Design and Reanalysis of Pile Cap with Five Piles under Eccentricity

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Abstract. The function of foundation in building system to let the load transfer from the column to the ground. Cracking and settlement of building are examples of issues that occur in foundation and to avoid that by having a proper design and construction of foundation. The issue that are encountered within the installation of pile cap does not consider within the design of pile cap. The possibility of pile eccentricity is highly to occur through the driven of pile. Therefore, a programme using computer supported was made in this study to solve the issues of design and analysis of pile cap due to the eccentricity. The method that is selected to analyze and design the pile cap is Beam Theory method due to its flexibility which is not limited to specific number of pile used for the foundation. All the design and analysis are done based on practice code EUROCODE MS EN 1992-1-1 2010. The system is analyzed by equivalent frame method as stated in Clause 9.8.1 in EN 1992-1-1:2004 (E). The first part of the result outcome is the detail drawing of the pile cap with include the dimension of pile cap, number of main reinforcement needed for the pile cap including the bar spacing and spacing between the piles. The second part of this project will determine whether the same design of pile cap for normal pile cap can be used when eccentricity occurs. The third part is same like the first part but we increase the number of piles and designing the pile cap with the new number of piles to increase the capacity of pile cap. The last part is checking the pile cap with the new number of pile under the same eccentric load that led to failure the old pile cap before addition the piles. The result of this study shows how the pile cap can sustain the eccentric load until a certain distance. Adding a new pile in a proper position led to retain the centroid of piles to the original centroid if the piles driven inaccurate.

Introduction

In some cases the soil bearing capacity is not sufficient to resist by the structure and pile foundation is needed to apply in these cases such as: type of loads on foundation, conditions at site, operational conditions, and the soil condition. Pile foundations are used extensively for the support of buildings, bridges, and other structures to safely transfer structural loads to the ground and to avoid excess settlement or lateral movement. Pile cap is a concrete block that is casted on the top of a group of piles, to transfer the load from the building to the group of piles. During installation of the pile might be faced some problem does not considered while designing the pile cap. The eccentricity of pile is the most common problem that always happened during the pile installation. When pile is not installed on the exact position as in the drawing, the eccentricity occurred. The purpose of this study is To produce a computer program using Microsoft Excel that can design a pile cap of 5 pile group and reanalyze the pile cap with pile eccentricity for 5 pile group and determine whether the same design can be used for both pile cap without eccentricity and pile cap with eccentricity and choose the most suitable location for the replacement pile. The number of piles in this study is limited to 5 piles only and will be increasing to 7 piles in order to rise up the capacity of the pile group. This research studies the capability of using the same pile cap under eccentricity and checking the optimum limit of the design under high eccentricity prior failure. Adding the new pile is required when the pile cap failed. The user need to insert all the required data for the new pile in the created excel sheet and then proposed location.

Literature Review

In the design of the pile cap must be stiff and adept to transferring the loads from column to the pile. The adequate thickness and number of piles is important to consider during the design to support the load applied. To avoid any failure on the pile cap, the checking should be carried out for punching shear, diagonal shear, bending and bond. In the design and detailing of the pile cap must consider the tolerance because on the site piles are usually not positioned at the exact locations as shown on the drawing.

Usually [1] for designing the pile cap there are two method used which are beam theory and truss analogy. In the beam theory method, the pile cap is assumed as an inverted beam and is designed for the usual conditions of bending and shear whereas for truss analogy, the force acting on pile cap is assumed to be in compression and tension. The type of structure, soil and site condition must be considered in the selection of type of pile. Moreover, the type and size of pile will impact the distribution of load. Pile limit for individual pile can be determine via did test on the pile load or indicated by the producer of the pile. There are three sorts of load that brought about by pile group:

1. Vertical load
2. Horizontal load
3. Moment in the column and the bending moment

Vertical load, the [2] vertical load presence is brought about by the distributed load of columns, slabs, and structural beams remain to pile underneath. This load will be distributed consistently to all pile on the cap if the vertical load which is forced by symmetry at the centroid of pile group.

