SMAR 2015

Shear Strength Models for Ferrocement Confined Shear Deficient Square RC Columns

A. B. M. A. Kaish[1]*, M. Jamil[1], S. N. Raman[1]* and M. F. M. Zain[1]

[1]Sustainable Construction Materials and Building Systems (SUCOMBS) Research Group, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Malaysia.*Email: amrul.cuet@gmail.com; snraman@ukm.edu.my

ABSTRACT: A variety of materials and methods have been tried to strengthen a shear deficient RC column. Ferrocement exhibits high in-plain shear strength, thus the material will perform well when it is used to confine RC columns to enhance their seismic performance. A number of models have been proposed for shear strengthening of RC columns. However, none of these models were verified using experimental results of other researchers. This paper provides an analytical review of existing shear strength models for ferrocement confined square RC columns. In this study, effort was made to find the most suitable shear strength models for ferrocement confined square RC columns. The experimental results of several other researchers were used to evaluate the suitability of the existing models. It was found that none of the model correlated well with existing experimental results of all types of ferrocement jacketed square RC columns available in literature. Therefore, it can be concluded that more experimental studies are required in order to propose a more feasible shear strength model.

1 INTRODUCTION

A large number of reinforced concrete (RC) structures are constructed worldwide every year. However, RC structures often suffer deterioration due to various environmental and structural factors (Kaish et al., 2012; 2015a). Sometimes, structures designed with old design code may become substandard because of upgrading the design code (Kaish et al, 2015b). Structures with deterioration and/or insufficient load carrying capacity need strengthening for further functioning.

RC columns experience lateral shaking during an earthquake event and may fail because of insufficient transverse confinement, and insufficient shear capacity during such event (Abdullah and Takiguchi, 2003). Moreover, typically lap-spliced transverse reinforcement with large spacing cannot provide sufficient anchorage as required in the modern seismic provisions (Takiguchi and Abdullah, 2001). Collapse of a RC building during an earthquake could be prevented by strengthening of its columns having inadequate strength and ductility.

A number of techniques have been employed for the strengthening of RC columns. Among them, jacketing with externally bonded materials is the most popular method for column strengthening. Steel jacketing and fiber reinforced polymers (FRP) jacketing have been widely used. However, the employment of these materials needs highly skilled workers (Takiguchi and Abdullah, 2001). On the other hand, as a low cost material, ferrocement has been used as a jacketing material in the developing countries (Kaish et al., 2013). Takiguchi and Abdullah (2000), Kazemi and Morshed (2005), and Kumar et al. (2005) investigated the behavior of ferrocement strengthened RC columns under seismic loading. It was also mentioned that ferrocement can be used effectively to strengthen shear deficient RC columns. A number of models for such columns have been proposed by the same authors; however, none of these models were verified by other researchers. This paper attempts to analytically review the existing shear strength models for ferrocement confined square RC columns. The aim of this study is to verify those models with experimental results obtained from published literatures in order to identify out the most suitable model for design and practical use.

2 ANALYTICAL SHEAR STRENGTH MODELS

A comprehensive review of literature revealed that only four studies have presented shear strength models for square RC columns. Those models are presented in the following sections.

2.1 *Takiguchi and Abdullah (2001)*

Takiguchi & Abdullah (2001) proposed a shear design equation for square RC columns confined with circular shaped ferrocement jacket. The proposed shear design equation is as following:

$$V_j = \frac{0.125\, n\pi^2 d_w^2 f_{yj}\, D'}{g_w} \qquad (1a)$$

Alternatively, the required number of wire mesh for the strengthening of a shear deficient square RC columns is given by the following equation:

$$n = \frac{0.81 g_w V_j}{d_w^2 f_{yj}\, D'} \qquad (1b)$$

Where, $V_j$is the nominal shear strength provided by the ferrocement jacket; d_w is the diameter of wire mesh; f_{yj} is the allowable stress of wire mesh; n is the number of wire mesh layers, D' is the core diameter of strengthening jacket; and g_w is the spacing of wires in mesh.

