The Analysis of Modified of Cakar Ayam (CAM) Designed with Concrete Plate Thickness Variation in Soft Soil

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Abstract. Modified of Cakar Ayam System (CAM) is a system that uses galvanized steel pipes as stiffener plate. This system had been implemented on the trial road of Pamanukan-Indramayu, Indonesia. Many advantages are obtained from the use of this system, for example reduction on deflection, durability, and application on road pavement. Full scale trials had been conducted in Indonesia, for the examples, the Waru-Surabaya Highway and Section IV Highway, Makassar. Despite this system is widely used but there are still many problems occur such as deflection and crack due to less plate thickness. This research will discuss about the deflection, moment and shear force of plate model on soft base ground using Finite Element Method (FEM). The system configurations for concrete plate applied in this research were 7.25 m in width and 14.0 m in length with thickness was varied by 0.15 m, 0.18 m and 0.22 m using 21 cakars. The loads represented semi-trailer truck loading with the weight of each axle propagated into 2 equal uniform loads. The position of test loading points were made in several variations to determine the largest deflection value. If the plate got thicker then, its stiffness value would increase and the deflection accorded smaller result. By using CAM System, cakar could function as a load restraint and plate grip. The stiffness of the plate would increase when the plate was applied with the CAM System and could reduce deflection by 2.74% to 39.77%. On the effect on the moment and shear force, it was found that the thicker the plate, the greater the moment and shear force value obtained. The difference in the value of the moment obtained from the comparison between the plate using the CAM System and the plate without the CAM System was 0.23% to 1.60%, while for shear force values, the difference was 7.56% to 11.19%.

1. Introduction

Roads are built on subgrade which have various characteristics ranging from hard to soft characteristics. Each characteristic has its own problems, for examples are degradation in embankment, high compressibility, low shear strength value. There are many ways to make subgrade can support the weight of the road structure, starting from soil stabilization using cement or lime, hoarding subgrade with better landfills, and carrying out the process of soil compaction. These methods are considered to be less effective so that another method needs to be applied to address existing problems. One of the methods is by implementing the Modified of Cakar Ayam System (CAM). This system is a development of the Cakar Ayam System (CA) which is designed to be able to withstand heavy vehicle loads.

The CA System was first used as the foundation of an electric tower building in Jakarta in 1961 and the foundation of the Soekarno-Hatta Airport runway. Not only limited to runways, the CA System was also applied in several toll roads in Malaysia such as Kayan-Sitiawan Village Toll Road. Examples for the use of the CAM System itself were in the construction of the Sediyatmo Toll Road, Indonesia and as a trial road on the Pamanukan-Indramayu road, Indonesia.
Several studies on CAM System on soft soils had been carried out by previous researchers. The load conditions made with the same distance and the number of cakar made more with the thicker condition of the plate would produce smaller deflection value[1]. In 2008 laboratory tests were conducted in order to obtain the results as the following, the greater the number of cakar the greater the moment of resistance given by the cakar and could reduce deflection[2]. Laboratory tests were also done in 2015 with the results of the study showed that the use of Cakar Ayam could reduce deflections by 59.46% to 89.64%[3].

This study continued from previous research[3] in which the concrete plate of the CAM System was located on soft soil. Cracks could be found on the toll road body even that road had used CAM System, so it was necessary to increase the thickness of the plate. This system was expected to overcome problems that arouse due to subgrade reduction in soft soils not only deflection but also the cracks due to imperfect soil compaction so that the road body could be traversed by heavy vehicles without experiencing significant damage.

The aims of this research are to analyze some parameters on the foundation plate and to know the influence of thickness variations of concrete plates by applying the load of semi-trailer trucks such as buses, tankers, box trucks and container trucks. These parameters included the value of deflection, the moment and shear force. Parameter analysis with variations in plate thickness could provide new research results using Finite Element Method (FEM). FEM is a method in which the analyzed object is divided into several parts into a finite number. Analysis was supported by using a program that could apply FEM to facilitate calculation. The program used in this study was SAP 2000 issued by CSI Berkeley.

2. Method of Analysis

2.1. Data parameters of soil, concrete and steel

Soil data was obtained from previous research[3] where soil samples came from Widodaren Village, Banjarjo District, Ngawi Regency, East Java, Indonesia as shown in Table 1 while the $k_h$ value ranged from 5 to 10 times the value of $k_v$. This study used the $k_h$ value of 5 times the $k_v$ value so that the $k_h$ was determined to be 240000 kN/m$^3$.

| Nr. | Data                             | Value   | Unit  |
|-----|----------------------------------|---------|-------|
| 1   | Undrained cohesion, $c_u$        | 243     | kN/m$^2$ |
| 2   | Adhesion factor, $\alpha$        | 0.3     | -     |
| 3   | Friction factor, $f_s'$          | 72.9    | kN/m$^2$ |
| 4   | Deflection, $\delta$            | 2.54    | mm    |
| 5   | Vertical reaction coefficient, $k_v$ | 48000 | kN/m$^3$ |
| 6   | Horizontal reaction coefficient, $k_h$ | 240000 | kN/m$^3$ |
| 7   | Friction reaction coefficient, $k_t$ | 28701  | kN/m$^3$ |

Table 1. Soil data

Secondary data on concrete, steel and soil property materials were obtained from previous research conducted in 2009[4]. Steel was determined using BJ37 because this type of steel was easy to get and counted strong so it could meet economic needs, while concrete was designed to have a $f_c'$ value of 25 MPa which was equivalent to 25000 kN/m$^2$. For soil material, modulus of elasticity was set on 100 kN/m$^2$ with 0.2 of poisson value.

