Effect of Pile Stiffness on Seismic Response of Structure

Mohit Dange[1], Pramod Shinde[2], Prof. Phule S.N[3]
[1, 2] Dept of civil Engineering
[1, 2] P.A.H. Solapur university, Maharastra, India.
[3]Solapur university, Maharastra, India.

Abstract- *Pile foundations are widely employed for a variety of structures on shaky ground. The importance of seismic design in ensuring the effective operation of a structure under severe seismic loading conditions cannot be overstated. For the analysis of seismic forces on a structure, IS 1893 will be employed. This research entails the choosing of a specific form of building structure. A comparison of buildings with and without pile foundations will be shown. Because of the differences in their properties, the seismic behaviour of the various structures differs. The influence of pile stiffness on the structure's seismic response will be investigated. The rigidity of the piling foundation could have an impact on the structure. With the rise in seismic activity, there may be a need for more efficient pile foundation design to withstand earthquake loads. The major goal of this study is to compare pile stiffness with changes in diameter and zone.*

Keywords- Pile Foundation, STADD-Pro, Structure, Stiffness, zone, Pile Cap, Load Estimation, Pile cap, Pattern of Pile.

I. INTRODUCTION

When the soil beneath the foundation is weak and has low w bearing capacity, piles, which are relatively long, slender members that are driven into the ground or cast-in-situ piles, are the most commonly used deep foundation to support massive structures such as multi- story buildings , bridges, towers, dams, and so on. Piles must resist dynamic lateral loads in addition to supporting vertical compression loads, which are typical in off-shore constructions, retaining walls, and structures in earthquake- prone areas. Designing pile foundations for seismic conditions is becoming increasingly important as infrastructure grows and seismic activity increase. Several studies on seismic analysis and pile foundation design were done by various researchers, leading to the development of distinct theories. The seismicity of a structure's location (zone) and the subsurface conditions of the site are used to estimate the loads that operate on it during an earthquake.

II. OBJECTIVES

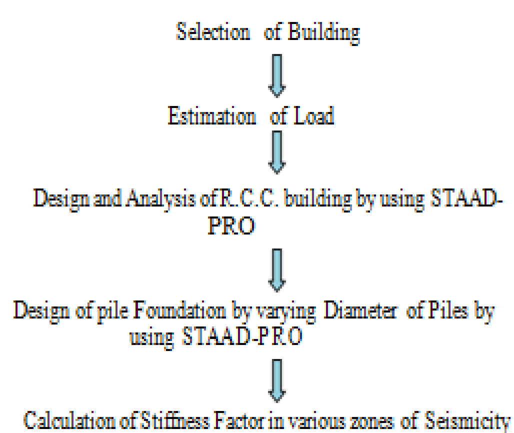
a) To analysis and investigate the effect of pile stiffness with varying diameter of piles.
b) To analysis and investigate the effect of pile stiffness with varying zones of seismicity.
c) Validation of Results.

III. METHODOLOGY

1. General

We were going to design a building utilizing staad-pro software and a pile foundation with varied diameter and zone in this assignment. It entails selecting numerous parameters for design purposes, as well as estimating various sorts of loads acting on the structure based on the structure type chosen in accordance with the code's recommendations. It also entails deciding on numerous criteria for the design of pile foundations, as well as determining the stiffness of the foundations after the piles have been designed.

2. Flow Chart of Methodology:



3. Selection of Building

Structure is a grouping of members chosen in such a way that they serve a single goal. There are various sorts of structures that are maintained, as seen below:

- **Rigid frame structure** - A rigid frame structure is one in which the members are connected by rigid joints.
- **Load bearing structure -**Is one in which the walls take all of the roof's weight and evenly distribute it throughout the foundation strata.

4. Estimation of Load

The structure is subjected to a variety of loads, including dead load, live load, wind load, and seismic load. The load can be determined using the height of the building, the number of occupants, the usage of the building, and the requirements specified in the various regulatory codes.

