Strengthening of Damaged RC Column Using Lateral Compression

Atul Gupta *, Er. Abhishek Murthy, and C. K. Murthy

CKMbT International Pte Ltd, Singapore; Email: abhi@ckmbt.com.sg, murthy@ckmbt.com
*Correspondence: atul@ckmbt.com.sg

***Abstract*—The objective of this paper is to present a new method for strengthening of RC column in a multi storey high rise building specifically for the splitting cracks at top of the column arisen due to cranks in the main rebar. The lateral compression force equal to split tensile strength of concrete 3.2 Mpa in the concrete grade of C32/40 was applied. External steel angles with steel rods were used to impart a lateral compression force on the RC columns using hydraulic jacks. This gain in the flexural strength is due to the confinement effect imparted on the concrete externally. The RC column was modelled in the 3D and FEM analysis was done to check the imparted stresses onto the steel angles and concrete. This method can effectively be used for the RC columns in the industry as it requires clamping of RC columns externally which can be achieved on site with ease.**

***Keywords*—RC column, structural strengthening, post tensioning, fibre Wrap, 3D FEM & flexural strength**

I. Introduction

RC column is most important structural member in reinforced concrete structure and the failure of RC column results in collapse of structure. There is an increase demand of high-rise building all over the world and many of these buildings are mixture of cast in situ columns with precast beams and slabs for faster construction. Since, the precast beams are fabricated in factory-controlled conditions and the columns are cast in-situ, there is always a possibility of having shorter/larger bearing length of precast beams on RC columns. Due to the increased bearing on the RC columns, cranks were made in the column rebars thereby having the outer surface as unreinforced and without confining links. Cracking occurred at outer face of column due to the loading from beam which was transferred to the column's outer unreinforced concrete. These cracks generally occur at top one third portion of the RC column and can be easily distinguished from the RC compression failure cracks which generally occurs at central portion of the RC column. The multi-story building under this structural strengthening program is a residential condominium which consists of a 7 Storey Car Park, a Transfer Structure and 4 no. 26 storey towers. The cracking was observed in cast in-situ RC columns at top one third portion.

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Following were the salient points in support of the fact that cracking occurred due to the rebar cranks;

- Generally, if the concrete is under strength and loaded with very heavy axial loading, the splitting cracks will form at the centre of the column due to column bulging and lateral strain and not at edges.
- Many of the columns that were cracked were also showing very high concrete core compressive strength.
- The cover meter survey done to identify the cover of RC columns showed that the cover was upto 150mm at the cracked locations.
- Since, the quality control at precast factory for beams fabrication is much better than in-situ column construction. This might have caused increased bearing on column.

Many options [1]-[12] were available for the strengtheing of RC columns for splitting cracks and for confining the concrete like steel jacketing of RC columns with steel plates/strips, wrapping the column with CFRP sheets and increasing the size of column by RC Jacketing outside. All these methods could not be used for this project due to the urgency of project and there was requirement for faster repair method & also there was limitations of others method. Steel jacketing requires onsite welding and concrete jacketing requires drilling into existing beam and slab while CFRP were not effective due to rectangular shape of column (aspect ratio of 1.5). So, a new method of strengthening works was proposed to strengthen RC Column by lateral compression using prestressing rods. The solution was a sustainable solution as it was designed based on the three important aspects of sustainability i.e. society/stakeholders (since the carpark was existing with the new method of strengthening such that there was no reduction in the car park lots), client/economic (the method was economical and easy to construct on site) and lastly the environment (proposed method avoided the use of concrete as to reduce the carbon footprint). The method proposed was easy to use and was able to increase the flexural strength of the RC column by 3.2 Mpa for a concrete grade of C32/40.

II. Methodologies

A. Testing Methodology

In total, 39 RC columns were reported with cracks in two towers and the concrete core test was recommended

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to check on the concrete compression strength for these RC columns. Over 100 core tests were done with a test result ranging from 18.5 Mpa to 59.5 Mpa. The columns with very high core compression strength also reported with cracks. Based on this observation and based on visual inspection it was noted that the cracks occurrence is not due to the under strength of columns and lower concrete core test results are may be due to the micro cracks formed inside the RC columns. This was further verified by Rebound hammer test results which shows overall very high concrete compression strength ranging from 45 Mpa to 60 Mpa, Rebound hammer test results can be relied upon as the age of building was less than 5 years and rebound hammer test results depends on hardness of concrete and not on the internal cracks. The cover meter test was used to ascertain the cover at the crack locations and was found to be 150mm which shows that cranks were made in the column rebar.

