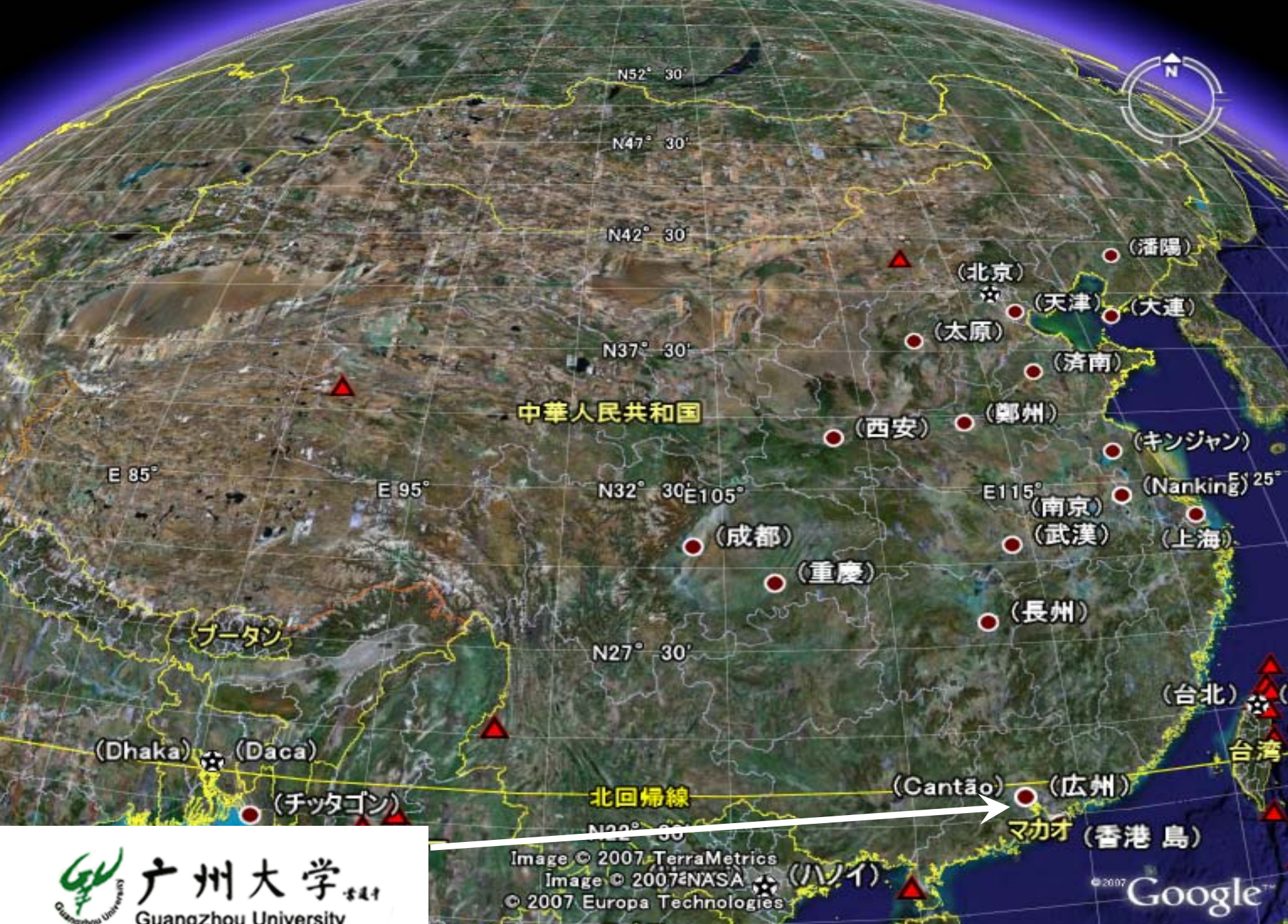


**RECENT DEVELOPMENT ON
SEISMIC ISOLATION,
ENERGY DISSIPATION,
AND CONTROL FOR STRUCTURES
IN CHINA**

Wenlihan · Heisha

EERTC, Guangzhou University, Guangzhou CHINA

08 Feb. 2007



Earthquake and Engineering Research and Test Center (EERTC)

Content

- 1. Severe threat of earthquakes for China**
- 2. Seismic Isolation**
- 3. Energy dissipation**
- 4. Semi-active control**
- 5. Suggestion for future development**

1. Serious Threat of Earthquake for China

China -- a very Frequently seismic country

Located in the Cross Area of

Two main seismic circus in the world

Over 60 % of national land is seismic area

80 % of large cities are located in seismic area

Most of EQ are stronger, over prediction

Many buildings and bridges are lack of capacity for anti- Earthquake,

People urgently require living in houses, that are ensured to be safe in strong EQ

Problems existed in tradi. anti-seismic technique

(1) It is not very **safe**:

difficult to **control** the structural **damage level**

dangerous in severe **over predicted EQ.**

80% of severe EQ were over prediction:

(2) It is **limited** to be used:

important structures, require **elastic**, protect **inside**,

(3) It is Limited for Architectural design

irregulative plan,

weak stories

(4) It is more **expensive**: people do not pay more money

Intensity	Ground motion	rise cost
-----------	---------------	-----------

7--9	0.10 g — 0.40g	5- 30 %.
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It causes **dangerous state** of many buildings at present

New technique – Seismic Control of Structures

The urgent task is to find out a new technique:

- (1) Safe: ensure safety in strong earthquake.**
- (2) Wide range of application: Civil structures and others**
- (3) Inexpensive**

The Seismic Control is one of the best way to be satisfied

- Base Isolation : 570 buildings, bridges**
- Energy Dissipation : 25 buildings**
- TMD or other Passive : 12 buildings**
- Active and Semi- Active control: 5 bridge**

2. Seismic Isolation

- 2.1 Isolator devices and testing research
- 2.2 Different locations of isolation layer
- 2.3 Stories isolation
- 2.4 Three directions (3D) isolation
- 2.5 Composite isolation
- 2.6 Isolation structures in near fault
- 2.7 Smart isolation
- 2.8 Application of isolation in China (Bld & Bridges)
- 2.9 Design code, rules and standards in China

2.1 Isolator devices and testing research

Five kinds of material used for isolators

- (1) Sand layer: 5 buildings
- (2) Graphite lime mortar layer: 12 buildings
- (3) Slide friction layer: 14 building
- (4) Roller: 2 buildings
- (5) Rubber bearing: over 570 civil buildings

Isolator devices



Graphite lime mortar layer



Slide friction layer

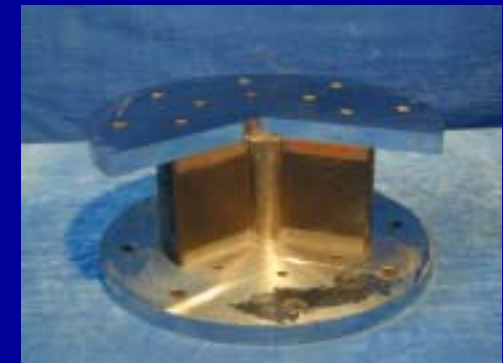
- **The Reasons of widely using RB or LRB**
- ▶ Effecting, decrease response to $1/4 - 1/12$
- ▶ Durability, working life 70 years
- ▶ Recover the displacement after EQ
- ▶ With Vertical tension characteristics
- ▶ Earthquake experiences



Steel bar (Damper) in the Graphite lime mortar layer



Slide friction devices

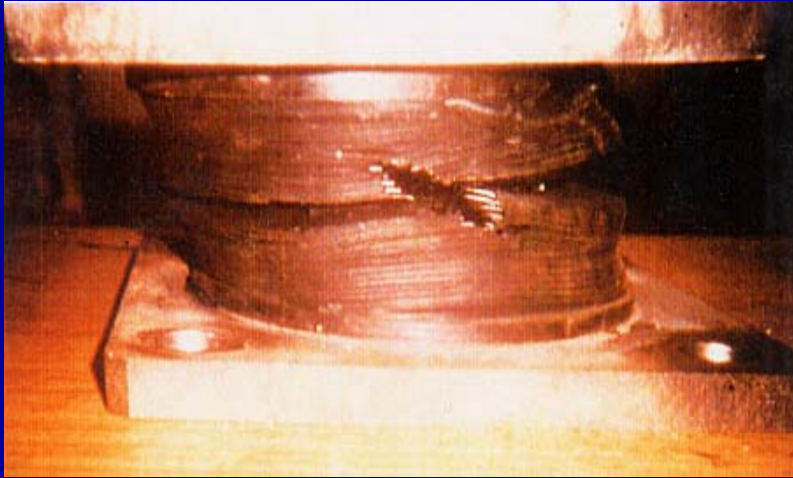


Laminated Rubber Bearing (RB or⁹LRB)

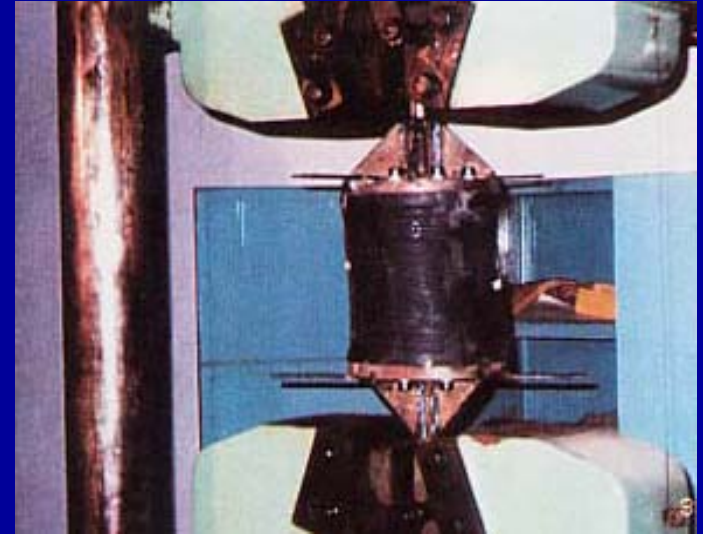
**Mechanics Test for
Rubber bearings
Vertical compression
10-15 Mpa,
Horizontal shear
 ± 400 mm**