2.2. Dimension and geometry of modified cakar ayam system

Dimension and geometry data of CAM System referred to the full scale model of the Pamanukan-Indramayu road. Geometry used rectangular pattern with the length and width of each plate, namely 27 m and 7.25 m. The rectangular pattern was chosen because it was easier to be implemented in the field compared to triangular pattern. The cakar applied had a height of 1.2 m and a thickness of 0.05 m with the distance of each cakar was 2.25 m, while koperan system had a height of 0.5 m. These parameters
were included in the dependent variable because the values were not changing. Variation in plate thickness was the independent variable in this study. The thickness of the plates was set at 15 cm, 18 cm and 22 cm. In addition, plates without cakar were used as comparison with the plates that used cakar without changing the thickness of the plates. This comparison would produce six variation of plates.

![Figure 1. The modified of cakar ayam system structural design.](image1)

2.3. Semi-truck loads
This study used two semi-trucks as the load where the placement of both semi-trucks were carried out at the same time. Two-load application was applied to describe and to know the condition when there were 2 semi-trucks that traversed at the same time. The road needed to be designed with more strength so it could support the weight of these vehicles. Loads were applied in the middle, on the edge and the corner of the plate to find out where the biggest deflection could occur.

The first semi-truck load was assumed to be located in front of the second semi-truck. The load was illustrated by a solid black circle, while the cakar was depicted with a black circle without solid as shown in Figure 2. The loading test results on the plates obtained from SAP 2000 were plotted using Microsoft Excel to procure graphs which showed how the deflection was depicted in certain section.

A-A section until D-D section were longitudinal section, while E-E section until J-J section were transverse section. The section were selected in the position because the largest deflection occurred on the plate under the applied load so it needed to be analyzed in longitudinal and transverse section. After semi-truck loads had been applied and section had been determined, load combination was assigned by referring to applicable regulation.

![Figure 2. The placement of loads and sections.](image2)

3. Result and discussion

3.1. Deflection
The following was given an overview of how deflection graph occurred on the plate. The graph was divided into 2, namely the graph on the longitudinal section (27 m distance) and the graph on the cross section (7.25 m distance). A-A section up to D-D section get the same load of 1866.667 kN. The load
came from one front axle wheel and two semi-truck rear axle wheels. E-E section and H-H section were loaded with two front axle wheels with a total of 1333.334 kN, while the F-F, G-G, I-I and J-J section bore the burden of two rear axle wheels of 1200 kN. The biggest deflection occurred at the D-D section (longitudinal direction). Then in the transverse direction, the biggest deflection occurred at the J-J section.

Figure 3 showed the deflection graph that occurred in the D-D section on the edge of the plate. The distance of 0 m to 13.75 m plate had a very small deflection. The graph experienced a large decrease at a distance of 12.5 m due to the application of the load coming from the second truck axle wheel.

The second decrease occurred due to the influence of the middle axle wheel at a distance of 19 m to 21.5 m. The third decrease began at a distance of 24.25 m to 27 m due to the truck's rear axle wheels. The graph showed 2.12 mm as the biggest deflection lied on the third decrease. The area of the front axle wheel load which was smaller than the other axle area caused the deflection to occur which did not show significant results as on the second or third decrease. The biggest deflection difference, between 15 cm thick plate without CAM System and 22 cm thick plate using CAM System, was 30% in terms of the influence of P2 load at a point of 21.5 m.

Figure 4 showed the deflection graph that occurred in the J-J section at the corner of the plate. The graph had decreased twice as a result of two rear axle truck wheel loads. The weight of each wheel was 600 kN so that in one section there was a total load of 1200 kN. The graph showed that at a distance of 2.25 m the plate began to rise from the previous decrease starting from a distance of 0 m and 1.38 m. Plates experienced a significant deflection due to the area of load applied at 0.1874 m². Comparison of 22 cm thick plates with CAM System and 15 cm thick plate without CAM System resulted in a difference of 2.74% to 39.77%. The thicker the plate, the smaller the deflection occurred. The deflection could give a smaller value if the plate applied the CAM System.
3.2. Moment value

The moment value of the modeling performed on SAP 2000 was shown in Table 2. The maximum moment value obtained was compared with the calculation of nominal moment value (M_n). The nominal moment was the capability of segment of the structure to accept the load using calculation followed from applicable regulation[6].

