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Intercontinental Hotel, Santiago, May 27, 2014

Japan's Key Technologies for Seismic Protection of New and Existing Buildings

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Summary of Experiences & Findings from 3.11 (Building Structures)

- Acceleration-induced failures and falling of ceiling, electrical & mechanical systems, and loss of building functions.
- Large displacements of super-tall bldgs. even at long epicentral distance, due to long period ground motions.
- Difficulty of quick evaluations of damage and functionality in judging continued use of major buildings.
- Strong motion records of major bldgs. & super-tall bldgs. in Tohoku (>0.4g) and Tokyo (≈ 0.1g), clarifying many issues.
- Protective systems (base isolation & added damping systems) performed well at various epicentral distances.

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1. Introduction to Protective Systems
2. Largest Shake Table Test of Building with Dampers
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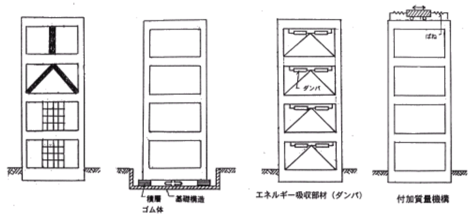
6. Conclusions

Coventional System vs. Two Protective Systems



Conventional Structure : Dissipates seismic energy by sacrificing main components such as columns, beams, and walls.
Base-Isolated Structure : Isolates building from ground shaking.
Damped Structure : Mitigates damage and vibration by dissipating seismic energy using dampers installed at building floors or top.

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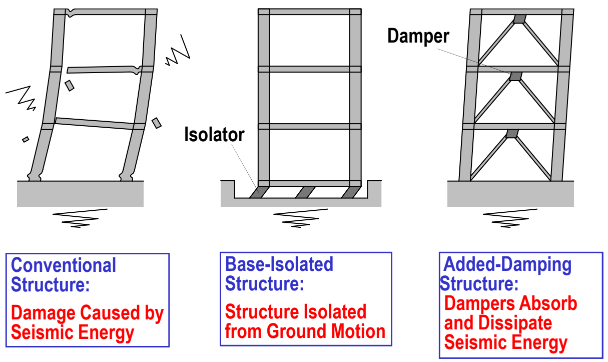
Conventional Structure vs. Two New Structures



Tokyo Institute of Technology Kasai Lab.

Demonstration of Added Damping Systems and Base Isolation Systems

← Damping Systems for Houses

Our patented techniques were commercialized by two companies.

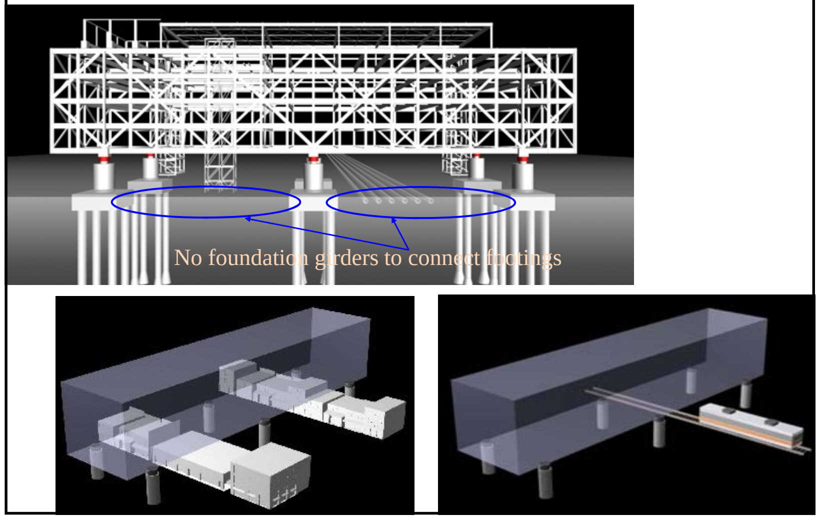
These damping systems are displayed in our campus.

