DESIGN AND ANALYSIS OF BRIDGE DESIGN USING STAAD PRO

S.N.KRISHNA KANTH 1*, DR.V.ANJANEYA PRASAD 2*

1. *M.Tech- Student , Dept of CIVIL, Chintalapudi Engineering College,JNTUK,AP,INDIA.*
2. *Prof, Head - Dept of CIVIL, Chintalapudi Engineering College,JNTUK,AP,INDIA.*

Abstract

Bridge is a structure having a total length of above 6 metres between the inner faces of the dirt walls for carrying traffic on road or railway. The bridges shall be classified as minor bridge and major bridge.

Minor bridge – Bridge having a total length up to 60 meters. Clause 101.1 of IRC 5:1998

Major bridge – Bridge having a total length above 60 meters.

The bridges are designed and constructed adopting the following IRC specifications.

- IRC 5:1998 Standard specification and code of practice for road bridges- Section I general features of design
- IRC 6:1966 Standard specification and code of practice for road bridges – Section II load and stress
- IRC 21:1987 Standard specification and code of practice for road bridges- Section III cement concrete
- IRC 40 : 1995 Standard specification and code of practice for road bridges- Section IV (bricks, stones and masonry)
- IRC 22:1986 Standard specification and code of practice for road bridges- Section VI composite construction
- IRC 78:1983 Standard specification and code of practice for road bridges- Section VII formation and sub structure
- IRC 83:1987 Standard specification and code of practice for road bridges- Section IX bearings
- IRC SP:20 2002 Rural Road Manual
- IRC SP 13:2001 Guideline for the design of small bridges and culvert

Component of Bridge

The component of the bridge is broadly grouped into

i) Foundation

ii) Substructure

iii) Superstructure

The foundations are different type viz., open foundation, well foundation, raft foundation and pile foundation. The substructure is the portion of the bridge structure such as pier and abutments above the foundation unit and supporting the superstructure. It shall also include returns and wing walls but exclude bearings. Superstructure is the portion of bridge structure above the substructure level viz., deck slab/beam, hand rail, foot path etc.

Introduction

Scope and Background

A bridge is a construction built to span physical obstacles such as a body of water, valley, or road, for the purpose of providing passage over the obstacle. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed, the material used for construction and the funds available to build it.

A bridge has three main elements. First, the substructure (foundation) transfers the loaded weight of the bridge to the ground; it consists of components such as columns (also called piers) and abutments. An abutment is the connection between the end of the bridge and the road carried by the earth; it provides support for the end sections of the bridge. Second, the superstructure of the bridge is the horizontal platform that spans the space between columns. Finally, the deck of the bridge. The guidelines for Non-linear analysis for bridge structure presents a collection of general recommendations for the modeling and analysis of highway bridges and overpasses subjected to earthquake ground motions, required for the design or evaluation of the capacity and ductility of critical bridge components and systems.

The specifications and guidelines presented throughout the document are applicable for Ordinary Standard Bridges as defined according to the 2004 Caltrans Seismic Design Criteria (SDC), Section 1.1. Some general recommendations can be extended to Ordinary Nonstandard Bridges and Important Bridges, where more rigorous and advanced nonlinear analysis is required due to geometric irregularities of the bridge structure, including curves and skew, long spans or significant total length, multiple expansion joints, massive substructure components, or unstable soil conditions. For these special cases, the design engineer must exercise judgment in the application of these recommendations and refer to additional resources in situations beyond the intended scope of this document.

The introductory chapter identifies the relevance and importance of nonlinear analysis procedures in bridge structures, including the advantages and drawbacks over simpler linear analysis. The different types of nonlinearities to be incorporated in the analytical bridge model are described briefly, with a list of the critical components of the structure that require detailed inelastic modeling to guarantee a desired level of accuracy. The appropriate model dimension (2D or 3D) recommended for the application of nonlinear analysis procedures is also justified in detail.