2.2 *Abdullah and Takiguchi (2003)*

Subsequently, Abdullah and Takiguchi (2003) presented a modified model from their previous model for shear deficient square RC columns confined with square ferrocement jacket, as following:

$$n = \frac{0.78 g_w V_j}{d_w^2 f_{yj}\, D'} \qquad (2)$$

2.3 *Kumar et al. (2005)*

Meanwhile, Kumar et al. (2005) proposed a shear strength model for square RC columns confined with square ferrocement jacket, by relying on their experimental findings. In this model, the number of wire mesh layers required to provide nominal shear strength provided by ferrocement is computed by,

$$n = \frac{0.637 g_w V_j}{f_{yj}\, d_w^2 h} \qquad (3)$$

Here, h is the overall dimension of column parallel to the applied shear force, and all other notations are the same as reported by Takiguchi and Abdullah (2001).

2.4 Kazemi and Morshed (2005)

Kazemi and Morshed (2005) proposed a shear strength equation of square ferrocement jacketed square RC columns, as following:

$$V_n = V_{no} + V_{sf} \quad (4)$$

$$V_{sf} = 2\eta V_f t_f \alpha_f f_{yf} \quad (5)$$

where, V_n is the nominal shear strength of the jacketed column, V_{no} is the nominal shear strength of core RC column, V_{sf} is the nominal shear strength provided by the ferrocement jacket, η is the global efficiency factor for ferrocement reinforcement (0.65 for long diagonal direction of expanded mesh; and 0.5 for woven and welded mesh), V_f is the volume fraction of wire mesh, t_f is the thickness of ferrocement jacket, α_f is the distance between the load point and edge of the jacket (a gap distance less than shear span) and f_{yf} is the yield strength of wire mesh.

Among these four models, the model proposed by Takiguchi and Abdullah (2001) is applicable for circular ferrocement jacketed square RC columns. Other models are applicable for square types of ferrocement jacket. Therefore, in the analysis, the model proposed by Takiguchi and Abdullah (2001) was not considered. Other three models were analyzed for the comparison.

3 EXPERIMENTAL DATABASE

The experimental database was collected through reviewing the literatures published between the years 2000 to 2014. An extensive review of literature revealed that only 8 research articles reported seismic behavior of ferrocement confined RC columns, i.e. Takiguchi and Abdullah (2000), Takiguchi and Abdullah (2001), Kazemi & Morshed (2005), Kumar et al. (2005), Choi (2008) and Kim and Choi (2010). Among them, Choi (2008) and Kim and Choi (2010) tested circular RC columns strengthened with ferrocement jacket. Therefore, the test results from their studies were excluded from the database. The test results included in the database are summarized in Table 1. Following selection criteria were chosen to ensure consistency of the database.

(a) Only specimens with square cross-section were included in the database.

(b) Only specimens confined with square ferrocement jacket were considered.

(c) Only the specimens that were confined with continuous ferrocement jacket were included.

(d) Specimens reported in insufficient material and geometric properties were excluded.

Considering total number of studies reported in published literatures and the selection criteria mentioned above, the size of the test database is very small with 7 ferrocement strengthened square RC column tested under seismic loading. Tests on these 7 specimens were carried out by three different research teams who have considered completely different specimen details. Although the test database is very small, it could be considered sufficient as all these three research teams proposed separate shear strength models with their limited test data.

