Assessment of Normal Strength Concrete and High Strength Concrete on Prefabricated Cage Systems in Near-Field Earthquakes

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SUMMARY:
Prefabricated Cage System is a new method which works as both the longitudinal and transverse reinforcement. This method can be used for retrofitting the existing structural members with insufficient reinforcement and it has corrosion and fire resistances better than or similar to those of RC members. PCS permits high degree of quality control through perfectly uniform transverse steel spacing which matches specified design values. In this study a column with PCS reinforcement is developed in ABAQUS finite element software. The comparison of the numerical results with the published experimental results shows a qualitative good agreement. After validating the model, column is subjected to numerous near field earthquakes and compressive strength of concrete is changed in order to achieve maximum displacement of column in both normal strength and high strength concretes. Results indicate that increasing the strength of concrete leads to increase in maximum displacement of column on its top.

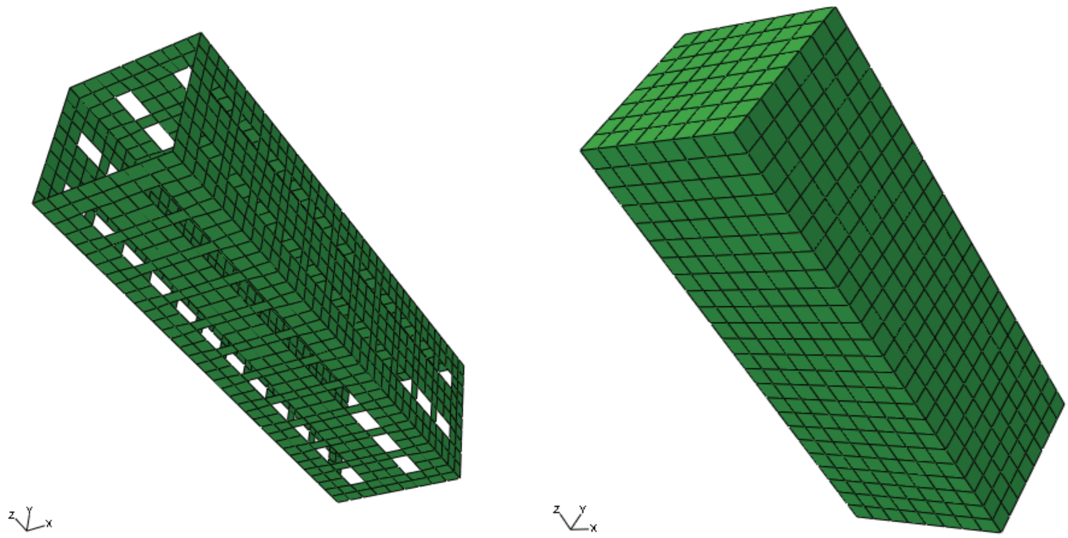
Keywords: Prefabricated Cage System, High Strength Concrete, Near-field earthquake

1. INTRODUCTION

Reinforced concrete has been used for many years. This system combined from concrete and a reinforcement system which is usually steel. Concrete is strong in compression and steel has high tension capacity. Steel can be used in areas with high tensile stress in order to compensate the low tensile strength of concrete. Steel can be used in forms of rebar, tubular and composite sections. Usually rebar is used for both longitudinal and transverse reinforcement. Prefabricate Cage System is a new steel reinforcement system which can be used to reinforce concrete members. In this system traditional rebar system is replaced by a prefabricated steel cage with openings. Openings can be developed by cutting as well as using laser. Cutting by laser is cheap and precise. In this method, many of detailing problems can be eliminated. It is easy to assemble in the construction site and there is no need to tie. This method is significantly economic as it reduces the construction time and labor which leads to cost reduction. PCS has better corrosion and fire resistant than steel members. In current research the effect of increasing concrete strength on PCS column base shear and maximum displacement is investigated, the PCS column is subjected to three near fault earthquake records.

