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IN-SITU DETERMINATION OF THE RESULTANT LOADING IN STEEL REINFORCEMENT USING ULTRASONIC

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BORANG PENYERAHAN TESIS

Judul: *In-Situ* Determination Of The Resultant Loading In Steel Reinforcement Using Ultrasonic

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This project report, which entitled **"*In-Situ* Determination Of The Resultant Loading In Steel Reinforcement Using Ultrasonic"** was prepared by Chooi Chick Ngee as a partial fulfillment for the Bachelor's Degree of Engineering with Honours (Mechanical Engineering and Manufacturing System) is hereby read and approved by:

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Dr. Ha How Ung

(Project Supervisor)

Date : 8/4/04

IN-SITU DETERMINATION OF THE RESULTANT LOADING IN STEEL REINFORCEMENT USING ULTRASONIC

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This project is submitted in partial fulfillment of the requirements for the degree of Bachelor of Engineering with Honours (Mechanical Engineering and Manufacturing System)

Faculty of Engineering
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Dedicated to my beloved family

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ABSTRACT

In-situ loading determination is an on-site method that determine loading in the original or natural place or site, which could give information of load within a structure instantly. This method eliminates the complicated and labourous processes involved in conventional loading determination method. It plays an utmost important role in condition monitoring of steel reinforced structural members such as post tensioned and pre-stressed concrete members whenever during fabrication stage or stage it serves the public. In this experimental study on specimen of mild steel, non-destructive testing (NDT) method of ultrasonic will be used based on acoutoelastic principle. Variation in flight time or wave speed variation of ultrasound within the specimen due to changes of resultant loading will be determined. Three samples or specimens of mild steel that assumed to be identical are used in this experiment. The results had shown the effect of stress-induced velocity changes but there were varying across samples and two samples do not exhibit the expected profile of graph due to some unavoidable factors. At the same time of experiment, strain gauge is used to obtain values of strain due to applied torque. In addition to applied torque, resultant loading is derived from values of strain. Confirmation test is performed by strain gauge on the resultant loading due to applied torque and the obtained ultrasound's velocity.

ABSTRAK

Penentuan bebanan *in-situ* ialah cara menentukan beban di tempat asal yang mana dapat memberikan maklumat tentang beban dalam suatu struktur serta-merta. Cara ini mengelakkan proses rumit dan memenatkan yang terlibat dalam cara penentuan beban yang biasa. Ia memainkan peranan yang amat penting dalam pemantauan keadaan bahagian struktur yang diperkuatkan oleh keluli seperti bahagian konkrit pasca-tegang dan pra-tegasan semasa peringkat pembuatan atau memberi perkhidmatan kepada umum. Dalam pembelajaran ujikaji ke atas spesimen keluli ini, cara Ujian Tanpa Musnah ultrasonik akan digunakan berdasarkan prinsip 'acoustoelastic'. Perubahan dalam masa terbang atau kelajuan gelombang ultrasonik dalam spesimen yang disebabkan oleh perubahan beban hasilan akan ditentukan. Tiga contoh spesimen keluli yang digunakan dianggap sama dalam ujikaji ini. Keputusan telah menunjukkan kesan perubahan kelajuan hasil daripada tegasan tetapi ia berbeza di kalangan contoh-contoh dan dua contoh tidak mempamerkan bentuk graf yang diharapkan kerana beberapa faktor. Semasa ujikaji, tolok keterikan digunakan untuk memperolehi nilai keterikan yang disebabkan oleh daya kilasan yang dikenakan. Selain daya kilasan, beban hasilan diterbit berasaskan nilai keterikan. Ujian pemastian dibuat dengan tolok keterikan terhadap beban hasilan yang dihasilkan daripada daya kilasan dan kelajuan ultrasonik yang diperolehi.

