Evaluation of Lateral Resistance of RCC Pile and Computation of Fragility Curve

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Abstract

Piles in most cases are subjected to lateral loads which govern the design. Characterizing the probabilistic nature, analysis can be done through the use of 'Fragility Curve' which assesses the probability that the seismic demand placed on the structure exceeds the capacity conditioned on a chosen 'Intensity Measure' (IM) representative of the seismic loading. This study presents the performance of axially loaded single RCC pile subjected to different earthquakes of varying PGAs. Finite Element Method (FEM) software called OpenSeesPL is used for Time-history analysis in which pile is modelled as a beam element and the soil strata is modelled as eight noded brick elements. Series of time history analysis are carried out using OpenSeesPL, with 22 pairs of far field synthetic ground motion records given in Federal Emergency Management Agency (FEMA) and six pairs of natural ground motion records given inCentre for Engineering Strong Motion Data (CESMD)to compute the maximum lateral deflections of the pile at top for the actually existing soil conditions.. Based on the analysis results, fragility curve is drawn which expresses the probability of a pile reaching certain damage state for a given ground motion parameter.

Keywords: Intensity measure; Seismic loading; Fragility curve.

1. Introduction

1.1 Load Transfer Mechanism

A Proper understanding of the load transfer mechanisms for pile is necessary for analysis and design. Piles transfer axial and lateral loads through different mechanisms.

1.2 Pile Behavior due to Vertical Load

In the case of axial (vertical) loads, piles maybe looked upon as axially loaded columns they transfer loads to the ground by shaft friction and base resistance. As a pile is loaded axially, it slightly settles and the surrounding soil offers resistance to the downward movement. Because soil is a frictional material, frictional forces develop at the interface of the pile shaft and the surrounding soil that oppose the downward pile movement. The frictional forces acting all along the pile shaft partly resist the applied axial load and are referred to as shaft resistance, shaft friction or skin friction. A part of the axial load is transferred to the ground through the bottom of the pile. As a pile tries to move down, the soil below the pile base offers compressive resistance to the movement. This mechanism is called base resistance or end-bearing resistance. The total resistance (shaft friction plus end-bearing resistance) keeps a pile in equilibrium with the applied load. Piles that transfer most of the axial load through the base are called end-bearing piles, while those that transfer most of the load through shaft friction are called friction piles. For end-bearing piles, it is necessary to have the pile base inserted into a strong layer of soil (e.g., dense sand, stiff clay or rock).

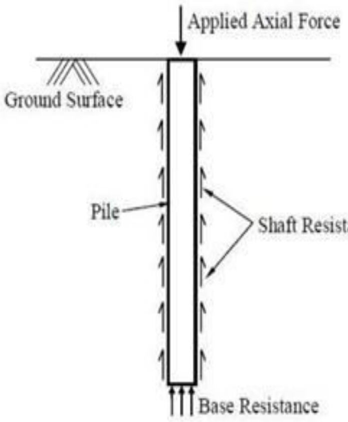


Fig.1. Load transfer mechanism of axially loaded pile

1.3 Pile Behavior Due to Lateral Load

In the case of lateral loads, piles behave as transversely loaded beams. They transfer lateral load to the surrounding soil by using the lateral resistance of soil. When a pile is loaded laterally, a part or whole of the pile tries to shift horizontally in the direction of the applied load, causing bending, rotation or translation of the pile. The pile presses against the soil in front of it generating compressive and shear stresses and strains in the soil that offers resistance to the pile movement. This is the primary mechanism of load transfer for lateral loads. The total soil resistance acting over the entire pile shaft balances the external horizontal forces. The soil resistance also allows satisfaction of moment equilibrium of the pile.

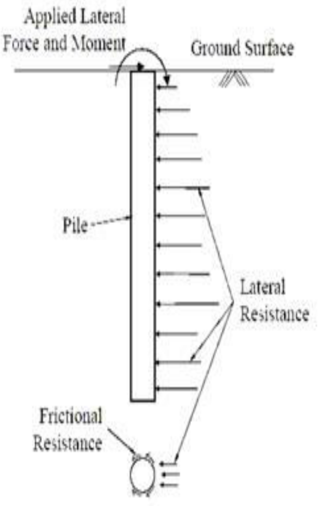


Fig.2. Load transfer mechanism of laterally loaded pile

2. Materials and Methodology

2.1 Load Carrying Capacities of Pile

2.1.1General

A bored cast in situ pile of 450 mm diameter was designed as per IS 2911:2010, Part I, Sec 2, for the following data.