2. ANALYTICAL MODELS

In this research, seismic performance of prefabricated cage systems with varying concrete strength is investigated through analytical analysis. A cage system with is developed in ABAQUS finite element software, Fig 2.1. As PCS provides high degree of confinement, the confinement model is used to simulate concrete’s behavior. After model verification with experimental study, the concrete strength of model changed. Two normal strengths and one high strength concrete are used in this study. Models are subjected to near-field earthquake records. Three records were used in this study. The effect of increasing concrete strength on column's seismic behavior is investigated. The size of openings, height of column, and distances between openings as well as concrete strength is mentioned in table 2.1 and Fig 2.2.



(a) (b)

Figure 2.1. Analytical Model. a) Prefabricated Cage model. b) column model.

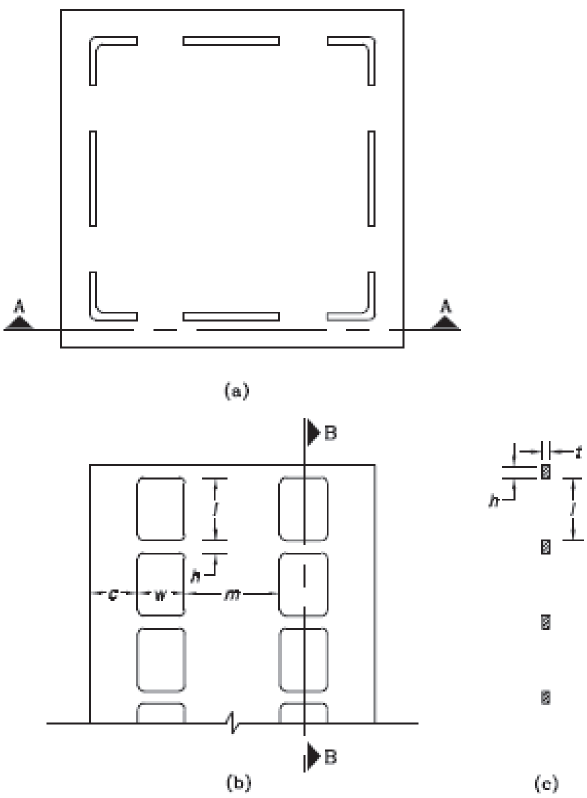


Figure 2.2. Parameters used in PCS column modeling. a) Plan section, b) section A-A, c) section B-B

Table 2.1. Properties of developed analytical models

specimens	Strength of concrete	Height of transverse reinf.	Wide of longitudinal reinf. at corners	Wide of the openings	Opening dimension	Wide of longitudinal reinf. in middle	Plate thickness
	F'c(ksi)	h (in.)	c (in.)	w(in.)	Width x length (in.xin.)	m(in.)	t(in.)
Control specimen	9.5	0.39	1.06	0.64	0.64x1.11	1.6	0.125
Model 1	8	0.39	1.06	0.64	0.64x1.11	1.6	0.125
Model 2	9	0.39	1.06	0.64	0.64x1.11	1.6	0.125
Model 3	10.5	0.39	1.06	0.64	0.64x1.11	1.6	0.125

3. FINITE ELEMENT ANALYSIS

ABAQUS finite element software was used to model seismic behavior of Prefabricated Cage System column. In this research four models were developed. First model was used to verify analytical model. In the second model, the concrete strength is changed to 8ksi as well as 9ksi and 10.5ksi in third and fourth models. All models are subjected to same near-field earthquakes.

3.1. Material Properties

3.1.1. Concrete

A confinement model for PCS which is developed by shamsaii is used to characterize the concrete. The model includes three main sections separated by two strength drops. The first section represents elastic behavior modeled using a slightly curved line up to the maximum strength followed by a relatively small strength drop. After this small strength drop, a constant stress or plateau is followed by another larger strength drop. The last section represents the residual strength behavior modeled by a linear descending line between the major strength drop and final failure. The initial elastic section is adopted from the model proposed by Bing et al. (2001), which defines the strength, f_c, as a quadratic function of strain, ε_c Passing through the origin and the maximum strength.