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CHAPTER 1

INTRODUCTION

1.1 Background

Steel is categorized as ferrous metal and its application as structural members such as I-beams in construction, bar products, axles and railroad rails are considered the most important technological development (S.Kalpakjian, 2001). Stress called residual stress are developed in steel during the forming and shaping of reinforcement steel at the stage of production; however, these stresses are released during the end of production by stress-relief annealing and cause insignificant effect. However, as steel reinforcement functioning as structural members, various kinds of applied loads are experienced causing bending, tensioning or compressing and stresses are then developed within these structural members. Resultant loading during stages of structure fabrication and their service periods, thus, steel reinforcement experiences stresses within the structural members, in which will give significant and crucial effect to the structure. For instance, brittle fracture will occur when structural members over loaded with substantial tensile stress, which could exists in form of nominal, residual or both (J.M.Barsom et al., 1987). So, by getting to know the resultant loading of structural members, indirectly, level of stresses in steel reinforcement, immediate action could be taken to avoid fatal accidents and deterioration of structure caused by failure of steel reinforcement when stresses in structural members beyond the acceptable stress level.

As stress and load has an intimate relationship, thus, by determine the resultant loading on the structural members, the stress experienced will be known. In order to determine and monitor the loading and stress experienced by structural members of steel reinforcement during the servicing period and fabrication stages, some sort of *in-situ* determination method must be used. Non-destructive testing (NDT) method is favorable to accomplish *in-situ* determination of resultant loading, where, after the test the structural members do not require any repair of deterioration and structural members could be used safely without causing harms to users. This is because NDT is one in which there is no impairment of the properties and performance in future use of the object under examination (J.Blitz and G.Simpson, 1996). In this project, ultrasonic that will be described in more details in the following section is identified to determine the resultant loading within the steel, which according to J.Blitz and G.Simpson (1996), ultrasonic method is effectively a mechanical method.

1.2 Ultrasonic

According to J.Blitz and G.Simpson (1996), ultrasonic is the name given to study and application of ultrasound. In other words, ultrasound is a type of sound, where the sound is produced when a pressure wave that generated by mechanical disturbances propagates through a medium (E.L.Cooper, 1999). The vibratory sound wave could exists in different frequency, the frequency with 16kHZ to 20kHz is at lower frequency, where this is the audible range of sound for human (D.Ensminger, 1988). The sound above this audible range of human beings is called ultrasound, where the vibration of ultrasound is too fast to be heard by human.

As the findings of ultrasonic mentioned before, ultrasound needs medium to allow the propagation of waves from one point to another such as air, liquid and solid. In contrast, ultrasound does not travel through the vacuum. The elastic property of medium is responsible for sustaining the vibration for propagation of waves; thus, ultrasonic wave is also termed as elastic waves. Although the researches and studies of ultrasonic as a form of energy (D.Ensminger, 1988) had been started by human since World War I, nevertheless the utilization capability of such energy is bestowed to the animals such as bats, dolphins, moths etc. for purpose of locating foods, navigation and detecting danger.

Generally, the applications of ultrasonic by introducing ultrasonic waves into medium are based on the intensity of ultrasonic. Applications of high intensity ultrasonic are intend to cause an effect on medium or its contents i.e. medical therapy or welding of plastics and metals while application of low intensity ultrasonic are purposely to pass information via medium or learn something about the medium without changing the state of medium i.e. non-destructive testing of materials, medial diagnose and depth sounding. Ultrasonic that used in non-destructive testing (NDT) involves applications such as distance gauging, flaw detection and measuring parameters related to material structure i.e. elastic moduli and grain size (Jack Blitz and Geoff Simpson, 1996). By using low intensity ultrasonic in NDT, object under examination will not ruin or experiences changes in dimension and structure as long as the applied stresses of ultrasound waves not exceeding the elastic limit, thus, object could be used even after the examination.

From another perspective, modes of ultrasonic waves propagate in the medium such as longitudinal wave, shear wave, Lamb wave, Love waves and Rayleigh waves also serve as basis for different applications of ultrasonic waves. Longitudinal and shear waves are useful in ultrasonic inspection while Rayleigh waves are useful because of its sensitivity detecting surface defects. Modes of wave traveling within medium are influenced by types of medium, medium of gases only capable of transmitting longitudinal waves, longitudinal and shear waves in liquids and large variety of waves in solids (D.Ensminger, 1988). The particle vibration in the wave differentiates each wave modes (Table 1.2.1).

