

Supplementary Materials

Appendix 1 Summary of experimental studies on the impact behavior of RC beams

Number	Specimen	Geometric size					Concrete	Longitudinal reinforcement				Shear reinforcement		Hammer		Test results			Reference
		b (mm)	h (mm)	l (mm)	l_n (mm)	a_s (mm)	f'_c (MPa)	A_s (mm ²)	f_y (MPa)	A'_s (mm ²)	f'_y (MPa)	f_{vy} (MPa)	ρ_v (%)	V (m/s)	M (kg)	F_p (kN)	S_{max} (mm)	Failure model	
T1	A37	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.21	3.67	384	750	8.1	Flexure	[35]
T2	A46	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.21	4.58	384	880	10.1	Flexure	
T3	A56	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.21	5.61	384	1000	13.1	Flexure-shear	
T4	A65	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.21	6.52	384	1110	16.0	Shear	
T5	A74	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.21	7.42	384	1290	22.0	Shear	
T6	A84	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.21	8.40	384	1400	24.4	Shear	
T7	B37	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.42	3.67	384	760	7.5	Flexure	
T8	B46	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.42	4.58	384	900	11.3	Flexure-shear	
T9	B65	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.42	6.52	384	1200	16.0	Shear	
T10	B74	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.42	7.42	384	1280	19.8	Flexure-shear	
T11	B84	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.42	8.40	384	1416	24.0	Flexure-shear	
T12	B93	200	400	2400	2000	50	41.2	1924	373	1924	373	373	0.42	9.30	384	1575	28.0	Flexure-shear	
T13	S1616-1	150	250	1700	1400	40	42.0	402	426	402	426	295	1.40	1.73	400	125	5.9	None	[1]
T14	S1616-2	150	250	1700	1400	40	42.0	402	426	402	426	295	1.40	2.45	400	180	11.0	None	
T15	S1616-3	150	250	1700	1400	40	42.0	402	426	402	426	295	1.40	3.46	400	248	20.1	Flexure	
T16	S1616-4	150	250	1700	1400	40	42.0	402	426	402	426	295	1.40	4.85	400	317	36.2	Flexure	
T17	S1322-1	150	250	1700	1400	40	42.0	760	397	265	397	295	1.40	2.45	400	190	7.8	None	
T18	S1322-2	150	250	1700	1400	40	42.0	760	397	265	397	295	1.40	3.46	400	260	11.4	Flexure	
T19	S1322-3	150	250	1700	1400	40	42.0	760	397	265	397	295	1.40	4.85	400	305	23.5	Flexure	
T20	S1322-4	150	250	1700	1400	40	42.0	760	397	265	397	295	1.40	6.86	400	340	27.0	Flexure	
T21	S2222-1	150	250	1700	1400	40	42.0	760	418	760	418	295	1.40	2.45	400	200	7.0	None	
T22	S2222-2	150	250	1700	1400	40	42.0	760	418	760	418	295	1.40	3.46	400	260	11.0	Flexure	
T23	S2222-3	150	250	1700	1400	40	42.0	760	418	760	418	295	1.40	4.85	400	313	21.4	Flexure	
T24	S2222-4	150	250	1700	1400	40	42.0	760	418	760	418	295	1.40	6.86	400	388	31.8	Flexure	

Appendix 1 (Continued)

