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A Review on Study and Analysis of Major Structural Elements of an Elevated Metro Bridge

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Abstract: A metro system is a railway transport system in an urban area with a high capacity, frequency and the grade separation from other traffic. Metro System is used in cities, agglomerations, and metropolitan areas to transport large numbers of people. An elevated metro system is more preferred type of metro system due to ease of construction and also it makes urban areas more accessible without any construction difficulty. An elevated metro system has two major elements pier and box girder. The present study focuses on two major elements, pier and box girder, of an elevated metro structural system. The parametric study on behaviour of box girder bridges showed that, as curvature decreases, responses such as longitudinal stresses at the top and bottom, shear, torsion, moment and deflection decreases for three types of box girder bridges and it shows not much variation for fundamental frequency of three types of box girder bridges due to the constant span length. It is observed that as the span length increases, longitudinal stresses at the top and bottom, shear, torsion, moment and deflection increases for three types of box girder bridges. As the span length increases, fundamental frequency decreases for three types of box girder bridges. Also, it is noted that as the span length to the radius of curvature ratio increases responses parameter longitudinal stresses at the top and bottom, shear, torsion, moment and deflection are increases for three types of box girder bridges. As the span length to the radius of curvature ratio increases fundamental frequency decreases for three types of box girder bridges.
Keywords: Elevated Metro Structure, Bridge Pier, Box Girder Bridge, Direct Displacement Based Seismic Design, Performance Based Design, Force Based Design.

I. INTRODUCTION

A metro system is an electric passenger railway transport system in an urban area with a high capacity, frequency and the grade separation from other traffic. Metro System is used in cities, agglomerations, and metropolitan areas to transport large numbers of people at high frequency. The grade separation allows the metro to move freely, with fewer interruptions and at higher overall speeds. Metro systems are typically located in underground tunnels, elevated viaducts above street level or grade separated at ground level. An elevated metro structural system is more preferred one due to ease of construction and also it makes urban areas more accessible without any construction difficulty. An elevated metro structural system has the advantage that it is more economic than an underground metro system and the construction time is much shorter.

An elevated metro system has two major components pier and box girder. A typical elevated.

Metro bridge model is shown in Figure Viaduct or box girder of a metro bridge requires pier to support the each span of the bridge and station structures. Piers are constructed in various cross sectional shapes like cylindrical, elliptical, square, rectangular and other forms. The piers considered for the present study are in rectangular cross section and it is located under station structure.

Box girders are used extensively in the construction of an elevated metro rail bridge and the use of horizontally curved in plan box girder bridges in modern metro rail systems is quite suitable in resisting torsional and warping effects induced by curvatures.

II. LITERATURE REVIEW

A. Overview

To provide a detailed review of literature related to Metro bridge pier and Box Girder Bridge in its entirety is too immense to address in this thesis. However, there are many good references that can be used as a starting point for research. This literature review focuses on design of metro bridge pier and also review on research related to box girder bridges.

The literature review is divided into two segments. First segment deals with the design of the pier and the second part deals box girder. The first part of the chapter reviews Design of Metro Bridge Pier by Force Based Design (FBD) Method and Direct Displacement Based Seismic Design (DDBD) Method. The Second part of this chapter is focused on Box Girder Bridges and brief discussion on its research.

B. Design Of Pier

Conventionally the pier of a metro bridge is designed using a force based approach. Recent studies (Priestley et al., 2007) show that the force based design may not necessarily guarantee the required target performances. The codes are now moving towards a performance-based design approach, which consider the design as per the target performances at the design stage. As the present study focus on the application of displacement based approaches to pier design, a brief introduction of the two methods, force-based and displacement based design is summarized in the following sections.

C. Force Based Design Method

Force Based Design Method (FBD) is the conventional method to design the metro bridge pier. In Force based design method, the fundamental time period of the structure is estimated from member elastic stiffness's, which is estimated based on the assumed geometry of the section. The appropriate force reduction factor (R) corresponding to the assessed ductility capacity of the structural system and material is selected in the force based design and applied to the base shear of the structure.