$$f_c = E_C\, \varepsilon_C + \frac{(f_\alpha^1 - E_C \varepsilon_C)}{\varepsilon_\alpha^2}\, \varepsilon_C^2 \tag{3.1}$$

Where E_c is concrete modulus of elasticity, f'cc is the maximum confined concrete strength and ε_{cc} is the strain at maximum strength. After reaching the maximum strength, the strength drops by amount of $\alpha\, f_c^1$, where α is the ratio of the minor drop to f'cc . A constant strength section (between the strain epsilon cc and epsilon beta) follows this strength drop and can be expressed as

$$f_c = f_\alpha^1 - \alpha f_\alpha^1 = (1-\alpha) f_\alpha^1 \tag{3.2}$$

At the end of this plateau, a major strength drop with a magnitude of $(\beta-\alpha) f_{cc}^1$ is observed. The strength drops to $(1-\beta) f_{cc}^1$ at a strain of ε_β where β is the ratio of the total strength drop to the maximum strength. The slow degradation of the residual strength is modeled by a descending straight line between the strain at major strength drop ε_β and the ultimate strain ε_{cu}.

In this section the strength drops by about γf_{cc} from $(1-\beta) f_{cc}^1$ at the beginning of the residual section to $(1-\gamma)(1-\beta) f_{cc}$ at final failure at a strain of ε_{cu}. The ultimate strain ε_{cu} can be estimated as a factor of $\varepsilon_{cc}(\varepsilon_{cu} = \lambda\varepsilon_{cc})$ where λ is the ultimate strain factor. The model can be summarized by the following equations.

$$\begin{aligned}
&f_c = E_C\, \varepsilon_C + (f_\alpha^1 - E_c\, \varepsilon_\alpha)\frac{\varepsilon_c^2}{\varepsilon_\alpha^2} && \text{if } 0 \le \varepsilon_c \le \varepsilon_\alpha \\
&f_c = (1-\alpha) f_\alpha^1 && \text{if } \varepsilon_\alpha \le \varepsilon_c \le \varepsilon_\beta \\
&f_c = (1-\beta) f_\alpha^1 - (\gamma(1-\beta) f_\alpha^1)\,\frac{\varepsilon_c - \varepsilon_\beta}{\varepsilon_{cu} - \varepsilon_\beta} && \text{if } \varepsilon_\beta \le \varepsilon_c \le \varepsilon_{cu}
\end{aligned} \tag{3.3}$$

The maximum confined concrete strength f_{cc}^1 is calculated from the mander et al.(1998)

$$f_{cc}^1 = f_{co}^1 \left[-1.254 + 2.254\sqrt{1 + 7.94\,\alpha \frac{f_1^1}{f_{co}^1}} - 2\alpha_s \frac{f_1^1}{f_{co}^1} \right] \tag{3.4}$$

Where f_{co}^1 is the maximum unconfined concrete strength, f_l^1 is the confining stress, and α_s is the strength modification factor. The confining stress f_l^1 can be estimated from the following equations for PCS. The confining stress f_l^1 of rectangular sections can be estimated by averaging the two confining stresses in the two perpendicular directions f_x^1 and $f_y^{\backprime}$ (Bing et al.2001)

$$f_1^1 = \frac{f_x^1 + f_y^1}{2} \tag{3.5}$$

$$f_x^{\backprime} = k_{.} . \rho_x . f_y \qquad\qquad f_y^{\backprime} = k_{.} . \rho_y . f_y \tag{3.6}$$

Where f_y is the yield strength of the steel reinforcement, K is the confinement effectiveness coefficient and ρ_x and ρ_y are the ratios of volume of transverse confining steel to volume of confined concrete core in the *x* and *y* directions.

$$\rho_x = \frac{A_{sx}}{sd_c} = \frac{2ht}{(l+h)d_c} \tag{3.7}$$

$$\rho_y = \frac{A_{sy}}{sb_c} = \frac{2ht}{(l+h)b_c} \tag{3.8}$$

The confinement effectiveness coefficient K_c for rectangular PCS can be estimated by the following relation:

$$k_c = \frac{\left(1 - \frac{nw^2}{6b_c d_c}\right)\left(1 - \frac{l}{2b_c}\right)\left(1 - \frac{l}{2d_c}\right)}{(1-\rho_{cc})} \tag{3.9}$$

