UNIVERSITI PUTRA MALAYSIA

EFFECTS OF CABLE DIAMETER REDUCTION AND SNAPPING ON THE BEHAVIOR OF CABLE-STAYED BRIDGES

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By

SAYED MAHAMED AJAJ

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

For The person who works
for the sake of ***Allah,*** *above all*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

EFFECTS OF CABLE DIAMETER REDUCTION AND SNAPPING ON THE BEHAVIOR OF CABLE-STAYED BRIDGES

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May 2007

Chairman: Associate Professor Waleed A. Thanoon, PhD

Faculty: Engineering

Cable–stayed bridges are usually constructed in coastal area in which the surrounding atmospheric is considered as severe environmental condition. This atmosphere helps in building up quickly the corrosion of steel cables with time.

Visual inspection of cable-stayed bridges built up worldwide shows that the bridge cables suffer from serious corrosion although the cables are protected using different techniques. There is a considerable reduction in cable diameter due to corrosion, which depends on the severity of the environmental condition.

There is no sufficient information regarding the effect of reduction in cable diameter on the structural response of cable-stayed bridge. Furthermore, snapping of cables due to accidental and /or corrosion is another important issue which affecting the structural response and safety of cable stayed bridges and need to be addressed for safe design.

In this research, the effect of reducing cables diameter, cables layout and snapping of individual cables on the structural behavior and safety of cable-stayed bridge are presented. Three cable layouts are analyzed in this study i.e. harp, semi harp and fan layouts. In each layout, five different reductions in cables diameters are considered i.e 12.50%, 25.00%, 37.50%, and 50.00%. To address snapping of cable, harp bridge layout is considered and the structural behavior of the bridge due to snapping individual cables in the bridge are presented and discussed.

The analysis starts with initial shape analysis to stress the cables to minimize the deformation under self-weight of the structure. The analysis was carried out using stiffness method considering the geometrical nonlinearities.

The results of initial shape analysis show that in all bridge layouts reflect comparable behavior. The cable forces were found to be the lowest in fan layout cable bridge compared to harp and semi harp layouts. Reducing cables diameter will lead to a redistribution of forces and moment in different components of the bridge and alter the structural behavior in a nonlinear fashion. Reducing cables diameter by 25% will compromise the bridge safety as the stresses in cables, deformation, and bending moment will be increased significantly.

The bridge cable layouts have little effect on the structure response of the cable-stayed bridge with reduced cables diameter. The fan layout shows better structural response compared to harp and semi harp layout, especially in term of cable forces and deformation profile. Notwithstanding this fact, 25% of cables reduction

diameter will significantly affect the moment in girder of fan bridge layout compared to other layouts of cables

Snapping the individual cable in the bridge has a significant effect on the cable force and bending moment distribution in the girder, tower and will cause bridge failure.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Matser Sains

KESAN SAIZ KABEL TERKURANG DAN KABEL TERSENTAP PADA KELAKUAN JAMBATAN GANTUNG

Oleh

SAYED MAHAMED AJAJ

Mei 2007

Pengerusi: Profesor Madya Waleed A. Thanoon, PhD

Fakulti: Kejuruteraan

Kabel jambatan gantung biasanya dibina di pesisir pantai di mana keadaan alam sekitar dianggap teruk. Suasana ini menyebabkan kakisan keluli kabel boleh berlaku dengan cepat.

Pemeriksaan visual kabel jambatan gantung menunjukkan bahawa kabel jambatan terjejas dari kakisan serius walaupun kabel terpelihara menerusi berbagai teknik. Kakisan ini boleh menyebabkan pengurangan saiz kabel yang banyak.

Tiada maklumat yang lengkap berkenaan dengan kesan pengurangan saiz kabel keatas kelakuan jambatan gantung. Kabel boleh tersentap disebabkan kemalangan dan/atau pengaratan. Ini merupakan isu tambahan yang memberi kesan kepada kelakuan struktur. Keselamatan jambatan gantung disebabkan oleh dua perkara ini perlu ditangani.

Dalam kajian ini, kesan pengurangan saiz kabel, susun atur kabel dan kesan kabel tersentap pada kelakuan dan keselamatan jambatan gantung dibentangkan. Tiga susunatur kabel iaitu '*harp*','*semi-harp*' dan kipas dianalisis dalam kajian ini. Untuk setiap susunatur lima pengurangan garispusat kabel telah dipertimbangkan iaitu 12.50%, 25.00%, 37.50%, dan 50.00%. Untuk mengambilkira kabel tersentap, jambatan susunatur ' *harp*' telah dipertimbangkan dan kelakuan struktur jambatan disebabkan oleh kabel tersentap dibentang dan dibincangkan.

Analisis bermula dengan analisis awalan dimana kabel ditegang untuk mengurangkan ubahbentuk di bawah beban diri. Analisis dilakukan dengan menggunakan kaedah kekukuhan dengan mengambilkira ketidaklurusan.

