Stress Intensity and Crack Pattern of Reinforced Concrete Beam Embedded With Lightning Protection Cable

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Abstract. The reinforced concrete beam with lightning protection cable used in this research to determine the stress intensity and crack pattern of the beam. In this research, commercially available software developed by ANSYS used to model the nonlinear behaviour of reinforced concrete beams. The beam will model by using the ANSYS parametric design language (APDL). The beam structure was modelling in 3D geometry with the reinforcement steel bar and lightning cable embedded in the reinforced concrete beam structure. The material uses to develop the beam are Grade 30 concrete and high yield steel for main reinforcement. The material for lightning cable used was galvanized steel iron, which is highly resistance to corrosion and oxidation. The beam model in simply supported with pinned support at two end of beam and three-point load is applied. From the result beam added with lightning cable at bottom can sustain a higher stress intensity compare to the beam without additional lightning cable and beams without lightning cable have developed largest crack compared to the beam with lightning cable.

1. Introduction
In the 20th century, lightning protection system (LPS) was introduce [1]. A. Harfield [2] explained LPS is design to protect a building or structure and contents from damage caused by the high voltage currents of a lightning strike that mostly exceeding a 1,000,000,000 Volt Amps. LPS act like a Faraday Cage for buildings when protect the building and its contents from external electric fields by migrating that energy around the cage instead of through its contents. The main ideas are to transfer the lightning charge to the ground safely. For a typical LPS, it consists lightning cable [3]. The lightning protection cable chosen because this is the common method to transfer the lightning charge to the ground in the building. LPS used to reduce the damages of equipment, fire on concrete structure or the safety of human life from high voltage current of lightning strikes [4]. The behaviour prediction of reinforced concrete beam until failure usually carried out using experimental testing. Due to the involvement of high cost of materials, testing machineries, labour and time, other prediction methods such as numerical methods (FEM) are the most preferred choices.
Finite element method (FEM) known as a numerical technique for finding approximate solutions to practical engineering problems, especially those with loading conditions, boundary conditions and complicated geometries. In this research, finite element analysis performed using ANSYS software to investigate some of the characteristics on the reinforced concrete beam with additional lightning cable. ANSYS consists high speed, high accuracy, low cost analysis and better visualization result of numerical calculation of finite element analysis software when it used in non-linear analysis of reinforced concrete structure [5]. The main objective of this research is to investigate stress intensity and crack pattern behaviour of reinforced concrete beam with different location of LPS installation.

2. Materials and Method
This research approach of modelling nonlinear analysis by using ANSYS Mechanical APDL (Finite Element Software). The material uses to construct the beam are G30 concrete and structural steel. The simply supported beam is 1200 mm long, with a section of 300 mm x 200 mm. The reinforcement of reinforced concrete beam are built up from 2 rebar’s of 10 mm diameter at top, 2 rebar’s of 12 mm diameter at bottom and stirrups of 2 legged 6 mm diameter at 150 mm spacing. The additional 50 mm² cross sectional area of lightning conductor cable (Galvanized steel) was installed at the top and bottom reinforcement. The Element type reference number using in ANSYS in table 1.

| Material Type        | ANSYS Element |
|----------------------|---------------|
| Concrete             | Solid65       |
| Steel Plates and Supports | Solid45    |
| Galvanized Steel     | Link180       |
| Steel Reinforcement  |               |

Figure 1. Control Beam (without the Cable)
Figure 2. Beam model with additional LPS Cable reinforcement at top.

Figure 3. Beam model with additional LPS Cable reinforcement at bottom.

Figure 1 until figure 3 demonstrated the cross section of 3 model of reinforced concrete beam used in this research. Meanwhile figure 4 and figure 5 illustrate the arrangement of additional lightning cable at bottom and top of the beam.
3. Results and Discussions

3.1. Stress Intensity

Stress intensity used to forecast the stress state near the tip of a crack caused by a load or stresses. It is a theoretical design usually applied to homogeneous, linear elastic material and it is effective for contributing failure criteria for brittle materials and show small scale yielding at a crack tip [6].

From the result of analysis stress intensity, maximum stress located on the support and gasket of the applying load. The critical section of beams are at top surface of beam which is in between the gasket of applying force which is indicated by the red colour as shown in figure 6, 7 and 8. Table 2 presented the stress intensity for model of reinforced concrete beam (RCB) with and without additional lightning cable.
Figure 6. Stress Intensity for RCB without additional lightning cable

Figure 7. Stress Intensity for RCB without additional lightning cable
Table 2. Maximum stress intensity for each RCB model

| Beam Model                        | Maximum Stress Intensity (MPa) |
|-----------------------------------|--------------------------------|
| Without lightning cable           | 4.05614                        |
| With lightning cable at bottom    | 4.83805                        |
| With lightning cable at top       | 4.44709                        |

By comparing the result of the three model, beam with lightning cable at bottom obtain the higher stress intensity, which is 4.83805 MPa, follow by beam with lightning cable at top with 4.44709 MPa and lowest is the normal beam with 4.05614 MPa. This showed that beam with lightning cable at bottom is the highest maximum stress intensity among the entire beam models, which indicates the presence of high tensile stresses due to maximal bending moment. The results validated by the methods proposed by Benarbia, D., & Benguediab, M. (2015) [7].

3.2. Crack Pattern
Cracking can occur in concrete structures for several reasons either mechanical loading or environmental effects. The beam model develop using ANSYS is capable of predicting cracking for concrete materials when the principal stress in any direction lies outside the failure surface. The crack pattern shows in figure 9, 10 and 11.
Figure 9. Crack pattern for RCB without additional lightning cable

Figure 10. Crack pattern for RCB without additional lightning cable
Figure 11. Crack pattern for RCB without additional lightning cable

The crack is notice to occur at the middle of beam. All the beams seem to have same similar pattern. From the FEM analysis, all tested models failed due to the ultimate load achieved the maximum deflection with excessive cracks occurred in the tension zone of the bottom beam. The small cracks also observed at the end of bottom beam near the support. The description of cracking pattern result shows in the table 3.

Table 3. Cracking Pattern

| Beam Model                      | Description Crack Pattern                                           |
|---------------------------------|---------------------------------------------------------------------|
| Without lightning cable         | The direction of crack pattern is horizontal with large crack opening. |
| With lightning cable at bottom   | The direction of crack pattern is horizontal due additional with smaller crack opening. |
| With lightning cable at top      | The direction of crack pattern is horizontal due additional with smaller crack opening. |

All models developed major horizontal cracks at the bottom middle and some angular cracks. It noticed that model without additional lightning cable develop largest cracks compared to the beam with additional lightning cable. Previous study reported that cracks initiate when the tensile stress in the concrete exceeds the tensile strength of concrete and when this occurs the force in the prism is transferred to the rebar [8].

4. Conclusions

Based on the comparison between the results obtained, different stress intensity, the beam added with lightning protection cable at bottom can sustain a higher stress intensity compare other beam models. Meanwhile, the crack pattern noticed to occur at the mid-span of the beam. The crack initiated from the end part of beam at the support. The quantity crack increase as the load increased. All beams developed major horizontal cracks at the mid-span. The lightning protection cable was shown excellent bonding behaviour with reinforcement to control the crack propagation.
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