Where, n is the number of longitudinal reinforcements, w is the width of the openings and ρ_{cc} is the ratio of area of longitudinal reinforcement, A_{sl} to area of core of the section.

$$\rho_{cc} = \frac{A_{sl}}{b_c d_c} \tag{3.10}$$

In recent study, for validating analytical model the concrete strength is f'_c=9.5ksi and other parameters are mentioned in table 3.1. The confined concrete model for the all models is presented in Fig. 3.1 to Fig. 3.4.

Table 3.1. Parameters for confined concrete model

f_x^1	$f_y^{\backprime}$	K	ρ_x	ρ_y	f_l^1	α	ρ_{cc}	f_{cc}^1
616.541	616.541	0.819	0.014	0.014	616.541	0.201	0.071	10334.51

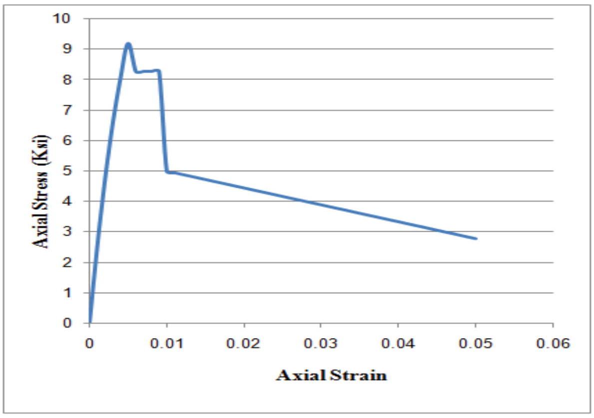


Figure 3.1. Confined Concrete Model for Control specimen (f'c=9.5 Ksi)

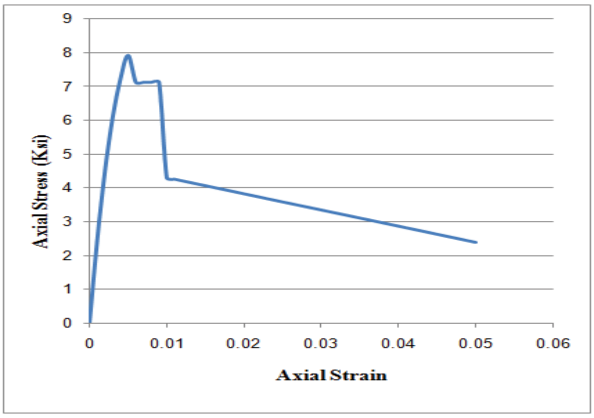


Figure 3.2. Confined concrete model for Model 1 (f'c=8 Ksi)

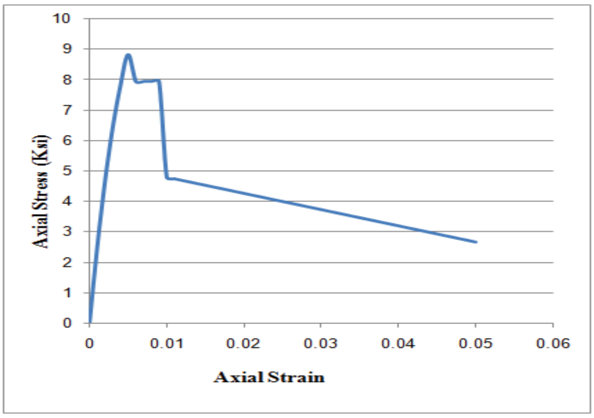


Figure 3.3 Confined concrete model for Model 2 (f'c=9 Ksi)

