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# RETROFITTING OF PIER FOUNDATION CAUSED DUE TO THE FAILURE OF EXISTING PILE GROUP

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**Abstract -** Now-a-days retrofitting is expanding its legs in the world like a wildfire, as many of the historical, public and private important structures get old and become weak due to flow of time. Retrofitting is one of the best options to make an existing inadequate building safe against future probable earthquake or other environmental forces. Retrofitting is the process of addition of new features to older buildings, heritage structures, bridges etc. Retrofitting reduces the vulnerability of damage of an existing structure during a near future seismic activity. It aims to strengthen a structure to satisfy the requirements of the current codes for seismic design. In this respect, retrofit is beyond conventional repair or even rehabilitation. It is the modification of existing structures to make them more resistant to seismic action, motion of ground, and failure of soil due to earthquakes or other natural calamities such as tornadoes, cyclones, and winds with high velocity caused by thunderstorm, snowfall, hailstorms etc. Structures lose their strength in due course of time, some structures are important in view of public, social or past importance. Retrofitting helps to increase the strength, resistivity and overall lifespan of the structure. However, retrofitting may also be referred to the strengthening of foundations failed due to excessive settlements.

***Key Words***: Pier .Pile.PileCap. Shear Force, FEM modeling

## 1. INTRODUCTION

A pier, in architecture, is an upright support for a structure or superstructure such as an arch or bridge. Sections of structural walls between openings (bays) can function as piers.

Foundations provide support to the structure, transfers the loads from the structure to the soil. But the layer at which the foundation transfers the load shall have an adequate bearing capacity and suitable settlement characteristics.

*Pile foundation*, a kind of deep foundation, is actually a slender column or long cylinder made of materials such as concrete or steel which are used to support the structure and transfer the load at desired depth either by end bearing or skin friction.

Following are the situations when using a pile foundation system can be

- When the groundwater table is high.
- Heavy and un-uniform loads from superstructure are imposed.
- Other types of foundations are costlier or not feasible.
- When the soil at shallow depth is compressible.
- When there is the possibility of scouring, due to its location near the river bed or seashore, etc.
- When there is a canal or deep drainage systems near the structure.

### 1.1. CASE STUDY

This is a case study of a failed pier foundation due to settlement of the piles. Along a riverbed an ongoing construction of bridge pier had failed due to the faulty construction practices, it was found that after through investigations that the pile was terminated within clayey soil strata. When the construction of superstructure was completed, the piles which were terminated within the soft soil strata begin to sink & eventually the entire pile cap along with the pier got tilted. Since it is not easy to dismantle & re-construct the entire pier & pile cap, it was decided to jack up the pier as per the as-built & repair/retrofit the entire structure. The pile cap was decided to retrofit with the drilled & bonded dowels by extending it to few meters there by connecting it to the micro piles which are bored up to the hard rock strata.

Thus, in this case study we have modelled the entire pier along with its foundation using FEM techniques. We have also ascertained for the overall stability of the retrofitted structure for Dead load, live load, & seismic actions by analysing the FEM model. Finally, this case tudy is concluded by evaluating the design/capacity ratio (D/C) of the pier for the worst enveloping combination of loads.

Fig no 1.1 settling pier

**Fig no 1.2 pile cap**

### 1.2. OBJECTIVE.

Retrofit in structures is done to increase the survivability functionality. The applications include different types of bridges, buildings, and industrial structures, transport structures in urban areas, earth retaining structures and marine structures.

### 1.3 METHODLOGY

1. To study the cause of failure of Pile Foundation by using engineering methods.

2. Retrofitting of the damaged PIER by using additional piles & design of pile cap.

3. Analyzing the structural adequacy of the retrofitted pile group for the given loading conditions

4. To prove how FEM has advantage over old methods of approximate analysis.

## 2. LITERATURE REVIEW

A Literature Review Is Carried Out On The Design And Analysis Of Failure Of Pile And Pier With Special Interest The Slide Present A Brief Report On Literature Review As A Part Of The Project.

1. Wanil Yung (1998) "**Research On The Nonlinear Performance Of The Pier Under Horizontal Force "**

This Paper Was Established This Paper Presented By Usually, A Large Horizontal Force Will Be Generated To The Pier In The Constriction Process, Which May Include Significant Influences O The Pier's Safety ,In Case Of Bridges With High Pier And Long Span. Some Cracks Emerged In The Foot Part Of A The Construction Stage And Horizontal Force Believed To Have Been Load On It ,Hence It Reliability Was Ducted.