A. **Self Weight** - The self-weight of the structure is taken into account while calculating the dead load. The slab's self- weight, the column's self-weight, the beam's self-weight, and the floor finish were all measured. Only the dead load of brickwork is considered in the analysis, not the brickwork itself. In this scenario, all brick walls are considered to be 230 mm thick, even if the internal walls may only be 115 mm thick in fact.
B. **Live Load -** The live load for all floors is the same, while the live load for the roof is different. The distribution of live load is comparable to the distribution of slab self- weight, and STAAD uses the floor load command. For the same reason, I vote yes.
C. **Earthquake load -** earthquake load is a term used to describe the amount of damage caused by an earthquake. IS 1893 (Part 1): 2002.

Analysis and Design of Building Using STADD-PRO Software:

In practise, commercially accessible software is frequently used to evaluate, design, and detail multi-story buildings. STAAD. Pro SAP 2000, ETABS, SAFE, Nastran, Midas

NFX, ANSYS, and STRUDS are some of the commercial software packages on the market. A number of free/open source apps, such as Open Sees, Frame3DD, and IDARC 2D, are also available. Many of these apps can perform analysis and design. Special structural design software are also available, and some engineers have created their own spreadsheets for the design of structural elements (for example, Computer Design Consultants' FRAME, RC Slab, RC Beam, and RC Foundation).

IV. ANALYSIS OF G + 6 BUILDING

This case study considers a seven-story RC structure with three bays in one way with spans of 8 m, 5 m, and 5 m, and three equal bays of 5 m each in the opposite direction. The rest of the information needed for the analysis and design lis listed below.

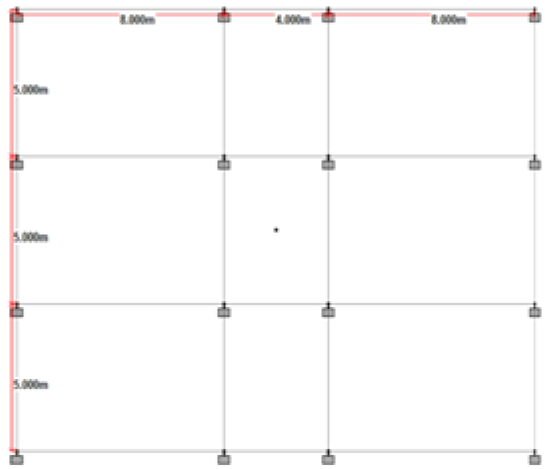


Fig. 1 Plan of Building

Details of Structure

- Details of Building=Ground+6storybuilding
- Location =Mumbai
- Walls= 230 mm thick brick masonry
- Typical floor to floor height= 3000 mm
- Height of Plinth = 450 mm
- Depth of Foundation = 2000 mm below ground level
- Bearing capacity of soil = 400 kN/m2

Loading on Structure

- Dead Load
- Roof Finish = 1.5 kN/m2
- Floor Finish= 1.0 kN/m2
- Live Load Roof= 1.5 kN/m2
- Floor= 5.0 kN/m2
- Wind Load=Not considered for design
- Seismic Load = Seismic Zone III
- Type of soil=Medium Soil

Other Information

- Concrete Grade = M25
- Reinforcement Grade= Fe 415
- posure Condition = Very Severe(Clear Cover =50)

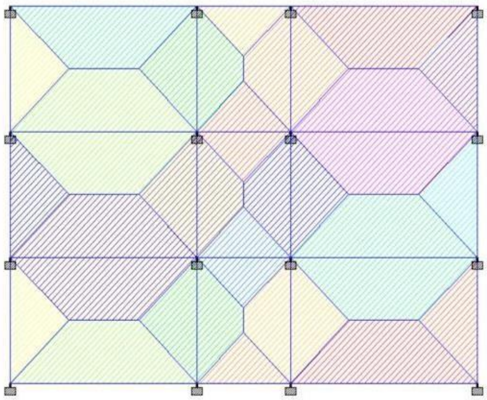


Fig.2 Typical distribution of slab loads on beams in STAAD.

