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BASE ISOLATIONE FOR THE PROTECTION OF BUILDINGS FROM EARTHQUAKE

WITH PARTICULAR REFERENCE TO PREFABRICATED AND TALL BUILDINGS

Agostino Marioni – New Delhi – 21 February 2017

How to protect a structure from the earthquake?

There are 2 systems

1. First system is to design the structure strong enough to resist the earthquake (Inca wall strategy)

- In case of earthquake structural damages are admitted but not the collapse of the structure

How to protect a structure from the earthquake?

2. Second system (PALM TREE STRATEGY) is to reduce the seismic action making the structure flexible.

- The seismic action in the structure is reduced
- Damages, if any, are concentrated in the devices
- The structure and its content are protected from damages

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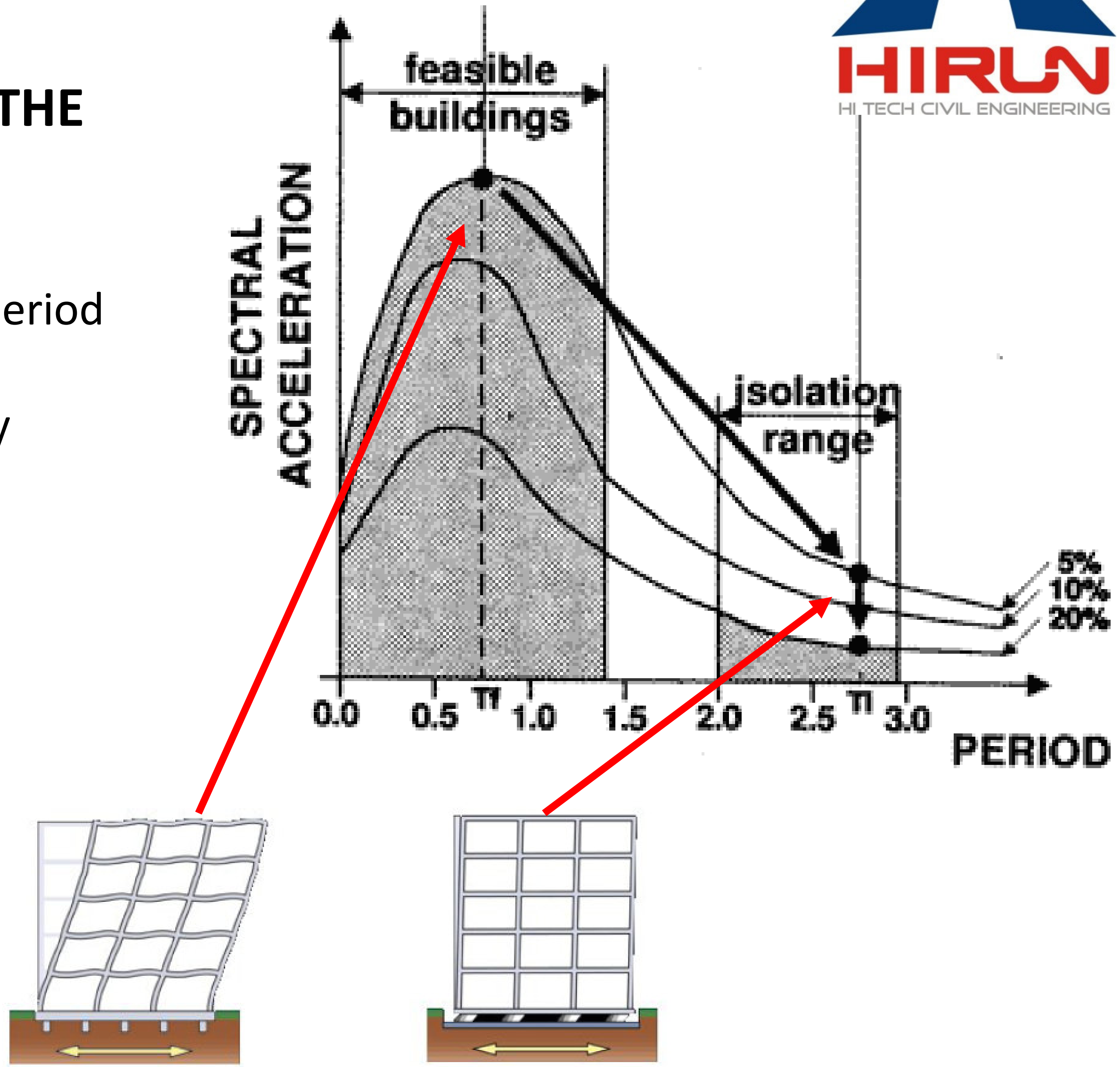
HOW TO REDUCE THE SEISMIC ACTION?