Horizontal load, pile is driving to bed rock keeping in mind the end goal to endure the load horizontal that are forced on it. On the off chance that the soil layer is situated far beneath, the horizontal burden to endure in the activity of resistance between the piles with the surrounding soil. In addition, presence of force from the basis and soil on the ground likewise give confrontation to horizontal load acts on the pile cap.

Moment in the column and the bending moment, considering the design of the column will present moment in the pile cap under the column fixity in the pile cap. The bending moment additionally will exist if the centroid of the column is not situated at the centroid of the group of piles. This will prompt unevenly load distribution either zero burden for the pile which is situated at the center or the most extreme burden on the pile that situated a long way from the centroid.

It [3] is important to design a pile cap with sufficient load capacity that can transfer the load to the ground with no failure. The thickness of the pile cap ought to be adequate for berth of the column dowels and pile reinforcement. The checking for punching shear and vertical shear must be completed to maintain a strategic distance from any failure because of shear

As per beam analysis theory, pile cap is considered as a simply supported and short beam. The method that use for the calculation of the moment of the beam by reversing the forces acting is the same method can use to calculate the moment in the pile cap. In beam theory analysis the two axial direction need to be considered which is in direction of x and y axis.

Beam Theory for Pile Cap with Five Piles: X and y direction must be considered in analyzing for pile cap with five piles. Therefore, the axial load comes from the column is distributed to all piles by load of N/5 for each pile.From the Figure 1,

$$\sin 45° = \frac{\sqrt{2}}{2}\left(\frac{\frac{L}{2}}{s}\right)$$

where L = S$\sqrt{2}$. Hence, MX @My = $\left(\frac{N}{5} \times 2\right)\left(\frac{S\sqrt{2}}{2}\right) = \frac{Ns\sqrt{2}}{5}$. The design shear force for pile cap with five piles is 2N/5 for both x and y axis.

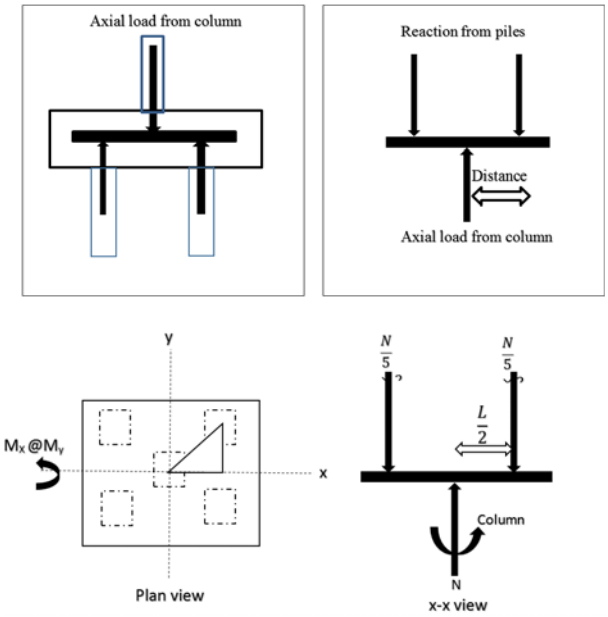

Figure 1: Analysis of pile cap design

Methodology

Microsoft Excel is selected to develop the program because it has more functions and uncomplicated to assist for analyzing, designing and determining the details of pile cap. The software has been selected to develop the programmed is Microsoft Excel because is more flexible, convenient and easier compared to other software. Flow chart in Figure 2 shows the outline for the solution to design and analyze the pile cap. The primary phase of the analysis and design of pile cap is to insert the information required for example, the load and the dimension of pile cap. Next the design checking for pile cap is proceed with shear resistance checking, punching shear checking and maximum punching shear checking. After that the drawing process and details of pile cap is next. During the construction work at site, when the pile is driven and eccentricity occurs, the pile cap should be reanalyzed again. If the load acting on each pile exceed the pile capacity or the design of the main reinforcement is not sufficient to support the bending moment due to the eccentricity, redesigning process for pile cap is needed to be repeated. For this study, the main objective is to tackle the issue of analysis and redesign of pile cap due to the pile failure and develop a program that can facilitates the engineer work. Thus, Microsoft Excel is used in this study to do all the calculations while AutoCAD is used to draw the detailing of the pile cap.