2. **J**. K. Jain (1998)**"An Analysis Of Recent Bridge Failures In The United States "** In This Paper Author Was Examined In Of Pier Foundation Are 3 780 Mm. In Traffic Direction And 10080 Mm. In Current Direction At R.L. 94.0um. The Pier Foundation Is Resting On Boundary Strata. During The Floods In The Year 1995 The Pier Constructed In Mid-Stream Failed. This Brought Down Both The Deck Slabs Of The Bridge At The Bed Level. Both The Deck Slabs Are In Good Condition And It Is Proposed To Use Them By Lifting Of Slabs And Reconstructing Central Pier After Complete Investigation Of Founding Strata. This Paper A Case Of Foundation Failure, Due To Which The Complete Bridge Structure Has Collapsed, Is Considered. The Bridge Is Situated Inkm. 26/6 On Langi Durg Road. It Was Constructed In The Year I 980-81. This Bridge Has Two Solid Slab Spans Of 15.25 Meters Each. The Substructure Is Of Solid Coarse Rubble Stone Masonry.

3. Nevin L. **Gómez (2014) Performance Of Circular Reinforced Concrete Bridge Piers Subjected To Vehicular Collisions"** In This Paper A Case Of Foundation Failure, Due To Which The Complete Bridge Structure Has Collapsed, Is Considered During The Floods In The Year The Pier Constructed In Mid-Stream Failed. A Sensitivity Analysis Suggests That Different Pier Parameters Have A Profound Effect On Failure Modes And Distribution Of Impact Forces. Piers With Large Stiffness Result In High Impact Forces, Low Lateral Displacements, And High Resistance To Shear Forces And Bending Moments. A Performance-Based Analysis Shows That Bridge Piers Can Be Designed Using Damage Ratios Associated With Particular Damage States.
4. Weibing Peng (2014) **Research on Mechanism of Overturning Failure for Single-column Pier Bridge"** This paper presents the research on mechanism of overturning failure on box girder under overload and partial load for the single-column pier bridges.The results indicate that the overturning load calculated by finite element simulation conforms to the measurements collected at the collapse site of Chunhui Bridge, reflecting the validity of the proposed study. The ultimate state of the overturning stability can be used to judge whether the bridge is overturning. It is more accurate than using the disengaging state of one side end bearing to judge, and the overturning ultimate load is 1.5-2 times than the rotating ultimate load.

5. SoroushSafakhah, Ali Kheyroddin (2018) **"Experimental study on damage detection of RC bridge piers under ambient vibration"** This paper presents an experimental method for damage detection of bridge piers as the basic and strategic elements in such engineering structures. Definition of percentage and location of damage are considered as initial data to solve damage detection problems. Nowadays, regarding the development of inverse methods for damage detection such as definition of objective functions and optimization approaches, the present experimental study can be utilized as initial stage of such methods. In this study, three 1/3 scaled test specimens of RC bridge piers are casted. Finally, the results revealed that the proposed method is an appropriate method to determine the severity of damage and its location as the primary information in reverse-optimization methods.

## 3. MANUAL ANALYSIS OF PILE CAPACITY

From Geo-technical data, we can re-analyses the pile load capacity as per IS 2911:2010 and find out the overall settlement. This analysis result will help us to know the main cause of failure of pile foundation. Following is the manual calculation of pile design.

| Pile Dimensions | |
|---|---|
| Pile Type | DCIS |
| Pile Length M | 20 |
| Pile dia M | 1000 |
| Pile section | Circular |
| Increased base % | 30 |
| Safety factors | |
| Shaft | 1.5 |
| End Bearing | 4.0 |
| Design Parameters | |
| K | 0.85 |
| Capacity when founded in rock | |
| Shaft %UCS | 10 |
| Base %UCS | 450.00 |
| Settlement Parameters | |
| *K1* | 2 |
| *K2* | 0.2 |
| *K3* | 0.5 |
| S/EB ratio % | 10 |
| Fines % | 30 |

**Design Load: 4000.00kN**

**3.1 Calculation of layer and total capacities:**

**Layer 1**

$C=K_{v.}P^{o.}\tan(\delta)$
$=0.85 \times 90 \times \tan(35)$
$=53.56$
Layer Friction Capacity
$F=\varphi.c.t.\pi$
$= 1x53.56x9x\pi$
$= 1514.543kN.$
Layer bearing capacity
Q=0kN.
Layer Total Capacity
$C_{ap} = f + q$
$=1514.5 + 0$
$= 1514.5kN$

