





Application of response surface method (RSM) on sensitivity analysis of reinforced concrete bridge pier wall

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ABSTRACT

In this paper, the nonlinear behaviour of a reinforced concrete (RC) bridge pier wall was evaluated by nonlinear finite element analyses (NLFEA) method. The NLFEA results were compared to the simulated seismic test results conducted on full-scale RC columns. Sensitivity of some of the design variables and their effects on the seismic behaviour of RC bridge pier wall has been investigated using response surface method (RSM). RSM prediction is based on results of finite element analysis. The variables include longitudinal rebar diameter (d), concrete compressive strength (f_c) and yield strength of rebars (f_y).

Key words: Concrete column, Finite element, Modelling, Sensitivity analysis, Bridge pier wall, RSM.

1. INTRODUCTION

Pier walls behaviour is important in evaluating the overall bridge performance under seismic load. Nonlinear finite element analysis (NLFEA) method provides an important option for studying the response and residual life of reinforced concrete (RC) pier walls. In the past years, significant efforts have been devoted in this field [1, 2]. Nonlinear behaviour of RC structures might be influenced by changing in material properties and geometry of the structure [3]. In this paper, effect of different parameters on nonlinear behaviour of RC bridge pier wall is quantified. The focus is on the influence on the shear capacity. The effect of three parameters is investigated using the response surface method (RSM) and non-linear finite element analysis. The parameters considered are longitudinal rebar diameter (d), concrete compressive strength (f_c) and yield strength of rebars (f_y).

2. FINITE ELEMENT MODELLING

Full 3D NLFEA were carried out using the finite element software ABAQUS. The pier wall for numerical simulations was selected from experimental tests by Bae et al. [4]. In this test, axial load was applied to a full scale RC concrete column when the column was subjected to gradually increasing lateral displacement cycles, simultaneously, see Figure 1.

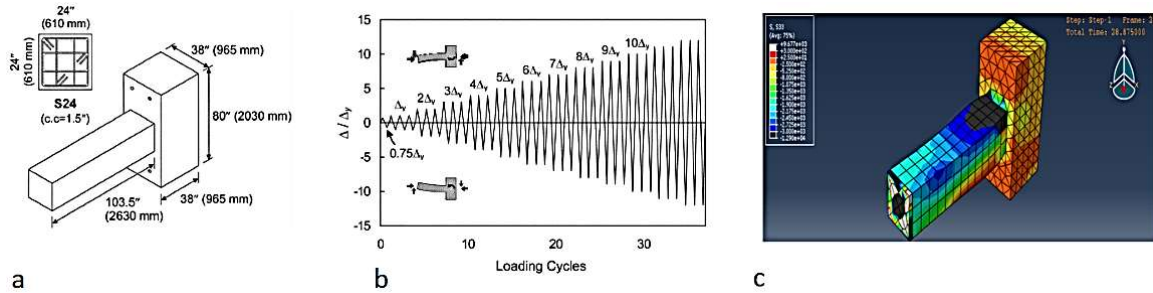


Figure 1 – a) Geometry of test specimen, b) applied lateral load [4] and c) simulated FE column.

For the concrete behaviour a smeared rotating crack model with tension softening and a modified Hognestad's model in compression were used [5]. For the constitutive behaviour of the rebars a standard elastic-plastic model was used. Introduced concrete and rebar properties can be found on the selected experimental column [4].

2.1 Comparison FE analysis results with experimental data

The NLFEA and experimental results were compared to examine the validity FE model. The test was conducted under cyclic lateral displacement loading. Figure 2 shows that load-displacement hysteresis curve of NLFEA are in an acceptable agreement with experimental lateral load-displacement (hysteresis) curve.

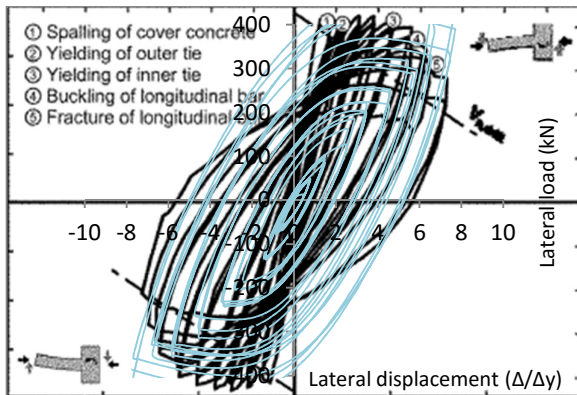


Figure 2 – Lateral load response of test specimens (black line) versus NLEFA (blue line), where horizontal axis is lateral displacement and vertical axis is load.

3 RESPONSE SURFACE METHOD (RSM)

The Response Surface Method (RSM) is a collection of statistical and mathematical techniques useful in reliability analysis. In this paper RSM is used to approximate and interpret the relationship between the maximum base shear of the simulated pier wall, termed as *response* and the rebar diameter (d), concrete compressive strength (f_c) and yield strength of rebars (f_y), termed as *variables*. The approximation of this relationship is termed “response surface”.

