Seismic Safety Evaluation of Bridges: A Review

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***Abstract*: This study considers uncertainties in material strengths and the modeling which have important effects on structural resistance force based on reliability theory. After analyzing the destruction mechanism of a RC bridge, structural functions and the reliability were given, then the safety level of the piers of a reinforced concrete continuous against earthquake was analyzed. Using response surface method to calculate the failure probabilities of bridge piers under high-level earthquake, their seismic reliability for different damage states within the design reference period were calculated applying two-stage design, which describes seismic safety level of the built bridges to some extent. Capacity design procedure for the earthquake-resistant reinforced concrete (RC) structures is effective when actual member capacities do not greatly exceed the assumed design capacities. Moreover, RC members are expected to undergo large inelastic deformations for adequate seismic energy dissipation. Since flexural capacity and post-yield behavior of an RC member is largely controlled by steel reinforcing bars, it places certain special requirements on their properties, such as, yield strength (YS), ultimate tensile strength to yield strength ratio (UTS/YS ratio) and elongation, which are sensitive to the method of manufacturing bars. Flexural tests on RC beams which used rebars of carefully controlled properties was conducted and it was observed that for dependable flexure behaviour, YS and UTS values should lie in a narrow band around values used in the member design. If these values are greater than the specified value, it may cause brittle shear failure instead of more ductile and desirable flexure mode of failure. Moreover, a high UTS/YS ratio equal to 1.25 is necessary to have dependable peak strength which is larger than the yield strength. This study investigates the effects of soil abutment interaction on seismic analysis abutment attract a large portion of seismic forces. A design drive methodology to model the abutment stiffness for either linear or non-linear analysis considering the backfill and pier foundation.**

***Keywords*: Reliability theory, response surface method, Earthquake-resistant, soil-abutment interaction, Reinforcing steel bars, tensile strength/yield strength ratio, Elongation.**

I. INTRODUCTION

The seismic safety level of engineering system determines that level of a city. With the rapid development of economy and urbanization, the contradictions between the requirement of safety and threats from severe seismic hazards have been confronted by the most cities in our country, which force us to give a clear and objective judgment on the seismic safety level of city engineering system in our country. In addition, as an integral part of lifeline engineering system, the safety level of urban bridges under earthquake cannot be underestimated. If the bridges are damaged seriously in an earthquake, it will lead to traffic disruption and more difficult earthquake relief work. What`s more, the seismic safety level of those bridges, which merely met the minimum requirement of seismic design code or which were designed according to the codes in different periods or which were designed based on performance based seismic design, is waiting for us to evaluate. Therefore, it is necessary to analyze and assess the bridge safety after the occurrence of an earthquake.

Earthquake-resistant design of reinforced concrete (RC) structures is based on maximizing energy absorbing capacity of various members without causing collapse. In order to ensure such an outcome, the capacity design procedures are used, which is effective when actual member capacities do not greatly exceed the design capacities and the pre-determined hierarchy of member strength is maintained (Paulay and Priestley, 1992). In addition, RC members are likely to experience large inelastic deformations and, therefore, adequate ductility is essential to avoid brittle failure mode and to enhance energy dissipation potential. Since strength and ductility related capacities in RC flexural members are largely controlled by steel reinforcing bars, it places certain special requirements on their properties, especially those controlling the inelastic portion of the stress-strain curve which largely depends on the method of manufacturing. Two most common types of manufacturing process for reinforcing bars of higher strength using mild steel involve either cold-working or a heat treatment process. The process of *cold working* involves stretching and twisting of mild steel beyond yield plateau to obtain cold twisted deformed (CTD) bars of increased strength (*proof strength*), though it reduces the available ductility in the material. The other method uses a thermo-mechanical treatment (TMT) process in which red hot rebars are quenched through a series of water jets causing a hardened outer layer (martensite structure) surrounding softer core (ferrite-pearlite structure). The resulting rebars has higher yield strength than parent mild steel and is characterized with definite yield point, superior ductility, weldability and bendability.

This study is concerned with the effect of reinforcing steel characteristics and their manufacturing process on the flexural behavior of beams upto failure, with an objective of identifying requirements of reinforcing bars for earthquake resistant construction. RC beams were tested with (a) five types of reinforcement differing in their yield strength (YS), ultimate tensile strength to yield strength ratio (UTS/YS ratio), elongation, manufacturing process (CTD vs. TMT) and degree of quality control (well controlled vs. poorly controlled).

This study investigates the effects of the soil-abutment interaction on seismic analysis and design of integral bridges. Past 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 the pier foundation, is presented. An iterative design procedure of successive linear dynamic response analyses that takes into account the non linear behaviour of the abutments caused by backfill soil. yielding is developed. Also, a non-linear static analysis of the bridge-soil system is conducted.

