
Externally Bonded FRP Strengthening for Shear Friction at RC Wall-to-Diaphragm Connections

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ABSTRACT

Shear transfer across reinforced concrete (RC) wall-to-diaphragm joints is critical for lateral load resistance. Deficiencies in these connections, arising from construction omissions, deterioration, or seismic upgrade requirements, necessitate effective strengthening strategies. This paper synthesises results from 32 published large-scale experimental tests to evaluate the effectiveness of externally bonded fibre-reinforced polymer (EB-FRP) systems for enhancing in-plane shear-friction capacity. Key parameters include FRP coverage ratio, concrete surface profile, anchor configuration, FRP strip geometry, and interface fillet radius. Results show that EB-FRP systems can substantially increase shear-friction capacity, with anchored continuous configurations providing the greatest improvement. The synthesis highlights the governing role of interface preparation and anchorage detailing and provides consolidated experimental evidence and practical guidance for EB-FRP shear-friction strengthening of RC wall-to-diaphragm joints.

1 INTRODUCTION

The lateral load resistance of reinforced concrete (RC) structures depends strongly on wall-to-diaphragm connections. Insufficient shear-friction capacity at construction cold joints can compromise seismic performance (Bari 1987; Arthi and Jaya 2020). Conventional strengthening methods, such as steel dowels or concrete encasement, are limited by corrosion, added mass, and disruptive construction (Greeshma and Jaya 2013; Salim and Sahib 2022). Externally bonded fibre-reinforced polymer (EB-FRP) systems provide a lightweight and corrosion-resistant alternative and have been widely studied for beams, columns, diaphragms, and beam-column joints (Kalfat et al. 2013; Del Vecchio et al. 2014; del Rey Castillo et al. 2024; Zhang et al. 2025; Zhang et al. 2026) but design protocols for improving shear-friction resistance at wall-to-diaphragm cold joints remain underdeveloped, particularly for in-plane diaphragm action (Zhao et al. 2009; Chalot et al.

2021; Liu et al. 2023). This paper synthesizes published experimental studies, identifies governing parameters, and proposes a preliminary design method for EB-FRP shear-friction strengthening.

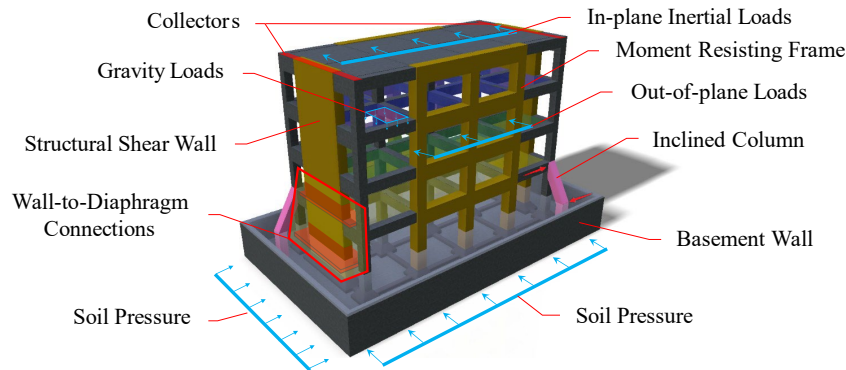


Figure 1: Representative wall-to-diaphragm connections in a reinforced concrete frame.

2 PUBLISHED WORK

2.1 Test setup

Three major experimental programs conducted at the University of California, Irvine (UCI) (Pardoen and Kazanjy 1996), North Carolina State University (NCSSU) (Abdullah 2023), and Idaho State University (ISU) (Deo et al. 2024) investigated the in-plane shear behaviour of reinforced concrete wall-to-diaphragm connections strengthened with externally bonded FRP systems. All programs employed large-scale wall–slab specimens with a construction cold joint at the interface, where EB-FRP was used to transfer shear forces across the joint. Specimens were subjected to quasi-static cyclic in-plane loading using servo-hydraulic actuators while the diaphragm was restrained to simulate realistic boundary conditions. A representative test setup is shown in Figure 2.

