Passive Control Reinforced Concrete Frame Mechanism with HighStrength Reinforcements and Its Potential Benefits Against Earthquakes

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Abstract:
Severe earthquakes continue to cause major catastrophes. Many devices in active, hybrid, and semi-active structural control systems which are used as controllable force devices are costly to build and maintain. The passive control reinforced concrete frame (PCRCF) reinforced with high strength steel only in the columns presented here provides structural systems more resistance to lateral earthquake loadings at comparatively lower cost. The effectiveness is demonstrated by a nonlinear static analysis using fiber model for a single story single bay frame. The study shows that the use of high performance steel in columns pre- vents formation of plastic hinges at the critical column base sections and failures are always initiated by re- inforcement yielding at the beam ends. Furthermore, after experiencing severe lateral drift, the passive con- trol design has small residual displacements compared to ordinary reinforced concrete frames. PCRCF re- habilitation and strengthening can be achieved more easily as compared with ordinary reinforced concrete frame.

Keywords: *earthquake; passive control; high strength reinforcement; failure mechanism; residual displacement*

Introduction

In most reinforced concrete (RC) structures, a large stiffness is needed in order to limit structural deforma- tion for service load conditions. In seismic resistant structures, however, the energy dissipation demandsare imposed and inelastic deformations are permittedin special detailed regions of structures when the se- vere earthquake attacks. In particular, moment resistant frames designed according to the strong column/weak beam concept are expected to undergo inelastic defor- mations by forming plastic hinges in the beams. The columns are supposed to remain elastic to maintain vertical load carrying capacity and prevent possible collapse. Although the required flexural strength dif- ference between beams and columns at joint locations enforces this ideal frame deformation mechanism, the deformations at the base of the first story columns must be excessive to initiate the frame to sway[1]. Therefore, the formation of plastic hinges at the base of the first story columns is inevitable as shown in Fig.

1. Although in some instances, the formation of plastic hinges at the column bases may not be so critical re- garding the safety of the structure, these formation re- quires extensive rehabilitation efforts.

Moreover, the frame does not possess the recentering ability after un- dergoing severe lateral drift during strong shaking, and the chances of complete demolition of the structure are always there in case of excessive yielding at the column base sections. Furthermore, the possibility of exceeding the moment capacity at the top of the first columns

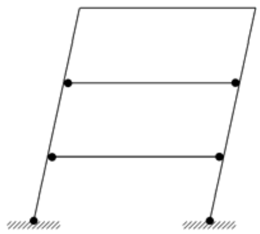


Fig. 1 Strong column/weak beam configuration

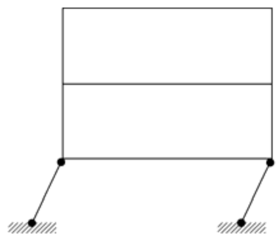


Fig. 2 Soft first story failure

This paper is to describe the alleviation and preven- tion of the formation of plastic hinges in frame col- umns by introducing high strength steel reinforcement in RC frame columns, which is called here after as pas- sive control RC frame (PCRCF). (Vasanthy and Jeganathan 2007, Vasanthy et.al., 2008, Raajasubramanian et.al., 2011, Jeganathan et.al., 2012, 2014, Sridhar et.al., 2012, Gunaselvi et.al., 2014, Premalatha et.al., 2015, Seshadri et.al., 2015, Shakila et.al., 2015, Ashok et.al., 2016, Satheesh Kumar et.al., 2016).

1 Mechanism of PCRCF

A conventional designed moment resistant frame usu- ally cannot successfully develop its ability against un- expected earthquake loadings due to limited flexural strength and the formation of plastic hinges at the base of the first story columns. Excessive yielding at the column base sections may lead to eventual collapse, and the soft first story failure mechanism is difficult to avoid. Moreover, even after the survival of structure against extreme lateral drift, the large residual defor- mations may suggest the need for complete demolition. By introducing high strength reinforcement in columns, PCRCF can safeguard its column base section from excessive yielding and can resultantly adjust structural characteristics by using the reserve flexural strength at the column base sections. Furthermore, the yielding will only occur at beams ends. Due to elasticity of high strength reinforcement in columns, recentering capacity can be improved with the reduced residual lateral displacement under extreme lateral loading. Therefore, repairs can be made easier. (Manikandan et.al., 2016, Sethuraman et.al., 2016, Senthil Thambi et.al., 2016, Ashok et.al., 2018, Senthilkumar et.al., 2018,).