**Layer 2**

$\omega = \frac{c_i}{P^0}$
$= \frac{25}{184.5}$
$= 0.1355$
$\alpha = 0.5 \cdot \omega^{-0.5}$
$=0.5x0.1355^{-0.5}$
$=1.358$
$c=c_i \times \alpha$
$=25x\ 1.3583$
$=33.958$
Layer Friction Capacity
$F=\varphi.c.t.\pi$
$=1x33.958x1.5x\pi$
$=160.023kN$
Layer bearing capacity
Q=0kN.
Layer Total Capacity
$C_{ap} = f + q$
$=160.02 + 0$
$= 160.02kN$

**Layer 3**

$C=K_v.P^o.\tan(\delta)$
$=0.85 \times 207 \times \tan(20)$
$=64.041$
Layer Friction Capacity
$F=\varphi.c.t.\pi$
$=1x64.041x4.5x\pi$
$=905.358kN$
Layer bearing capacity
Q=0kN.
Layer Total Capacity
$C_{ap} = f + q$
$=905.35 + 0$
$= 905.350kN$

**Layer 4**

$\omega = \frac{c_i}{P^0}$
$= \frac{50}{245}$
$= 0.2041$
$\alpha = 0.5 \cdot \omega^{-0.5}$
$=0.5x0.20408^{-0.5}$
$=55.340$
Layer Friction Capacity
$F=\varphi.c.t.\pi$
$=1x55.34x5x\pi$
$=869.279kN$
Pile base effective diameter
$D_{iae}=1.3 \times d_{ia}$
$=1.3 \times 1000$
$=1300.00mm$
Base bearing area

$$A = \frac{d_{iae}^2 \Pi}{4}$$

$$= \frac{1300^2 \times \Pi}{4}$$

$=1.327x10^6 mm^2$.

Layer Bearing Capacity

$Q=9 \times C_i \times A$

= 9 x 50 x 1.3273

=597.285kN.

$C_{apd}=f_{totd}+b_{totd}$

=2299.5 + 149.32

=2448.820kN.

**Friction force transfer**

$F_f=F_{ult} \times [1-e^{-1xkxd}]$

=2414x0

=0kN.

Total Friction Capacity – all layers

$F_{tot}$=3449.19kN

Total Bearing Capacity – bottom Layer

$B_{tot}$=579.30kN

Total Capacity

$C_{ap}=f_{tot}+b_{tot}$

=3449.2 + 597.3

**=4046.500kN**

**Total Design Friction Capacity – all layers**

$$ftotd = \frac{ftot}{S_F}$$

$$= \frac{3449.2}{1.5}$$

**=2299.467kN**

**Total Design Friction Capacity – bottom layers**

$$btotd = \frac{btot}{S_F}$$

$$= \frac{597.3}{4}$$

**=149.325kN**

**Total Design Capacity = 2299.467 +149.326 = 2448.792kN<4000.00kN.**

The case study us clearly the main reason for failure of pile foundation, which was due to local shear failure of pile leading to excessive settlement. In this chapter we shall deal about the retro fitting of the pile foundation by using additional micro piles, which are bored up to the level of hard rock area. Also, we shall design a suitable pile cap for the failed pier & analyze for various loading combinations using suitable FEM tool. And ensure the structural safety and adequacy of the micro piles.

In this retrofitting method, a model of pile foundation with micro pile is modeled using FEM tool SAP 2000. The pile cap is designed for dead loads, live loads & for seismic actions the loads are considered as per IRC gives the schematic view of the bridge foundation retrofitted by micro piles. The existing piles group of 8 numbers is having a diameter 1.0m while the surrounded micro piles are having diameters of 300mm. The spacing of micro pile is kept 2.5 times the diameter of the micro pile. Finally, design of pile cap was carried for enveloping load case.

