EFFECTIVENESS OF GRID ANALOGY FOR BRIDGE DECK ANALYSIS

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ABSTRACT

Bridge decks have traditionally been designed using a simplified model known as the Grillage Analogy Method. Grillage Analogy Method shows how complex structures can be analyzed with physical reasoning and relatively simple computer models, and without complicated mathematics. In recent years the computer methods of grillage has become very popular and accessible as microcomputers and software have developed rapidly. Bridge deck analysis provides bridge designers with the knowledge to understand the behaviour of bridge decks, to be familiar with and to understand the various numerical modeling techniques and to know which technique is best suited to each bridge type.

This study focuses on the analysis of the bridge deck using Grillage Analogy Method and Finite Element Method, identifying the effectiveness of Grillage Analogy Method for bridge deck analysis. Tasks being addressed by this case study are the analysis for various types of bridge deck structures which included right angle solid slab deck, skew angle solid slab deck, right angle T-beam bridge deck with 2 end diaphragms, right angle T-beam bridge deck with 5 diaphragms, skew angle T-beam bridge deck with 2 end diaphragms, curved solid slab deck, single box girder and voided slab deck. The structural details for each bridge deck are further illustrated in each chapter. This study provided information structures that show the percentage differences of the Grillage Analogy Method compared to Finite Element Method in bridge deck analysis using LUSAS Finite Element Software.

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LIST OF ABBREVIATIONS

BS	British Standard
E	Modulus of Elasticity
etc.	Excetera
FEM	Finite Element Method
G	Shear Modulus
GAM	Grillage Analogy Method
GP	Gauss Point
I	Flexural Moment of Inertia
J	Torsional Inertia
JKR	Jabatan Kerja Raya
KEL	Knife Edge Load
LC	Load Combination
LTAL	Long Term Axle Loading
MED	Member End Displacement
MEF	Member End Forces
NL	Notional Lane
STAL	Short Term Axle Loading
SV	Special Vehicle Loading
UDL	Uniformly Distributed Load
ULS	Ultimate Limit State

CHAPTER 1

INTRODUCTION

1.1.0 GRILLAGE ANALOGY

Grillage analogy is probably one of the most popular computer-aided methods for analyzing bridge decks. The method consists of representing the actual decking system of the bridge by an equivalent grillage of beams. The dispersed bending and torsional stiffness of the decking system are assumed, for the purpose of analysis, to be concentrated in these beams. The stiffnesses of the beams are chosen so that the prototype bridge deck and the equivalent grillage of beams are subjected to identical deformations under loading. The actual deck loading is replaced by an equivalent nodal loading. The method is applicable to bridge decks with simple as well as complex configurations with almost the same ease and confidence. The method is easy to comprehend and use. The analysis is relatively inexpensive and has been proved to be reliably accurate for a wide variety of bridges. The grillage representation helps in giving the designer a feel of the structural behaviour of the bridge and the manner in which the loading is distributed and eventually taken to the supports. [2]

1.2.0 BRIDGE

A bridge is a structure facilitating a communication route for carrying road traffic or other moving loads over a depression or obstruction such as river, stream, channel, road or railway. The communication route may be a railway track, a tramway, a roadway, a footpath, a cycle track or a combination of them.

1.2.1 Components of A Bridge

A bridge structure consists of two basic parts: superstructure, substructure and miscellaneous components. The superstructure serves to take traffic loads and transfer them to the substructure, which generally consists of the piers and abutments. The superstructure consists of the span between supports which carry the highway or railway and transfers this load to the substructure. Substructure takes the load and transfers it to the ground.

i) Superstructure

Superstructure consists of structural members carrying a communication route. Thus, handrails, guard stones and flooring supported by any structural system such as beams, girders, arches and cables above the level of bearings constitutes the superstructure.

Superstructure basically consists of the following parts:

- Elements that transfer the traffic load along the span onto the substructure, generally parallel to the longitudinal bridge axis. These elements are called the main carrying bridge members. Because the main bridge loading is vertical, the main carrying bridge members are vertical. These members, in the shape of plate girders, deflect under the loading and the resulting stresses are taken by the flanges. The webs of the plate girders and diagonals of trusses take shear forces.

- Elements that transfer pressures from the vertical loads to the main carrying members in the transverse direction normal to the bridge axis, and connecting main carrying members in the transverse direction, are called the deck and transverse bracings or transverse construction. This transverse construction is necessary because the main carrying members, installed as the plane walls, are placed at a certain distance from each other and, therefore, cannot take pressure from the loads that are placed between them. Apart from this, main carrying members as plane structure are unstable without a transverse connection.
- Elements that transfer to the supports load resulting from the wind and centrifugal force. These loads are horizontal and the elements transferring these loads are located in horizontal planes, usually at the planes of flanges of the main carrying members. They are called the wind bracings because the main load acting on them is the wind. They are also called the transverse bracings because they are working in the transverse direction when they transfer wind loading to the supports. The main carrying members together with the deck and bracings constitute a superstructure unit. It is generally rectangular; its vertical sides are the main and secondary loading-vertical and horizontal- is located along the horizontal side.