Modes Of Wave	Particle Vibration
Longitudinal	Parallel to wave direction
Shear	Perpendicular to wave direction
Plate wave - Lamb	Component perpendicular to surface (extensional wave)
Plate wave - Love	Parallel to plane layer, perpendicular to wave direction
Rayleigh	Elliptical orbit - symmetrical mode

Table 1.2.1: Modes of wave and its particle vibration [18].

1.3 Project Objectives

By doing this project, there are several objectives that hope to be achieve, which listed as follow:

- Devise a method to determine resultant loading by using Non-Destructive Method (NDT) technique.
- Correlate the speed of ultrasound with resultant loading experienced by steel reinforcement.
- Correlate the results of NDT method to that obtained by direct strain gauge measurements.

Finally, it is hope that ultrasonic will be value-added for successful correlation of resultant load and ultrasonic wave speed through the project and the application of ultrasonic could be broader as an inspection tool.

CHAPTER 2

LITERATURE REVIEW

References had been done to get information regarding the subject of study as much as possible by mainly browsing the websites in the Internet. Besides that, books, journals, engineering magazines and thesis are also sources of information. The information that obtained is based on several topics that related to the interests of subject of this study.

2.1 Post-tensioning and Loading

An article entitled "Full-Scale Test of Prestressed Double-Tee Beam" in magazine of Concrete International had shown how the prestressed and post-tensioned Double-Tee (DT) concrete beam (Figure 2.1.1) was fabricated by using prestressed tendons of carbon fibre-reinforced polymer (CFRP) and post-tensioned carbon fibre composite cable (CFCC). The investigation had been carried out by N.F.Grace et al. and observation on the condition of both types of tendons when applied with load during test also was done.

The test was carried out to examine the DT structure, prestressed and post-tensioned tendons. One of the results, which is of our interest is the test had showed the changes of force experienced by the post-tensioned tendon when the structure was loaded with external loading. During the stage of fabrication, the loading applied to the CFCC strands (post-tensioned tendon) was identified. Prior the test of DT beam with loading, the average force measured in CFCC tendons was 443 kN. When test was carried out with hydraulic jacks by applying load to the DT beam that consists of prestressed and post-

