FINITE ELEMENT ANALYSIS ON THE FLEXURAL BEHAVIOUR OF INTERNALLY PRE-STRESSED I-BEAM

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ABSTRACT

Many bridges will be distress after a certain life span. Larger increase in the deflection will develop and also a very deep crack may develop instantaneously if the loads are kept constant after cracking happen to the structure. Therefore, cracking and deformation characteristics of the structural members are important in design. Deterioration of the existing bridges is mainly caused by the increased in the traffic loading on those bridges, progressive structural aging of the bridges and the corrosion of the reinforcement from various causes such as the weathering condition which has become the major causes all over the world. The traffic volumes that are coming from the heavy trucks on the bridges have risen to the level that exceeds the values design at the time of the design. Therefore, many of the bridges has suffered fatigue damage from the case of heavy traffic volume and in need of urgent repair and strengthening. The purposes of this study are to analyze the flexural behaviour of the internal pre-stressed beams under the applied loading and to investigate and evaluate the use of finite element analysis of the pre-stressed concrete beams. Result showed that the flexural behaviour of the pre-stressed beam can be varied with the different applied loading and cracking also may be happened.

ABSTRAK

Kebanyakan jambatan akan mengalami kesesakan selepas suatu jangka hayat tertentu. Sekiranya beban yang berat ditanggung dalam suatu tempoh masa yang lama dan berterusan, kelendutan akan berlaku kepada jambatan tersebut. Hal ini jika dibiarkan berterusan akan menyebabkan keretakan juga berlaku kepada struktur jambatan. Oleh itu, faktor keretakan dan ciri-ciri ubah bentuk dalam sesuatu reka bentuk amat penting untuk sesebuah struktur. Kekuatan sesebuah jambatan sedia ada semakin berkurang pada hari ini adalah terutamanya disebabkan oleh peningkatan beban dalam bentuk trafik, penuaan struktur sesebuah jambatan itu sendiri dan hakisan struktur besi jambatan akibat daripada pelbagai punca seperti keadaan cuaca yang menjadi punca dan sebab utama di seluruh dunia. Oleh yang demikian, kebanyakan jambatan telah mengalami kerosakan akibat daripada menanggung beban yang berlebihan daripada jumlah trafik dan memerlukan pembaikan dan pengukuhan yang segera. Tujuan kajian ini dijalankan adalah untuk menganalisa kelenturan rasuk konkrit dalaman jambatan di bawah tekanan beban yang diaplikasikan. Hasil daripada kajian yang dijalankan menunjukkan bahawa kelenturan rasuk konkrit berubah apabila nilai beban yang diaplikasi berbeza dan keretakan juga boleh berlaku sekiranya beban yang diaplikasi berlebihan.

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LIST OF ABBREVIATIONS

M	Applied moment on a section
E	initial Young'smodulus
I	second moment of inertia
ɵ, $ɵ_r$	section curvature and section residual curvature
v	Poisson`s ratio
E_c	elastic modulus of concrete
$f_c^{'}$	ultimate compressive strength
f_r	ultimate tensile strength (modulus of rupture)
f_y	strength of reinforcing steel for stirrup
f	stress at any strain ε
β_t	shear transfer coefficient
ε	strain at stress f
ε_0	strain at the ultimate compressive strength $f_c^{'}$
ε_{ps}	strain of prestressing steel
E_s	elastic modulus of steel
f_p	ultimate strength of prestressing steel
E_p	elastic modulus of prestessing steel

CHAPTER 1

INTRODUCTION

1.0 Introduction

In designing the bridges, an engineer need to completely understand the problem to be solved. To design a safety and longevity bridges, they have to consider different types of loads, how and where they need to apply the load. They also have to undergo several steps that usually need in designing bridges such as understanding the problems, determining the potential loads of bridges, calculating the highest possible loads and calculate the amount of material need to counteract the loads.

Retrofit is one of the important features of maintenance. It is can be defined as upgrading or strengthening the bridge structural quality to enhance the performance of the bridge. Strengthening and retrofit methods are different from the repairing and it includes a component host. Most bridges are in need for the retrofit and strengthening every 15 years. There are a lot of strengthening methods like steel pre-stressed girders, micro piles, pile caps, extended footings, abutment wall, wall piers and column bent pier. Other than that, there are also concrete deck repair by patching, epoxy injection, silica fumes and salvaging of existing railing and beam where it is customary to retain the existing ones. If demolition needs to be conducted, extra care is strictly prohibited to ensure the features that required for continuity are not damage.