L.A. City Hall

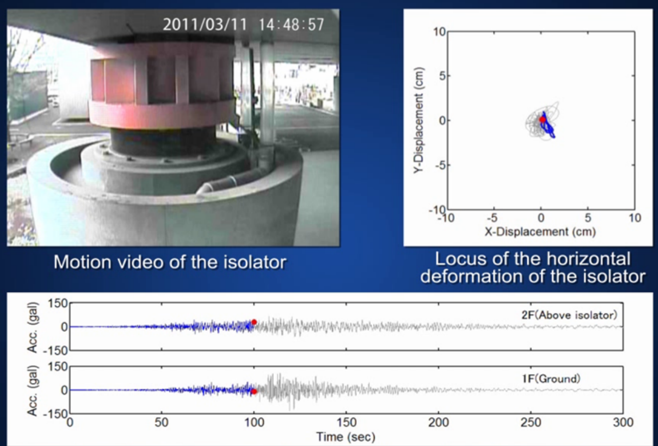
- Originally Built in 1928
- Retrofitted in 2001, the Largest Retrofit Project Using Base Isolation
- Historical Super-Tall Building (137m tall)
- 575 Japanese Isolators Adopted (High-Damping Rubber + Sliding)

Devices for Base-Isolation Systems

March 11 Performance: Structural Concept



Movement of Lead Rubber Bearing



Motion video of the isolator

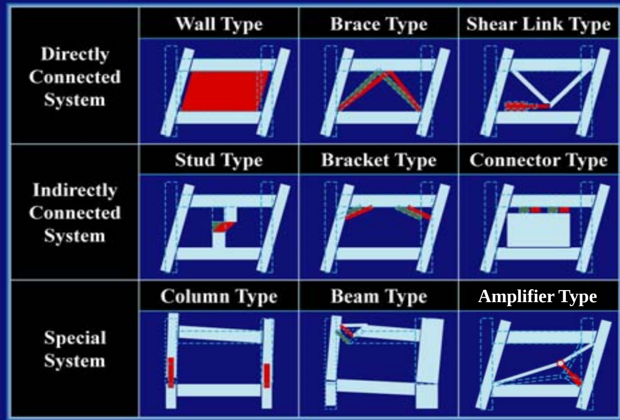
Locus of the horizontal deformation of the isolator

Acceleration waves on the second floor and on the ground

11

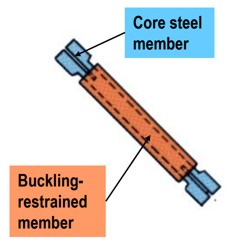
Manual Outline: Applicability

Framing Types of Passive Control Systems

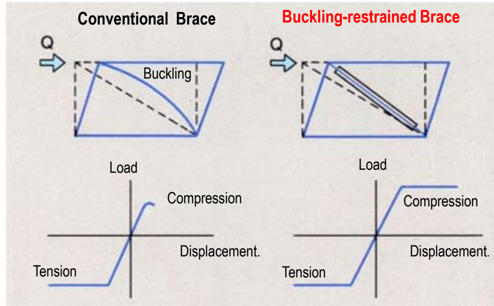


Buckling-restrained Brace

Brace type damper with core steel member whose buckling is restrained by concrete/steel member



Configuration of Buckling-restrained Brace



Comparison of mechanical behavior between Buckling-restrained Brace and Conventional Brace

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Major Damper Types Used in Japan

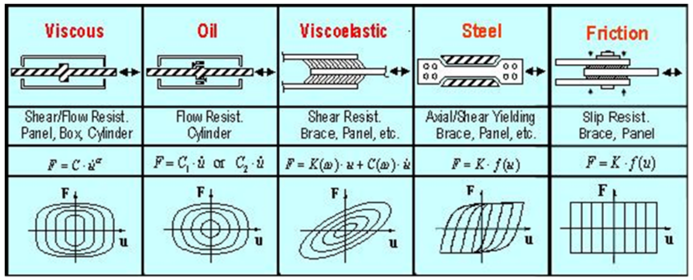
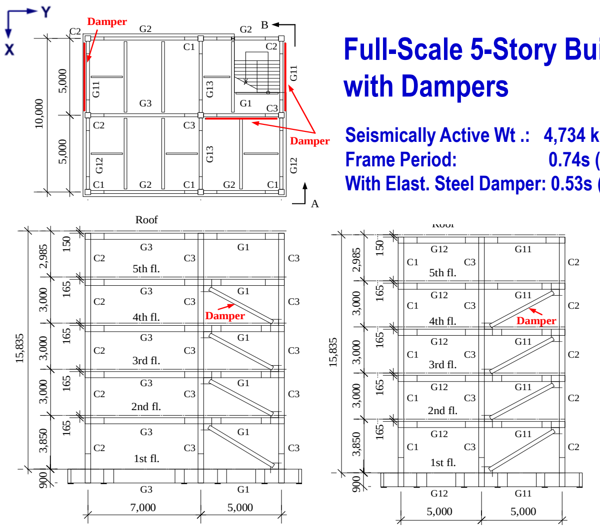