Compression failure tests



Tension failure tests



Durability testing for isolators

1. low cycle fatigue test (180 cycle).
2. Ozone Ageing test (ask for 60ys)
3. Creep test (full scale testing 2001-2050)



fatigue test



Ozone Ageing test

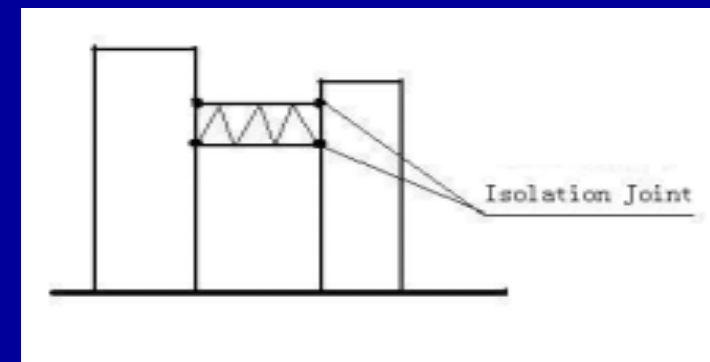
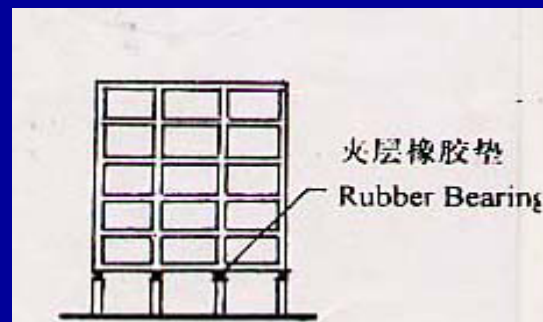
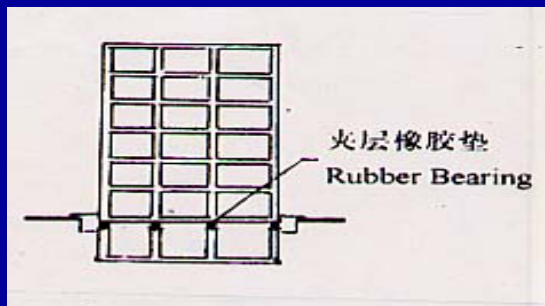
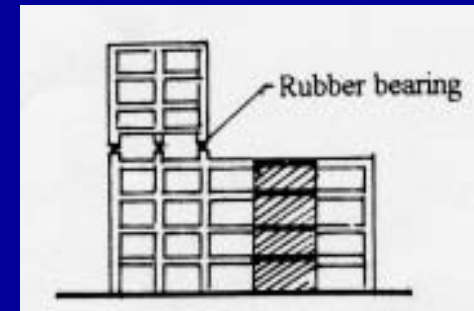
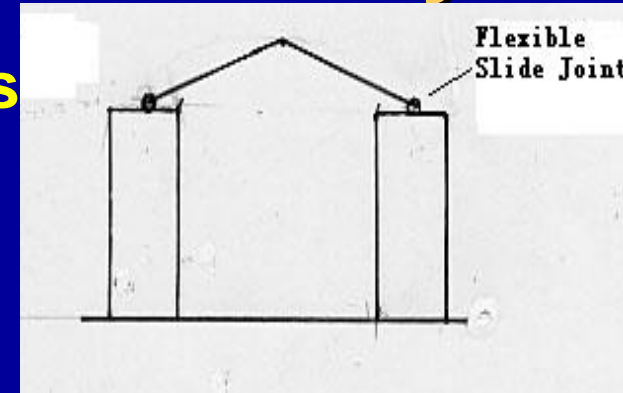


Creep test

2.2 Different locations of isolation layer

Six kinds of location of rubber bearings

- (1) Base isolation
- (2) Basement isolation (building with basement)
- (3) First story isolation (building without basement)
- (4) Storied isolation
(on the stories which irregularly changing structural shape, mass or stiffness)
- (5) Over bridge between two building using isolation joint (decouple the different model shapes of two buildings)
- (6) Isolation bearings for long span space structures



2.3 Stories isolation

EERTC

Background:

Weak stories are existed in buildings

Sudden Change of Mass or Stiffness are existed in buildings

Damage in Stories of Buildings in Shaking table Tests

So Stories Isolation is Effective and necessary.



深圳市长大厦¹³

Theoretical Research for Stories Isolation

Design optimize:

Relation of **stiffness** (刚度关系)

between supper and sub-structure

Relation of **mass** (质量关系)

between supper and sub-structure

Choose the **stiffness and damping** for

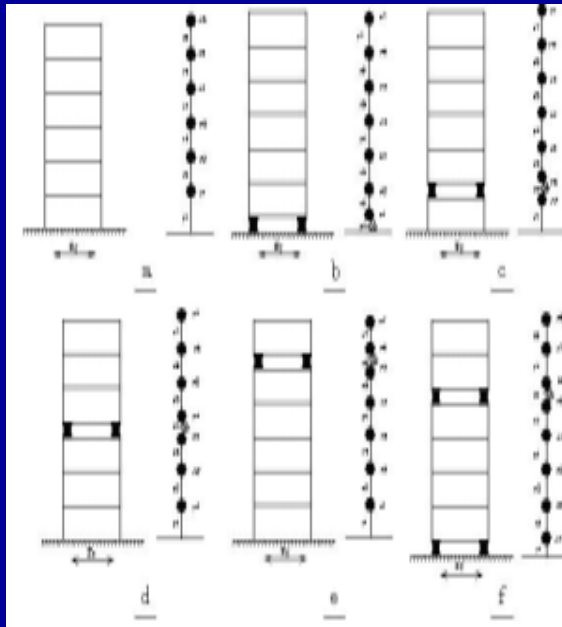
isolation layer (隔震层的刚度和阻尼)

Compute Analysis for Stories Isolation (计算分析)

Mathematical model (质点模型)

3D analysis (三维有限元分析)

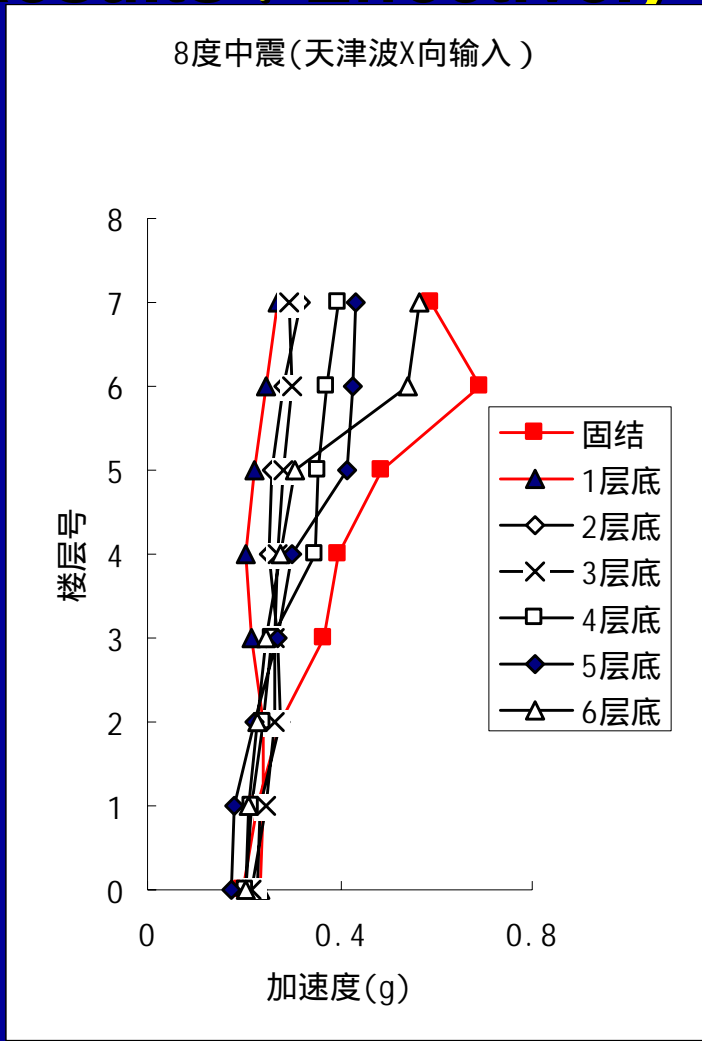
Shaking table tests for Stories isolation systems (Guangzhou University EERTC) 2005



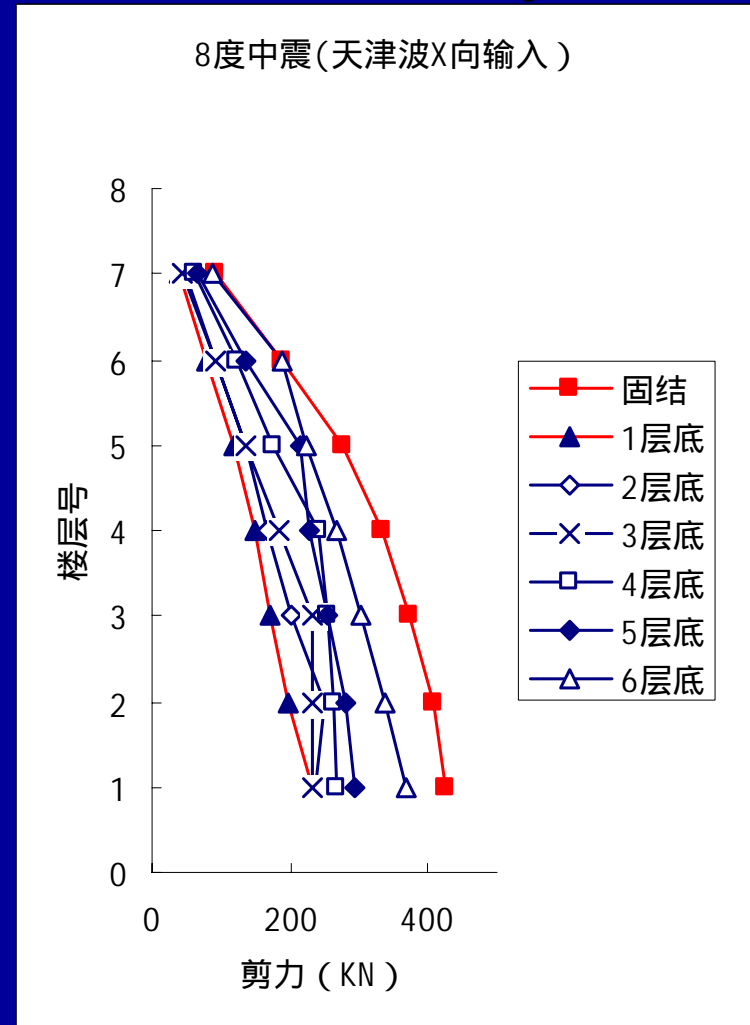
Models for Stories isolation systems

Acceleration and Shear Force 加速度和剪力变化

Results : Effectively to reduce the response



Acceleration

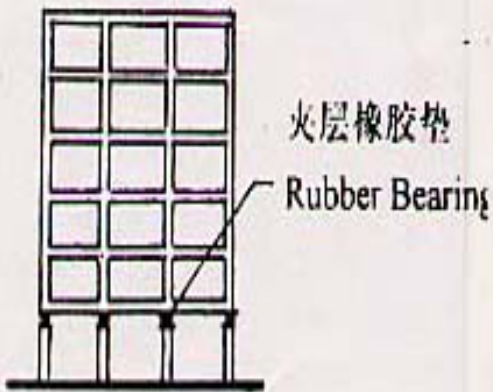


Shear Force

Seismic Isolation Houses buildings in southern China



Seismic Isolation Museum in southern China



**Isolator: Top
of 1st Story**



Guangzhou City E.Q. Observing Center in southern China

with isolation layer at the top of 1st story
首层隔震 广州市地震监测指挥中心 2000年



Isolators 首层隔震

Isolated buildings group---- Stories Isolation

-- The largest area of isolation in the world in 2003



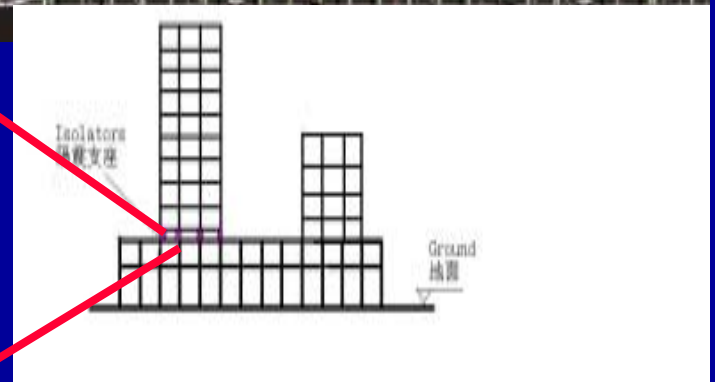
Isolation House Buildings group on Subway Hub in Beijing

- ◆ Large platforms (2 storie RC frame)
with 1500m wide × 2000m long
cover a railway area in Beijing City
- ◆ 50 isolationed house buildings (7 ~ 9 stories RC frame)
built on the top floor of the platforms
- ◆ floor area of all isolation buildings is
approximately 480,000 M²

New system of Isolated buildings structures



Isolation RB Layer : located on the top floor of the platform



公园街景立面

Technical and economical comparison of isolation with no-isolation

Comparison isolation, energy dissipa. & traditional design

	Seismic shear force	Construction cost
Traditional design	100 %	100 %
Energy dissipation	80 %	95 %
Stories Isolation	25-35 %	75 %

Shaking table tests– 1/25 scale model



model of rubber bearings

(M) 17p04 BJ ISO 01

Stories-isolation Shaking table tests

Isolation 隔震
El Centro (N-S)
(Transverse) X
Ground Motion
地面 $A_g = 0.366 g$

Isolation
Structural Acc.
结构 $A_s = 0.122 g$



Stories-isolation

Isolation 隔震

No damage

El Centro wave

Tianjing wave

Local Site wave

Ground Motion

地震 $A_g = 0.60 g$

Isolation

Structural Acc.