The design of a pier by force based seismic design method is carried out as per IS 1893: 2002 Code. The design procedure to find the base shear of the pier by FBD method.

D. Direct Displacement Based Design Method

The direct displacement based seismic design (DDBD) is proposed by Priestley et al. (2007) is used in the present study to design a metro bridge pier. The design philosophy of DDBD is based on the determination of the optimum structural strength to achieve a given performance limit state, related to a defined level of damage, under a specified level of seismic intensity., Priestley et al. (2007). The pier designed by DDBD method gives the uniform risk factor for the whole structure.

E. Box Girder Bridges

In the past three decades, the finite element method of analysis has rapidly become popular and effective technique for the analysis of box girder bridges. So many researchers conducted studies on Box girder bridges by using finite element method. Khalid et al. (2001, 2002) have conducted detailed literature review on analysis of box girder bridges. Based on Khalid et al. (2001, 2002), the following literature review has been done and presented.

Malcolm and Redwood (1970) and Moffatt and Dowling (1975) studied the shear lag phenomena in steel box-girder bridges. Sisodiya et al. (1970) approximated the curvilinear boundaries of finite elements used to model the curved box-girder bridges by a series of straight boundaries using parallelogram

Elements. This approximation would require a large number of elements to achieve a satisfactory solution. Such an approach is impractical, especially for highly curved box bridges.

Komatsu and Nakai (1966, 1970) presented several studies on the free vibration and forced vibration of horizontally curved single, and twin box-girder bridges using the fundamental equation of motion along with Vlahos's thin-walled beam theory. Field tests on bridges excited either by a shaker or by a truck travelling at various speeds showed reasonable agreement between the theory and experimental results. Lim et al. (1971) proposed an element that has a beam-like-in-plane displacement field. The element is trapezoidal in shape, and hence, can be used to analyse right, skew, or curved box- girder bridges with constant depth and width.

Ramesh et al. (1976) uncoupled in-plane and out-of-plane forces and neglected shear deformation to introduce a curved element with 6 degrees of freedom at each node. Their method is applicable to single and multi-cell sections.

Moffat and Lim (1976) presented a finite-element technique to analyse straight composite box-girder bridges will complete or incomplete interaction with respect to the distribution of the shear connectors.

Daniels et al. (1979) presented the results of a finite-element study concerning the effect of spacing of the rigid interior diaphragms on the fatigue strength of curved steel box girders. The results showed that reducing the interior diaphragms spacing effectively controls the distortional normal and bending stresses and increases the fatigue strength of curved steel box girders.

Kou et al. (1992) presented a theory that incorporates a special treatment of warping in the free-vibration analysis of continuous curved thin-walled girder bridges. Also, Kou (1989) examined the dynamic response of curved continuous box girder bridges.

F. Summary

This chapter reviewed the literature regarding the two major elements of an elevated bridge. First segment dealt with the design of the pier and second part dealt with the box girder. The first part of the chapter reviewed Design of Metro Bridge Pier by Force Based Design (FBD) Method and Direct Displacement Based Seismic Design (DDBD) Method.

The Second part of this chapter is focused on Box Girder Bridges and brief discussion on its research. Based on the critical assessment of literature of box girder, it can be concluded that box girder bridges can be analyzed by using finite element method and there are only limited numbers of parametric studies are available on curved in plan box girder bridges by considering all the parameters. So it is necessary to carry out the parametric study on curved box girder bridges to know the response parameters.