TABLE 1. Standard penetration test value

Depth below EGL	Description of strata	SPT - 'N' value
0.0 – 4.0 m	Fill up soil (Clayey sand)	7
4.1 - 6.0 m	Silty clay	11
6.1 – 9.0 m	Clayey Silty sand	12
9.1 – 12.0 m	Silty sand	18
12.1 – 16.0 m	Silty clay	36
16.1 – 21.0m	Clayey silty sand	76
21.1 – 24.0 m	(Weathered rock) Granitic Gneiss	> 100
24.1 – 29.0 m	(Weathered rock) Granitic Gneiss	> 100

2.1.2 Design data

Inside diameter of tank - 8 m

Height of tank above GL -10.5 m

Location - Chennai

Storage liquid - Filtered water

Dead load -230kN

Live load -5026kN

Total Design load -5260 kN

Depth of foundation -23m

(Beyond 21m – weathered rock – Granitic Gneiss)

Pile diameter considered - 450mm

Socketing depth (2d) -0.90m into rock

$f_{ck} = 25$ N/mm $^{2 \text{ and}}$ f_y =415 N/mm2

Bored cast in situ pile of end bearing type

2.1.3 Axial load capacity

$$Q = [Ap * Nc * Cp] + [\alpha * C * As]/\ [F.O.S]$$

$$Q = [Cp * Nc * \frac{\pi}{4} * D * \frac{2}{3} + \alpha * \hat{c} * \pi * D * \frac{L}{3}]$$

C_p=1000 kN/m^2

(Shear strength of rock at tip)

N_c= 9 (Bearing capacity factor)

D = 0.45 m (Diameter of pile)

α= 0.9 (Adhesion factor)

Ĉ=1000 kN/m2 (Shear strength of rock)

L= 0.9 m (Socketing length @ 2*pile diameter)

Factor of safety = 3

Q=850 kN

2.1.4 Uplift capacity

$$Q = [\alpha * C * As]/[F.O.S]$$

$$Q = [\alpha * \hat{c} * \pi * D * \frac{L}{3}]$$

D = 0.45 m (Diameter of pile)

L = 0.9 m (Socketing length @ 2*pile diameter)

α = 0.9 (Adhesion factor)

$\hat{C}$= 1000 kN/m^2 (Shear strength of rock)

Factor of safety = 3

Q = 350 kN

2.1.4 Lateral load

For determining the lateral pile load capacity, the depth of fixity of piles (the equivalent cantilever length of the pile) has to be determined.The depth of fixity is determined based on the Modulus of horizontal sub grade reaction which in turn based on the relative density of soil as observed in the bore holes. Its value is taken from table-3 of appendix-c of IS: 2911:2010, Part-I/Sec 2. (Loose sand, submerged condition η_h = 0.2 X 103 kN/m3)

Stiffness factor T = $\left[\frac{EIp}{\eta h}\right]$^2.5

T = 3.02m

Depth of fixity is calculated based on the graph given in IS: 2911-2010, Part I/ Sec 2, for fixed head case.

Depth of fixity = 6.6m

For a permissible deflection of 5mm,

Lateral load carrying capacity=

$$= 12yEI/(L1 + Lf)3$$

= 10.5 kN

(y = 5mm, E – Modulus of Elasticity of concrete, I – Moment of Inertia of pile, L1 –depth of pile above GL and Lf- Depth of fixity)

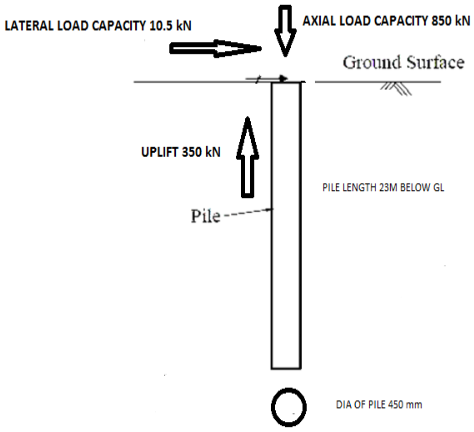


Fig.3. Calculation of load carrying capacity

2.1.5Results for pile foundation

Vertical load carrying capacity -850 kN

Uplift capacity -350 kN

Lateral capacity - 10.5 KN

Depth of fixity (fixed head) -6.6m

No of piles - 12 numbers

Depth of founding the pile -23m

Socketing depth -0.9 m

Structural design for 450mm diameter pile, 6number of 18mm diameter Fe 415 rods with 8mm diameter ties.

