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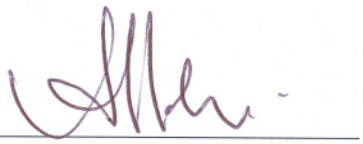
Signature	:	
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ABSTRACT

This project dissertation paper is a study on the repair and strengthening method for the support of a flyover affected by structural cracks. The study focuses on the techniques used to structurally repair or strengthen the concrete bridge piers of the selected case study involving the combination of external pre-stressing and composite method. Factor and requirement for repair and strengthening of the bridge supports have been reviewed whereby the technical aspects with respect to structural strength are studied. A hypothetical detail of bridge support has been created and investigated to study the effect on the flexural capacity of concrete section when pre-tensioning force imposed the CFRP strip prior to the adhesion of the plate onto the concrete bridge support. A general flow of repair and strengthening of concrete bridge support has been developed based on the analysis of the case study and results of the section analysis of the hypothetical detail. It is found that the choice of repair and strengthening method of bridge supports required a comprehensive structural investigation, careful design and construction. Data of the existing structure and its material properties, as well as the innovative approach of the construction technique are important factors for a successful implementation of the repair / strengthening method. In this particular case study, the repair and strengthening scheme which utilized a combination of external pre-stressing and composite system has been successfully applied to the bridge supports. Continuous monitoring and maintenance are required to ensure that the repair is effective in providing the solution to the structural problem.

ABSTRAK

Disertasi ini adalah untuk mengkaji teknik pembaikan dan penguatan sokong jambatan yang mengalami keretakan. Kajian ini dijalankan dengan memilih kajian kes dan memfokuskan terhadap teknik pembaikan dan penguatan sokong jambatan secara struktur. Faktor-faktor dan keperluan untuk membaiki dan menguatkan sokong jambatan telah dikaji dengan memberikan tumpuan kepada aspek kekuatan struktur. Satu butiran hipotesis sokong telah dibentuk untuk mengkaji kesan daya pra-tegangan terhadap kekuatan lenturan muktamad keratan konkrit apabila daya pra-tegangan dikenakan kepada kepingan CFRP sebelum kepingan tersebut dilekatkan ke permukaan sokong konkrit. Satu carta aliran umum berkenaan tatacara pembaikan dan penguatan sokong jambatan konkrit telah dirangka berdasarkan kajian kes dan hasil analisis keratan butiran hipotesis tadi. Adalah didapati bahawa pemilihan cara pembaikan dan penguatan memerlukan penyiasatan struktur yang komprehensif serta rekabentuk dan pembinaan yang teliti. Data untuk struktur sediada dan sifat bahan di samping pendekatan inovatif dalam teknik pembinaan adalah faktor-faktor penting untuk perlaksanaan kaedah pembaikan dan penguatan yang berjaya. Dalam kajian kes ini, skim pembaikan dan penguatan yang mengunakan gabungan pra-tegasan luaran dan sistem komposit telah didapati berjaya diaplikasikan untuk sokong jambatan. Pemantauan dan penyelenggaraan yang berterusan terhadap kaedah pembaikan tersebut adalah diperlukan untuk memastikan bahawa ianya berkesan dalam penyelesaian sesuatu masalah struktur.

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a	-	Shear span or distance from beam support to the nearest loading point
A_c	-	Gross section area of concrete section
A'_c	-	Area of crack concrete section
A_{ps}	-	Area of external tendon
$A_{s,}\ A_{si}$	-	Area of internal steel reinforcement
$b_c,\ b$	-	Width of beam
$c,\ x,$	-	Neutral axis
d_{frp}	-	Depth of FRP
f_c'	-	Cylinder compressive strength of concrete
f_{cu}	-	Concrete ultimate strength (Concrete grade)
f_{pe}	-	Effective tendon pre-stress
$f_{ps},$	-	Stress in external tendon
$f_{si},\ \sigma_{si}$	-	Stress in internal steel
f_y	-	Ultimate strength for steel (Steel yield stress)
F_c	-	Compression strut
F_t	-	Tension tie
F_s	-	Pre-stress force tie
d	-	Effective depth of un-strengthened section (with respect to steel)
d_{pso},d_u	-	Effective tendon depth at ultimate
E_{frp}	-	Modulus of elasticity for FRP
e	-	Eccentricity of steel tie frame
e'	-	Eccentricity of CFRP strip
E_{st}	-	Modulus of elasticity for steel
h	-	Overall beam height
k_1	-	The mean stress factor