- Shifting the natural period

- Increasing the energy dissipation

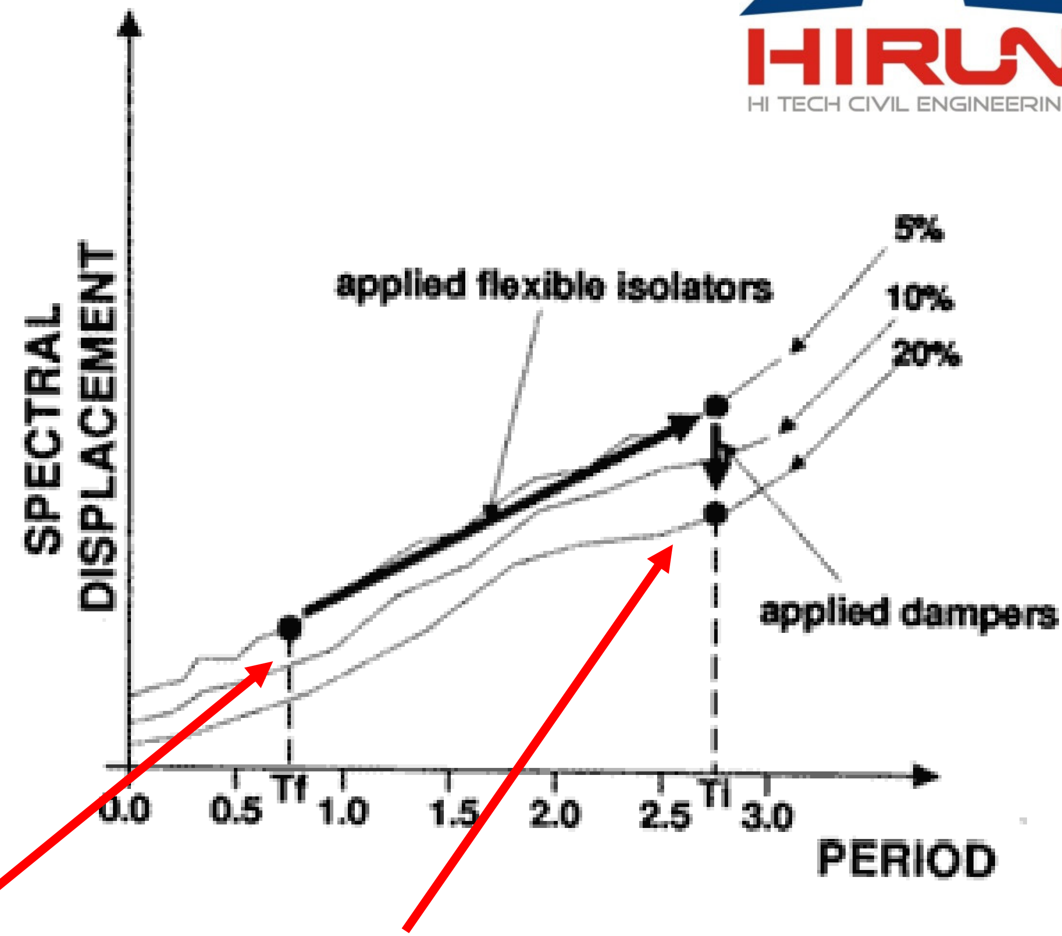


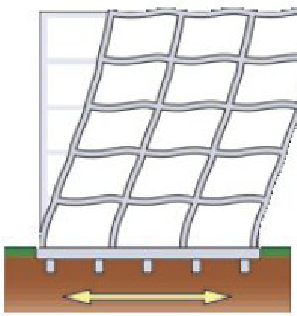
Struttura non isolata

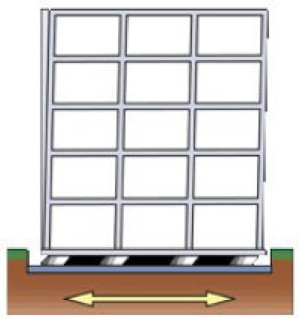