III. SCOPE AND OBJECTIVE

1) The present study is limited to those practical cases that come across in an elevated metro project.
2) With regard to the geometry of the pier considered, the present study is limited to,
   a. Rectangular pier cross section
   b. Single pier structural system
   c. Reinforced concrete pier

3) Parametric Study on Box Girder is limited to,
   a. Linear static and dynamic analysis and Nonlinear analysis is not considered
   b. Rectangular box section with flanges.
   c. Reinforced concrete box girder section and not applicable to pre-stressed bridges.
   d. Single Cell and Multi Cell Box Girder and not applicable to Multi Spine box girder.
   e. Zero percentage gradient of the superstructure and super elevation is not considered in the modelling.

A. Objective

- To study the performance of a pier designed by Force Based Design Method (FBD) and Direct Displacement Based Design (DDBD) Method.
- To study the parametric behaviour of a Curved Box Girder Bridges.

IV. METHODOLOGY

A. Define Scope & Objective

• Behaviour of piers under seismic loading
• Behaviour of box girders under varying span / curvature
• Comparison of force-based vs. displacement-based design
• Parametric study with different materials / cross sections etc.

B. Literature Review

Survey previous studies (like “Studies on Major Elements” by Venkata Laxmi & Manikanta Reddy IRJET comparative studies etc.), to get baseline values, typical ranges of span, curvature, cross-section shapes, material strengths, code provisions.

C. Define Geometries & Models

Choose representative models:
• Define pier types: cross-sections (rectangular, circular etc.), heights, reinforcement, etc.
• Define girder types: single-cell/double-cell/triple-cell box girders; straight vs. curved in plan; span lengths; span-to-radius ratios; material (restressed concrete, composite, etc.)
• Define the connecting conditions: e.g. piers supporting box girders; pier cap; foundation assumptions.

D. Define loading conditions & design codes

• Dead load, live load (train + maintenance load etc.)
• Seismic loads (as per relevant code, e.g. in India IS 1893, maybe newer edition)
• Wind loads, temperature effects if relevant
• other dynamic effects: e.g. vibration from moving trains
• Support/foundation stiffness etc.

E. Select design methodologies / comparison approaches

- Force-based design method
- Direct displacement-based design method (or other performance-based design)
- possibly non-linear analysis vs. linear elastic analysis
- Parametric variations (span, curvature, pier height, cross-section etc.)
- Comparative performance evaluation.

F. Finite Element / Analytical Modeling

- Build models (using software like SAP2000 / Staad Pro / ANSYS / ABAQUS etc.) for box girder + pier combinations
- Mesh, boundary conditions, material properties
- Include curvature, warping etc. if modeling curved box girders
- Validate model if possible against experimental or published results (benchmark)

G. Parametric Study

Vary one parameter at a time to see effect on output behavior. For example:

- Span length
- Radius of curvature (for curved girders)
- Span/R ratio
- Cross-section (single / multi cell)
- Pier cross-section shape / height
- Material properties (concrete grade, steel grade)

H. Documentation & Validation

Document assumptions, data, modelling decisions clearly

Validate wherever possible with experiments or published data

Sensitivity analyses to see how sensitive results are to assumptions (e.g. foundation stiffness, material variation).

V. CONCLUSION

The performance assessment of selected designed pier showed that,

Force Based Design Method may not always guarantee the performance parameter required and in the present case the pier just achieved the target required.

In case of Direct Displacement Based Design Method, selected pier achieved the behaviour factors more than targeted Values.

As the radius of curvature increases, responses parameter longitudinal stresses at the top and bottom, shear, torsion, moment and deflection are decreases for three types of box girder bridges and it shows not much variation for fundamental frequency of three types of box girder bridges due to the constant span length.

As the span length increases, responses parameter longitudinal stresses at the top and bottom, shear, torsion, moment and deflection are increases for three types of box girder bridges and fundamental frequency decreases for three types of box girder bridges.

As the span length to the radius of curvature ratio increases responses parameter longitudinal stresses at the top and bottom, shear, torsion, moment and deflection are increases for three types of box girder bridges and as span length to the radius of curvature ratio increases fundamental frequency decreases for three types of box girder bridges.