Fig. 4 Five Types of Dampers Considered by JSSI Manual

Manual by JSSI (Japan Society for Seismic Isolation)
1st, 2nd, and 3rd Editions, 2002, 2005, 2007, and 2013



Full-Scale 5-Story Building with Dampers

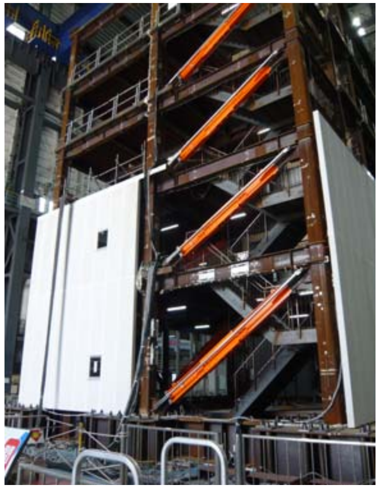
Seismically Active Wt .: 4,734 kN
Frame Period: 0.74s (x), 0.79s(y)
With Elast. Steel Damper: 0.53s (x), 0.56s(y)

Full-Scale 5-story Steel building with Steel Damper

Steel Damper

Viscous Damper

Oil Damper



Viscoelastic Damper

Summary

The 5-story building with dampers kept the story drift angle below the target limit of 1% rad against the catastrophic motion of unscaled Takatori record.

It was so for all four cases of using steel, viscous, oil, and viscoelastic dampers, respectively. Main frame was kept almost elastic.

Peak displacements were 0.45 ~ 0.65 times, and peak accelerations were 0.6 ~ 0.85 times those of the case of undamped building. These indicate good seismic protection of both building and its contents.

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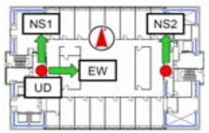
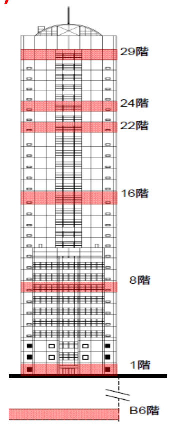
29-Story Building (No Dampers)

Name	Kogakuin University
Completion	1989
Number of Floors	29 floors above ground 6 floors below ground 1 floor penthouse
Aspect Ratio	EW(X): 3.73; NS(Y): 5.59
Frame Type	Steel frame with brace
Period (s) (obtained by Kasai lab.)	EW (X): 2.96s, 1.00s NS (Y) : 3.09s, 0.94s





(From Prof. Hisada)

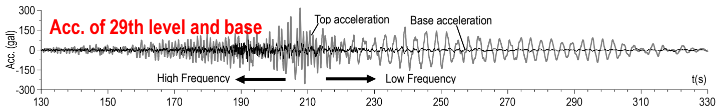
Damage to Nonstructural Components (From Prof.Hisada)

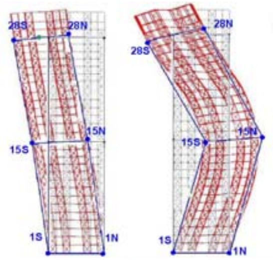
Movement of copy machine（25F）

Falling of books（25F）

Falling of ceiling：28F（21F, 14F, etc.）

Elevator cable damage
(another tall bldg., repaired in 3 weeks）





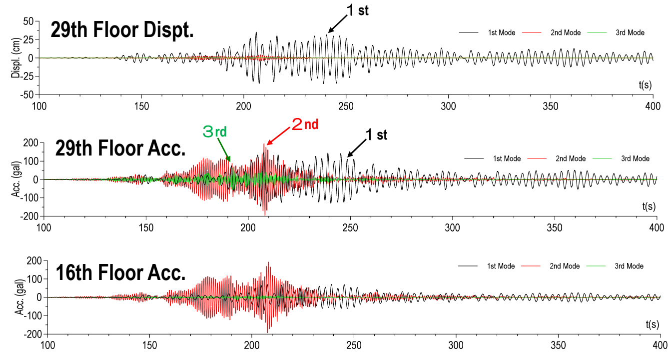
1st mode 2nd mode
(Y-direction)

The 2nd mode dominated at 16th floor.

