | 38         | 1544   | 408    | 1107.4    | 378.73      | 0.462         |    |
| 9   | M₆   | 0-2.4     | Grayish sandy silty CLAY soil, medium consistency | 1.5    | 16.18         | 14.5           | 144      | 0     | 306       | 111        | 57.9          | 20.33          | 0.424|
|     | 2.4-15| Grayish silty sand soil, medium dense | 18.44  | 16.5          | 0              | 38         | 450    | 183     | 176.33    | 62.98       | 0.4           |    |
| 10  | SW₁  | 0-0.5     | Dense white to yellow slightly to moderately gypseous silty SAND with gravel (SP,SM) | 0.8    | 18.8          | 18             | 0       | 37    | 1433      | 284       | 457.0          | 154.6          | 0.478|
|     | 4.5-12| Dense to very dense white to yellow SAND with silt (SP,SM) | 19.4   | 18            | 0              | 35         | 1733   | 550    | 1727.2    | 598.46      | 0.443         |    |
|     | 12-25| Very dense white to yellow SAND with silt to silty SAND (SP,SM) | 19.4   | 18            | 0              | 35         | 1650   | 563    | 1801      | 627.1       | 0.436         |    |
| 11  | SW₂  | 0-10.5    | Stiff brown silty to moderately gypseous fat CLAY (CH) | 1.5    | 18.5          | 14.7           | 100      | 0     | 1416      | 312       | 541.76         | 183.65         | 0.475|
|     | 10.5-14| Very loose to medium green to yellow marly SAND (SM) | 19     | 17.1          | 0              | 50         | 1474   | 289    | 479       | 161.83      | 0.48          |    |
| No. | Site | Depth (m) | Soil Type | WT (m) | \(\sigma_{ Holt}^e\) (kN/m²) | \(\sigma_{ O' la}^e\) (kN/m²) | c (kN/m²) | \(\phi^*\) (°) | \(V_p\) (m/s) | \(V_s\) (m/s) | \(E_s* 10^6\) (kN/m²) | \(G_s* 10^6\) (kN/m²) | v |
|-----|------|----------|-----------|--------|-----------------|-----------------|---------|-------------|----------|----------|-----------------|-----------------|---------|
| 12  | SW1  | 0-1-2    | Medium- dense light brown slightly gypseous silty SAND (SM) | 0.9    | 19.1           | 17               | 43      | 805         | 268      | 458.15   | 159.3           | 0.438           |         |
|     |      | 1.2-7    | Medium- dense to very dense light brown SAND (SP) |        | 19.5           | 18               | 40      | 1450        | 557      | 1743.5   | 616.95          | 0.413           |         |
|     |      | 7-10     | Very dense light brown silty SAND (SM) |        | 19.6           | 18               | 39      | 1812        | 659      | 2472.2   | 868.03          | 0.424           |         |
| 13  | ES1  | 0-7-6    | Medium stiff to stiff brown lean to fat CLAY (CL,CH) | 0.6    | 19.5           | 15.1              | 80      | 500         | 176      | 175.96   | 61.57            | 0.429           |         |
|     |      | 7-6-9    | Loose grey silty SAND |        | 19.5           | 15.7              | 0       | 29          | 600      | 228.51   | 79.51            | 0.437           |         |
|     |      | 9-10     | Stiff brown lean CLAY (CL) |        | 19.5           | 15.7              | 60      | 8           | 600      | 250      | 346.6           | 124.23          | 0.395   |
| 14  | ES2  | 0-5      | Medium stiff to stiff brown lean to fat CLAY (CL,CH) | 0.6    | 18.0           | 14.6              | 65      | 377         | 131      | 90.15    | 31.5             | 0.431           |         |
|     |      | 5-8      | Stiff brown lean to fat CLAY (CL,CH) |        | 19.5           | 15.8              | 60      | 604        | 250      | 347.98   | 124.28          | 0.4           |         |
|     |      | 8-17     | Stiff brown lean CLAY (CL) |        | 20.8           | 15.9              | 60      | 8           | 1362     | 420      | 1082.8          | 374.17          | 0.447   |
| 15  | ES3  | 0-9      | Medium stiff to stiff brown lean to fat CLAY (CL,CH) | 0.6    | 19.7           | 15.7              | 80      | 696         | 179      | 188.5    | 64.37            | 0.464           |         |
|     |      | 9-18     | Stiff brown lean CLAY (CL) |        | 20.9           | 16.1              | 60      | 1167        | 380      | 886.78   | 307.76          | 0.44           |         |
| 16  | S1   | 0-1-5    | Brown lean CLAY (CL) | 0.3    | 18.5           | 14.4              | 94      | 625         | 188      | 193.28   | 66.65            | 0.45           |         |
|     |      | 1.5-2    | Loose grey silty SAND layer(SM) |        | 20.0           | 15.0              | 0       | 909         | 185      | 213.45   | 72.21            | 0.478           |         |
|     |      | 2-10     | Medium stiff to very stiff brown to green marly lean to fat CLAY (CL,CH) | | 19.3 | 14.7 | 60 | 909 | 200 | 232.17 | 78.73 | 0.475 |
| 17  | S2   | 0-4      | Very stiff brown lean CLAY(CL) | 4      | 19.07 | 15.1 | 34 | 600 | 200 | 223.45 | 77.75 | 0.437 |
|     |      | 4-10     | Stiff to hard brown lean to fat CLAY (CL,CH) | | 19.93 | 15 | 112 | 0 | 750 | 240 | 337.6 | 117.1 | 0.442 |
| 18  | S3   | 0-12     | Soft to medium black, brown, green light, green lean to fat CLAY (CL,CH) | 1.7    | 19.5 | 15.2 | 90 | 3 | 434 | 110 | 70.54 | 24.06 | 0.466 |
|     |      | 12-14    | Loose grey silty SAND (SM) | | 20.8 | 18 | 0 | 41 | 500 | 145 | 129.7 | 44.6 | 0.454 |
|     |      | 14-15    | Very stiff brown, green lean CLAY(CL) | | 20.8 | 17 | 191 | 0 | 600 | 166 | 170.56 | 58.45 | 0.459 |
| 19  | S4   | 0-10     | Very soft to very stiff brown lean or fat CLAY(CL,CH) | 1.0    | 18.37 | 13.92 | 40 | 0 | 550 | 138 | 104.6 | 35.7 | 0.466 |
|     |      | 10-13    | Grey silty SAND (SM) | | 19.63 | 15.54 | 0 | 37 | 334 | 103 | 61.8 | 21.23 | 0.455 |
|     |      | 13-15    | Very soft to very stiff brown lean CLAY (CL) | | 20.02 | 16.03 | 48 | 0 | 450 | 102 | 62.57 | 21.24 | 0.473 |
| 20  | S5   | 0-3-7    | Grey gypseous SAND (SM) | | 18.18 | - | 3.53 | 86.6 | 366 | 230 | 244.6 | 87.29 | 0.401 |
|     |      | 3-7-15   | Grey gypseous silty SAND(SM) | | 19.16 | - | 8.4 | 40.5 | 1404 | 365 | 682.52 | 233.14 | 0.463 |

