

Experimental Study on the Effect of Strengthening Inadequate Seismically Designed Column using Pre-tensioned Steel Straps Confinement

Jia-Yang Tan^{1*}, Chau-Khun Ma^{2,3}, Chee-Loong Chin¹, Abdullah Zawawi Awang², and Wahid Omar⁴

¹ Ph.D Candidate, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia

² Ph.D, Senior Lecturer, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia

³ Ph.D, Full Research Fellow, Forensic Engineering Centre, Institute for Smart Infrastructure and Innovative Construction, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia

⁴ Ph.D, Professor, Office of Vice Chancellor, Universiti Teknologi Malaysia

*Corresponding author: jytan6@graduate.utm.my

Abstract. Earthquake happens around the world almost every day. These phenomena have alarmed structural engineers to consider seismic actions in structural design. Research and development of strengthening inadequate seismically designed columns have become important in Malaysia. This is because most of the structures in Malaysia were not designed to resist seismic actions. Confinement has emerged as a popular and effective strengthening method under cyclic loading. In this study, two 1/6 scale reinforced concrete column specimens are tested to investigate the effect of confinement on their structural behaviour. The specimens are loaded under cyclic lateral loading with 100 mm eccentricity to explore the behaviour of RC columns under the presence of both flexural and torsional moments. The effectiveness of strengthening is evaluated based on the differences in strength, stiffness and ductility. It is shown that the strengthened specimen performed better in term of strength and ductility. However, the strengthened specimen exhibited some reduction in stiffness.

1. Introduction

The earthquakes happen on daily basis, either in small or large magnitude. In fact, the National Earthquake Information Centre detected approximately 12,000-14,000 earthquakes annually [1]. Earthquake is one of the dangerous natural catastrophes which threatens humans' life and property. During an earthquake, concrete structures such as buildings and bridge are affected by the seismic loading. Concrete structures normally are designed to have adequate structural resistance, serviceability and durability during their service life. The structures should sustain all the loadings and remain fit during execution. The cause of damage of RC columns are insufficient transverse confinement and ductility as well as inadequate shear or flexural capacity [2].

Earthquake disaster may cause the building and bridge columns to undergo complex combined shear, bending, and torsional loadings[3]. However, most of the columns are not designed using the seismic design provisions, for instance Eurocode 8 (EC8) in Malaysia as the design engineers are unaware of the importance of seismic design and were not expecting a natural disasters like an earthquake, such as



what happened in Sabah in 2015. It is important to have ample of time for the public to excavate before the structures collapsed to save humans' life. Therefore, the pre-earthquake strengthening of the susceptible concrete columns is needed to avoid the structure damage or even collapse due to insufficient shear strength [4]. Therefore, in this study, steel strap confinement is used to determine the contribution of active confinement to strengthen the column for resisting seismic load involving combined effect of shear, bending and torsional loading.

The objective of this study is to investigate the effect of strengthening of inadequate seismically designed reinforced concrete columns under combined cyclic loading effects such as bending, shear and torsion through experimental using steel straps tensioning techniques (SSTT). The strength improvement, ductility and stiffness indices of actively confined column as compare to existing unconfined columns are the parameter that being utilised to examine the performance of the RC columns after strengthened with SSTT.

This testing focused on testing of two 1/6 scale columns with diameter of 150mm and clear height of 1.0m confined with active confinement and another unconfined column act as control specimen under combined cyclic loading effects such as bending, shear and torsion with torsional moment-to-flexural moment ratios (T/M) of 0.1.

2. Literature Review

During earthquake, RC columns undergo complex combined axial, shear, bending and torsional loadings. Thus, it needed to be strengthened to ensure the column still can enough time for the public to be excavate before it collapses. In most of the previous researches, researchers used cyclic loading to test the structural response that encounter earthquake. The available strengthening methods such as concrete jacketing, fibre reinforced polymer (FRP) and steel jacketing demonstrated good results in increasing the strength and ductility of the columns or bridge piers. For resisting torsion loading, the outer portion of concrete column is the most effective in resisting torsion [5]. Therefore, the SSTT method can provide a good way to overcome the torsion loading in this paper. The effective lateral stress exerted by the pretensioned strap layers pronounced in enhancing the performance of the confined high strength concrete specimens, especially strength and ductility [6].