This section covers the development of data using Microsoft Excel to facilitate the process of analyzing pile cap system.

First stage of pile cap analysis

At the early stage of design, the focus is more on recalculate the load on pile cap and analysis of the load in individual pile and number of pile need to be used.

Second stage of pile cap analysis

Second stage of the design focuses more on the designing of the pile cap based on the data obtained from the recalculating and analyzing of the load at the early stage.

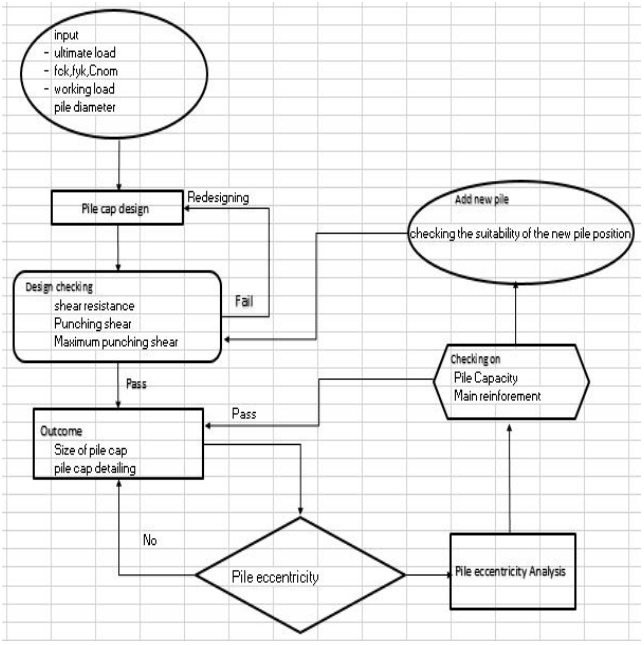

Figure 2: Flow Chart of Analysis and Redesign of Pile Cap

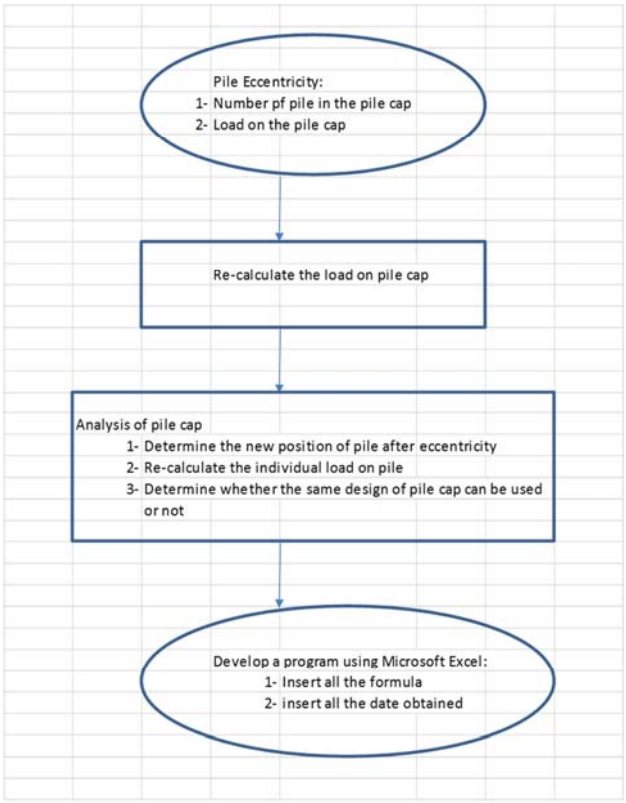

Figure 3: Flow chart of methodology of analysis and redesign of pile cap due to pile eccentricity