The second chapter titled load calculations includes considerations of traffic volume , general considerations and converting vehicle load into uni-axial load etc

The third chapter, titled *Bridge Modeling,* establishes a set of recommendations for the simplification of the geometry of the structure, definition of elements and materials, and the assignment of mass and boundary conditions, among others. A thorough explanation is presented that addresses the minimum requirements in the modeling in column bents. The nonlinear behavior of bridge abutments and foundations, as well as expansion joints integrated along the superstructure is discussed briefly.

The fourth chapter, titled *Bridge Analysis,* specifies the procedures and parameters used to simulate the seismic demand on the bridge structure in the form of imposed static and dynamic forces or displacements. The chapter provides an adequate and detailed methodology that allows the design engineer to conduct modal, gravity load, pushover, response spectra, and time history analysis, as well as to analyze the resulting response data of the bridge. References are provided to other resources for the use of response spectrum curves, selection and scaling of ground motions, and definition of additional parameters required for the different nonlinear analysis types.

The guidelines document presents ample recommendations for linear and nonlinear analysis of bridge structures appropriate for any structural analysis program, as well as specific details on the use of Staad ProVi8 for such procedures. Additionally, a general review and definitions related to structural dynamics, applicable to both linear and nonlinear analysis, are presented throughout. The emphasis of the present document is the implementation of nonlinear analysis procedures used primarily for the estimation of the demand on a bridge structure, not the evaluation of its capacity for design purposes. The design engineer must determine the appropriate methods and level of refinement necessary to analyze each bridge structure on a case-by-case basis. This document is intended for use on bridges designed by and for the California Department of Transportation, reflecting the current state of practice at Caltrans. This document contains references specific and unique to Caltrans and may not be applicable to other parties, either institutional or private.

Terminology:

Clearance: Is the shortest distance between the boundaries at a specified Position of a bridge.

Free Board: Free board at any point is the difference between the highest flood level after allowing for afflux if any, and the formation level of road embankment on the approaches or top level of guide bunds at that point. Free Board for high-level bridge shall in no case be less than 600 mm

Linear Water way: is the width of waterway between the extreme edge of water surface at the highest flood level measured at right angles to the abutment faces.

Effective Linear Water way: is the total width of the waterway of the bridge at HFL minus the effective width of obstruction.

Afflux: The rise in flood level of the river immediately on the up steam of the bridge as a result of obstruction to the natural flow caused by the construction of bridge and its approaches.

Scour Depth: In natural stream, the scouring action of the current is not uniform all along the bed width particularly at the bends and also round obstructions to the flow eg. The piers of bridges there is deeper scour than normal. The assessment of the scour depth is relevant for the design of bridge foundations and protective works. Whenever possible such assessment should be based on data made available from actual Sounding taken at the proposed bridge site or in its vicinity. Such soundings are being taken during immediately after a flood before the scour holes have had time to silt up appreciably. Necessary allowance shall be made in the observed scour depth for increased depth for various reasons.

Vertical clearance: Adequate vertical clearance shall be provided in case of all high level bridges which is usually the height from the designed HFL with afflux to the lowest point of the bridge superstructure. Such clearance shall be allowed as follows.

Discharge in cu.meters	Minimum vertical clearance in mm
Upto 0.3	150
Above 0.3 and upto 3	450
Above 3 and upto 30	600
Above 30 and upto300	900
Above 300 and upto 3000	1200
Above 3000	1500

The minimum clearance shall be measured from the lowest point of deck structure inclusive of main girders in the central half of the clear opening unless otherwise specified.

In case of slab bridges the difference between deck level and affluxes HFL shall not be less than 1.75 m.

APPLICABILITY OF NONLINEAR ANALYSIS

The seismic demands on a bridge structure subjected to a particular ground motion can be estimated through an equivalent analysis of a mathematical model that incorporates the behavior of the superstructure, piers, footing, and soil system. To achieve confident results for a variety of earthquake scenarios, the idealized model should properly represent the actual geometry, boundary conditions, gravity load, mass distribution, energy dissipation, and nonlinear properties of all major components of the bridge.

