PEER Annual Meeting 2011

RESEARCH PLAN OF HIGH PERFORMANCE CONCRETE STRUCTURAL WALLS FOR TALL BUILDINGS

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1. Background

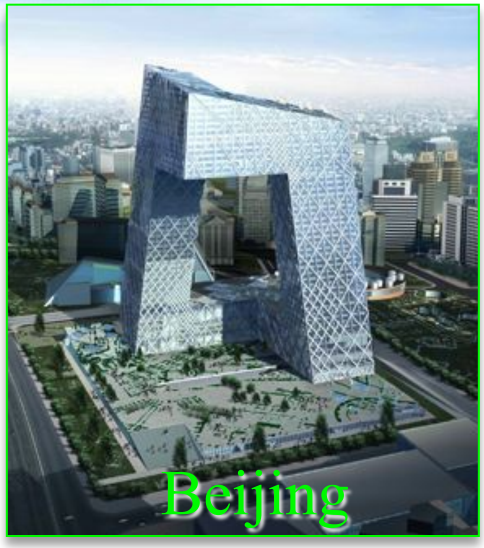
1.1 Current development of tall buildings worldwide

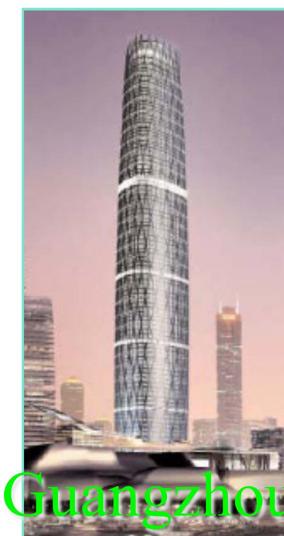
- **Council on Tall Buildings and Urban Habitant (CTUBH):**
- **Top 15 tallest buildings: 9 (China)**
- **Top 38 tallest buildings (2005~2010): 17 (China); 8 (Dubai)**
- **The construction center of tall buildings has transferred from North America to Asian and Middle East.**

CTBUH, 2011/8/4

#	-	building name	city	meters	feet	fl.	year	material	use
1.		Burj Khalifa	Dubai (AE)	828	2,716	163	2010	steel-concrete	hotel / residential / office
2.		Taipei 101	Taipei (TW)	508	1,666	101	2004	composite	office
3.		Shanghai World Financial Center	Shanghai (CN)	492	1,614	101	2008	composite	office / hotel
4.		International Commerce Centre	Hong Kong (CN)	484	1,588	108	2010	composite	office / hotel
5.		Petronas Tower 1	Kuala Lumpur (MY)	452	1,482	88	1998	composite	office
5.		Petronas Tower 2	Kuala Lumpur (MY)	452	1,482	88	1998	composite	office
7.		Zifeng Tower	Nanjing (CN)	450	1,476	66	2010	composite	office / hotel
8.		Willis Tower	Chicago (US)	442	1,450	108	1974	steel	office
9.		Guangzhou International Finance Center	Guangzhou (CN)	439	1,439	103	2010	composite	office / hotel
10.		Trump International Hotel & Tower	Chicago (US)	423	1,388	98	2009	concrete	hotel / residential
11.		Jin Mao Building	Shanghai (CN)	421	1,379	88	1999	composite	office / hotel
12.		Two International Finance Centre	Hong Kong (CN)	412	1,351	88	2003	composite	office
13.		CITIC Plaza	Guangzhou (CN)	390	1,280	80	1996	concrete	office
14.		Shun Hing Square	Shenzhen (CN)	384	1,260	69	1996	composite	office
15.		Empire State Building	New York City (US)	381	1,250	102	1931	steel	office