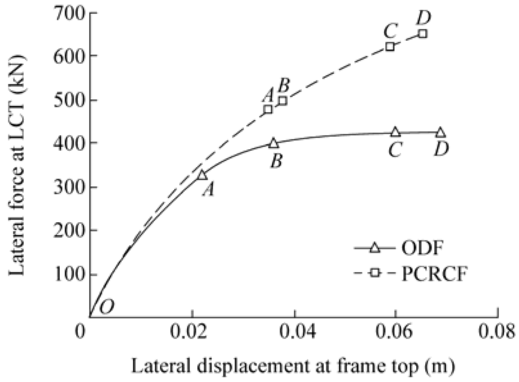
2 Analysis Models and Method

To demonstrate the PCRCF mechanism and to investi- gate the behavior difference between the ordinary frame and the PCRCF, two single-story single-bay frames, ordinary frame (ODF), and PCRCF, were ana- lyzed. The behaviors and failure mechanism of both the frames were estimated with nonlinear static analy- sis. Figure 4 presents the selected geometry and the loading pattern for both the frames.

3 Analysis of Results

Response stages

For comparative study, both the ODF and PCRCF were analyzed and the results at each of the response stages were described. The lateral load and displacement rela- tions are shown in Fig. 9 for the ODF and PCRCF. The lateral load displacement relation of both the frames can be divided into four response stages. The end of each response stage is marked as *A*, *B*, *C*, and *D*. The four response stages are described as follows.



FAILURE MECHANISM

From the observed fiber strains which are summarized in Table 4, the extent of yielding at the four response stages at the critical sections can easily be studied. Moreover, the strains also provide guidance in the ex- act determination of the failure mechanism in each of the frame studied. From the available data in Table 4, Fig. 10 shows the location of plastic hinges in theframes at the 4 response stages studied.

Figure 10 and values of the fiber strains given in Ta- ble 4 show that at the response Stage 2, the failure mechanism developed in the ODF; however, PCRCF yielded only at BRE. Further even up to Stage 4, po- tential failure mechanism did not appear in the PCRCF. After the first significant yield at RCB, the ODF has shown displacement ductility of smaller magnitude as compared to the PCRCF. The lateral displacement val-ues given in Table 3 show that the ODF at the end of response Stage 1 has 22.0 mm lateral displacement and at response Stage 2 ended was 36.0 mm, where failure mechanism developed in the ODF. However, thePCRCF laterally displaced to 35.0 mm at the end of re- sponse Stage 1 and until the end of the

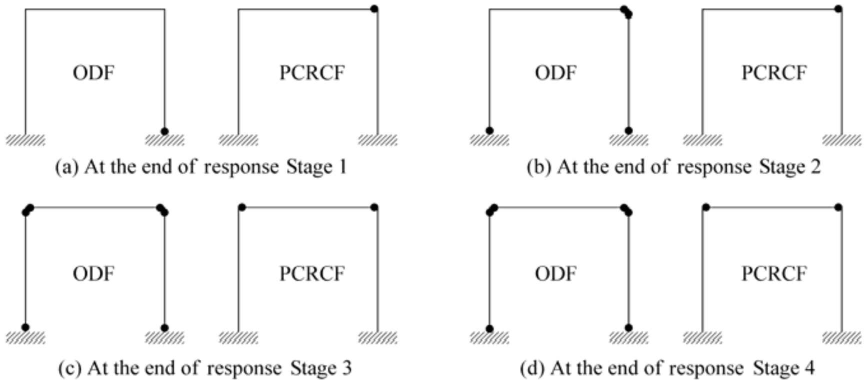


Fig. 10 Location of the plastic hinges in ODF and PCRCF

4 CONCLUSIONS

The passive control RC frame with high strength rein- forcement and its expected benefits against earth- quakes has been compared with ordinary RC frames. Two single-bay single-story frames were selected and compared. The following conclusions can be drawn.

(1) The PCRCF prevents the soft story failure and provides more lateral load resistance capacity with less reparable cost by simple replacement of ordinary con- ventional steel in the frame columns with high tensile strength steel.

(2) The PCRCF shows signs of distress mainly at the beam end sections which are potentially safe from the stability point of view of the entire frame as compared with the ODF where column base sections are badly yielded.

(3) Compared to the ODF, the PCRCF rehabilitation and strengthening is easier because the repairs focus onbeam end sections instead of the more restricted col- umn base sections.

(4) PCRCF reduces the residual displacement in the frames after the large lateral displacement.

(5) The PCRCF mechanism reduces the chances of complete demolition by avoiding excessive yielding at column base sections.

