Seismic Analysis of Bridge Abutment-Soil Systems

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Abstract: This study investigates the effects of the soil-abutment interaction on seismic analysis and design of bridge abutment. Experience and recent research indicates that soil-structure interaction plays a very important role on seismic response of bridge structures. Abutments attract a large portion of seismic forces, particularly in the longitudinal direction. Therefore, participation of backfill soil at the abutments must be considered. A design driven methodology to model the abutment stiffness for either linear or non-linear analysis, considering the backfill and free-standing cantilever bridge abutment. An iterative design procedure of successive linear dynamic response analyses that considers the non-linear behavior of the abutments caused by backfill soil yielding is developed. Also, a non-linear static analysis of the bridge-soil system conducted. Parametric studies demonstrate that, if the bridge is analyzed with the proposed methodology instead of a simple procedure that ignores backfill stiffness reduction, the calculated forces and moments at the abutment are greater by 25%-60% and the displacements by 25%-75%, depending on soil properties.

Keywords: Soil-abutment interaction, Earthquake Engineering, STAAD pro, non-linear static analysis.

I. INTRODUCTION

The present study is aimed at an investigation of longitudinal seismic response of free-standing seat type cantilever bridge abutment supported on spread footing. This type of abutment is generally used in multi-span-simply-supported (MSSS) and single-span-simply supported (SSSS) bridges different components associated with an abutment are bridge superstructure, connection between the superstructure and abutment, backfill soil, wing walls, and the foundation soil. Considering all the components together, investigation of abutment response under earthquake ground shaking is a complex three- dimensional dynamic soil-structure-interaction problem. Therefore, the challenges involved in designing such structures under seismic condition increase manifolds. However, two dimensional simplified pseudo-static approaches can also be used to estimate the earthquake induced forces on abutment.

II. OBJECTIVE OF THE PRESENT STUDY

1. The investigation study, introduces the subject and reviews the performance of bridge abutments in past and identifies the problem through state-of-the-art literature review.

2. Recommendations will make for designing such structure using simplified pseudo-static analysis.

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3. Hence in the present study, an attempt is made to observe the effects of soil-structure interaction on the change displacement and reaction of free-standing cantilever bridge abutments considering different types of retaining wall system and variations of factors such as different earthquake zones (viz., 2, 3, 4, 5) and different support conditions (viz., fixed, fixed but, and foundation). The analysis of a retaining wall model has been modeled and analyzed using STAAD PRO software

4. Study computational model of the bridge abutment-soil (BAS) system this study is discussed in detail. The procedure will perform nonlinear dynamic analysis present. Study difficulties while simulating the seismic response are noted. The free vibration characteristics of the computational model i.e. natural periods and mode shapes will discuss.

5. Study Seismic response of BAS system through the nonlinear dynamic analysis.

6. Considering these parameters, a comparison will make between pseudo-static analysis and nonlinear dynamic analysis. Thus, some recommendations are made for designing such structure using simplified pseudo-static analysis.

III. PROBLEM STATEMENT

In this study, longitudinal seismic response of free-standing cantilever bridge abutments supported on spread footing were investigated considering soil-structure-interaction though finite element (FE) simulation design such structures through simplified pseudo-static analysis. Realistic seat type cantilever bridge abutments supported on spread footing were considered.

Furthermore, the behavior of the abutment was studied without the superstructure which simulates the field conditions before the construction of the superstructure. Backfill and foundation soil was incorporated in the FE simulation model to account for the abutment-soil interaction. Nonlinear hysteretic behavior of soil was simulated using a pressure dependent nested yield surface plasticity model. Sliding and de-bonding at the soil-structure interfaces were simulated in coupled manner using contact elements. Nonlinear dynamic analysis will carry using two recorded accelerograms in STAAD Pro. V8i. Variation of different response parameters will study with varying PGA. Dynamic analysis will carry the results indicate that the superstructure inertia and nonlinear inelastic behavior of soil have significant influence on the seismic response of such abutments. Pseudo-static analysis using M-O theory is carried out with varying seismic coefficients for the same abutments, and the results obtained are compared with the dynamic analysis.

