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Dynamic Analysis of Bridge under Seismic Condition in All Zones and Type of Soils

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ABSTRACT

Earthquake damage in most bridges is the result of excessive seismic displacements and large force demands that have been substantially underestimated during design. The detailed study is carried out for continuous box superstructure & substructure for two lane spans 25 m-35 m-25 m, using IRC class A & 70R loadings. For analysis SAP2000 software is used. The results for 12 different cases have been studied and variation of each parameter is documented in a detailed manner. The impact of class of seismic zones corresponding to different soil conditions are studied. The impact of class of seismic zones corresponding to different soil conditions are compared in Spectral Acceleration coefficient Sa/g, Horizontal seismic coefficient Ah, Vertical seismic coefficient Av, Base shear Vb, Displacement at superstructure level. When comparing spectral acceleration, which depends on dynamic property of structure and supporting soil medium, it varies from 1.36 to 1.67 times, when the soil from hard to soft nature. As far as base shear, displacements are concerned, it increases from 1.6 times of hard soil to medium soil, whereas from medium to soft soil it increases to 1.5 times of medium soil.

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Introduction

Normally, structures are subjected to two types of load, namely static and dynamic. However, the majority of civil engineering structures are designed with the assumption that all applied loads are static. The effect of dynamic load is not considered because the structure is rarely subjected to dynamic loads; more so, its consideration in analysis makes the solution more complicated and time consuming. This feature of neglecting the dynamic forces may sometimes become the cause of disaster, particularly in the case of earthquake. Nowadays, there is a growing interest in the process of designing structures capable to withstand dynamic loads, particularly, earthquake-induced load. This is needed to be done, because, in present scenario where earthquakes are occurring frequently, dynamic force cannot be neglected [2]. Bridges are unique in their structural response. First, they are longitudinally lengthy, and consist of many structural components which contribute to the overall resistance capability of the system. Decks are often skewed and curved, and intermediate expansion joints divide a bridge system into several structural segments with different natural periods. Second, there are various structural types with complex geometries and dynamic response characteristics.

Suspension bridges and cable stayed bridges generally display a very complex structural response with long natural periods, often exceeding 10 seconds. Many modes with closely spaced natural periods contribute to the complexity of the structural response. Third, bridges are generally constructed at soft soil sites such as rivers and bay areas. Because ground motions are amplified at these sites, greater attention should be paid to seismic design for large ground motion. Failure of foundations associated with the instability of surrounding ground is a common occurrence. Fourth, the degree of statical indeterminacy is smaller in bridges than in buildings, and therefore ductility of piers/ columns needs to be carefully examined to prevent failure during strong earthquakes [5].Various analytical methods have been developed to predict the seismic response of bridges. This has enabled to construct bridges which were difficult to design when computer analysis was not available. For example, precise linear and nonlinear seismic response analysis is essential for long span bridges, bridges with complex geometric features, cable supported bridges, and tall bridges. Computers have also greatly assisted in the analysis of bridges which have failed during past earthquakes, and have greatly contributed to the improvement of seismic design methods.

Therefore it is proposed to do "dynamic analysis of bridge structure" for various classes of zones & by varying soil conditions. The detailed study is carried out for "continuous PSC box superstructure & substructure", for two lane spans 25m-35m-25m, using IRC class A & 70R loadings. For analysis SAP2000 software is used. Finally, to envelope the serviceability, then bridge responses are obtained.

Bridge Modelling

General Description of Bridge

The bridge considered in the analysis is a continuous three-span cast-in-place reinforced concrete box girder bridge, which is supported by bearing pads on the seat-type abutments with an expansion gap and rigidly connected to a single reinforced concrete column at the bent caps [9]. The bridge has a total length of 85m. The bridge is 85m long with spans measuring 25m, 35m and 25m, respectively as shown in Fig.1.

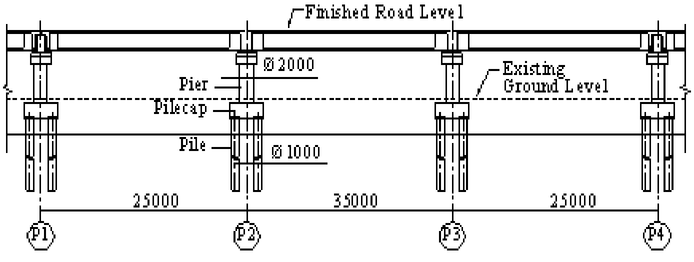

Figure 1. Longitudinal Elevation of Bridge

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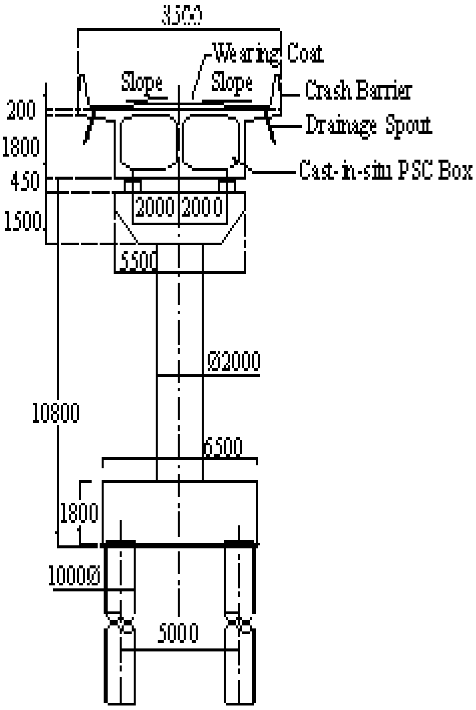


