UNIVERSITI PUTRA MALAYSIA

NONLINEAR FINITE ELEMENT ANALYSIS OF INTEGRAL BRIDGE INCLUDING FOUNDATION SOIL INTERACTION (WINKLER ANALOGY)

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A Project Report Submitted in Partial Fulfillment

Of the Requirements for the Degree of

Master of Science in Structural Engineering and Construction

In the Faculty of Engineering

University Putra Malaysia

2006

ACKNOWLEDGEMENT

Be all praise for the almighty ALLAH S.W.T the most Benevolent and the most Merciful, for giving me the strength and spirit to have this project completed successfully.

I would like to take this opportunity to express my sincere thanks and deepest gratitude to my supervisor, Associate Professor Ir. Dr Jamaloddin Noorzaei for his deep insight and guidance during the course of my studies at University Putra Malaysia. I also would like to thank Associate Professor Ir. Dr Mohd. Saleh Jaafar and Assoc. Prof. Ir. Dr. Mohd. Razali B. Abdul Kadir for their advices and assistance.

Finally, I sincerely express my appreciation to my beloved wife; Sarini, and my son Muhammad Ariff Irfan for their companionship, understanding and continuous encouragement throughout this challenging endeavor.

ABSTRACT

Bridges without expansion joints are called “integral bridges.” Eliminating joints from bridges crates concerns for the piles and the abutments of integral bridges because the abutments and the piles are subjected to temperature-induced lateral loads. This kind of bridges are becoming very popular due to different aspects such as good response under seismic loading, low initial costs, elimination of bearings, and less maintenance. However, the main issue related to the analysis of this type of structures is dealing with the soil-structure interaction of the abutment walls and the supporting piles.

This study describes the implementation of a two dimensional finite element model of integral bridge system which explicitly incorporates the nonlinear soil response. The superstructure members have been represented by means of three-noded isoperimetric beam elements with three degree of freedom per node which take into account the effect of transverse shear deformation.

The soil mass is idealized by eight noded isoperimetric quadrilateral element at near field and five noded isoperimetric infinite element to simulate the far field behavior of the soil media. The nonlinearity of the soil mass has been represented by using the Duncan and Chang approach. In order to study the behavior of integral bridge under varies loading condition including the effect of temperature load, three type of

analysis was carried out, which are Winkler's spring analysis, linear analysis and nonlinear analysis. The results show that, the soil nonlinearity has significant effect on the results, where the displacement which obtained form nonlinear analysis is much higher than that obtained from linear analysis and spring analysis.

APPROVAL SHEET

This project attached here, entitled " **NONLINEAR FINITE ELEMENT ANALYSIS OF INTEGRAL BRIDGE INCLUDING FOUNDATION SOIL INTERACTION (WINKLER ANALOGY) "** prepared and submitted by **MOHAMMAD SOFFI BIN MD. NOH (GS 15733)** in partial fulfillment of the requirements for the Degree in Master of Science in Structural Engineering and Construction is hereby approved.

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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.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Introduction of Bridge Structure

Bridge structure built to provide ready passage over natural or artificial obstacles, or under another passageway. Bridges serve highways, railways, canals, aqueducts, utility pipelines, and pedestrian walkways. In many jurisdictions, bridges are defined as those structures spanning an arbitrary minimum distance, generally about 10–20 ft (3–6 m); shorter structures are classified as culverts or tunnels. In addition, natural formations eroded into bridge like form are often called bridges. This article covers only bridges providing conventional transportation passageways.

Bridges generally are considered to be composed of three separate parts: substructure, superstructure, and deck. The substructure or foundation of a bridge consists of the piers and abutments which carry the superimposed load of the superstructure to the underlying soil or rock. The superstructure is that portion of a bridge or trestle lying above the piers and abutments. The deck or flooring is supported on the bridge superstructure; it carries and is in direct contact with the traffic for which passage is provided.

Bridges are classified in several ways. Thus, according to the use they serve, they may be termed railway, highway, canal, aqueduct, utility pipeline, or pedestrian bridges. If they are classified by the materials of which they are constructed (principally the superstructure), they are called steel, concrete, timber, stone, or aluminum bridges. Deck bridges carry the deck on the very top of the superstructure. Through bridges carry the deck within the superstructure. The type of structural action is denoted by the application of terms such as truss, arch, suspension, stringer or girder, stayed-girder, composite construction, hybrid girder, continuous, cantilever, or orthotropic (steel deck plate).

Bridge designs differ in the way they support loads. These loads include the weight of the bridges themselves, the weight of the material used to build the bridges, and the weight and stresses of the vehicles crossing them. There are basically eight common bridge designs: beam, cantilever, arch, truss, suspension, cable-stayed, movable, and floating bridges. Combination bridges may incorporate two or more of the above designs into a bridge. Each design differs in appearance, construction methods and materials used, and overall expense. Some designs are better for long spans. Beam bridges typically span the shortest distances, while suspension and cable-stayed bridges span the greatest distances.