结构 $A_s = 0.11 \sim 0.16 g$



(M) 17p04 BJ ISO 07

Stories no- isolation Shaking table tests)

No- Isolation 不隔震

Damage, Collapse

El Centro (N-S)

(Transverse)

Ground Motion

地震 $A_g = 0.366 \text{ g}$

Structural Acc.

结构 $A_s = 0.834 \text{ g}$

Comparison:

隔震/不隔震 = 1/4



Shaking table tests – Compare testing



Isolation

Input 300 gal

Response 140 gal

Input 600 gal

no any damage



no-isolation

Input 300 gal

Response 720 gal

input 400 gal

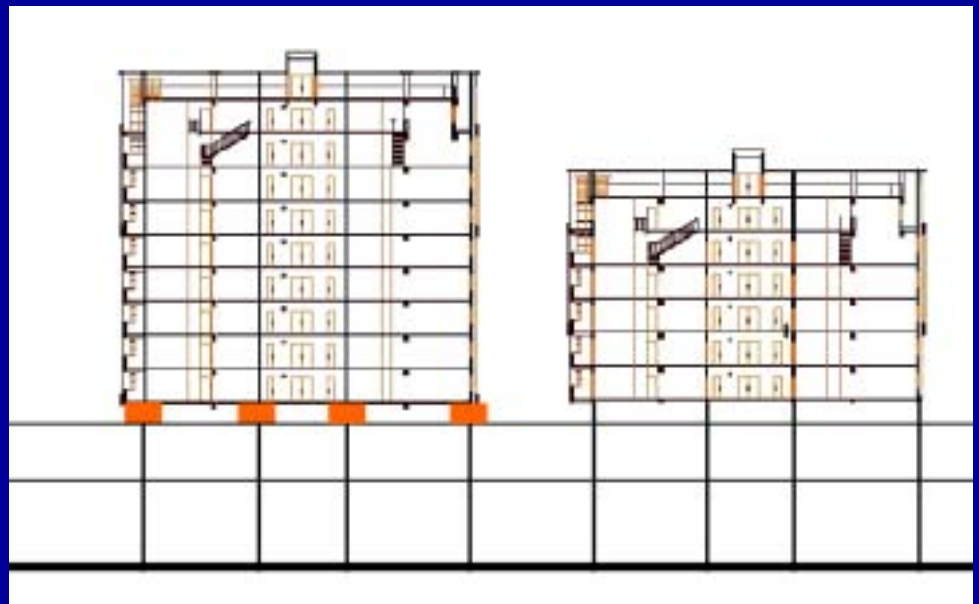
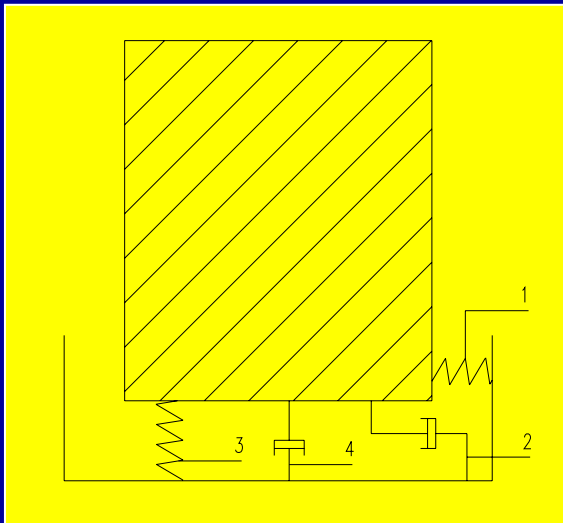
Damage, nearly collapse

2.4 Three directions (3D) isolation

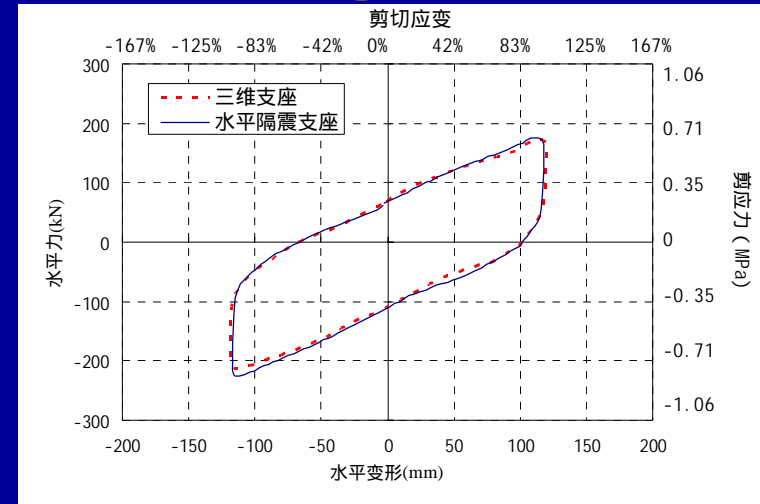
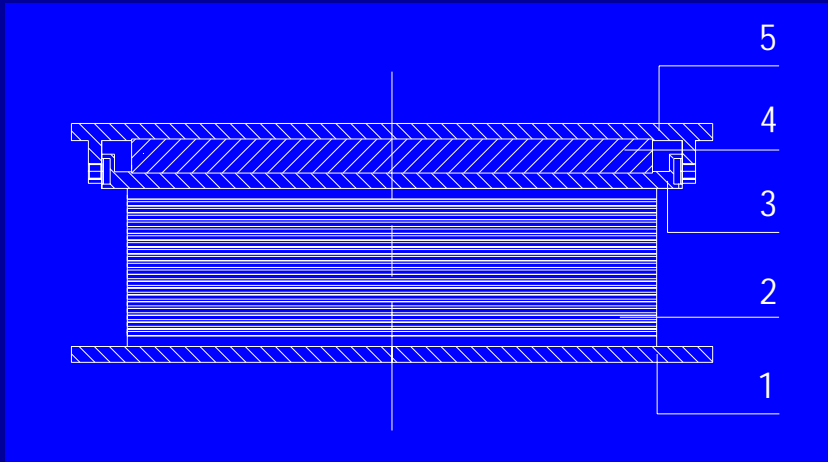
(Guangzhou University EERTC)

Background and mathematics model

- **Seismic isolation, Horizontal only**
- **Vertical vibrations** always occur by highway, railway, machines or others make people not comfortable
- **mathematics model for 3D isolation**



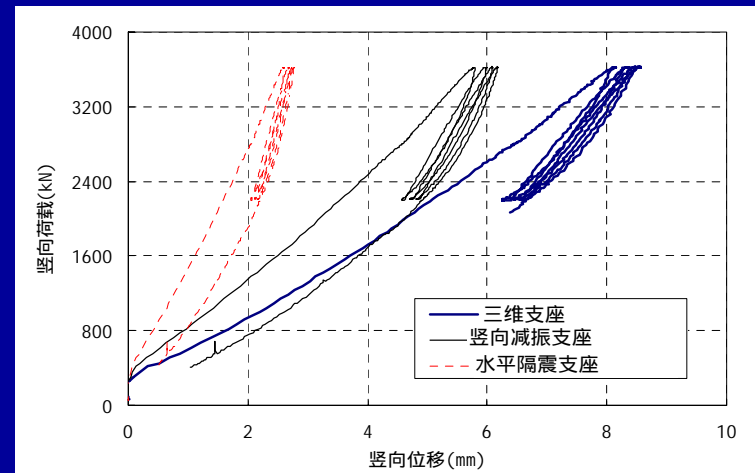
3D Isolator: Device and design



Design:

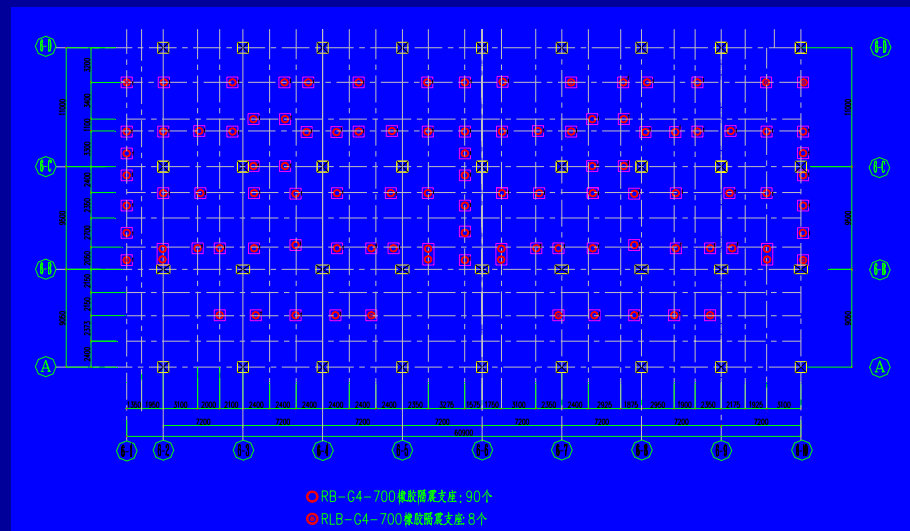
Couple of Horiz. -- Verti. Vibra.
Effect of isolation in Hori. And Verti.
Cost, install easily

Test for 3D Rubber bearings
 $K_{vv}=1131$ $K_{vh}=2525$ $K_v=774$
(kN/mm)



Application of 3D Isolation in China

---北京地铁 地面枢纽平台上 隔震住宅楼



3D isolator

三维隔震支座

Records :

If no-isolation, Vibra. be amplified

传统结构对地铁振动放大，人感明显

3D reduce 50% of Verti. Vibra.

