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A STUDY ON FAILURE OF PILE FOUNDATIONS AND ITS REMEDIAL MEASURES

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Abstract:

Pile Foundation is a type of foundation where the super structural load is transferred to the weak or compressive layers of soil. This type of pile foundations are majorly used for the construction of bridges, buildings as a support system to avoid excess settlement, the super structural load is safely transferred to the mother earth. Due to the heavy major earthquake, Failure of pile foundations has been observed in many cases. In this paper, three Building model are considered for the study (1 regular building and 2 irregular buildings). The Building consists of G+5 storied RCC structure. The analysis was carried out in "ETABS" software. First the building was analyzed for dead load and imposed load combinations and then the structure was analyzed by Equivalent static method. In this paper black cotton soil was considered for the design of Pile foundation. Design of piles was done using Indian Standards IS 2911 (Part-1 /Sec-2), IS 456:2000 and IS 1893:2002 (Part-1). Graphs were plotted for all three types' structures. It was found that for C-Type of structure more number of piles has to be provided for seismic analysis rather than static analysis, were as for L-Type number of piles for static analysis yielded more compared to seismic analysis.

Key Words: Pile Foundation, ETABS 2015 & Equivalent Static Method.

1. Introduction:

"Pile foundations are mainly used for the buildings as a supports, bridges etc... The load is transferred safely to the mother earth without much horizontal movement and excess of settlement. Pile foundations are more useful to transfer the structural loads on weak or compressive layers of soil. These pile foundations are having a very huge range of applications, also which has found various drawbacks, depending upon their considered aspects such as cost, Durability of materials, Ground conditions, the nature of support which required load, Proximity to other structures, Sensitivity to vibration and Noise, Presence of water and Accessibility. The piles are also majorly used for supporting tall structures on the seismic prone areas, basically when the soils can be liquefied because of seismic trembling. Soil liquidity is resulted in severe damage in the structures such has tunnels, bridges, buildings and other substructures. As per the damage records of buildings, bridges and other infrastructures, in that past shaking which were found over the last thirty years, the super structures along with the pile foundation will have a better a performance on seismic whose the foundations of pile, also various damages had seen on the pier foundations. The soil is not capable near the ground surface that won't support to the structure; the deep strata must have the capacity to bear the load of deep foundation. The classification of piles is based on the transmission load, Load construction Material and the effect of soil. End bearing piles and Friction piles are the main types on the transmission on the loads. The other name for end bearing pile is also called as point bearing pile. These piles are referred to the load bearing layer and they transmit loads to rock, sand and other hard strata. This type of pile which is driven to the soft compressible soil and touch to the firm soil. Friction piles are the type of piles transmits it's the layers through the loads and majorly pass to the skin friction along with the soil in the surroundings. In this type, the frictional resistance is improved on the load which is transferred to the piles to the driven piles. The pile is compressed to the soil when the stiffness is more. This pile gets transferred to some layers of the soil.

There are many types of pile construction using materials such as steel pile, timber pile, concrete pile and composite pile which plays an important role in the Materials in construction of Pile. There are several damages which cause pile foundation during the earthquake process. Some of the aspects are Ground shaking majorly the shaking in the ground will cause earthquake. The large earthquake will majorly give huge amplitudes for more duration to produce ground vibration. The type of material, magnitude of earthquake, type of faulting, distance of the earthquake focus and depth are the important factors which determine the amount of ground shaking at the particular site. The small earthquake produces small damages to the land and the structures, but the in the huge big areas the shaking will be more. Landslides is caused the structures can get damages when the vibrations takes place in the ground. This can be of liquefaction of soil, landslide where the settlement takes place. A flood can cause if the landslide occur into a lake or reservoirs down streams. Ground movement can change into river if an earthquake or landslide happens. This damage is not unique to earthquake but it can be affected by earthquake. Liquefaction is the process in which the shear resistance of soil is lost with huge percentage when compared to cyclic, monotonic or shock loading and flows in such a way that resembles the shear stress till liquid is reduced and the mass acting on shear resistance. Soil liquefaction is normally failures in ground which are commonly caused with huge number of earthquakes.

2. Methodology:

ETABS is the analysis software. In this the analysis results was determined and also the modeling was carried out. The model is analyzed with two type of analysis such as Static analysis and Equivalent static analysis. Material of concrete mix of M30 and Fe500 as reinforcing steel is considered for the analysis of the structure. The load capacity of pile in various soil conditions is calculated using various Indian standards such as IS: 2911 (Part-1 / sec 2) and also the super structural load the earthquake data such as zone factor, Importance factor, response reduction factor and also the time period is given in the IS:1893-2002 (Part 1). The pile design is made and various reinforcements are designed as per IS: 456-2000. A 6 storey RCC buildings were considered (1 regular building and 2 Irregular Buildings) and analyzed.