Result and Discussion

Pile Cap under Various Cases of Eccentric Load

In the design of this pile cap, eccentricity needs to be checked in all cases that might occur in site. In this spreadsheet we consider 5 cases for eccentricity. These cases are:

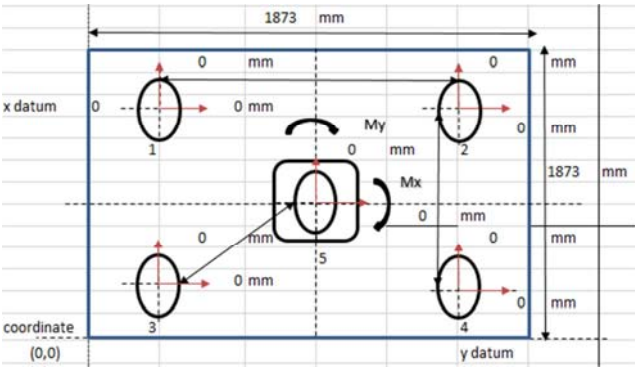

Figure 4: The original positions of all piles

Movement of pile number 1 only from the original position. Figure 5(a) shows the maximum eccentricity for pile in case 1. The blue line represents the first case which is the movement of pile 1 only. From the obtained data, the maximum distance in x direction is 250 mm with 0 movement in y direction and 370 in y direction with 0 movement in x direction. The combined movement in both direction is limited to 150 mm in x direction and 148 mm in y direction. This result shows how the movement of one pile could not have a significant impact on the pile cap. It is seldom to occur in site for the first case.

Movement of pile number 1 and pile number 2 only from the original position. The orange line represents the movement of pile 1 and pile 2 only among the five piles. The furthest distance in x direction can reach 150 mm with 0 movement in y direction and 200 mm in y direction with 0 movement in x direction without any failure. Nevertheless, in the movement of the pile in both directions, the furthest safe distance in x direction is 80 mm however in y direction is 80 mm. As shown in the Figure 5(b).

Movement of pile number 1 and pile number 2 and pile number 3 concurrently from the original position. The case 3 which is represented by the gray line is obtained by the movement of pile 1 and pile 2 and pile 3 together in Figure 5(c). The three piles can move together in x direction with a distance of 93 mm conditional upon 0 movement in y direction. The same concept can be applied to the three piles when they move together in y direction with a maximum distance equal to 110 mm with 0 movement in x direction. The three piles could move together in both directions with limited distances to 46 mm in x direction and 55 mm in y direction.

Movement of pile number 3 and pile number 5 only from the original position. The yellow line represents the movement of pile 3 and 5 only among the five piles in Figure 5(d). The furthest distance in x direction can reach 137 mm with 0 movement in y direction and 135 mm in y direction with 0 movement in x direction without any failure. Nevertheless, in the movement of the pile in both directions, the furthest safe distance in x direction is 75 mm however in y direction is 68 mm.

Movement of all piles concurrently from the original position. Figure 5(e) shows the case 5 that might happen in the site due to eccentricity. Moving to the last case which is represented by the pink line. It is resulted by the movement of all piles together. From the obtained result the furthest safe distance in x direction is 60 mm with 0 movement in y direction and 60 mm in y direction with 0 movement in x direction. In the case of the simultaneous movement of the all piles in both directions, the furthest distance in x direction is dropped to 30 mm as well as the significant drop in y direction to 30 mm only. The safest case for any construction of pile cap is the last case. In this case guarantees that all piles can manage the load without any failure. In comparison with the applied principle in most of design codes that the most maximum distance for each pile is 75 mm from the original location can be taken into account.