1.2 Tall buildings in China





1.3 Structural systems for tall buildings

Planar members
- Frames
- Shear walls
- Bracings

Spacial members
- Framed tubes
- Core tubes

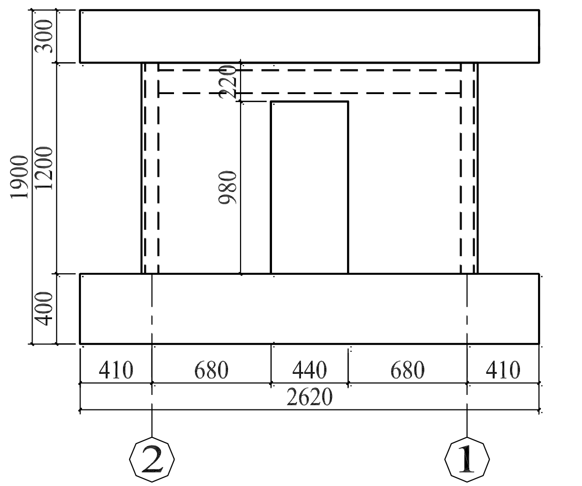
Structural systems
- Frame structures
- Shear wall structures
- Frame-shear wall structures
- Frame-core tube structures
- Bracing-framed tube structures
- Tube-in-tube structures
- Bundled tube structures
- Mega frame-core tube structures
- ...

Structural walls are indispensable elements of tall and super-tall buildings to sustain the vertical gravity and horizontal earthquake effects and wind loads.

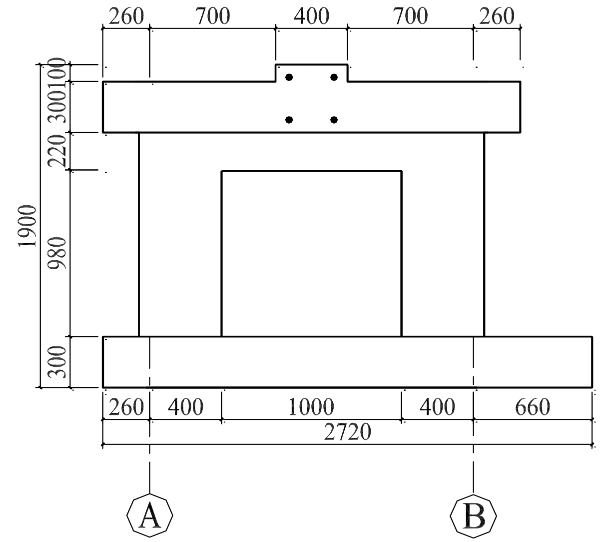
2. Structural walls of tall buildings

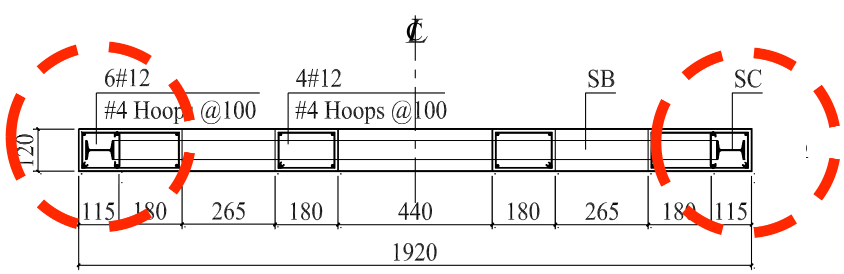
2.1 SRC shear walls (1)