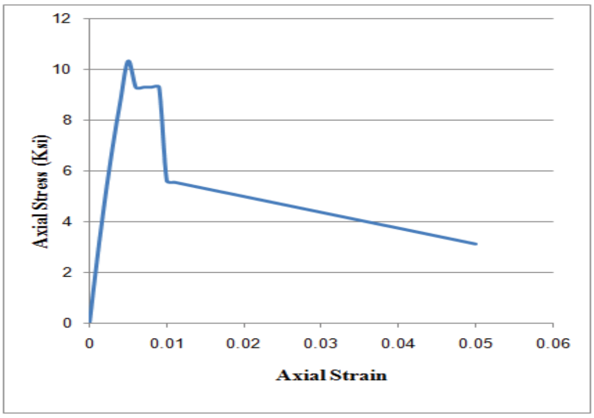


Figure 3.4 Confined concrete model for Model 3 (f'c=10.5 Ksi)

3.1.2. Steel

Steel is used as cage system. Steel is assumed as an elastic-perfectly plastic material. The Poisson's ratio is 0.2. Properties of steel types used in experimental work are shown in table 3.2.

Table 3.2. properties of longitudinal steel

F_y(ksi)	E_s(ksi)	ε_{sh}	ε_{su}	f_{su} (ksi)
55	29,000	0.003	0.1	65

3.3. Loading

According to Experimental study, the uniform axial load is applied to control specimen. Models 1, 2 and 3 are subjected to near-fault earthquake records which are applied at the base of column. Three near-field earthquake records used in this study were, Northridge, Imperial Valley and Duzce .The shape of records were as shown in Fig 3.5 to Fig. 3.7.

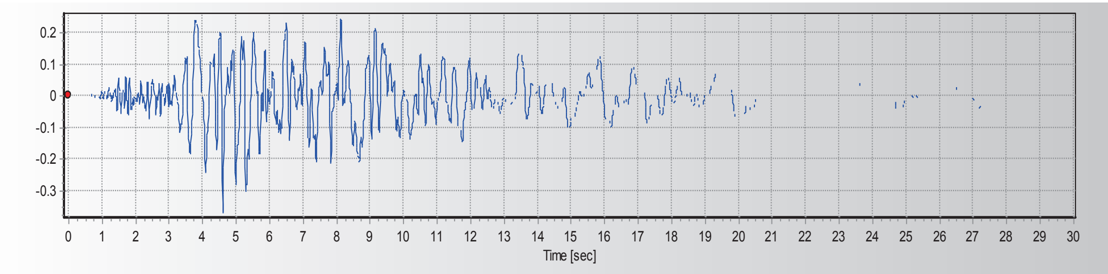


Figure 3.5. Shape of Northridge Near-field record

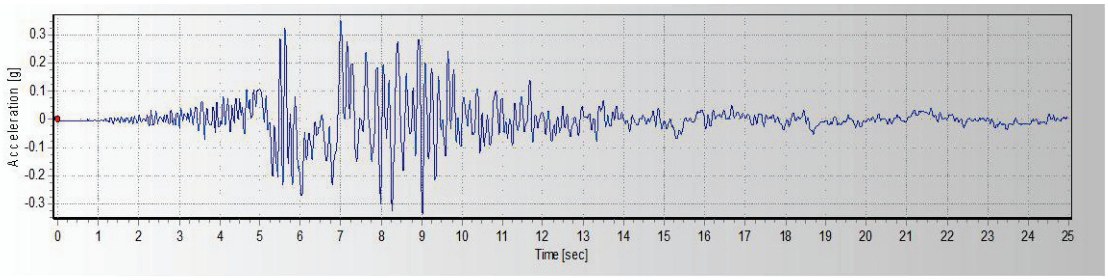


Figure 3.6. Shape of Imperial Valley Near-field record

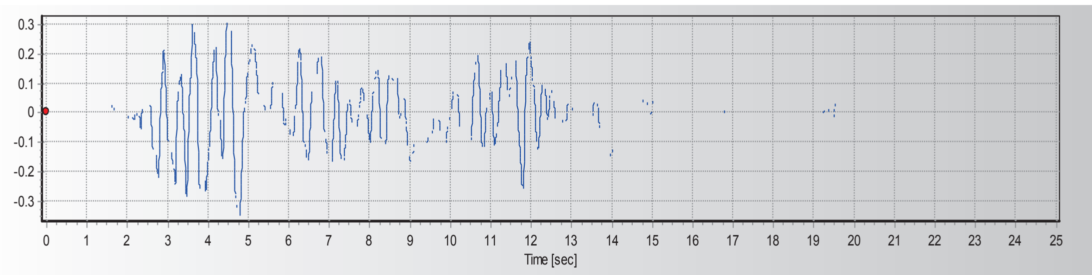


Figure 3.7. Shape of Duzce Near-field record

Properties of near-field earthquakes used in this study were summarized in table 3.3.