If a simple linear elastic model of a bridge structure is used, the corresponding analysis will only accurately capture the static and dynamic behavior of the system when stresses in all elements of the bridge do not exceed their elastic limit. Beyond that demand level, the forces and displacements generated by a linear elastic analysis will differ considerably from the actual force demands on the structure. Such a linear model will fail to represent many sources of inelastic response of the bridge including the effects of the surrounding soil according to its strain level, cyclic yielding of structural components, opening and closing of superstructure expansion joints, engagement, yielding and release of restrainers, and the complex nonlinear abutment behavior. Nonlinear modeling and analysis allows more accurate determination of stresses, strains, deformations, forces, and displacements of critical components, results that can then be utilized for the final design of the bridge subsystems or evaluation of the bridge global capacity and ductility.

However, the precise definition of material and geometric nonlinearities in the model is a delicate task, as the resulting response values are generally highly sensitive to small variations in the input parameters. To obtain an accurate representation of the nonlinear behavior of the bridge structure, it is necessary for the design engineer to have a clear understanding of basic nonlinear analysis concepts to correctly follow the recommendations offered in the present document. A final verification of selected response parameters will be necessary at the end of the analysis to evaluate the reliability of the results by a comparison to an expected range of response, estimated previously following the recommendations of Section 3.6.4. Unfortunately, the additional level of sophistication of the nonlinear model will also increase the computational effort required for the analysis, as well as the difficulty in the interpretation of results. The accurate estimation of the peak demand and response of the bridge structure under dynamic excitation will require the use of a large suite of ground motions, and will therefore further increase the complexity level of the analysis process and size of the output information. The present guidelines for nonlinear analysis were established by pursuing a balance between model complexities and the corresponding gain in accuracy of the results. The level of refinement in the definition of materials, elements, and sections of all major components was calibrated based on the stability of the result values.

In general, the modeling assumptions should be independent of the computer program used to perform the static and dynamic analysis; however, mathematical models are often limited by the capabilities of the computer program utilized. Therefore, the present guidelines include recommendations and limitations in the modeling and analysis of bridges by Saad pro vi8 Nonlinear, a general purpose, three-dimensional structural analysis program, commonly used by Caltrans. These recommendations can be adapted accordingly for the use of other structural analysis software.

NONLINEAR BEHAVIOR

Two categories of nonlinear behavior are incorporated in the bridge model to properly represent the expected response under moderate to intense levels of seismic demand. The first category consists of inelastic behavior of elements and cross sections due to nonlinear material stress strain relations, as well as the presence of gaps, dampers, or nonlinear springs in special bridge components. The second category consists of geometric nonlinearities that represent second order or P-Δ effects on a structure, as well as stability hazard under large deformations, where the equilibrium condition is determined under the deformed shape of the structure. The second nonlinearity category is incorporated directly in the analysis algorithm.

Bridge Modeling

BRIDGE GEOMETRY

Compilation of General Characteristics

The following information is required for the modeling of the basic bridge structural geometry:

- Total length of the bridge (L Total)=800m
- Number of spans and length of each superstructure span
- Total superstructure width (W superstructure)=16m
- Superstructure cross-sectional geometry
- Number and clear height of each column bent (H col)
- Column cross-sectional dimension in the direction of interest (Dc)

- Distance from column top to center of gravity of superstructure (Dc.g.)

- Length of cab beam to centroid of column (L cap)

- Cap beam width (Bcap)

- Location of expansion joints

- Support details for boundary conditions

The definition of the individual behavior of major bridge components entails the following data:

- Concrete material properties for concrete of superstructure (f'c, Ec)

- Concrete and reinforcing steel material properties (σ−ε) of column bents

- Reinforcement details of column bent cross section

- Foundation soil geotechnical properties

- Abutment general geometry

- Number and properties of abutment bearing pads

- Size of expansion joints

MODEL DIMENSION

A three-dimensional (3D) model of the structural system is required to capture the response of the entire bridge system and individual components under specific seismic demand characteristics. The interaction between the response in the orthogonal bridge directions and the variation of axial loads in column bents throughout the analysis are captured more accurately in a 3D model. This enables correct evaluation of the capacity and ductility of the system under seismic loads or displacements applied along any given direction, not necessary aligned with the principal axis of the bridge.

