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# Effect of Pile Cap Thickness on Bending Moment and Shear Stress: A Parametric Study of Bridge Substructure (Piers)

Sandeep Kumar, Atul Kaushik
M. Tech Students, Department of Civil Engineering,
World College of Technology and Management,
Gurugram-122506, India

Ankit Sethi
Assistant Professor, Department of Civil Engineering, World College of Technology and Management, Gurugram-122506, India

**Abstract - This study examines the effect of thickness of pile cap of bridge substructure (pier) foundation under constant loading and support conditions by the method of finite element modeling. Analysis has covered different pile cap depths 0.8m to 2.6m and it has been established that the depth of the cap decreased by 49.8 % and shear stress by 88.2 % as depth of the cap increased. Results showed that increased thickness of pile caps leads to better distribution of loads and shear capability where it affects shear more than it affects bending resistance although concrete and reinforcement quantity also increased. This study focused to assist design engineers and researchers in understanding the relationship between geometry of pile cap and stress behavior for more efficient substructure design.**

**Keywords - Pile cap, Substructure, Bridge pier, Bending moment, Stress distribution, Finite element analysis, Parametric study**

## 1. INTRODUCTION:

Pile caps are essential structural elements of bridge substructure foundation, transferring loads from bridge superstructure and substructure (piers & abutments) to piles, securing stability and durability of the bridge foundation system. The thickness of a pile cap is a critical parameter affecting internal stresses, bending moments, and also affect overall load distribution. The main objective of this research is to evaluate the behavior of pile cap with varying thickness with subject to stress and bending. The study also aims to check how much there is changes on the key structural performance like bending moment and shear stress with changes in the thickness of pile cap.

## 2. LITERATURE-REVIEW:

Previous research by **Anwar, K. S., & Patil, P. S. (2019)** studied the effect of thickness of pile cap for differential settlement using SAFE 2012 for RC high rise buildings. This technical research on the subject foundations such as pile in high rise buildings highlight the settlement prediction. Analyses of the structures in structural software (ETABS and SAFE) demonstrated that the with increase in the thickness of pile cap, bending moments also increased due to the increase in dead loads and decreases settlement and differential settlement. Moreover, it was also proved that rafts with high thickness resist punching shear in more efficient manner. On the bases of these research studies, it was find out that pile cap design with proper way and raft thickness, results in increased the stability and more efficient load transfer, which validated the efficiency of the foundations (pile) in case of deep foundations in high-rise building construction [1]. Subsequent studies by **Abbas, J. M., Chik, Z. H., & Taha, M. R. (2008)** employed numerical methods to analyse stress distribution and flexibility effects in pile cap systems [2].

**Huang, J., Shield, C. K., & French, C. E. (2008)** further elaborated and investigated an experimental study for parametric study by using design parameters which included the type, size, fixity, soil type and diameter & length of piles, and the span of bridge. It was find out that that bridge length and the type of the soil in the location highly influenced behavior of bridge. It was found by the researchers to be important to have a balance between the stresses in foundation (piles) and the superstructure, particularly in the long span and the stiffer soil. Hinged connections were not effective because of the rotation of piles on the pile cap and only the cast-in-situ piles were suitable only to short span bridges [3].

More recent developments in finite element modeling make analysis of nonlinear responses of reinforced concrete piles tops under heavy loading conditions more precise. The reason why the current investigation was carried out is because the relationship between

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the change in thickness of pile cap and its effect on the bending moments and stress distribution in bridge piers change, was not directly quantified.

## 3. BRIDGE INPUT DATA:

In figures, Fig.1 shows the details of bridge elevation, Fig.2 shows the pier cross-section and Fig.3 shows pier pile cap top plan. The details of the bridge for the input data are mentioned below.