Table 3.3. Near-field earthquakes properties

Record Name	PGA(g)	Hypo central Distance(Km)	Duration(sec)
NORTHRIDGE	0.368	13.30	30
IMPERIAL VALLEY	0.352	5.30	25
DUZCE	0.348	8.20	25

3.4. Method of Analysis

Static riks method and dynamic explicit method is used to analysis of models. Static riks analysis method is used to verification of models with experimental studies. Static riks analysis method is a powerful statical analysis of models with material and geometric nonlinearity with large displacement in the Dynamic Explicit analysis is used to determine effect of near-field earthquakes on columns base shear and maximum displacement.

4. VERIFICATION OF ANALYTICAL MODELS

To verify the finite element model, a column from an experimental study that previously carried out at the Ohio state university. The results from finite element method compared with published experimental analysis. Load- displacement curves for both experimental work and finite element analysis are shown in Fig. 4.1. There is a good agreement between two curves.

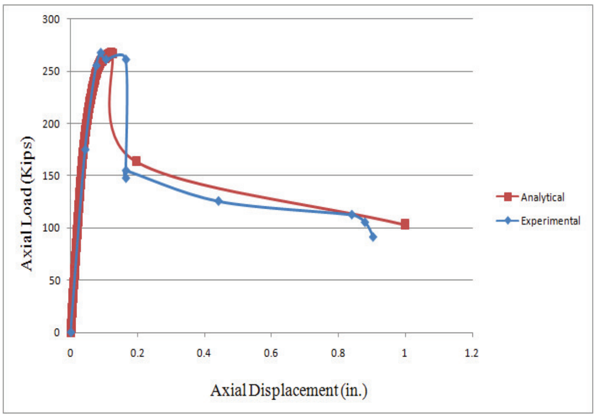


Figure 4.1. Comparison of Numerical results with Experimental results in control model

5. RESULTS

Models 1,2,3 are subjected to three mentioned records. Their Base shear as well maximum displacement is measured.

5.1. Effect of Increasing Concrete Strength on Prefabricated Cage System Columns Base Shear in Near-Fault Earthquakes

The Models are subjected to Near-fault records and the results regarding base shear are listed in table 5.1.

Table 5.1. Results for Base shear in near-field earthquakes in PCS column

Model	Northridge	Imperial Valley	Duzce
Model 1	4608.43	Aborted	Aborted
Model 2	4770.11	3145.77	2608.57
Model 3	5838.76	3503.38	3455.18

Analytical results shown in table 5.1 indicate that increasing in concrete strength leads to increase in base shear.

5.2. Effect of Increasing Concrete Strength on Prefabricated Cage System Columns Maximum Displacement in Near-Fault Earthquakes

The Models are subjected to Near-fault records and the results regarding maximum displacement are listed in table 5.2.

Table 5.2. Results for Maximum displacement (in.) in near-field earthquakes in PCS column

Model	Northridge	Imperial Valley	Duzce
Model 1	0.02	Aborted	Aborted
Model 2	0.0342	0.0246	0.0435
Model 3	0.05	0.0251	0.0470

Analytical results shown in table 5.2 indicate that increasing in concrete strength leads to increase the maximum displacement on top of the columns.

6. CONCLUSION

Results indicate that increasing the strength of concrete leads to increase in maximum displacement of column on its top which is a criterion for investigating the amount of ductility in column. Also results show that with increasing the strength of concrete the base shear that column could withstand increased. Finally results of this research show that with increasing the strength of concrete, ductility of column increased.

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