Struttura isolata

CONSEQUENCES OF THE BASE ISOLATION

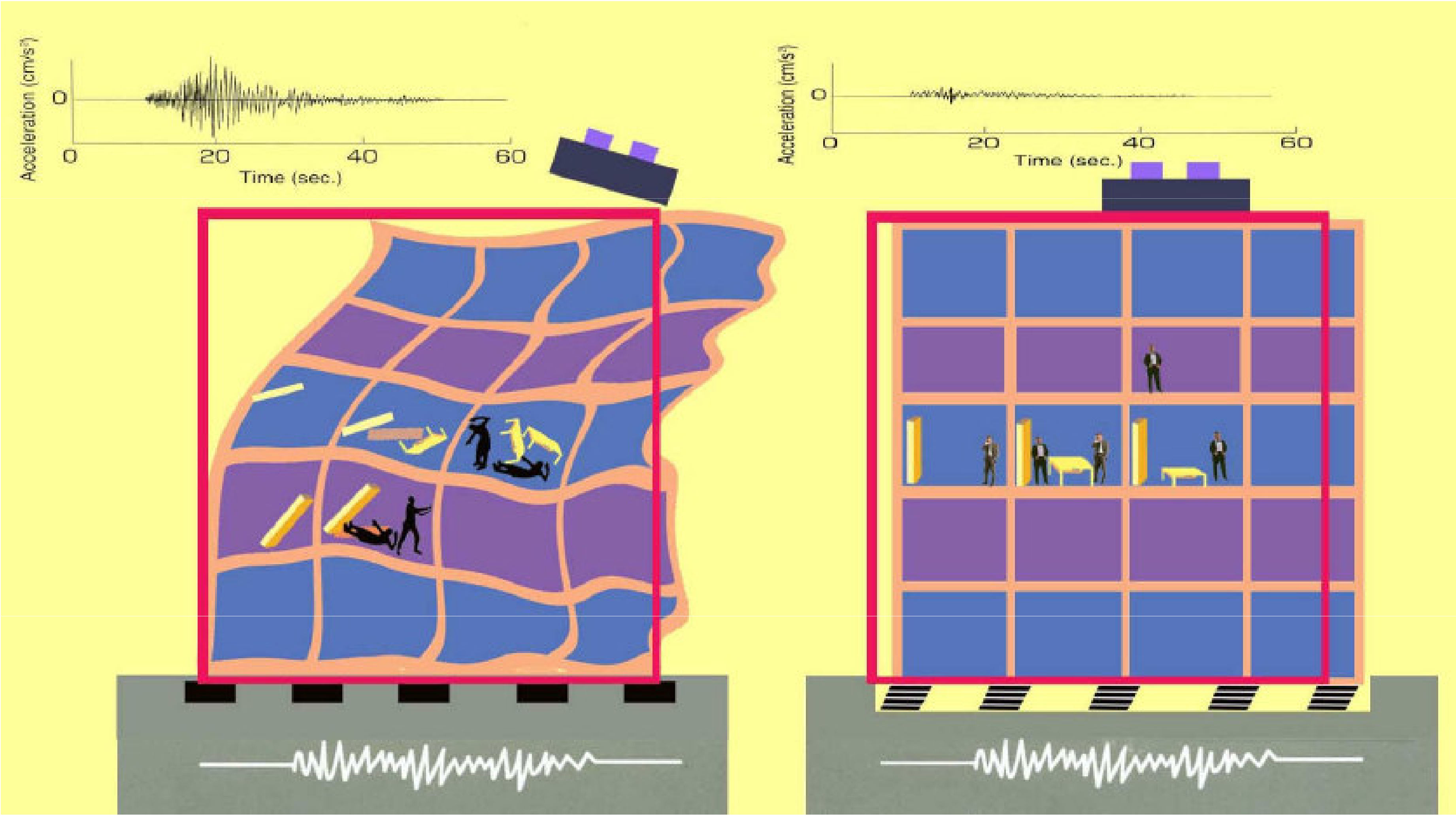
- Significant increase of the displacement
- Energy dissipation will reduce the displacement