*Span:* *40m*
*Deck Width:* *15.100m*
*Deck Thickness* *0.220m*
*No. of Girders:* *5 Nos. @ 3.2m c/c (Transverse)*
*Girder Depth:* *2.1m*
*Substructure:* *2 Column Portal Pier*
*Pier Dia.:* *1.8m*
*No. of Piles:* *6 Nos. @ 3.6m c/c (Longitudinal & Transverse)*
*Pile Dia.:* *1.2m*

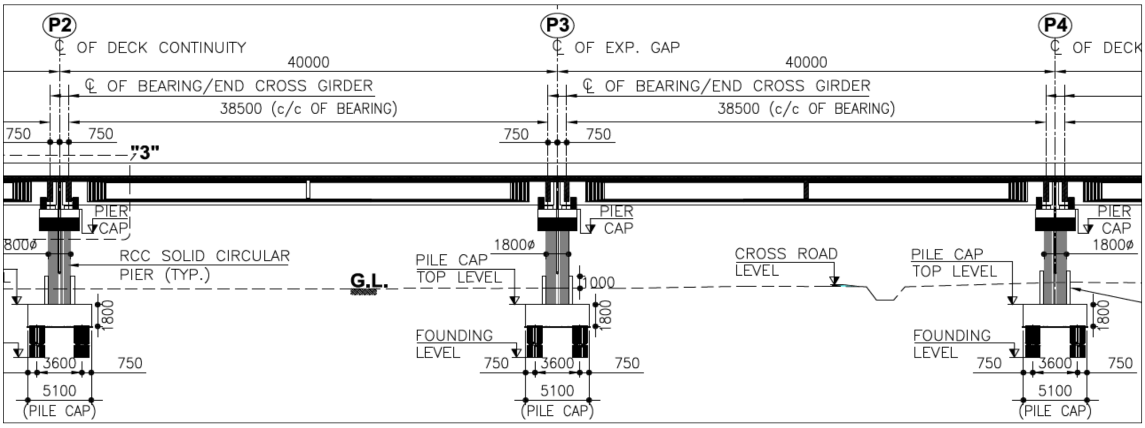


Fig. 1- Details of Bridge Elevation

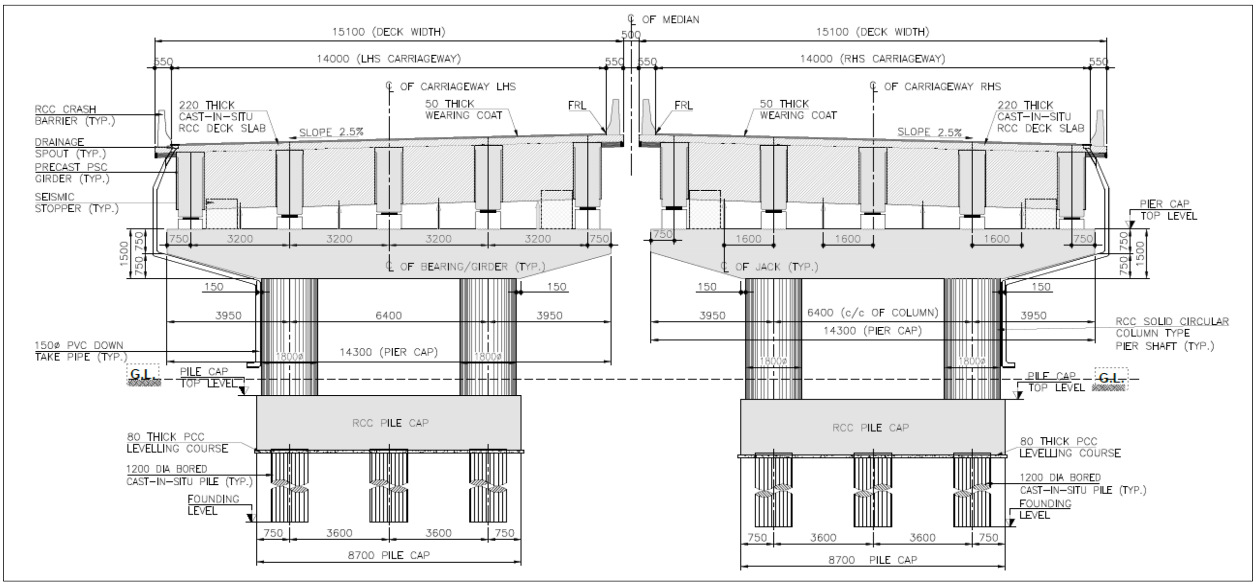


Fig. 2- Pier Cross-Section

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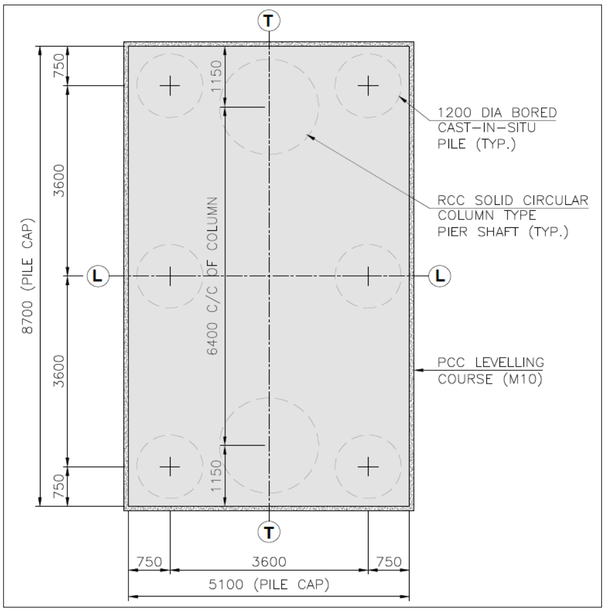


Fig. 3- Pier Pile Cap Top Plan

## 4. METHODOLOGY:

A three-dimensional finite element model was developed using STAAD. Pro V8i software to simulate bridge portal pier. Pier model was subjected to ULS & SLS load combination as per IRC load combination to replicate realistic service conditions for applied loads. The base of portal pier was modeled as fixed support. Then pier model analyzed for pile reactions. A three-dimensional finite element plate model was developed to simulate bridge pier pile cap on which pile reactions were applied as the loads. The concrete grade