Number	Specimen	Geometric size					Concrete	Longitudinal reinforcement				Shear reinforcement		Hammer		Test results			Reference
		b (mm)	h (mm)	l (mm)	l_n (mm)	a_s (mm)	f'_c (MPa)	A_s (mm ²)	f_y (MPa)	A'_s (mm ²)	f'_y (MPa)	f_{vy} (MPa)	ρ_v (%)	V (m/s)	M (kg)	F_p (kN)	S_{max} (mm)	Failure model	
T25	A1	150	250	1400	1000	40	24.0	265	345	265	345	295	0.75	5.00	300	434	24.1	n/p	[2]
T26	A2-1	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	3.46	150	321	13.6	Flexure	
T27	A2-2	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	2.45	300	293	25.4	Flexure	
T28	A2-3	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	2.00	450	245	37.0	Flexure	
T29	A2-4	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	4.90	150	453	16.3	Flexure	
T30	A2-5	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	3.50	300	417	31.6	Flexure	
T31	A2-6	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	2.80	450	346	43.7	Flexure	
T32	A2-7	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	6.00	150	573	17.9	Flexure	
T33	A2-8	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	4.24	300	513	33.3	Flexure	
T34	A2-9	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	3.46	450	445	48.4	Flexure	
T35	A2-10	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	1.00	300	65	4.5	Flexure	
T36	A2-11	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	2.00	300	253	12.6	Flexure	
T37	A2-12	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	3.00	300	426	26.9	Flexure	
T38	A2-13	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	4.00	300	489	41.4	Flexure	
T39	A2-14	150	250	2400	2000	40	24.0	265	345	265	345	295	0.75	5.00	300	466	58.3	Flexure	
T40	A4	150	250	4400	4000	40	24.0	265	345	265	345	295	0.75	5.00	300	452	114.9	n/p	[38]
T41	B	300	150	2400	2000	40	24.0	530	345	530	345	295	0.75	5.00	300	667	77.0	n/p	
T42	C	150	250	2400	2000	40	24.0	402	345	402	345	295	0.75	5.00	300	650	42.4	n/p	
T43	D	150	250	2400	2000	40	24.0	157	345	157	345	295	0.75	5.00	300	639	94.0	n/p	
T44	E	150	400	2400	2000	40	24.0	265	345	265	345	295	0.75	5.00	300	742	29.1	n/p	
T45	F	150	400	2400	2000	40	24.0	157	345	157	345	295	0.75	5.00	300	664	43.9	n/p	
T46	BD1	150	310	3000	1860	33	45.8	603	394	0	394	0	0.00	4.43	333	912	n/p	Shear	
T47	BD2	150	310	3000	1860	33	45.8	603	394	0	394	0	0.00	8.85	333	1708	n/p	Shear	
T48	BD3	150	310	3000	1860	33	45.8	603	394	0	394	0	0.00	5.71	200	1184	n/p	Shear	
T49	BD4	150	310	3000	1860	33	45.8	603	394	0	394	0	0.00	4.43	200	768	n/p	Flexure	
T50	BD5	150	310	3000	1860	33	45.8	603	394	0	394	0	0.00	5.71	200	1360	n/p	Flexure-shear	

Appendix 1 (Continued)

Number	Specimen	Geometric size					Concrete	Longitudinal reinforcement				Shear reinforcement		Hammer		Test results			Reference
		b (mm)	h (mm)	l (mm)	l_n (mm)	a_s (mm)	f'_c (MPa)	A_s (mm ²)	f_y (MPa)	A'_s (mm ²)	f'_y (MPa)	f_{vy} (MPa)	ρ_v (%)	V (m/s)	M (kg)	F_p (kN)	S_{max} (mm)	Failure model	
T51	G1-1	200	300	3400	3000	40	33.7	567	379	567	379	295	0.07	7.00	300	1496	64.3	n/p	[10]
T52	G1-1S	200	300	3400	3000	40	33.7	567	379	567	379	295	0.07	7.00	300	1601	58.0	n/p	
T53	G2-1	150	250	2400	2000	40	32.2	265	373	265	373	295	0.13	4.00	300	510	28.3	n/p	
T54	G2-2	150	250	2400	2000	40	32.2	265	373	265	373	295	0.13	5.00	300	779	44.0	n/p	
T55	G2-3	150	250	2400	2000	40	32.2	265	373	265	373	295	0.13	6.00	300	854	57.0	n/p	
T56	G2L-1	150	250	2400	2000	40	32.2	265	373	265	373	295	0.13	4.00	400	447	44.2	Flexure	
T57	G2L-2	150	250	2400	2000	40	32.2	265	373	265	373	295	0.13	5.00	400	668	66.8	Flexure	
T58	G2L-3	150	250	2400	2000	40	32.2	265	373	265	373	295	0.13	6.00	400	787	89.7	Flexure	
T59	G3-1	150	250	2400	2000	40	34.6	265	393	265	393	295	0.13	4.00	300	609	36.7	n/p	
T60	G3-2	150	250	2400	2000	40	34.6	265	393	265	393	295	0.13	5.00	300	770	52.0	n/p	
T61	G3-3	150	250	2400	2000	40	34.6	265	393	265	393	295	0.13	6.00	300	839	70.6	n/p	
T62	G4-1	150	250	2400	2000	40	32.3	265	373	265	373	295	0.13	4.00	300	800	39.7	n/p	
T63	G4-2	150	250	2400	2000	40	32.3	265	373	265	373	295	0.13	5.00	300	986	56.1	n/p	
T64	G5-1	200	300	3400	3000	40	39.2	567	379	567	379	295	0.07	6.00	400	1313	63.5	Flexure	
T65	G5-2	200	300	3400	3000	40	39.2	567	379	567	379	295	0.07	7.00	400	1557	83.4	Flexure	
T66	G6-1	250	250	2400	2000	40	34.7	567	392	567	392	295	0.13	5.00	300	1336	26.4	n/p	
T67	G7-1	250	250	3400	3000	40	34.7	567	392	567	392	295	0.09	5.00	300	1243	45.8	n/p	
T68	G7-2	250	250	3400	3000	40	34.7	567	392	567	392	295	0.09	6.00	300	1588	60.9	n/p	
T69	G8-1	200	200	2400	2000	40	34.7	982	383	982	383	295	0.16	6.00	300	1192	36.5	n/p	
T70	G9-1	200	200	3400	3000	40	34.7	982	383	982	383	295	0.12	5.00	300	931	43.2	n/p	
T71	G9-2	200	200	3400	3000	40	34.7	982	383	982	383	295	0.12	6.00	300	1103	57.9	n/p	
T72	G10-1	200	250	3400	3000	40	23.5	567	404	567	404	295	0.09	4.00	300	751	33.7	None	
T73	G10-2	200	250	3400	3000	40	23.5	567	404	567	404	295	0.09	5.00	300	922	49.5	Flexure	
T74	G10-3	200	250	3400	3000	40	23.5	567	404	567	404	295	0.09	6.00	300	1017	67.8	Flexure	
T75	G10-4	200	250	3400	3000	40	23.5	567	404	567	404	295	0.09	7.00	300	1042	83.9	Flexure	
T76	G11-1	200	300	3100	2700	50	23.6	760	401	760	401	295	0.08	3.13	500	703	20.5	n/p	