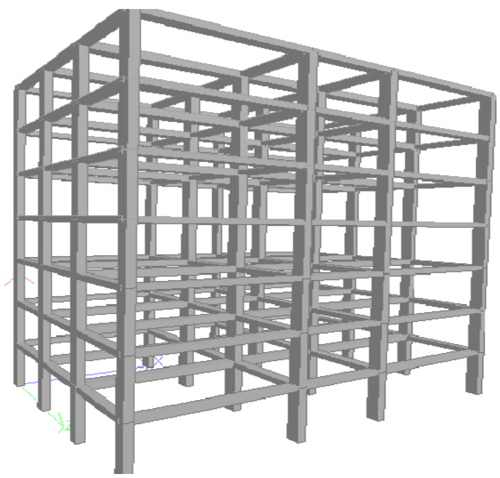


Fig.3 Beam Column Frame structure

Fig.4 Slab Plates

Result of Beam Design

Beams are designed in its STAAD.Pro through its in built program. IS 13920 is used for the design and result of beam. The length of beam is 5000 mm and size of beam is 400mm X 600mm.The cover required for beam is 50mm.Thearea required for to preinforcement for section 5000 mm is 2604.17 mm2. The area required for bottom reinforcement for section 5000 mm is 1579.55mm2. Shear reinforcement are provided in the form of stirrups. Two legged 8mm diameter stirrups are provided @ 130 mm c/c. Shear result of design at 740 mm away from face of support is also taken. For this shear reinforcement, two legged 8mm diameter stirrups are provided @ 190 mm c/c.

Result of Column Design

Columns are designed in its STAAD Pro through its in built program. IS 13920 is used for the design and result of column. STAAD Pro number for column is 15. The length of column is 3000mm and cross section of columnis400mm X 700 mm. The cover required for column is 50mm. The required steel area of column is 1816.55 m2. The required concrete area is 358183.44 m2. The main reinforcement required for column is equally distributed. It is reinforced with12-20diameterofbar.Theshear reinforcement can be referred to with tie reinforcement, hoop reinforcement. In confining reinforcement, 12 mm diameter of rectangular ties@100mmc/covermmlength800isprovided.Itis provided from each joint face towards mid span as per Clause 7.4.6 of IS 13920. Three number overlapping hoop along with crossties are provided along Y direction as per Clause 7.3.2 IS 13920. Also three number overlapping hoop along with crossties are provided along Z direction as per Clause 7.3.2 IS 13920. Rectangular ties of8mmdiameter@ 225mm c/care provided. The interactionratiois0.99as perclause 39.6 IS 456:2000.

Analysis and Design of Building Foundation Using STADD-PRO Software

Design of piles:

Step 1: structure run in STAAD foundation

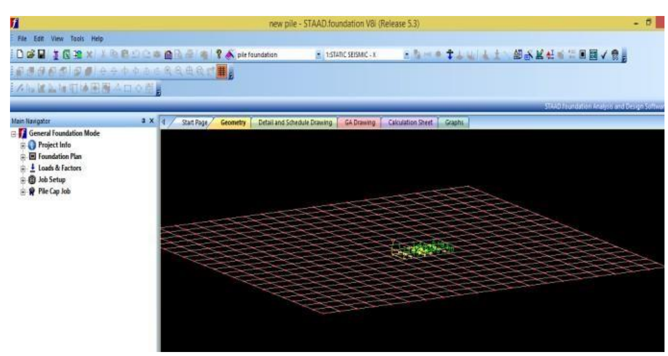


Fig.5 Foundation arrangement in STADD-Pro

Step 2: Generate the load combination

Fig.6 Load Generation Step 3: To create the job setup

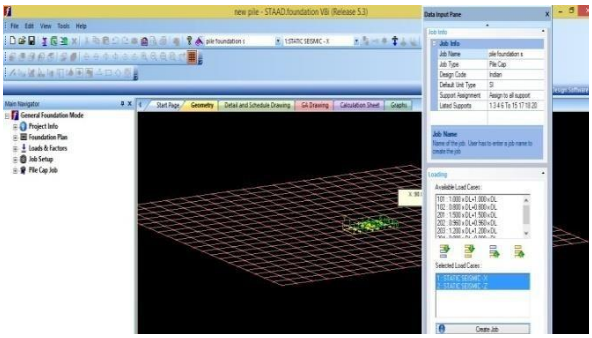


Fig.7 Job Setup Creation Step4: Input the design parameter

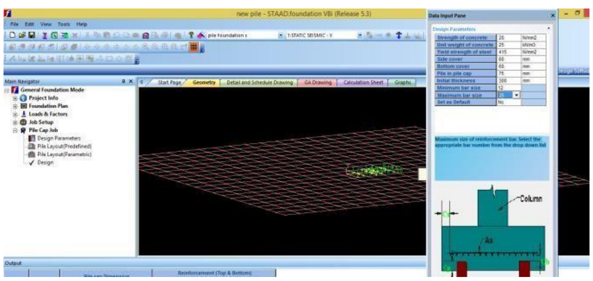


Fig.8 Input the design parameter

Step 5: Input the pile details

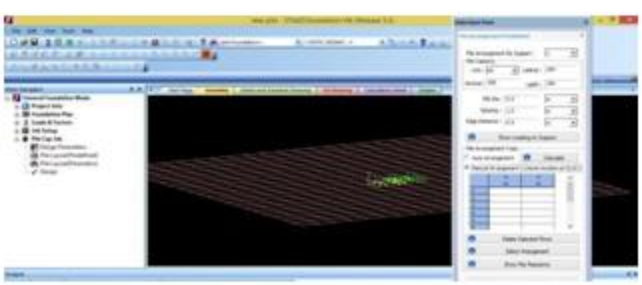


Fig.9 Pile arrangement

Step 6: Selection pile arrangement

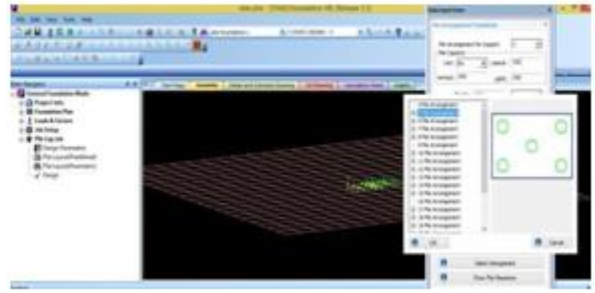


Fig.10 SelectionofPattern

Step 7: pile layout

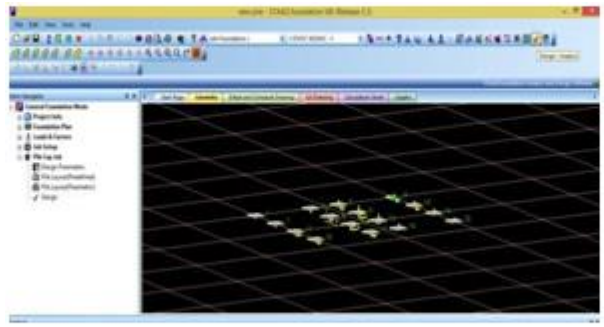


Fig.11 Pile Layout Step 8: calculation sheet of pile after design

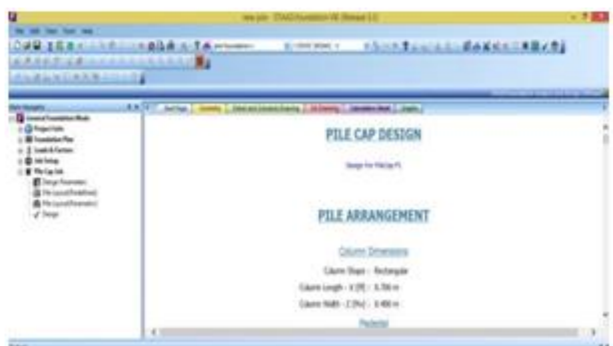


Fig.12 Design Result

Step 9: GA drawing of pile

Fig.13 Drawing of Pile, Column

V. RESULT AND DISCUSSION

PILE DESIGN

Arrangement of pile is such that it consist of five piles under one column. Shape of column is rectangular its length is 700mm and width is 400mm, pile spacing is 1500mm is taken also the pile edge distance is 500mm and pile diameter is 1000mm .piles consist of pile cap in which pile cap length is 3598mmand pile cap width is 2500mmthe thickness of pile cap is 300m axial capacity of pile is 250kn, lateral capacity of pile is 250kn anduplift capacity of pile is 250kn. Bottom clear concrete cover for pile is 60mm and side clear concrete cover is 60mm. Grade of concrete used m25 and grade of steel is 415 . Shape of pile cap is rectangular its width is 2500 mm and its length is 3598mm.