2.5 Composite isolation

复合隔震体系 (Guangzhou Uni. EERTC)

Composite isolation devices:

Rubber bearings + Elastic Sliders + Dampers

Advances of Composite isolation:

Large Compression capacity: from 10 to 20Mpa

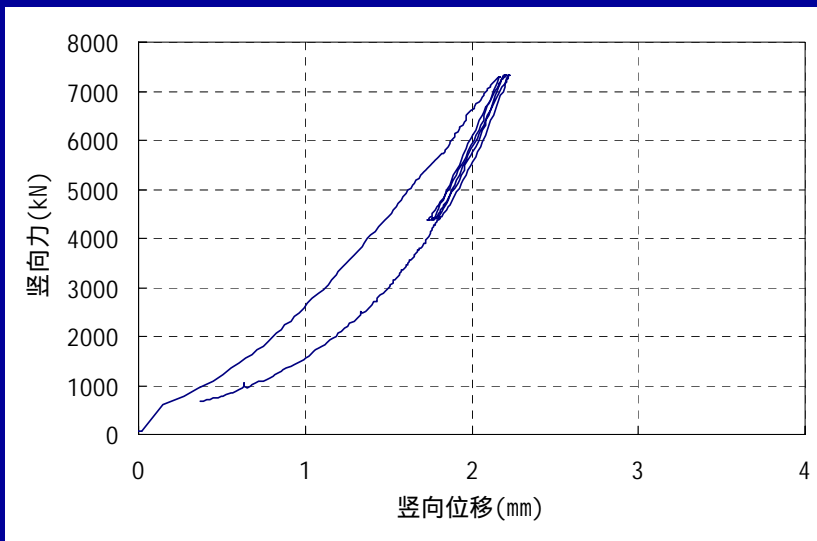
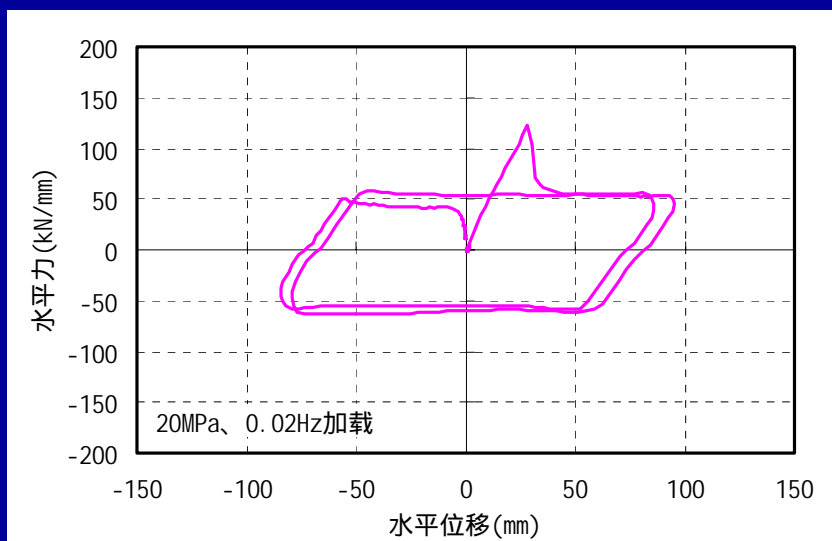
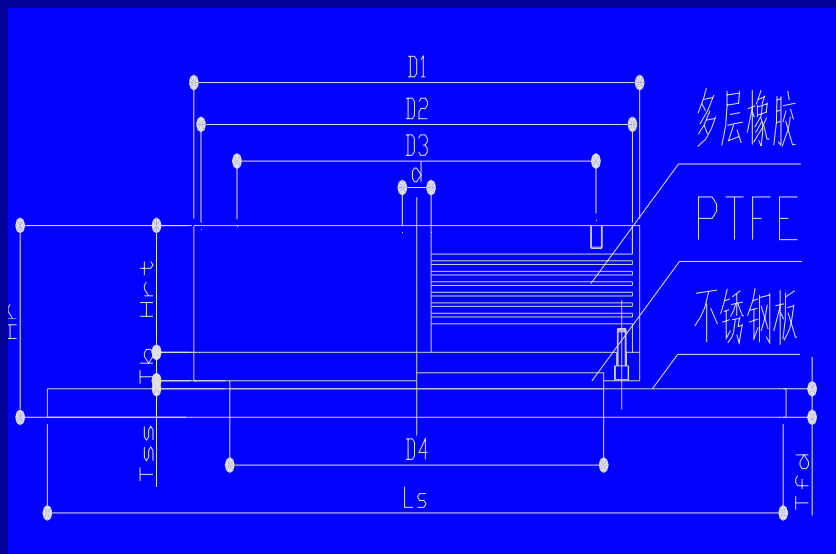
Effectively reduce response

Make period T_s longer, using H.R. buildings

low cost comparing with Rubber bearing

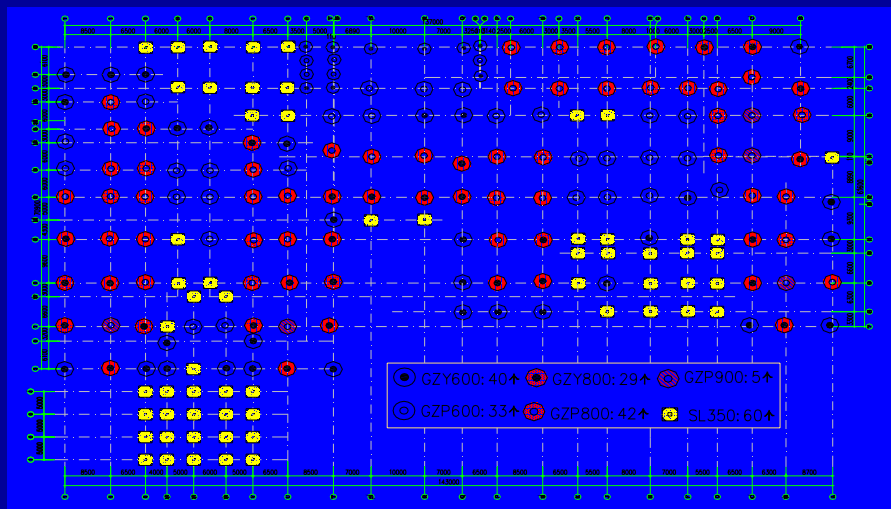
Mechanics Test for Elastic Slide isolator (EERTC)

Patent 专利号 : ZL200420043522.1; ZL200420043521.7



Application for Composite isolation system

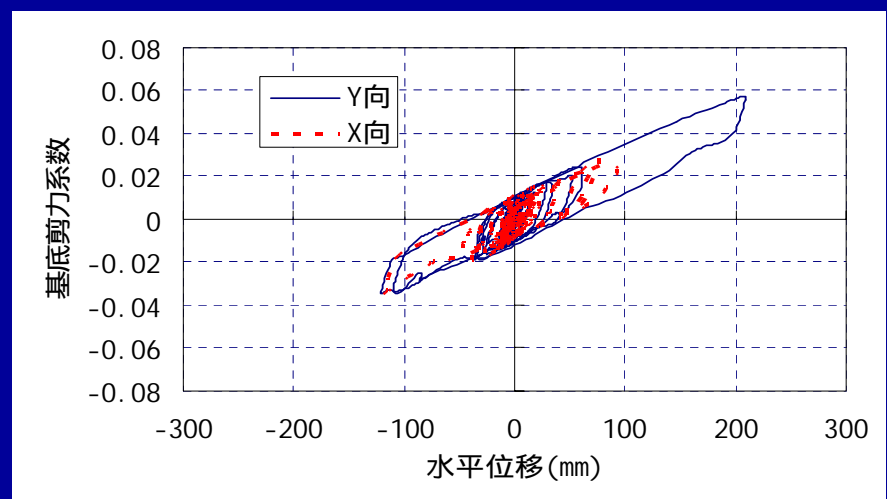
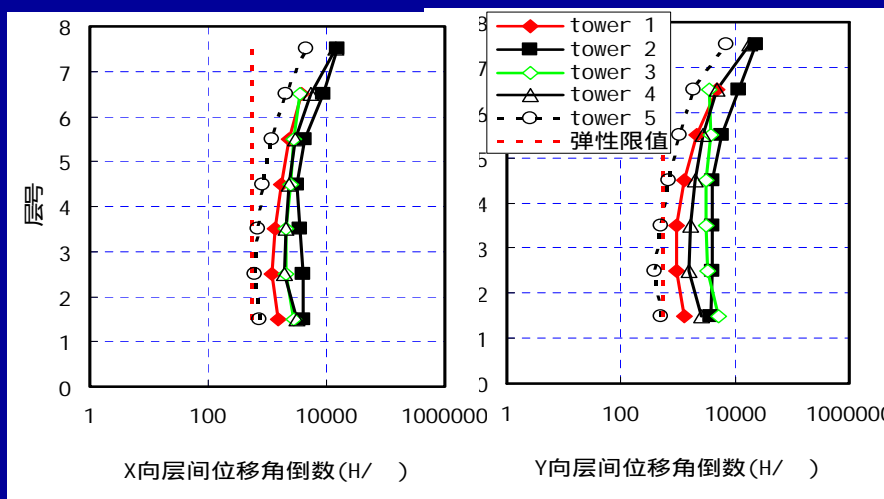
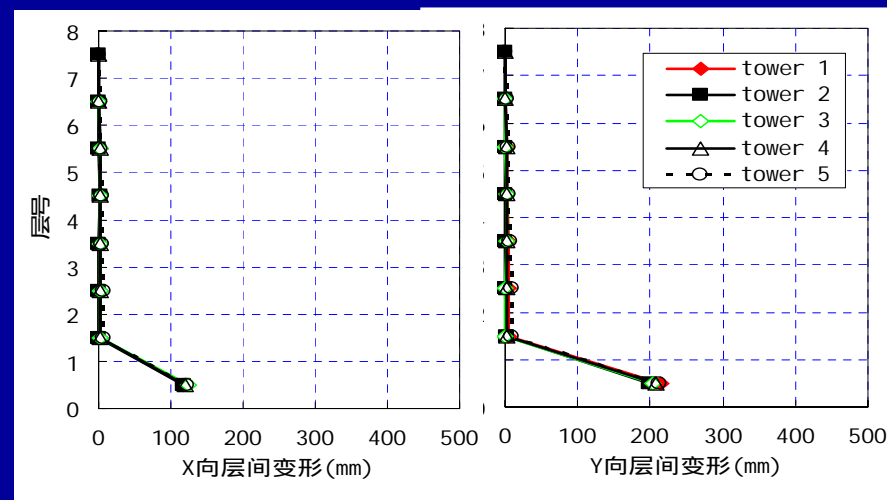
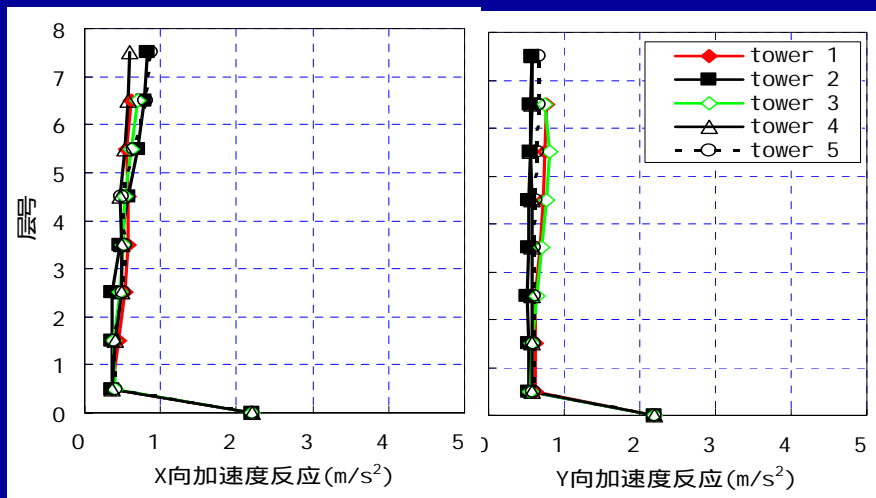
Office buildings of Guangzhou Uni. (广州大学城, 办公楼)



Analysis of Response for structure with Composite isolation system

(广州大学城)