1.2 Design Selection of Bridge

Engineers must consider several factors when designing a bridge. They consider the distance to be crossed and the feature, such as a river, valley, or other transportation routes, to be crossed. Engineers must anticipate the type of traffic and the amount of load the bridge will have to carry and the minimum span and height required for traffic traveling across and under the bridge. Temperature, environmental conditions, and the physical nature of the building site (such as the geometry of the approaches, the strength of the ground, and the depth to firm bedrock) also determine the best bridge design for a particular situation.

Once engineers have the data they need in order to design a bridge, they create a work plan for constructing it. Factors to be considered include availability of materials, equipment, and trained labor; availability of workshop facilities; and local transportation to the site. These factors, in combination with the funding and time available for bridge design and construction, are the major requirements and constraints on design decisions for a particular site.

1.3 Nature of Problem

A bridge should be designed such that it is safe, aesthetically pleasing, and economical. Prior to the 1960s, almost every bridge in the world was built with expansion joints and bearings. These traditional expansion joint/bearing systems has been found to perform more or less as intended conceptually but at the cost of being a high maintenance item, especially for relatively short-span bridges. The primary problem is the corrosion and other physical deterioration of the bridge bearings that occurs with time. They required considerable maintenance, which undermined the economical operation of the bridges. Therefore, integral bridges have been found to outperform jointed bridges, decreasing maintenance costs, and enhancing the life expectancy of the superstructures. Integral abutment and joint-less bridges cost less to construct and require less maintenance then equivalent bridges with expansion joints and bearings.

Because of the increased use of integral bridge, there is now greater awareness of and interest in their post-construction, in-service problems. Fundamentally, these problems are due to a complex soil structure interaction mechanism involving relative movement between the bridge (more specifically, its abutments) and adjacent retained soil. Because this movement is the result of natural, seasonal thermal variations, it is inherent in all integral bridges.

The main issue related to the analysis of integral abutment bridge is dealing with the soil-structure interaction of the abutment walls and the supporting piles. The behavior of the structural components including the piles can either be linear or nonlinear depending on the amount of the applied forces. The behavior of the soil on the other hand is nonlinear. Therefore, the analysis of integral bridge should take into account the nonlinearity of soil behind the abutment and the piles foundation.

1.4 Objectives of Study

The primary objectives of this study are:

1. Investigate the behavior of structural elements of the integral bridge under various load cases through finite element analysis.

2. Study the significance of thermal expansion load induced displacement.

3. Investigate the significance differences and similarities between the Winkler's spring analysis, linear analysis and nonlinear analysis of integral bridges.

1.5 Scope of Study

In order to study the behavior of integral bridge under different of load cases, this study have been carried out within the following scope.

1. Finding a literature review to establish the current state of knowledge with regard to the behavior of integral abutment bridges.

2. Implement finite element analysis for three different type of analysis which is Winkler spring, linear elastic and nonlinear elastic analysis.

3. Descretized the finite element models through the following elements;

   a) Three noded beam bending element

   b) Eight noded isoparametric elements

   c) Five noded infinite elements

4. Loading analysis of integral bridge is based on code of practice, BD 37/88.

5. Collect the actual temperature data based on the Malaysian temperature different obtained from Department of Meteorology Malaysia.

6. Preparation of the actual data required for the nonlinear elastic analysis based on Malaysian soil condition.

7. Analyze the structure and soil media using existing two dimensional finite element program available at Structural Engineering Unit, Civil Engineering Department, Universiti Putra Malaysia.

1.6 Organization of Report

In order to achieve the objectives of this study, this report is implemented and organized as follows.

Chapter 2: Present an overview of integral bridge in order to enhance the current state of knowledge with regard to behavior of integral bridge system, characteristic and type of integral abutment of the bridge. Advantages and problem associated with integral bridge also discussed in this chapter.

Chapter 3: Present the formulation of finite element and infinite element of structure and surrounding soil media, it also present the load of integral bridge which has been taken in consideration in the analysis. The non-linear elastic model (Duncan 1970) and Winkler's model was discussed in details in this chapter. Explanation of the computer implementation (2-D finite element program) also discussed in this chapter.

Chapter 4: Presents the selection of case study and bridge dimension and load calculation for gravity, highway bridge live load and thermal expansion loads. Defined the finite element meshing and also the derivation of the soil parameters according to actual laboratory tests for Malaysian soil, and calculation of the Winkler spring constant. It also presents the results and discussion obtained from the analysis of integral bridge by using different techniques. Finally, presents the comparative study on different proposed models.

Chapter 5: Contains the conclusions and recommendations drawn from the research. Recommendations for future studies and research are given at the end of this chapter.

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