There are a few ways to retrofit bridge structure to prevent it from collapse. It is because these physical strengthening or restoration has its own style of design and construction. Any method of strengthening should be investigated first so that it will comply with the situation of the damaged bridge. The method chosen must be also economical and constructible with as low as possible impact to the traveling public.

Many bridges will be distress after a certain life span. It is more economical to strengthen the bridge rather than demolish it and build a new one. This can be done by using an external pre-stressing and other strengthening method (Muthuramu, Jeyakumar, Sadish-Kumar, & Palanichamy, Strengthening of reinforced concrete beam using external prestressing, 2002). External pre-stressing is a way where concrete structural members are pre-stressed longitudinally by using tendons that is located completely at the outside of the concrete section. Nowadays, external pre-stressing has been considered as one of the most powerful techniques in strengthening or rehabilitating the existing concrete bridges (Lou & Xiang, Introduction, 2006). It has been commonly used in the construction of concrete bridges because it provides advantages of economic feasibility and easy applicability. Furthermore, it can also be applied to not only bridge structures but to building structures too. Some more studies have to be carried out to enhance a better understanding of this technique.

Larger increase in the deflection will develop and also a very deep crack may develop instantaneously if the loads are kept constant after cracking happen to the structure. Therefore, cracking and deformation characteristics of the structural members are important in design. The composite beam that is externally pre-stressed is purposely employed in the bridge engineering to strengthen the existing structures mainly. This practice can also be applied to either the deck of concrete bridges and continuous steel beam or to only single span bridges. Deterioration of the existing bridges is mainly caused by the increased in the traffic loading on those bridges, progressive structural aging of the bridges and the corrosion of the reinforcement from various causes such as the weathering condition which has become the major causes all over the world. The traffic volumes that are coming from the heavy trucks on the bridges have risen to the level that exceeds the values design at the time of the design. Therefore, many of the bridges has suffered fatigue damage from the case of heavy traffic volume and in need of urgent repair and strengthening.

External pre-stressing can also be identified by which the tendons are placed outside of structural element. This is to facilitate the flexural resistance and can be refers to a post-tensioning method (Ng & Tan, Introduction, 2005). It will be efficiently in strengthening the existing concrete beam and also in the construction of segmental box girder. Pre-stressed concrete beam's advantages include large flexural rigidity, torsion rigidity, good integral performance and high stability and others. However, there is no provision of design for the pre-stressed concrete beams in the current standard. At ultimate state, the stress in the external pre-stressing tendons needs to be identified to calculate the ultimate strength of the strengthened member.

In response to the demand of efficient and faster transportation systems, there are an increase in the traffic volume and weight of the highway system around the world. The increases of vehicle loads will also cause the over- loading on the bridges. This problem should be considered in designing or assessing the bridge. As a result, most bridges today required to carry loads greater than the original design (Daly & Witarnawan, 1997). The technique of external pre-stressing has become popular because of the minimal disruption to the traffic flow and only need a short time to install the system or rapid installation. This is the major cause that leads to the failure or cracking of bridge that need an urgent repair and strengthening to maintain its function.

1.2 Problem Statement

For certain bridges such as flyover, there is a limitation for the height of vehicle to pass under the flyover. Sometimes, there is a certain vehicle such as lorry especially that are not allowed to pass under it because of the height limitation that will cause the failure to the bridge when it rammed the beam girder of the bridge. The cracking that caused by the body of the lorry will decrease the strength of the beam itself and also the entire bridge. Once the cracking is formed, the strengthening method or bridge repair and rehabilitation should be taken immediately to prevent the spreading out of the cracking. If the cracking is serious, it may lead to the collapse of the bridge. Rather than need to build a new bridge, it would be preferable to only just strengthening the existing one by using a suitable method. Bridge cracking can also result from the extra load or over loading acting on that bridge. This loading may come from the increasing number of vehicle nowadays. Even bridge that has been design with appropriate loading specification can be under strength if these incidents happen. In order to strengthen the bridge, we have to consider the seriousness of the problems for that particular bridge before any action can be taken.