Table No.1.Loading applied at the top of Cap

Load Case	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
1	90.552	240.850	0.216	0.226	0.000	-233.221
2	0.324	428.991	96.732	185.091	0.000	-0.350

Pile Cap Design Calculation

Total pile number N = 5

Table No.2.Pile Reaction

Pile No.	Arrangement		Reaction		
	X(m)	Y(m)	Axial (kN)	Lateral (kN)	Uplift (kN)
1	-1.299	-0.750	0.000	18.111	-15.339
2	-1.299	0.750	0.000	18.111	-15.533
3	0.000	0.000	0.000	18.111	34.678
4	1.299	0.750	-15.533	18.111	0.000
	1.299	-0.750	-15.339	18.111	0.000

Reinforcement Calculations

Maximum bar size allowed along length 25mm Maximum bar size allowed along width 20mm

Bending Moment at Critical Section=137.812 kNm (Along Length)

Bending Moment at Critical Section=160.299kNm (Along Width)

Pile Cap thickness = 0.294 m Selected bar size along length 12 mm Selected bar size along width12mm

Selected bar spacing along length = 81.66 mm Selected bar spacing along Width = 105.03 mm Pile Cap Thickness Check

Calculated thickness (t) = 0.294 mm

Check for Moment (Along length)

Critical load case for thickness is reported only when required thickness is more than the given minimum thickness.

Table No.3.Moment (Along length)

Pile No.	Moment along x1-x1(kNm)	Moment along x2-x2(kNm)
1	136.266	0.000
2	0.805	0.000
3	0.414	0.414
4	0.000	0.969
5	0.000	136.429

Check for Moment along Width

Critical load case for thickness is reported only when required thickness is more than the given minimum thickness.

Table No.4.Moment along Width

Pile No.	Moment along y1-y1(knm)	Moment along y2-y2(knm)
1	78.974	0.000
2	0.000	0.467
3	2.257	2.257
4	0.000	0.562
5	79.068	0.000

Governing moment (Mu) =160.299 kNm

Check for one way shear (along length)

Table No.5.one way shear (along length)

Pile No.	Shear Force x1-x1(kN)	Shear Force x2-x2(kN)
1	143.591	0.000
2	0.849	0.000
3	0.000	0.000
4	0.000	1.021
5	0.000	143.763
TOTAL	144.440	144.784

Design Shear Force for One-Way Action Vu= 144.784kN

Check for one way Shear (along width)

Table No.6.one way Shear (along width)

Pile No.	Shear Force y1-y1(kN)	Shear Force y2-y2(kN)
1	128.873	0.000
2	0.000	0.762
3	10.665	10.665
4	0.000	0.916
5	129.028	0.000
TOTAL	268.566	12.343

Design Shear force (Vu) = 268.566kN

Check for two way shear (along length)

Table No.7.Two way shear

Pile No	Two-way Shear at column face (kN)
1	143.591
2	0.849
3	6.132
4	1.021
5	143.763
TOTAL	295.356

Design Two-Way Shear force= 295.356 kN

Calculation of maximum bar size (along length)

Selected maximum bar size = 25 mm

Bar diameter corresponding to max bar size (db) =25 mm

As Per IS 456-200 Cl. No 26.2.1

Development Length(ld) = $\frac{0.87 \times d_b \times f_y}{4 \times \tau_{bd}}$

Where, fy=strength of steel

db= bar diameter, Tbd= bond stress =1.126m

Allowable Length(ldb) = Where, $0.5 \times (B - b) - C_s$

B= width of column

Cs= side cover, ld= desirable length.

