INTERNATIONAL JOURNAL OF RESEARCH IN MECHANICAL, MECHATRONICS AND AUTOMOBILE ENGINEERING (IJRMMAE)
ISSN: 2454-1435 (Print) | 2454-1443 (online)
Volume 4 Issue 2 – www.ijrmmae.in – Pages 19-22

SHEAR STRENGTHENING OF REINFORCED CONCRETE COLUMNS USING FIBER REINFORCED POLYMER SHEET WITH BONDED ANCHORAGE

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Abstract

The paper aims to contribute to a better understanding and modeling of the shear behavior of reinforced-concrete (RC) beams strengthened with carbon fiber reinforced polymer (FRP) sheets. The study is based on an experimental program carried out on Columns with and without transverse steel reinforcement, and with different amounts of FRP shear strengthening. The test results provide some new insights into the complex failure mechanisms that characterize the ultimate shear capacity of RC members with steel reinforcement and FRP sheets. After the discussion of the above topics, a new upper bound of the shear strength is introduced. It should be capable of taking into account how the cracking pattern in the column fails under shear is modified by the presence of FRP sheets, and how such a modified cracking pattern actually modifies the anchorage conditions of the sheets and their effective contribution to the ultimate shear strength of the beams.

Keywords: Shear strength; Steel; Fiber-reinforced materials; Polymers; Columns; Concrete reinforced.

I. INTRODUCTION

Failure of RC columns, subjected to cyclic lateral loads by earthquake, can be due to insufficiency in shear strength, in flexural strength, or ductility. The most undesirable mode of failure is shear failure. Column shear failure is possible if the transverse reinforcement in the column is poorly detailed or inadequately anchored. FRP(Fiber Reinforced Polymer) can enhance both the shear capacity and ductility of columns. Shear retrofit methods using FRP are popular because of its properties such as anti-corrosiveness, lightweight, and workability. The objective of this research was to evaluate the structural behavior and shear retrofit performance of RC column with FRP from the experimental and analytical works. Experimental works were conducted for five specimens varied in the reinforcement quantity and adhesion method of FRP. Throughout cyclic test, the strength, stiffness, failure modes, ductility, and energy dissipation capacity were discussed. Test results are compared with FEM analysis results.

Seismic retrofitting and/or the strengthening of RC columns has been a popular area of research for decades. This is primarily because, in a building frame system or a bridge, the imposed seismic energy demand is dissipated by the displacement of the columns, thereby resulting in slight to severe damage depending on the severity of the earthquake, and hence

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the need for repair emerges to ensure the smooth post-earthquake recovery of the facility. Secondly, RC building structures that were designed prior to the incorporation of seismic detailing guidelines of the 1970s generally possess non-ductile RC columns, which make them inherently vulnerable during an earthquake. Strengthening techniques can be used to upgrade columns of this nature and allow them to conform to the latest code requirements.

Researchers over the past two to three decades have been endeavouring to develop appropriate strengthening and repair techniques for RC columns that balances the structural requirement to enhance the strength, ductility and drift with various non-structural requirements, such as minimising implementation/construction costs, limiting any disruption to building occupants during construction, maintaining the aesthetics of the structure, maintaining or increasing durability and ensuring work safety. Time of repair is another crucial factor, particularly for post-disaster facilities, such as hospitals or emergency services facilities, and shelters that house a significant number of people. Similarly, the functionality of bridges also needs to be maintained or quickly restored immediately after an earthquake, which underscores the importance of rapid strengthening and repair techniques. There are also other challenges and complexities associated with strengthening and repair that need to be dealt with, such as localised changes to the member stiffness, which can possibly change the dynamic properties of the structure and, consequently, change the seismic demands on individual elements or the building as a whole.