The bridge superstructure is supported by the bearings. Bearings transfer the weight of the superstructure and traffic loadings to the supports at definite locations. The intermediate supports are piers and the end supports are abutments. The intermediate supports have the shape of columns; in the cross section they are configures such that the water will not produce whirlpool and scour. The abutments take the end reactions from the superstructure and also act as retaining walls.

ii) Substructure

Substructure is a supporting system for the superstructure. It consists of the following:

- Abutments,
- Piers and Abutment piers,
- Wing walls,
- Foundations for the piers and abutments.

The other main parts of bridge structure are approaches, bearings and river training works, like aprons, revetment for slopes at abutments, etc.

iii) Miscellaneous Components

The miscellaneous components include bridge surfacing or pavement, approach slab, expansion joints, drainage, slope and bank protection, railings, kerbs, sidewalks, etc.

1.2.2 Classification of Bridges

Bridges can be classified into various types depending upon the following:

- Alignment
- Degree of Redundancy
- Fixed or Movable
- Loadings
- Location of Bridge Floor
- Life
- Material used for Construction
- Nature of Superstructure
- Position of High Flood Level
- Purpose
- Swinging Bridges
- Type of Connection

1.2.3 Bridge Decks

Bridge deck can be classified as part of the bridge superstructure. This is the part where all the loading which occur as the patch load, uniformly distributed load, line load, point load, dynamic load and other external forces apply on and distribute through it (bridge deck) to the bearings, through the piers and down to the foundation.

Bridge decks are developing today as fast as they have at any time since the beginning of the Industrial Revolution. The diversity of sites is increasingly challenging the ingenuity of engineers to produce new structural forms and appropriate materials. The types of bridge deck are divided into beam, grid, slab, beam-and-slab and cellular, to differentiate their individual geometric and behavioural characteristics. Inevitable many decks fall into more than one category, but they can usually be analysed by using a judicious combination of the methods applicable to the different types.

1.2.3.1 Beam Deck

A bridge deck can be considered to behave as a beam when its lengths exceeds its width by such an amount that when loads cause it to bend and twist along its length, cross-sections displace bodily and do not change shape such as footbridges. It can be in reinforced concrete or prestressed concrete which are often continuous over two or more spans. Long span bridges behave as beams because the dominant load is concentric so that the distortion of the cross-section under eccentric loads has relatively little influence on the principal bending stresses.

1.2.3.2 Grid Deck

The primary structural member of a grid deck is a grid of two or more longitudinal beams with transverse beams (or diaphragms) supporting the running slab. Loads are distributed between the main longitudinal beams by the bending and twisting of the transverse beams. Due to difficulty of the method of construction to fabricate or shutter the transverse beams, this system is being replaced by slab and beam-and-slab decks with no or a few transverse diaphragms. The analysis in effect sets out a set of simultaneous slope-deflection equations for the moments and torsions in the beams at each joint and then solves the equations for the load cases required.

1.2.3.3 Slab Deck

Slab deck behaves like a flat plate which is structurally continuous for the transfer of moments and torsions in all directions within the plane of the plate. When a load is placed on part of a slab, the slab deflects locally as a 'dish' causing a two-dimensional system of moments and torsions which transfer and share the load to neighbouring parts of the deck which are less severely loaded. A slab is 'isotropic' when its stiffnesses are the same in all directions in the plane of the slab. A slab is 'orthotropic' when the stiffnesses are different in two directions at right angles.

A shear-key deck does not fit neatly into any of the main categories of the deck. Shear-key deck is constructed of contiguous prestressed/reinforced concrete beams of rectangular or box sections, connected along their length by in-situ concrete joints. It is not prestressed transversely and thus is not fully continuous for transverse moments. Although such deck have little or no transverse bending stiffness, distribution of loads between beams still takes place because differential deflection of the beams is resisted by the torsional stiffness of the beams and a vertical shear force is transferred across the keyed joints.

1.2.3.4 Beam-and-Slab Deck

A beam-and slab deck consists of a number of longitudinal beams connected across their tops by a thin continuous structural slab. In transfer of the load longitudinally to the supports, the slab acts in concert with the beams as their top flanges. At the same time the greater deflection of the most heavily loaded beams bends the slab transversely so that it transfers and shares out the load to the neighbouring beams. Sometimes his transverse distribution of load is assisted by a number of transverse diaphragms at points along the span, so that behaviour of more similar to that of a grid deck. The use of diaphragms is becoming less popular because of the construction problems they cause and because their localized stiffnesses attract forces which can cause unnecessary stress concentrations. Beam-and-slab construction has the advantage over slab that it is very much lighter while retaining the necessary longitudinal stiffness. Consequently it is suitable for a much wider range of spans, and it lends itself to precast and prefabricated construction. The transverse flexibility help a deck on skew supports to deflect and twist 'comfortably' under load without excessively loading the nearest supports to the load or lifting off. Beam-and-slab decks can be divided into two main groups:

- Contiguous beam-and-slab

  Slab with beams at close centers or touching. When a load is placed on part of a deck, the slab will defects in a smooth wave so that for load distribution its behaviour can be considered similar to that of an orthotropic slab with longitudinal stiffening. This decks have been designed with precast prestressed concrete beams or steel beams supporting a concrete slab.