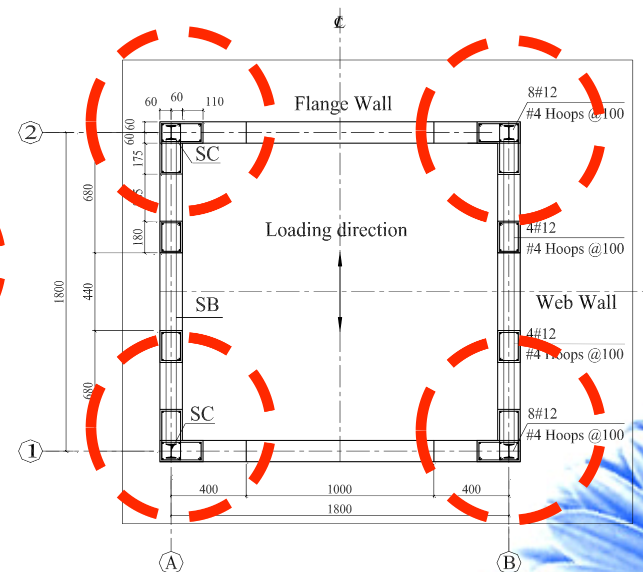
Test Specimen



Geometry of SCW Specimens



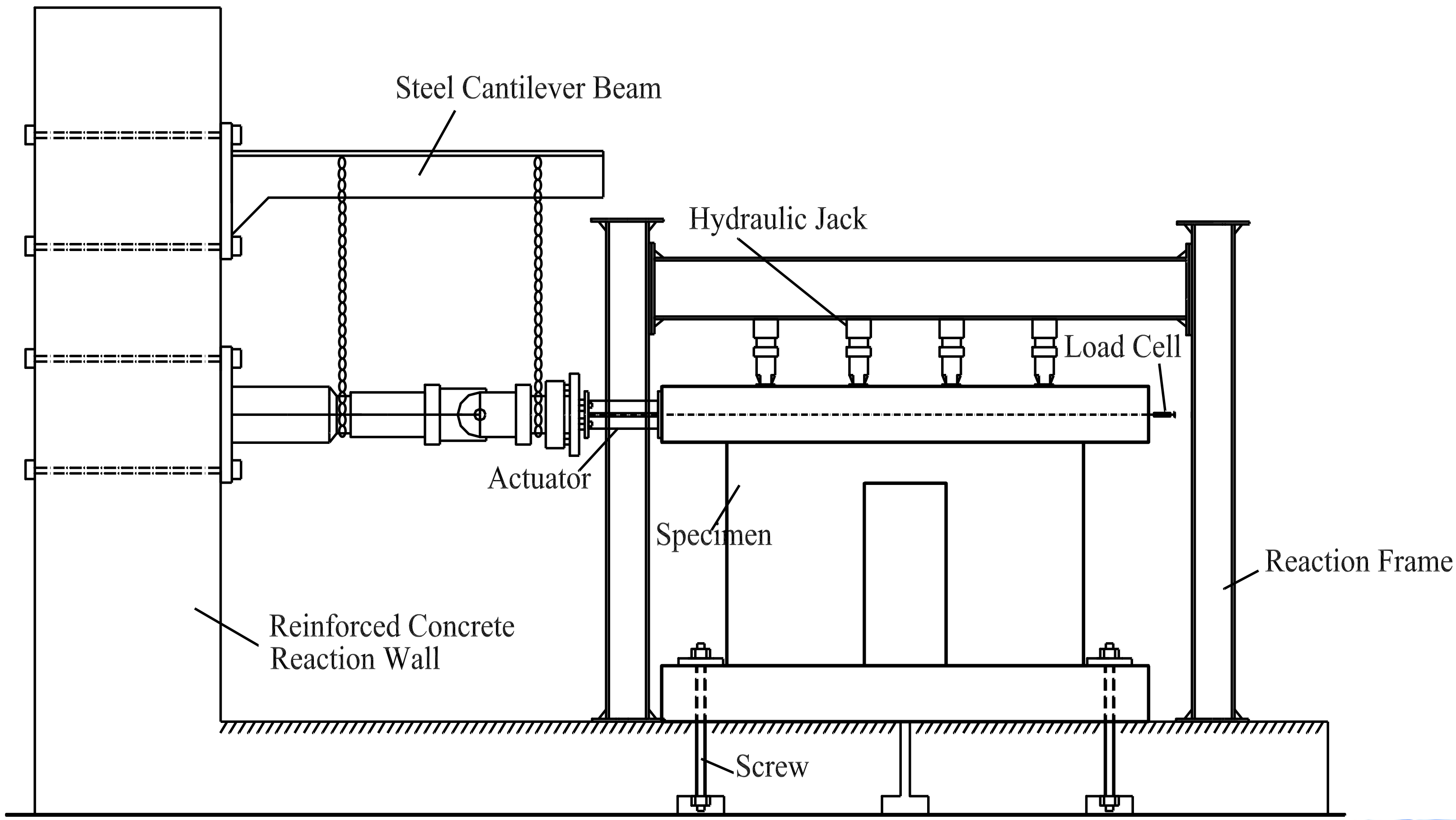




Angel steels embedded at boundary columns

2.1 SRC shear walls (2)

Test Setup

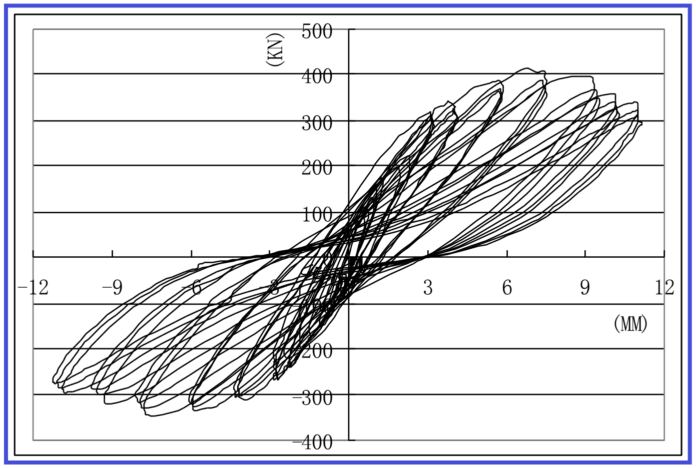


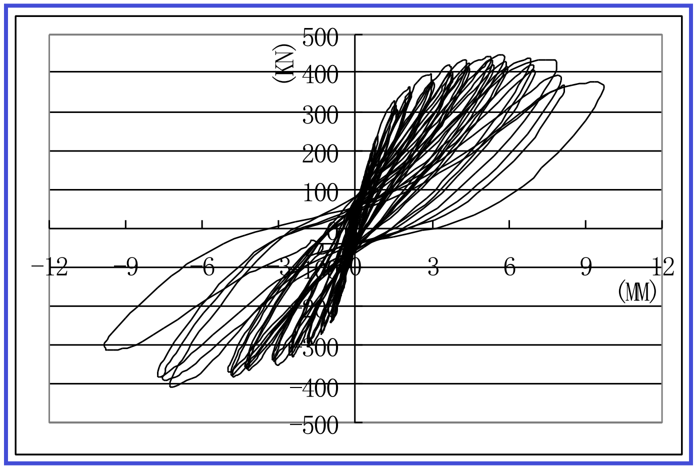
2.1 SRC shear walls (3)

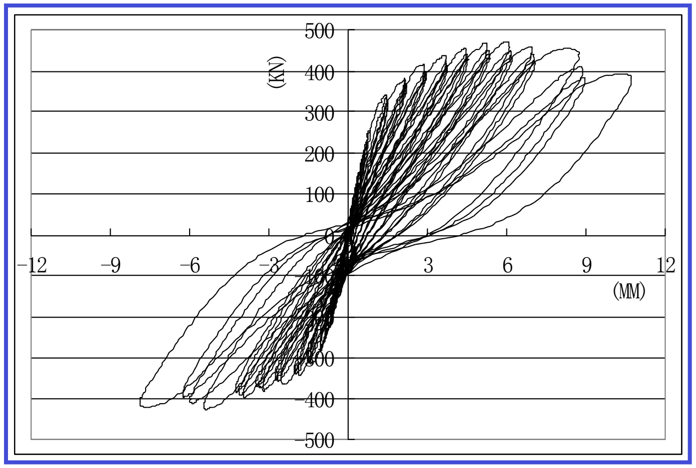
Observations

2.1 SRC shear walls (4)

Observations







2.1 SRC shear walls (5)

Formulations

$$V_u = V_c + V_a + V_t$$

Arch mechanism contribution and primarily related to the geometry and axial load

The contribution from the truss mechanism primarily from the shear reinforcement

The concrete contribution primarily from the concrete aggregate interlock mechanism