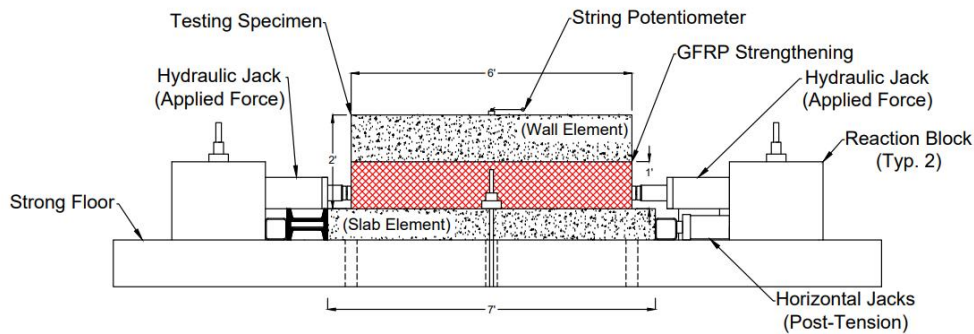


Figure 2: Typical wall-to-diaphragm strengthening test setup (Abdullah 2023).

2.2 Summary of existing tests

Table 1 summarises the existing experimental tests. Material properties include concrete compressive strength f'_c (MPa) and FRP elastic modulus E_f (GPa). Geometric properties include internal connection reinforcement, height of load application on the wall h_p (mm) for overturning moment, and diaphragm length l_c (mm). Interface and strengthening detailing include the concrete surface profile (CSP), fillet radius R_f (mm), strengthened sides, and wall-to-diaphragm strengthening height ratio α (%), FRP configuration includes FRP type, thickness t_f (mm), width b_f (mm), length l_f (mm), coverage ratio β (%), and layers (n). Fibre anchor parameters include dowel diameter d_0 , embedment depth h_{ef} (mm), installed number (N), spacing l_a (mm) and anchor layout. Ultimate strength (kN) and corresponding failure modes were recorded.

Table 1: Summary of existing wall–diaphragm test specimens and parameters.

No.	Name	Rebar Diameter (mm)	h_p (mm)	l_c (mm)	f'_c (MPa)	CSP	R_f (mm)	FRP Types	E_f (GPa)	Sides	l_f (mm)	b_f (mm)	α (%)	t_f (mm)	β (%)	n	d_0 (mm)	h_{ef} (mm)	l_a (mm)	Anchor layout	N	Peak Load (kN)	Failure mode
1	UCI-1	-	180	2135	-	1	20	Glass	18	2	3660	-	100	0.86	86	2	-	-	-	-	-	213.5	D
2	UCI-2	-	-	2135	-	1	20	Glass	18	2	3660	-	100	0.86	86	2	19	150	1220	T	8	266.9	FD
3	UCI-3	-	180	2135	-	3	65	Glass	18	2	3660	-	100	0.86	86	2	19	150	1220	S	8	587.2	D
4	UCI-4	-	360	2135	-	3	65	Glass	18	2	3660	-	100	0.86	86	2	19	150	1220	S	8	645	D
5	NCSU-1	9.5	100	1830	21.4	3	65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	262.4	RS
6	NCSU-2	-	100	1830	21.4	3	65	Glass	31.7	1	1830	305	100	0.86	100	1	-	-	-	-	-	569.4	D
7	NCSU-3	9.5	100	1830	21.4	3	65	Glass	31.7	1	1830	305	100	0.86	100	1	-	-	-	-	-	791.8	D
8	NCSU-4	-	100	1830	21.4	3	65	Glass	31.7	2	3660	305	100	0.86	100	1	-	-	-	-	-	867.4	D
9	NCSU-5	9.5	100	1830	21.4	3	65	Glass	31.7	2	3660	305	100	0.86	100	1	-	-	-	-	-	836.3	D
10	NCSU-6	9.5	200	1830	24.9	3	65	Glass	31.7	1	915	305	100	0.86	50	2	-	-	-	-	-	266.9	D
11	NCSU-7	9.5	200	1830	24.9	3	65	Glass	31.7	2	1830	305	100	0.86	50	2	-	-	-	-	-	311.4	D
12	NCSU-8	-	200	1830	24.9	3	65	Glass	31.7	2	1830	305	100	0.86	50	2	-	-	-	-	-	173.5	D
13	NCSU-9	9.5	200	1830	24.9	3	65	Glass	31.7	2	3660	305	100	0.86	100	2	-	-	-	-	-	444.8	D
14	NCSU-10	-	200	1830	24.9	3	65	Carbon	41	2	2440	305	100	0.86	67	2	16	100	150/305	T	32	711.7	RA