Table 1. Details and test results of specimens

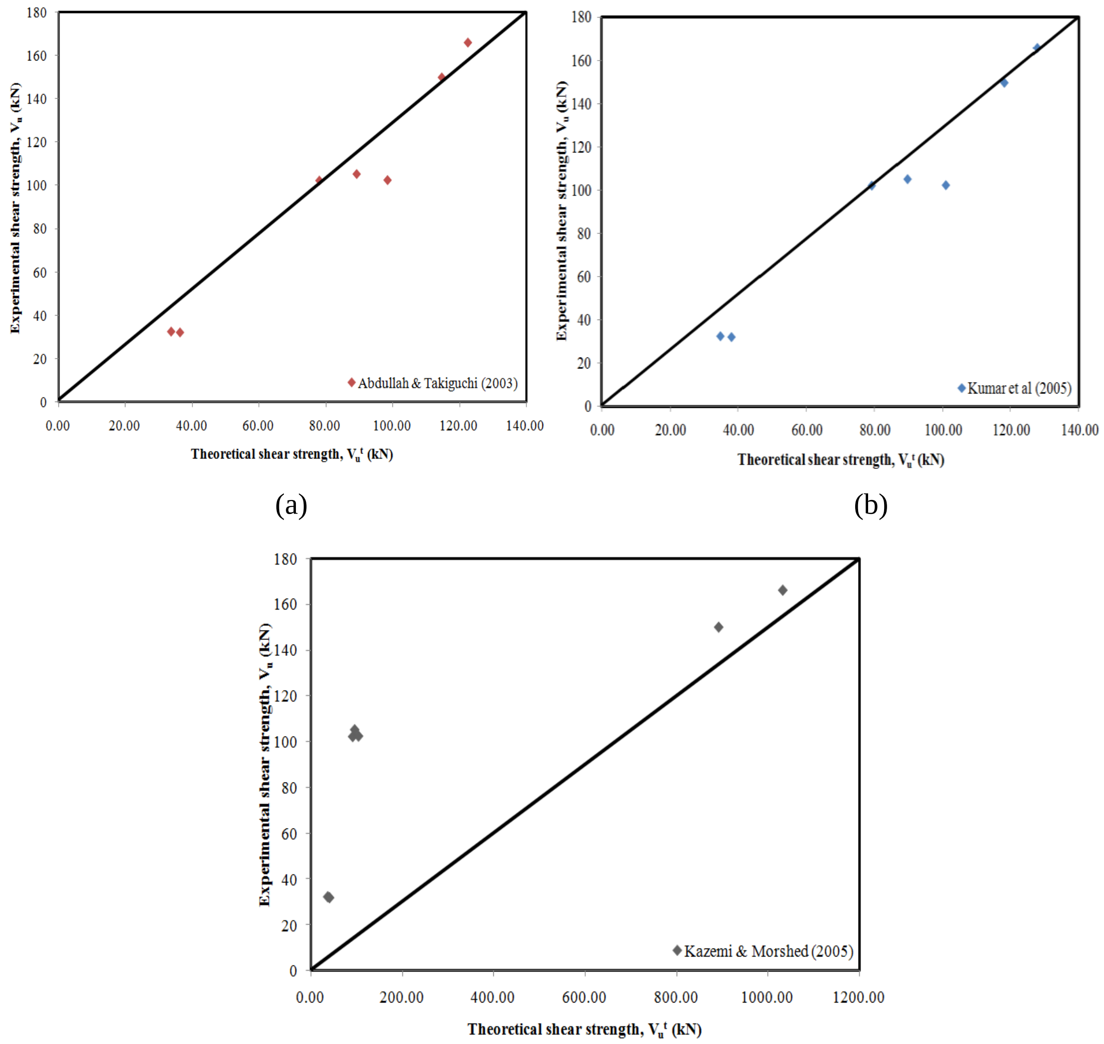
Research study	Specimen designation	Cross-section, *b* (mm)	Height of specimen, *H* (mm)	Number of mesh layers	Volume fraction, V_f	Yield strength of mesh (MPa)	Unconfined shear strength, V_n (kN)	Confined shear strength, V_u (kN)
Abdullah and Takiguchi (2003)	A1	120	600	4	0.051	267	28.3	32.5
	A2	120	600	6	0.0763	267	28.3	32.1
Kazemi and Morshed (2005)	B1	150	400	1	0.024	400	72.4	102.2
	B2	150	400	2	0.016	400	87.2	102.4
	B3	150	400	1	0.008	400	87.2	105.2
Kumar et al. (2005)	C1	360	1000	4	2.94	300	99.1	149.8
	C2	360	1000	6	3.46	300	99.1	165.9

4 ANALYSIS AND DISCUSSION OF RESULTS

All three models were analyzed for their applicability in predicting shear strength of ferrocement confined RC columns subjected to seismic loading. Table 2 presents the computed shear strength of different types of RC columns confined with ferrocement jacket using available (three) theoretical models. It is observed that the theoretical shear strength computed by the models proposed by Abdullah and Takiguchi (2003) and Kumar et al (2005) are comparable with the experimental results of all types of RC columns. However, the models proposed by Kazemi and Morshed (2005) cannot predict the strength of large size RC columns jacketed with high volume fraction of wire mesh.

Table 2. Evaluation of shear strength models

Specimens' designation	Theoretical shear strength of ferrocement jacket, V_j (kN)			Theoretical shear strength of confined RC column, V_u^t (kN)			Observed shear strength, V_u (kN)
	using Eqn. (2)	using Eqn. (3)	using Eqn. (5)	using Eqn. (2)	using Eqn. (3)	using Eqn. (4)	
A1	5.32	6.52	8.17	33.62	34.82	36.47	32.5
A2	7.99	9.78	12.22	36.29	38.08	40.52	32.1
B1	5.62	6.88	18.72	78.02	79.28	91.12	102.2
B2	11.23	13.75	16.64	98.43	100.95	103.84	102.4
B3	1.99	2.44	8.32	89.19	89.64	95.52	105.2
C1	15.60	19.10	793.80	114.70	118.20	892.90	149.8
C2	23.39	28.65	934.20	122.49	127.75	1033.30	165.9



(a) (b)

(c)

Figure 1. Applicability of shear strength models; (a) proposed by Abdullah and Takiguchi (2003); (b) Kumar et al. (2005);(c) proposed by Kazemi and Morshed (2005).

