PERFORMANCE OF REINFORCED CONCRETE BEAM WITH EMBEDDED GALVANIZED STEEL AS LIGHTNING DOWN CONDUCTOR CABLE

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by

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LIST OF SYMBOLS

α	Protective Angle
A	Tips
r	Rolling sphere
f_c	Compressive Strength
F	Maximum Load at Failure
A_c	Cross Section Area of the Sample
E	Electrical energy
I	current (kA)
t	time

LIST OF ABBREVIATIONS

BS	British Standard
LPS	Lightning Protection System
SPD	Surge Protection Device
IEC	International of Electrotechnical Commission
MS	Malaysia Standard
EC	European Commission
kA	Kilo Ampere
C2G	Cloud-to-Ground
LPL	Lightning Protection Level
ASTM	American Society for Testing and Materials
LVDT	Linear Variable Displacement Transducer

PRESTASI RASUK KONKRIT BERTETULANG DENGAN MEMASUKKAN KELULI GALVANI SEBAGAI KABEL BAWAH PENGALIR KILAT

ABSTRAK

Kilat adalah peristiwa semula jadi yang tidak boleh dihalang. Satu sistem perlu diwujudkan khusus untuk melindungi bangunan daripada kerosakan oleh caj kilat dan memindahkannya dengan selamat ke tanah. Oleh kerana masalah dengan sistem perlindungan kilat yang sedia ada seperti pengaratan dan kabel yang dicuri, sistem baru yang boleh dipasang dalam struktur konkrit telah diperkenalkan oleh Suruhanjaya Elektrik Antarabangsa (IEC). Walau bagaimanapun, garis panduan pemasangan terperinci tidak disediakan dan kajian sebelumnya menunjukkan bahawa teknik pemasangan yang tidak betul dan bahan yang tidak sesuai yang dimasukkan di dalam struktur konkrit boleh menyebabkan kerosakan fizikal kepada konkrit. Oleh itu, susunan baru bagi kabel keluli galvani dicadangkan dalam kajian ini. Kesan simulasi kilat pada rasuk konkrit ditentukan. Rasuk konkrit berukuran 200 x 300 x 1200 mm telah digunakan dan beberapa ujian dijalankan untuk menyiasat prestasi rasuk konkrit. Ia didapati bahawa; peningkatan suhu adalah sangat minimum di dalam rasuk konkrit yang dikenakan dengan arus elektrik yang tinggi. Dari ujian frekuensi, pengurangan frekuensi semulajadi sebelum dan selepas simulasi kilat boleh dianggap sebagai diabaikan. Dari segi prestasi struktur, analisis beban-anjakan menunjukkan tiada pengurangan beban oleh arus tinggi. Susunan baru bagi kabel keluli galvani juga didapati meningkatkan kapasiti struktur bergantung kepada lokasi pemasangannya.

PERFORMANCE OF REINFORCED CONCRETE BEAM WITH EMBEDDED GALVANIZED STEEL AS LIGHTNING DOWN CONDUCTOR CABLE

ABSTRACT

Lightning is a natural event that cannot be prevented. A system needs to be created specifically to protect buildings from damage by the lightning charge and safely transferring the charge into ground. Due to current problem with existing lightning protection systems such corrosion and stolen cable, a new system that can be installed within concrete structures has been introduced by the International of Electrotechnical Commission (IEC). However, detailed installation guidelines were not provided and previous study indicated that improper installation techniques and unsuitable materials embedded inside the concrete structure could cause physical damage to the concrete. Therefore, a newly proposed arrangement of galvanized steel cable was studied in this research. The impact of lightning simulation towards the concrete beams was determined. Concrete beams of 200 x 300 x 1200 mm sizes were used and several tests were conducted in order to investigate the performance of concrete beams. It was found that; very minimum temperature increases inside the concrete beams that were charged with high electric current. From the frequency test, reduction of natural frequency before and after the lightning simulation can be assume as negligible. In term of structural performance, load-displacement analysis indicated no significant load reduction by the high current. The newly arranged galvanized steel cable was also found to increase the structural capacity depending on its location of installation.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Lightning is a natural phenomenon which occurred when the upper atmosphere becomes unstable due to rising air currents. These rising air currents carry water vapor which, upon meeting cooler air, condense and gives rise to convective storm activity Agussalim (2004); (Erictech, 2009). Lightning can be one of the natural causes of human injuries or damage to electrical equipment (Zoro, 2013). According to the Lightning Protection Handbook (Erictech, 2009), the highest occurrence of thunderstorms in the world takes place around the equator as shown in Figure 1.1 Malaysia is one of the countries located around the equator that experiences 100 -140 days of thunderstorms per year. Based on this number, it is necessary to protect buildings from possible lightning impacts.