The performance of PCRCF can be further improved by providing concrete confinement at the beam ends and column base sections, since confinements at the beam and column ends, as well as high strength steel reinforced columns, increase the ultimate deformation capacity at the plastic hinges, and raise the deformation capacity of the whole frame.Since the demonstration of the PCRCF mechanism has been performed by using the single-story single- bay frame, the PCRCF response needs to be demon- strated for multi-story frames with dynamic loadings infuture studies. It may be helpful to mix some propor- tion of the high performance steel with ordinary one to achieve the response benefits. Hence, the optimum use of high performance steel in multi-story frame columns also needs to be investigated.

References

1. Paulay T, Priestley M J N. Seismic Design of Reinforced Concrete and Masonry Buildings. New York: John Wiley and Sons, Inc., 1992: 98-106.
2. Priestley M J N, Sritharan S S, Conley J R. Preliminary re- sults and conclusions from PRESSS five-story precast concrete test building. *PCI Journal*, 1999, (11-12): 42-67.
3. El-Sheikh M T, Sause R, Pessiki S. Seismic behavior and design of unbonded post tensioned precast concrete frames. *PCI Journal*, 1999, (5-6): 54-71.
4. Kurama Y, Pessiki S, Sause R. Seimic behavior and design of unbonded post tensioned precast concrete walls. *PCI Journal*, 1999, (5-6): 72-89.
5. Ricles J M, Sause R, Garlock M M. Post tensioned seismic resistant connections for steel frames. *ASCE Journal of Structural Engineering*, 2001, **127**(2): 113-121.
6. Zatar W A, Mutsuyoshi H. Residual displacements of con- crete bridge piers subjected to near field earthquakes. *ACI Structural Journal*, 2002, **99**(6): 740-749.
7. Kwan W P, Billington S L. Unbonded post-tensioned bridge piers I: Monotonic and cyclic analyses. *ASCE*, *Journal of Bridge Engineering*, 2003, **8**(2): 92-101.
8. Naaman S E, Jeong S M. Structural ductility of concrete beams prestressed with FRP tendons. In: Proceedings of the Second International RILEM Symposium, Non- Metallic Reinforcement for Concrete Structures. Belgium, 1995: 379-386.
9. Alsayed S H, Alhozaimy A M. Ductility of concrete beams reinforced with FRP bars and steel fibers. *Journal of Com-posite Materials*, 1999, **33**(19): 1792-1806.
10. Harris H G, Samboonsong W, Ko F K. New ductile FRP bars for concrete structures. *ASCE*, *Journal for Composite Construction*, 1998, **2**(1): 28-37.
11. Fischer G, Li V C. Intrinsic response control of moment resisting frames utilizing advanced composite materials and structural elements. *ACI Structural Journal*, 2003, **100**(2): 166-176
12. Vasanthy M and M. Jeganathan. 2007. Ambient air quality in terms of NOx in and around Ariyalur, Perambalur DT, Tamil Nadu. Jr. of Industrial pollution Control., 23(1):141-144.
13. Vasanthy. M ,A.Geetha, M. Jeganathan,and A.Anitha. 2007. A study on drinking water quality in Ariyalur area. J.Nature Environment and Pollution Technology. 8(1):253-256.
14. Ramanathan R ,M. Jeganathan, and T. Jeyakavitha. 2006. Impact of cement dust on azadirachtain dicaleaves – ameasure of air pollution in and Around Ariyalur. J. Industrial Pollution Control. 22 (2): 273-276.
15. Vasanthy M and M. Jeganathan. 2007. Ambient air quality in terms of NOx in and around Ariyalur, Perambalur DT, Tamil Nadu. Pollution Research., 27(1):165-167.
16. Vasanthy M and M. Jeganathan. 2008.Monitoring of air quality in terms of respirable particulate matter – A case study. Jr. of Industrial pollution Control.,24(1):53 - 55.
17. Vasanthy M, A.Geetha, M. Jeganathan, and M. Buvaneswari. 2008. Phytoremediation of aqueous dye solution using blue devil (Eichhornia crassipes). J. Current Science. 9 (2): 903-906.
18. Raajasubramanian D, P. Sundaramoorthy, L. Baskaran, K. Sankar Ganesh, AL.A. Chidambaram and M. Jeganathan. 2011. Effect of cement dust pollution on germination and

growth of groundnut (*Arachis hypogaea* L.). IRMJ-Ecology. International Multidisciplinary Research Journal 2011, 1/1:25-30 : ISSN: 2231-6302: Available Online: http://irjs.info/.