Struttura non isolata


Struttura isolata

THE ADVANTAGES OF THE BASE ISOLATION



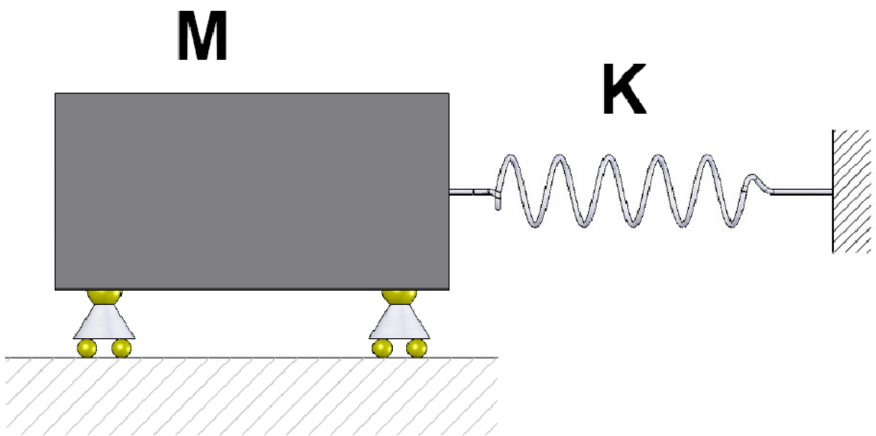
- FIXED BASE
- Damages to structure and content
- BASE ISOLATED
- No damages

How to increase the natural period of a structure?

- Placing between the structure and the foundations a harmonic oscillator forcing the structure to swing according to the period of the oscillator

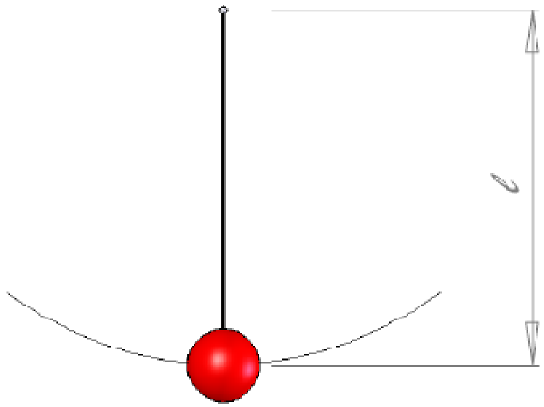
Harmonic oscillators

- Spring with stiffness K



$$T = 2\pi\sqrt{\frac{M}{K}}$$

- Pendulum with length L



$$T = 2\pi\sqrt{\frac{l}{g}}$$

How to dissipate energy?