2.1 SRC shear walls (6)

Formulations

For SRC walls,

$$V_u^{SRCW} = \frac{1}{\lambda - 0.5}\left(0.04 f_c b h_0 + 0.1N \frac{A_w}{A}\right) + 0.8 f_{yv} \frac{A_{sh}}{s} h_0 + \frac{0.5}{\lambda} f_a A_a$$

The dowel action and confinement effect of edge structural steels

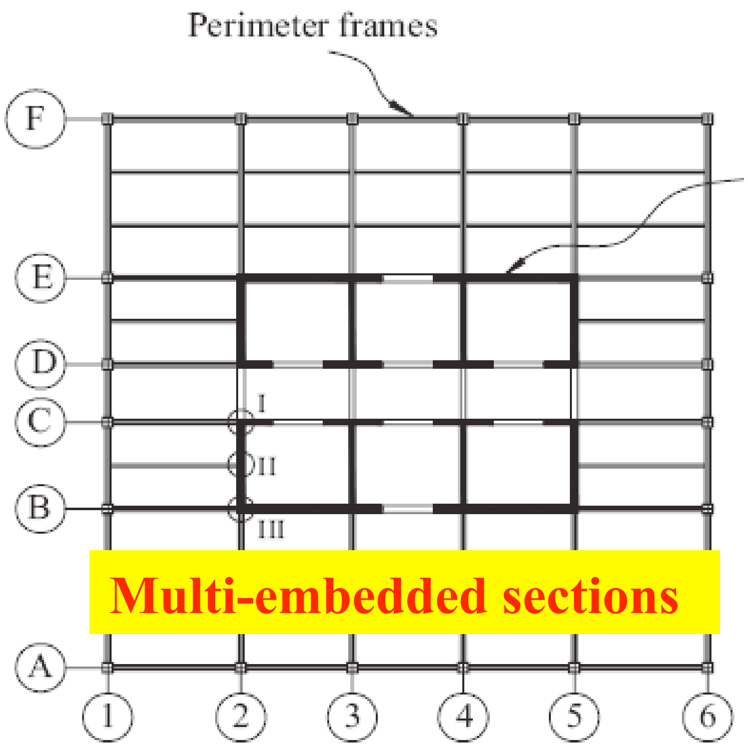
For SRC tubes,

$$V_u^{ST} = \frac{1}{\lambda - 0.5}\left(0.04 \beta_r f_c b h_0 + 0.1N \frac{A_w}{A}\right) + 0.8 f_{yv} \frac{A_{sh}}{s} h_0 + \frac{0.5}{\lambda} f_a A_a$$