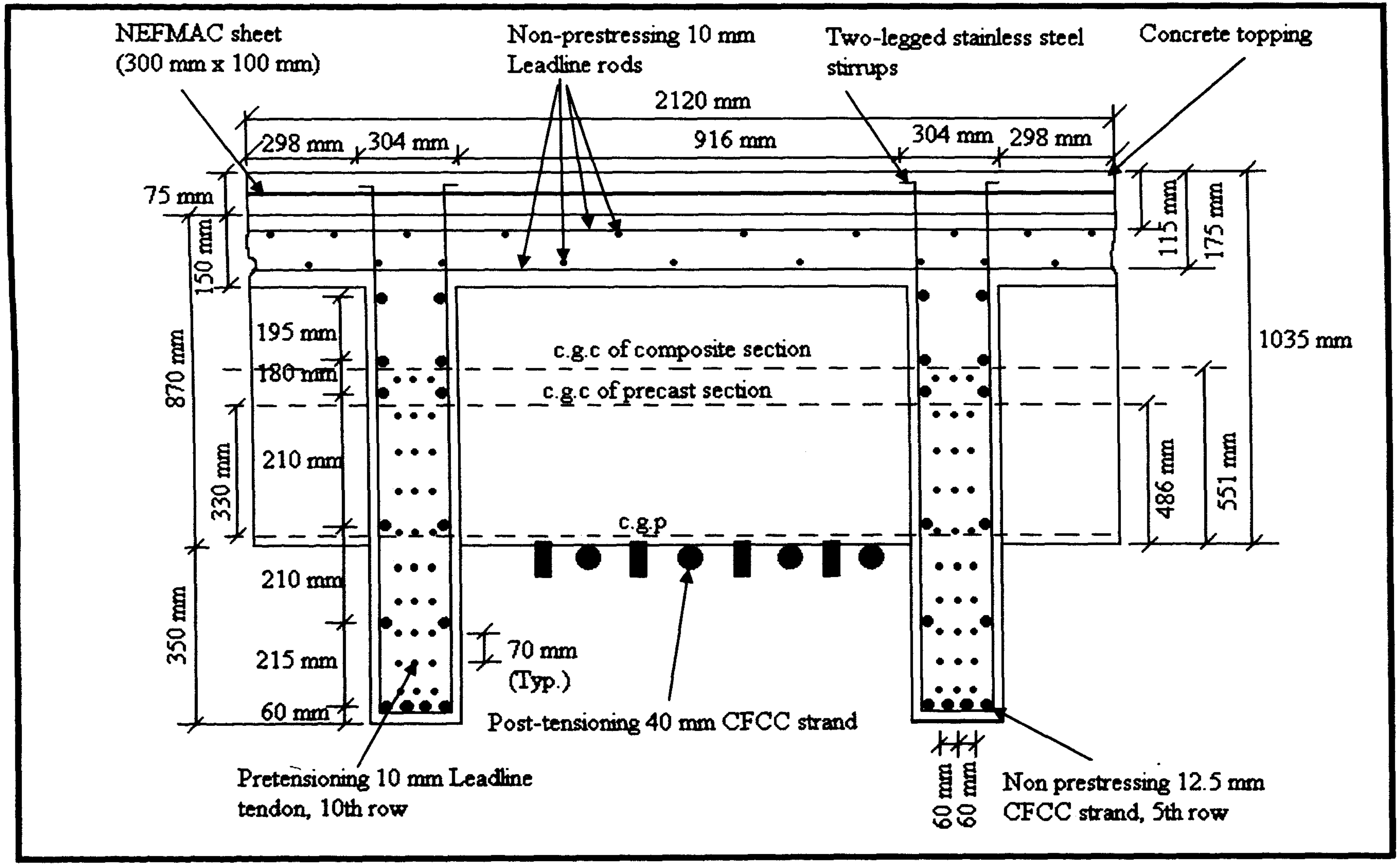

Figure 2.1.1: Mid span cross section of DT test beam [8].

tensioned tendons until flexural failure reached and the collapsed of DT beam, all 60 prestressed CFPR tendons (prestressed tendons) within the structure were ruptured while neither one of the CFCC tendons (post-tensioned tendons) nor their built-in anchorages failed. However, when ultimate load was reached during the test, the force in the four post-tensioned strands were nearly doubled to 807 kN, which is 75% of the tensile capacity of the strands.

Thus, from this article, without considering material of the post tensioning element, it shows that during the fabrication of post-tensioned concrete structure, when load is applied to the anchored post-tensioning element with whatever methods such as torque or hydraulic ram to tense the post tensioning element in order to introduce the compressive strain within concrete structure, the post tensioning element will experience a measurable tensile loading. Furthermore, during the servicing period of the structure, external loading applied to the structure cause the post tensioning element to experience a more significant tensile loading.

2.2 Torque And Applied Load

In the thesis of L.P.Wong, which titled "Relationship Between Torque And Applied Load In A Bolt For Different Coefficient Of Frictions", the study of relationship between torque and applied load had been carried out by using bolt and nut assembly with variation of coefficient of frictions between the thread of bolt and nut.

The relationship of torque and applied load had been stated in two conditions, where with lubricant applied to the thread of bolt and nut that yields to a lower coefficient of friction and without lubricant that yields to a higher coefficient of friction. The test had been carried out with applying a measurable value of torque by using torque wrench to the nut for tightening of bolt and nut assembly that was fitted in test rig and introducing loading in form of uniaxial stress to the bolt. Strain gauge is used simultaneously to measure the strain experienced by the bolt when the load was applied. Thus, by assuming that the elasticity modulus, E of steel is 200 GPa, the stress experienced by bolt was determined.

The results of study had shown that the stresses or applied load in the bolt (derived from bolt's strain) was proportional to the torque applied to it when the nut was tightened by a measurable torque (Figure 2.2.1). This relationship is valid for both conditions i.e. with and without lubricant. For the condition with lubrication that causes lower coefficient of friction, the stresses that recorded are higher compare to the other for the same value of applied torque. The bolt may confront with problem of over loading, which could lead to damage of components and decrease of fatigue life. In contrast, the higher coefficient of friction that caused by rusty thread recorded a lower stress and bolt is under tightening, which it may cause the problems like leakage and premature looseness of assembly.