3. Simulation of Pile under Earthquake Excitation using PLAXIS 3D 2013

3.1 Model Geometry
In order to study the effect of earthquake on piles, a PLAXIS 3D 2013 model of a single pile embedded in a 40x30x25 soil model is simulated as shown in figure (2). The available geophysical investigation reports provided dynamic parameters for maximum depths ranging between 10m and 22m. Therefore a total model depth of 25m was chosen.

3.2 Soil Modeling
The soil is simulated as Mohr-Coulomb model. Drainage type is set to (Undrained A). Soil parameters (c, \(\phi^*\), \(\gamma\), \(V_p\), \(V_s\), \(E_s\), \(G_s\) and v), layers depths and water table levels are taken from the geotechnical site investigation reports as mentioned in table (3). A damping ratio \(\xi = 5\%\) was assumed according to PLAXIS 3D Manual[8], [1], [9] and [2].
3.3 Pile and Point Load Modeling

A pile of 1(m) diameter and 20(m) length is modeled as an embedded pile and is simulated as linear-elastic model. In figure (3) a typical model is given showing the soil layers together with the embedded pile, point load and prescribed displacements for M5 site in Baghdad. The pile is modeled to have no fixity at the top. The material properties are shown in table (4). The soil-pile interaction was modeled by the interface element. The allowable bearing capacity of the pile for each site is calculated then entered as base resistance $F_{\text{max}}$ in (kN) and skin resistance $T_{\text{bot,max}}$ and $T_{\text{top,max}}$ in (kN/m) divided by pile length. A point load is inserted at pile head. The magnitude was calculated according to PLAXIS 3D Manual using the relation given in equation (1), where $L_{\text{pile}}$ is the length of pile [8].

$$N_{\text{pile}}= F_{\text{max}} + \frac{1}{2} L_{\text{pile}} (T_{\text{bot,max}} + T_{\text{top,max}})$$

(1)

