SEISMIC BEHAVIOR OF TRM AND GFRP UPGRADED RC EXTERIOR BEAM-COLUMN JOINTS

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Abstract

Textile reinforced Mortar (TRM) was experimentally investigated in this study as a new material for strengthening and seismic retrofitting of RC beam-column joints. The results of TRM-upgraded joints were then compared with that of Glass Fiber Reinforced Polymer (GFRP)-strengthened joint specimens. Three as-built joint specimens were constructed with non-optimal design parameters (inadequate joint shear strength with no transverse reinforcement) representing extreme case of pre-seismic code design construction practice of joints and encompassing the vast majority of existing beam-column connections. Out of these three as-built specimens, one specimen was used as baseline specimen (control specimen) and the other two were strengthened with TRM and GFRP sheets respectively. All these three sub-assemblages were subjected to quasi-static cyclic lateral load histories so as to provide the equivalent of severe earthquake damage. Response histories of control and strengthened specimens were then compared. The test results demonstrated that TRM can effectively improve both the shear strength and deformation capacity of seismically deficient beam-column joints to an extent which is comparable to the strength and ductility achieved by well-established GFRP-strengthening of joints.

1 Introduction

In many earthquake prone countries, pre-seismic code designed reinforced concrete (RC) buildings do not comply with the current seismic codes requirements. Recent earthquakes have illustrated that inadequate shear strength and ductility in the existing beam-column joints, especially exterior ones, is the prime cause of failure/collapse of moment resisting RC frame buildings. Hence, effective and economical rehabilitation techniques to upgrade poor joint shear-resistance and inadequate ductility of seismically deficient RC structures are needed. Use of FRP composites is a modern way of strengthening deficient and weak concrete members. There are several advantages of using Fiber Reinforced Polymers (FRP) for rehabilitation of RC structures. These advantages are very well reported in the literature. However, there are some drawbacks which require the attention of FRP users. These drawbacks are: (a) poor behavior of epoxy resins at temperatures above the glass transition temperature;(b) relatively high cost of epoxy and polymer materials; (c) hazards for the manual worker; (d) inability to apply FRP on wet surfaces or at low temperatures; (e) lack of vapor permeability, which may cause damage to the concrete structure; (f) incompatibility of epoxy resins and substrate materials; and (g) difficulty to conduct post-earthquake assessment of the damage suffered by the reinforced concrete behind (undamaged) FRP jackets. One possible solution to the above problems would be the replacement of organic binders with inorganic ones, e.g. cement-based mortars, and use of textiles in place of fiber sheets. Textiles comprise fabric meshes made of long woven, knitted or even unwoven fiber roving in at least two (typically orthogonal) directions.

A detailed review of the literature [e.g. 1-4] shows that substantial research has been conducted on adequacy of FRP composites as strengthening material for seismically deficient beam-column joints. However, a very limited research is available on the use of TRM as strengthening material for concrete structures including RC beam-column joints. Keeping this scope in view, authors have studied effectiveness and efficiency of TRM on strengthening of beam-column joints to demonstrate that TRM-upgrading can effectively improve both the shear strength and ductility of seismically deficient beam-column joints to an extent which is comparable to the strength and deformability achieved by well established GFRP-strengthening of joints.

2 Experimental Program

One of the main objectives of the present study was to conduct an experimental program to evaluate seismic performance of TRM-strengthened beam-column joint specimen, and compare its performance with GFRP-upgraded beam-column exterior joint specimens. To accomplish this, three reinforced concrete as-built specimens were cast. The first specimen was used as control specimen (ECON), and the second and the third specimens were strengthened using TRM and GFRP respectively (ECTRM and EGFRP) as shown in Figure 1.