IV. PSEUDO-STATIC ANALYSIS

Pseudo-static analysis is the simplest form of seismic analysis. In this analysis, the dynamics of complex earthquake shaking is neglected and the effects of horizontal and vertical inertia forces are considered by two constant pseudo-static acceleration coefficients generally known as seismic coefficients, one in horizontal (i.e. k_h) and the other in vertical direction (i.e. k_v), respectively. A major difficulty of this method has been the proper selection of seismic coefficient. In this investigation, an attempt was made to establish a rational basis of selecting appropriate seismic coefficient for pseudo-static analysis.

M-O method, discussed with analysis of abutment and design was used to estimate seismic earth pressures. Vertical shaking was neglected in dynamic analysis and hence, only k_h was considered

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for pseudo-static analysis. In the case of a vertical smooth wall, retaining dry cohesion less backfill of friction angle =30°, M-O method can only be used up to a maximum kh of 0.577 g when kv =0 (see Appendix-A). This maximum value of kh is generally referred to as limiting acceleration. The pseudo-static analysis was carried out by varying kh from 0 to a maximum of 0.57 g at an increment of 0.0001g. For each value of kh, seismic earth pressure was obtained using M-O method and the inertia forces in each component of the abutment and structural wedge were calculated by multiplying kh with the weight of that component. Total active thrust and its line of action along the height were calculated using the simplified recommendations made by Seed and Whitman (1970) as discussed.

V. MATHEMATICAL MODELING AND DNYAMIC ANALYSIS

Simple harmonic motion (SHM) of single degree of freedom (SDOF) of the modified prototype bridge abutment was also modeled using FEM package software (STAAD pro). The modeling construction was done as 3-dimensional plate's structure (framing structure) with meshing of element 0.58m for accuracy. For various abutment configurations and soil conditions, a general form of abutment wall-backfill stiffness equation that considers passive resistance of soil, as recommended by Wilson [Wilson 1988] can be used to estimate the longitudinal stiffness of the end-wall and the transverse stiffness of the wing-wall.

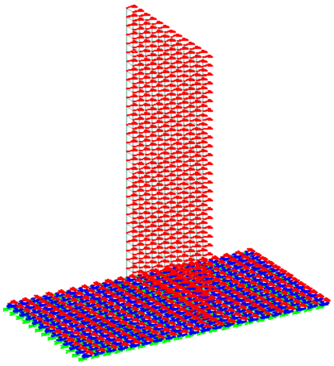

Figure 1. Modeling of Abutment

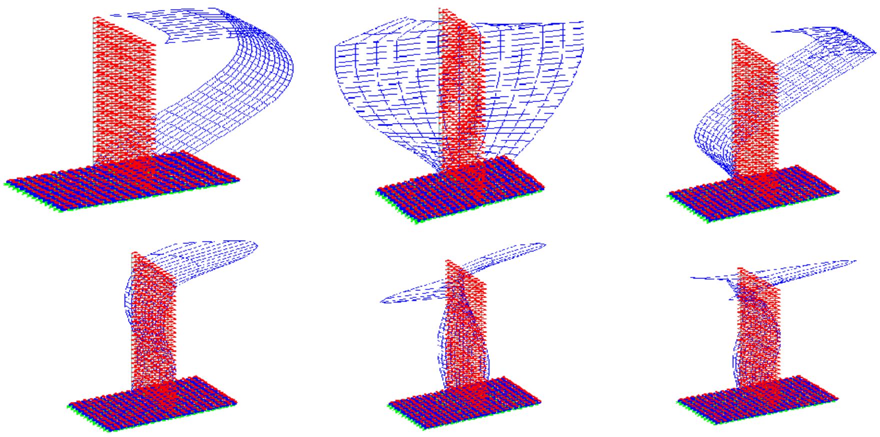

Figure 2. Different Mode Shapes

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VI. RESULTS AND DISCUSSION

6.1 Comparison of Absolute Moments between Pseudo Static Analysis and Dynamic Analysis for Free Standing Cantilever Bridge Abutment Considering Back Fill Soil Stiffness

