



Damage of Buildings

by

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Road Maps

- Overview
- Statistics of damaged buildings
- Performance of Old and New RC Buildings
- Case study: Nagano-machi apartment complex building in Sendai
- Beam-column joint : Full Scale Shaking Table Test on E-Defense
- Concluding remarks



Direct material damage from the disaster estimates 16.9 trillion yen

Building	10.4	61.5%
Civil infrastructure	2.2	13.0%
Agriculture & Fishery	1.9	11.2%
Lifeline	1.3	7.7%
Others	1.1	6.5%
Total	16.9	100.0%

Unit: trillion yen (1 trillion yen = 12.5 B US\$)

loss due to failure of nucleus four power plant units excluded



Tsunami : 10 meter high

Minami Sanriku, Miyagi

Source: Mainichi News Paper

Only RC buildings remained intact from deadly collapse

Typical Tsunami Damage to Buildings

(in Watari, W)



(in Yamada, RC)

(in Watari, Concrete Block)

Simplified Water Pressure Formula for Design



Tsunami Resistance of Buildings

- Reinforce concrete buildings have potential to survive.
- Tsunami evacuation buildings are necessary for saving the lives who can not relocate quickly to safer place.
- Simplified water pressure formula for design are evaluated by examining the tsunami survived and collapsed buildings inventory

Statistics of Damaged Non-residential Buildings

fecture Number	~
kaido 470	
nori 1,184	- okkaido (470)
te 1,538	ri (1184)
agi 17,315	(1538)
ushima 1,015 Sendai, Miyagi	(17.315)
raki 8,449 Fukush	nima (1,015)
higi 295 Tsunami damage Ibaraki ((8449)
mma 195)
ama 33	
ba 708	IL PROPERTY
/0 20	The second
agawa 2	
Da708/O20agawa2the National Police Age	ency

Statistics of Housing Severely Damaged

Prefecture	Death &	Severe
Trefecture	missing	Damage
Hokkaido	1	0
Aomori	3	306
Iwate	4,709	20,998
Miyagi	9,194	65,462
Fukushima	1,709	15,897
Ibaraki	24	2,163
Tochigi	4	257
Gunmma	1	0
Saitama	1	7
Chiba	20	771
Tokyo	7	11
Kanagawa	4	0

Credit: the Fire Defense Agency



Tsunami damage buildings included





Statistics of Damaged Buildings

- Brief history of RC buildings and seismic codes in Japan
- The rate of damaged buildings are low but Damage buildings location widely distributed in east Japan

Revisions of Japanese seismic provisions in codes



Inventory Study of RC School Buildings in Miyagi



Inventory of School RC Buildings in Miyagi



Typical Damage to Structural & Nonstructural Members



Shear Failure of RC Captive Column



Shear Failure of RC Shear Wall



Shear Failure of RC Boundary Beam



Failure of RC Stair Anchorage





Fallen non-structural Concrete Brick

Fallen non-structural Ceiling

Performance of Old and New Buildings

- Inventory Study of RC School Buildings were made
- Similar pattern of damage compared to past building damaged observed
 - shear failure structural members
 - non-structural elements
- Effectiveness of seismic retrofit is proved

Case Study:

Nagano-machi Apartment Complex

Nagano-machi Apartment Complex

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THE REAL PROPERTY

Nagano-machi Dwelling Building Complex

- in Sendai City
- RC/SRC 9 floors.
- Completed in 1969
- Survived major earthquakes in 1978, 2003 and 2005.
- Seismic vulnerability was assessed in 2010
- No rehabilitation yet
- Fc 210 & 180
- Grade SD35 rebars
- to be demolished



Elevation of X₁ frame in transverse direction



1st floor plan and damage rate



2nd floor plan and damage rate



3rd floor plan and damage rate



Elevation of X₁ frame in longitudinal direction



flexural failure and buckling of rebars at the bottom of column

Damage grade : V



Elevation of Y₄ frame in longitudinal direction







Detailing : Beam-column Joints



(a) Beam-column joint at 7F (X_5 - Y_4)