Figure 2. Cross Section of Bridge

Analytical model of bridge

Three-dimensional analytical finite element models are developed as a computational representation of various bridge structures. In order for the analytical models to accurately predict bridge-structure response, realistic boundary conditions are essential part of the models. For the single-span bridge structures, the dynamic behavior of the structural system is completely dominated by the boundary conditions at the beginning and end of the analytical model . These boundary conditions for a single-span bridge are the nonlinear abutment-backfill and nonlinear abutment shear keys in the longitudinal and transverse directions, respectively. For the multi-span bridge structures, in addition to boundary conditions at the beginning and end of the bridge system, nonlinear boundary conditions of the deck-column-soil-structure-foundation must be modeled accurately[7]. For the dynamic analysis of bridge systems considered in this work, the beginning and ending boundary conditions (bridge piers) are modeled as a set of restraints in both transverse and longitudinal directions. Fixed connections are used at the base of the columns.

Structural System

The three-dimensional bridge model was developed using the finite element computer program SAP 2000 (CSI, 2005) using plate elements for the bridge deck and beam elements for the columns with sectional properties. The bottom of the column was modelled as a fixed connection and the top had a plastic hinge. The frame element with moment curvature and cracked sectional properties was used to model bridge column. For dynamic response analysis, the stiffness, mass and damping properties of each finite element must be realistically defined [13].

Stiffness Idealization

The finite element idealization of a complete bridge system results in a stiffness matrix which is an assemblage of the generalized stiffness matrices for individual elements as

$$K = \sum_{i=1}^{N} k_i \qquad (1)$$

where,

K - Total stiffness matrix for the entire bridge system,
k - Stiffness matrix for element i, and
N - Total number of elements in the bridge system.

The total stiffness matrix for the entire structure may be written as

$$K_t = \sum_{i=1}^{N} k_{ti} \qquad (2)$$

where,

K - Total stiffness matrix at time t, and
k_{ti} - Stiffness matrix for element i at time t.

Nonlinearity arising from large geometry changes is not generally included as it is negligible.

Bridge geometry

Under this topic, geometric details of bridge to be collected and incorporated in the model. The number of parameters is explained in subsequent paragraphs about both general characteristics and material characteristics.

Compilation of General Characteristics

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

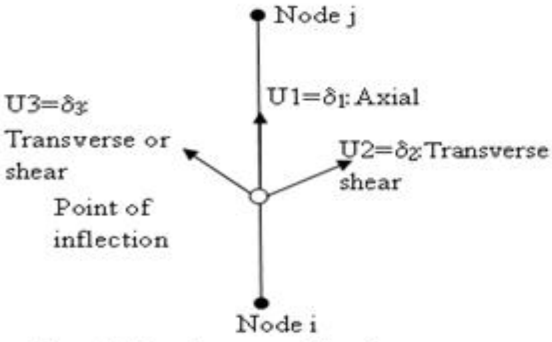
- Total length of the bridge (L_{Total})
- Number of spans and length of each superstructure span
- Total superstructure width ($W_{superstructure}$)
- Superstructure cross-sectional geometry
- Number and clear height of each column bent (H_{col})
- Column cross-sectional dimension in the direction of interest (D_c)
- Length of cab beam to centroid of column (L_{cap})
- Cap beam width (B_{cap})
- Support details for boundary conditions

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

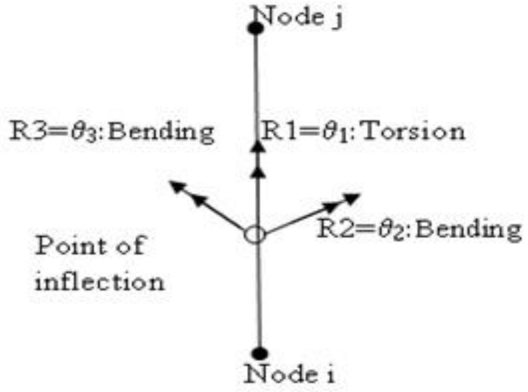
○ Concrete material properties for concrete of superstructure (f'_c, E_c)
○ Foundation soil geotechnical properties

Coordinate System

The coordinate system used for the modeling and analysis of the bridge is shown in Fig.3.The global X-axis is in the direction of the chord connecting the piers, denoted as the longitudinal direction; the global Y-axis is orthogonal to the chord in the horizontal plane, representing the transverse direction; while the global Z-axis defines the vertical direction of the bridge. For the analysis and design of elements of the bridge using two-noded elements, a local coordinate system is used, as shown in Fig 3. It is recommended that the orientation of all frame elements in a bridge structure without a skew coincides with the positive direction of the global axis; namely, the coordinate of node I of the frame will be smaller than node j. In the case of bridge structures with skew supports, the orientation of the superstructure elements should coincide with the skew coordinates, not the global axis [4].The nomenclature for twist or torsion, as well as axial force or deformation of an element will be denoted as the direction 1-1 or axial direction. Shear forces and deformations, as well as moments and rotations will be specified as directions 2-2 or 3-3 in Fig.4.