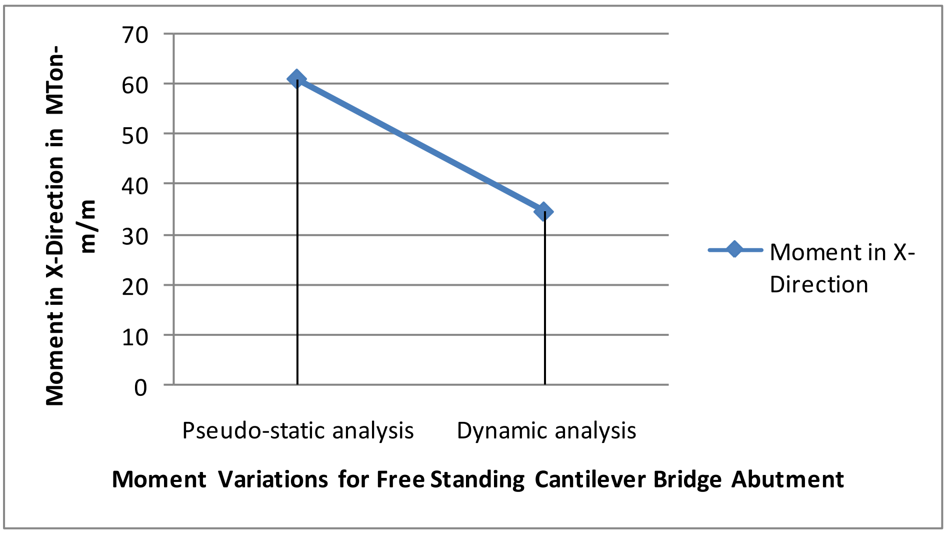

Figure 3. Moment Variations for Free Standing Cantilever Bridge Abutment

6.2 Comparison of Joint Displacements between Pseudo Static Analysis and Dynamic Analysis for Free Standing Cantilever Bridge Abutment Considering Back Fill Soil Stiffness

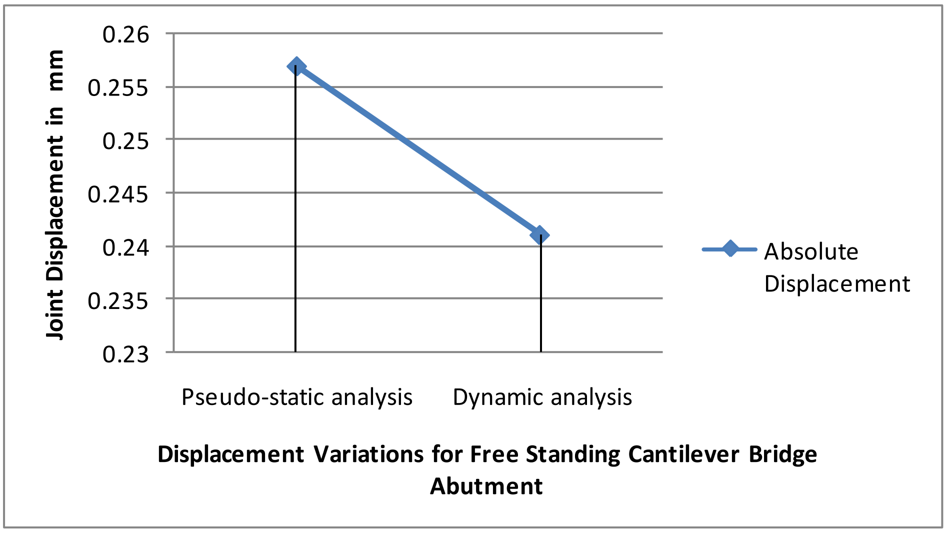

Figure 4. Displacement Variations for Free Standing Cantilever Bridge Abutment

VII. CONCLUSIONS

The salient conclusions drawn from this study could be divided into two categories (i) conclusions based on dynamic analysis, and (ii) conclusions based on the comparison of dynamic and pseudo-static analyses.

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a) Based on Dynamic Analysis

The following conclusions were drawn based on the nonlinear dynamic soil-structure-interaction analysis of bridge abutments.

1. The computational model developed in this investigation can provide a detailed insight into the dynamic behavior of seat type cantilever bridge abutments and retaining walls considering soil structure interaction effects.