Table 2. The results of concrete plate moment analysis

| System type                        | Plate thickness (cm) | Maximum moment SAP2000 (kNm) | Nominal moment | Deviation |
|------------------------------------|----------------------|------------------------------|----------------|-----------|
|                                    |                      | Axis xy (M_11)               | Axis yz (M_22) | M_max    | M_n      |                  |
| Using Modified of Cakar Ayam System (CAM) | 15                   | 24.464                       | 25.011         | 26.115   | 98.615   | -73.52%          |
|                                    | 18                   | 26.358                       | 26.723         | 28.082   | 151.631  | -81.48%          |
|                                    | 22                   | 28.635                       | 28.426         | 30.386   | 239.990  | -87.34%          |
| Without using Modified of Cakar Ayam System (CAM) | 15                   | 23.967                       | 23.967         | 24.538   | 98.615   | -75.12%          |
|                                    | 18                   | 26.534                       | 26.534         | 26.880   | 151.631  | -82.27%          |
|                                    | 22                   | 29.458                       | 29.458         | 29.842   | 239.990  | -87.57%          |

Plates without CAM System resulted a smaller moment. The smallest moment value occurred on the plate with a thickness of 15 cm. Each of the moment value on the 15 cm thick plate with CAM System and without CAM System was 26.115 kNm and 24.538 kNm. It can be seen from the results of the comparison that with the use of the CAM System on the plate will cause the value of the moment that happened to be even greater. Comparison of maximum moment values with nominal moment values produced a difference of 73.52% to 87.57%. The nominal moment must be greater than the maximum moment that occurred on the plate because in designing, if the nominal moment is smaller than the maximum moment that occurred it will cause structural failure.

3.3. Shear forces

The design in the CAM System not only calculate the deflection results and moment values, it is also necessary to calculate how much shear force is working on the plate so that the design can be applied in a field with a high service period. This shear force is used as one of the parameters in designing the structure to determine the dimensions of the structure, the material to be used or the shape and size suitable for application in the field. Table 3 showed the value of shear force obtained from the modeling using SAP 2000.

Table 3. The shear force that works on each plate

| System type                        | Plate thickness (cm) | Shear force (kN/m’) | Deviation |
|------------------------------------|----------------------|---------------------|-----------|
|                                    |                      | Axis xy (V_13)      | Axis yz (V_23) | V_max    |          |
| Using Modified of Cakar Ayam System (CAM) | 15                   | 1486.15             | 1605.20     | 1699.59  | 11.19%   |
|                                    | 18                   | 1499.25             | 1577.59     | 1697.38  | 9.07%    |
|                                    | 22                   | 1508.56             | 1578.98     | 1703.69  | 7.56%    |
| Without using Modified of Cakar Ayam System (CAM) | 15                   | 1297.27             | 1373.47     | 1509.47  | -12.60%  |
| Modified of Cakar Ayam System (CAM) | 18                   | 1327.33             | 1381.22     | 1543.47  | -9.97%   |
|                                    | 22                   | 1359.86             | 1427.98     | 1574.93  | -8.18%   |

The table showed that the shear force was increasing with the use of thicker plates. The highest maximum shear force (V_max) occurred in the 22 cm thick plate with a CAM System of 1703.69 kN/m’ and the smallest maximum shear force occurred in 15 cm thick plates without a CAM System of 1509.47 kN/m’. The difference on plate using CAM System with plate without using CAM System showed a value of 7.56% to 11.19%.
4. Conclusion
Based on the analysis that had been done, it could be concluded that:

4.1. Effect on deflection
- Plate thickness affected the deflection results, the thicker the plate the smaller the deflection value occurred. Braces, brackets and parentheses should be used in the following order: \([([\text{()})])\]. The same ordering of brackets should be used within each size. However, this ordering can be ignored if the brackets have a special meaning (e.g. if they denote an average or a function).
- Deflection increased if the load was greater.
- Plate deflection due to the load on the plate corner was greater than the plate deflection due to the load in the middle or edge position.
- The plate with the CAM System produced a smaller deflection value compared to the plate without using a CAM System. The difference in deflection values between plates using a CAM System with a plate without a CAM System were obtained by 2.74% to 39.77%.

4.2. Influence on moments
- The thicker the plate the greater the moment value obtained.
- Nominal moments derived from manual calculations had a greater value than the maximum moment value obtained from SAP 2000. The difference that occurred was 73.52% to 87.57%.

4.3. Influence on shear force
- The thicker the plate, the greater the shear force that occurred.
- The difference in shear force values on the plate using a CAM System with a plate without a CAM System was obtained at 7.56% to 11.19%. Equation numbering

5. References
[1] Wulandari N W 2008 Effect of Soil Reduction on Cakar Ayam System (2 Dimensional Model) (Yogyakarta : Gadjah Mada University)
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[6] Anonymous 2016 Ind. Patent No. 03-2847-2002