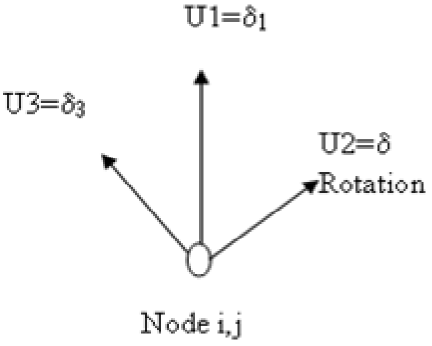


Translation degrees of freedom

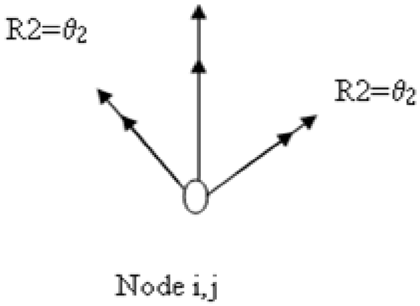


Rotational degrees of freedom

Figure 3. Degrees of freedom in SAP2000 for finite-length element



Translation degrees of freedom



Rotational degrees of freedom

Figure 4. Degrees of freedom in SAP2000 for zero-length element

For the seismic analysis of highway bridges it is customary to use three-dimensional beam column elements (line or frame elements) with corresponding cross-sectional properties, to represent the superstructure and the components of the bents (columns and cap beams). The geometry, nodes, and connectivity of the elements in the model will be determined according to plans, following the recommendations of this chapter. This chapter focuses on the three-dimensional spine model of the bridge structure with line elements located at the centroid of the cross section, following the alignment of the bridge; however, some of the recommendations offered in the document can be extended to three-dimensional shell or frame grillage models of the bridge.

ATC-32 suggests that a minimum of three elements per column and four elements per span shall be used in a linear elastic model. However, it is recommended for all analysis cases that the superstructure, cap beam, and column bents be discredited using a minimum of five elements of equal length, except for spans with intermediate hinges or expansion joints. This discretization helps approximate the distributed (translational) mass of the bridge components with lumped masses at the nodes between segments, generated automatically by SAP2000. The additional assignment of rotational mass of the superstructure is required in the model, as well as of the columns, when a global torsional mode is excited under certain dynamic conditions. The use of fewer (displacement-based) elements, even for the linear elastic superstructure element, could result in loss of accuracy in the mass formulation, and therefore is discouraged unless distributed mass properties can be specified. The nodes lie along the line of the geometric centroid of the bridge's components, and are assigned a translational and rotational mass corresponding to the tributary mass associated with each node, according to SDC[2].

Material and Mass properties

The expected material strength and stress-strain (σ−ε) relation should be used for unconfined and confined concrete, as well as reinforcing steel, to more accurately capture the bridge's capacity and behavior.

Material Properties

The reinforcement details of the piers and other major bridge components are required. The properties of normal weight Cement concrete should be applied according to section 203 of IRC:6, model is to be used to represent the uniaxial stress-strain behavior for unconfined and confined concrete. It is recommended that the concrete tensile strength for both confined and unconfined concrete be included. The tensile strength is estimated by IRC:112 as ft = 7.5 f 'c (N/mm2) for normal weight concrete, defined with an initial Modulus of Elasticity Ec according to Section 3.2.6 of SDC 2004. The initial stiffness of RC columns can be significantly altered due to the tensile resistance of uncracked concrete fibers between cracks, denoted as tension-stiffening of a section When a moment-curvature (M-φ) analysis is to be carried out for the concrete column, the properties of the steel longitudinal and transverse reinforcement are to be used according to the guidelines for steel given in IRC:112. The steel material model with symmetric behavior in tension and compression assumes an initial elastic behavior up to yield, a yield plateau, followed by a strain-hardening region. The onset of strain hardening and the reduced ultimate tensile strain defining the point of fracture are defined according to bar size for each column cross section. According to SDC 2004, sections 3.2.3, the yield stress Fy and ultimate stress Fu for all bar sizes are to be taken as 500 and 500 MPa, respectively. The definition of the σ−ε relation in SAP2000 must be carried out with a sufficient number of points in the curve to capture the nonlinear behavior of the material, specifically the degradation of strength beyond the elastic or yield point in confined and unconfined concrete, and the variation in the strain-hardening slope in the reinforcing steel [14].

Translational Mass

The weight of normal concrete is specified by IRC:6 of Section 203 as w=25 kN/m3) and therefore a mass of concrete ρ =(245.25 kg-sec2/m4) is to be used when specifying material properties for confined and unconfined concrete. It is desired to approximate all bridge elements with a distributed mass along their length. However, the program SAP2000, as well as other analysis software packages, automatically calculates the translational mass of all longitudinal elements in the three global directions of the bridge (longitudinal, transverse, and vertical) and assigns them as lumped mass at each node, based on tributary lengths. To approximate the distributed mass with lumped masses, a sufficient number of nodes and segments are to be defined, with a minimum recommended of 5 segments per superstructure span and column bent.