1.3 Objective

The objectives of this research are;

- To analyze the flexural behavior of the internal pre-stressed beams under the applied loading.
- To investigate and evaluate the use of finite element analysis on the pre-stressed concrete beams.

1.4 Scope of Study

The member analysis is quite tedious and may be simplified by a "pseudo-section analysis". This pseudo-section analysis is not covered for this research since this will predicts the responses of a simply supported beam which is subjected to two symmetrical concentrated loads. It will only cover the flexural behavior of the internal pre-stressed beam. The behavior and performance of the beam will be analyzed and observed before and after the load is installed. For this study only dead load is going to be used.

For this research, I-beam girder will be using to carry out the test. The model is build by using ANSYS. The flexural behavior of the beam is test on the model.

From previous investigation report, most of them reported that span-to-depth ratio has a significant effect to the flexural behavior on external tendon stress. Under bridge design, loads combining for a particular bridge such as dead load, live load and environmental load are important step. Under flexural behavior, the beam would experiences compressive force on the top of beam while tensile force will act at the bottom of the beam.

1.5 Research Significant

External tendons system is used to strengthening the existing concrete bridge. External tendons will constitute the primary reinforcement in the new design of bridges. There are some advantages of using external tendon which are the construction is more economical, easier tendon layout, placement and consolidation of concrete. Other than that, it gives better corrosion protection compared to the conventional one and it reduce in pre-stressing force losses. This research is conducted to examine the benefits of external pre-stressing that being used in strengthening the cracked flexural members. Moreover, the effect on service load behavior and also nominal flexural resistance can be evaluated.

The study of the behavior of flexural pre-stressed beam will help the engineers to design a more safe and long-lasting bridges. This research will be conducted a second order effect analysis. Identification of loads before design a bridges is very important factor. Determining the potential forces or loads that reacting on the bridge is depend on the location and purpose of the bridge. Dead loads will include the self weight of the bridge and together with other permanent object that fixed to the bridge like toll booth, guardrails, concrete road surface, highway sign and gates. Other than that, live loads are loads that are temporary which act on a bridge such as pedestrians and vehicles. Other temporary load that acts on the bridge is environmental loads. This load is due to the weather or other environmental influences, for example high gusts, earthquakes, wind from hurricane and so on. If there is no proper drainage provided, rainwater collecting can also be a factor.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Post-tensioned bridges construction has been adopted for medium and large span bridges since it demonstrated advantages in terms of buildability, cost and aesthetical aspect (Pearson-Kirk, 2003).After a considerable life span, most bridges will become distress. Instead of demolish and build a new one, it is more economical to strengthen the bridge by this external pre-stressing or external post tensioning. This method is a significant method in strengthening the existing bridges. Nowadays, the external pre-stressing method has become well-known in strengthening the bridges (Muthuramu, Jeyakumar, Sadish-Kumar, & Palanichamy, Strenghtening of reinforced concrete beam using external pre-stressing, 2002). These external pre-stressing or reinforcement can be installed either before or after failure or cracking occur to that components (Shamsai, Sezen, & Khaloo, 2006). Usually, this system is well establish on a new structures but sometimes it has always been difficult for external pre-stressing on existing structures especially in terms of space restrictions, corrosion of reinforcement, end anchorages and lateral instability (Mukherjee & L.Rai, 2008). This method has a basic concept which is based on the fact where pre-stressing of the tendons intentionally will provide stress with an opposite sign from the existing in the original one and usually the tendons are located along the girders of main bridges (Radomski, 2002). Other than that, external pre-stressing has been widely used in reinforcing damaged structure of existing bridges and also to increase the optimum capacity when there are larger loads applied than the designed one (Zona, Ragni, & Dall'Asta, Introduction, 2008). Pre-stressing system can be applied to both continuous and simple beam. External pre-stressing tendons can be either rectilinear or draped in a path that is fixed by intermediate saddle points and end anchorages to encourage forces on beam where external loads are being opposed (Chen, Wang, & Jia, Introduction, 2009).