There are many confinements that can be applied on the damaged RC column, including active confinement and passive confinement. Steel, RC and FRP are some examples of material that can be used to apply the passive confinement. The performance of passive confinement is wholly identified by dilation of concrete core. The commonly used retrofit approaches for RC columns are concrete jacketing and thick steel jacketing which broadens the cross-sectional area of columns that increases the dead load and stiffness of existing columns. This will be attracting more seismic demands to the retrofitted columns due to a shortened vibration period of the jacketed structures [7]. Steel jacketing will have the problem of corrosion also [8]. Besides, these two methods normally required lots of time and labour together with on-site heavy-lifting equipment during installation.

Unlike passive confinement, active confinement effectiveness shall be altered through initial pressure induced by mechanical pre-stressing and thermally induced stressing respectively. Prestressed strands and shape memory alloy (SMA) spirals are some examples of active confinement. Although both passive and active confinement managed to enhance the RC columns, it was reported that active confinement was more effective due to the early application of confinement pressure around the concrete core, which lag in the damage sustained by the concrete. However, the concrete would have to deform laterally for the confinement pressure to be fully activated for passive confinement effect to take place [9]. Therefore, in this study pretensioned steel straps tensioning was used to actively confined the column to investigate the effect of strengthening.

3. Methodology

This laboratory investigation consisted of three key methodology, preparation of specimens, experimental testing set-up, and loading protocol.

3.1. Specimen Detail

In this study, high strength columns are chosen due to their brittleness during concrete failure [10]. Two formworks will be prepared based on the dimension, provided the thickness of the formwork is 12 mm. Both specimens has a dimension of 600 × 600 × 300 mm for the base footing followed with a circular column with a diameter of 150 mm and 1000mm clear height, on the top part of the column there will concrete block attached to it with a dimension of 400 × 200 × 200 mm. Concrete mix of 60 MPa was used throughout the study. The reinforcement bars used for the base footing and the top block are 16mm diameter while the columns consist of 6 number of 12 mm diameter bars. Steel strap are wrapped into one column in 2 layers, the steel strap is then tightened using pneumatic tensioner and the spacing between the steel straps are 10mm as shown Figure 1(b). Figure 2 showed schematic drawing of specimen including the detail of reinforcement bar.

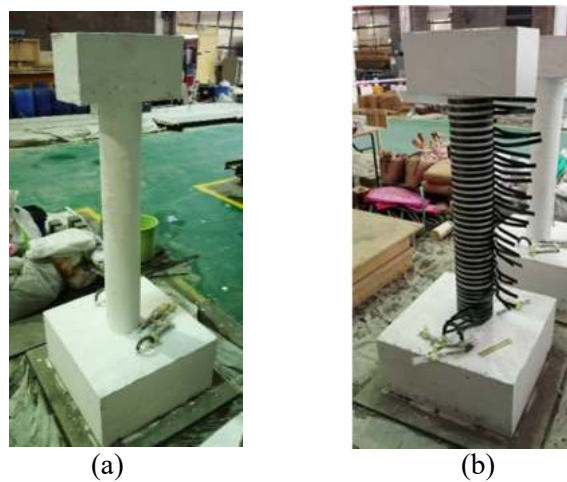


Figure 1. (a) Unconfined specimen (b) Confined Specimen.