2. 2Collection of earthquake ground motion records

TABLE 2. Indian earthquakes

S. No	**Event**	**Magnitude**	**PGA, g**	
			Direction	
			I	*II*
1	Chamoli Aftershock 1999-03-29 08:49:45 Utc	4.6	0.1	0.11

2	Chamoli1999-03-28 19:05:11 Utc	6.6	0.16	0.22
3	Chamba1995-03-24 11:52:33 Utc	4.9	0.24	0.29
4	India-Burma Border 1995-05-06 01:59:07 Utc	6.4	0.30	0.42
5	Uttarkashi1991-10-19 21:23:15 Utc	7.0	0.12	0.12
6	Bhuj/Kachch 2001-01-26 03:16:40	7.0	0.10	0.10

TABLE 3. International earthquakes

S.No	**Event**	**PGA, g**	
		Direction	
		I	*II*
1	Northridge 1994	0.42	0.52
2	Northridge 1994	0.41	0.48
3	Duzce, Turkey 1999	0.73	0.82
4	Hector Mine 1999	0.27	0.34
5	Imperial Valley1979	0.24	0.35
6	Imperial Valley 1979	0.36	0.38
7	Kobe, Japan 1995	0.51	0.5
8	Kobe, Japan 1995	0.24	0.21
9	Kocaeli, Turkey 1999	0.31	0.36
10	Kocaeli, Turkey 1999	0.22	0.15
11	Landers 1992	0.24	0.15
12	Landers 1992	0.28	0.42
13	Loma Prieta1989	0.53	0.44
14	Loma Prieta 1989	0.56	0.37
15	Manjil, Iran 1990	0.51	0.5
16	Superstition Hills 1987	0.36	0.26
17	Superstition Hills 1987	0.45	0.3
18	Cape Mendocino 1992	0.39	0.55
19	Chi-Chi, Taiwan 1999	0.35	0.44
20	Chi-Chi, Taiwan 1999	0.47	0.51
21	San Fernando 1971	0.21	0.17
22	Friuli, Italy 1976	0.35	0.31

2.3Analysis by OpenSeesPL

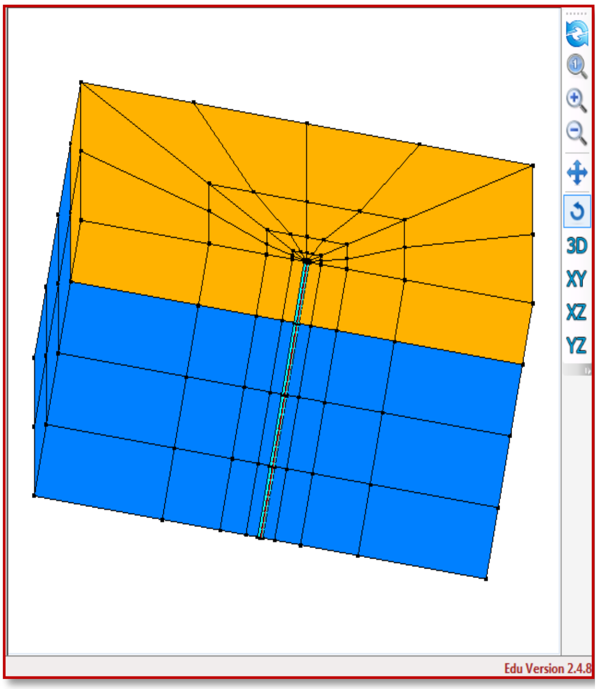
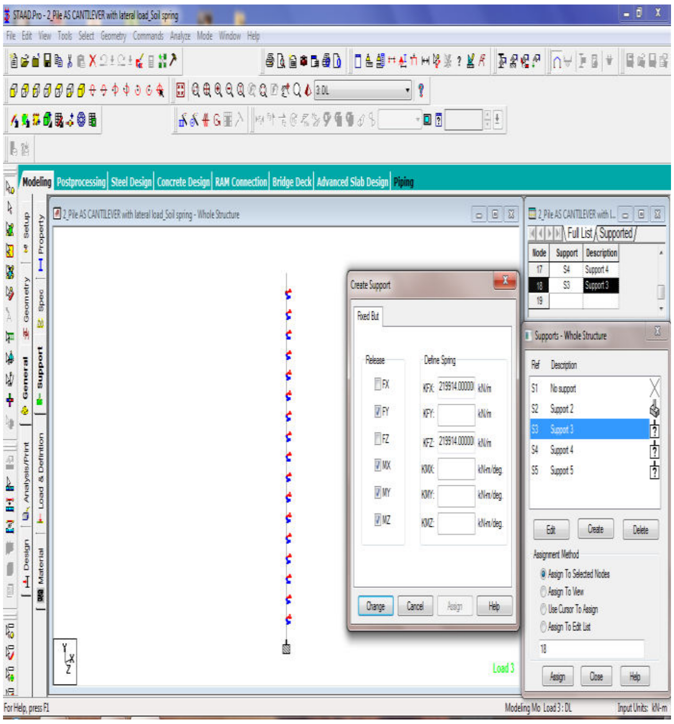