The behavior of the externally pre-stressed bridges is different from those internally pre-stressed bridges where there are related to un-bonded natures of external pre-stressing (Aparicio, Ramos, & R.Casas, 2001). There are features that distinguish between externally and internally pre-stressed beams. The features are coming in two which are the first one is tendon stress that depends on overall beam deformation and the second one is tendons are free to move according to section depth that resulting in eccentricity variations. These variations are known as second-order effects (Ng & Tan, Introduction, 2005). For external tendon system, strain compatibility between the surrounding of concrete and the tendons are no longer valid where the analysis should be based on the whole member's deformation. (Lou & Xiang, Introduction, 2006). In previous investigations, there some people claim that span-to-depth ratio has a significant effect on the flexural behavior of the beams. But some people said that there is no effect at all by the span-to-depth ratio on the behavior of the beam. According to the article journal prepared, it is stated that in a separate investigation, span-to-depth ratio was literally found give no significant effect on the external tendon stress of the tested beams if the second-order effects are being minimized (Ng & Tan, Introduction, 2005).

In the last decade, they had mainly focused on the study of flexural behavior of non pre-stressed beam rather than pre-stressed beam (Shaowei, 2013). Nowadays, the use of external pre-stressing is very wide. This approach also can be seen as one of the most efficient approaches for strengthening the existing bridges. According to Chee Khoon Ng and Kiang Hwee Tan based on their journal, external pre-stressing also defines as a post-tensioning method where tendons are placed at the outside of structural element with a purpose to facilitate a flexural resistance (Ng & Tan, Introduction, 2005). The location of anchorages and deviators together with the profile of the tendon must be according to relevant calculation that is also performed for bridges of pre-stressed concrete (Radomski, 2002).

According to the journal produced by Hu Shaowei in 2013, it states that there is no specific design of pre-stressed composite beam at present. In these recent years, pre-stressed beam structures have been used widely because of various types of bridges had being used in railway and highway bridges and also in urban overpass. (Shaowei, 2013). Pre-stressed concrete rehabilitation and maintenance will be different from the conventional one where in pre-stressed concrete, it used pre-stressing tendons to develop the strength and it makes used concrete of higher-strength (Radomski, 2002). The analysis of external pre-stressed beams is different from internal unbounded pre-stressed beams and ordinary bonded pre-stressed beams. This is because there is a lack of bond between concrete and tendons and also due to the effective depth of tendon which reduced during the second-order effect (Ghallab & Beeby, Introduction, 2005). Pre-stressing system using the external pre-stressing is a system where the concrete structure members are longitudinally pre-stressed using tendons that located completely outside the concrete section. External pre-stressing has been considered as one of the most powerful techniques in strengthening and rehabilitating the existing concrete bridges. Other than that, because of the construction improvement and speed together with the economy associated with this external tendon system, it has becoming popular in the new bridges construction (Muthuramu, Jeyakumar, Sadish-Kumar, & Palanichamy, Strenghtening of reinforced concrete beam using external pre-stressing, 2002). In the bridge design, un-bonded tendons are used primarily in construction of building while the bonded tendons are just the norm (Radomski, 2002).

The analysis of internal pre-stressed beam actually serves one additional level of easiness if compared to externally pre-stressed beams. Therefore, ultimate steel stress pre-stressing cannot be calculated accurately with sectional analysis (Aparicio, Ramos, & R.Casas, 2001). According to (Ng & Tan, Introduction, 2005) , they stated that one of the reason that leads to the complexity for the analysis of external pre-stressing beams is the variations of eccentricity of external tendons that is under load and particularly referred as second –order effect. So, more experimental need to be carried out and more experimental data are needed in order to address this issue. Most of the European codes do not allow any increase of ultimate pre-stressing steel stress (Δf_{ps}=0) unless there is an accurate analysis is performed. By the way, American codes and also some European codes recommend some formulas or values to estimate (Δf_{ps}). They believe that European codes are conservative while American codes sometimes unreasonably give high stress increment. Therefore, to neutralize these extreme positions, there is a research conducted at the Technical University of Catalunya (UPC) to analyze the bridges behavior with these external pre-stressing (Aparicio, Ramos, & R.Casas, 2001). Design of pre-stressed concrete is to ensure that the concrete should not produce tensile stresses that result from normal force and bending moment at working load (Benaim, 2008).

One of the most popular materials that have been used for bridge construction is concrete. This is because of its easiness in construction activity, good corrosion resistance and most important is economical. Concrete have being used widely in bridges slab, bridges girder and many other type of bridges. The deviation of the bridge deck design is acknowledged as inevitable (Au, Cheng, & Cheung, 2000).