Foundation behaviour plays a major role on the performance of highway bridges during earthquakes. For many highway bridges, abutments attract a large portion of the seismic force, particularly in the longitudinal direction. On many bridges, abutment damage was the only damage reported indicating that abutments attracted a large portion of the seismic force. Soil-abutment interaction under seismic loads is a highly non-linear phenomenon. This non-linearity plays important role in the overall structural response [Spyrakos 1990, Spyrakos 1992, Maragakis 1989]. As a result there is a definite need to develop a proper methodology to design bridges including the effects of soil-abutment interaction. Some guidance is currently provided by Caltrans Bridge Design Aids and the AASHTO [Caltrans 1989, FHWA 1986]. Both documents recognise the highly non-linear behaviour that could be caused by large deformations in the backfill at the abutments during seismic excitations. This paper presents seismic design oriented procedures of modelling and analysing highway bridges including soil-structure interaction. Emphasis is placed on modelling of abutment system, and the development of two analysis procedures that account for the non-linear behaviour of abutments. The first is an iterative design procedure utilising successive linear analyses. The second is a non-linear static analysis using non-linear springs to account for backfill soil stiffness.

II. LITERATURE REVIEW

1. AHMED MOHD. ATTA

The beam column joint is one of the important structural joint elements of reinforced concrete structures. It has been the subject of intensive research for the past four decades. Most of the designs procedures have been devoted to ordinary strength concrete as implemented in the design codes.

2. PONNUSWAMY

Bridge engineering has been thoroughly revised to reflect the changes in technology that have occurred in the past. The coverage is not dealt with isolation, but discussed in relation to basic approaches to design of bridges, supported by numerous case studies.

3. MURAT DICLELI, JUNG-YOON LEE

The effect of soil-structure interaction on the seismic performance of seismic bridges is studied. The analyses results have that soil-structure interaction effects may be neglected in the seismic analysis of bridges with heavy superstructure and light substructure constructed on stiff soil. However, the soil-structure interaction effects need to be considered for bridges with light superstructure and heavy substructure regardless of the stiffness of the foundation soil.

4. CHINMOY KOLAY

Conventional seismic design for bridge abutment uses pseudo-static analysis methods based on the approach. However, these methods, originally developed for gravity type retaining walls, do not provide any rational basis for selecting appropriate seismic co-efficient of bridge abutments. Further, it is observed that the displacement at the abutment seat due to combined rigid body sliding and rotation of the abutment depends upon the yield acceleration.

5. JUN ZHAO, JUNQI LIN, JINLONG LIU, JIA LI

This study considers uncertainties in material strengths and the modeling which have important effects on structural resistance force based on reliability theory. After analyzing the destruction mechanism of a RC bridge, structural functions and the reliability were given, then the safety level of the piers of a reinforced concrete continuous against earthquake was analyzed. Using response surface method to calculate the failure probabilities of bridge piers under high-level earthquake, their seismic reliability for different damage states within the design reference period were calculated applying two-stage design, which describes seismic safety level of the built bridges to some extent.

6. A.M. Avossa, P. Famigliuolo & P. Malangone

The paper presents the analytical and experimental modal analysis of an existing reinforced concrete arch bridge, built in the fifties across the Volturno river on ‘‘Domitiana’’ state road. First the modal properties of different 3D finite element models of the bridge were determined with/without reference to some structural strengthening carried out in the seventies. Then ambient vibration tests under traffic excitation are designed and developed in order to identify the bridge modal properties and calibrate its theoretical model. Finally starting from results obtained by that model, the structural response under different load conditions (traffic and seismic loads) was carried out in order to evaluate the real bridge behaviour and the structural safety assessment according to current seismic code provisions.

7. Tarek Omar and Moncef L. Nehdi

The present study provides a critical overview of the state-of-the-art existing condition assessment techniques for reinforced concrete bridges, with an emphasis on current practice in North America. The techniques were classified into five categories, including visual inspection, load testing, non-destructive evaluation, structural health monitoring, and finite element modelling. It is shown that there is need for concerted research efforts to achieve automated data collection and interpretation analyses. Also, the configuration of monitoring systems was found to be paramount in effectively assessing bridge performance parameters of interest. The study suggests appropriate investigation methods for some bridge deterioration mechanisms. Knowledge gaps and challenges in this field are outlined in order to motivate further research and development of these technologies.

III. CONCLUSION

Based on the experiment observation and data present in above sections, following broad conclusions can be drawn.

1. A strict control on YS value of rebars is essential as it determines the strength of member in variosr behavioral modes. If the YS value is greater than the specified value, it may cause premature failure of beam in an undesirable failure mode, such as brittle shear failure instead of more ductile and desirable flexure mode. If YS is lower than the specified value, as observed in the case of non standard TMT bars, the yield strength will be lower than the expected design value and thus reducing the margin of safety and increasing risk of premature failure.

2. A high UTS/YS ratio is necessary to have dependable peak strength greater than the yield value. Beams with standard TMT bars of UTS/YS ratio of 1.25 were better than those with UTS/YS ratio equal to 1.15. However, the rebars with higher UTS/YS ratio had a higher yield strength causing the yield moments to be greater than expected values

3. The results of this study also demonstrate the inadequacy of the IS 1786 (BIS, 2008) specifications as it has no provisions to control higher values of YS, minimum UTS/YS ratio, an upper limit of UTS to limit overstrength and higher uniform elongation to prevent premature fracture.

4. Parametric studies demonstrate that if the bridges is analysed with the propsed methodology instead of a simple procedure that ignores backfill stiffness reduction, the calculated forces and moments at the piers are greater by 25-60% and the displacements by 25-75% depending on the soil properties.

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