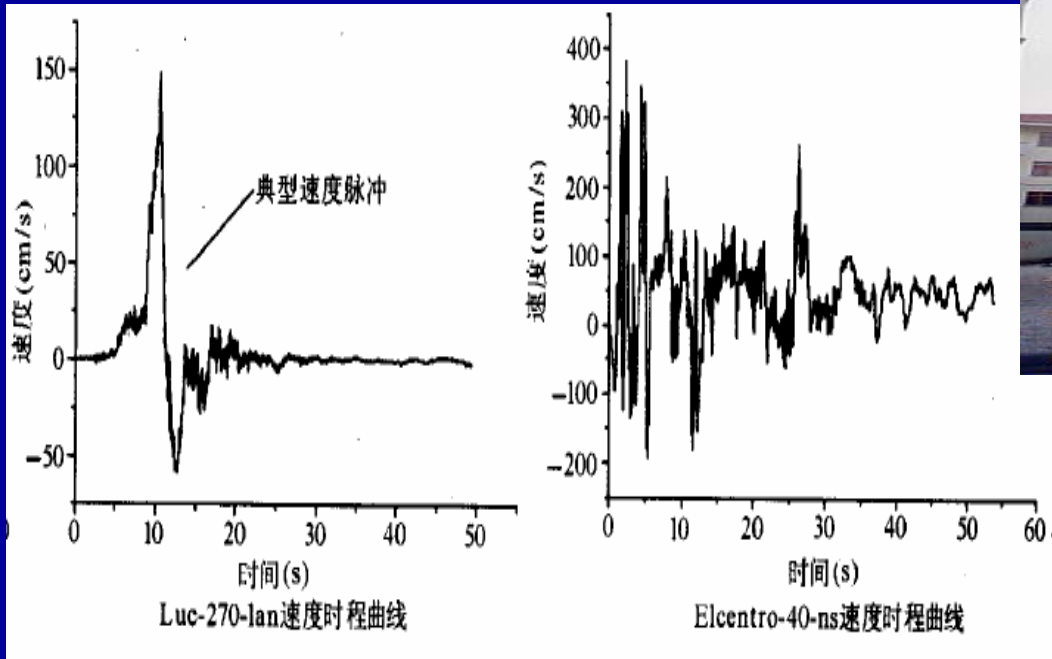
EI Centro波双向作用：



2.6 Isolation structures in near faults

field (近场地面运动下隔震结构安全性研究)

(Guangzhou Uni. EERTC)



Shock wave
induce very large shear force
in first story Turkey 1999

Velocity history Acceleration history

Ground motion History in near faults field

(M) Isolation structure is attacked by Super large Earthquake (near faults)

近断裂带 特大地震(1, 10g) 隔震结构的安全, 北京 8 部委办公楼

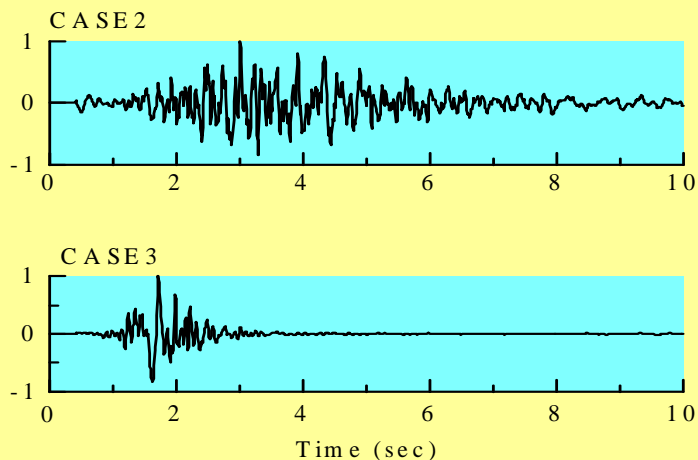
$X_{max}=950gal$, $Y_{max}=980gal$,
 $Z_{max}=750gal$, M_x, M_y, M_z



Damage to column of non-isolated building

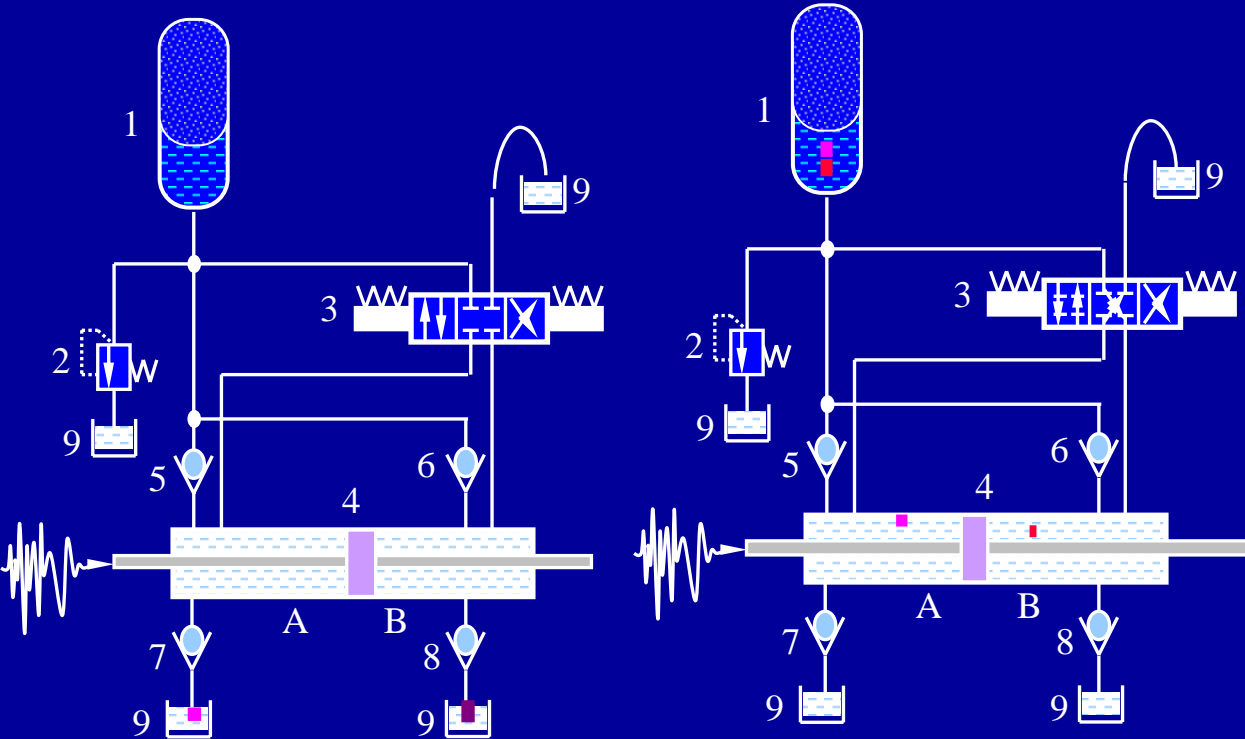
Different damage state of RC str. in Near and Far E.Q.

Shock-Resistant Capacity of Rubber Shock testing



2.7 Smart isolation

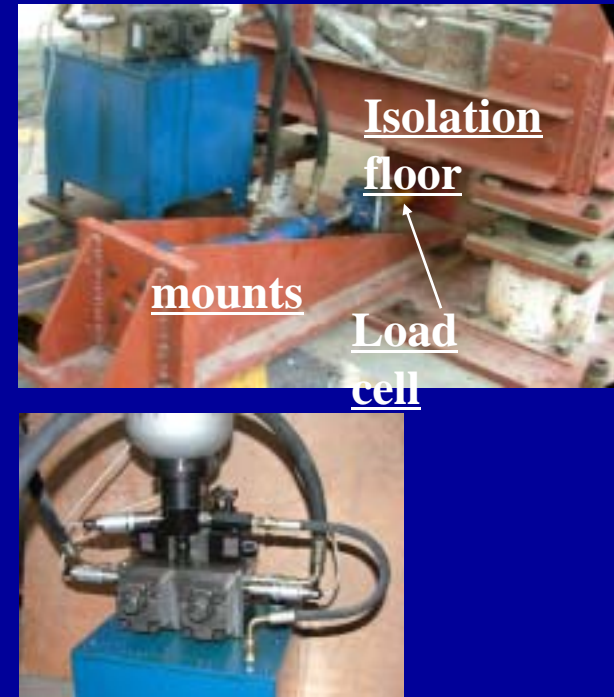
Seismic isolation system control by Smart control device (Guangzhou Uni. EERTC)



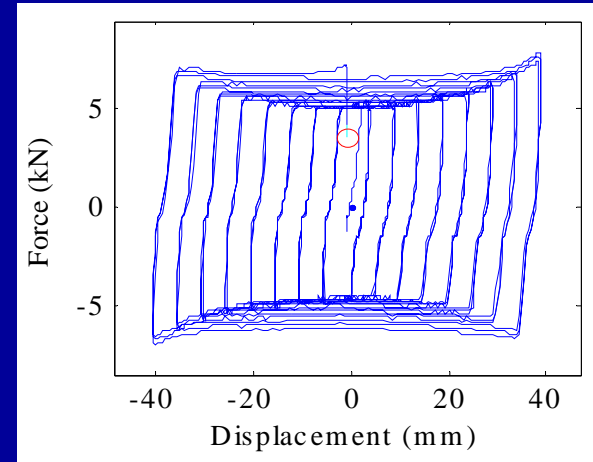
1. Energy from g. m. in EQ

2. Control using E.

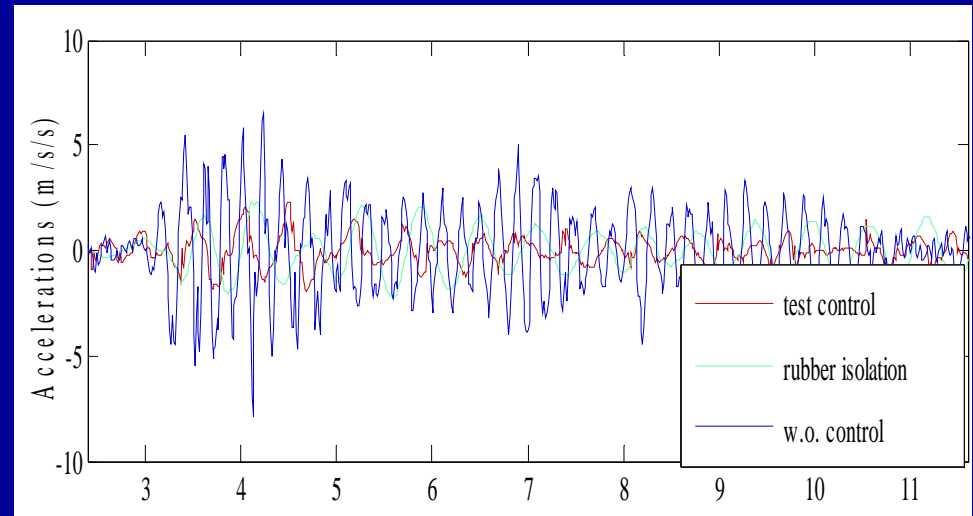
- 1. gas accumulator
- 2. valve
- 3. servo valve,
- 4. hydraulic cylinder
- 5. oil tank



Shaking Table tests (Guangzhou Uni. EERTC)



Force displacement relationship



Comparing Control and no Control

2.8 Application of isolation in China

(1) Projects in the Cities or Provinces : isolation

Buildings:16 Provinces or Cities

广东, 福建, 山西, 陕西, 云南, 四川, 宁夏, 内蒙古, 新疆, 河北, 河南, 江苏, 北京, 上海, 天津 等

(2) Numbers of isolation buildings : 570 buildings have been built in China, 80% are Residential house buildings