assigned was M35. The mesh was refined near critical stress zones for accuracy. Then for different thicknesses (ranging from 0.8 m to 2.6 m), the pile cap was analyzed for bending moments and shear stress.

### 4.1 Analysis of Pier:

Load (average) per Bearing Applied mentioned as below:

| | |
|---|---|
| Dead Load (i/c Girder Self Weight, Deck Slab, Cross Diaphragm): | 90 ton |
| SIDL (i/c Crash Barrier and Wearing Coat): | 15 ton |
| Live Load (Max. Reaction Case, 4 Lane Loading): | 18 ton |
| Live Load (Max. Longitudinal Moment Case): | 11 ton |
| Live Load (Max. Transverse Moment Case): | 11 ton |
| Braking Force: | 4.6 ton |
| Temperature: | 45°C |
| Seismic Longitudinal (Zone III): | 8.5 ton |
| Seismic Transverse+Vertical: | 8.5 ton |
| Special Vehicle (SV) Loading: | 30 ton |
| Wind Load: | 1.5 ton |

Fig. 4 shows the 3D Model of Pier (Excluding Pile Cap) in STAAD. Pro V8i software. The different load cases applied with above load values are shown in fig. 5. In fig. 6 typical loadings on pier are shown. The analysis of pier has been carried out for the input reaction in pier pile cap.