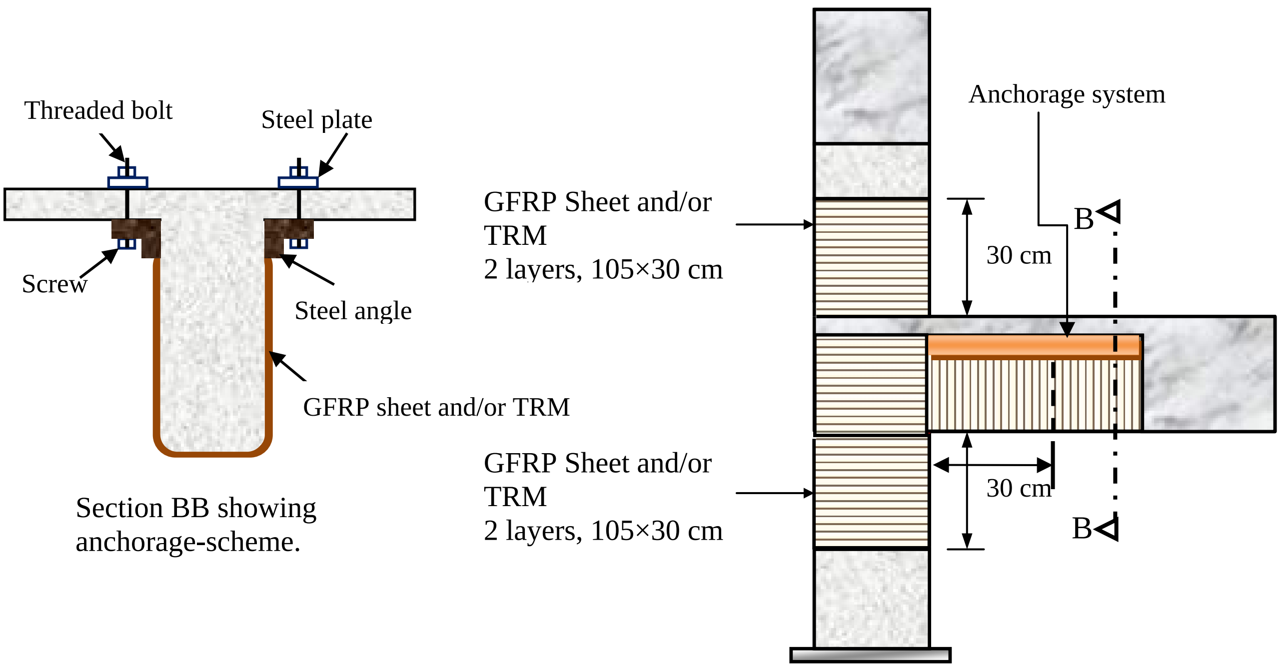

Figure 1. GFRP and TRM strengthening schemes applied to as-built exterior joint

The above specimens (i.e. as-built control, GFRP- and TRM-strengthened) were tested using the testing apparatus designed and installed in the Structural Test Hall, Department of Civil Engineering, King Saud University, Saudi Arabia. The horizontal-loading regime was based on the conventional guidelines of quasi-static type testing as followed by most researchers in simulating seismic forces to test reinforced concrete structures [5, 6]. The loading cycles were controlled by the peak displacement until failure. For each displacement level (i.e. for a constant value of displacement), three fully reversed cycles were completed. All cycles were started with the pull direction first then went into the push direction.

3 Discussion of Test Results

In order to study the load carrying capacity and ductility of control and strengthened exterior joint specimens, envelopes of load-displacement hysteretic curves were plotted and using these envelopes the peak load, ultimate displacements, ductility, joint shear strength and diagonal tension for the specimens were obtained and listed in Table 1. The second column of Table 1 shows the average peak load (i.e. average of peak push and pull values) and the third column shows the displacement corresponding to the first yield of steel bars. This displacement is required to calculate ductility of the specimens. The estimated ductility, an important parameter for earthquake-resistant members, is shown in the fourth column of Table 1. The ductility is computed as the ratio of ultimate displacement to the displacement at first yield of internal steel. For computation, the ultimate displacement was set at a displacement corresponding to 20% drops of peak load. The values of ductility clearly show that the application of FRP sheets and TRM has improved the ductility of strengthened specimen significantly. The first column of Table 1 indicates that the increase in strength due to GFRP-strengthening is higher than due to TRM. This trend is very well expected as fibers of glass are the stronger and textile-fibers are the weaker. The trend may be altered by changing the governing parameters e.g. number of layers. The ductility is also substantially increased due to strengthening, and it is higher for GFRP-strengthened sheets.

It is worth mentioning that the peak load and deformation capacity of FRP or TRM-strengthened specimens are very much dependent on the number of layers used in the upgrading. It is possible to increase the strength of strengthened specimens further with the use of more number of layers. However, before increasing the number of layers it is essential to make sure that (i) change in the stiffness of the system (due to increased number of layers) does not adversely affect the load sharing between the members, and (ii) does not result in early debonding, if not prevented against debonding, without development of FRP strength.

Specimen	**Peak load (Average) kN**	**Disp. at first yield of steel, Δ_y (mm)**	**Ultimate displacement after 20% drop in peak load Δ_{20} (mm)**	**Ductility Factor Δ_{20} / Δ_y**	**Shear strength in terms of $\gamma\sqrt{f_c^{'}}$ (MPa)**	**Diagonal tension (MPa)**
ECON	47.1	15.7	26.6	1.69	$0.78\sqrt{f_c^{'}}$	2.43
EGFRP	59.71	12.11	41	3.36	$1.06\sqrt{f_c^{'}}$	3.83
ECTRM	50.88	11.54	33	2.84	$0.85\sqrt{f_c^{'}}$	2.77

Table 1: Peak test load and maximum ductility

4 Conclusions

In the present study, effectiveness of TRM in improving the load carrying capacity and ductility of shear deficient exterior joint was studied and its performance was compared with the specimen strengthened using GFRP sheets. Following are the major conclusions which can be drawn from the present experimental study:

- The TRM can effectively improve both the shear strength and ductility of seismically deficient beam-column joints to that extent which is comparable to GFRP-upgraded joints.
- The increase in peak load and ductility by TRM upgrading is very much dependent on the number of layers used in the strengthening. It is possible for TRM-upgraded specimen to achieve comparable GFRP-upgraded beam-column joint ultimate load values with the use of sufficient number of layers.
- Before increasing the number of TRM or FRP layers it is essential to make sure that (i) change in the stiffness of the system (due to increased number of layers) does not adversely affect the load sharing between the members, and (ii) does not result in early debonding, if not prevented through mechanical anchorages.

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