### Table 4. Material properties for embedded pile

| Pile Material | $L_p$ (m) | $D_p$ (m) | $\gamma_p$ (kN/m$^3$) | $E_p$ (kN/m$^2$) | $\nu_p$ |
|---------------|-----------|-----------|------------------------|-----------------|--------|
| Concrete      | 20        | 1         | 24                     | $3\times10^7$   | 0.15   |

3.4 Earthquake Modeling

One of the strongest earthquake in south of Iraq hit Ali Al-Gharbi in Missan Province on April 20, 2012 is shown in figure (4). The earthquake record was used as input dynamic prescribed displacement applied at the bottom of the model along the x-direction in the form of acceleration-time readings in (m/s$^2$) and (s), respectively. A 60 seconds section was applied to the model at intervals of 0.1 second.
3.5 Boundary Conditions of the Model

The boundary conditions of the geometry model are as the following:

- The vertical edges parallel to the yz-plane are free in y- and z-direction and fixed in x-direction meaning that $u_x = 0$.
- The vertical edges parallel to the xz-plane are free in x- and z-direction and fixed in y-direction meaning that $u_y = 0$.
- The vertical edges with their perpendicular plane neither in y- nor in x-axis are free in z-direction and fixed in x- and y-direction meaning that $u_z = u_y = 0$.
- The bedrock of the model is fixed in all directions ($u_x = u_y = u_z = 0$).
- The upper ground surface is free in x, y and z directions.
- In order to prevent waves’ reflection, absorbent boundary conditions applied on the model vertical boundaries to absorb outing waves [8], using viscous option for boundary $X_{\max}$, $X_{\min}$, $Y_{\max}$ and $Y_{\min}$ but None for boundary $Z_{\max}$ and $Z_{\min}$ for bedrock plane.

3.6 Mesh Generation

Due to the large dimensions of the model, medium mesh was created. The mesh consists of nearly (27319) elements (10-node tetrahedrons) with over than (40676) nodes as shown in figure (5).

4. Influence of Soil Dynamic Parameters on Pile Bending Moment

The results show that the maximum bending moment occurs at N$_2$ site in North zone, M$_5$ in Middle zone, WS$_1$ in Western south zone, ES$_2$ in Eastern south zone and S$_5$ in South zone.
Values of bending moments calculated along pile length are given in figures (6), (7) (8), (9), and (10). As can be seen in these figures the moment at pile head and tip are zero. This is because neither the top nor the tip of the pile is fixed. Moment values in between are either positive or negative or both which depends on soil type, number and depths of soil layers. The maximum bending moment value calculated is 2699 (kN.m) at depth 15 (m) for M₅ site. The vertical bearing capacity of 4000(kN/m²) for this site was the maximum bearing capacity among the other sites. It can be indicated that the maximum bending moment is obtained at the interface between the clay and sand layers located at 15(m) depth from ground surface as shown in figure (3). Rajapakse [10] indicated that the pile under earthquake is subjected to differential forces due to different seismic waves passing through two soil layers. Kinematic bending of pile can also occur in homogeneous soils, depending on the fact that the different strengths of seismic wave forms depend on soil layer depth and surrounding structures that could damp the wave in a non-uniform manner, the maximum bending moment occurs at the interface of two soil layers due to the different wave velocity of soil layers.

The data base seen in table (3) shows that the velocities of compression and shear are higher in sandy soils than in clayey soils and the highest difference in shear and compressional wave velocity for the different successive soil layers occur at M₅ site. The maximum value of bending moment occur at interface of different soil layers as the compression or shear wave passes from sandy soil of higher wave velocity to the clayey soil of the lower wave velocity. In most of soil profiles both wave velocities increased generally with depth. Depending on the fact that the effective stresses increase with depth, so in general will the strength, as the frictional nature of sand and cohesion of clay indicate the strength of soil and depend on the effective stresses occur in the soil. Concluding that the compression and shear wave velocities are increased in proportion with soil strength.

Mylonakis and Nikolaou [11] classified the curvatures and subsequent bending imposed to piles by the surrounding soil during the passage of strong seismic waves into (a) bending moment due to the up and down- propagating waves in the soil (“kinematic” bending) and (b) bending moment due to liquefaction and subsequent lateral soil movement (“liquefaction-induced” bending) as shown in figure (11).

In the present study when the pile tip embedded through sand or gravel soil with clayey soil for the upper layers the bending moment values are negative at the upper layers and goes positive at pile tip for (N₂, M₁, M₂, M₅ and WS₂) sites.

For soil profiles consist of multi sandy soil layers, bending moment values are positive along pile length for (WS₁, WS₃ and S₅) sites.