- Spaced beam-and-slab

Slab with beams at wide centers. When a load is placed above on beam of a spaced beam-and-slab deck, the slab does not necessarily deflect transversely in a single wave but sometimes in a series of waves between beams especially if the beams have high torsional stiffnesses.

1.2.3.5 Cellular Deck

The cross section of a cellular or box deck is made up of a number of thin slabs and thin or thick webs which totally enclose a number of cells. Due to the low materials content, low weight and high longitudinal bending stiffness, it provided high torsional stiffnesses which give better stability and load distribution characteristics. For the long, high spans, where false work is inappropriate, the deck is erected in elements as a beam cantilevering out from supports or the deck has been constructed and launched across the piers from an abutment. The cellular decks can be divided into two categories due to its structural behaviour which are multicellular slabs and box-girders.

Multicellular slabs are wide shallow decks with numerous large cells. The cross-sectional shape does not lend itself to precast segmental construction, and construction is usually in-situ concrete or contiguous precast box beams or top hat beams with large voids. When a load is placed on one part of such a deck, the high torsional stiffness and transverse bending stiffness of the deck transfer and share out the load over a wide area. The distribution is not as effective as that of a slab since the thin top and bottom slabs flex independently when transferring vertical shear forces between webs, and the cross-section is said to 'distort' like a Vierendeel truss in elevation. Distortion can be reduced by incorporating transverse diaphragms at various points along the deck.

Box-girder decks have a cross-section composed of one or a few large cells, the edge cells often having triangular cross-section with inclined outside web. Frequently the top slab is much wider than the box, with the edges cantilevering out transversely. Excessive twisting of the deck under eccentric loads on the cantilevers is resisted by the high torsional stiffness of the structure.

1.3.0 OBJECTIVES

The main objective of the study is to find out the effectiveness of the grillage analogy for bridge deck analysis.

The objectives of this study include:

1. Analysis: To analyze the various type of bridge decks for different loading cases obtained by using grid analogy method and finite element method.
2. Comparison: To compare the observed response using grid analogy method with that using finite element method in analytical models.
3. Evaluation: To estimate the accuracy of the grid analogy method for analysis of different types of bridge decks as compared to the finite element method.

1.4.0 SIGNIFICANCE OF THE STUDY

Finite element method is complex and requires large manual and computational efforts for the analysis of the bridge structures. Grid analogy is presented herein that allows, within reasonable calculations, adequate results concerning both the forces and the displacements for the most coarse mesh. This formulation is based on intensive analysis of various grid parameters and has been extended to the non-linear domain. Incorporation of a powerful finite element model for the analysis of bridge decks under symmetrical and eccentric loading has resulted in the development of a new simplified method for bridge decks analysis.

Grillage analogy seems to be completely universal with the exception of Finite Element and Finite Strip Methods, which always carry a heavy cost penalty for a structure as simple as a slab bridge. In addition, the rigorous methods of analysis such as finite element method, even today, are considered too complex by bridge designers.

In recent years, the Grillage Analogy Method, which is a computer-oriented technique, is increasingly being used in the analysis and design of bridges. The method is also suitable in cases where bridge exhibits complicating features such as heavy skew, edge stiffening and isolated supports. The use of computer facilities the investigation of several load cases in shortest possible time. The method is versatile in nature and the contribution of kerb beams and the effect of differential sinking of girder ends over yielding bearings (such as neoprene bearing) can also be taken into account and large variety of bridge decks can be analysed with sufficient practical accuracy.

Furthermore, the method is easy to comprehend and use. The analysis is relatively inexpensive and has been proved to be reliably accurate for a wide variety of bridges. The grillage representation helps in giving the designer a feel of the structural behaviour of the bridge and the manner in which the loading is distributed and eventually taken to the supports.

The significance of using the grillage analogy method in bridge deck analysis is discussed further in Chapter 2.

1.5.0 SCOPE OF THE STUDY

The scope of study under this project is to determine the effectiveness and accuracy of the grid analogy method in bridge deck analysis. The study has been carried out within the following scope:

1. Types of Analysis Method: Finite element method and grid analogy method.
2. Type of Analysis Structures: Solid Slab Deck, Void Slab Deck, Beam-and-Slab Deck (T-Beam Deck) and Box Girder Deck.
3. Bridge Alignment: Right, skew and curved.
4. Support condition: All the bridge decks are simply supported.
5. Material used: Reinforced concrete.
6. Analysis Scope: Elastic analysis has been conducted for all the bridge deck structures.
7. Bridge Width: Two lanes Carriageway bridge have been chosen for analysis. Footway at both sides of the bridge are ignored.
8. Span Length: 10m, 15m, 20m and 30m spans are used according to the type of the bridge deck.
9. All the load cases follow the JKR Specification For Bridge Live Load and BD 37/88.

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