Seismic design and pseudo-dynamic tests of blind-bolted CFT frames with buckling-restrained braces

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Captions for Tables

Table 1. Information of the test specimens

Specimen	Story	Height (mm)	Colum section $B\times t$ (mm)	Beam section $h_b\times b_f\times t_w\times t_f$ (mm)	BRB core plate $b_{brb}\times t_{brb}$ (mm)	End plate type
BBFD1	1F	1475	○ 200×8	H 300×150×6.5×9	□ 100×8	Extended-rectangular end plate
	2F	1550	○ 200×8	H 300×150×6.5×9	□ 100×8	Flush-rectangular end plate
BBCF2	1F	1475	□ 200×8	H 300×150×6.5×9	□ 100×8	Extended-curved end plate
	2F	1550	□ 200×8	H 300×150×6.5×9	□ 100×8	Flush-curved end plate

Table 2. Computation of BRB design ductility and dual system equivalent SDOF properties

Story	α_c	$\theta_{brb,yi}$ (mrad)	$\theta_{brb,di}$ (mrad)	$\mu_{brb,i}$	μ_{brb}	δ_i (mm)	m_i (t)	δ_{eq} (mm)	m_{eq} (t)	H_{eq} (mm)
1F	0.40	1.53	12.5	8.19	8.79	18.44	61.47	31.15	105.86	2492.36
2F	0.36	1.33	12.5	9.39		37.81	57.25			

Table 3. Computation process of frame design ductility (Specimen BBCF2)

Story	$M_{jR,ne}$ (N·mm)	$M_{jR,po}$ (N·mm)	$M_{bR,ne}$ (N·mm)	$M_{bR,po}$ (N·mm)	$m_{jR,ne}$	$m_{jR,po}$
1F	2.02×10^8	1.43×10^8	2.39×10^8	3.79×10^8	0.84	0.39
2F	1.69×10^8	1.09×10^8	2.39×10^8	3.79×10^8	0.71	0.29
Story	$S_{jini,ne}$ (N·mm/rad)	$S_{jini,po}$ (N·mm/rad)	$I_{b,ne}$ (mm^4)	$I_{b,po}$ (mm^4)	$\phi_{by,ne}$	$\phi_{by,po}$
1F	2.81×10^{10}	1.93×10^{10}	8.29×10^7	2.35×10^8	0.028	0.016
2F	2.50×10^{10}	1.61×10^{10}	8.29×10^7	2.35×10^8	0.028	0.016
Story	$k_{j,ne}$	$k_{j,po}$	$\psi_{jb,ne}$	$\psi_{jb,po}$	$\theta_{fy,ne}$ (mrad)	$\theta_{fy,po}$ (mrad)
1F	3.29	0.80	2.82	8.54	12.04	9.05
2F	2.88	0.66	3.08	10.05	10.99	8.07
Story	$\theta_{f,yi}$	$\theta_{f,di}$	$\mu_{f,i}$	μ_f		
1F	10.80	12.5	1.16	1.21		
2F	9.84	12.5	1.27			

Table 4. Overturning moment calculation from equivalent force profiles (Specimen BBCF2)

Story	F_i	V_i	$V_{f,i}$	$V_{brb,i}$	H_i(m)	$F_{brb,i}$	$F_{f,i}$	M_{brb}	M_f
2F	0.66	0.66	0.3	0.36	3.025	0.36	0.5	1.08	1.51
1F	0.34	1.0	0.5	0.5	1.475	0.14	0	0.21	0

Table 5. Computation of design base shear and force demand on BRB (Specimen BBCF2)

	T_{eq}(s)	k_{eq}(kN/m)	V_{eq}(kN)	F_i(kN)	V_i(kN)	$V_{brb,i}$(kN)	$P_{brb,i}$(kN)
China's code	0.445	21104.96	657.52	431.57(2F) 225.95(1F)	431.57(2F) 657.52(1F)	328.76 302.10	408.50 382.22