Mass Moment of Inertia

Additional assignment of rotational mass (mass moment of inertia) is required for the superstructure and the column bents of a spine model of the bridge, since it is not generated automatically in SAP2000. The assignment of superstructure rotational mass helps represent with greater accuracy the dynamic response and fundamental modes of the bridge associated with the transverse direction. The rotational moment of inertia of the superstructure shall be assigned according to the following Fig.5

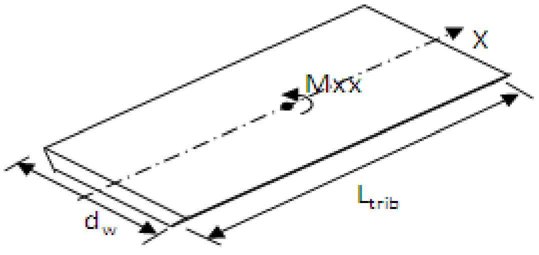


Figure 5. Rotational mass of superstructure

$$M_{xx} = \frac{Md_w^2}{12} = \frac{(m/L)L_{trib}d_w^2}{12} \qquad (3)$$

where

M_{XX} -Rotational mass of superstructure, assigned as lumped mass in axial direction 1-1 or global X-X (R1)

M -Total mass of superstructure segment, tributary to the node

m/L -Mass of superstructure per length

L_{trib} -Tributary length according to node definition

d -Superstructure width, which can be taken as average of bottom and top flanges

The global torsional mode of the entire bridge, defined in SDC,must be captured accurately through a correct mass definition. The torsional mode is generally not dominant for most real structures with realistic abutment model and boundary conditions. However, if such mode of deformation is a dominant and primary mode of response that significantly affects the seismic behavior of the entire structure, an additional rotational mass assignment is required for the column bents, according to the following Fig. 6

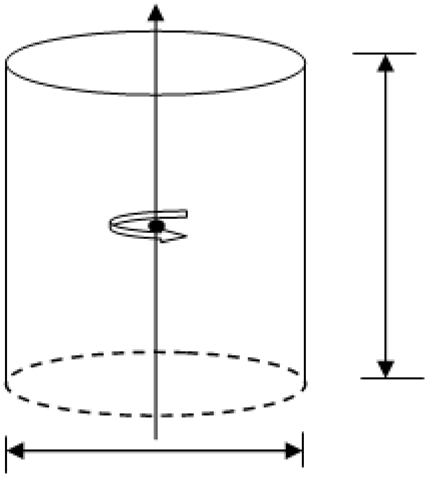


Figure 6. Rotational mass of column bent

$$M_{zz} = \frac{1}{2}MR_{col}^2 = \frac{(m/L)L_{trib}D_c^2}{8} \qquad (4)$$

where,

M_{ZZ} - Rotational mass of column, assigned as lumped mass in local direction *1- 1* or global direction *Z-Z* (R3)

M - Total mass of column segment, tributary to the node

R_{col} - Half of the average column dimension equivalent to the radius of circular columns

m/L - Mass of column per length

L_{trib} - Tributary length according to node definition

Dc - Column dimension, which can be taken for cross sections with biaxial symmetry as the average of the transverse and longitudinal dimensions.

Boundary Conditions

The dynamic interaction between the soil and the pile shaft of bridge foundations has a significant effect on the seismic response of bridges. Soil-structure interaction is usually classified into kinematic and inertial effects. Kinematic interaction is the modification of the free-field ground motion by the presence of the mass less foundation, while the inertial soil-structure interaction is caused by the deformation of the soil by the time-varying inertia induced forces developed in the foundation.

Soil-Structure Interaction

Although it is impractical to include all the effects of the soil and foundation on the earthquake response of a bridge, the design engineer should recognize that soil-structure interaction introduces flexibility and energy dissipation into the system compared with an assumption of a rigid or pinned support. The stiffness and damping properties of a foundation depend on the characteristics of the soil, piles, and the connections between the piles and the pilecap. The group effects of the large number of piles in bridge foundations can significantly affect the dynamic properties [12].

According to geotechnical specifications, in the case of ordinary standard bridge structures with normal soil conditions, the underlying soil can be assumed rigid and soil-structure interaction neglected. In such cases, the column foundation may still be considered to have semi rigid behaviour through the assignment of a rotational spring if a reduction in the cross section is specified for the column base. For non-conventional soil conditions in ordinary standard bridges, a semi-rigid connection will be defined for the column base, according to section 2.6.2 of SDC. Soil-structure interaction should always be considered in the analysis of non standard and important bridge structures, especially very rigid systems with short natural periods. For such cases, it is also expected that the modal damping ratios of the soil system differ significantly from the remaining structure, with values in the range of 15–20% compared to 3–5%, respectively [2].

The assumptions of classical damping are no longer appropriate for combined soil-structure systems with different damping levels, requiring an adjustment in the modal damping definition through substructure method, Anil K Chopra (2001). Section 4.2.2 of ATC 32 provides general guidelines for the consideration of soil structure interaction effects in the modelling of bridge structures.These equivalent viscous damping forces are intended to model the energy dissipation within the linear elastic limit of the structural system.

Column Supports

The definition of boundary conditions in a structural system is a key factor in the assemblage of its stiffness matrix, thus affecting both the static and dynamic behaviour of the structure. The boundary conditions must be assigned correctly through simplified and realistic models of the abutments and foundation system of the bridge to correctly approximate the ductility capacity and seismic demand on major structural components. In a dynamic analysis of the bridge, the modal periods and mode shapes, as well as other related properties are greatly affected by such assignment. Depending on the details of the foundations, a pinned, semi-rigid, or fixed connection should be specified at the column base. If a reduction in the column base (built hinge) is detailed in the plans of multi-column bent bridges, a completely pinned connection can be used for simplicity (restraints on degrees of freedom U1, U2, and U3 corresponding to translation). In such cases, a rigid connection between the column top and the superstructure is also specified to maintain the stability of the bridge under transverse loads. For single-column bent bridges, the stability of the structure in the transverse direction is obtained through an idealized fixed connection at the column base and a rigid connection between the superstructure and column bent top.