Modal contribution and manner of vibration depend on story level.

The vibration continued for more than 6 min. The recorded responses are well explained based on the modes and modal responses.

29-Story Bldg. (No Dampers), Y-direction
Modal Contributions to Disp. and Acc.



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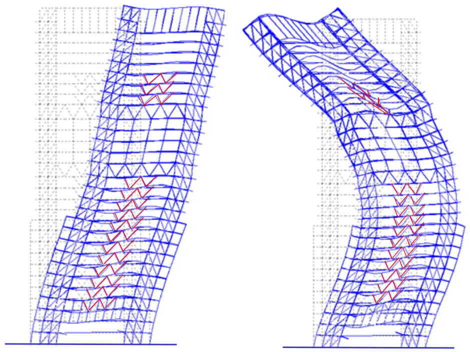
X-Direction（Finding Good Damper Locations）
Damper shown by red color：
(Zero-stiffness assigned in the eigenvalue analysis)



１次モード 2次モード

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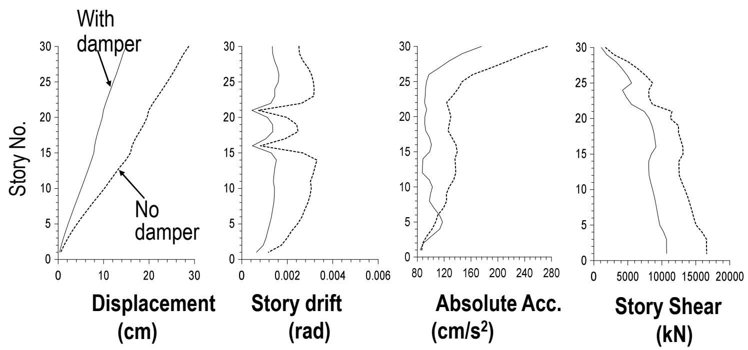
Against March 11 Base Motion (Recorded):
Actual Case vs. Retrofitted Case (Oil dampers)



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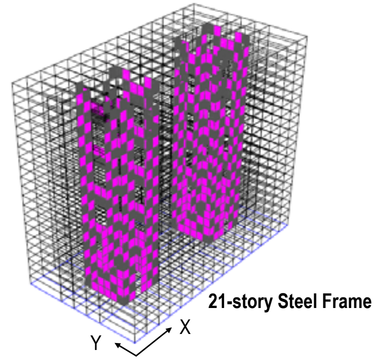
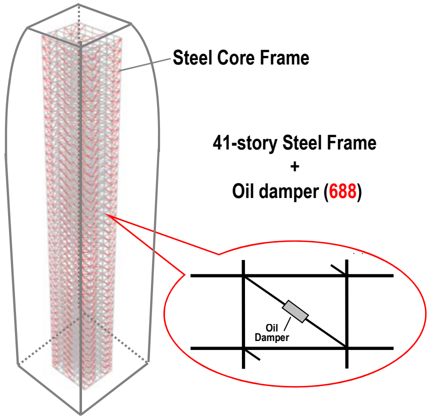
21-Story Bldg. with 336 Steel Dampers & 284 Viscous Dampers

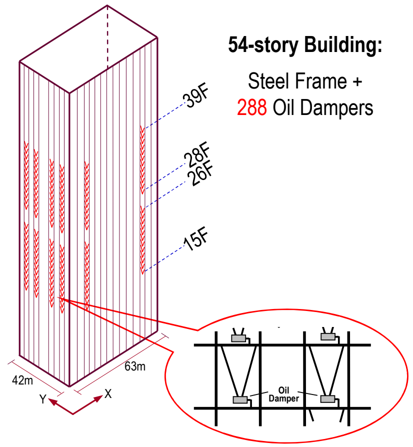


■ Viscous damper (284)
■ Steel damper (336)