Appendix 1 (Continued)

Number	Specimen	Geometric size					Concrete	Longitudinal reinforcement				Shear reinforcement		Hammer		Test results			Reference
		b (mm)	h (mm)	l (mm)	l_n (mm)	a_s (mm)	f'_c (MPa)	A_s (mm ²)	f_y (MPa)	A'_s (mm ²)	f'_y (MPa)	f_{vy} (MPa)	ρ_v (%)	V (m/s)	M (kg)	F_p (kN)	S_{max} (mm)	Failure model	
T77	G11-2	200	300	3100	2700	50	23.6	760	401	760	401	295	0.08	4.20	500	971	33.2	n/p	[10]
T78	G11-3	200	300	3100	2700	50	23.6	760	401	760	401	295	0.08	5.05	500	1462	43.1	n/p	
T79	G11-4	200	300	3100	2700	50	23.6	760	401	760	401	295	0.08	5.78	500	1878	55.5	n/p	
T80	G11-5	200	300	3100	2700	50	23.6	760	401	760	401	295	0.08	6.42	500	1765	67.2	n/p	
T81	G11-6	200	300	3100	2700	50	23.6	760	401	760	401	295	0.08	7.00	500	1907	83.4	n/p	
T82	G12-1	200	300	3100	2700	50	23.6	1473	407	1473	407	295	0.08	7.67	500	1675	85.4	n/p	
T83	G13-1	200	400	3100	2700	50	23.6	982	406	982	406	295	0.06	7.67	500	2150	60.6	n/p	
T84	G14-1	200	350	3100	2700	50	23.6	982	406	982	406	295	0.07	7.67	500	2258	63.7	n/p	
T85	G15-1	200	400	3100	2700	50	23.6	982	406	982	406	295	0.06	7.67	500	2063	40.5	n/p	
T86	G16-1	200	370	3100	2700	50	23.6	982	406	982	406	295	0.06	7.67	500	2023	52.9	n/p	
T87	B1	200	400	2800	2400	42	20.1	982	429	402	429	314	0.50	5.90	253	1500	12.4	Flexure-shear	[41]
T88	B2	200	400	2800	2400	42	20.1	982	429	402	429	314	0.50	15.20	253	2203	79.8	Flexure	
T89	B3	200	400	2800	2400	42	20.1	982	429	402	429	314	0.50	7.20	393	1689	44.8	Flexure	
T90	B4	200	400	2800	2400	42	38.5	1473	429	402	429	0	0.00	7.20	393	2014	142.6	Shear	
T91	B5	200	400	2800	2400	42	38.5	1473	429	402	429	314	0.50	7.20	393	1948	20.3	Flexure	
T92	B6	200	400	2800	2400	42	38.5	1473	429	402	429	314	0.25	7.20	393	2214	31.4	Flexure-shear	
T93	B-1700-4.60	200	500	6000	5000	40	27.0	1257	495	402	495	344	0.09	4.60	1700	1360	83.7	Flexure	[7]
T94	B-1052-6.40	200	500	6000	5000	40	27.9	1257	495	402	495	344	0.09	6.40	1052	1900	79.3	Flexure-shear	
T95	B-868-7.14	200	500	6000	5000	40	24.8	1257	495	402	495	344	0.09	7.14	868	1450	209.0	Shear	
T96	C-1700-4.60	200	500	4000	3000	40	32.1	1257	495	402	495	344	0.09	4.60	1700	1380	118.0	Shear	
T97	C-1300-5.56	200	500	4000	3000	40	30.3	1257	495	402	495	344	0.09	5.56	1300	1500	67.4	Shear	
T98	C-868-7.14	200	500	4000	3000	40	26.3	1257	495	402	495	344	0.09	7.14	868	1780	67.9	Shear	
T99	D-1700-4.60	200	500	4000	3000	40	32.7	1257	495	402	495	344	0.19	4.60	1700	1380	41.5	Flexure	
T100	D-1300-5.56	200	500	4000	3000	40	25.6	1257	495	402	495	344	0.19	5.56	1300	1500	48.0	Flexure	
T101	D-868-7.14	200	500	4000	3000	40	25.0	1257	495	402	495	344	0.19	7.14	868	1780	47.5	Flexure-shear	