Boundary conditions must be verified with the geotechnical data for the site and assigned to the model through joint restraints at the column base. However, since the actual bridge system is more complex, its displacement capacity is affected by components other than the ductile members within the frame, mainly the flexibility of the column bent foundations. This feature is included in the model to represent the realistic boundary conditions of the system, according to Section 2.2.4 of SDC 2004, using either the uncoupled hinge or the zero-length NL-Link in SAP2000 for the model. In the case of flexible foundations with appropriate lateral restraint, a pinned connection is specified at the column base through joints restraints at the degrees of freedom U1, U2, and U3 corresponding to translation, while the linear or nonlinear behaviour of the foundations is introduced at the degrees of freedom corresponding to rotations R2 and R3 . The effective height of the column should also be adjusted to the idealized location of column fixity [2].

The increase in the rotational stiffness and the corresponding degree of semi-rigidity of the column base will produce an upward shift in the point of inflection of the column under lateral load or deformation. This shift in the inflection point will modify and redistribute the rotational demand on the column between the top and bottom sections. It will also produce and overall increase in base shear, a reduction in the displacement ductility capacity of the bridge and could significantly modify other response parameters of the bridge. Therefore, the estimation of the column base degree of semi-rigidity must be made with caution. A similar modelling approach can be taken for the translational degrees of freedom. If such foundation response is expected in the longitudinal, transverse, or vertical directions, the column base can be modelled as a semi-rigid connection using elastic or nonlinear springs. In general, the parameters used for the assignment of semi-rigid column bases are defined according to the geotechnical specifications for the site. The assigned boundary conditions or springs must guarantee the stability of the bridge model in any direction to carry out the analysis successfully. The geometrical properties of the column cross section at the transition point between the foundation footing or piles and the column bent are also considered in the model.

Torsional restraints in the degree of freedom R1 should not be specified for the column base with an idealized pinned connection, specifically in the case of single-column bent bridges, where the torsional modes of the structure could be significantly impacted. section 5.3 of ATC 32 provides some additional recommendations for foundation modelling.

Bridge Analysis

Following the completion of the modelling phase of the bridge structure, including geometry, elements, cross sections, materials, masses, boundary conditions, and sources of nonlinear behaviour, 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 seismic 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 behaviour 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.

Equivalent static analysis (ESA) 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 is recommended for the estimation of the structural response of all bridge types for which behaviour is essentially elastic.
- Nonlinear static analysis 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 behaviour than elastic analysis procedures.
- 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 behaviour 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.
- The correct determination of the dynamic properties of a designed bridge structure can also assist in the detection of invisible structural damage after a seismic event.

Modal analysis

The dynamic characteristics of a bridge structure are explicitly portrayed through modal analysis procedures. The frequencies at which vibrations naturally occur and the mode shapes assumed by the bridge are determined analytically, based on the mass, stiffness, and damping properties of the system. These modal results, specifically modal periods, are the main parameters used for response spectrum analysis and time history analysis. Such procedures allow a realistic evaluation of the seismic demand and the corresponding structural response of the bridge, through an acceleration spectra or ground motion simulation [8].

Modal pushover analysis is not considered for ordinary standard bridges, since the natural modes of the structure generally present low correlation . Since bridges are complex structural systems, they are particularly prone to seismic demand amplification due to specific ground motion excitation characteristics. These resonance effects can cause premature or unanticipated failure. To account for these hazardous situations in the design process, modal analysis procedures can be conducted iteratively to obtain the dynamic characteristics of the bridge for different stages of damage. The correct determination of the dynamic properties of a designed bridge structure can also assist in the detection of invisible structural damage after a seismic event, obtained specifically from the variation or lengthening of its modal periods, which is evaluated experimentally. The principal modes of deformation of an Ordinary Standard bridge structure generally include the transverse and longitudinal translation of the bridge, the global torsion of the bridge and superstructure, and several modes of flexural deformation of the superstructure, primarily in the vertical direction or simple in-plane bending.

The modal analysis can be carried out for Ordinary Standard bridge systems in SAP2000 through an Eigenvector analysis or Ritz-vector modes analysis. Eigenvector analysis determines the undamped elastic mode shapes and frequencies of the system, while Ritz-vector analysis seeks to find modes that are excited by a particular loading. Ritz-vectors representative of the expected vibration modes of a structure can provide a good basis when used for response spectrum or time history analyses that are based on modal superposition. However, modal time history analysis is not recommended for bridge structures, since it does not account for all model nonlinearities . Ritz modes are only representative of the selected Ritz shapes and may be biased compared to the eigen modes. The use of Ritz modes for a modal analysis is recommended for the bridge when a distributed gravity load or wind load pattern is of concern for the bridge. For such cases, AASHTO LRFD, 3rd edition, is applicable for determining the initial force vector. For ordinary bridge structures, defined by SDC 2004 as with a total span length smaller than 90 m and conventional traffic loads, the modal results using Eigenvector analysis and Ritz modes in SAP2000 are similar when the initial load vector is not specified or when typical gravity loading conditions are used instead. For special bridge structures, both Eigen vector analysis and Ritz modes analysis should be conducted on the bridge to evaluate the dynamic response of the bridge due to free-vibration and special load patterns on the bridge. The parameters to be specified in the Eigenvector modal analysis case are the number of modes to be found, a convergence tolerance, and the frequency range of interest, which should not be limited. For the Ritz vector modes, the additional parameters to be specified are the starting load vectors, which indicate the spatial distribution of the dynamic load vector, and the number of generation cycles performed for each starting load vector [2]. The generation cycle is the static solution or displacement vector obtained by a recurrence relationship where the mass matrix is multiplied by the previously obtained Ritz vector and used as the load vector. The Ritz vectors are orthogonalized using standard eigensolution techniques. SAP2000 conducts a linear modal analysis based on the elastic properties of the elements, defined with effective cross section properties to account for concrete cracking. However, it is also possible to perform a modal analysis to approximate the post-earthquake (damaged) dynamic characteristics of the bridge under P- δ effects.