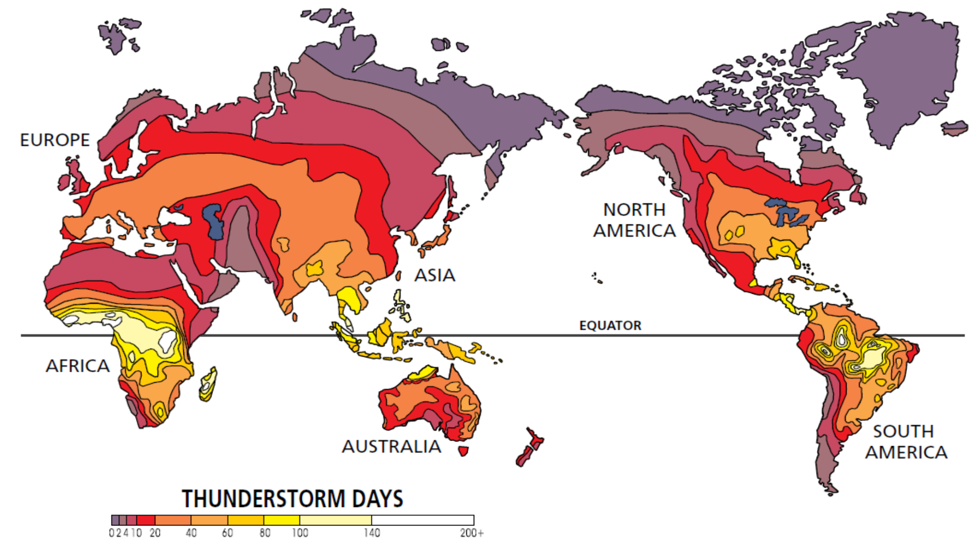

Figure 1.1 : Thunderstorm Days (Erictech, 2009)

In order to create a system to protect buildings from this natural phenomena, the Lightning Protection System (LPS) was introduced in the 20th century (Heidler, Zischank, Flisowski, Bouquegneau, & Mazzetti, 2008). LPS is needed to reduce equipment damage and the loss of human life caused by direct lightning strikes and fires. The main function of LPS is to transfer the lighting strikes to the ground. LPS can be classified into two categories; external LPS and internal LPS. Internal LPS is an electronic device called the Surge Protection Device (SPD). It is usually installed inside buildings to protect electrical equipment from direct lightning strikes. In the case of external LPS, the conductor wire of LPS is bonded externally to the roof structure, wall structure and finally transferred into the ground, as shown in Figure 1.2.

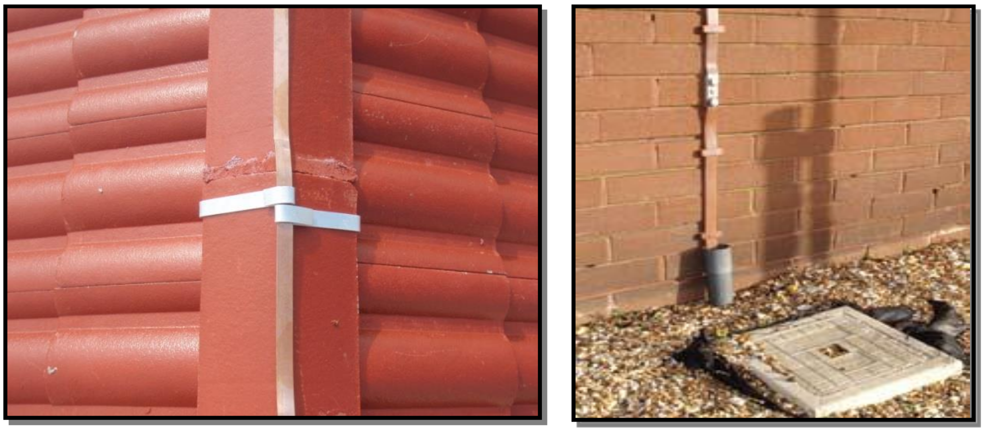

Figure 1.2 : Externally bonding LPS to structure

As external LPS can be either damaged or stolen, the new guidelines in EN IEC 62305-3 Standard (2011) allow the lightning protection cables to be concealed within concrete bonded with steel bars. This method is called the structural bonding method. Some of the previous works on LPS are related to topics such as induced voltage and current from lightning (Ishii, Miyabe, & Tatematsu, 2012) and external lightning protection systems for main office buildings in areas with high lightning density (Zoro, 2013). An intensive literature search in established databases such as ScienceDirect and Scopus indicated a lack of investigations on the integrity of the structural systems. Previous studies and investigations mostly focused on the physical damage of concrete structures due to lightning strikes (Kokkinos et al., 2006). As of now, there is no relevant data on the performance of concrete structures due to the lightning impact. The performance and strength of concrete structures may decrease to withstand the load originally designed for those specific structures or any impact to the original concrete structure.

1.2 Problem Statement

The popular lightning protection method used in buildings is an externally bonded lightning protection cable. This method has been widely used in buildings for decades. The selection of this method is because of the lack of other option available. However, various problems have been associated with this conventional method. A common problem related to external lightning protection cables is corrosion. The unprotected lightning protection cable is often corroded due to exposure to moisture from the surrounding environment and oxygen. According to Larter (2013) as illustrated in Figure 1.3, lightning protection cables made of bronze and copper materials corrode when they come in contact with external painted steel surfaces or galvanized surfaces. This is because corrosion takes place over time.

Galvanic corrosion commonly occurs to conventional lightning protection cables as shown in Figure 1.4. Galvanic corrosion is the outcome of the interaction of dissimilar metals with each other under specific environmental conditions, such as the same electrolyte (Ghavamian, Maghami, Dehghan, & Gomes, 2015).