(3) Numbers of isolation Bridges : Examples

河北(He bei) 石家庄新津桥 (1998), 南疆(xin jian)铁路布谷孜铁路隔震桥 (9孔,各32米), 2000年, 澳门(Maco)澳氹大桥(2004年通车), 西藏(xi zhan)柳梧大桥(在建), 灵芝(lin zhi)八一大桥(在建), 晋江(jin jian)大桥引桥工程(在建)

Application areas of using Isolation for buildings in China (500 Buildings) 1993 – 2005

隔震技术应用分布图



Earthquake Experience (994.9.16)

Shantou project -- UNIDO, **two buildings** for comparing in EQ
Same structure (8 stories RC frame house) on **same site**
one is **base isolated**, another is **base fixed**

1994.9.16 Southern China sea Earthquake (M 7.3)

Shantou City: ground $A = 0.11 g$

Building with base fixed

person **difficult to stand**

shaking severely in building

slip down on floor

people **jump out of window**

water in bucket, shaking, spatter out 1/3

Building with base isolation

persons, **no any feeling**

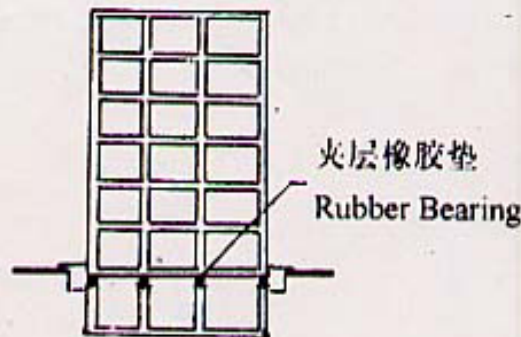
Houses group

36 buildings, Floor area
130.000 M², western China,



Houses group

38 buildings, Floor area
140.000 M², western China



**Seismic Isolation
Basement Isolation**

Seismic Isolation Library building in Taiyuan City, northern China

Basement Isolation



Isolation bearings for long span space structures

To solve the Temperature deformation and E.Q problem

采用了组合隔震支座: 盆式支座 + 橡胶支座
共采用 40个支座



隔震支座

Sport Stadium— Flexible Slide Isolation Joint EERTC



柔性滑动支座

Guangzhou Sport stadium

大跨空间结构----广州体育馆
(EERTC 广州市设计院)



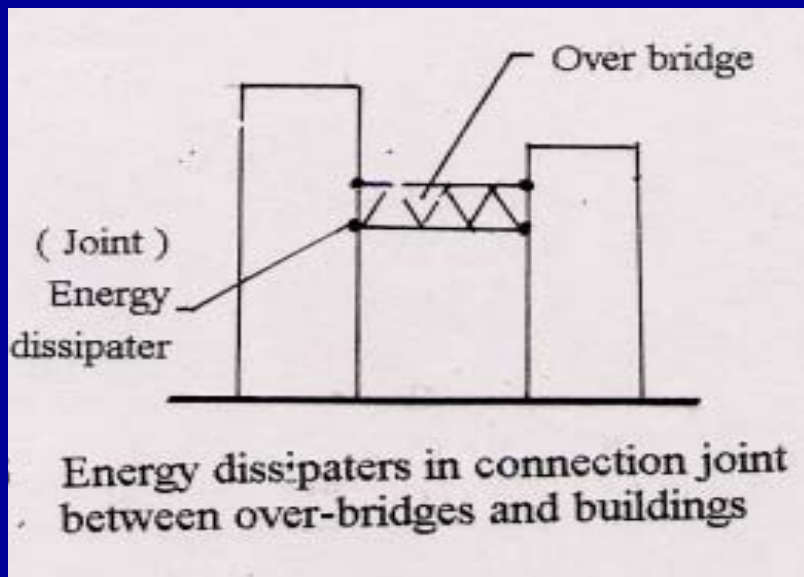
隔震支座



Over bridge between two buildings using isolation joint 连廊结构柔性（隔震）节点

Decouple the different
model shapes
of two buildings

由于两高楼振型不同
端节点受力复杂，严重破坏
宜采用柔性隔震节点



Shaking table test (EERTC, 广州市规划院)



**Traditional
Rigid joint**

**Flexible
joint**



Guangzhou Zhen Jia Plaza

广州正佳广场 志诚商场连廊 2005
(广州市设计院, 广州大学)



Seismic Isolation Bridge



**9 - 32m railway bridge used isolation in Xinjian,
western China, experience Xinjiang EQ M6.2 2003.2.24**

No damages

3 - 18m highway isolation bridge in ShiJiaZuang, China



Isolation used in
Subway in
Guangzhou China
Vibration be
reduced to be 1/4



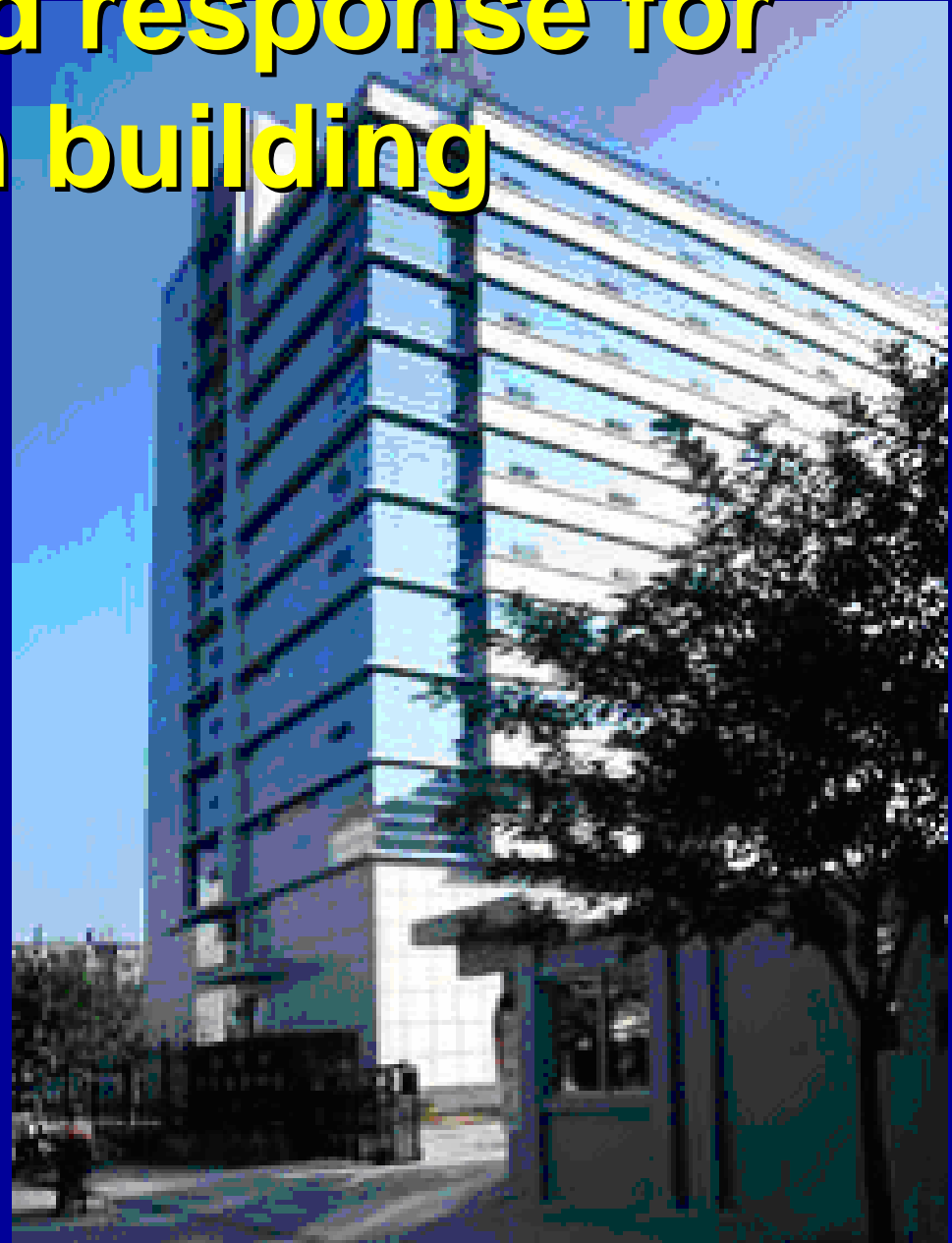
2.9 Observed response for isolation building



**Earthquake Bureau
building
of Fujian Province,
China.**

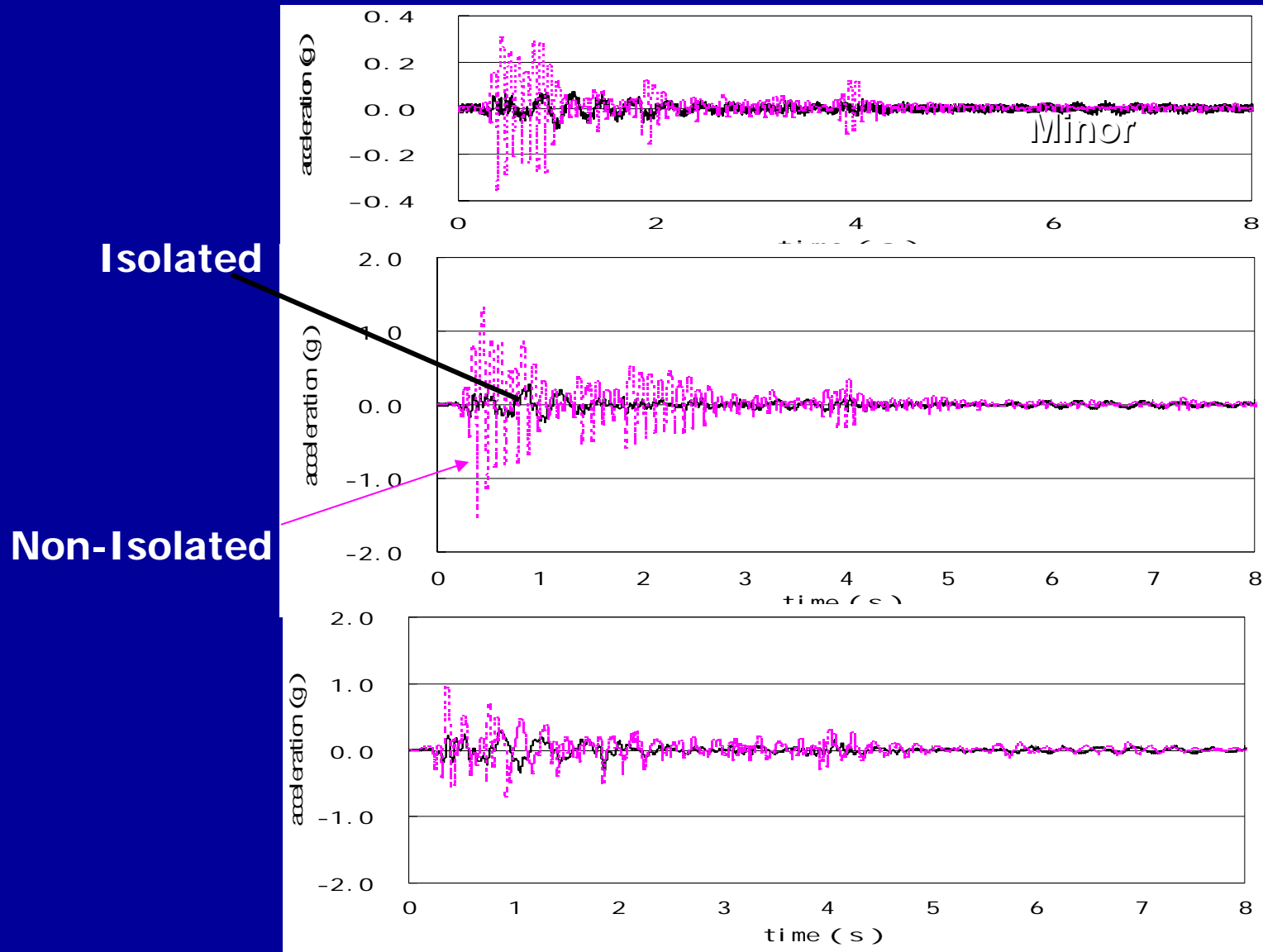
**Isolation Building
2005**

RC Structure -1,+11



Results from shaking table test

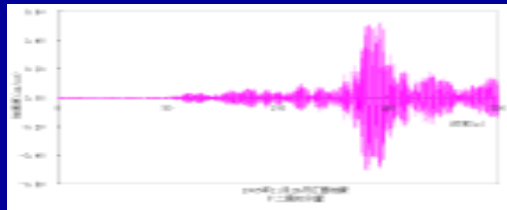
广州大学 2003
国家地震局 陆鸣



El Centro wave

Observed response

Earthquake Bureau of Fujian Province 福建省地震局隔震楼
Jianxi EQ(M 5.7) 2005.11.26



12 story

Isolat.