Free vibration test

A free vibration test is generally performed on an experimental specimen to verify its dynamic properties such as modal damping and natural frequencies. The test is carried out by imposing an initial deformation on the system, within the expected elastic range of response, and then releasing it and allowing it to vibrate without any forced excitation. The decay of motion, as well as the duration of each cycle will allow determining the damping and vibration frequencies of the system. To capture the response of a specific mode, the initial deformed shape must coincide with the corresponding mode shape of the structure. A free vibration test can also be performed on the analytical model of the bridge and used to verify the dynamic properties of the system prior to conducting pushover, response spectrum or time history analysis procedures. However, most of the results of the free vibration test must be known previously in order to properly conduct this analysis type. Therefore, a significant insight into the structural system behaviour will not be gained through such an analysis procedure [5]. The mode shapes of the bridge must be obtained previously through a modal analysis, as well as the yield displacement of the structure (or the column bent in a specific direction), determined according to Section 3.1.3 of SDC 2004. The damping in the system must be estimated as well for the transient analysis procedure. Nevertheless, the free vibration test can be used to verify that dynamic analysis is properly executed in the structural analysis program used for the bridge. In SAP2000, a free vibration test is performed on a complete bridge model through a time history analysis (transient analysis) with zero initial conditions, by specifying a unitary impulse time history function to excite the structure and obtain an initial deformed shape. The duration of the impulse must be shorter than 25% of the first mode period. The duration of the entire time history duration can be equal to 10 times the first mode elastic period of the bridge to capture a sufficient number of vibration cycles and observe the decay of motion. The impulse will allow the structure to vibrate freely after the initial excitation with respect to its original undeformed position.To achieve a displacement of the structure within its elastic range of response, the scale factor for the unit impulse must be iterated upon.P-δ geometric nonlinearities are not considered in the analysis, since second-order effects are not expected to occur under small displacements of the structure.

Equivalent Static Analysis (ESA)

According to Section 5.2 of SDC 2004, Equivalent Static Analysis (ESA) can be used to estimate displacement demands for structures where a more sophisticated dynamic analysis will not provide additional insight into its behaviour. It is considered to be best suited for structures or individual frames with well-balanced spans and uniformly distributed stiffness where the response can be captured by a predominant translational mode of vibration. According to ATC 32, this procedure should be limited to one- and two-span structures without intermediate expansion joints and with small or no skew.The seismic demand is assumed as an equivalent static horizontal force applied to individual frames. The total applied force is determined as the product of the spectral acceleration obtained from the 5% damped Acceleration Response Spectra (ARS) curves and the tributary weight. The total horizontal force is applied at the vertical centre of mass of the superstructure and distributed horizontally in proportion to the mass distribution.

Dynamic analysis—Response spectrum analysis (RSA)

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 behaviour 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 [3].

Analysis of Models

There are 12 models of different parameters are modelled in SAP 2000 has been analyzed for various class of seismic zones and all type of soils for a chosen superstructure of three span of continuous box girder and single column pier substructure. The classification of the models are based class of zones and type of soils as per IRC: 6 (2014).For the selected bridge arrangement, there are 12 models which are listed in Table 1. The other input parameters are taken from IRC:6 (2014) for analysis purpose and the results of the analysis are presented in the following Table 2 and the same is shown in graphical chart to give quick glance about the variation of vital parameters. The comparison is done between different soil conditions of various class of zones and between direction of seismic force acting and perpendicular to bridge also taken into this study.

Hard soil indicates rocky sites with N > 30
Medium soil indicates sandy sites with 10 < N < 30
Soft soil indicates clayey silt sites with N < 10

Base shear in Horizontal and Vertical direction in Various zones

The Fig.7 to 9 shows the clear indication of the variance of the maximum base shear in increasing manner from zone II to IV .The base shear in zone III is 1.6 times more than that of zone II and 1.5 times more than that of zone IV when compared from zone III. Similarly from zone V is 1.5 times more than that of immediate one level below zone IV.

When base shear is compared in longitudinal traffic direction-X with transverse direction-Z, keeping zone and soil in same category then base shear in Z-direction is 1.22 times of X-direction in Hard soil stratum. In medium soil category,the factor of 1.26 times of X-direction. In soft soil category, base shear in Z-direction will be 1.24 times of X-direction.