The applicability of the available shear strength models proposed by different researchers are shown in Figure 1. In this figure, experimentally obtained shear strengths are plotted against theoretically obtained shear strengths. The figure shows that the models proposed by Abdullah and Takiguchi (2003) and Kumar et al. (2005) can predict the shear strength which is very close to the experimental strength. However, these two models (in some cases) tends to overestimate the strength of ferrocement confined RC column. On contrary, the model proposed by Kazemi and Morshed (2005) tends to underestimate the shear strength, and in some cases the level of underestimation is high. Therefore, this model is not applicable for practical shear strength designing of deficient RC columns.

5 CONCLUSION

Ferrocement exhibits high in-plane shear strength, and thus applicable for strengthening shear deficient RC columns. However, the lack of research and literatures in this field has hindered its practical application. Result of this study shows that none of the available shear strength models can predict the strength of all types of ferrocement jacketed square RC columns up to a desired level. Consequently, these models may not applicable for practical design purposes. Hence, extensive experimental research together with the development of new shear strength model is required to warrant its practical application.

6 ACKNOWLEDGEMENT

The authors would like acknowledge the Ministry of Education of Malaysia for providing the necessary funding required for research through the ERGS Grant Scheme (ERGS/1/2011/TK/UKM/02/10 and ERGS/1/2013/TK03/UKM/02/6). The first author would also like to extend his gratitude to Universiti Kebangsaan Malaysia for the financial support provided through the Research University Zamalah Scholarship.

7 REFERENCES

Abdullah, K. and Takiguchi, 2003, An investigation into the behavior and strength of reinforced concrete columns strengthened with ferrocement jackets. *Cement and Concrete Composites*, 25(2) 233–242.

Choi, J.H., 2008, Seismic retrofit of reinforced concrete circular columns using stainless steel wire mesh composite. *Canadian Journal of Civil Engineering*, 35(2): 140 –147.

Kaish, A.B.M.A., M. Jamil, S. N. Raman and M. F. M. Zain, 2015a, An approach to improve conventional square ferrocement jacket for strengthening application of short square RC column. *Materials and Structures* 02/2015; In Press. DOI:10.1617/s11527-015-0556-z.

Kaish, A.B.M.A., M. Jamil, S. N. Raman, and M. F. M. Zain, 2015b, Axial Behavior of Ferrocement Confined Cylindrical Concrete Specimens with different sizes. *Construction and Building Materials*, 78(c): 50-59.

Kaish, A.B.M.A., M.R. Alam, M. Jamil, and M.A. Wahed, 2013, Ferrocement jacketing for restrengthening of square reinforced concrete column under concentric compressive load. *Procedia Engineering*, 54(2013), 720-728.

Kaish, A.B.M.A., M.R. Alam, M. Jamil, M. F. M. Zain, and M.A. Wahed, 2012, Improved ferrocement jacketing for restrengthening of square RC short column. *Construction and Building Materials*, 36(11): 228–237.

Kazemi, M.T., and R. Morshed, 2005, Seismic shear strengthening of R/C columns with ferrocement jacket. *Cement and Concrete Composites*, 27(4): 834–842.

Kim, S.H., J.H. Choi, 2010, Repair of earthquake damaged RC columns with stainless steel wire mesh composite. *Advances in Structural Engineering*, 13(2): 393-401.

Kumar, P.R., T. Oshima, S. Mikami, and T. Yamazaki, 2005, Seismic retrofit of square reinforced concrete piers by ferrocement jacketing. *Structure & Infrastructure Engineering*, 1(4): 253-262.

Takiguchi, K., and Abdullah, 2000a, Experimental investigation on ferrocement as an alternative material to strengthen reinforced concrete column, *Journal of Ferrocement*, 30(2): 177-190.

Takiguchi, K., and Abdullah. 2001, Shear strengthening of reinforced concrete columns using ferrocement jacket. *ACI Structural Journal*, 98(5): 696-704.