15	ISU-1	-	-	760	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	190.8	-	
16	ISU-2	-	-	760	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	226.4	-	
17	ISU-3	-	-	760	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	230.9	-	
18	ISU-4	-	-	760	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39.1	-	
19	ISU-5	-	-	760	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45.4	-	
20	ISU-6	-	-	760	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39.1	-	
21	ISU-7	-	-	760	-	1	40	Carbon	69	2	1220	305	100	1.25	80	1	-	-	-	-	-	145.9	
22	ISU-8	-	-	760	-	1	40	Carbon	69	2	1220	305	100	1.25	86	2	-	-	-	-	-	182.8	D
23	ISU-9	-	-	760	-	1	40	GFRP	28.8	2	1220	205	100	1.3	86	1	-	-	-	-	-	119.2	D
24	ISU-10	-	-	760	-	1	40	GFRP	28.8	2	1220	205	100	1.3	86	2	-	-	-	-	-	153.9	D
25	ISU-11	-	-	760	-	1	-	GFRP	28.8	2	1220	150	0	1.3	86	2	16	100	305	T	4	203.1	CF
26	ISU-12	-	-	760	-	1	-	GFRP	28.8	2	1220	150	0	1.3	86	2	13	100	305	T	4	183.9	CF
27	ISU-13	-	-	760	-	1	40	GFRP	28.8	2	1220	305	100	1.3	86	2	16	100	305	B	4	274.5	D
28	ISU-14	-	-	760	-	1	40	CFRP	69	2	1220	305	100	1.25	86	2	16	100	305	B	4	291.4	D
29	ISU-15	-	-	760	-	1	40	GFRP	28.8	2	1220	305	100	1.3	86	2	16&13	100	150	S	22	374.5	FR
30	ISU-16	-	-	760	-	1	40	CFRP	69	2	1220	305	100	1.25	86	2	16&13	100	150	S	22	347.9	D
31	ISU-17	-	-	760	-	1	40	GFRP	28.8	2	1220	305	100	1.3	86	4	16&13	100	150	S	22	398.6	D
32	ISU-18	-	-	760	-	1	40	CFRP	69	2	1220	305	100	1.25	86	4	16&13	100	150	S	22	359.4	D

Note:

1. Failure modes: D = FRP debonding from the concrete substrate; FD = anchor fan-out debonding; RS = rupture of internal steel starter bars; RA = failure of the anchored FRP system; CF = concrete joint shear failure; FR = FRP fabric fracture.
2. Anchor layout: T = fibre anchors installed after FRP strips; B = fibre anchors installed prior to FRP strips; S = fibre anchors installed between FRP strips (sandwiched configuration).

2.3 Parametric analysis

A parametric analysis evaluated 20 design, material, and geometric parameters influencing the peak shear-friction load. Absolute Pearson correlation coefficients, R^2 values and true importance (percentage change in peak load) were used to quantify parameter influence, as shown in Figure 3. Influence levels were classified as very high, high, medium, or low based on true importance and absolute correlation. The most influential parameters were β , CSP, N , b_f , l_f , α , l_c , h_{ef} , t_f , R_f , and h_p , which exhibited the highest influence on peak shear-friction capacity, ranked in descending order. Most parameters showed positive correlation with peak load, with concrete surface condition and FRP sheet configuration governing performance. Interpretation of the trends requires caution because parameter ranges remained limited. Only two CSP levels were collected, and most specimens adopted β around 80%, restricting statistical variation and sensitivity assessment.