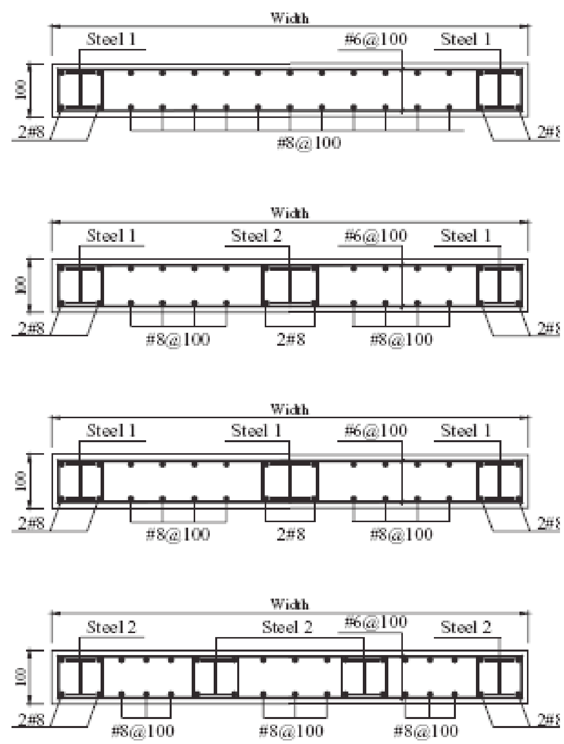
First Conference on Advances in Experimental Structural Engineering (2005)

Confined factor of the flange walls to the web walls, use $\beta_r = 1.3$ here

2.2 SRC shear walls (1)



Multi-embedded sections



-1:3;
-16 specimens;
-0.8/1.5/ 2.0/3.75 aspect ratio;
-shear type flexual type.

- **Steel embedded in the middle and at boundaries**

2.2 SRC shear walls (2)

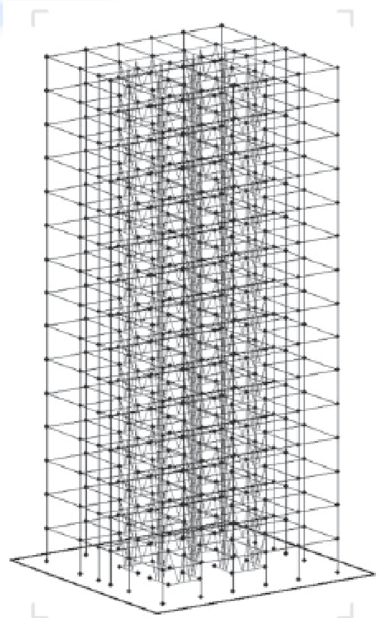
Only boundaries

Both boundaries and middle sections

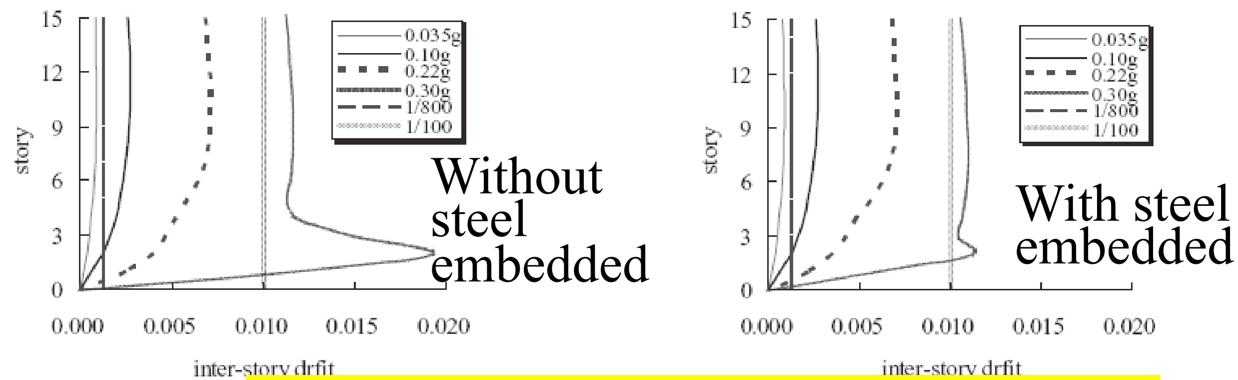
Specimen name	Aspect ratio	Axial force ratio	Crack load P_{cr} (kN)	Disp. at the crack load D_{cr} (mm)	Yield load P_y (kN)	Disp. at the yield load D_y (mm)	Maximum load P_m (kN)	Disp. at the max. load D_m (mm)	Ultimate load P_u (kN)	Disp. at the ultimate load D_u (mm)	Disp. ductility factor μ
CSW-2	3.75	0.09	30	4.7	64	11.3	107	21.7	91	85.0	7.5
CSW-3	3.75	0.18	50	3.6	66	10.4	116	24.8	99	68.0	6.5
CSW-4	2.00	0.18	100	3.6	260	8.6	307	20.2	261	37.7	4.4
CSW-5	1.50	0.18	200	3.2	402	7.3	489	14.4	416	28.0	3.8
CSW-6	1.50	0.18	100	2.3	379	8.1	419	13.2	356	27.0	3.3
CSW-7	1.50	0.18	200	2.3	384	8.5	523	20.0	445	34.7	4.1
CSW-8	1.50	0.09	150	3.3	376	9.0	480	23.0	408	40.3	4.5
CSW-9	1.50	0.09	150	3.0	339	8.9	426	15.3	362	37.8	4.3
CSW-10	1.50	0.09	150	2.8	385	8.7	484	19.8	412	39.3	4.5
CSW-11	1.50	0.18	150	2.5	383	7.4	512	20.0	435	35.2	4.7
CSW-12	1.50	0.18	200	2.9	383	7.5	517	20.5	439	36.8	4.8
CSW-13	1.50	0.18	150	2.3	364	5.0	475	10.1	404	20.0	4.0
CSW-14	0.80	0.18	170	1.8	504	4.8	566	8.8	481	10.0	2.1
CSW-15	0.80	0.24	200	1.7	590	6.5	597	10.3	507	11.3	1.7
CSW-16	0.80	0.18	170	2.3	589	6.4	598	11.3	508	14.1	2.2