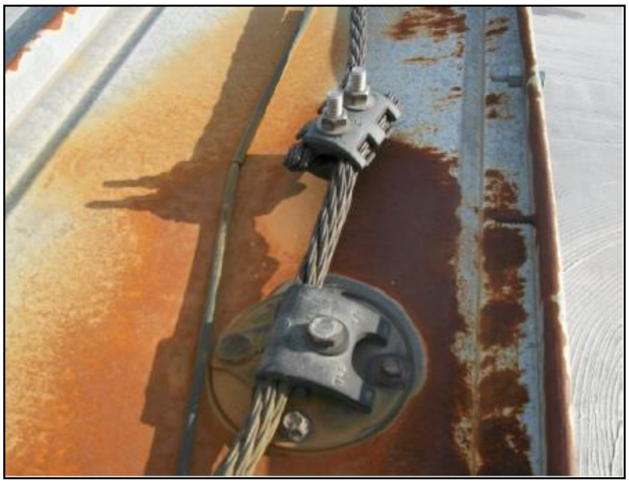

Figure 1.3: Copper and bronze in contact with Galvanized steel (Larter, 2013)

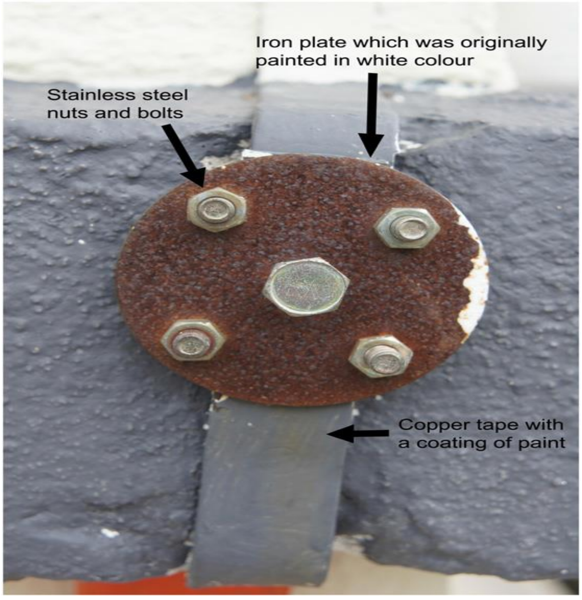

Figure 1.4: Corrosion damage for conductor materials (Copper, iron and stainless steel) (Ghavamian et al., 2015)

The second issue is related to the maintenance of conventional lightning protection systems. Maintenance can be divided into two categories namely, routine maintenance activity and unexpectable maintenance activity. Maintenance is a regular inspection which ensures the reliable maintenance of LPS is always in accordance with the fundamental conditions. However, the maintenance procedure of LPS depends on the weather and environmental conditions, exposure to actual lightning damage and the protection level assigned to the structures. Maintenance is a must to maintain the service life of LPSs especially for conventional LPSs. Thus, it can be concluded that conventional LPSs which are installed externally are subjected to maintenance. Maintenance activities such as replacing damaged and non-functioning materials or instruments in the overall lightning protection system can be difficult to perform especially for high rise building. The maintenance work is not only time-consuming and incurs high cost, but also requires the service of expert workers.

Undesirable maintenance activity is commonly the result of human issues. The down conductor cable for conventional LPSs is made of copper tape. This is because copper materials have good electric conductivity. However, many cases related to stolen LPS components especially copper cables have been reported. The attractive market price of externally installed lightning cable material attracts theft. As a result, extra cost is needed to replace the materials to ensure the service life of LPSs. A survey conducted in Brazil by SINDICEL (Sindicato da Indústria de Condutores Elétricos, Trefilação e Laminação de Metais Não-ferrosos do Estado de São Paulo) and ABC (Associação Brasileira do Cobre) reported that between January to August 2006, 650 tonnes of copper materials was stolen. Meanwhile, 421 tonnes of metal were stolen between January 2007 to May 2007 leading to total loss of 3.8 billion US dollars. At the Sao Paolo University, lightning cables from 10 buildings were stolen by thieves (Leite, Sueta, Geraldo, & José Aquiles, 2007).

In Malaysia, there are frequent reports of copper theft. Tenaga Nasional Berhad (TNB), the main electric utility company in Malaysia and Telekom Malaysia (TM) experienced the same problem with copper theft. In 2014, a total of 159 cable theft cases have been reported in eight months in Sabah with a total loss of nearly RM1 million. The Electrical and Electronics Association of Malaysia (Teeam) also reported 17 cases of copper theft in Klang Valley and Johor in the last 6 months in 2007. The cases started increasing due to the rising prices of copper and aluminium in the market. In 2006, the International Electrotechnical Commission (IEC) had introduced another option for the installation of lightning protection systems in buildings. The first revision for Protection against Lightning-Part 3: Physical damage to structures and life hazard (Standard, 2011) is the main standard to be referred for the new installation guidelines. The guideline allows the lightning cable for the down conductor to be embedded into the reinforced concrete structure. In the guidelines, five materials which can be used as lightning cables namely, copper, hot galvanized steel, stainless steel, aluminium and lead were listed. However, aluminium and lead are not suitable to be used in concrete. Therefore, suitable and economical materials need to be selected from the listed materials. The arrangement of the cable installation in the concrete structure, method of connecting the LPS cable within the concrete structure and other details related to the installation were not provided. There were several issues regarding the new installation. Previous research revealed that the gap distance between the down conductor cable and reinforcement steel bars could cause different damages to concrete structures as shown in Figure 1.5 (Kokkinos et al., 2006).