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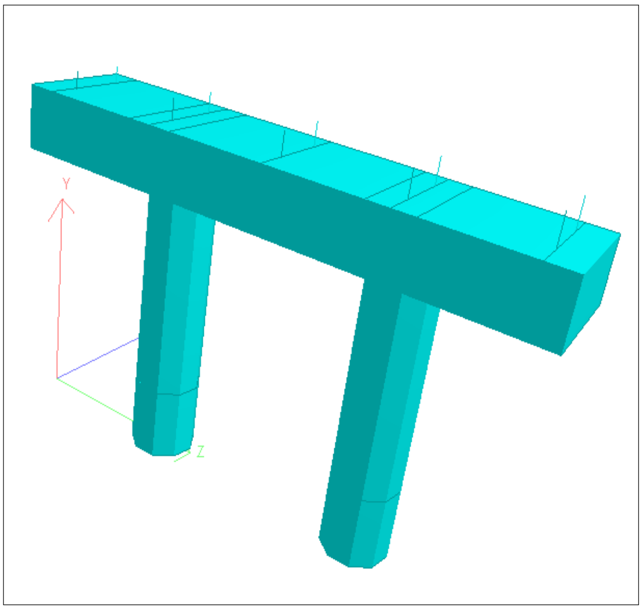

Fig. 4- 3D Model of Pier (Excluding Pile Cap)

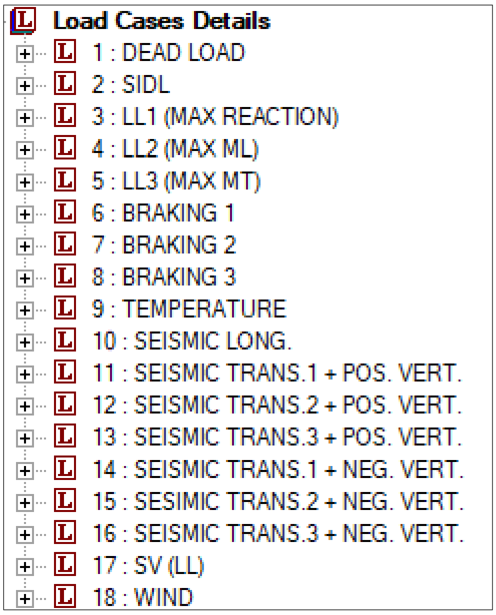


Fig. 5- Applied Load Cases

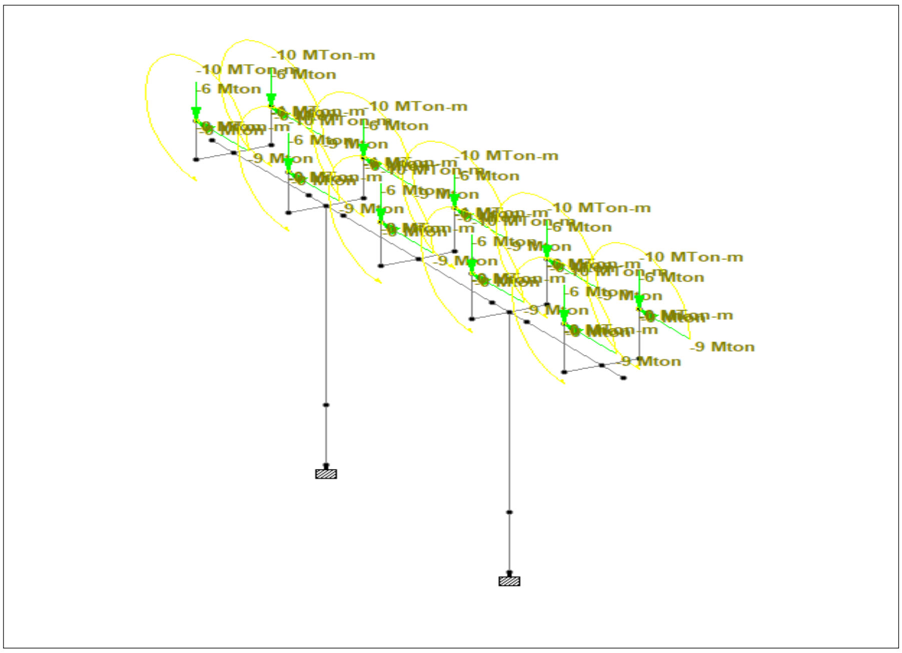


Fig. 6- Showing Typical Load Applied on Pier

4.2 **Analysis of Pier Pile Cap:**

Pile Reaction extracted from pier analysis are applied on plate model of pile cap. Fig. 8 shows the pier pile cap Plate model. Fig. 9 shows the typical load application pattern on pile cap model. Fig. 10 and 11 shows the results Plate Model Result Extraction for Bending Moment and Shear stress respectively.