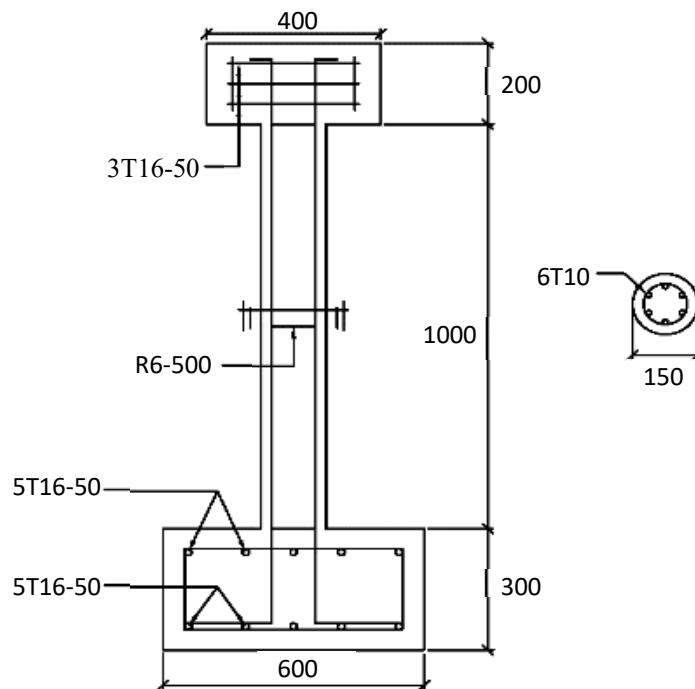


Figure 2. Schematic drawing of specimen.

3.2. Experimental setup

Steel frame was prepared and set-up in the Structure Laboratory of School of Civil Engineering, Universiti Teknologi Malaysia to test the specimens. The footing of columns was restrained against both vertical and horizontal movements. This was done by using the steel frame to fix the footing of the specimens to the floor, the gap between the frame and the footing are filled with steel plates in order to make sure the footing are fully fixed to the floor as shown in Figure 3. There are total of 6 linear variable displacement transducers (LVDTs) were used to record the lateral displacements, 2 LVDTs with 100-mm displacement range are placed at the left side of the top block, the first LVDT are located at the centre of the top block and the second LVDT are located at 75mm from the centre of the top block as shown in Figure 4(a), same setup are being applied on the right side of the top block. Another LVDT with 50-mm displacement range are placed on the left side of the column at 500mm height as shown is Figure 4(b), same setup was being applied on the right side of the column. Hydraulic jack was positioned horizontally on the left side of the top block located at 100mm from the centre to apply a cyclic lateral loading to induce the torque-to-moment ratio of 0.1, similar setup was being applied on the right side of the top block as shown in Figure 3.

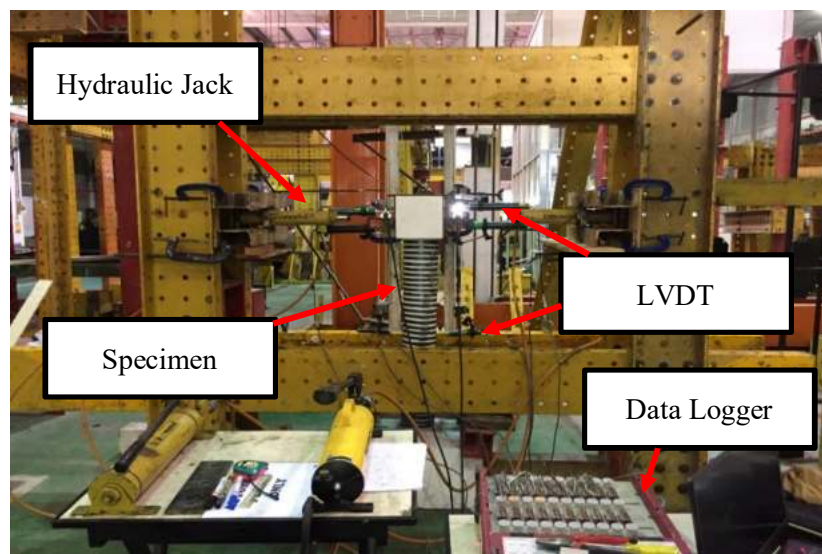


Figure 3. Test setup.