Figure 1.5: Damage of structure by lightning simulation (Kokkinos et al., 2006)

In practice nowadays, no detailed guidelines are available on the installation of down conductor cables inside concrete structures. As shown in Figure 1.6, the gaps between the cable and steel reinforcement could promote the transfer of electric current to the nearest conductor material. This process could cause damage to concrete structures as the process can create sparking or explosion within the concrete structure. Figure 1.7 shows the placement of the cables in concrete columns. No clamping was applied to the cable and the cable was left hanging freely from the structure. The installation of non-regulated cables could create possible danger.

Figure 1.6: Placement of the conductor cable in concrete beam (Kokkinos et al., 2006)

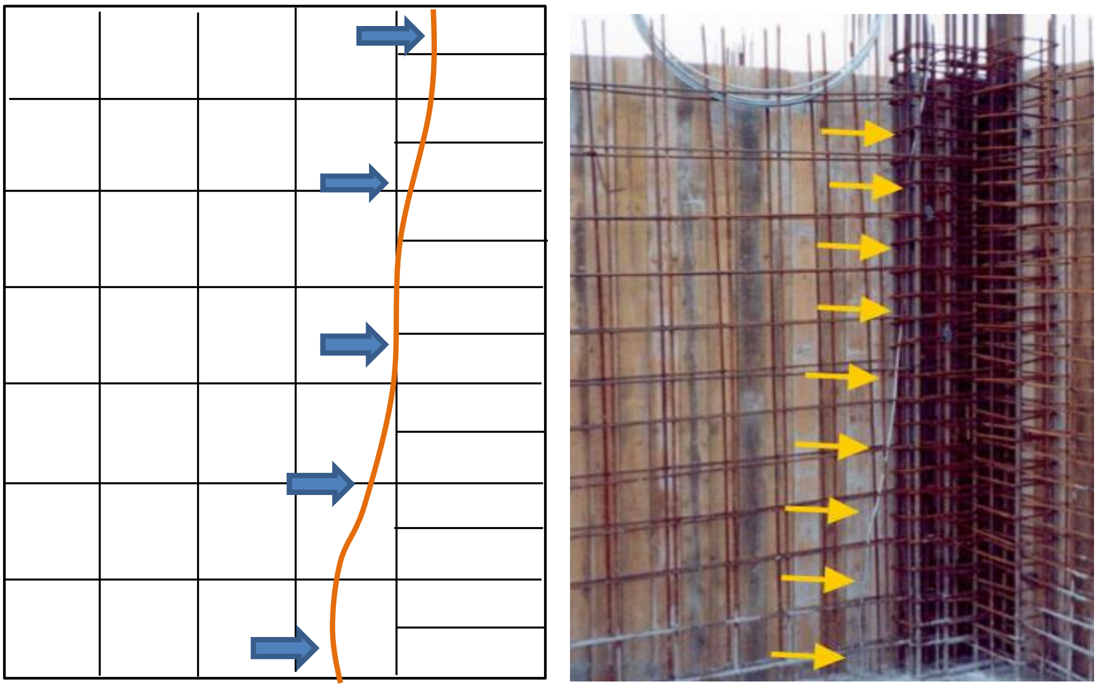

Figure 1.7 : Placement of the conductor cable (Kokkinos et al., 2006)

In civil engineering, the size of bars, the number of bars, the size of links, the number of links and also the size of structures are designed according to the loading applied to the structure. However, the effect of this type of cables installed inside the structure has never been investigated. In addition, the impact from lightning may produce additional load or weaken the structure because of the possible heat generated. Therefore, the remaining question is, will the integrity of a structure be compromised because of the inclusion of the lightning protection system inside it. No relevant tests have been done to investigate the performance of structures containing LPSs. Previous work focused more on the performance of conducting wires in terms of the conduction of lightning current into the ground.

The detailed guidelines on installation procedures must be proposed to overcome the above-mentioned problems related to conventional lightning protection systems and provide option to embed lightning cables into concrete structures. The proposed method of installation needs to be tested to investigate any adverse impact on the overall performance of the structure components. Therefore, the aim of this work is to study the impact of lightning and lightning cables on the integrity of structural systems. This study focuses on beam components and seeks to find out if its integrity can be compromised by cables and lightning.

1.3 Research Question

The evaluation of the new lightning protection system in buildings is to understand the overall performance of the installation of the LPS in reinforced concrete structure, especially reinforced concrete beams. The temperature variation during the lightning impact will also be determined. In general, the research was conducted to answer specific questions as listed below:

Q1: Is the temperature inside concrete beams affected by the high electric current from the lightning simulation strike?

Q2: What is the immediate effect from high electric current to the stiffness of concrete beam?

Q3: How does the load-displacement behaviour of concrete beam with embedded lightning cable?

Q4: What is the suitable material and arrangement for the lightning protection components to be embedded inside the reinforced concrete beam without affecting its structural integrity?

1.4 Objectives of Study

Specific objectives were outlined to achieve the research outcomes regarding the evaluation of the LPS installation in reinforced concrete beams:

1) To quantify the possible temperature variation effects of reinforced concrete beams during lightning simulation strike.

2) To determine integrity of reinforced concrete beam by using the impact hammer test before and after lightning simulation strike.

3) To determine load-displacement behaviors of reinforced concrete beam with embedded lightning cable.

4) To suggest preliminary guidelines and techniques for LPS installation within reinforced concrete beams.