0.14

(Observe)

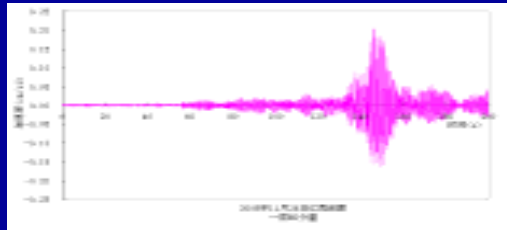
no Isola.

0.59

(Calcu.)

Iso / no iso.

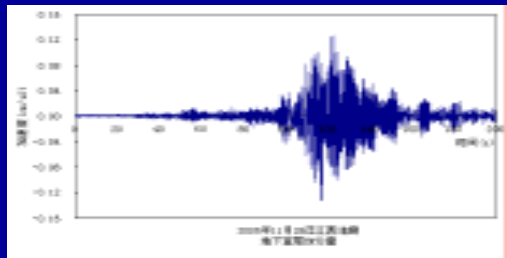
1 / 4.2



1st story

0.10

0.12



Ground

0.12

0.12

2.10 Design code, rules and standards for isolation in China

Design Code for isolation

- 1. The Seismic Design Code for Buildings (GB 50011-2001)**
- 2. Technical Rule for Seismic Isolation with Laminated Rubber Bearing Isolators (CSCE 126:2001)**

Standards for isolator products

- 1. Seismic Isolation Rubber bearings (JG 118- 2000)**
- 2. Rubber Bearing (GB2005-101)**

China could producing Large diameter RB isolators

(1) Rubber Bearing

Diameter $\phi 200 \sim 1200$ mm

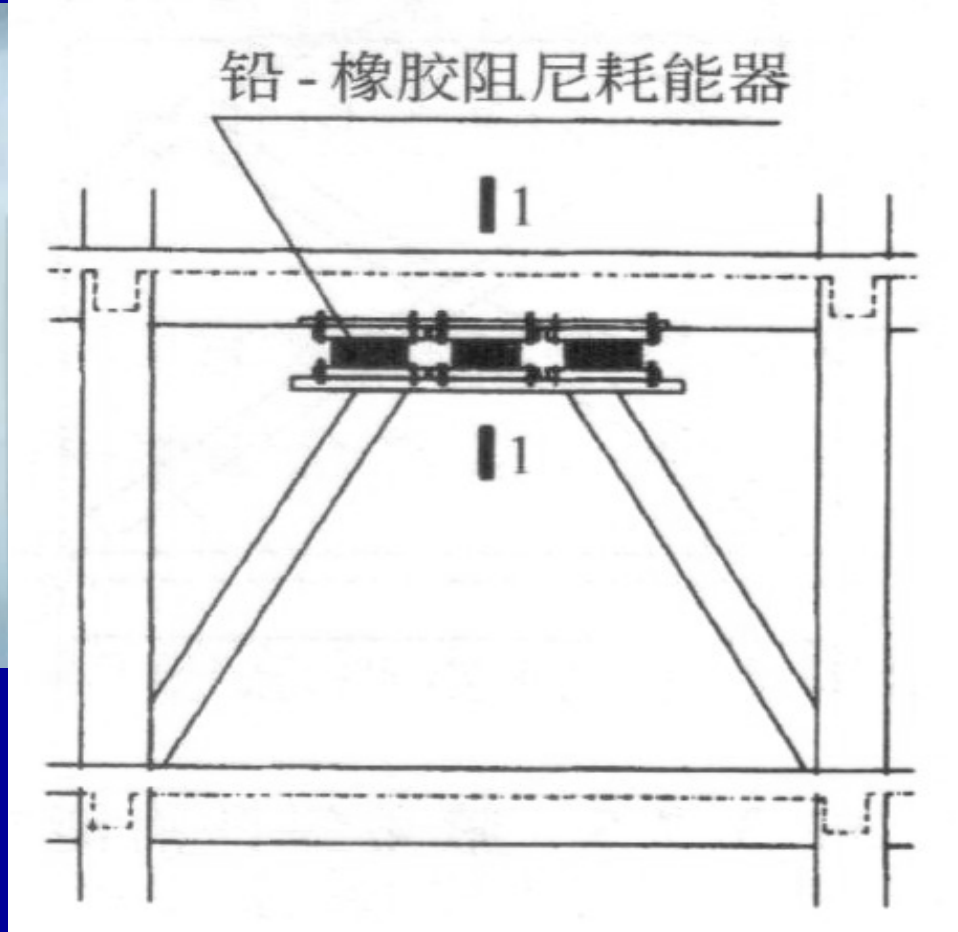
Ask to prod. $\phi 200 \sim 1600$ mm

(2) Rubber Bearings with high quality also low price

(3) Provide to be used in China and other countries In the world

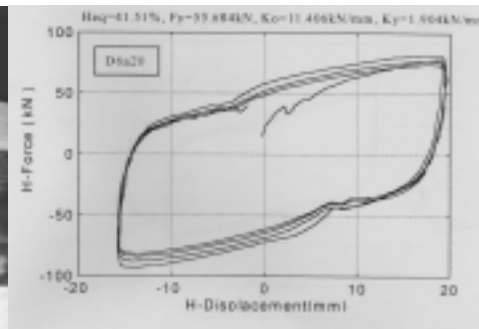


3. Energy Dissipation

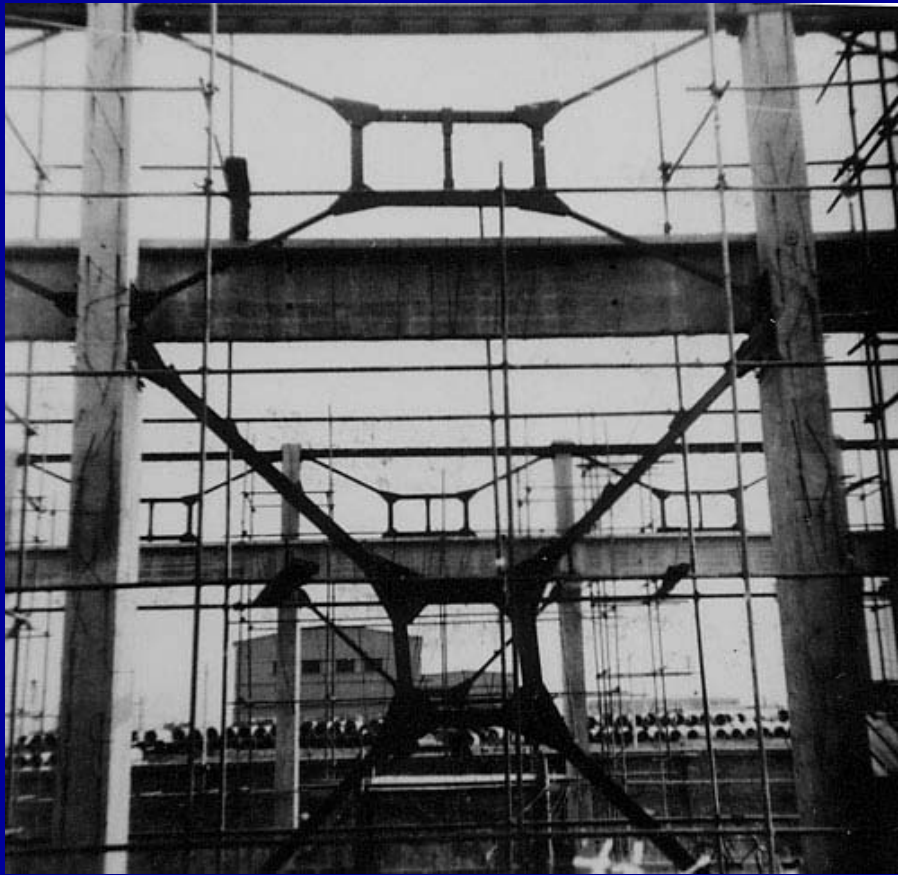


Office building in Shanghai
(Prof. Lu X. L.)

Lead Damper (EERTC)



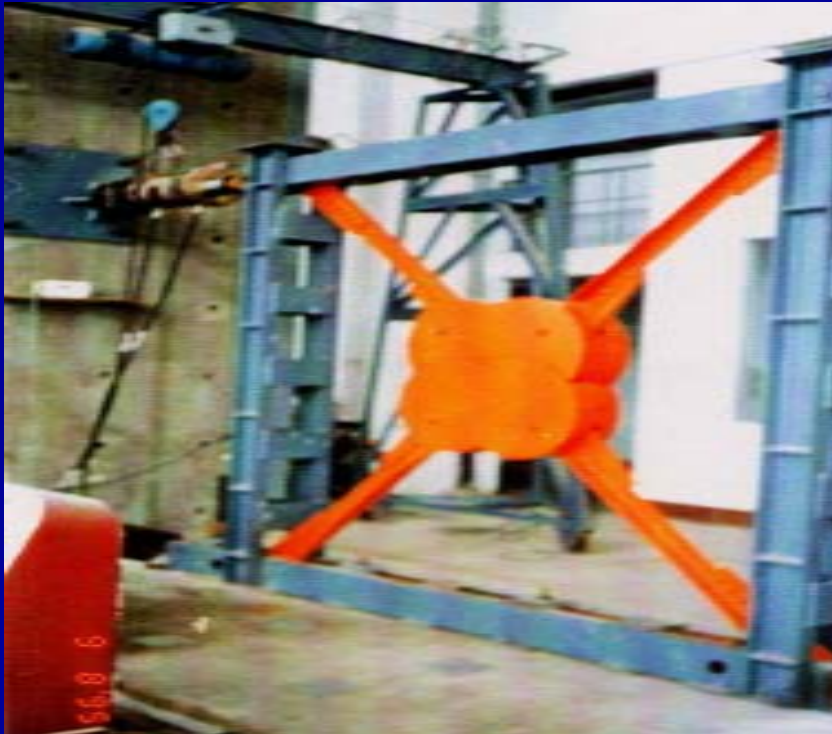
Energy dissipation bracing using **steel** in Henan, China 河南洛阳 厂房 (1979)