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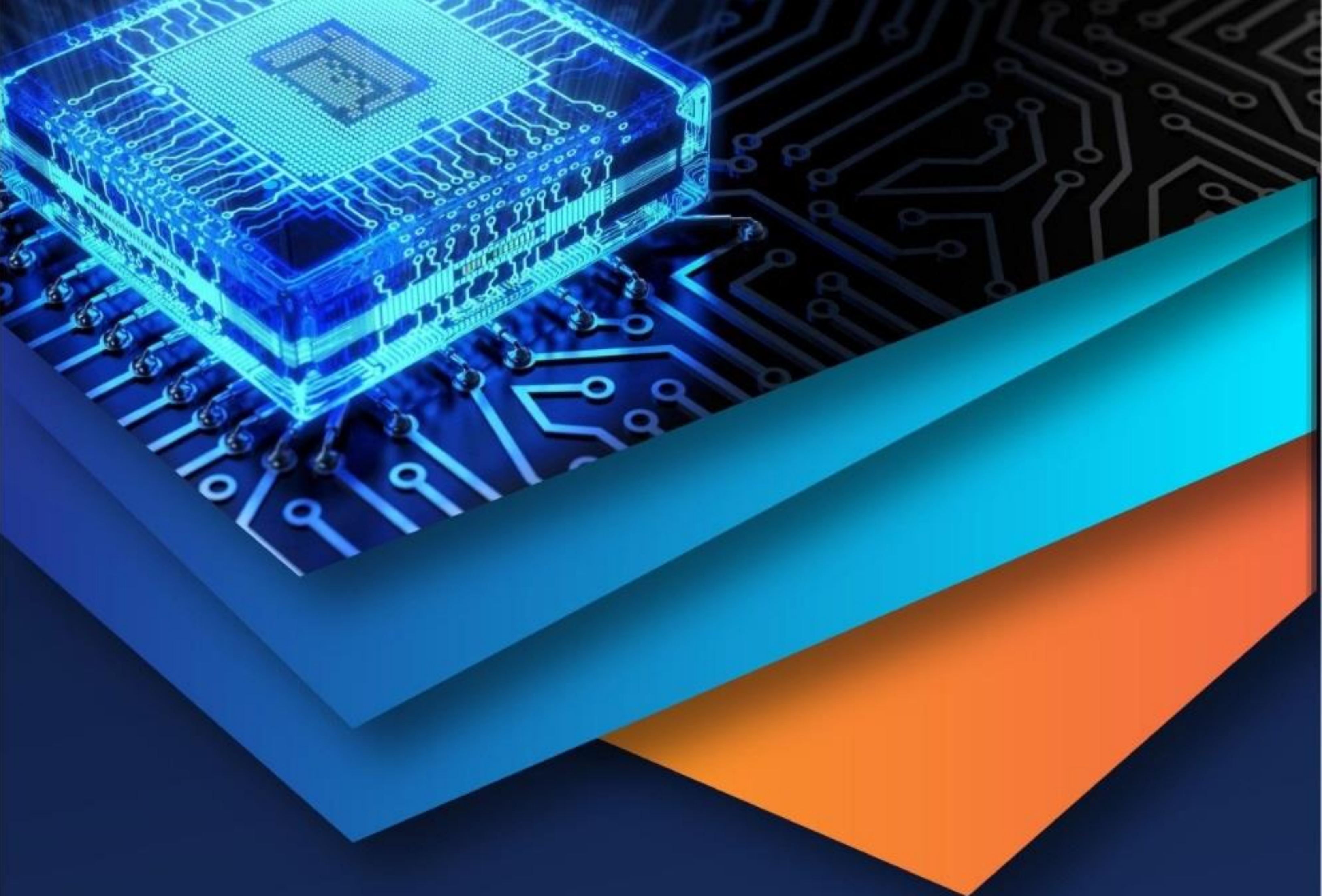

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