Appendix 1 (Continued)

Number	Specimen	Geometric size					Concrete	Longitudinal reinforcement				Shear reinforcement		Hammer		Test results			Reference
		b (mm)	h (mm)	l (mm)	l_n (mm)	a_s (mm)	f'_c (MPa)	A_s (mm ²)	f_y (MPa)	A'_s (mm ²)	f'_y (MPa)	f_{vy} (MPa)	ρ_v (%)	V (m/s)	M (kg)	F_p (kN)	S_{max} (mm)	Failure model	
T102	DR3.3_2.4-1	150	250	1700	1400	40	40.0	760	520	760	520	310	0.00	2.43	300	n/p	3.8	None	[36]
T103	DR3.3_2.4-2	150	250	1700	1400	40	40.0	760	520	760	520	310	0.00	3.43	300	n/p	6.9	Shear	
T104	DR3.3_2.4-3	150	250	1700	1400	40	40.0	760	520	760	520	310	0.00	4.20	300	n/p	12.7	Shear	
T105	DR3.3_2.4-4	150	250	1700	1400	40	40.0	760	520	760	520	310	0.00	4.85	300	n/p	30.0	Shear	
T106	DR3.3_2.4_0.12-1	150	250	1700	1400	40	40.0	760	520	760	520	310	0.11	2.43	300	n/p	6.4	Shear	
T107	DR3.3_2.4_0.12-2	150	250	1700	1400	40	40.0	760	520	760	520	310	0.11	3.43	300	n/p	11.5	Shear	
T108	DR3.3_2.4_0.12-3	150	250	1700	1400	40	40.0	760	520	760	520	310	0.11	4.20	300	n/p	18.2	Shear	
T109	DR3.3_2.4_0.12-4	150	250	1700	1400	40	40.0	760	520	760	520	310	0.11	4.85	300	n/p	21.6	Shear	
T110	DR3.3_2.4_0.56-1	150	250	1700	1400	40	40.0	760	520	760	520	310	0.54	3.43	300	n/p	9.0	None	
T111	DR3.3_2.4_0.56-2	150	250	1700	1400	40	40.0	760	520	760	520	310	0.54	4.20	300	n/p	13.4	Flexure	
T112	DR3.3_2.4_0.56-3	150	250	1700	1400	40	40.0	760	520	760	520	310	0.54	4.85	300	n/p	15.7	Shear	
T113	DR3.3_2.4_0.56-4	150	250	1700	1400	40	40.0	760	520	760	520	310	0.54	5.60	300	n/p	19.2	Shear	
T114	SR3.8_0.8-1	160	240	2000	1600	30	40.0	265	520	0	520	310	0.00	2.43	300	n/p	10.8	Flexure	
T115	SR3.8_0.8-2	160	240	2000	1600	30	40.0	265	520	0	520	310	0.00	3.43	300	n/p	20.2	Flexure	
T116	SR3.8_0.8-3	160	240	2000	1600	30	40.0	265	520	0	520	310	0.00	4.20	300	n/p	29.5	Flexure	
T117	DR3.8_0.8_0.11-1	160	240	2000	1600	30	40.0	265	520	265	520	310	0.11	3.43	300	n/p	18.6	Flexure	
T118	DR3.8_0.8_0.11-2	160	240	2000	1600	30	40.0	265	520	265	520	310	0.11	4.20	300	n/p	34.5	Flexure	
T119	DR3.8_0.8_0.11-3	160	240	2000	1600	30	40.0	265	520	265	520	310	0.11	4.85	300	n/p	41.0	Flexure	
T120	DR3.8_0.8_0.15-1	160	240	2000	1600	30	40.0	265	520	265	520	310	0.15	3.43	300	n/p	19.6	Flexure	
T121	DR3.8_0.8_0.15-2	160	240	2000	1600	30	40.0	265	520	265	520	310	0.15	4.20	300	n/p	28.8	Flexure	
T122	DR3.8_0.8_0.15-3	160	240	2000	1600	30	40.0	265	520	265	520	310	0.15	4.85	300	n/p	39.2	Flexure	
T123	SR5.7_1.6-1	120	170	2000	1600	30	40.0	265	520	0	520	310	0.00	2.43	300	n/p	20.0	Flexure	
T124	SR5.7_1.6-2	120	170	2000	1600	30	40.0	265	520	0	520	310	0.00	2.97	300	n/p	28.8	Flexure	
T125	SR5.7_1.6-3	120	170	2000	1600	30	40.0	265	520	0	520	310	0.00	3.43	300	n/p	37.1	Flexure	
T126	DR5.7_1.6_0.15-1	120	170	2000	1600	30	40.0	265	520	265	520	310	0.15	2.43	300	n/p	20.0	Flexure	
T127	DR5.7_1.6_0.15-2	120	170	2000	1600	30	40.0	265	520	265	520	310	0.15	2.97	300	n/p	30.0	Flexure	