=1.389Mldb>ldhence,safe

Along width

Selected maximum bar size = 20 mm

Bar diameter corresponding to max b $\frac{0.87 \times d_b \times f_y}{4 \times \tau_{bd}}$

As Per IS 456-2000 Cl.No 26.2.1

Development Length(ld) = $\frac{0.87 \times d_b \times f_y}{4 \times \tau_{bd}}$

Where, fy=strength of steel

db=bardiameter,Tbd= bondstress=0.901M

Allowable Length(ldb)= $0.5 \times (H - h) - Cs$

Where, H= Height of column

Cs=sidecover,ld=desirablelength.

=0.990M ldb >ld hence, safe

Top reinforcement is provided same as bottom reinforcement.

Along Length

As Per IS 456-2000 Cl. No 26.5.2.1

Minimum Area of Steel (Astmin) = $0.12\% \times B \times h_{cap}$

Where,

hcap =height of pile cap,

B=width of column, = 868.500 mm2

As Per IS456-2000 annex G, G-1.1b Area of steel required (Asq)

$$= 0.5 \times \left(\frac{f_c}{f_y}\right) \times \left(1 - \sqrt{1 - \frac{4.5977 \times M_u}{f_c \times b \times d \times d}}\right) \times b \times d$$

Where, fc=compressive strength of concrete

Mu= ultimate moment

fy= strength of steel = 3340.172 mm^2

Area of steel provided (Ast) = 3340.172mm^2 Astmin<= Ast

Steel area is accepted.

Minimum spacing allowed (Smin) = 40 + db= 52 mm Selected spacing (S) = 81.66 mm

Smin <= S <= 450 mm selected bar size<selected maximum bar size Along width

As Per IS456-2000 Clause 26.5.2.1

Minimum Area of Steel (Astmin)= $0.12\% \times B \times h_{cap}$

= 1230.516 mm^2

Design Two-Way Shear force= 295.356 kN **Calculation of maximum bar size (along length)** Selected maximum bar size = 25 mm

Bar diameter corresponding to max bar size (db) =25 mm As Per IS 456-200Cl.No 26.2.1

Development Length(ld) =

Where,

fy=strength of steel

db= bar diameter,

Tbd= bond stress =1.126m

Allowable Length(ldb) = Where, B= width of column

Cs= side cover, ld= desirable length.

=1.389Mldb>ldhence, safe Along width

Selected maximum bar size = 20 mm

Bar diameter corresponding to max bar size(db)=20mm As Per IS 456-2000 Cl.No 26.2.1

Development Length(ld) =

Where, fy=strength of steel

db=bar diameter, Tbd= bondstress=0.901M

Allowable Length(ldb)= $0.5 \times (H - h) - Cs$ Where, H= Height of column

Cs=side cover, ld=desirable length.

=0.990M ldb >ld hence, safe

Top reinforcement is providedsame as bottom reinforcement.

Where, hcap=height of pile cap,

B=width of pile cap

As Per IS456 -2000 annex G,G-1.1 b Area of steel required(Asq)=-

$$0.5 \times \left(\frac{f_c}{f_y}\right) \times \left(1 - \sqrt{1 - \frac{4.5977 \times M_u}{f_c \times b \times d \times d}}\right) \times b \times d$$

Where, fc=compressive strength of concrete
Mu= ultimate moment
fy= strength of steel = 3750.902 mm^2
Area of steel provided(Ast)=3750.902mm^2
Astmin<= Ast
Steel area is accepted
Minimum spacing allowed (Smin)=40+db=52.00mm
Selected spacing (S) = 105.03 Mm
Smin <= S <= 450 mm
Where, Smin=Minimum spacing, S=spacing allowed The reinforcement is accepted
selected bar size < selected maximum bar size

Result of Stiffness Calculation

Pile stiffness in zone 3 by pile diameter changing

a) Diameter of pile = 500mm

Area of pile = 0.196 m^2, Length of pile = 3.598m,
Modulus of elasticity=29580N/mm^2
Moment of inertia=3.06x10-3m4
Stiffness Calculation
Refer IS 2911 Part1/Sec 2 2010 Annex C Cl.6.5.2, For piles in sand and normally loaded clays Stiffness factor= (EI/K1)1/5
Where,
E = Young's modulus of pile material
I=Moment of inertia of the pile cross section
K1=Modulus of sub grade reaction
Solving above Stiffness factor = 1.767
As,IS2911 Part1/Sec22010 AnnexCCl.3
L≤2T: Indicates short (rigid) pile
L ≥ 4T: Indicates long (flexible) pile From above, pile stiffness in zone3 with pile diameter 500mm is 1.767. It satisfies the condition
L≤2T, soitisa case of rigid pile behaviour.