**3.2 Parameters Considered for the Analysis**

Material Properties

Concrete grade (fck) 50 N/mm²

Steel grade (fe) 500 N/mm²

Allowable stress of steel in tension and shear

σst = 240 N/mm²

Allowable stress of steel in direct compression

σsc = 205 N/mm²

Allowable compressive stress in concrete in flexure σcbc = 16.00 N/mm²

Allowable comp. stress in concrete in direct compression

σcc = 12.0 N/mm²

IRC:21-2000, 303.2.1, Table 9,10

**Levels**

High Flood Level = 906.5 m

Average Ground Level = 903.4 m

Total depth of longitudinal Girder including Slab = 3.00 m

Thickness of pier cap = 0.9 m

Top level of Pile Cap (PCL) = 902.5 m

Thickness of Pile Cap = 2.250 m

Bottom level of Pile Cap (PBL) = 900.25 m

Thickness of Bearing = 0.3 m

Thickness of Bearing concrete Pad = 0.2 m

Hence the total height of PierH = 24.5 m

*As per IRC: 6-2000, 217.1 for Equivalent live load Surcharge*

**Soil Data & Seismic Data**

| | |
|---|---|
| Unit weight of backfill soilγ | $16kN/m^2$ |
| Unit weight of concrete$\omega_{conc}$ | $24kN/m^3$ |
| Zone Factor (z) | 0.36 |
| Importance Factor (I) | 1.2 |
| Angle between the pier cap& the earth α | 0 |
| Angle of internal friction of soil φ | 35 |

**3.3FRICTIONAL FORCE DUE TO RESISTANCE OF BEARINGS**

**For Pot Bearing**

Vertical dead Load 2140 kN

Total No of Bearing Per Pier 4

Contact area of Pot Bearing (Assuming size 500mmX500mm) 250000 mm2

Contact Stress ($6_p$) 8.756 kN/mm2

Pot bearing constant (k) 1.00

Max. Friction Coefficient $\mu_{max}$= 0.065

Maximum Frictional Force 138.36 kN

Total Lateral force due to frictional resistance of bearings, 276.72 kN

Lateral force due to frictional resistance of bearings, 276.72 kN

**Breaking Force :( As Per IRC:6-2000, 214.2)**

Braking force = 20% of the weight of the design vehicle (Class 70 R)

And this force acts along the bridge at 1.2m above the road level 12.10 m from base

Total weight of the IRC Class 70R vehicle = 700kN

**Seismic Forces on Pier**

Seismic Forces Due to Horizontal & Vertical excitation are considered

**Horizontal seismic forces:**

Superstructure: 732.00 kN
Pier: 621.76kN
Backfill soil mass: 526.67kN

**Vertical seismic forces:**

Superstructure: 412.00 kN
Pier: 256.86kN

**Loads and Moment Calculation**

Taking Moments about the C.G of Pier.

Following section involves about Finite Elemental Modelling of the micro pile & pile cap from pre-processing to post processing. Here we have shown different steps of modelling like, material definition, section data, loads, meshing and also post processing data like stress analysis, punching check, design data to D/C design vs capacity ratio etc

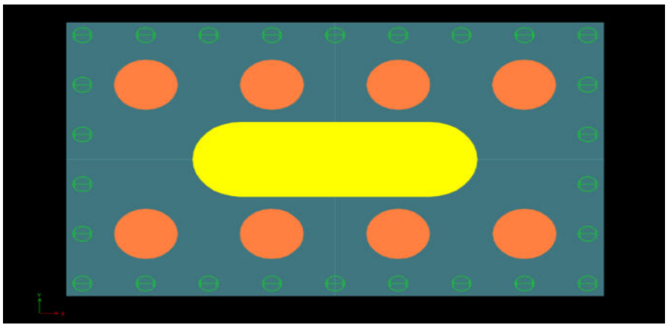

Fig 2 Plan View of Micro Pile & Pile Cap

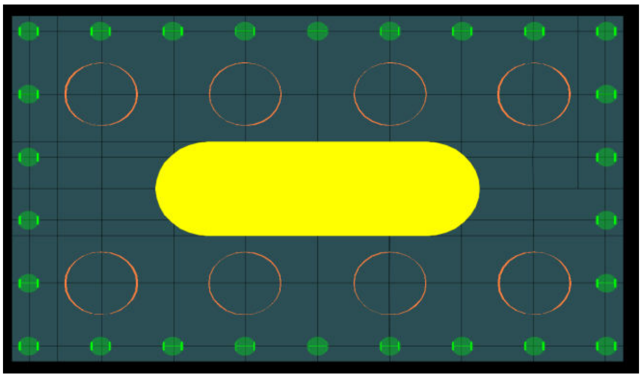

Fig 3.1 Meshing View of Micro Pile & Pile Cap

We can see that the meshing is done in an ordered manner where there is a possibility of high concentration of stress there the size of meshing is less compared to other sections. Near the micro piles very fine meshing is done to capture the punching shear checks. As we increase the accuracy that can be obtained from any FEA model is directly related to the finite element mesh that is used. Proper meshing allows for accurate analysis, regardless of whether the process is automated or manual. For any product development project to be successful, analysis is critical, and proper meshing is an important part of that analysis.