- Friction
- Yield of metals
- Viscosity of fluids or rubbers

In any case an amount of heath equivalent to the dissipated energy is generated

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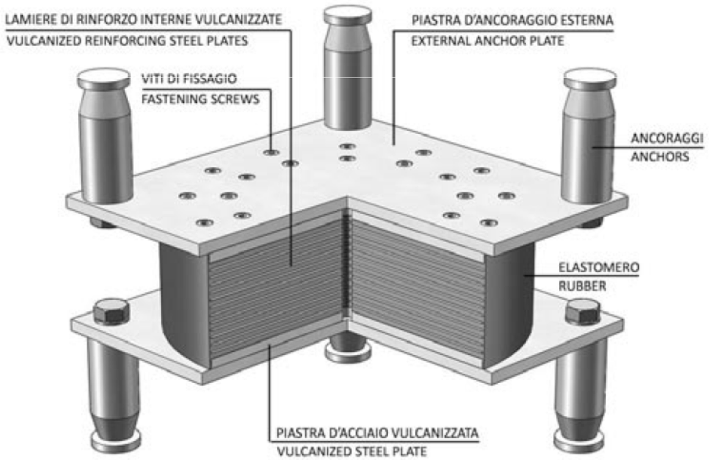
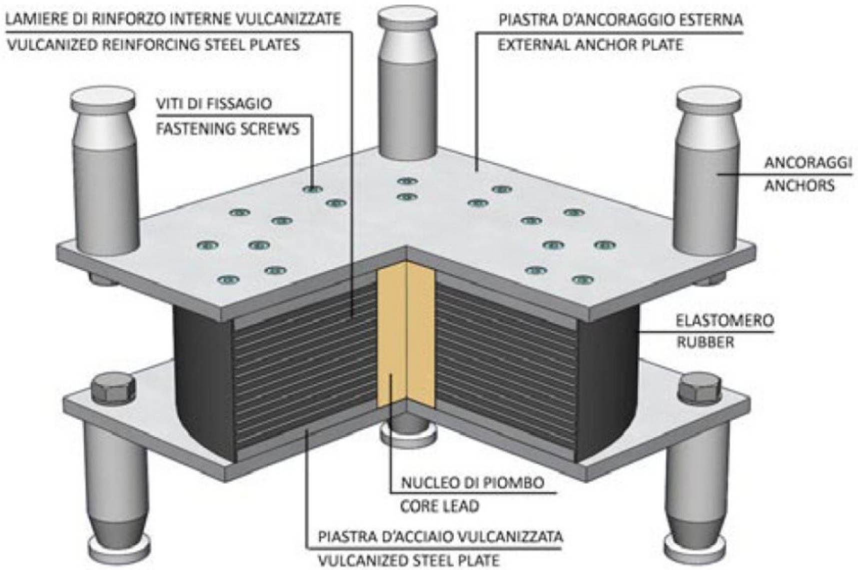
Main types of Isolators

- High Damping Rubber Bearing
  - The spring effect is given by the rubber elasticity (elastic energy storage)
  - The energy dissipation is given by the rubber viscosity