Different Properties and parameters for the analysis of the structure are given in following table:

S.No	Variable	Data
1.	Type of structures	Ordinary Moment Resisting frame.
2.	Number of stories	6
3.	Height of floors (floor to floor)	3.4m.
4.	Live load	3.0 kN/m^2.
5.	Floor finish	1.0 kN/m^2.
6.	Roof load	1.5 kN/m^2.
7.	Wall Load external	14.kN/m.
8.	Parapet wall load (at roof)	3.0 kN/m.
9.	Beam size	(250 x600)mm.
10.	Column size	(450 x 450)mm.
11.	Slab thickness	150mm.
12.	Specific weight of RCC	25 kN/m^3.
13.	Seismic Zone	III
14.	Importance factor	1.0
15.	Response reduction factor	3.0
16.	Soil condition	Black cotton soil (Medium).
17.	Thickness of wall	250mm.
18.	Type of supports	Fixed at each column base.
19.	Time period (Tax)	0.5666 sec.
20.	Time period (Tay)	0.5666 sec.
21.	Characteristics strength of concrete (fck)	30 Mpa.
22.	Yield strength for steel (Fy)	500 Mpa.

Table 2.1: Properties and Parameters considered for Analysis

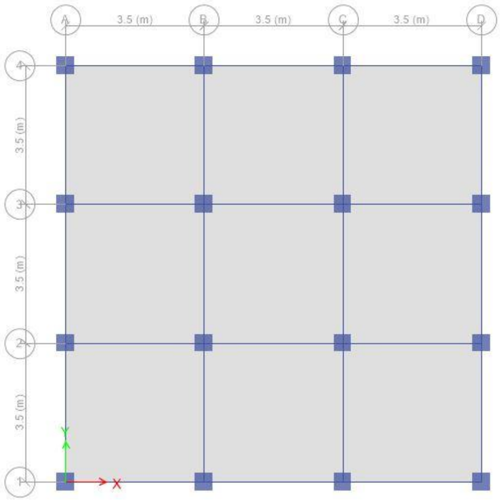

Figure 2.1(a): Plan View of Regular Building

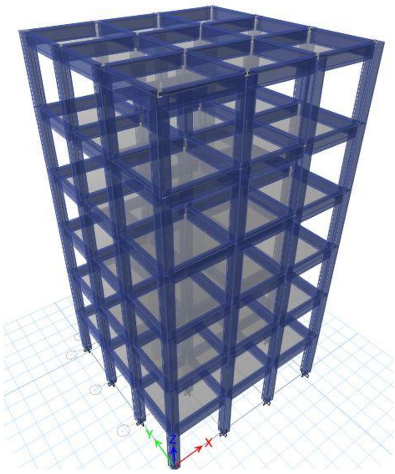

Figure 2.1(b): 3-D View of Model 1

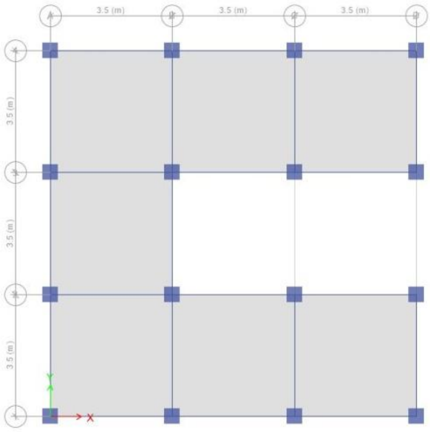

Figure 2.2(a): Plan View of Irregular Building

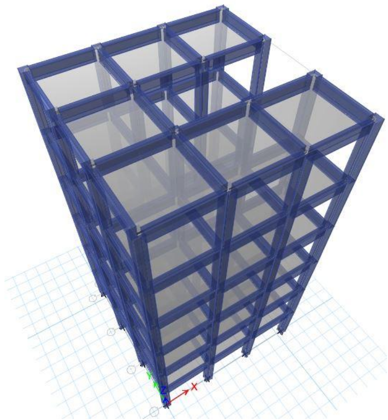

Figure 2.2(b): 3-D View of Model 2

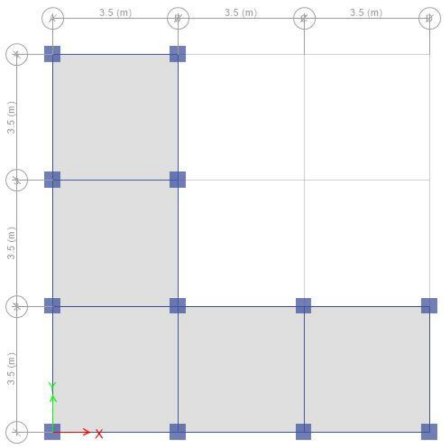

Figure 2.3(a): Plan View of Irregular Building

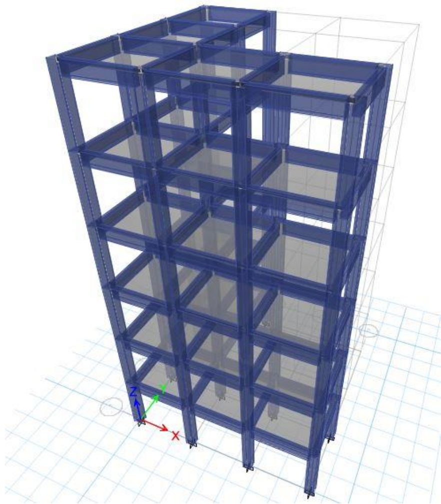

Figure 2.3(b): 3-D View of Model 3

The Load combinations play an important role while analyzing the G+5 frame model (1 Regular structure and 2 irregular Structures). Here the set of load combinations are arranged for Equivalent static analysis and Seismic Analysis such as Dead load, Live load and Earthquake load. The First Analysis is done using static analysis where only dead and imposed load are considered. Next Equivalent static analysis (Seismic analysis) is carried out and analyzed. The Following Load combinations for Static and Seismic Analysis is shown below.