b) Diameter of pile = 700 mm

Area of pile = 0.384 m^2
Length of pile = 3.598m Modulus of elasticity = 29580 N/mm^2
Moment of inertia = 0.0117 m4
Stiffness Calculation
As, IS 2911 Part1/Sec 2 2010 Annex C Cl.6.5.2. For piles in sand and normally loaded clays Stiffness factor= (EI/K1)1/5
Where,
E = Young's modulus of pile material
I=Moment of inertia of the pile cross section
K1=Modulus of sub grade reaction
Solving above Stiffness factor = 2.311 As, IS 2911 Part1/Sec 2 2010 Annex C Cl.3.
L≤ 2T: Indicates short (rigid) pile
L ≥ 4T: Indicates long (flexible) pile
From above, pile stiffness in zone 2 with pile diameter 700 mm is 2.311. It satisfies the condition
L≤2T, so it is a case of rigid pile behavior.

Pile stiffness in zone 2 by pile diameter changing.

a) Diameter of pile = 500mm
Area of pile=0.196 m^2**,**
Length of pile=3.598m
Modulus of elasticity=29580 N/mm^2
Moment of inertia=3.06x10-3m^4

Stiffness Calculation
Refer IS 2911 Part1/Sec 2 2010 Annex CCl.6.5.2. For piles in sand and normally loaded clays Stiffness factor= (EI/K1)1/5
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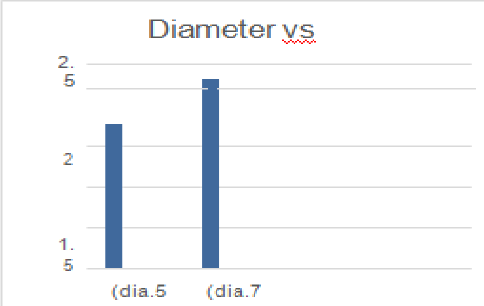

Chart 1 Graph of Stiffness Vs Diameter in Zone II

From above graph shows that stiffness of 500mm diameter pile is 1.76 and 700mm diameter pile is 2.31 hence rigidity of pile increase to in the same zone, When zone changes there is no change in stiffness as rigidity of pile remains same.

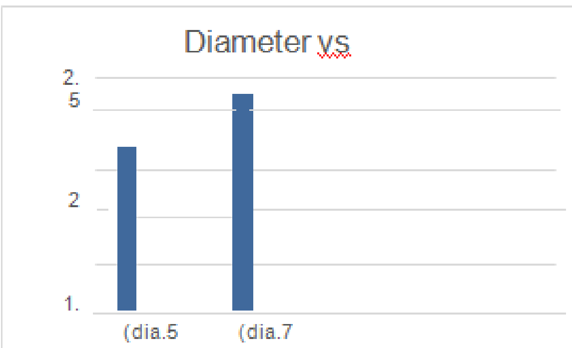

Chart- 2 Graph of Stiffness Vs Diameter in Zone III

VI. CONCLUSIONS

1) It is observed the pile cap has a good contribution against the lateral load.
2) By changing the zone there is no change stiffness of pile.
3) By changing the diameter of pile from 500 mm to 700 mm there is changeinstiffnessof32%insamezone.
4) The different factor like length of pile, position of pile cap from ground level implies lateral resistance of pile cap.
5) The pile stiffness is directly proportional to modulus of elasticity of pile, the higher the modulus of elasticity of pile, higher is the pile stiffness. The material of pile and cap influences the pile cap stiffness.
6) Pile nature is rigid so behaviour of structure is also rigid against seismic response.
7) It is also represented highlighting the key points to be considered for seismic design of pile foundation.

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