Energy dissipaters using **steel** (1979) full scale tests

Energy Dissipation: friction

Application in China (EERTC 1996)



Energy dissipation
bracings in Guangzhou



28 stories high rise building in
southern China



RB Isolators

800

24 9:16



Oil Damper

24 9:15

**high rise
building with
oil damper**



**A large sport stadium
building in China
(Prof. W.Q.Liu)**



(M)Test of Oil Dampers

Testing is carried out
in the Energy
Dissipation
Testing System
EERTC
上海材料研究所



Smart Material (SMA) for retrofit

Seismic-Resistance retrofit by using smart material
(guangta mosque with 1200 years history)

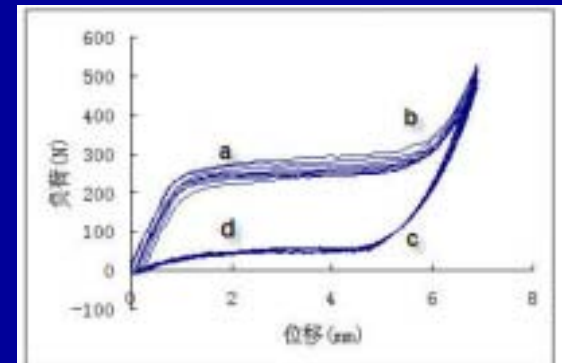
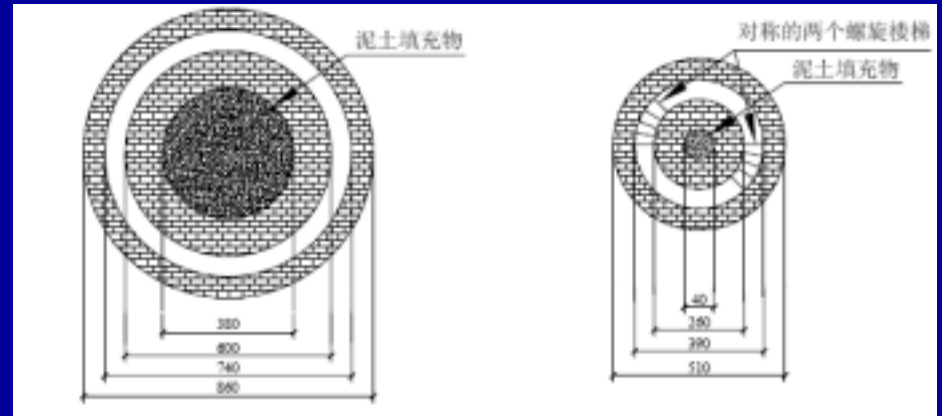
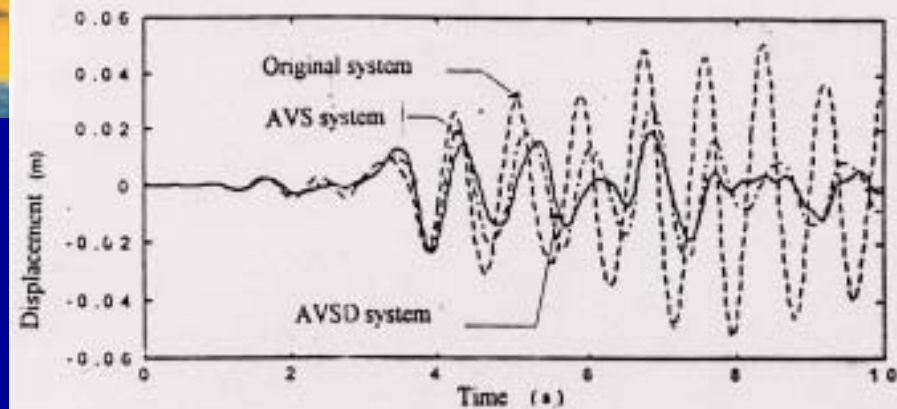


图 2-5 SMA 拉伸试验的力-位移滞回曲线

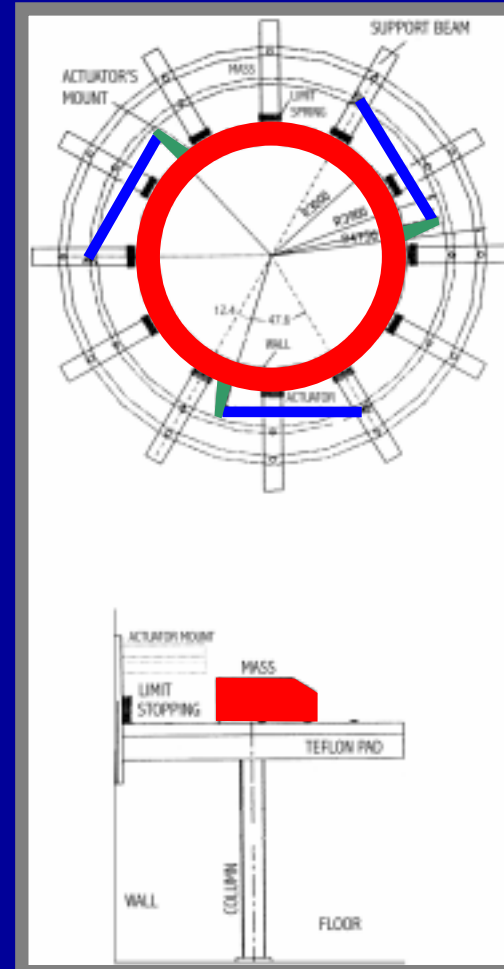
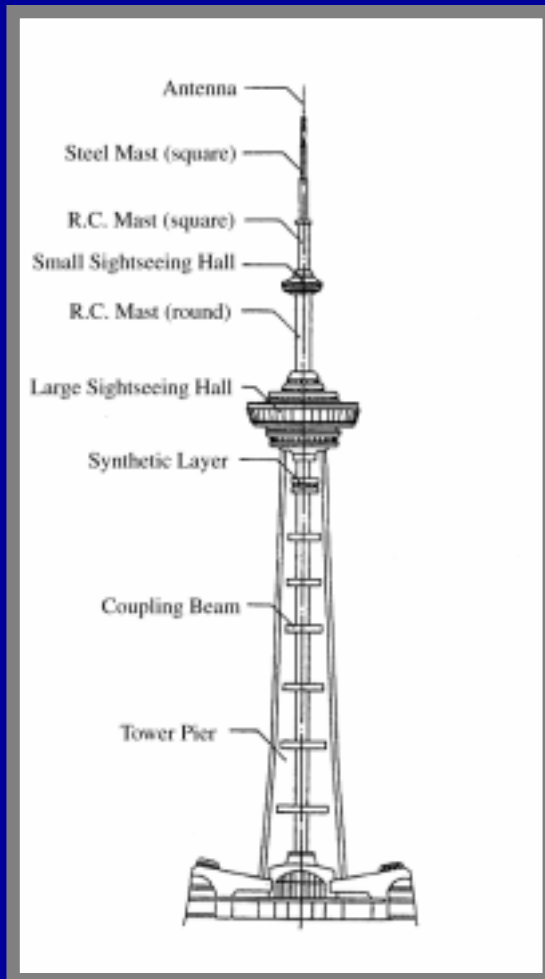
4 . Semi-Active Control

Shaking Table tests EERTC 1998



主动控制技术：AMD

南京 TV Tower (Prof. 李爱群,2000)



Semi Active Control

广州

A TV tower

高塔 618 M

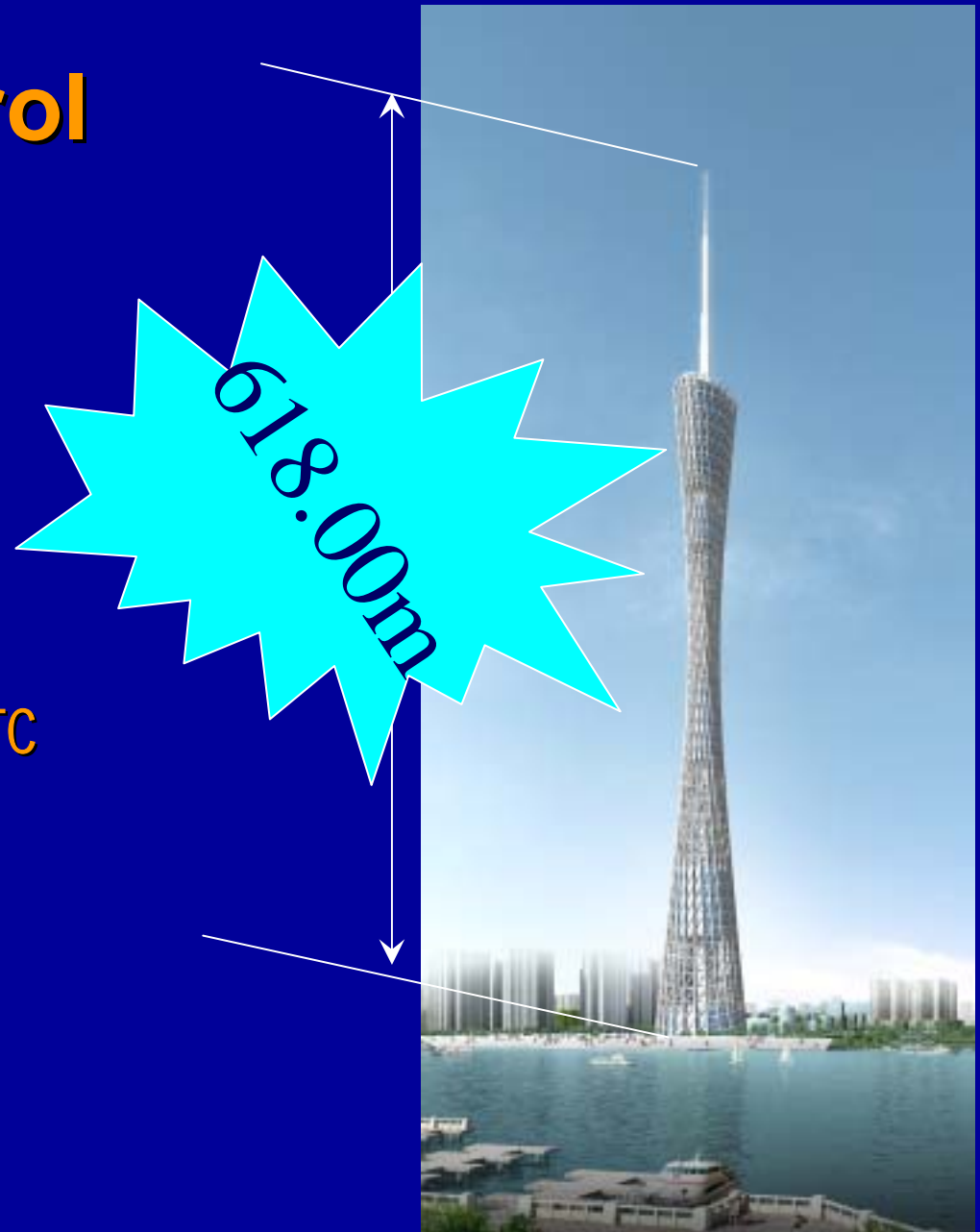
(2008年建成)

广州大学, 哈工大, 广州市院, ARUP

Guangzhou University EERTC

风振! 地震!

采用控制装置



5. Suggestion for future development

- 1. Compile the Design guideline:
Seismic Isolation for Structures
Energy Dissipation for Structures**
- 2. Compile the Standard:
Energy Dissipation Device – Oil Damper**

Thank you !

ありがとうございました！

谢谢！