- **MSS did not affect the final failure mode of the CSW, but they would restrain the development of cracks and prevent the concrete from serious spalling.**

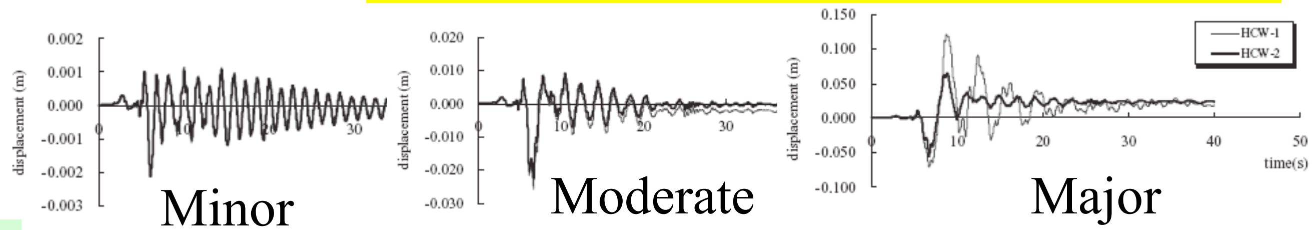
2.2 SRC shear walls (3)



Analytical model



Difference in inter-story drift



Difference in time-history displacement

- **The effect of the embedded steel sections is not significant at the elastic stage. When structure entered nonlinear stage, however, the steel members encased in the reinforced concrete shear walls contributed to the good performance of structures.** *SDTSB* (2010)