1.5 Scope of Study

This research presents the numerical data and findings for the assessment of galvanized steel as the main cable for down conductors embedded in concrete beams. This study is based on the faraday cage system, which the concept of cages on the building structure is to protect the building and allow the electric charge caused by lightning to flow into the ground. According to the faraday cage concept, the lightning protection system starts from the air termination system (rooftop), followed by the down conductor system (in column and beam) and finally to the ground. This research focuses on the beam as it is the main component of the lightning system in the faraday cage method. The lightning cable can be found in the concrete beam along the parameter of the building.

The reinforcement of concrete beams with a cross section of 200 mm x 300 mm and the length of 1200 mm was done according to the latest design standards i.e. the Eurocode BS EN 1992-1-1: Eurocode 2: Design of concrete structures - Part 1-1. The concrete beam was designed as a double-reinforcement beam structure using 2T10 and 2T12 as the main reinforcements. The details of the design can be found in Chapter 3 as well as in the Appendix B in the form of a design sheet. From the previous data on the occurrence of lightning strikes in Malaysia as highlighted in Chapter 2, the average lightning strike in Malaysia produces a current between 25 to 30 kA (Department, 2013). In this work, the lightning strike simulation was conducted using electric currents which are equal to the actual lightning charge (measured in kilo-amperes, kA). According to the Specification for Lightning Protection Systems for Structures: LS-9 Section 1 from Public Work Department Malaysia (2011), the minimum 1.5 kA impulse current in 1.5 microseconds is considered equivalent to lightning strikes. In this study, high electric currents from the scale of 15 kA, 30 kA and 45 kA were used. This range was determined from previous data on lightning strikes and the capability of the Generator Set (Impulse Machine Machine) to produce the high electric current.

1.6 Limitation of Study

In this study, galvanized steel was used as the main cable for the down conductor embedded in reinforced concrete beams. No other cable materials as stated in EN IEC 62305-3 Standard (2011) were used in this experimental work. This research only focused on galvanized steel cables with the minimum cross section allowed i.e. 50 mm^2. Two main experimental works in this study included the impact hammer frequency test in order to investigate the immediate performance of the beam structure after the lightning simulation and the flexural test to investigate the overall structural performance of the concrete beam.

1.7 Significance of Study

This research assesses the performance of concrete beams embedded with lightning protection cables attached to the main reinforcement in the structure. The significance of the research is described below:

1) This research topic is related to the new guidelines for installing lightning protection systems within building structures as described in EN IEC 62305-3 Standard (2011), Protection against Lightning-Part 3: Physical damage to structures and life hazard.

2) This research validates the use of galvanized steel as a material to be used for down conductors installed within concrete beams.

3) This research provides laboratory results and software analysis to investigate the impact of galvanized steel cable as the main cable for the lightning down conductor in concrete beams.

4) The outcome of this study to proposes preliminary guidelines and techniques for installation of the lightning cable in concrete beams including material selection for the cable, the location of installation, the clamping method of the cable and other basic information related with the installation procedures.

The above findings and documentation should fill the gaps of knowledge for lightning protection systems especially related with latest guidelines for the installation of LPS within reinforced concrete beams.

1.8 Research Approach and Methods

Various stages of research work are involved in this study in order to answer the research questions and objectives. The flowchart of the research work is shown in Figure 1.8 below.

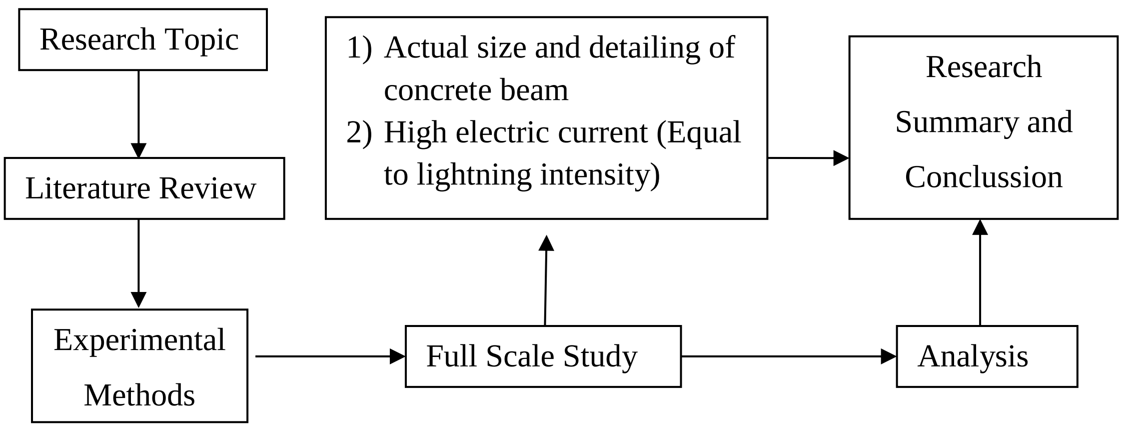

Figure 1.8: Summary of research methodology

The full-scale experimental study uses reinforced concrete beams with a cross section of 200 mm x 300 mm. The concrete grade used is C30 while the main reinforcement sizes of 2T12 and 2T10 were used for the bottom reinforcement and top reinforcement, respectively. The link used measured 6 mm. The reinforcement tensile strength was 500 N/mm^2. The high current was set up from the lowest 15 kilo-ampere (kA) to the highest 45 kA in the full-scale study as the minimum lightning current was 1.5 kA. The experiment work was conducted at Universiti Teknologi MARA, Permatang Pauh, Pulau Pinang, involving both heavy structure and high electric current laboratories. Details of the experimental work are explained in Chapter 3.