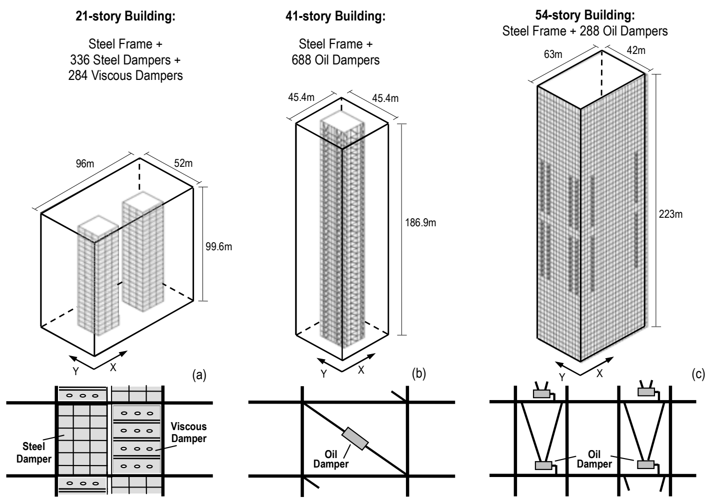
41-Story Bldg. with 688 Oil Dampers



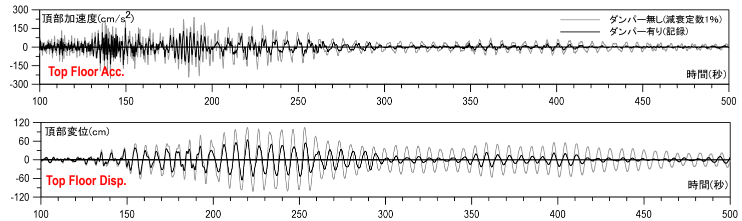
54-Story Bldg. Retrofitted by 288 Oil Dampers.



54-story Building:
Steel Frame +
288 Oil Dampers



Black: With damper, actual recorded acc. and disp. (double integration).
Gray: No damper, modal analysis by assuming 1% damping ratio.



54-Story Bldg. (continued):
Without damper, the acc. and disp. will increase considerably.

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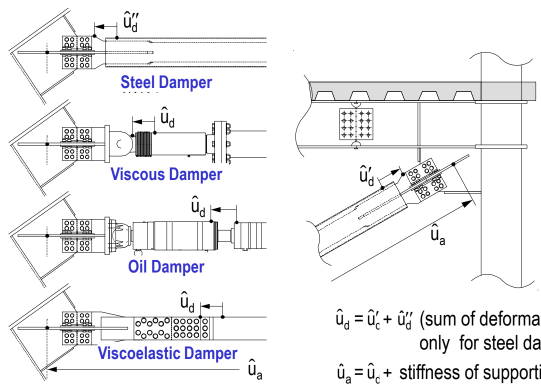
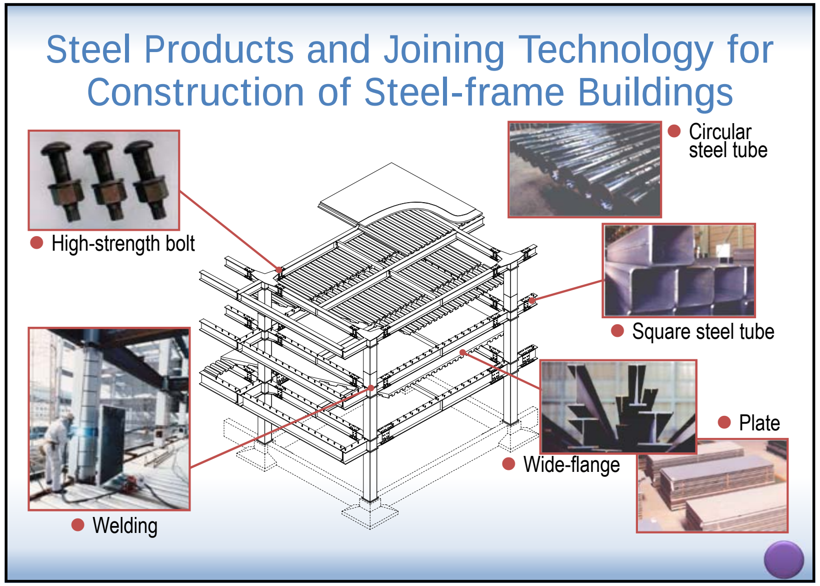
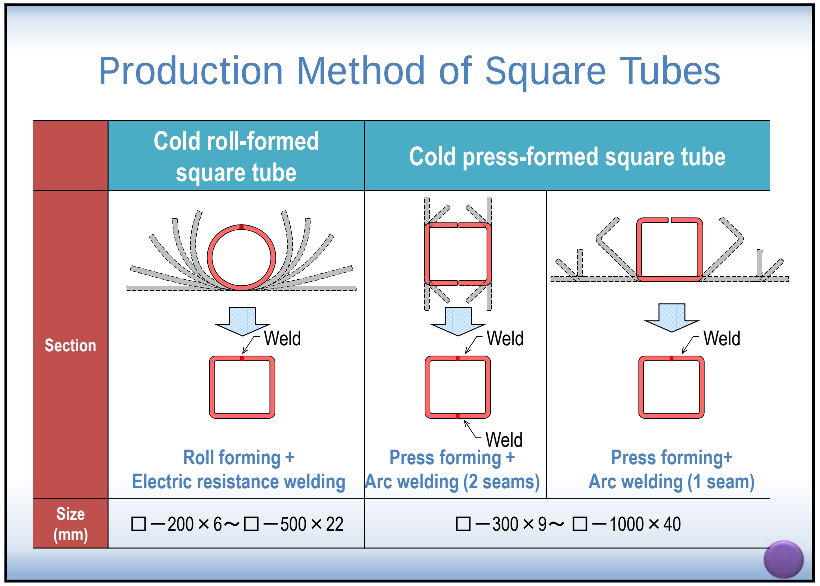
Steel frame is the easiest one to connect dampers !