Behind pre-stressed concrete design; the fundamental concept is the transfer of compression force that is from steel pre-stressing strands to the surrounding of the concrete. This is to achieve a member that is free from crack under service loads. The transfer of stress occurs because of the strand and concrete properties which take within a relatively short distance from the end of the girder (Okumus, Oliva, & Becker, Introduction, 2012). Long term assessment of such large civil infrastructures such as pre-stressed bridges is one of the challenging tasks. Usually, the action taken is the use of Finite Element Models (FEMs). However, short term behavior such as load tests still can be interpreted with Finite Element Model analysis with the satisfactory accuracy while the long term prediction is not straightforward (Sousa, Bento, & Figueiras, Introduction, 2013). For the structures that are pre-stressed, the pre-stressing force has been transmitted by bond. That was a property that manifests itself into two parts differently which then the development of the pre-stressing steel length is divided. The first one is the transfer length is the embedded length where pre-tensioned strand is required in order to transfer the effective pre-stressing stress to the concrete immediately before pre-stress is released. The second one is the flexural bond length. It is the distance in addition to the transfer length which is required for the development of stress associated with the nominal strength of the member of bonded pre-stressing steel. This study has been focusing on fully developed strands which consequently equal to the yield strength of the strand (Vázquez-Herrero, Martínez-Lage, & Vázquez-Vázquez, 2013).

Engineering solutions for the protection of civil structure need to be developed and being improved. This is to ensure the structure's safety. Pre-stressed technique have been introduced to overcome the problem of concrete's weakness especially in tension and the growth of cracks both in military constructions and civilians. This type of pre-stressing concrete may increase the crack control and the stiffness of the structural performance (Chen, Hao, & Chen, 2014). All inaccuracies in the construction of bridge as well as the subsequent degradation of the deck surfacing will give rise the roughness of the road surface. Meanwhile, under the sustained stresses the concrete will creep and resulting in long term deflection. This condition often happened to the pre-stressed concrete girder bridges and also cable-stayed bridges where the deck of the bridges are always under the compressive stress even there are under the most severe loading design (Au, Cheng, & Cheung, 2000).

The design and analysis of reinforced and pre-stressed concrete structures has been based on the conditions of simple equilibrium and also the empirical rules for almost a century. These methods generally resulted in safer results but sometimes contain inherent inconsistencies. This is also frequently does not reflect a better and clear understanding of the actual material's composite action (OWEN, FIGUEIRAS, & DAMJANIC, 1983). The cracks that occur to the bridge might lead to the durability problems especially when they are not enclosed in the end diaphragm and being exposed to the environment. Corrosion and losses of the strength together with the losses of bond between strands and concrete may lead to the failure of the structures because of the structural capacity losses. This condition may happen if the salt water seeping through the cracks and reaches the strands (Okumus, Oliva, & Becker, Introduction, 2012).

For the updated design of the bridge, the materials have been continuously changes its properties and the advance in the method of construction have been employed in the civil engineering domain (Sousa, Bento, & Figueiras, Introduction, 2013).

2.2 Case Study

Several researchers have attempted to take into account the variation of eccentricity for the analysis in their model of external pre-stressing. The beams will be divided into finite section and the compatibility of member deformation has to be considered together with the equilibrium of moments and forces. Then total elongation of external tendons for the applied load can be assumed as the concrete strains integral at the tendon level (Ng & Tan, Introduction, 2005). In this journal, (Lou & Xiang, Introduction, 2006) has developed analytical model pre-stressed beams with external tendons for analysis. Those models are based on finite element method also and encountered for compatibility deformation of entire member, geometrical nonlinearities and materials. The largest testing was conducted at CEBTP (France), with all together 11 beams were tested that consist of simply supported beams, monolithic and segmental beams, 6m spanning beams that combine internal and external pre-stressing with different types of tendon duct's filter material and different amount of reinforcing steel and pre-stressing (Aparicio, Ramos, & R.Casas, 2001). Another nine prototype concrete with T-beams cross-section has been prepared with the internal longitudinal reinforcement made of two T16 at bottom bars and at top bar consists of four R8 while the yield strength fy and $f'y$ of 530 MPa and 338 MPa respectively. Figure 2.1 was prepared to distinguish between the two tests (Ng & Tan, Test program, 2005).