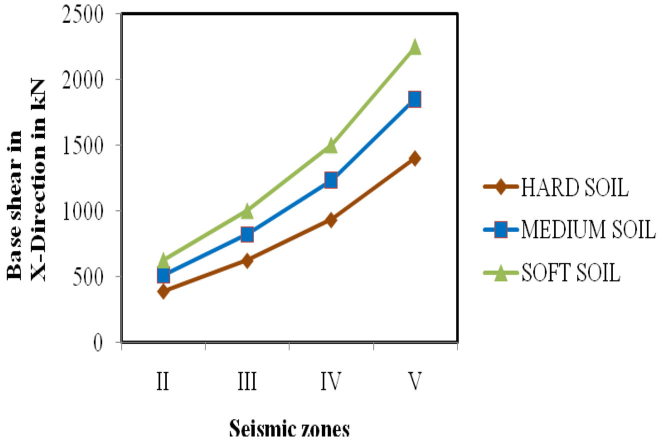


Figure 7. Base shear in X-direction in various seismic zones

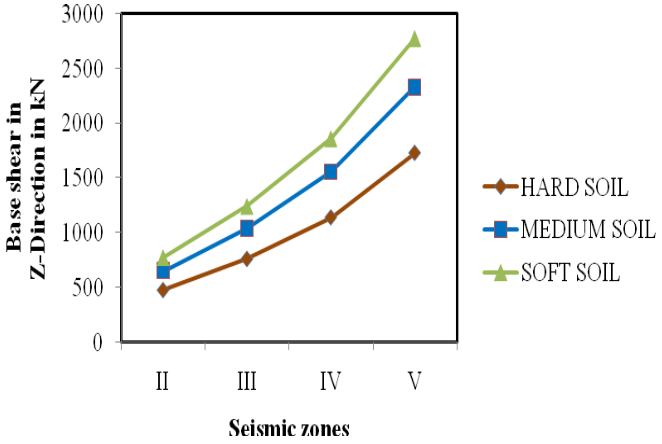


Figure 8. Base shear in Z-direction in various seismic zones

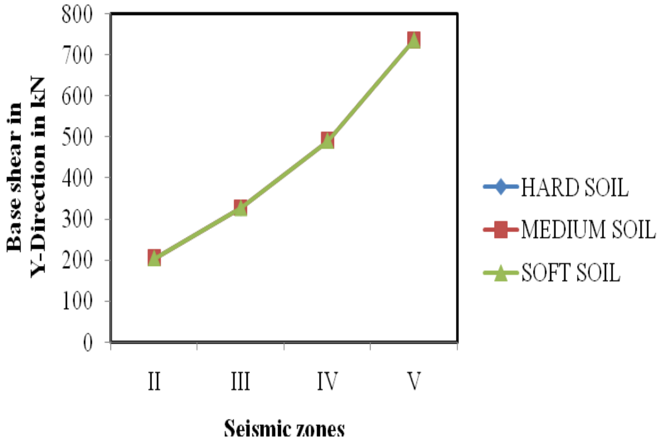


Figure 9. Base shear in Y-direction in various seismic zones

Hard soil indicates rocky sites with N > 30
Medium soil indicates sandy sites with 10 < N < 30
Soft soil indicates clayey silt sites with N < 10

Displacements in Horizontal and Vertical direction in various zones

The Fig.10 to 12 shows the clear indication of the variance of the maximum displacements in increasing manner from zone II to IV .The displacement in zone III is 1.6 times more than that of zone II and 1.5 times more than that of zone IV when compared from zone III. Similarly from zone V is 1.5 times more than that of immediate one level below zone IV.

Table 1. Classification of model used for analysis

S.No.	Zone	Soil Type	Bridge Model and other Parameters
1	Z-II	Hard	Bridge Superstructure of 25m+35m+25m with single column pier substructure and Pile foundation. Importance factor = 1.2 Damping =5% Response reduction factor =4.0
2	Z-III	Hard	
3	Z-IV	Hard	
4	Z-V	Hard	
5	Z-II	Medium	
6	Z-III	Medium	
7	Z-IV	Medium	
8	Z-V	Medium	
9	Z-II	Soft	
10	Z-III	Soft	
11	Z-IV	Soft	
12	Z-V	Soft	

Table 2 .Comparison of Seismic coefficient and Base shear under different seismic zones and soil conditions

Seismic parameters			Seismic coefficient			Base shear kN		
Zone	Soil Type	Sa/g	Ahx	Ahz	Ahy	Vbx	Vbz	Vby
Z-II	HARD	1.333	0.020	0.020	0.009	389	474	205
Z-III			0.032	0.032	0.014	622	758	328
Z-IV			0.048	0.048	0.021	933	1138	491
Z-V			0.072	0.072	0.032	1404	1726	737
Z-II	MEDIUM	1.813	0.027	0.027	0.012	515	649	205
Z-III			0.044	0.044	0.019	824	1038	328
Z-IV			0.065	0.065	0.029	1236	1557	491
Z-V			0.098	0.098	0.044	1855	2335	737
Z-II	SOFT	2.226	0.033	0.033	0.015	625	772	205
Z-III			0.053	0.053	0.024	1000	1240	328
Z-IV			0.080	0.080	0.036	1500	1860	491
Z-V			0.120	0.120	0.053	2250	2778	737

Table 3. Comparison of Displacements under different seismic zones and soil conditions