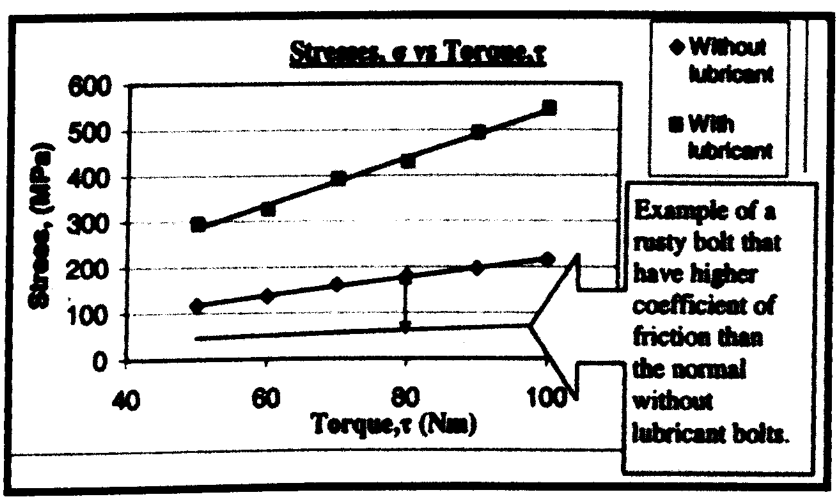

Figure 2.2.1: Relationship between applied torque and stress induced [7].

2.3 Wave Speed And Material Factors

In a website, which titled "Properties Of Waves", according to T.Henderson, two investigations on relationship of wave speed and property of material that had been conducted and mentioned, which were "Exploring Waves Simulation" and "Speed of Standing Wave Lab".

In the "Exploring Waves Simulation", it was aimed to study the effect of wave properties and properties of medium on wave speed. In this simulation, the properties of a wave such as frequency, wavelength, and amplitude were altered systematically followed by properties of medium such as mass density, spring constant, and damping coefficient to observe their effects to wave speed. The result from the simulation showed that wave speed was independent of wave properties. The wave speed, in contrast, was dependant on the properties of medium or material.

In another investigation called "Speed of Standing Wave Lab" that studies the relationship between characteristics of waves speed and the medium or material factor i.e. tensile stress of medium. In the investigation, several waves were generated within a rope of a measurable tension with a generator. The characteristics of waves such as wavelength, frequency and speed were determined. Mathematically, as equation (2A), speed of sound

$$\text{Wave speed} = \text{wavelength} \times \text{frequency} \qquad (2A)$$

wave is equivalent of multiplication of wavelength and frequency. Thus, frequency of generator vibration was then altered systematically to observe the changes of wave speed. After that, the characteristic of medium i.e. tensioning of rope was increased to study the effect of tensile stress within the rope to wave speed. From the investigation the result that obtained was as shown in Table 2.3.1.

Trial	Tension (N)	Frequency (Hz)	Wavelength (m)	Speed (m/s)
1	2.0	4.05	4.00	16.2
2	2.0	8.03	2.00	16.1
3	2.0	12.30	1.33	16.4
4	2.0	16.25	1.00	16.3
5	2.0	20.25	0.800	16.2
6	5.0	12.8	2.00	25.6
7	5.0	19.3	1.33	25.7
8	5.0	25.45	1.33	25.5

Table 2.3.1: Sample data of speed of a standing wave lab [16].

As a result, it could be concluded that the changes of vibration frequency did not change the value of wave speed instead the wavelength, where the small variation of wave speed might be caused by experimental errors. On the other hand, by altering the tensioning of rope from 2N to 5N, obviously, the value of wave speed was changed. The wave speed is significantly faster in a material that has higher tensile stress.

In an article, which titled Bolt Stress Measurement Using Ultrasonic, it had mentioned that the travel speed of longitudinal wave of ultrasonic is determined by properties of materials or material factors such as density, temperature and stress. As a fastener is tightened and stretched, it experiences tensile stress and velocity of ultrasound travel through the fastener will decrease. In order to make changes on sound velocity, the applied stress must be in same direction as the travelling direction of ultrasound. Thus, stress due to shear