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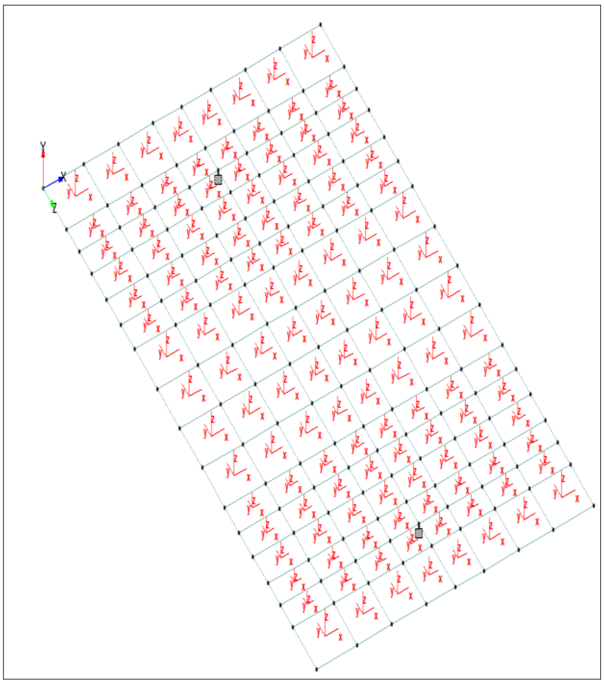