II. REINFORCED CONCRETE/MORTAR JACKETING

RC jacketing has been used extensively for strengthening and repairing deficient and damaged RC columns, respectively. In traditional reinforced concrete jacketing, the section of the column is enlarged by casting a new reinforced concrete/mortar section over a part or the entire length of the column. The new section is bonded to the original section through anchor rebars or high-strength bolts. Although this technique improves the seismic performance of the column in terms of axial load carrying capacity, flexural strength and ductility, it is costly and time consuming due to the installation of the formwork. Moreover, the improvement in ductility is relatively small because the jacketing material (i.e., concrete) is brittle. Furthermore, it results in a change in the cross-sectional area of the column, thereby changing the mass and stiffness of the structure, and hence reducing the natural period of the structure, which consequently results in higher seismic demands on the structure. Therefore, high-performance RC materials have been used more recently for jacketing purposes, so that the specimen is strengthened/repaired without a change in the cross-sectional size.

III EXTERNALLY BONDED FIBER-REINFORCED POLYMER (FRP) JACKETING

FRP jacketing is one of the most popular seismic retrofitting methods all over the world, primarily because of the many advantages FRP composites have to offer over traditional strengthening methods (RC and steel jacketing), such as ease and speed of installation, less labour work, minimum change to the original geometry and aesthetics of the structure, high strength-to-weight ratio, and, most importantly, its occupant-friendly nature. However, it has certain disadvantages as well, such as, the effective utilization of externally bonded FRP is just 30–35%, due to premature de-bonding. Moreover, FRP is relatively costly and shows poor properties when exposed to high temperatures or wet environment. FRP is generally bonded externally to the column using epoxy resins. Different types of FRP composites have been utilized by different researchers for strengthening purposes

IV FRP STRENGTHENING

A large number of studies have been conducted to assess the impact of FRP strengthening on the general behaviour and failure modes of the strengthened RC columns. Ma et al reported that deficient RC columns retro-fitted with external FRP jacketing exhibited stable flexural response with improved ductility and energy dissipation capacity by preventing brittle shear failure. Similarly, Ye et al found that shear strength of the RC column with inadequate transverse reinforcement can be improved with the FRP sheets. Moreover, the shear resistance mechanism of FRP sheets was observed to be similar to reinforcement hoops where it became effective after the diagonal shear cracking of concrete.

V FRP SHEETS WITH STEEL JACKETING

FRP Sheets with Steel Jacketing Li et al evaluated the effectiveness of combined FRP and steel jackets in improving the seismic performance of corrosion-damaged RC columns. It was reported that the repair of damaged columns with combined FRP and steel was more effective in improving the strength and ductility than strengthening with the individual material. Also, in damaged columns with higher levels of reinforcement corrosion, the improvements of strengthening were more prominent than those with a lower degree of corrosion.

ElSouri and Harajli compared the seismic performance of lap-spliced RC columns on strengthening with internal steel ties, external fiber-reinforced polymer sheets and a combination of both. It was found that the repair/strengthening of the columns with internal ties, external FRP sheets or a combination of both improved the seismic performance significantly in terms of lateral load, energy dissipation and drift capacity. More over repaired/strengthened columns experienced much less damage than the as built un-strengthened columns. Recently, Chouet al proposed an innovative hybrid jacketing method in which a FRP-wrapped corrugated steeltube, was used to improve the seismic performance of RC columns. The presence of a corrugated tube allowed for the creation of a ribbed surface between the concrete and FRP. The results of the experimental study showed a significant increase in the drift capacity of the columns with the increase in the number of FRP layers. Moreover, the failure mode changed from shear to flexure with the increase in FRP wraps. Furthermore, the proposed strengthening technique also resulted in increased energy dissipation and the high shear strength of the specimens.

CONCLUSION

This paper presented a detailed overview of various strengthening and repair methods for reinforced concrete columns. These techniques can contribute to the sustainability of existing reinforced concrete infrastructure by ensuring the enhancement of their existing capacity without the need for rebuilding or replacement. Each technique is discussed extensively noting the advantages and disadvantages. The review of the findings of different researchers leads to the conclusion that although the strength, ductility and drift capacity of the damaged columns can be recovered and even enhanced by repair, it is very difficult to fully restore the initial stiffness of the damaged column. Further, based on the review of the different strengthening and repair techniques, the authors are of the view that hybrid jacketing techniques, which combine the benefits of different materials/strengthening methods can often be the most effective since they have a relatively fast installation, can significantly improve the strength, ductility and drift and can maintain the aesthetics and original geometry/configuration of the structure.

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