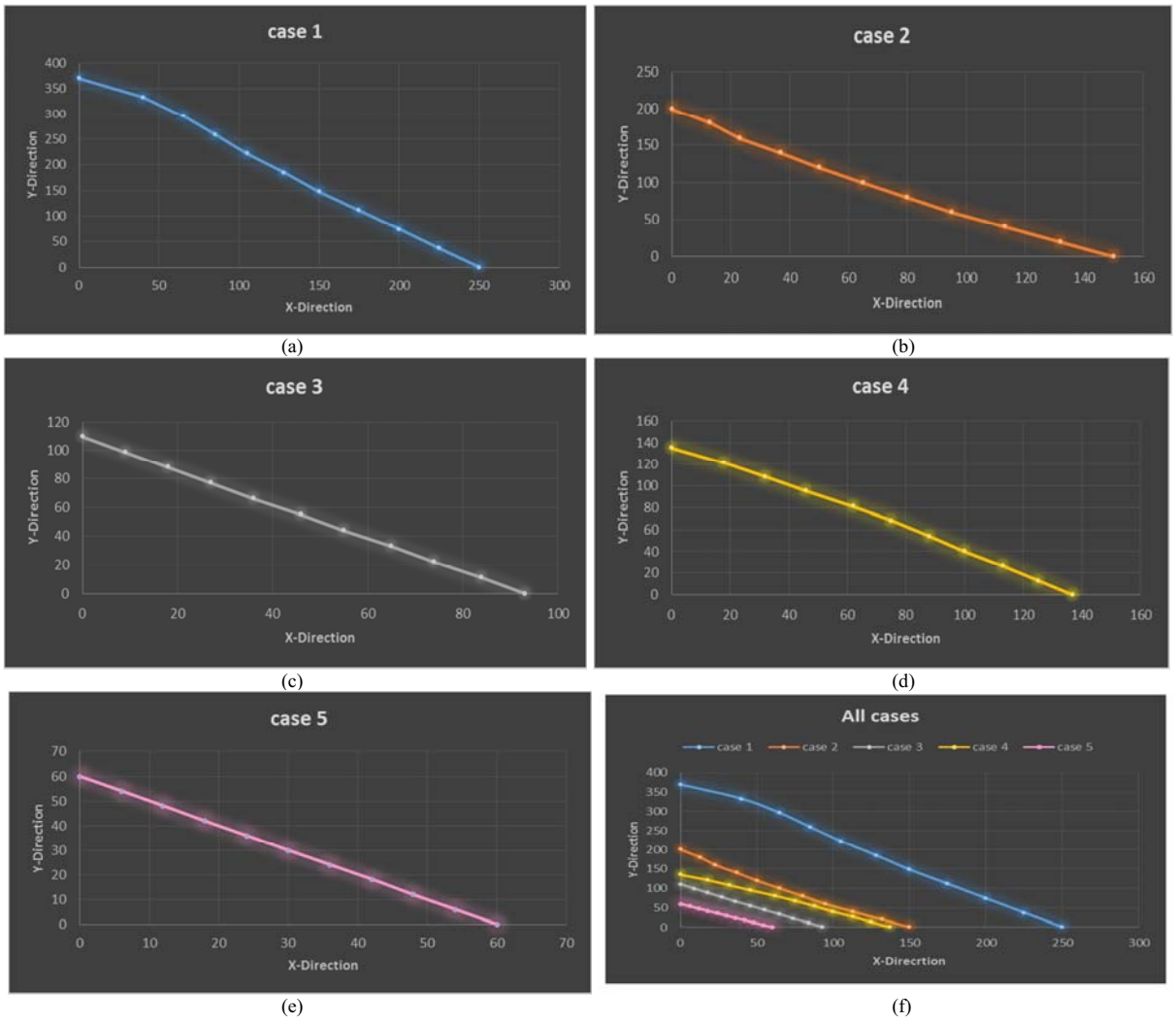

Figure 5: Maximum eccentricity for pile cap for (a) case 1, (b) case 2, (c) case 3, (d) case 4, (e) case 5 and (f) all cases

However, this value cannot be restricted anymore since this study proved that eccentricity depends on the movement of all pile together not on only 1 pile. In more specific way, the movement of piles produce an eccentric load which can reduce the pile capacity however, this reduction can be controlled if the movement of all piles are still in the limited safe zone. This limited safe zone assures the safety of the pile cap under even eccentric load. Adding a new pile in a new position is the solution for pile cap failure under high eccentric which can retain the centroid of pile group to the original centroid.