Fig. 7- Showing Local & Global Axis

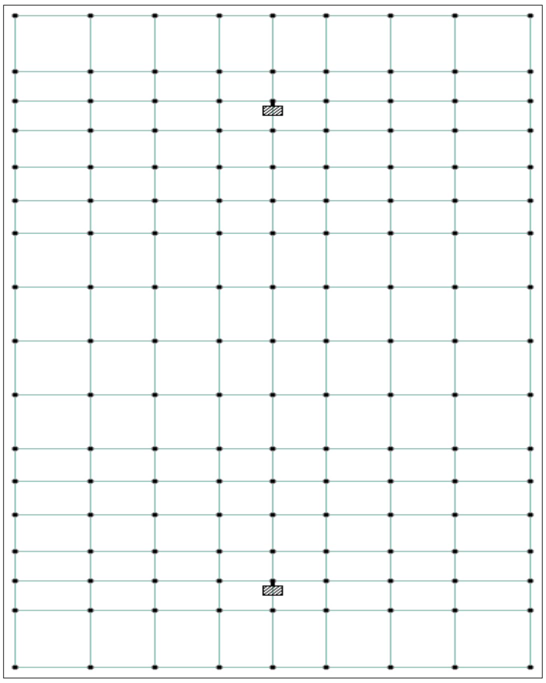

Fig. 8- Showing Plate Model of Pile Cap

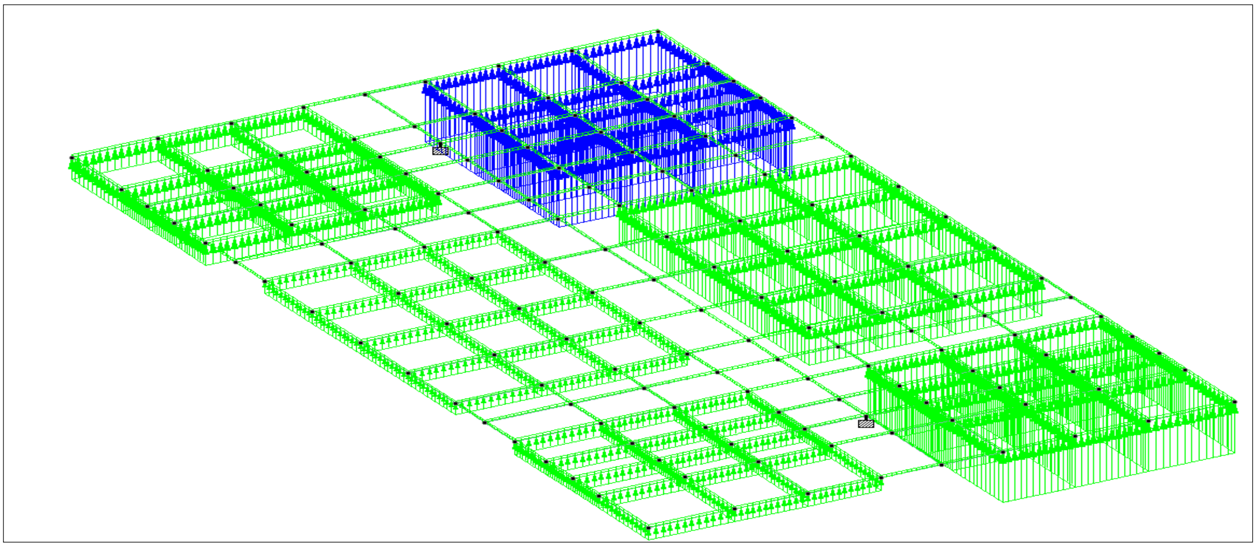

Fig. 9- Showing Typical Load Application Pattern

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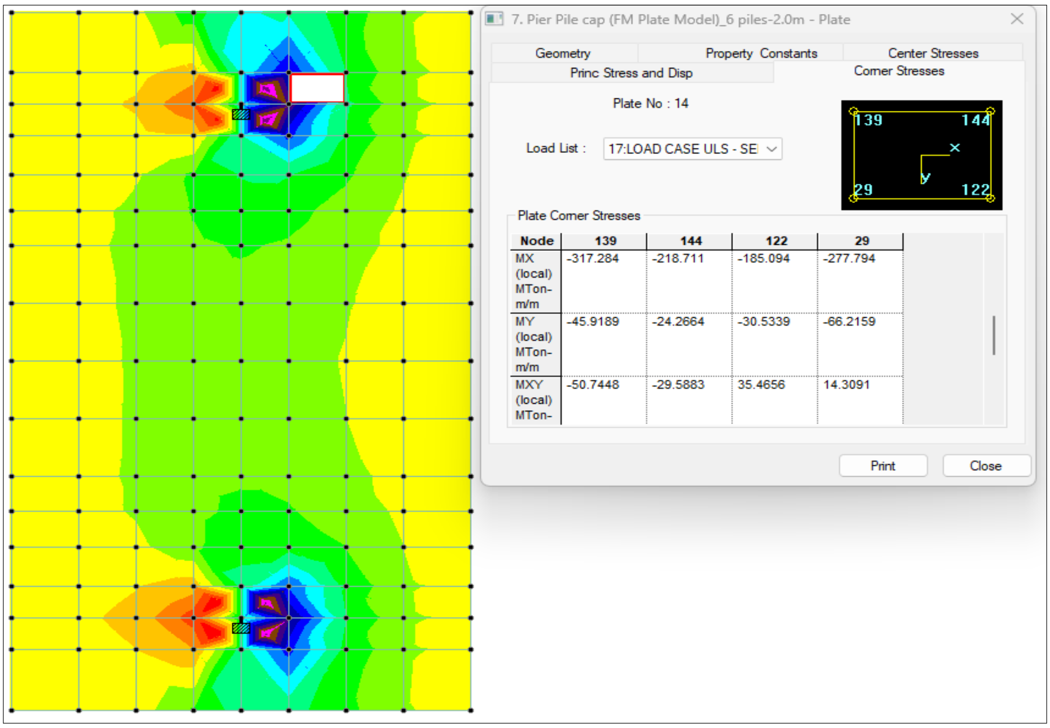