19. Raajasubramanian D, P. Sundaramoorthy, L. Baskaran, K. Sankar Ganesh, AL.A. Chidambaram and M. Jeganathan. 2011. Cement dust pollution on growth and yield attributes of groundnut. (*Arachis hypogaea* L.). IRMJ-Ecology. International Multidisciplinary Research Journal 2011, 1/1:31-36.ISSN: 2231-6302. Available Online: http://irjs.info/
20. Jeganathan M, K. Sridhar and J.Abbas Mohaideen. 2012. Analysis of meterological conditions of Ariyalur and construction of wind roses for the period of 5 years from January 2002. J.Ecotoxicol.Environ.Monit., 22(4): 375-384.
21. Sridhar K, J.Abbas Mohaideen M. Jeganathan and P Jayakumar. 2012. Monitoring of air quality in terms of respirable particulate matter at Ariyalur, Tamilnadu. J.Ecotoxicol.Environ.Monit., 22(5): 401-406.
22. Jeganathan M, K Maharajan C Sivasubramaniyan and A Manisekar. 2014. Impact of cement dust pollution on floral morphology and chlorophyll of *healianthus annus* plant – a case study. J.Ecotoxicol.Environ.Monit., 24(1): 29-34.
23. Jeganathan M, C Sivasubramaniyan A Manisekar and M Vasanthy. 2014. Determination of cement kiln exhaust on air quality of ariyalur in terms of suspended particulate matter – a case study. IJPBA. 5(3): 1235-1243. ISSN:0976-3333.
24. Jeganathan M, S Gunaselvi K C Pazhani and M Vasanthy. 2014. Impact of cement dust pollution on floral morphology and chlorophyll of *healianthus annus.*plant a case study. IJPBA. 5(3): 1231-1234. ISSN:0976-3333.
25. Gunaselvi S, K C Pazhani and M. Jeganathan. 2014. Energy conservation and environmental management on uncertainty reduction in pollution by combustion of swirl burners. J. Ecotoxicol. Environ.Monit., 24(1): 1-11.
26. Jeganathan M, G Nageswari and M Vasanthy. 2014. A Survey of traditional medicinal plant of Ariyalur District in Tamilnadu. IJPBA. 5(3): 1244-1248. ISSN:0976-3333.
27. Premalatha P, C. Sivasubramanian, P Satheeshkumar, M. Jeganathan and M. Balakumari.2015. Effect of cement dust pollution on certain physical and biochemical parameters of castor plant (*ricinus communis*). IAJMR.1(2): 181-185.ISSN: 2454-1370.
28. Premalatha P, C. Sivasubramanian, P Satheeshkumar, M. Jeganathan and M. Balakumari.2015. Estimation of physico-chemical parameters on silver beach marine water of cuddalore district. Life Science Archives. 1(2): 196-199.ISSN: 2454-1354.
29. Seshadri V, C. Sivasubramanian P. Satheeshkumar M. Jeganathan and Balakumari.2015. Comparative macronutrient, micronutrient and biochemical constituents analysis of *arachis hypogaea.* IAJMR.1(2): 186-190.ISSN: 2454-1370.
30. Seshadri V, C. Sivasubramanian P. Satheeshkumar M. Jeganathan and Balakumari.2015. A detailed study on the effect of air pollution on certain physical and bio chemical parameters of *mangifera indica* plant.Life Science Archives. 1(2): 200-203.ISSN: 2454-1354.
31. Shakila N, C. Sivasubramanian, P. Satheeshkumar, M. Jeganathan and Balakumari.2015. Effect of municipal sewage water on soil chemical composition- A executive summary. IAJMR.1(2): 191-195.ISSN: 2454-1370.
32. Shakila N, C. Sivasubramanian, P. Satheeshkumar, M. Jeganathan and Balakumari.2015. Bacterial enumeration in surface and bottom waters of two different fresh water aquatic eco systems in Ariyalur, Tamillnadu. Life Science Archives. 1(2): 204-207.ISSN: 2454-1354.
33. Ashok J, S. Senthamil kumar, P. Satheesh kumar and M. Jeganathan. 2016. Analysis of meteorological conditions of ariyalur district. Life Science Archives. 2(3): 579-585.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
34. Ashok J, S. Senthamil Kumar, P. Satheesh Kumar and M. Jeganathan. 2016. Analysis of meteorological conditions of cuddalore district. IAJMR.2 (3): 603-608.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.