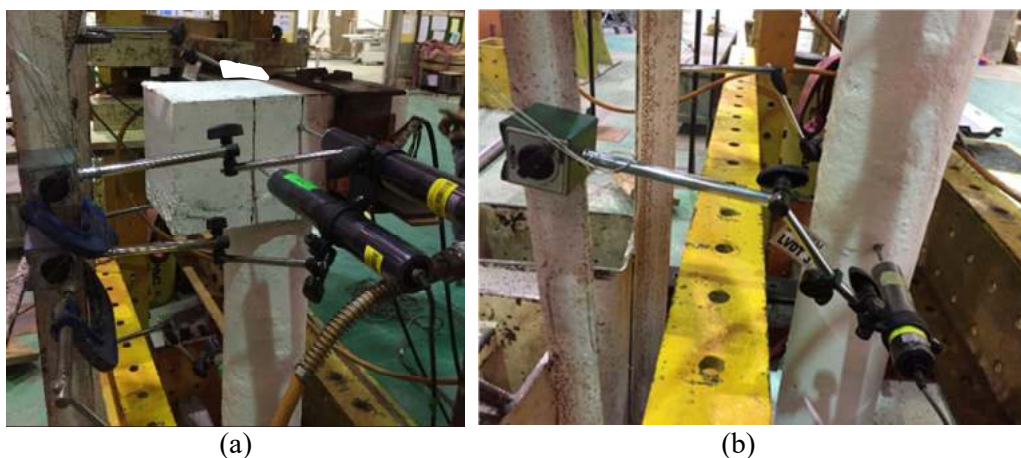


Figure 4. Position of LVDT (a) top block (b) column.

3.3. Loading Protocol

The testing procedure for confined and unconfined columns was similar as they are initiated in force control and then continued in displacement control. FEMA 461 recommend applying two cycles at each displacement level. The lateral load was applied 25%, 50%, 75% from right side to obtain the displacement of specimen as $\Delta y+$. Then it will be continued on the left side [11].

Under displacement control, start with displacement ductility level equal to 1.0 for seventh and eighth cycle. Force applied at the ductility level recorded. The next cycle continues with incremental of displacement ductility ($\mu \Delta = 2, 3, 4, 5\dots$) as shown in Figure 5 until the strength deteriorated to more than 80% of the peak capacity.

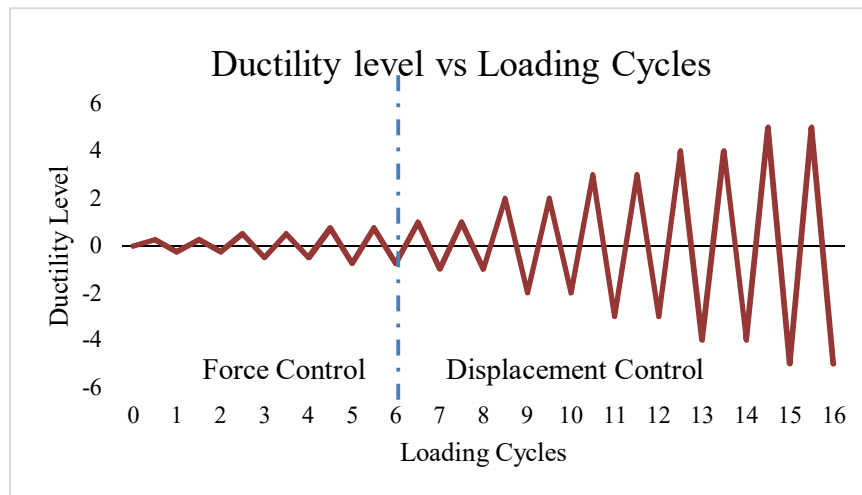


Figure 5. Loading protocol.

4. Result and discussion

The two columns were being tested and analysed in term of their strength, ductility and stiffness. Based on the results, graph was plotted based on the load-deflection value.

4.1. Hysteresis Curve

Hysteresis curves of lateral load-displacement curve was plotted using the data obtained from the laboratory testing and the result from both unconfined and confined specimens are compared (Figure 6 (a) and (b)). The envelope load deflection curve was overlapped to observe the increasement easier as shown in Figure 7.