If the primary modes of the structure are highly correlated due to special mass distribution or geometry characteristics, they will significantly affect the dynamic response of the bridge, which must then be represented adequately through a three-dimensional model. Since the modal contribution is a key aspect in bridge analysis, and since the ground motions applied in a time history analysis are decomposed into three orthogonal directions and applied at an angle with respect to the principal axes of the bridge, a global analysis of the system is required. A two-dimensional (2D) model consisting of plane frames or cantilevers will fail to capture the particular geometric characteristics of the entire bridge and the interaction between structural subsystems. The actual distribution of forces among critical components of the bridge is determined according to their relative stiffness. The flexibility of the superstructure in the transverse direction, the relative stiffness of the column bents according to their heights and cross-sectional properties, and the abutment characteristics are imperative aspects to consider in the analysis that cannot be modeled correctly using a two-dimensional model.

The use of combinations rules for the interaction of responses in orthogonal directions to estimate the maximum demand on critical bridge components are applicable only for linear elastic structures, and could result in significant errors when extrapolated to the inelastic range.

Particularly in the case of special bridge systems with irregular geometry, curved or skewed, with multiple transverse expansion joints, massive substructure components, and foundations supported by soft soil, the dynamic response characteristics exhibited are not necessarily obvious beforehand and may not be captured in a separate subsystem analysis. According to Section 5.2 of SDC 2004, for structures supported on highly non-uniform soils, a separate analysis of each individual frame is recommended in addition to the conventional three-dimensional multi-frame analysis.

Local analysis of an individual component or subsystem may be used to assess the critical values of their strength and ductility capacity and provide a general approximation of the expected range of response of the entire bridge system. If desired, local analysis is performed in the transverse and longitudinal directions for bridge column cross sections with biaxial symmetry, following the recommendations of Sections 5.3–5.5 of SDC 2004. Local analysis fails to capture the interaction between different components or subsystems of the bridge, and could therefore result in significant errors in the estimation of the demand on the analyzed component.

Traffic study

The traffic in terms of the cumulative number of Standard axles (8160 Kg) to be carried by the pavement during the design life. The following information is needed:

i) Initial traffic after construction in terms of number of commercial vehicles per day (CVPD)

ii) Traffic growth rate during the design life in percentage

iii) Design life in number of years

iv) Vehicle damage factor (VDF)

v) Distribution of Commercial traffic over the carriageway.

- Initial Traffic: Estimate of initial daily average traffic flow for any road should normally be based on atleast 7 days, 24 hour classified traffic counts. In case of new roads, traffic estimates can be made on the basis of potential land use and traffic on existing routes in the area.

- Traffic growth rate: Traffic growth rates should be estimated by study. If adequate data is not available, average annual growth rate of 7.5% may be adopted. The factor is reduced to 6% for roads desiged adopting IRC:SP 20-2002

- Design life: The Design life is defined in terms of cumulative number of Standard axles that can be carried before strengthening of the pavement. Normally the pavement for NH & SH is the designed for life of 15 years, Expressways and Urban roads for 20 years and other roads for 10 to 15 years. When it is not possible to provide the full thickness of pavement at the time of initial construction, stage construction technique should be resorted to. Roads in Rural areas should be designed for a design life of 10 years.

- Vehicle damage factor (VDF): VDF is arrived at from axle load surveys. The indicative value of VDF factor is given below:

Initial traffic in terms of commercial vehicle per day	Terrain (Rolling/Plain Hilly)
0-150	1.5 0.5
150-1500	3.5 1.5
More than 1500	4.5 2.5

o Distribution of Commercial traffic over the carriage way:

i) Single lane : Design should be based on total number of commercial vehicle in both directions multiplied by two

ii) Two lane (single Carriageway) : 75% of the total number of commercial vehicle in both the direction.

iii) Four lane (single Carriage way) : 40% of the –do iv) Dual Carriageway: 75% of the number of commercial vehicle in each direction. For dual 3 lane and dual 4 lane carriageway, the distribution factor will be 60% and 45% respectively.