k_2	-	Concrete compressive force centroid factor
k_s	-	Second order effect
L	-	Beam span
L_u	-	Horizontal distance between end of the pre-stress tensioning strands
M_s	-	Service moment during construction
M'_s	-	Additional service moment after the release of steel tie frame
M_u	-	Ultimate Flexural strength of strengthen beam
M_{un}	-	Ultimate flexural strength of un-strengthen beam
P_i	-	Initial pre-stressing force in CFRP
P'_{st}	-	Portion of pre-stressing force from the steel tie frame
P_{rup}	-	CFRP rupture strength
P_{st}	-	Total effective pre-stressing force from the steel tie frame
x_{cr}	-	The critical depth of neutral axis of strengthened section
x_1, x_2	-	The depth of neutral axis of the section which takes into consideration the curve shape of pier crossbeam
T	-	The applied horizontal load along with
V	-	Vertical force
Z_b	-	Section modulus for bottom fibre of un-crack concrete section
Z_t	-	Section modulus for bottom fibre of un-crack concrete section
Z'_b	-	Section modulus for bottom fibre of crack concrete section
Z'_t	-	Section modulus for top fibre of crack concrete section
Z_{cb}	-	Section modulus for bottom fibre of composite section
Z_{ct}	-	Section modulus for bottom fibre of composite concrete section
z	-	Lever arm of concrete section
β	-	Estimated loses in pre-stressing of CFRP
β_1	-	Compression stress block depth factor to ACI Building Code (ACI Committee 1999)
ε_{co}	-	The compressive strain of unconfined concrete, at the peak stress of concrete
ε_{cf}	-	Strain in concrete
ε_{cu}	-	Ultimate strain of concrete
ε_{frp}	-	Strain in FRP
$\varepsilon_{frp\text{-}rup}$	-	Strain in FRP at rupture for composite section
$\varepsilon_{frp\text{-}ini}$	-	Initial strain in FRP

$\varepsilon_{frp\text{-}max}$ - Maximum strain in FRP

ε_{si} - The strain in the steel

γ_c - Partial safety factor material (concrete) safety factor

γ_{mwE} - Partial safety factor for the modulus of the fibres in tension and compression

γ_{mwy} - Partial safety factor for the compressive strength of the fibres

$\gamma_{mw\varepsilon}$ – Partial safety factor for the strain capacity of the fibres in tension and compression and the strain at 'failure' in the fibres in compression.

ρ_{frp} - The ratio of CFRP

$\rho_{frp\text{-}cr}$ - The critical ratio of CFRP

σ_c - Stress in concrete before strengthening

σ'_c - Stress in concrete after strengthening

σ_{frp} - Stress in FRP

ρ_{si} - The ratio of internal steel

Ω_u - Bond reduction coefficient at the ultimate limit state

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CHAPTER 1

INTRODUCTION

Bridge generally needs structural modification when there is insufficiency strength caused by design inadequacies, incorrect detailing, improper construction or loss of stiffness due to material deterioration. Sometimes combination of these factors exists. The most common methods of structural modification are in the form of repairing, stiffening or strengthening the existing structure. Strengthening and stiffening are also necessary due to increase in live load and design code revision.

Failure in serviceability limit state attracts concern from the public. The safety of public facilities and infrastructure always become an issue when there is apparent concrete crack, excessive deflection and unacceptable vibration. Occurrence of this symptom is also the warning to the ultimate safety of a structure. As for bridge, these symptoms need particular repair or strengthening method to reinstate the bridge to it original service level.

Bridge support; the pier, pier cap and abutment, are considerably important to be maintained, repaired and strengthened where necessary. Damage of bridge support that is not repaired or strengthened properly would affect the bridge integrity as a whole.

When reconstruction or demolition is not an option, innovation in method of structural repair or strengthening should be the solution. However, repair and strengthening method need to consider a suitable theoretical background for a successful scheme. Cause of failure, existing condition of structure, the material compatibility and constructability are all equally important in short listing the possible solutions for repair or strengthening a structure. For concrete bridge structure whether by attaching the repair material directly onto the concrete surface to form composite, crack grouting or reinstating the structure via external pre-stressing, must undergo proper evaluation and selection.

Recent development in advanced civil engineering material provides variety of options for repair technique to suit the required condition of a deficient structure. Furthermore, the cost factor must be taken into consideration and in most cases this is the major determining factor.

1.1 Significance of Study

The study provides more evidence on the applicability of the existing theoretical background for repair and strengthening of bridge superstructure. Compiling the state-of-the-art technology in repair, stiffening and strengthening of bridge support provides a possibility for improvement of the existing engineering judgements or assumption made in designing the bridge repair and strengthening. If the technical aspects in state-of-the-art-technique such as safety factor, material mechanical properties, and static mechanic involves as well as the suitable assumptions made in bridge support modification work is continuously collected, a general guidelines for structural repair, stiffening and strengthening of bridge support is possible. Furthermore, through a case study, the necessary measure or good engineering practices adopted during the process of modification of bridge support can be documented. This is important to identify what are the do’s and don’ts during

the repair and strengthening work for an acceptable level of performance and durability of the repair material and the modified bridge support as a whole.

2.1 Objective of Study

The objective of this case study is to review the factors and requirements for strengthening of concrete bridge support. The study will also investigate the technical aspects of strengthening techniques for concrete bridge support through a selected case study.