### 3.4 MATERIAL & LOAD DEFINITION

We have shown the material definition used for the purpose of analysis. Here the software has all the inbuilt materials or we can call them default materials used for the purpose of engineering analysis. Concrete we have defined the grades of M35, M40 & M50.

Steel rebar of grade Fe500 is also defined. Structural steel of grade Fe345 is defined for I-section used in the composite section of micro piles. Further, we can define any custom material in the FEM tool by defining their physical & mechanical properties. We have defined the loads used in the analysis, there loads are taken from the respective codes like IS 1893:2016, IS 875:1985, IRC 6..etc.

### 3.5 PUNCHING CHECK OF PILE & PILE CAP

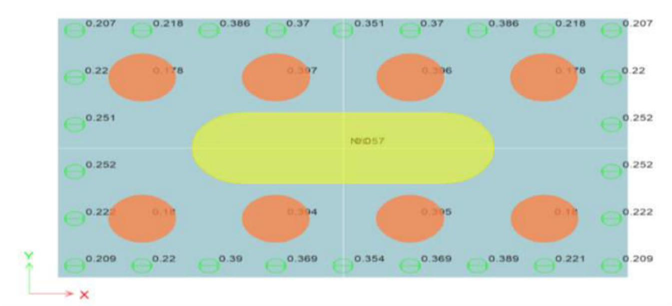

**Fig 3.2 Punching Check b/w Pile &Pile Cap**

The above figure shows the punching ratio between micro pile & pile cap for enveloping load case. Always for a safer design the punching ratio should not exceed 1. In our case we can clearly conclude that the micro pile retrofitting what we have done is safe since all punching ratios are within 1.

### 3.6 DESIGN VALIDATION OF FEM MODEL

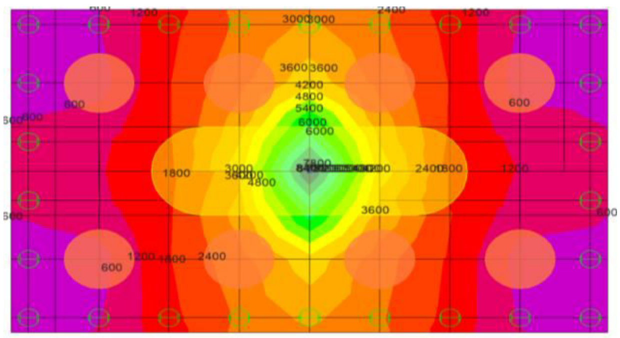

Fig 3.3 Maximum Resultant Bending Stress.

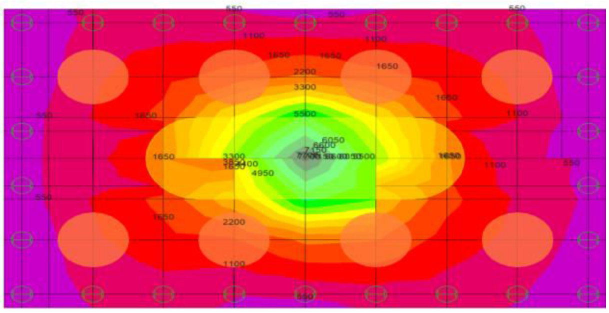

**Fig 3.4 Maximum Resultant Shear Stress.**

## 4. CONCLUSION

Here in this chapter we will give the final conclusions and references made in this case study.

1. Retrofitting is a new term in Indian construction industry which requires specialised skills to bring it to execution.
2. Construction chemicals now a days play a vital role in retrofitting of concrete structures wheather it's a old monumental structure or a bridge, we can repair and rehabilate easily.
3. FEM is very important tool in validating the retrofitting the works. In our case Finite Elements has played a effective role in predicting the sutiability of the system.
4. Its economical if we use micro piles for retrofitting works of bridge foudations compared to other methods of retrofitting.
5. This case study can be further taken up for research purpose for studying the soil structure interation between the micro piles and the soils.

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