Parameters	**Load combinations**
DCon1	"1.50*DL"
Dcon2	"1.50*DL + 1.50*LL"
Dcon3	"1.20*DL + 1.20*LL + 1.20*EL (X)"
Dcon4	"1.20*DL + 1.20*LL – 1.20*EL (X)"
Dcon5	"1.20*DL + 1.20*LL + 1.20*EL (Y)"
Dcon6	"1.20*DL + 1.20*LL – 1.20*EL (Y)"
Dcon7	"1.50*DL + 1.50*EL (X)"
Dcon8	"1.50*DL – 1.50*EL (X)"
Dcon9	"1.50*DL + 1.50*EL (Y)"
Dcon10	"1.50*DL – 1.50*EL (Y)"
Dcon11	"0.90*DL + 1.50*EL (X)"
Dcon12	"0.90*DL – 1.50*EL (X)"
Dcon13	"0.90*DL + 1.50*EL (Y)"
Dcon14	"0.90*DL – 1.50*EL (Y)"

Table 2.2: Different Load Combinations for Analysis

3. Analysis of the Structure:

Model - 1 (Regular Frame Structure)

The Column loads of this structure are analyzed using ETABS software. The following are the Axial Loads of the structure at ground floor.

Col. No.	Axial Load (kN)
C1	964.05
C2	1355.66
C3	1355.66
C4	964.05
C5	1355.66
C6	1866.92
C7	1866.92
C8	1355.66
C9	1355.66
C10	1866.92
C11	1866.92
C12	1355.66
C13	964.05
C14	1355.66
C15	1355.66
C16	964.05

Table 3.1 (a): Axial Loads for Static Analysis

The seismic analysis of the Structure is analyzed and the Values are inputted in the ETABS software. The following are the column loads for the Seismic analysis shown below

Col. No.	Axial Load (kN)	MAX S.F (kN)	MAX B.M (kN-m)
C1	1310.09	74.507	153.87
C2	1647.78	89.07	170
C3	1647.78	89.07	170
C4	1310.09	74.507	153.87
C5	1647.78	89.07	169.42
C6	1866.92	90.47	170.90
C7	1866.92	90.47	171.56
C8	1647.78	89.07	170
C9	1647.78	89.07	169.42
C10	1866.92	90.47	170.90
C11	1866.92	90.47	171.56
C12	1647.78	89.07	170
C13	1310.09	74.507	153.87
C14	1647.78	89.07	170
C15	1647.78	89.07	170
C16	1310.09	74.507	153.87

Table 3.1 (b): Axial Loads, SF and BM for Seismic Analysis

Model - 2 (Irregular Frame Structure)

The Column loads of this structure are analyzed using ETABS software. The following are the Axial Loads of the structure at ground floor.