The concrete quality was further verified by using Ultrasonic Pulse velocity method in the RC columns which shows an overall good quality of concrete.

B. Structural Strengthening Methodology

Fig. 1 shows the crank made in rebar to install the precast beam on site and thereby having outer surface unreinforced which leads to the cracking in concrete. Fig. 2 shows the bursting force due to crank on the concrete. The cracked RC column was located at the car park location and the proposed method need to be selected so that it should not decrease the number of car park lots. Based on site constraints, external post compression using steel T sections and steel bars on two sides of the columns out of 4 sides was proposed. Since the cracks were observed on the top portion of the RC columns, strengthening was limited to first half of the column. The steel bars were stressed with a pre-calculated force, so as to impart a post compression onto the RC columns and hence increasing the flexural strength of the concrete. The size of the RC columns was 1200mm x 800mm and with an overall height of 3000mm. In total 6 numbers of Steel T sections were used with 12 no. of steel bars, See Fig. 3 for reference. The post compression stress was calculated based on the exposed area of concrete and the estimated flexural stress on the concrete area. The stress imparted onto the RC columns and steel angles were further verified and checked by doing 3D FEM analysis in STAAD Pro.

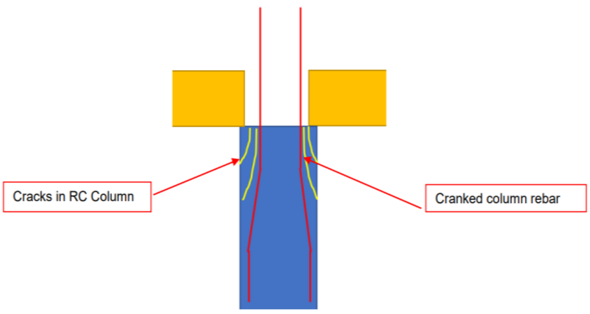

Figure 1. Crack in RC column due to cranked rebar

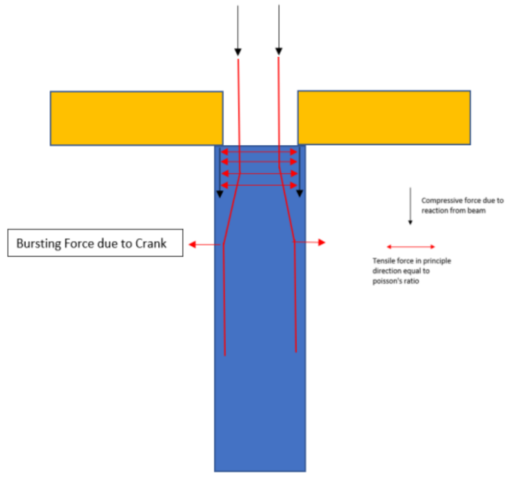

Figure 2. Bursting force due to cranked rebar

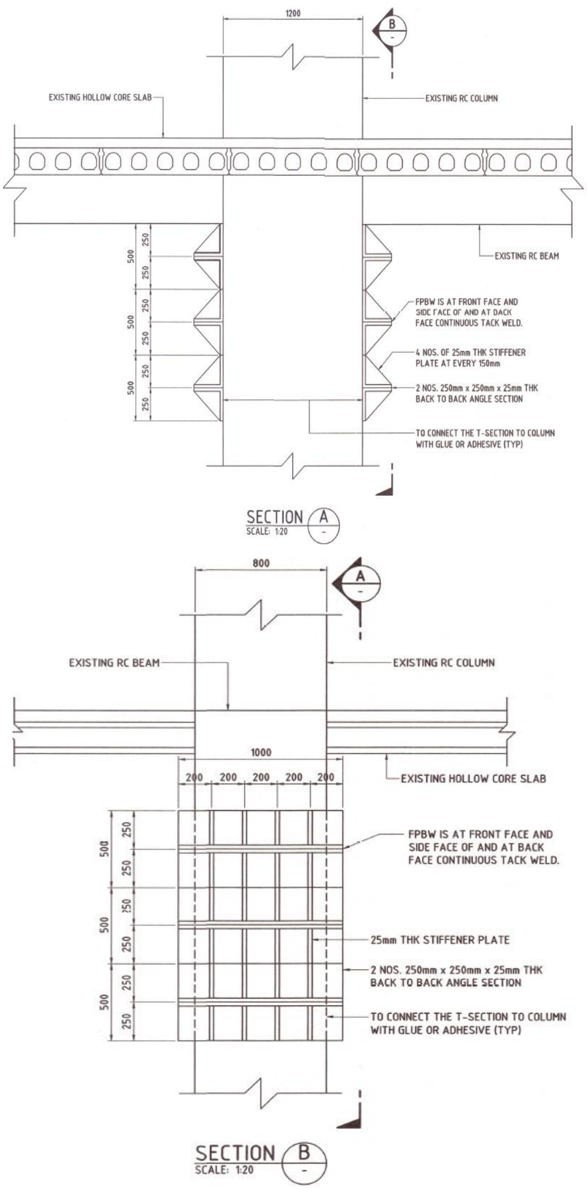

Figure 3. Proposed strengthening using steel T section

III. Finite Element Modelling & 3D Analysis Results

The RC columns and steel T sections were modelled as 3D using plate elements in STAAD Pro and the stresses observed in steel and concrete are within the allowable stresses. See Fig. 4 & Fig. 5 for FEM Analysis results.

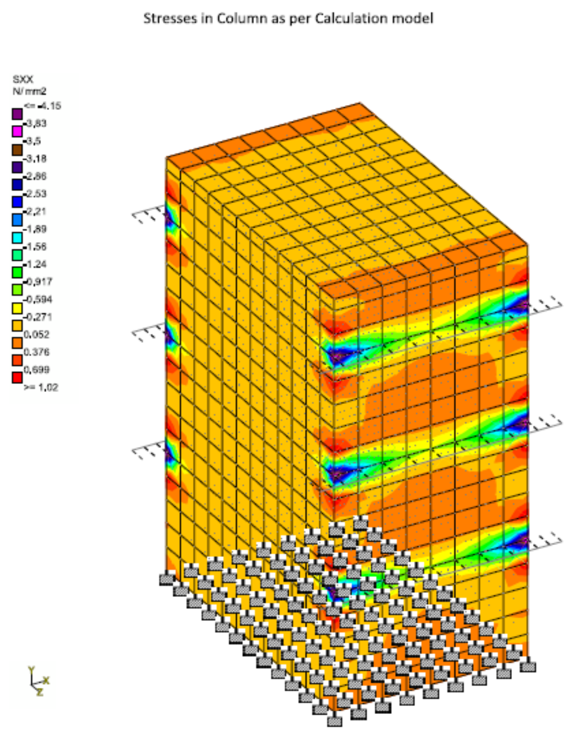

Figure 4. FEM Model showing stress in concrete

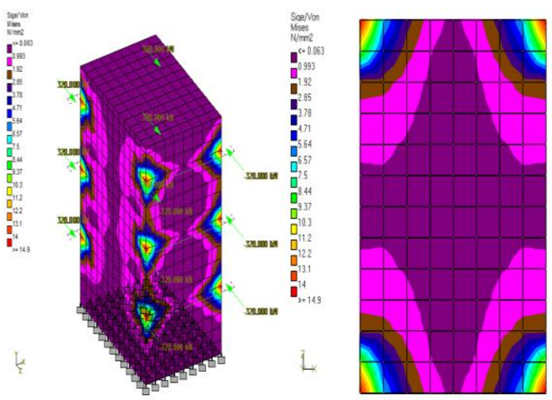

Figure 5. FEM Model showing stress in concrete

IV. Work Methodology

The T sections were fabricated offsite using equal steel angle and other works were carried out on site. Fig. 6 shows the final works carried out on site. The site installation was done based on the following procedure:

- The micro cracks were sealed with epoxy resin material before the start of strengthening works.
- Surface of column was made free of undulation and debris.
- Bottom two opposing T sections of steel then lifted up using chain block and forklifts to desired position.
- After that 4 numbers of steel bars were slotted into corresponding steel section holes along with 8 numbers of bearing plates and 8 sets of nuts and washers.
- Nuts are initially tightened by hand to limit free movement prior to stressing.
- Using spirit level, the steel section was checked for horizontal alignment. Adjustment of position was performed if necessary.
- 4 sets of couplers and lead bars were screwed onto the steel bars. Stressing with jacks was performed from one side only.
- 4 numbers stressing jacks and stressing chairs were placed in position making sure the jack ram is at retracted position.
- Stressing pump was connected to 4 numbers of jacks securely and pressure gauge was checked.
- Incremental stressing was performed in maximum increments of 10% until desired stressing percentage was achieved. The 4 numbers of steel bars were stressed simultaneously. Elongation of steel bars was measured and recorded at the jack ram.
- Upon achieving desired load induced to bar. The lock nut was tightened to lock off the bar.
- Stressing pump shall be depressurized so as to return the ram to initial position.
- Repeat from start for corresponding top sections until 3 layers of steel sections were completed.

Figure 6. Final completed column on site

V. Inspection & Testing

Lift off method was used for the testing of stressed bars as per the following procedure:

- 1 set of coupler and lead bar was screwed onto the installed steel bar.
- 1 number of stressing jack and stressing chair was placed in position making sure the jack ram is at retracted position.
- Stressing pump was connected to 1 number of jack securely and pressure gauge was checked.
- Stressing pump pressure was increased until achieving 95% of lock off pressure recorded during installation.
- At 95%, the lock off nut was tested for movement. If no free movement of nut was observed, the test indicates the stress induced in bar is maintained
- Stressing pump shall be depressurized so as to return the ram to initial position

VI. CONCLUSIONS

- This research paper presents the effectiveness of post compression method for the increase in flexural strength of concrete in RC Columns. Overall, there was an increase of 3.2 Mpa in the flexural strength of the RC column with a concrete grade of C32/40.
- Finite Element Modelling was used to check the allowable stresses in steel and concrete.
- Lift off test was used on site to verify the imparted psot tensioned in the rods.
- The current proposed method is used in case of precast beams on one side of the column and the method can be further revised for the case of beams in both directions of RC column.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Atul Gupta conducted the research for the paper along with the guidance of Er. Abhishek Murthy and Dr. CK Murthy. Atul Gupta has carried out the structural analysis and has proposed the structural members. Dr. C.K. Murthy and Er. Abhishek Murthy proposed the sequence of works and testing arrangements. Atul Gupta, Er. Abhishek Murthy and Dr. Murthy contributed in writing the research paper.

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Atul Gupta was born in India in 1990 and did his undergraduate in Civil Engineering from NIT Kurukshetra followed by his Master's in Civil Engineering from National University of Singapore. He has overall 9 years of experience in field of structural engineering and is currently working as Associate Director with CKMbT International Pte Ltd Singapore.

Er. Abhishek Murthy was born in Singapore and had graduated with honours in Civil Engineering from National University of Singapore. He is currently working as the Managing Director, at CKMbT International Pte Ltd.

Er Murthy is a registered Professional Engineer in Singapore and currently serving as the president of Precast and Prestressed Concrete Society, Singapore. He is also a member of Association of Consulting Engineers, Singapore, Singapore Institute of Arbitrators and American Society of Civil Engineers, and is a senior member of Institute of Engineers, Singapore.

Dr. C.K. Murthy was born in India and had graduated with honours in Civil Engineering from University of Mysore and completed his PhD at University of Liverpool.

He is working as Chairman at CKMbT International Pte Ltd. Dr. Murthy is both a registered Accredited Checker and Professional Engineer (PE) in Singapore and has published about 70 papers in local and international journals and conference proceedings. These research and review papers include topics on tall buildings structures, prestressed concrete, appraisal of building structures and economics of building structures. Dr. Murthy is a fellow of Institution of Engineer, Singapore, a fellow of the Institution of Engineers, India, a member of the Association of Consulting Engineers, Singapore and a member of the American Society of Civil Engineers.