3.1 Design of response surface

In this study the performance function is approximated with a second-order polynomial function, which for k random variables is expressed as:

$$Y = \beta_0 + \sum_{i=1}^k \beta_i X_i + \sum_{i=1}^k \beta_{ii} X_i^2 + \sum_{i < j}^k \beta_{ij} X_i X_j \quad (1)$$

where, Y is the predicted response, X_i is the coded level of a design variable i , k is the total number of variables present in the problem, coefficient β_0 is a constant and β_i , β_{ii} and β_{ij} are the regression coefficients for the linear, quadratic and interaction effects, respectively.

3.2 Variables and levels

In order to study the combined effects of these variables, FE analyses and RSM method were conducted with different combinations of variables. Table 1 lists the variables, and the design of the considered levels. According to central composite design (CCD), with three control factors, a total of 15 numerical experiments was performed.

Table 1 – Uncoded values of independent variables used for the experimental design.

No.	Variable	Unit	Notation	Levels				
				Axial ($-\alpha$)	Factorial			Axial ($+\alpha$)
					Low (-1)	Centre (0)	High (1)	
1	Rebar diameter	mm	d	20	24	28	32	36
2	Concrete compressive strength	MPa	f_c	25	30	35	40	45
3	Tensile rebar yield strength	MPa	f_y	400	450	500	550	600

4 MAXIMUM BASE SHEAR AFTER RSM RESULTS

Obtained RSM regression formula using coded variables is presented in Equation 2. For all 15 numerical experiments, the predicted results of the maximum base shear using Equation 2 (RSM) agree with the FE analyses results with reasonable accuracy.

Max base shear (kN) =

$$172.8 + 20.28 f_c - 0.121 f_y - 19.77 d - 0.2008 f_c^2 - 0.000314 f_y^2 + 0.3963 d^2 - 0.00385 f_c \times f_y + 0.0450 f_c \times d + 0.03980 f_y \times d \quad (2)$$

Each response surface function is really a three-dimensional predictive model. However, for illustration purposes, the plot is presented in a two-dimension, see Figure 3. Figure 3a illustrates the interaction effect of f_y and f_c on shear strength when rebar diameter is a hold value. The variable parameters in Figure 3b are d and f_c and in Figure 3c are d and f_y . The values for the rebar diameter, rebar yield strength and concrete compressive strength are fixed at their respective central point values (see centre point in Table 2).

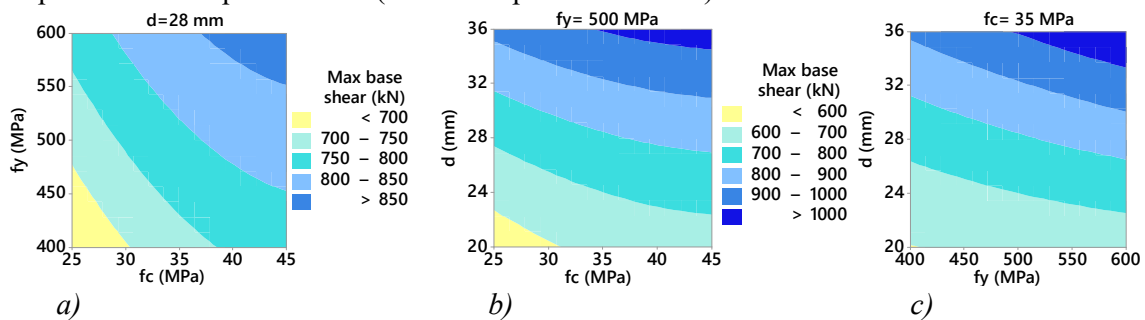


Figure 3 – Contour plot of the maximum base shear versus a) f_y and f_c , b) d and f_c , and c) d and f_y . The hold values are $d=28$ mm, $f_y=500$ (MPa) and $f_c=35$ (MPa).

According to the RSM results, increasing the f_y and f_c with fix rebar diameter leads to increase in shear strength of pier wall. By increasing f_y from 400 to 600 MPa and f_c from 25 to 35 MPa, with the rebar diameter of 20 mm, the shear strength increases up to 30%. This percentage becomes greater by increasing the rebar size. Interaction effect of rebar diameter and concrete compressive strength has significant effect on the shear strength. However, it was shown that the percentage of increasing shear strength has not been influenced by changing of f_y .

Increasing both rebar diameter and rebar tensile strength leads to increase of the shear strength. According to RSM Regression model, this increase percentage will be intensified by increasing the fixed value of f_c from 25 to 35 MPa. After 35 MPa, changing f_c does not effect on the shear strength. This results is in good agreement with FE analysis where it was shown that maximum base shear of pier wall is almost identical for values of f_c from 35 to 45 MPa, see Figure 4.

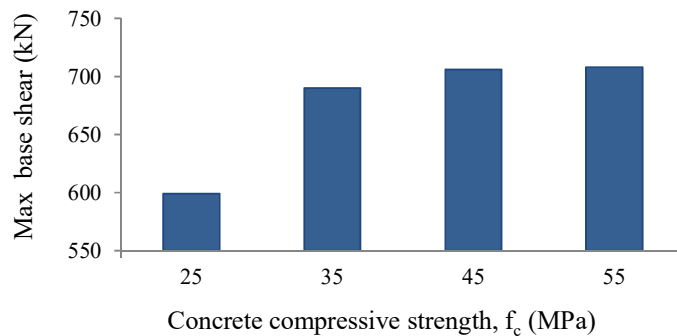


Figure 4 – Maximum base shear versus different concrete compressive strength, f_c (MPa).

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