Table 6. Design results of gusset plates

Check content \ Gusset plate type	Gusset plate-1	Gusset plate-2	Gusset plate-3	Gusset plate-4
L_h (mm)	208	384	353	351
L_v (mm)	256	236	226	225
V_{ub} (kN)	128.17	132.95	139.83	140.10
H_{ub} (kN)	226.63	233.44	223.08	222.91
V_{uc} (kN)	109.37	104.59	105.34	105.08
H_{uc} (kN)	85.47	88.64	93.22	93.40
M_{ub} (kN.mm)	22164.80	9489.32	8781.84	8848.29
H_{FA} (kN)	214.77	317.19	305.79	305.06
V_{FA} (kN)	264.33	194.94	195.78	195.55
$h_{f,c}$ (mm)	8	8	8	8
$h_{f,b}$ (mm)	14	8	8	8
DCR_{gty}	0.63	0.50	0.52	0.52
DCR_{gb}	0.72	0.81	0.70	0.71
DCR_{cw}	0.73	0.67	0.69	0.69
DCR_{bw}	0.96	0.79	0.83	0.83
$DCR_{c,von}$	0.90	0.84	0.87	0.87
$DCR_{b,von}$	1.40	0.88	0.92	0.92

Note: V_{ub} and H_{ub} are the vertical and horizontal force components on the gusset-to-beam interfaces induced by BRB axial force, respectively; V_{uc} and H_{uc} are the vertical and horizontal force components on the gusset-to-column induced by BRB axial force, respectively; H_{FA} and V_{FA} are the horizontal and vertical force components of the improved equivalent strut model, respectively.

Table 7 Test schedule

Test number	Description	Excitation	Hazard level
Test No.1	FOE level	EI-Centro	PGA=0.1g (63% in 50 years)
Test No.2	DBE level	EI-Centro	PGA=0.3g (10% in 50 years)
Test No.3	MCE level	EI-Centro	PGA=0.5g (3% in 50 years)
Test No.4	MCE-after I	EI-Centro	PGA=0.8g
Test No.5	MCE-after II	EI-Centro	PGA=1.0g
Test No.6	MCE-after III	EI-Centro	PGA=1.2g

Table 8. Test results of steel material

Category	Steel wall thickness (mm)	Yield stress (N/mm^2)	Ultimate stress (N/mm^2)	Young's modulus (N/mm^2)	Elongation at fracture (%)
Steel beam flange	9	381.2	498.5	2.01×10^5	20.3
Steel beam web	6.5	358.1	485.2	2.14×10^5	21.5
End plate	12	363.8	473.9	2.08×10^5	20.8
Circular steel tube	8	335.7	478.2	2.03×10^5	21.0
Square steel tube	8	338.3	485.7	1.97×10^5	20.1
Gusset plate	8	358.7	481.3	2.05×10^5	20.8
Core plate of BRB	8	289.8	401.5	2.00×10^5	23.4
Restrainer	8	368.8	497.9	1.98×10^5	21.1
TC / BC rebar	8	386.5	438.2	2.06×10^5	22.5
TD / EC rebar	12	364.3	417.4	2.06×10^5	20.6

Table 9. Characteristic points of skeleton curve and ductility ratio

Specimen			Yield point		Maximum point		Failure point		Ductility
			δ_y（%）	P_y（kN）	δ_{max}（%）	P_{max}（kN）	δ_f（%）	P_f（kN）	μ
BBFD1	1F	（+）	0.304	424.38	4.259	1030.69	8.071	876.09	27
		（-）	0.177	254.69	4.791	1190.18	4.791	1190.18	27
	2F	（+）	0.221	274.61	1.389	592.07	1.710	589.65	8
		（-）	0.122	209.39	1.264	629.39	1.264	629.39	10
BBCF2	1F	（+）	0.221	413.54	7.561	1164.46	7.561	1164.46	34
		（-）	0.324	479.89	3.301	1477.18	3.301	1477.18	10
	2F	（+）	0.163	145.40	4.830	729.74	4.830	729.74	30
		（-）	0.180	122.35	1.912	863.31	1.912	863.31	11

Note: ‘(+)’ and ‘(-)’ mean ‘Positive Direction’ and ‘Negative Direction’, respectively.

Table 10 Final dissipated energy of specimens

Specimen	BBFD1		BBCF2	
	1st story (kN.mm)	2nd story (kN.mm)	1st story (kN.mm)	2nd story (kN.mm)
Test No.1	430	32	237	23
Test No.2	4619	1700	3345	2253
Test No.3	20949	7235	15854	7389
Test No.4	82068	20336	62814	22784
Test No.5	118999	27482	85776	29153
Test No.6	206640	14980	89239	34550