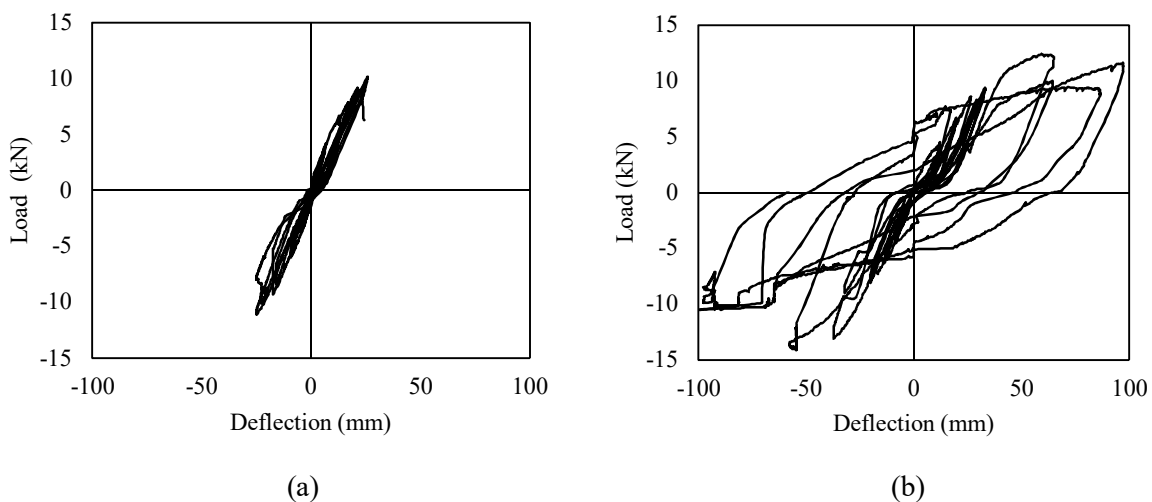


Figure 6. Load deflection curve (a) unconfined specimen (b) confined specimen.

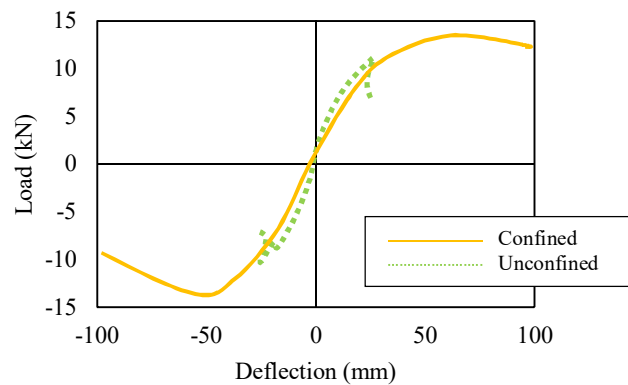


Figure 7. Comparison of load deflection curve envelope for both specimens.

4.2. Lateral Strength Improvement

The interested strength is the maximum measured lateral load applied during the laboratory testing. Strength index is calculated by dividing the confined column strength by the unconfined column strength to know the contribution of confinement towards lateral strength improvement. The obtained peak strength of the unconfined column is 10.1 kN and 12.5 kN for the confined column. From this experiment, it showed that retrofitting column with pre-tensioned steel straps has expectedly leading to increase of strength by 23%.

4.3. Ductility Index

In general, plastic deformation and energy dissipation capacities of the structure is controlled by ductility of the column [12]. In order to resist earthquake, ductility capacity is one of the significant parameters that need to be observed. In this study, the ductility capacity was obtained by calculating the ratio of displacement at 85% of peak strength capacity to the yield displacement for the unconfined specimen. For confined specimen, ratio of displacement of the peak capacity to the yield displacement are taken due to different stress strain curve obtained as shown in Table 1. From the experiment, it showed that the ductility capacity of retrofitted column with pre-tensioned steel straps has increase by 64%.

Table 1. Comparison of Ductility capacity of specimens.