Computation of design traffic under IRC 37: 2002

The design traffic is considered in terms of Cumulative number of standard axles to be carried during the design life of the road. Computed by the equation

$N= 365x\ [(1+r)n-1]\ x\ A\ x\ D\ x\ Fr$

Where

o N: The cumulative number of standard axles to be catered for in the design in terms of MSA

o A: Initial traffic in the year of completion of construction in terms of number of commercial vehicles per day

o D: Lane distribution factor

o F: VDF

o n: Design life in years

o r : Annual growth rate of commercial vehicles (for 7.5% annual growth rate r=0.075)

The traffic in the year of completion is estimated using the following formula:

$A= P\ (1+r)\ x$

Where

P = Number of Commercial vehicle as per last count

x = Number of years between the last count and the year of completion of construction

Computation of design traffic under SP 20:2002

The traffic for design life is computed as –

Number of commercial vehicles per day for design $A = P(1+r)n+x$

Where

r= Annual growth rate of commercial vehicle (i.e 6%)

P, x & n = as above

Bridge Analysis

GENERAL CONSIDERATIONS

Following the completion of the modeling phase of the bridge structure, including geometry, elements, cross sections, materials, masses, boundary conditions, and sources of nonlinear behavior, the structural model must be evaluated to comply with the stiffness and period requirements in Section 7.1.1 and 7.1.2 of the SDC 2004 guidelines. Subsequently, the seismi analysis of the bridge is carried out to determine the force and deformation demands on the structural system and its individual components. The evaluation of the capacity of the bridge structure for design purposes is not the main emphasis of the present document.

The extent of the nonlinear behavior recommended for a particular bridge model depends on the classification and importance, the level of geometric, structural, and geotechnical irregularity, as well as the performance level required for the structure. Since great computational and analytical effort is required to perform nonlinear dynamic analysis, the analysis procedures for Ordinary Standard bridges can be simplified in some cases using linear models and static analysis procedures.

Dynamic analysis of a bridge model can only estimate the complex response of a structure to an earthquake, since inherent uncertainties in the specification of the ground motion, soil-structure interaction effects, and the expected linear or nonlinear behavior of structural components can produce significant inaccuracies in the analysis results. These uncertainties are generally accounted for in the design process through demand amplification and capacity reduction factors. However, additional engineering criteria must be applied to recognize fundamental sources of error in the analysis and verify the results through a simplified structural model and analysis procedures.

According to Sections 4.1.7 and 4.2 of ATC 32, Section 5.2 of SDC 2004 and the findings of the present document, the following recommendations are provided for the selection of the analysis type to be carried out for Caltrans bridges, classified according to Seismic Design Criteria Memo To Designers 20-1, January 1999 (MTD 20-1). The applicability and limitations of each analysis type is described in detail in the remaining sections of this chapter.

- Equivalent static analysis (ESA, see Section 3.5) is considered an appropriate analytical tool for estimating the response of Ordinary Standard bridges with properties specified in Section 5.2.1 of SDC 2004.

- Linear elastic dynamic analysis (RSA, see Section 3.7) is recommended for the estimation of the structural response of all bridge types for which behavior is essentially elastic.

- Nonlinear static analysis (pushover, see Section 3.6) allows for a more realistic determination of the interaction of critical components and the evaluation of the bridge strength and deformation capacity. It accounts for the redistribution of internal actions as components respond inelastically, and therefore provides a better measure of behavior than elastic analysis procedures. It is a recommended procedure for establishing actual strength and displacement capacities for all bridge types.

- Dynamic analysis is recommended for all bridges, except one- and two-span structures without intermediate expansion joints and with small or no skew, where static analysis is sufficient.

- The use of nonlinear models in dynamic analysis is required for Important Bridges and highly irregular bridges (Ordinary Nonstandard bridges). Elastic dynamic analysis can be used otherwise, using modal spectral analysis .

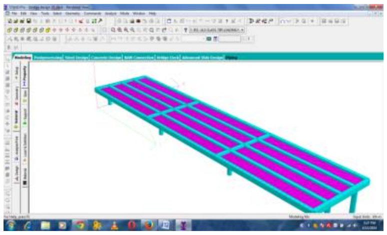
- Nonlinear dynamic behavior can be appropriately represented using nonlinear time history analysis- direct integration formulation (THA, see Section 3.8). Time history analysis using modal superposition or nonlinear response spectrum analysis procedures are not recommended for the evaluation of the dynamic response of highly nonlinear structures.