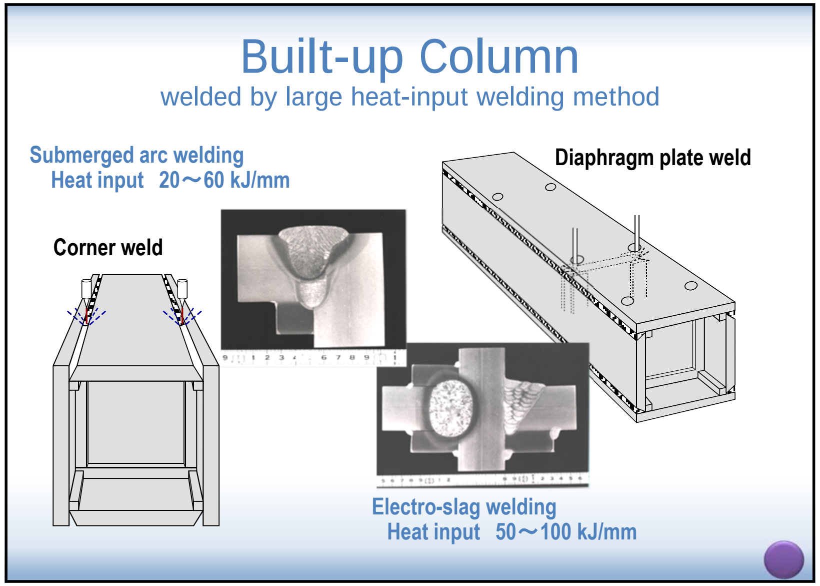


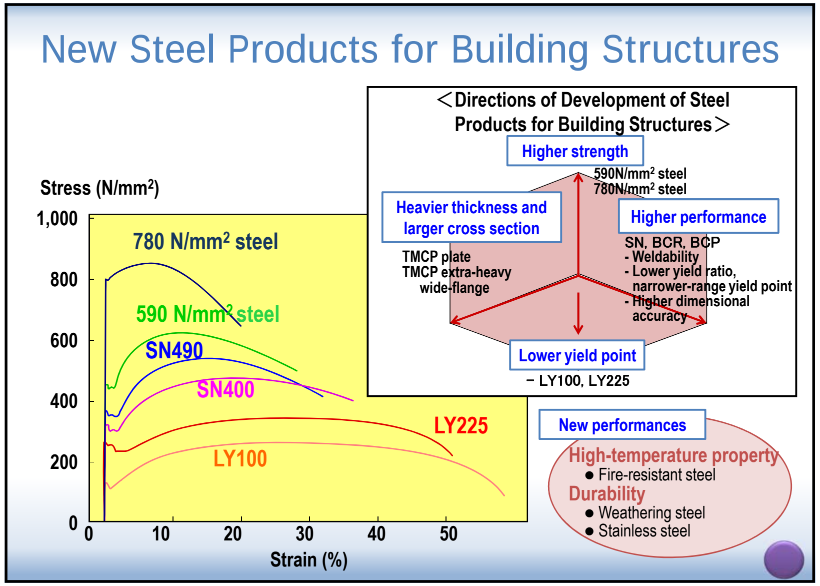
$\hat{u}_d = \hat{u}'_d + \hat{u}''_d$ (sum of deformation at both side only for steel damper)

$\hat{u}_a = \hat{u}_c +$ stiffness of supporting member


Steel Products and Joining Technology for Construction of Steel-frame Buildings
High-strength bolt
Circular steel tube
Square steel tube
Plate
Wide-flange
Welding

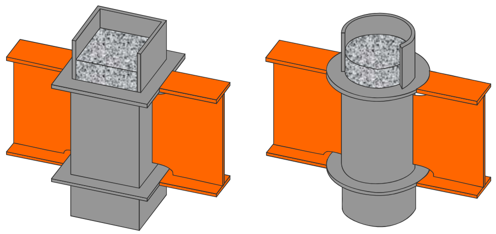

Production Method of Square Tubes
Cold roll-formed square tube
Cold press-formed square tube
Section
Weld
Weld
Weld
Weld
Roll forming + Electric resistance welding
Press forming + Arc welding (2 seams)
Press forming+ Arc welding (1 seam)
Size (mm)
□－200×6～□－500×22
□－300×9～□－1000×40


Built-up Column
welded by large heat-input welding method
Submerged arc welding
Heat input 20～60 kJ/mm
Corner weld
Diaphragm plate weld