Fig. 10- Showing Plate Model Result Extraction for Bending Moment

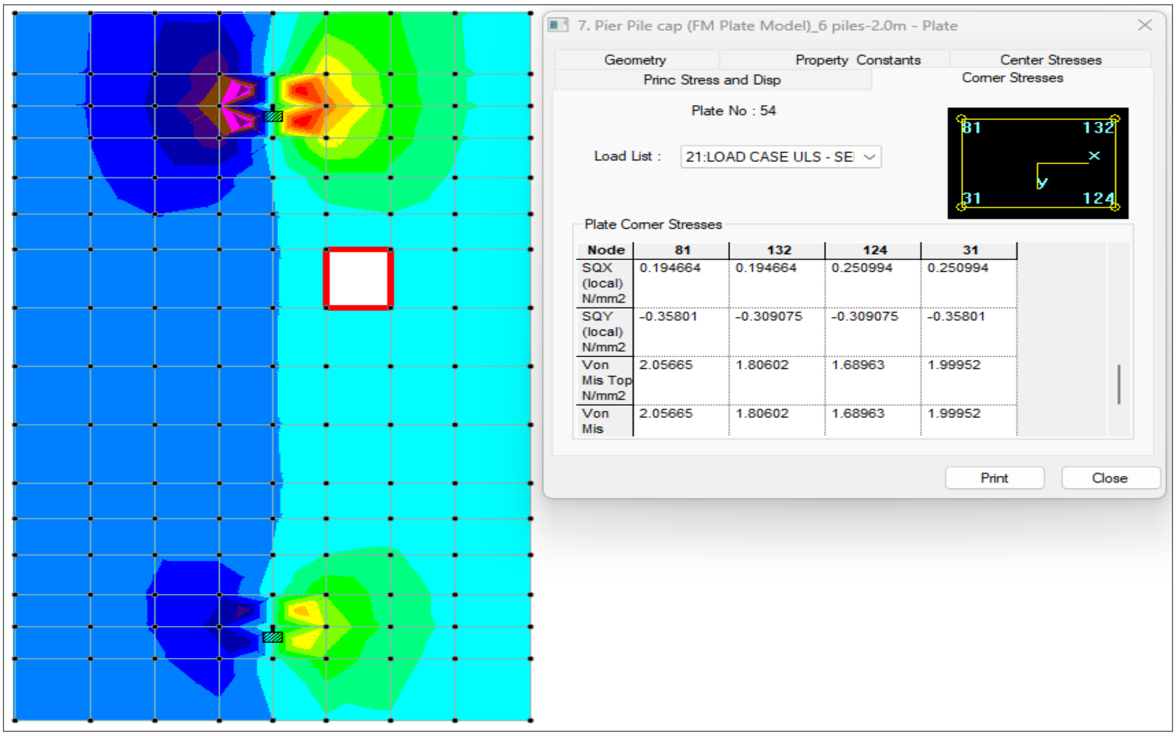


Fig. 11- Showing Plate Model Result Extraction for Shear Stress

## 5. RESULTS AND DISCUSSIONS

The pier pile cap analysis is carried out for different thickness varying from 0.8m to 2.6m. The results for bending moment and shear stress for different depths are shown in table 1. The bending moment and shear stress are plotted in fig. 12 and 13 respectively.

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From fig. 12 and 13, it is found that with increase in pile cap depth bending moment and shear stresses are reduced. In this analysis for depth of pile cap varying from 0.8m to 2.6m the bending moment is reduced by 49.8% and shear stress reduced by 88.2%. This shows that when depth of pile cap is increased, the pile cap shear capacity is increased more than the pile cap bending capacity.