For soil profiles consist of multi clayey soil layers or clayey layer at pile tip with sandy upper layer bending moment values are positive at upper layers then changed to negative at pile tip for (N₁, N₃, ES₁, ES₂, ES₃, S₁, S₂, S₃ and S₄) sites.

The shapes of the bending moment profiles give an indication that the pile deformed in double curvature shape which is caused by opposite loading directions at the surrounding top and bottom soil layers. The double curvature shape indicates that the non-liquefied shallow layer pushed the pile laterally to resist this bending action [12].
Figure 6. Bending moment diagrams of pile for North zone.

Figure (7.) Bending moment diagrams of pile for Middle zone.

Figure 8. Bending moment diagrams of pile for Western south zone.

Figure 9. Bending moment diagrams of pile for Eastern south zone.

Figure (10) Bending moment diagrams of pile for South zone.

Figure (11) Bending moment diagram of single pile without superstructure under seismic excitation (a) Kinematic bending. (b) Liquefaction- induced bending (after Mylonakis and Nikolaou, 2002).
5. Influence of Soil Dynamic Parameters on Pile Horizontal Displacement

According to soil-pile interaction, pile horizontal displacement, $u_x$, occurs due to movement of the surrounding soil particles under seismic excitation. Figures, (12), (13), (14), (15) and (16) show the horizontal displacement of single pile which is imbedded in different soil layers and for different zones in Iraq.

The results were examined well and it was found that the profile of minimum bending moment for $M_3$ site shown in figure (7) gives the maximum horizontal displacement value as shown in figure (13) while the maximum curvature of the deflected shape is evaluated at $M_5$ site in the Middle zone soils of Iraq as shown in figure (13), knowing that this site gives maximum bending moment values shown in figure (7).

Figure 12. Horizontal displacement of pile per diameter with depth for North zone.

Figure 13. Horizontal displacement of pile per diameter with depth for Middle zone.

Figure 14. Horizontal displacement of pile per diameter with depth for Western south zone.

Figure 15. Horizontal displacement of pile per diameter with depth for Eastern south zone.
The horizontal displacement of the embedded pile is affected by type of soil, number and depth of soil layers also the difference in wave velocity for the successive soil layers. From figures (13), (14) and (16) it is seen that the horizontal displacement of pile embedded in sandy soil models have the same behavior for (M6, WS1, WS3 and S5) sites.

The horizontal displacement of pile embedded in clayey soil are as in figures (12) and (15), (N1, N2, N3, ES2 and ES3) sites.

Figures (15) and (16) show horizontal displacement of pile in two clayey soil layers confining thin sandy layers in between as in (ES1, S1, S3 and S4) sites.

6. Conclusions
From the present study, the following conclusions may be drawn:

1. The soil dynamic parameters for active seismic zones in Iraq are prepared as database to be used as input parameters to simulate a piles under earthquake excitation using FEM software.

2. The maximum bending moment during earthquake occurs at the interface of different soil layers for each soil profile along the pile depth, thus the kinematic pile moments occurs at relatively deep interfaces between soil layers with very different stiffnesses. Concluding that the compression and shear wave velocities play an important role in estimating the dynamic behavior of piles and design of foundations.

3. Maximum bending moment value obtained is 2699.617 (kN.m) and at depth 15 (m) at the interface of sand and clay layers for M5 site. The values of compression and shear waves velocities are higher in sandy soils than in clayey soils and the highest difference in compression and shear wave velocities for the different successive soil layers occurs at M5 site. Concluding that the maximum bending moment occurs at the interface of two soil layers have very different wave velocities.

4. For soil profiles consist of clayey soil at the upper layers and sand or gravel soil for the lower layer the bending moment values changed directions (were positive at pile tip and negative at the upper layers) for (N2, M1, M2 and WS2) sites. And for soil profiles consist of multi sandy soil layers, bending moment values were all in the same direction (were positive along pile length) for
(WS₁, WS₃ and S₄) sites. Similar for soil profiles consist of clayey layer at pile tip with sandy upper layer bending moment values changed directions (were negative at pile tip and positive at upper layers) for (N₁, N₃, ES₁, ES₂, ES₃, S₁, S₂, S₃ and S₄) sites.

5. According to soil-pile interaction, pile deflection occur due to movement of the surrounding soil particles under seismic excitation, the deflected shape have the same behavior for pile embedded in sand soil models as in (M₆, WS₁, WS₃ and S₅) sites. Also for pile embedded in clayey soil as in (N₁, N₂, N₃, ES₂ and ES₃) sites. As well as the pile that embedded in two clayey soil layers with thin sandy layers in between as in (ES₁, S₁, S₃ and S₄) sites.

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