To fulfil the research objectives, various parameters were recorded. The parameters involved the temperature variation inside the concrete beam, impact hammer data (natural frequency analysis), flexural strength (load-displacement analysis) and software analysis. The full-scale study, however, only focused on the reinforced concrete beam and galvanized steel cables. The selection of cable was made by following the guidelines of the first revision for Protection against Lightning-Part 3: Physical damage to structures and life hazard (Standard, 2011).

1.9 Organisation of Thesis

The chapters of the thesis are organised as follows:

Chapter 1 presents the introduction of the thesis including research background, problem statement, research question, research objectives, scope of study, limitation of study, significance of the study, research approach and method and the organisation of the thesis.

Chapter 2 covers the literature review related to the formation of lightning, classification of lightning, previous data of lightning, lightning protection system and ANSYS. This chapter also covers temperature impact for concrete structure, physical damage of concrete structures and summary for the chapter.

Chapter 3 describes the materials and methods involved in the experimental work. The items covered are the experimental methods, pilot experimental study, experimental set-up and ANSYS analysis.

Chapter 4 presents the findings and discussion on the pilot test and experimental tests starting from the preliminary material test, temperature variation test, impact hammer test assessment, load-displacement and ANSYS analysis. Preliminary guidelines and techniques for LPS Installation within reinforced concrete beams were also discussed in this chapter.

Chapter 5 concludes the major research findings based on the objectives outlined at the beginning of the research and proposes recommendations for further work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lightning is formed when air and water move around inside the cloud and are forced by warm air currents and gravity. These processes compress the cloud. When lightning strikes, it may reach a temperature up to 30,000°C with a current of up to 100, 000 amperes and an average of 100, 000, 000 volts of electricity (Brüesch, 2016). On average, there are 100 lightning strikes per second occurring on the surface of our planet. A 100-watt bulb can light up for three months from the energy from each lightning bolt (Malavika & Visha, 2013). In half a second, a lightning flash can happen and this will lead to a process where the temperature of surrounding air become five times hotter than that on the surface of the sun. When lightning strikes, it occurs in all directions and creates temperatures hotter than the surface of the sun. Lightning becomes an issue when it strikes on the ground. It can damage building structures and cause harm to humans and animals, either directly or indirectly through fires and explosions. Lightning has claimed many lives and caused injuries and extensive damage to properties and the environment. Therefore, a single lightning bolt can cause a huge damage as it can completely wipe out huge trees and buildings (Gatewood & Zane, 2004).

2.2 Formation of Lightning

Lightning is a process of electricity discharged from the storm clouds to the earth. Excessive positive charges are on top of the clouds while excessive negative charge is at the bottom of the clouds. The earth’s surface is filled with a massive amount of positive charge. Thus, an electric field with high strength is formed due to existence of opposite charges between the bottom of storm clouds and ground surface. This electric field needs to be of some considerable strength in order to bridge the distance between the bottom of the cloud and the earth’s surface (Poelman, 2010). Normally, lightning produces the brightest light and the loudest sound (Dwyer & Uman, 2014). The analogy of this process is given as the head of a step leader facing downwards and split into several compartments which produce an ionised path transmitting charge along the channel (Figure 2.1). A strong electric field is produced as the stepped leader is approaching the earth. This process happens when an electric field brings along positive charges to neutralise negative charges along the path. The returning stroke that is formed will result in brighter light than the stepped leader and discharge extensive energy (Figure 2.2). The discussion was supported by other researchers that the formation of lighting is caused by positive and negative electricity charge (Kai-chung). A summary of previous research studies in different countries on the formation of lightning is given in Table 2.1.