Electro-slag welding
Heat input 50～100 kJ/mm

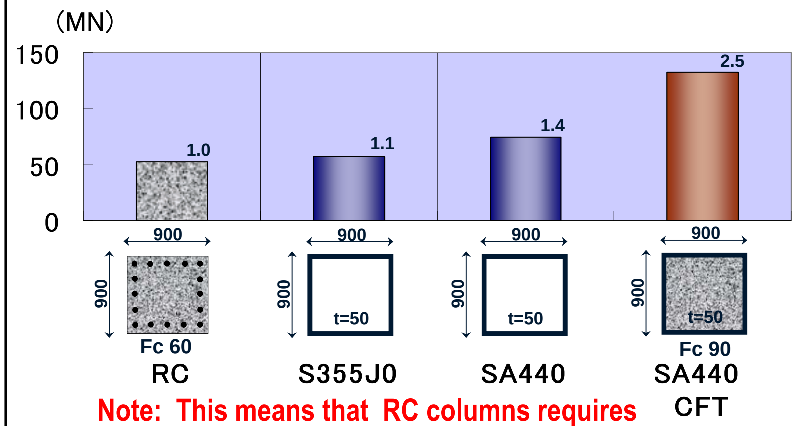

New Steel Products for Building Structures
Stress (N/mm²)
1,000
800
600
400
200
0
0
10
20
30
40
50
Strain (%)
780 N/mm² steel
590 N/mm² steel
SN490
SN400
LY225
LY100
＜Directions of Development of Steel Products for Building Structures＞
Higher strength
590N/mm² steel
780N/mm² steel
Heavier thickness and larger cross section
TMCP plate
TMCP extra-heavy wide-flange
Higher performance
SN, BCR, BCP
- Weldability
- Lower yield ratio, narrower-range yield point
- Higher dimensional accuracy
Lower yield point
－LY100, LY225
New performances
High-temperature property
● Fire-resistant steel
Durability
● Weathering steel
● Stainless steel

- Concrete-Filled Steel Tube (CFT) -

Compensates for demerits of the RC and steel structures, realizing higher seismic and fire resistance.