35. Satheesh Kumar P, C. Sivasubramanian, M. Jeganathan and J. Ashok. 2016. South Indian vernacular architecture -A executive summary. IAJMR.2 (4): 655-661.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.
36. Satheesh Kumar P, C. Sivasubramanian, M. Jeganathan and J. Ashok. 2016. Green buildings - A review. Life Science Archives. 2(3): 586-590.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
37. Satheesh Kumar P, C. Sivasubramanian, M. Jeganathan and J. Ashok. 2016. Indoor outdoor green plantation in buildings - A case study. IAJMR.2 (3): 649-654.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.
38. Manikandan R, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. Assessment of ground water quality in Cuddalore district, Tamilnadu, India. Life Science Archives. 2(4): 628-636.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
39. Manikandan R, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. A study on water quality assessment of Ariyalur district, Tamilnadu, India. IAJMR.2 (4): 687-692.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.
40. Sethuraman G, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. Assessment of air quality in Ariyalur, Tamilnadu, India. Life Science Archives. 2(4): 637-640.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
41. Sethuraman G, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. A study on air quality assessment of Neyveli, Tamilnadu, India. IAJMR.2 (4): 693-697.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.
42. Senthil Thambi J, C. Sivasubramanian and M. Jeganathan. 2018. Ambient Air quality monitoring in terms of (Nitrogen di oxide in and around Ariyalur District, Tamilnadu, India. IAJMR.4 (3): 1414-1417.ISSN: 2454-1370. DOI: 10.22192/iajmr.2018.4.3.2.
43. Senthil Thambi J, C. Sivasubramanian and M. Jeganathan. 2018. Study of Air pollution due to vehicle emission in Ariyalur District, Tamilnadu, India. Life Science Archives. 4(4): 1409-1416.ISSN: 2454-1354. DOI: 10.22192/lsa.2018.4.4.3.
44. Ashok J, S.Senthamil kumar, P.Satheesh kumar and M.Jeganathan. 2018. Estimation of Cement kiln exhaust on Air quality of Ariyalur in terms of suspended particulate matter - A Case Study. International Journal Of Civil Engineering And Technology. 9 (12): Scopus Indexed Journal ISSN: 0976 – 6316.
45. Ashok J, S.Senthamil kumar, P.Satheesh kumar and M.Jeganathan.2018. Air quality assessment of Neyveli in Cuddalore District, Tamilnadu, India. International Journal Of Civil Engineering And Technology. 9 (12): Scopus Indexed Journal ISSN: 0976 – 6316.
46. Senthilkumar M, N. Nagarajan, M. Jeganathan and M. Santhiya. 2018. Survey of Medicinal Plants diversity on Bodha Hills in Salem District, Tamil Nadu, India. Indo – Asian Journal Of Multidisciplinary Research (IAJMR) ISSN: 2454-1370.
47. Senthilkumar M, N. Nagarajan, M. Jeganathan and M. Santhiya. 2018. Survey of Traditional Medicinal Plants in and around Ariyalur in TamilNadu, India. Life Science Archives (LSA) ISSN: 2454-1354. DOI: 10.22192/lsa.2018.4.6.5.
48. Malarvannan J, C. Sivasubramanian, R. Sivasankar, M. Jeganathan and M. Balakumari. 2016. Shading of building as a preventive measure for passive cooling and energy conservation – A case study. Indo – Asian Journal of Multidisciplinary Research (IAJMR): ISSN: 2454-1370. Volume – 2; Issue - 6; Year – 2016; Page: 906 – 910. DOI: 10.21276.iajmr.2016.2.6.10.
49. Malarvannan J, C. Sivasubramanian, R. Sivasankar, M. Jeganathan and M. Balakumari. 2016. Assessment of water resource consumption in building construction in tamilnadu, India. Life Science Archives (LSA) ISSN: 2454-1354 Volume – 2; Issue - 6; Year – 2016; Page: 827 – 831 DOI: 10.21276/lsa.2016.2.6.7.
50. Sivasankar R, C. Sivasubramanian, J. Malarvannan, M. Jeganathan and M. Balakumari. 2016. A Study on water conservation aspects of green buildings. Life Science Archives (LSA),ISSN: 2454-1354. Volume – 2; Issue - 6; Year – 2016; Page: 832 – 836, DOI: 10.21276/lsa.2016.2.6.8.

51. Ashok J , S. Senthamil Kumar , P. Satheesh Kumar and M. Jeganathan. 2016. Analysis and design of heat resistant in building structures. Life Science Archives (LSA), ISSN: 2454-1354. Volume – 2; Issue - 6; Year – 2016; Page: 842 – 847. DOI: 10.21276/lsa.2016.2.6.10.