Specimens	Displacement at peak Strength, Δ_{max} (mm)	Displacement after 15% strength deteriorated, $\Delta_{0.85}$ (mm)	Yield Displacement, Δ_y (mm)	Ductility
Unconfined	26	24	6	4
Confined	59	-	9	6.56

4.4. Stiffness Index

The stiffness of columns is another important parameter to assess the performance of retrofitted columns. In this experiment, the ratio of the retrofitted column’s initial stiffness to the control column’s initial stiffness was calculated. From the experiment, it showed that the initial stiffness of unconfined specimen and confined specimen are 0.6 and 0.26 respectively and the stiffness index is 43%.

Although the stiffness index showed a decrease in stiffness after confined with pretensioned steel strap, it brings benefits to the building or bridge during the earthquake indeed. This is because flexible columns tend to attract less seismic load while more stiff columns attract greater seismic load of the seismic input [13].

5. Conclusions

The strengthening of inadequate seismic-designed columns by using pre-tensioned confinement with steel straps was presented. Two 1/6 -scale column was constructed and tested to failure under combined lateral cyclic loading. Seismic performance parameters such as strength, ductility capacity, and stiffness of the two tested specimens were then extracted from the tested specimens and compared. The following conclusions was drawn after comparing the results of the two specimens to know the effectiveness of steel straps in strengthening.

- The effect of steel straps towards the column shows that there is significant strength improvement as the obtained peak strength of the unconfined column is 10.1 kN and 12.5 kN for the confined column indicating the ability of pre-tensioned steel straps to strengthen column by 23%.
- The active confinement shows a good contribution in strengthening inadequate seismic-designed column as the ductility index of the specimens was 164% and for the stiffness index of the specimens is only 43%.

6. References

- [1] Incorporated Research Institutions for Seismology 2019 *How Often Do Earthquakes Occur?* Retrived on September 30, 2019 https://www.iris.edu/hq/inclass/factsheet/how_often_do_earthquakes_occur
- [2] Wang D, Wang Z, Yu T and Li H 2018 Seismic performance of CFRP-retrofitted large-scale rectangular RC columns under lateral loading in different directions *Compos. Struct.* **192** 475–488
- [3] He R, Sneed L H and Belarbi A 2013 Rapid repair of severely damaged RC columns with different damage conditions: An experimental study, *Int. J. Concr. Struct. M.* **7** 35-50
- [4] Deng M, Zhang Y 2017 Cyclic loading tests of RC columns strengthened with high ductile fiber reinforced concrete jacket *Constr. Build. Mater.* **153** 986–995
- [5] Belarbi A, Shanmugam S P and You Y-M 2009 Effect of spiral reinforcement on flexural-shear-torsional seismic behavior of reinforced concrete circular bridge columns *Struct. Eng. Mech.* **33** 137-158
- [6] Awang A Z, Omar W, Lee H P and Ma C K 2012 Behaviour of Externally-Confined High Strength Concrete Column Under Uniaxial Compression Load *Innovative Construction Material – ICM6 (Surabaya)*
- [7] He R 2014 *Rapid repair of severely damaged RC columns under combined loading of flexure, shear, and torsion with externally bonded CFRP* PhD Thesis (Missouri: Missouri University of Science and Technology) pp 12-13
- [8] Tong T, Yuan S, Zhuo W, He Z and Liu Z 2019 Seismic retrofitting of rectangular bridge piers using ultra-high performance fiber reinforced concrete jackets, *Compos. Struct.* **228** 111367
- [9] Shin M 2012 *Seismic retrofit and repair of reinforced concrete bridge columns using shape memory alloy spirals* PhD Thesis (Urbana: University of Illinois at Urbana-Champaign) pp 2
- [10] Taerwe L 2018 Brittleness versus Ductility of High Strength Concrete, *Struct. Eng. Int.* **1** 40-45
- [11] Liu J 2013 *Seismic behaviour of reinforced concrete columns* PhD Thesis (Toronto: University of Toronto) pp 84
- [12] Wang H, Zhou X and Wang L 2019 Experimental investigation of damaged circular reinforced concrete columns with pre-tensioned steel hoops, *Eng. Struct.* **197** 109384
- [13] Prakash S, Belarbi A and You Y-M 2010 Seismic performance of circular RC columns subjected to axial force, bending, and torsion with low and moderate shear *Eng. Struct.* **32** 46-59

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