Appendix 1 (Continued)

Number	Specimen	Geometric size					Concrete	Longitudinal reinforcement				Shear reinforcement		Hammer		Test results			Reference
		b (mm)	h (mm)	l (mm)	l_n (mm)	a_s (mm)	f'_c (MPa)	A_s (mm ²)	f_y (MPa)	A'_s (mm ²)	f'_y (MPa)	f_{vy} (MPa)	ρ_v (%)	V (m/s)	M (kg)	F_p (kN)	S_{max} (mm)	Failure model	
T128	DR5.7_1.6_0.15-3	120	170	2000	1600	30	40.0	265	520	265	520	310	0.15	3.43	300	n/p	39.1	Flexure	[36]
T129	DR5.7_1.6_0.20-1	120	170	2000	1600	30	40.0	265	520	265	520	310	0.21	2.43	300	n/p	19.1	Flexure	
T130	DR5.7_1.6_0.20-2	120	170	2000	1600	30	40.0	265	520	265	520	310	0.21	2.97	300	n/p	28.8	Flexure	
T131	DR5.7_1.6_0.20-3	120	170	2000	1600	30	40.0	265	520	265	520	310	0.21	3.43	300	n/p	37.9	Flexure	
T132	BD1	150	310	2700	1860	33	28.1	603	477	603	477	550	0.22	4.15	253	891	12.0	Flexure	[39]
T133	BD2	150	310	2700	1860	33	26.9	603	477	603	477	550	0.22	7.11	253	1396	24.0	Flexure	
T134	BD3	150	310	2700	1860	33	26.9	603	477	603	477	550	0.22	11.96	253	1940	75.0	Shear	
T135	BD4	150	310	2700	1860	33	41.4	603	477	603	477	550	0.22	7.81	578	1466	80.0	Flexure	
T136	BD5	150	310	2700	1860	33	41.4	603	477	603	477	550	0.22	5.10	578	983	38.0	Flexure-shear	
T137	A-1	100	250	3000	2500	28	30.0	402	490	402	490	340	0.38	3.12	968	260	81.0	Flexure	[40]
T138	A-2	100	250	3000	2500	28	30.0	402	490	402	490	340	0.38	4.00	587	420	74.0	Flexure	
T139	A-3	100	250	3000	2500	28	30.0	402	490	402	490	340	0.38	5.70	392	790	83.6	Flexure	
T140	A-4	100	250	3000	2500	28	30.0	402	490	402	490	340	0.38	8.50	197	800	89.5	Flexure	
T141	B-0-00	200	400	2800	2400	42.5	41.9	1473	460	402	460	0	0.00	7.20	393	2014	142.6	Shear	[37]
T142	B-0-25	200	400	2800	2400	42.5	41.9	1473	460	402	460	314	0.25	7.20	393	2214	31.4	Flexure-shear	
T143	B-0-50	200	400	2800	2400	42.5	41.9	1473	460	402	460	314	0.50	7.20	393	1948	20.3	Flexure	

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