Hasil dari analisis awalan menunjukkan semua jambatan dengan susunatur kabel yang berbeza menunjukkan kelakuan yang setara. Daya kabel didapati paling rendah untuk susunatur kipas, berbanding dengan susunatur '*harp*' dan '*semi-harp*'. Pengurangan garispusat kebal akan mengakibatkan pengagihan semula daya dan momen pada berbagai komponen jambatan dan merubah kelakuan dalam bentuk tidak 'lelurus'. Pengurangan saiz kabel sebanyak 25% boleh mengancam keselamatan jambatan kerana tegasan kabel, ubahbentuk jambatan dan momen lenturan akan meningkat secara mendadak.

Susunatur berbagai kabel mempunyai kesan kecil pada respon struktur bila saiz kabel dikurangkan. Susunatur kipas menunjukken respon yang lebih baik berbanding dengan susun atur '*harp*' *dan* '*semi-harp*'. Walaubagaimanapun, pengurangan

25% saiz kabel memberi kesan besar kepada rasuk pada jambatan susunatur kipas, berbanding dengan susunatur lain.

Kabel inidividu yang tersentap mempunyai kesan siginifikan kepada daya kabel dan agihan momen dalam rasuk dan menara, dan boleh menyebabkan kegagalan jambatan.

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Last but not least, I wish to express my gratitude to my family for the support they gave throughout my studies. Long absent hours from home are *often* met with a warm welcome and a forgiving smile.

I certify that an Examination Committee has met on May 03, 2007 to conduct the final examination of Sayed Mahamed Ajaj on his Master of Science thesis entitled "Effects of cable diameter reduction and snapping on the behavior of cable-stayed bridges" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the reward degree.

Members of the Examination Committee are as follows:

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Date: 17 JUNE 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

SAYED MAHAMED AJAJ

Date: 15 APRIL 2007

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CHAPTER 1

INTRODUCTION

1.1 General

Cable-stayed bridges have been serving humankind since early times. In ancient times, Egyptians built their boats in the form of cable-stayed structures. Many years after, advancements of the cable-stayed concept and materials are most notable and can be divided into two periods. The first period was from the 1600s to 1950, where the new style and concept of cable-stayed bridges were developed. The second period was from the 1950s until nowadays, where new cables are made from high-strength strands, bars and wires, and high load-carrying capacity and ease of installation are offered. Moreover, rapid progress in the analysis and construction of cable-stayed bridges has been also made. This progress is mainly due to developments in the fields of computer technology, high-strength steel cables, and orthotropic steel decks.

A cable-stayed bridge consists of three principal components, namely girders, towers and inclined cable stays. The girder is supported elastically at points along its length by inclined cable stays so that, the girder can span a much longer distance without intermediate piers. The dead load and traffic load on the girders are transmitted to the towers by inclined cables. High-tension forces exist in cable-stays, which induce high compression forces in towers and part of girders. Since high pretension force exists in inclined cables before live loads are applied, the initial geometry and the prestress of cable-stayed bridges are dependent on each other. They cannot be specified independently as conventional steel or reinforced concrete bridges. Therefore, the initial shape, i.e., the geometric configuration and the pre-stress distribution of cable-stayed bridges has to be determined prior to analyze them. Therefore, the initial shape has to be determined correctly prior to analyze the bridge. Only based on the correct initial shape a correct non-linear analysis can be achieved. The sources of nonlinearity in cable-stayed bridges mainly include the cable sag, beam-column, and large deflection effects

Cable stayed bridge usually built in coastal areas, which often exposed in the open air, are inevitably subjected to atmospheric corrosion. Cables, which play the main key in the performance and the behavior of the bridge, can suffer a reduction in cable diameter due to the corrosion.

Nevertheless, most the cables are preserved by rust preventive methods, which have been used in Europe and America. In Japan, no protection was provided as the existing because that rust preventive methods were not effective enough under Japan's weather conditions with high humidity and large temperature change (Yukikazu et al 2002). New York State Bridge Authority has presented studied many types of cable structures system, since 2003 and it was found that, most of tested cables have broken wires (Engineering News-Record.com, 2003).

1.2 Problem Statement

There is no sufficient information regarding the effect of reduction in cable diameter on the structural response of cable-stayed bridge. Furthermore, snapping of cables due to accidental events during the life of the structure and /or corrosion, which usually happened due to poor maintenance of the bridge which is another important issue which affecting the structural response and safety of cable stayed bridges and need to be addressed for safe design.

1.3 Objectives

The aim of this research is

1. To investigate the effect of reducing the cables diameter on the structural response of the cable stayed bridges with different cable layout considering the actual non-linear behavior of the bridge structure.

2. The effect of snapping individual cables in harp cable stayed bridge on the structural safety of the bridge.

1.4 Scope

This study performs linear and nonlinear analysis of cable-stayed bridge, including initial shape analysis. A computer code is also developed based on stiffness method to