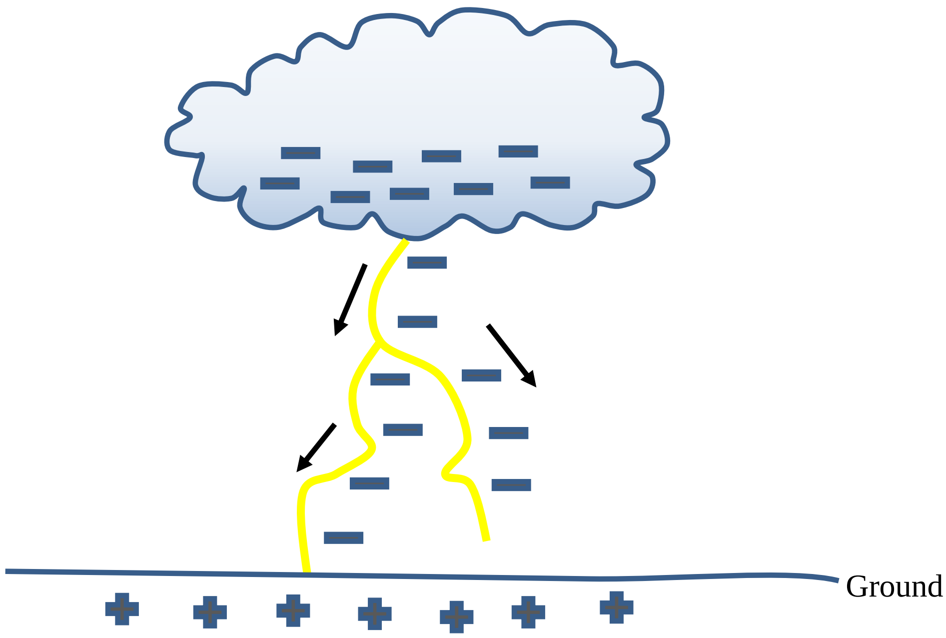

Figure 2.1: Formation of stepped leader

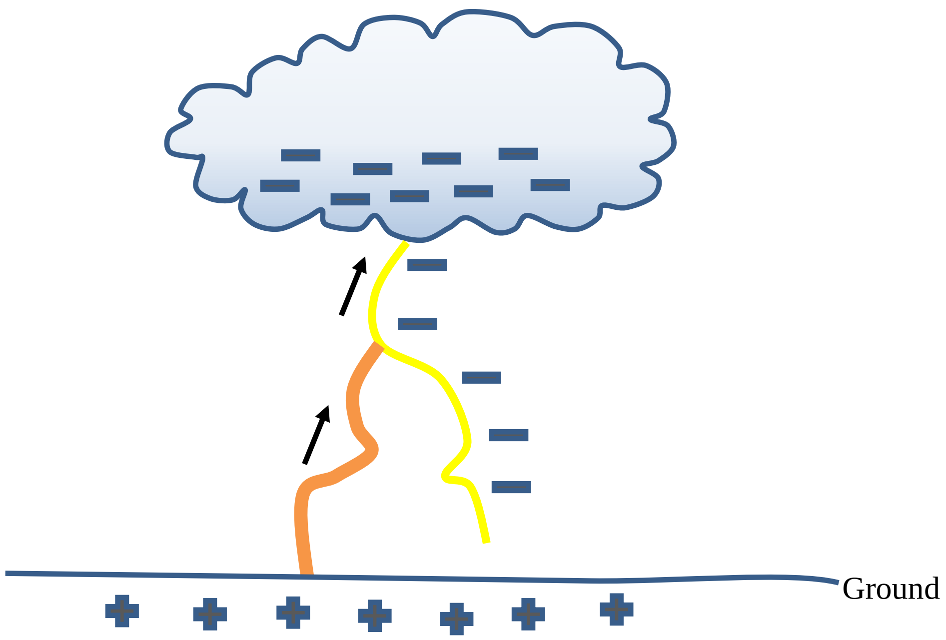

Figure 2.2 Formation of returning stroke

Table 2.1: Research study about the formation of lightning.

Author	Location	Content of research
Hassan, Rahman, Soh, and Ab Kadir (2011)	Malaysia	The lightning strikes on the earth's surface has been estimated at 100 times every second. Lightning occurs due to the difference in positively and negatively charged particles.
Baharudin et al. (2012)	Malaysia	Lightning is developed by motion of charge and electrostatic fields. Cloud-to-ground flashes initially develop in an overall downward direction, and transport negative charges to the ground.
Nag and Rakov (2014)	USA	Highest directly measured lightning currents and the largest charge transfers to the ground are associated with positive lightning.
Ghavamian et al. (2015)	Malaysia	Lightning is a charge of electricity that travels from a thunder cloud and produces high currents that are transferred to the earth.

2.3 Classification of Lightning

Lightning can be classified into 3 categories as shown in Table 2.2. The 3 categories are negative lightning (-C2G), flash lightning and positive lightning (+C2G). C2G means the discharge of cloud-to-ground lightning (Hassan et al., 2011). The sign convention which is + (positive) or – (negative) represents the direction of the lightning strike. If all strokes are of positive polarity, then flashes are considered positive (Schulz, Pichler, Diendorfer, Vergeiner, & Pack, 2013). High peak currents, large impulse and long continuing currents come together with a stroke from positive lightning where they begin at the top, around 30-60,000 feet up. Since lightning can travel for long distances, so it can be 10 times stronger and last up to 10 times longer than negative lightning. As a result, it can extend to 1 billion volts and 300,000 amps of power (wxbrad) . However, probably 90 % of overall lightning are negative lightning according to past literature which stated that 90% of all negative cloud-to ground flashes are developed in the cloud with a downward direction which later transfer negative charge to the ground (Baharudin et al., 2012). A typical negative charge bolt has 300, 000, 000 volts and 30, 000 amps of power and can be very dangerous (wxbrad).

Table 2.2: Category of lightning (Hassan et al., 2011)

Input: Current (A)	Category of Lightning
< 0	Negative lightning (-C2G)
= 0	Flash
> 0	Positive Lightning (+C2G)

Cloud-to-ground flash is the most dangerous among all types of lightning as it has a high impact on living things or objects (Fahmee, 2016). The majority of flashes develop near the centre of lower negative charge and disperse negative charge to the earth (Arif, 2009). High rise buildings are affected by this type of flashes although they normally strike to the ground. Figure 2.3 (a) shows a typical cloud-to-ground flash that happened in Kavala, Greece.

(a) (b)

Figure 2.3**:** (a) Cloud-to-ground flash and (b) Intercloud flash (Wirth)

Cloud flash does not strike the ground because it discharges the flash to the air around the storm through its visible path (Fahmee, 2016). There are two categories of cloud flashes namely, intra-cloud flash and inter-cloud flash. The intra-cloud flash occurs in the same thundercloud which contains both positive and negative charges. The flash is produced between the thundercloud boundaries only. Inter-cloud flash happens between two different clouds as it will emit charges to the ground (Fahmee, 2016). It is called cloud-to-cloud lightning and is visible from the ground. Inter-cloud flash happens the least compared to other types of lightning (Song, 2005). Figure 2.3 (b) shows a typical inter-cloud flash.