Additional Pile

The pile capacity is highly effect by eccentricity. A big failure will happen to the pile group due the eccentricity that produce a load more than the capability of the pile. One of the solutions to overcome the problem of high eccentricity is by drive a new pile to resist the high eccentric load.

The location of the new pile to be driven is most be suitable to reduce the effect of eccentricity on the pile group and retain the centroid of the pile group to the original center and it's the critical part. The user able to find the new location for the additional pile in the condition of failure by the spreadsheet been created. The user can insert the new position of the new pile and the result will come out in the spreadsheet and check whether the location that proposed by the user can be applied in the field or not.

This spreadsheet is appropriate when no less than one of the piles is failed to receive higher load than the pile capacity itself due to the high eccentricity. A new sheet is created for a group of 7 piles to be designed. The new piles have been located one below the pile 5 and the other one between pile 1 and pile 3 in the middle. These piles has the same characteristics of the other piles and the same cross sectional area of piles and the same working load is applied.

The additional piles will reduce the efficiency of the group pile and this reduction is due to the overlapping of stresses between the piles when the spacing is less than 3d. Inserting a new value of the eccentricity that be outside the safe zone by the user before starting the analysis to check whether the additional pile can resist the eccentric load and protect the group of pile from failure or not.

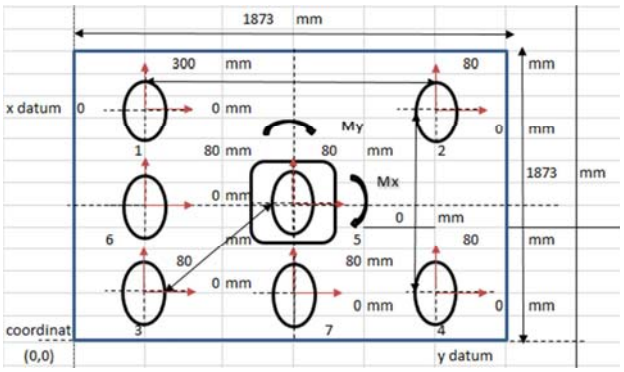

Figure 6: The location of the additional pile

Conclusion

By using a computer program assist the investigation has been done in the paper due to the effect of pile cap system on the behavior of pile group subjected to axial load. The objectives have been achieved successfully in this research. The solving of pile cap system problem has become easy by using the program that was created in this study.

In this study, we found out that is hard to underestimate the problem of pile cap due to eccentricity because of the serious failure that might arise even if the eccentricity of the pile is below 75 mm in accordance with Jabatan Kerja Raya. From the study, the movement of all piles in both directions, the furthest distance in x direction is dropped to 30 mm as well as the significant drop in y direction to 30 mm only. Accordance to Jabatan Kerja Raya the movement considered safe if it's less than 75 mm while in the study the values are less than that.

In most critical situations adding new piles might be help especially when the dimension of the pile cap cannot be changed anymore. The location of the new pile to be driven is most be suitable to reduce the effect of eccentricity on the pile group and retain the centroid of the pile group to the original center.

References

[1] Chantelot, G. and Mathern, A. Strut-and-tie modelling of reinforced concrete pile caps. 2010.

[2] Choo, B. S. and MacGinley, T. J. Reinforced concrete: design theory and examples. CRC Press. 2002.

[3] Henry, F. D. C. The design and construction of engineering foundations. Chapman and Hall. 1986.

[4] Salleh Yassin, M. Reinforced Concrete Design to Eurocode 2. Faculty of Civil Engineering, Universiti Teknologi Malaysia. 2011.

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