Col. No.	Axial Load (kN)
C1	970.03
C2	1336.49
C3	1318.07
C4	918.57
C5	1354.45
C6	1681.29
C7	1357.97
C8	918.80
C9	1354.45
C10	1681.29
C11	1357.97
C12	918.80
C13	970.03
C14	1336.49
C15	1318.07
C16	918.57

Table 3.2 (a): Axial Loads for Static Analysis

The seismic analysis of the Structure is analyzed and the Values are inputted in the ETABS software. The following are the column loads for the Seismic analysis shown below.

Col. No.	Axial Load (kN)	MAX S.F (kN)	MAX B.M (kN-m)
C1	1341.76	72.75	149.00
C2	1611.92	86.39	165.24
C3	1611.92	86.39	165.24
C4	1341.76	72.75	149.58
C5	1651.79	80.75	152.95
C6	1681.29	87.00	165.63
C7	1681.29	87.00	165.63
C8	1654.79	80.75	154.28
C9	1675.40	80.36	153.57
C10	1652.21	81.00	154.06
C11	1652.21	81.00	154.06
C12	1675.40	80.36	153.57
C13	1317.63	70.30	146.78
C14	1345.56	70.06	145.78
C15	1345.56	70.06	145.78
C16	1317.63	70.29	146.23

Table 3.2 (b): Axial Loads, SF and BM for Seismic Analysis

Model - 3 (Irregular Frame Structure)

The Column loads of this structure are analyzed using ETABS software. The following are the Axial Loads of the structure.

Column No.	C1	C2	C3	C4	C5	C6
Axial Load (kN)	926.95	915.84	1323.75	1346.14	1343.67	1646.55
Column No.	C7	C8	C9	C10	C11	C12
Axial Load (kN)	1346.14	915.84	973.19	1343.67	1323.75	926.95

Table 3.3(a): Axial Loads for Equivalent Static Analysis

The seismic analysis of the Structure is analyzed and the Values are inputted in the ETABS software. The following are the column loads for the Seismic analysis shown below

Col. No	Axial Load (kN)	MAX S.F (kN)	MAX B.M (kN-m)
C1	1313.09	68.06	140.52
C2	1628.93	80.88	154.70
C3	1651.85	80.65	154.08
C4	1298.23	68.65	142.55
C5	1628.93	80.88	154.70
C6	1646.55	82.99	157.42
C7	1619.07	82.31	156.79
C8	1319.27	68.53	141.72
C9	1651.85	80.65	154.08
C10	1619.07	82.31	156.80
C11	1298.23	68.66	142.55
C12	1319.27	68.53	141.72

Table 3.3 (b): Axial Loads, SF and BM for Seismic Analysis

Load Carrying Capacity Analysis of Piles on Different Soil Conditions:

Soil Type - 1 [Black Cotton Soil (Clay) Extended to Depth of Pile]

The soil properties have stated as, sand is considered as 25%, fines are adopted as 73% and the Gravel is just taken as 2%. The cohesion of the Pile is considered C=65kN/m^2. The ultimate load carrying Pile capacity is evaluated by the formula which is given in IS 2911 (Part 1/sec2) as shown below:

$$Qu = CNcAp + \alpha CAs \quad \text{-----} \ (1)$$

Where first section of the equation shows resistance end bearing and second section shows the skin frictional resistance. Ap= Area of cross section at tip of pile, Nc= capacity bearing factor, C= Average Cohesion at Tip of the pile, As= Area surface of the pile for ith layer, diameter of pile = 0.6m. Depth of pile =9m. The different parameters calculated and tabulated in the following table.

Parameters	Values	Units
C	65	kN/m^2.
Nc	9	---

Ap	0.2827	m^2
α	0.6	---
As	16.96	m^2

Table 3.4: Calculated Parameters for the Design of Piles

The above tabulated values are substituted in the equation (1) and the Load capacity of single pile is found to be= 827 kN. Load capacity for two Piles = 1654 kN and Load capacity for three piles = 2481 kN. These load capacity of Pile for Black Cotton Soil, the values are kept for all 3 models as same. The no. of piles for both static and dynamic analysis are found out comparing the above Static and Seismic tables.