(b) Beam-column joint at $5F(X_5-Y_4)$

Performance Evaluation of Beam-column Joint



floor plan Tributary area of gravity load

	Joint	Shear f	ailure	Beam Flexural hinge in kN		Column- strengt	Joint shear		
	column	beam	joint	column case 1*	column case 2*	beam	case 1 Wall+Column	case 2 Column	strength margin*
9FL	544.4	858.7	863.4	522.5	396.7	231.7	2.25	1.71	3.73
8FL	555.0	929.1	984.0	650.8	454.0	320.2	2.03	1.42	3.07
7FL	589.2	1043.2	1112.3	751.5	496.7	335.0	2.24	1.48	3.32
6FL	799.7	1148.5	1150.1	906.6	574.8	432.2	2.10	1.33	2.66
5FL	907.8	1162.5	1624.0	1082.9	664.0	528.3	2.05	1.26	3.07

Case Study: Nagano-machi Apartment Complex

- Structural system and the damage rate of structural components
- Seismic vulnerability assessment
- Beam-column joint
- Conclusions

Beam-column joint: Full Scale Shaking Table Test at E-Defense

1493 E-Defense Shak

E-Defense test on RC Building in December 2011



List of Column					
		C1	C2		
	Section				
4F1.	BxD	500 x 500	500 x 500		
3Fl.	Rebar	8-D22	10-D22		
	Ноор	2,2-D10@100	2,2-D10@100		
	Joint	2,2-D10@140	2,2-D10@140		
	Section	00			
2F1.	BxD	500 x 500	500 x 500		
	Rebar	8-D22	10-D22		
	Ноор	2,3-D10@100	2,4-D10@100		
	Joint	2,2-D10@140	2,2 - D10@140		
	Top Section	00			
	BxD	500 x 500			
	Rebar	8-D22			
	Ноор	2,3-D10@100			
1 F1	Joint	2,2-D10@140			
	Bottom Section				
	B x D	500 x 500	500 x 500		
	Rebar	10-D22	10-D22		
	Ноор	3,4-D10@100	3,4-D10@100		
	Joint	2,2-D10@140	2,2-D10@140		

List of Girder					
		G1			
	Location	End	Center	End	
R F1	Section	,, ,, ,,	 ee	0 0 0 0 0 0	
4F1.	B x D	300 x 600			
	Тор	4-D22 3-D22		4-D22	
	Bottom	3-D22 3-D22		3-D22	
	Web		4-D10		
	Stirrup	2-	D10@20	00	
	Section	ه ه , , ه ه م	, ,, ,,		
3F1.	B x D	300 x 600			
	Тор	5-D22	3-D22	5-D22	
	Bottom	3-D22	3-D22	3-D22	
	Web	4-D10			
	Stirrup	2-	D10@20	00	
2F1.	Section	600 , , 600	 e	6 6 8 	
	B x D	300 x 600			
	Тор	6-D22	3-D22	6-D22	
	Bottom	3-D22	3-D22	3-D22	
	Web	4-D10			
	Stirrup	2-D10@200			

Margin of Joint Shear Capacity



Joint shear / Nominal joint shear capacity

Column-to-beam strength ratio



Column-to-beam strength ratios

JMA Kobe 50%

2010/12/13 16:29:46.000

JMA Kobe 50%

E-Defense

q.

JMA Kobe 100%

2010/12/15 15:02:37.230

Beam-column joint: Full Scale Shaking Table Test on E-Defense

- Nagamachi Dwelling Complex Building
- Flexural failure of the first story SRC column
 - deficiency of steel lattice not embedded into the foundation which just ends at the first floor level.
 - abrupt change of section caused the damage.
- Shear failure of lightly reinforced beam-column joints.
 - calculated margin of joint shear strength is 2.0 or more.
 - column-to-beam strength ratio is in the range of 1.26 to 1.48.
 - vulnerablity of column-to-beam strength ratio between 1.0 and 1.5 are to joint shear failure.
 - problem in failure mode prediction

Further information : Recommended Resources on Building Damage

PREFACE

Devastating damage in the Tohoku region of Japan occurred during and after the earthquake off the Pacific coast of Tohoku earthquake on March 11, 2011.

The report summarizes damage associated with **ground failures** including landslide and liquefaction as well as **non-structural damages** such as to equipment and facilities, partitioning walls and ceilings, and **functional failures in skyscrapers**. Also brief description of the Japanese Seismic Design Code will be provided in the Appendix. A proposed scheme of **antitsunami design for buildings** is also included.

Thank you for your kind attention.