Table 1: Results for bending moment and shear stress for different depths of pile cap

| Depth (m) | BM (tm) | Stress (N/mm$^2$) |
|---|---|---|
| 0.80 | 500 | 0.970 |
| 1.00 | 468 | 0.680 |
| 1.20 | 388 | 0.440 |
| 1.40 | 378 | 0.380 |
| 1.60 | 372 | 0.299 |
| 1.80 | 294 | 0.223 |
| 2.00 | 287 | 0.195 |
| 2.20 | 293 | 0.160 |
| 2.40 | 271 | 0.134 |
| 2.60 | 251 | 0.114 |

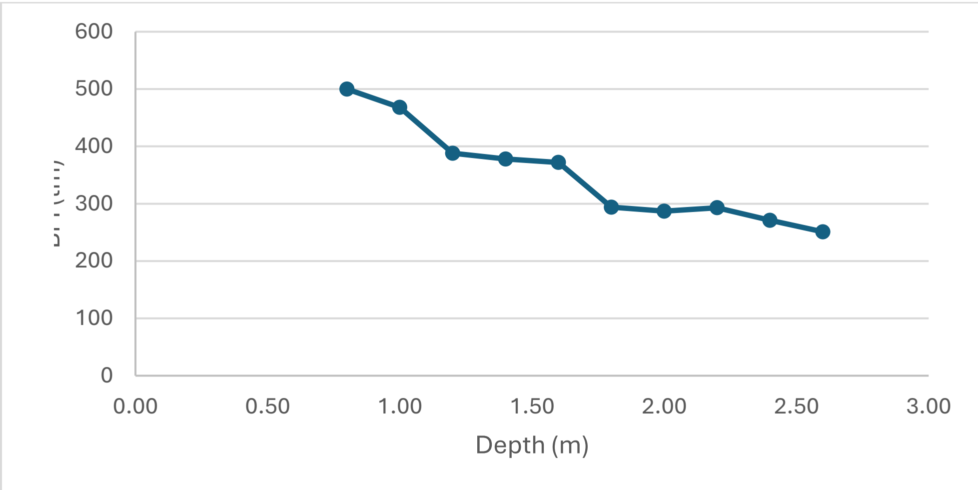


Fig. 12- Variation of Bending Moment (BM) with pile cap depth

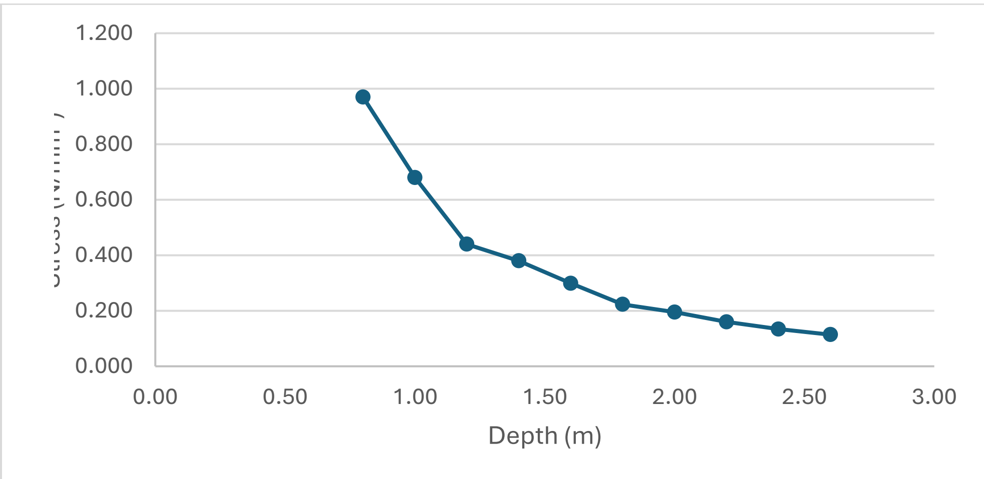


Fig. 13- Variation of Shear stress with pile cap depth

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## 6. CONCLUSION

A Parametric Study of Bridge substructure (Piers) to see effect of Thickness of Pile Cap on Bending Moment and shear stress is carried out. It is found that with increase in pile cap depth, bending moment and shear stresses are reduced. In this analysis for depth of pile cap varying from 0.8m to 2.6m, the bending moment is reduced by 49.8% and shear stress reduced by 88.2%. This shows that when depth of pile cap is increased, the pile cap shear capacity is increased more than the pile cap bending capacity.

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