2.4 Previous Data of Lightning

Almost every day, lightning discharge happens all over the world. Lightning discharge towards the surface of the earth with an estimated value of nearly 1000 lightning discharges per second or 5000 storms per day occurs around the world (Legrand, 2007). Furthermore, approximately 8 million lightning strikes are discharged to surface of the earth per day. This is equivalent to 100 lightning discharges from the progression of 200 thunderstorms (Ab-Kadir, 2016). Moreover, almost 1.4 billion flashes occur yearly around the world (Christian et al., 2003).

It has been recorded that there are approximately 2 million lightning discharges to the ground surface yearly in France, especially in Spain or Italy (Legrand, 2007) . In Germany, there are around 1.5 million lightning discharges in a year as reported by the Lightning Protection Guide. It is acclaimed that countries situated near to the equator have more lightning density. Figure 2.4 shows the number of strokes of lightning around the world for average 5 days.

NASA has officially announced that the highest monthly lightning flash rate was recorded in Brahmaputra Valley in far eastern India between April and May in 2014. This is due to thunderous activity during the annual monsoon. However, according to the Guinness Book of Records, Venezuela's Lake Maracaibo has the "highest concentration of lightning" as it receives 250 lightning flashes per square kilometre each year (Davies).

Africa was recorded as the area which receives the most lightning strikes. In addition, there are 283 lightning hotspots in Africa out of the 500 lightning hotspots around the world. Asia comes in second with 87 sites, followed by South America, North America and Oceania with 67 sites, 53 sites and 43 sites, respectively (Albrecht, Goodman, Buechler, Blakeslee, & Christian, 2016).

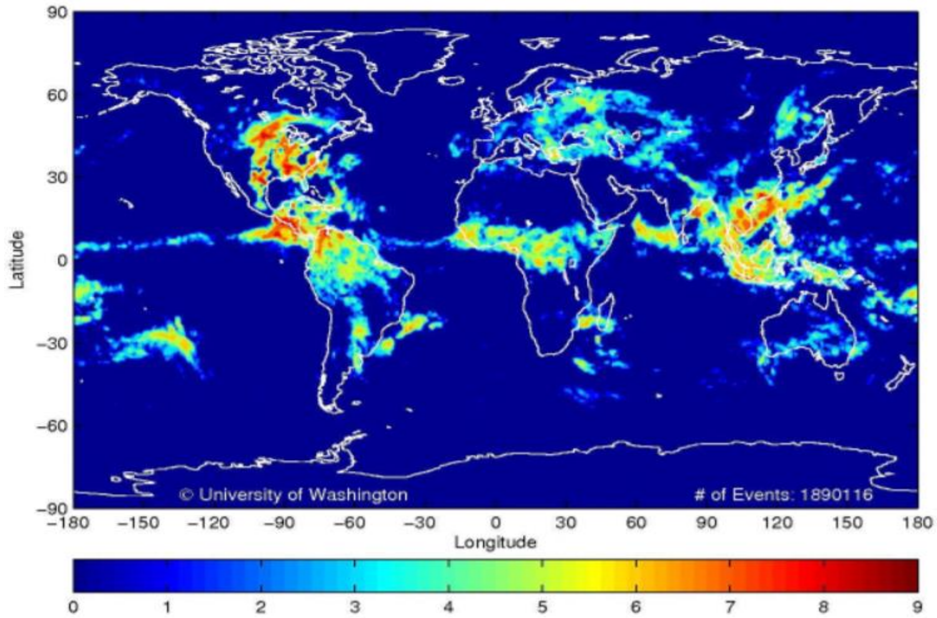

Figure 2.4: Average density image (Strokes Number for Five Days) (Poelman, 2010)

The Malaysian Meteorological Service estimated that thunder occurs 200 days a year in Malaysia. This number has been recorded based on their observation. Moreover, until 2015, 40 principal meteorological stations recorded occurrences of lightning in Malaysia. From the analysis, KLIA, Sepang, was found to have the highest number of days with lightning in a year which is 316 days. On the other hand, back in 1987, Subang recorded 362 days of lightning, which is the yearly highest number of days with lightning. Thus, Subang recorded the highest number of lightning incidences in the world based on a record of a minimum number of 240 days a year. This translates to 25 and 40 lightning ground flashes per km in the area in a year (Department, 2011).

Above all, Kuala Lumpur is ranked 5th in the world in terms of lightning density. Thus, Malaysia is described as a lightning core in Asia (Fahmee, 2016). In addition, Malaysia is among the top three countries in the world in terms of lightning density (Ab-Kadir, 2016). Even though Malaysia is among the countries with one of the highest lightning densities, it has not received much attention from the public. It is essential to have proper safety precautions to avoid fatal incidents caused by lightning. Table 2.3 shows a summary of previous research studies carried out on lightning in Malaysia.

Table 2.3: Research study about lightning that occur in Malaysia.

Author	**Country**	**Topic of Study**
Abdullah, Yahaya, and Hudi (2008)	Malaysia	Implementation and Use of Lightning Detection Network in Malaysia.
Arif (2009)	Malaysia	Assessment of Lightning Protection System (LPS) For Asset Management Enhancement: FKE UTM Skudai Campus.
Ab-Kadir (2016)	Malaysia	Lightning Severity in Malaysia and Some Parameters of Interest For Engineering Application.
Fahmee (2016)	Malaysia	Analysis of LPS Using Roll Sphere Method For PRZS and P19A Using Rolling Sphere Method.