Zone	Soil Type	X-Trans mm	Z-Trans mm	Y-Trans mm
Z-II	HARD	3.582	2.595	18.935
Z-III		5.729	4.231	19.069
Z-IV		8.591	6.412	19.249
Z-V		12.883	9.685	19.518
Z-II	MEDIUM	4.866	3.576	18.935
Z-III		7.783	5.801	19.07
Z-IV		11.672	8.768	19.25
Z-V		17.505	13.217	19.52
Z-II	SOFT	5.972	4.308	18.935
Z-III		9.553	6.971	19.07
Z-IV		14.327	10.523	19.251
Z-V		21.487	15.85	19.521

When displacement is compared in longitudinal traffic direction-X with transverse direction-Z, keeping zone and soil in same category then displacement in Z-direction is 1.38 times of X-direction in Hard soil stratum. In medium soil category, the factor of 1.32 times of X-direction. In soft soil category, displacement in Z-direction will be 1.36 times of X-direction.

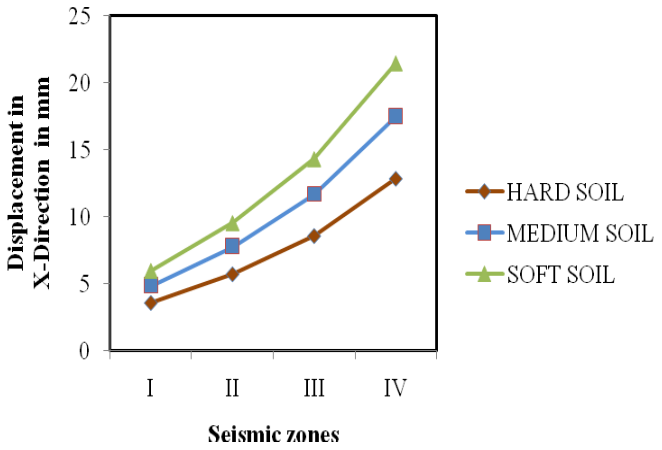


Figure 10. Displacement in X-direction in various seismic zones

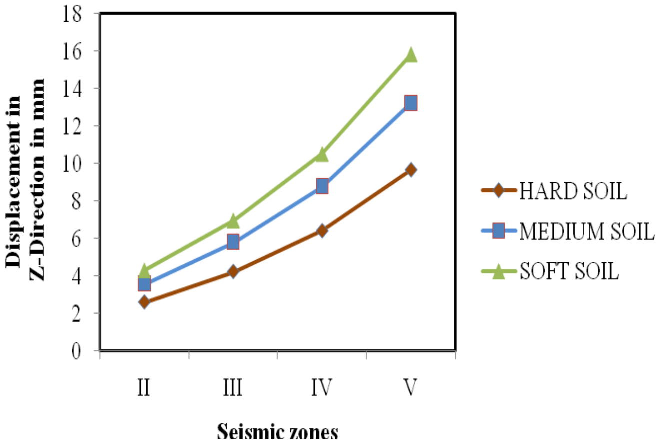


Figure 11. Displacement in Z-direction in various seismic zones

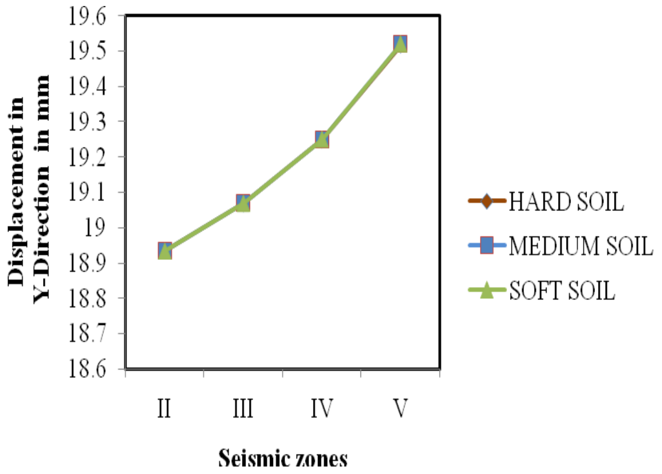


Figure 12. Displacement in Y-direction in various seismic zones

Conclusion

In this work, through an analytical work analysis of dynamic response of bridge superstructure and substructure under the influence of class of seismic zones and of different soil conditions. Finally, the results considered for evaluation are spectral acceleration, base shear, displacements etc. The conclusion arrived at are:

- Of the four seismic zones and three soil types considered, namely, when a bridge structure located in soft soil in zone V is found to be the most critical one. The results indicates that the base shear in zone III is 1.6 times more than that of zone II and 1.5 times more than that of zone IV when compared from zone III. Similarly from zone V is 1.5 times more than that of immediate one level below zone IV. The above variation is same for displacement also.
- When base shear is compared in longitudinal traffic direction-X with transverse direction-Z, keeping zone and soil in same category then base shear in Z-direction is 1.22 times of X-direction in Hard soil stratum. In medium soil category, the factor of 1.26 times of X-direction. In soft soil category, base shear in Z-direction will be 1.24 times of X-direction.
- When displacement is compared in longitudinal traffic direction-X with transverse direction-Z, keeping zone and soil in same category then displacement in Z-direction is 1.38 times of X-direction in Hard soil stratum. In medium soil category, the factor of 1.32 times of X-direction. In soft soil category, displacement in Z-direction will be 1.36 times of X-direction.

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