Fig.4. Modelling by OpenSeesPL

2.4 Lateral analysis of pile using STAAD.Pro

The p-delta analysis option in STAAD.Pro can also be used to compute the lateral deflection of an axially loaded pile subjected to lateral loads. In this analysis, pile is considered as a three dimensional beam element and the soil is represented by a series of linear elastic springs at each node level. The above model can take into account the various factors such as variation of soil with depth and non-linearity. The pile is idealised as three dimensional beam element and the soil as a series of linear elastic springs at each node level. The beam element of the STAAD.Pro computer code considers torsion and bending about two axes, axial and shearing deformations. The element is prismatic. The soil support is assumed in the form of elastic spring throughout the depth of pile. The spring stiffness of the linear springs are estimated using Newmark's distribution. Pile is modelled as beam element with 19 nodes and 18 beam elements each of 1.25m length, Bottom of pile is assigned fixed end condition.At each node spring supports are assigned for the considered soil profile in lateral direction. To assign spring stiffness's of soil springsNewmark's Distribution is used. The stiffness's of the first spring, intermediate spring and last spring are estimated.



Create Support

Fixed But

Release: ☐ FX ☑ FY ☐ FZ ☑ MX ☑ MY ☑ MZ

Define Spring:
KFX: 219914.00000 kN/m
KFY: kN/m
KFZ: 219914.00000 kN/m
KMX: kN-m/deg.
KMY: kN-m/deg.
KMZ: kN-m/deg.

Change | Cancel | Assign | Help

Node	Support	Description
17	S4	Support 4
18	S3	Support 3
19		

Supports - Whole Structure

Ref	Description
S1	No support
S2	Support 2
S3	Support 3
S4	Support 4
S5	Support 5

Edit | Create | Delete

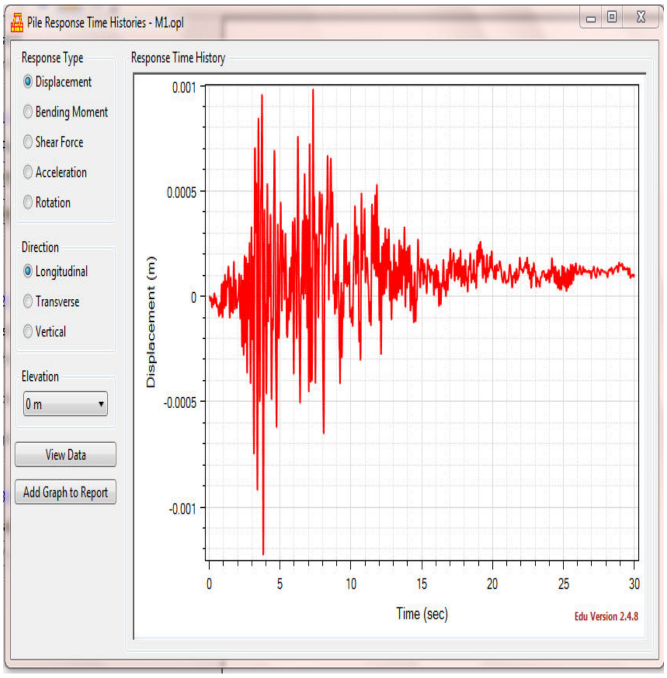
Assignment Method
● Assign To Selected Nodes
○ Assign To View
○ Use Cursor To Assign
○ Assign To Edit List

18

Assign | Close | Help

For Help, press F1 Modeling Mo Load 3 : DL Input Units : kN-m

Fig.5 STAAD.Pro analysis



Response Type
● Displacement
○ Bending Moment
○ Shear Force
○ Acceleration
○ Rotation

Direction
● Longitudinal
○ Transverse
○ Vertical

Elevation
0 m

View Data
Add Graph to Report

Fig.6. Time History Analysis

3. Summary & Conclusion

In this study a method for the evaluation of the seismic fragility curve of Pile is presented. This method belongs to the category of analytical approaches to the fragility estimation. This method is demonstrated through an application of a single bored cast in situ pile designed for a pile foundation system. This pile foundation system is designed as per Indian code IS 2911:2010, for supporting a filtered water storage tank of an industry site at Manali in Chennai. The capacity of pile in Axial, Lateral and Uplift are computed by following the stipulated codal provisions of IS 2911:2010, Part I/Sec2.

The designed single pile is subjected to a suite of synthetic and natural ground motion of earthquake loading and time history analyses are carried out using OpenseesPL a FEM based software. Peak Ground Acceleration (PGA) has been chosen to characterize the ground motion level. The response (lateral displacement) of the axially loaded pile under earthquake loading, which is considered as Engineering Demand Parameter (EDP) has been studied in a probabilistic manner.

4. Acknowledgment

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5. References

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