Comparison of Axial Strength



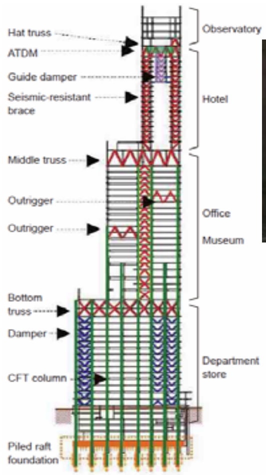
Note: This means that RC columns requires much larger cross section for the same strength.

SA440 (Tensile Strength 590N／mm²)

Landmark Tower in Yokohama (296.0m, 70-story, Built in 1993)

Roppongi-Hills Tower (238.1m, 54-story, Built in 2003)

Japan's Tallest Bldg.



CURRENT STATUS OF BUILDING PASSIVE CONTROL IN JAPAN

Development of Damage-Free Structure & Design Specifications by ANUHT

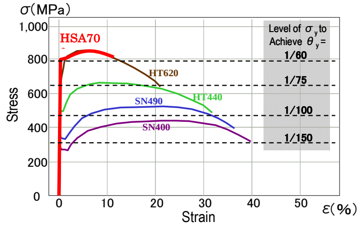


Fig. 8 Super High Strength Steel Considered

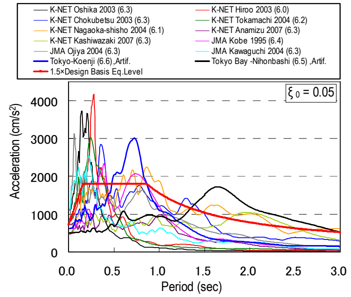


Fig. 9 Catastrophic Earthquakes Considered

The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

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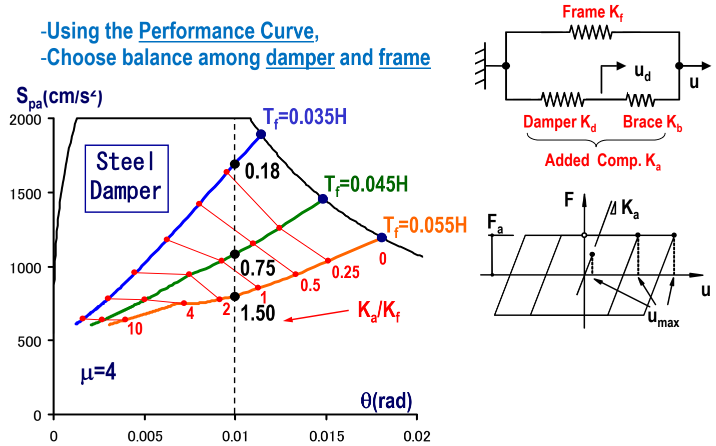
Direct Design Method for Required Performance: E-Defense 5-Story Bldg.

-Using the Performance Curve,
-Choose balance among damper and frame



Tokyo Institute of Technology Kasai Lab.

Performance curve gives a variety of solutions for damper stiffness and frame stiffness satisfying the story drift limit. For example,

Solution 1. Relatively stiff damper and flexible frame.
Solution 2. Relatively flexible damper and stiff frame.

Solution 1 can lead to smaller response acc. But the frame's restoring capability will be less, meaning increased potential of residual deform. and non-uniform story drifts over the height of the building.

Solution 2, if acc. is well-controlled, would be a good choice by the above reasons, and the rectangular square tube section is suited best to provide adequate frame stiffness in both x- and y-directions.

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Seismic base isolation systems and added damping systems have become the standard technology to protect human lives, building functionality, and assets against major earthquakes.

Such protective systems are discussed, with emphasis on added damping which most new tall buildings in Japan utilize now. Full-scale tests results using the world's largest shake table (E-Defense), as well as response records of major buildings at the 2011 Tohoku earthquake indicate beneficial effects of dampers for existing or new buildings.

Supplemental damping technology and steel frame match well, since; 1) dampers are most securely and easily connected to the steel members through welds or bolts; 2) a steel frame, below the yield limit, has a clear undamaged state warranting continued post-quake use of the building, and; 3) a steel frame with square tube columns provides sufficient stiffness for any lateral direction.