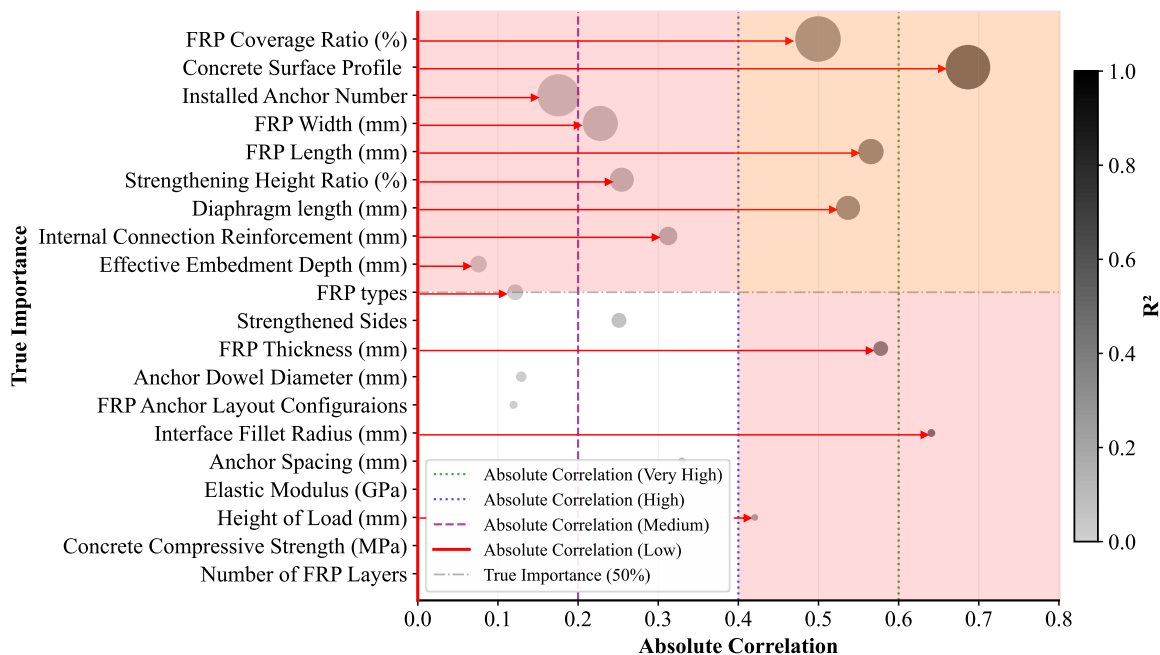


Figure 3: Parametric effect fence plot summarizing parameter R^2 , importance and correlation strength.

3 DESIGN RECOMMENDATIONS

The parametric analysis indicates that FRP coverage ratio, concrete surface profile, anchor configuration, and the interface fillet radius are the most influential parameters for enhancing shear-friction capacity at wall-to-diaphragm connections strengthened with EB- FRP systems. Continuous FRP layouts with adequate anchorage are recommended to mitigate debonding, while increased surface roughness and fillet radius improve bond performance and stress distribution. FRP stiffness and overall bonded length provide additional capacity gains but are secondary to detailing and interface conditions. The proposed empirical model offers a preliminary design tool for estimating peak shear-friction strength, though further validation with expanded experimental datasets is required.

4 CONCLUSION

This study synthesised and analysed 32 large-scale experimental tests from the literature to investigate the shear-friction behaviour of reinforced concrete wall-to-diaphragm connections strengthened with externally bonded FRP (EB-FRP) systems. Parametric evaluation identified FRP coverage ratio, concrete surface profile, fibre-anchor configuration, FRP strip geometry, and interface fillet radius as the most influential parameters governing shear-friction capacity. Results consistently show that anchored, continuous EB-FRP layouts combined with adequate surface preparation provide the greatest strength enhancement and mitigate premature debonding. The findings emphasise that interface condition and anchorage detailing govern performance more strongly than FRP material properties alone. The compiled database provides consolidated experimental evidence and practical insight into effective EB-FRP strengthening strategies for RC wall-to-diaphragm cold joints. However, the available test data remain limited in parameter range and configuration diversity. Further large-scale experiments covering broader detailing variations and loading conditions are required to improve understanding and support the development of reliable design provisions.

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