2. The response of the abutment was found to be influenced significantly by the nonlinear inelastic response of the backfill and foundation soil.

3. Amplification of peak acceleration was found to reduce with increasing intensity of shaking i.e. with increasing nonlinearity in soils.

4. Superstructure inertia force has significant influence on the longitudinal response of the bridge abutments and should not be neglected.

5. Shorter height abutment was more susceptible to uplifting and sliding compared to longer height of abutment.

6. The mode of displacement of the abutment depends on the structure and the ground motion considered for the analysis.

b) Based on Comparison of Dynamic and Pseudo-Static Analysis

The following conclusions were drawn based on the comparison of sophisticated nonlinear dynamic soil-structure interaction analysis and simple approximate pseudo-static analysis.

1. Shear force at the base of the stem wall is slightly underestimated in pseudo-static analysis at low level of ground shaking.

2. Displacement of Pseudo-Static Analysis is more Dynamic Analysis for Free Standing Cantilever Bridge Abutment.

3. Moment of Pseudo-Static Analysis is more Dynamic Analysis for Free Standing Cantilever Bridge Abutment.

4. At high level of shaking pseudo-static analysis highly overestimates the forces (Displacement and bending moment) at the stem wall.

5. Wong’s simplified expression may be useful in estimating the displacement at the abutment seat due to combined sliding and rotation and for which the connection is to be designed

6. Height of abutment does not influence significantly the afore mentioned conclusions.

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Conflict of interest: The authors declare that they have no conflict of interest**.**

Ethical statement: The authors declare that they have followed ethical responsibilities.

REFERENCES

[1] Kolay.C, Amit Prashant, and Jain. S.K (2009). "Nonlinear Dynamic Analysis and Seismic Coefficient for Abutments and Retaining Walls", Earthquake Spectra, May 2013, Vol. 29, No. 2, pp. 427-451.

[2] Doshi. T.D, Urmani. U.S (2015) "Seismic Analysis of Cantilever Retaining Wall, Including Soil-Structure Interaction'', IUP Journal of Structural Engineering, Vol. VIII, No. 1, 2015.

[3] Karantzikis. M.J, Spyrakos. C.C (2009), "Seismic Analysis of Bridge, Including Soil-Abutment Interaction", 12WCEE, 2000.

[4] Frosch. R.J, Kreger. M.A, Talbott. A.M, (200). **"**Earthquake resistance of integral abutment bridges" INDOT Research, FHWA/IN/JTRP-2008/11

[5] Thakkar. S.K, Maheshwari. R, (1995) **"**Study of Seismic Base Isolation of Bridge Considering Soil Structure Interaction" Missouri S &T, Apri12-7, 1995, Volume I, St. Louis, Missouri.

[6] Garia.S, Neethu.B, Das.D**,** (2016**)** **"**Dynamic soil structure interaction effects on the seismic response of isolated bridges"

[7] Fukushima.H, (2009), "coefficient of dynamic horizontal Sub-grade reaction of pile Foundations on Problematic Ground In Hokkaido", Senior Research Engineer, Geotechnical Research Team, Civil Engineering Research.

[8] Hamid.N.H.A, Jaafar.M.S, Othman.N.S.U, (2016), "Analysis of Multi-Column Pier of Bridge Using STAAD.Pro Under Static and Dynamic Loading", Research Gate, DOI: 10.1007/978-981-10-0155-0_17

[9] Patel.N.M, Raval.D.H, (2015), "Analysis and Economic Implications of Tall Pier Bridges under Seismic Condition" International Journal for Scientific Research & Development, Vol. 3, Issue 03, 2015 | ISSN (online): 2321-0613

[10] IS: 1893 (Part-1)-2002, "Indian Standard Criteria for Earthquake Resistant Design of Structures," Bureau of Indian Standards, India.

[11] P. Agrawal, and M. Shrikhande, "Earthquake Resistant Design of Structures", Prentice-Hall of India Learning Private limited, India, 2012.

[12] Johnson Victor - Essentials of Bridge Engineering Fifth Edition, Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi

[13] V.K. Raina Concrete Bridge Practice Analysis, design and Economics, Tata McGraw Hill

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