International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 7, July-2018

Non-Linear Analysis of Slender Bridge Pier and Design of Its Foundation

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***Abstract**—Current trends in bridge design/construction indicates increasing use of slender reinforced concrete compression members as bridge piers. This is primarily due to growing utilization of higher compressive strength concrete and higher yield point reinforcing steel along with a shift to more material efficient factored load design procedures. In this present project, an existing bridge pier is analysed for second order moments using three different methods of analysis viz. Moment Magnification method enlisted in Euro Code 2-1992, Nominal curvature method enlisted in IRC 112:2011, 2nd order analysis method by Dr. V. K. Raina. The analysis is performed manually using Microsoft Excel. From the results obtained suitable design of pile foundation is done.*

***Keywords**— Non-Linear analysis, slender piers, bridge piers, 2nd order effect, 2nd order analysis, bridge foundation, pile foundation, rehabilitation, second order effects.*

I. INTRODUCTION

The practical design of slender compression members, or whole structures, with regard to second order effects is normally made with simplified methods, like for most types of design problems. In some cases, the design can be based directly on a reliable physical model, like for bending moment in cross sections with or without normal force. Another example of a physical model, although less obvious and less reliable than that for bending, is the truss model for shear in members with shear reinforcement, where different degrees of complication and realism can be included. For other problems, however, reliable physical models are lacking, like for instance shear in members without shear reinforcement, punching, anchorage of reinforcement etc. In such cases, empirical models calibrated against test results are used.

For slender compression members with second order effects, there are reliable methods, based on physical models and nonlinear analysis. However, such methods are not (at least not yet) much used in practical design, due to their degree of complication; simplified methods that can be used for “hand calculations” are still dominating. However, it is not practicable to develop such methods empirically on the basis of tests, like for shear. The number of variables involved, their range of variation and their influence are such that they cannot be covered within test series of realistic proportions. Although a large number of test results can be found out, but they are still not sufficient as a basis for purely empirical models.

II. AIM AND OBJECTIVE

The main aim of the paper is to analyse a slender bridge pier using various methods for second order effects, choosing the correct values from the various analysis reports and designing (rehabilitating) its foundation.

Objectives –

- To explain various methodologies and procedures to perform 2nd order analysis.
- To discuss the gained results.
- To discuss the structure built previously.
- To discuss the failure of existing structure.
- To explain the procedure of rehabilitation of foundation.

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III. METHODOLOGY

The methods for taking second order effects in slender columns are mentioned below:

1) Method based on magnification of first-order moments (MMM), reference EC2.
2) Method based on maximum predicted Nominal curvature Method (NCM), reference EC2.
3) Analysis of slender column by second order theory, reference from book "Raina's Concrete Bridge Practice" by V.K. Raina.

A. Moment Magnification Method:-

As per EN 1992-2 Cl 5.8.7, this method is based on the elastic theory that the total moments in a pin-ended strut including second order effect can be derived by multiplying first order moments by magnifier that depends on axial force and Euler buckling load of the Pier.

B. Nominal Curvature Method:-

As per EN 1992-2 Cl 5.8.8, this method is based on maximum possible curvature at failure. This method takes into consideration of creep effect, material property and axial load.

C. Second order theory by V. K. Raina:-

This method does the actual buckling analysis based on second order theory and forms the differential equations and get the unknowns using initial conditions. This method assumes the sinusoidal variation of deflected shape.

IV. APPLICABILITY

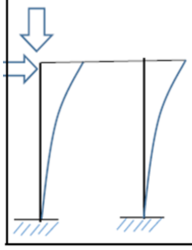
Cases	MMM	NCM	V.K.Raina	Remark
1 A) Isolated member (Cantilever Pier) 	✗	✓	✗	a.)MMM is not applicable as base moment is zero and therefore increse in moment is also Zero. b.)V.K.Raina does not provide solution for cantilever case as the deflected shape is not Sinusoidal curve and does not fit solution for computation of additional moments.
1 B) 	✓	✓	✗	c.)V.K.Raina does not provide solution for cantilever case as the deflected shape is not Sinusoidal curve and does not fit solution for computation of additional moments.
2) Unbraced Frame (Sway Frame) 	✓	✗	✓	d.)As per cl.5.8.8.1 of EN 1992-2 ,NCM is primarily intended for the use with members that is isolated from the rest of bridge i.e this method not applicalble for frames to calculate second order moment.

Fig. 1Applicability of 2nd order analysis

Conclusions

A. Non-Linear Analysis:-

Based on the requirement of performing non-linear analysis, three methods have been adopted. The conclusion drawn from these methods are as follows:-

- Moment magnification method considers the effect of creep and shrinkage in calculation of 2nd order moments.
- Since we have to consider our structure as portal frame, Nominal curvature method does not give any guidelines regarding non-linear analysis of framed structure.
- From practicality point of view, the additional moments obtained from analysis according to Dr. V. K. Raina's method are very less and hence designer should not rely on such unconfirmed values. So this method is not considered for design purpose.

B. DESIGN OF FOUNDATION:-

Design of pile cap is done using method of sections. This is a conventional method for designing of pile cap. Strut and tie method is also an method of analysis and design which could be used, but due to complex geometry and arrangement of piles this method was not adopted.

Piles are designed as both combined end bearing and friction piles.

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