Col. No	**Model - 1**		**Model - 2**		**Model - 3**	
	No. of Piles		No. of Piles		No. of Piles	
	Static Analysis	Seismic Analysis	Static Analysis	Seismic Analysis	Static Analysis	Seismic Analysis
C1	02	02	02	02	03	02
C2	02	02	02	02	02	02
C3	02	02	02	02	02	02
C4	02	02	02	02	02	02
C5	02	02	02	03	02	02
C6	03	03	03	03	03	02
C7	03	03	02	03	02	02
C8	02	02	02	03	02	02
C9	02	02	02	03	02	02
C10	03	03	03	02	02	02
C11	03	03	02	02	02	02
C12	02	02	02	03	02	02
C13	02	02	02	02	-	-
C14	02	02	02	02	-	-
C15	02	02	02	02	-	-
C16	02	02	02	02	-	-
Total No. of Piles	**36**	**36**	**34**	**38**	**26**	**24**

Table 3.5: No. of Piles for Static and Seismic Analysis for model 1, 2, 3

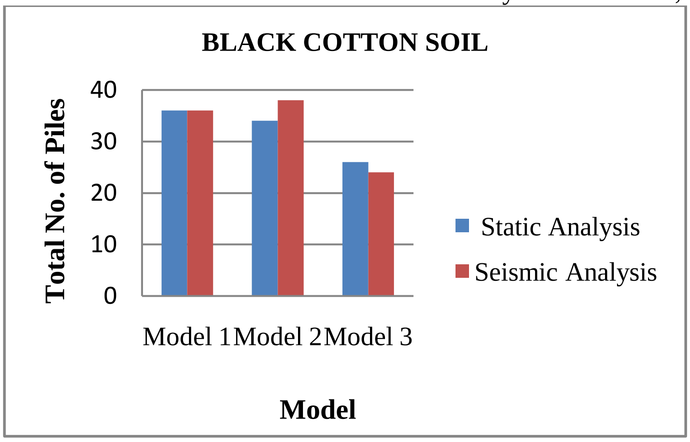

Figure 3: Graph showing No. of Piles for different Models

Design of Piles for Black Cotton Soil:

For Equivalent Static Loading:

The pile design RCC is done as per the code IS 2911 (part 1/ sec 2) and IS: 456-2000 for resisting the shear force, axial force and bending moment which is shown below:

All the piles are same designed

Use TMT 6# of 16mm ϕ as the main reinforcements,

Use TMT 12mm ϕ bar @ 100mm spiral to form pitch.

The stiffeners rings are also provided and are given 16mm ϕ are prevented buckling inside of reinforcement wire mesh @ 1.5m center to center.

For Dynamic Loading:

In this type of Loading, two various types Piles are designed. The pile design at $C_{1,2,3,4,5,8,9,12,13,14,15,16}$ Use TMT 6# of 16mm ϕ as "the" main reinforcements. Use TMT 12mm ϕ bar @ 100mm"spiral to form pitch. The stiffeners rings are also provided and are given at 16mm ϕ are prevented buckling inside of reinforcement wire mesh @ 1.5m center to center. The pile design at $C_{6,7,10,11.}$ Use TMT 9# of 25mm ϕ as the main reinforcements. Use TMT 12mm ϕ bar @ 100mm spiral to form pitch. The stiffeners rings are also provided and are given 16mm ϕ are prevented buckling inside of reinforcement wire mesh @ 1.5m center to center.

4. Conclusions:

- The pile capacity load which is due to the presence of estimation of layer which is sandy is very high in the presence throughout the clay soil and the depth in the conditions which is static.
- We analyze that the pile capacity load is in the huge loss is that of two stratified layer in soil type, in the dynamic conditions it is delaying the support from the soil sandy layer which is liquefied.
- As a result there will be a loss in the excessive settlement, if the pile is designed under seismic condition, then it can be considered from the liquefiable soil.
- The piles passing into the non liquefiable deep crust and which is standing on the liquefied soil, it can cause tilting, carries settlement or explosive to the vibrations. This must be taken care in practice."
- The use of huge pile cap or the huge foundation mat has more positive considerations,
- The settlement of foundation can be reduced. This is because of liquefaction; the pile will lose its resistance of the soil zone in the liquefied region, thus leads to the settling to the supporting superstructure. However the is part of integrity pier foundation system, it's a part of load above the ground level is transferred into the foundation mat and reduces slinkiness in the soil in the ground.
- A sudden collapse risk of the pile can be reduced and it will be very difficult to punching of large foundation raft into the soil even if the upper layer of the soil is also liquefied."
- Hence the design should be carried out for the liquefied soil layers according to the Indian standards code.

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