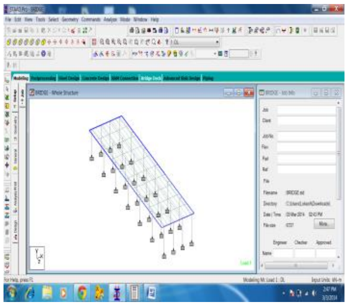
- The proper evaluation of the maximum response of bridge

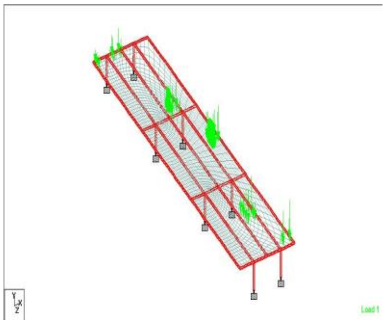
- structures due to dynamic excitation can only be carried out using an adequate suite of earthquake ground motions and reasonable criteria to estimate the variance in the results .

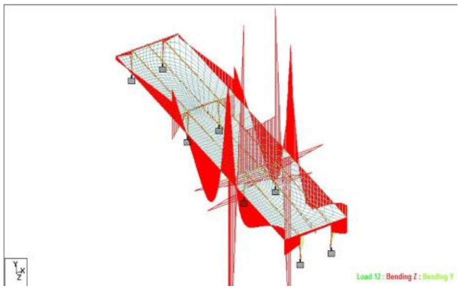
- For Important Bridges, the dynamic analysis should be supplemented with a static inelastic analysis (pushover) to evaluate local demands on yielding members.

Here design of structure is done with the help of software tool (staad pro v8i) and the step by step of its design procedure is shown below









CONCLUSION

In our project, we are going to design minor Bridge. We plan on covering every aspect of the redesign. This is going to include the design of the actual replacement bridge, the affect this bridge will have on the surrounding area through an environmental impact, and the logistics associated with the construction phase. In completing this project, we are going to have to use a number of tools. We will have to get bridge history reports in order to see the deficiencies of the current bridge, including height issues and pier quality. We are also going to have to determine what the ASHTO design standards are and apply them to this bridge. Through these events, along with others, we expect to get a good understanding of the construction phase and end up with a product similar to what was designed and approved by Mass Highway for this bridge.

STAAD PRO has the capability to calculate the reinforcement needed for any concrete section. The program contains a number of parameters which are designed as per IS: 456(2000). Beams are designed for flexure, shear and torsion.

Design for Flexure:

Maximum sagging (creating tensile stress at the bottom face of the beam) and hogging (creating tensile stress at the top face) moments are calculated for all active load cases at each of the above mentioned sections. Each of these sections are designed to resist both of these critical sagging and hogging moments. Where ever the rectangular section is inadequate as singly reinforced section, doubly reinforced section is tried.

Design for Shear:

Shear reinforcement is calculated to resist both shear forces and torsional moments. Shear capacity calculation at different sections without the shear reinforcement is based on the actual tensile reinforcement provided by STAAD program. Two-legged stirrups are provided to take care of the balance shear forces acting on these sections.

Beam Design Output:

The default design output of the beam contains flexural and shear reinforcement provided along the length of the beam.

Desk slab Design:

Desk slab are designed for axial forces and biaxial moments at the ends. All active load cases are tested to calculate reinforcement. The loading which yield maximum reinforcement is called the critical load. Desk slab is done for square section. Square columns are designed with reinforcement distributed on each side equally for the sections under biaxial moments and with reinforcement distributed equally in two faces for sections under uni-axial moment. All major criteria for selecting longitudinal and transverse reinforcement as stipulated by IS: 456 have been taken care of in the Desk slab design of STAAD.

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- IRC 22:1986 Standard specification and code of practice for road bridges- Section

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- IRC 78:1983 Standard specification and code of practice for road bridges- Section

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IX bearings

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- IRC SP 13:2001 Guideline for the design of small bridges and culvert