2.3 Problems

2008 Wenchuan Earthquake

2010 Chile Earthquake

Experiment

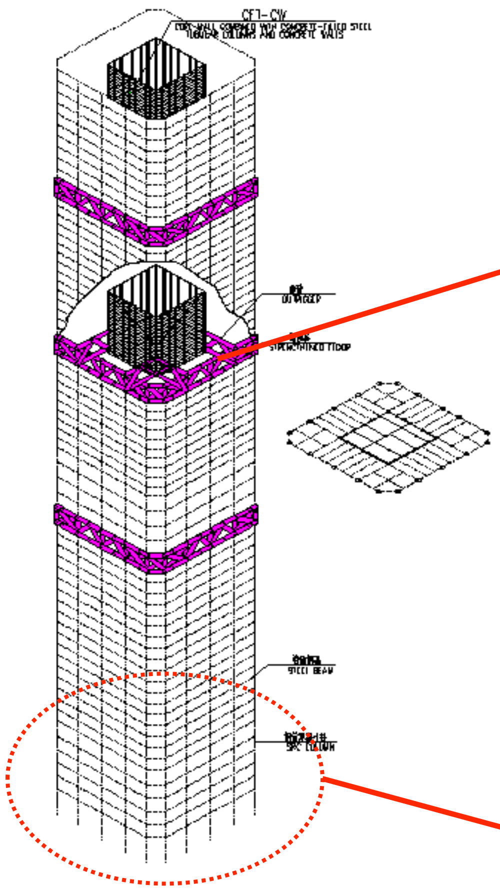
There still are damages to shear walls.

3. Earthquake resilience of tall buildings

3.1 Earthquake resilient structures

- **Structures without damages or with only minor damages happened after earthquakes are called "*Earthquake resilient structures*", which recently has been a worldwide hot issue in earthquake engineering.**

3.2 Earthquake resilience of tall bldgs



Elastic

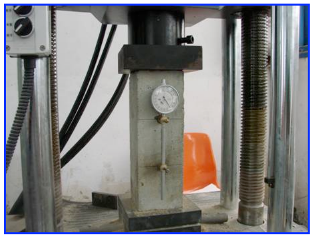
(NSFC project, 2011-2013)

High performance concrete shear walls

4. HP concrete structural walls of tall buildings

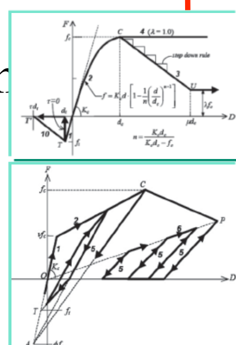
4.1 Research plan

Material



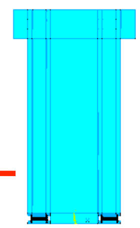
Mechanical properties:
- Hybrid effect
- Compressive strength
- Tensile strength
- Flexural strength
- Impact toughness

Ductility properties:
- Fatigue
- Impermeability
- Cracking resistance
- Frost resistance
- Corrosion resistance

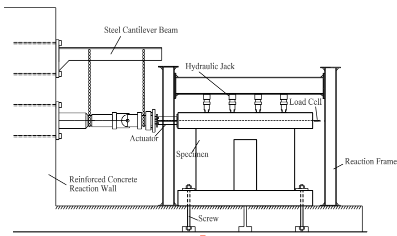


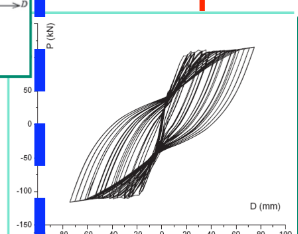
Member

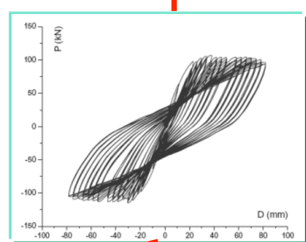
Analysis



Test

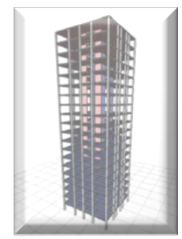






System

Analysis



Test

Earthquake resilience of tall buildings

Conclusions

- In the next couple of years there will be increasing design and construction of tall buildings in China.
- To improve the seismic performance of shear walls for tall buildings, steel reinforced concrete (SRC) walls have been experimentally and analytically studied.
- High performance concrete shear wall will be explored for the earthquake resilience of tall buildings.
- Collaboration with professors in material is strongly needed for this research.

Thanks for your attention!

- Any Question?
- Any Suggestion?