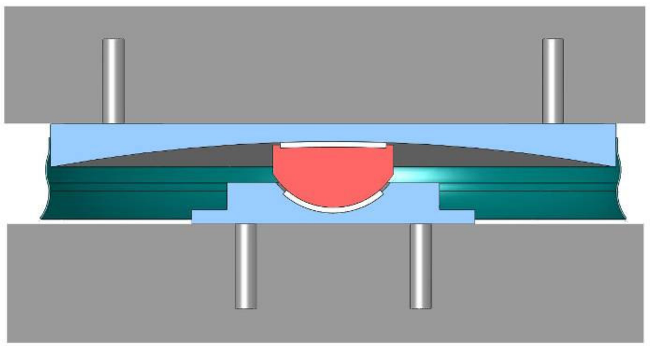
Main types of Isolators

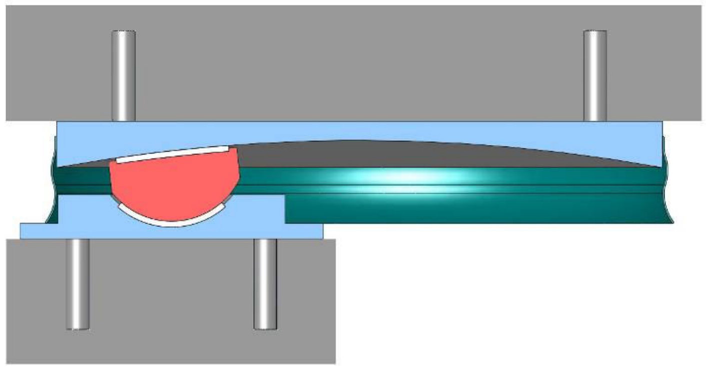
- Lead Rubber Bearing
  - The spring effect is given by the rubber elasticity (elastic energy storage)
  - The energy dissipation is given by the yield of the lead core



Main types of Isolators

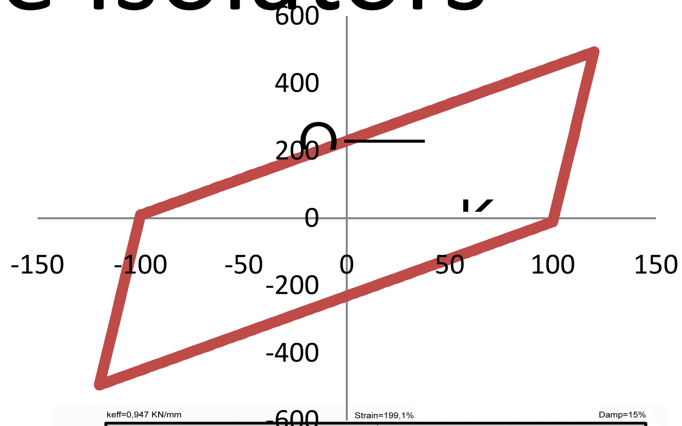
- Sliding Pendulum
  - The spring effect is provided by the potential energy storage
  - The energy dissipation is provided by the friction of the sliding material



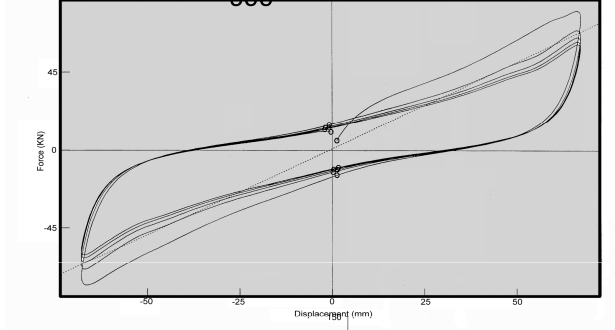


Hysteresis Cicles of the Isolators

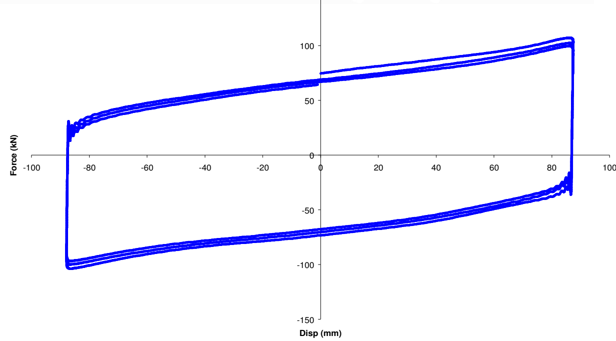
- LRB



- HDRB



- Sliding Pendulum



Functions of a base isolation system

- Support the vertical load
- Provide lateral flexibility
- Provide a restoring force
- Damp the energy

Isolators are devices providing the four functions

The Standards for the Antiseismic Devices

In Europe:

- EN 1998 (Eurocode 8)
- EN 15129 European Standard for Antiseismic Devices

In USA:

- AASHTO Guide Specification for Seismic Isolation Design
- ASCE/SEI 7 Minimum Design Loads

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The Standards for the Antiseismic Devices

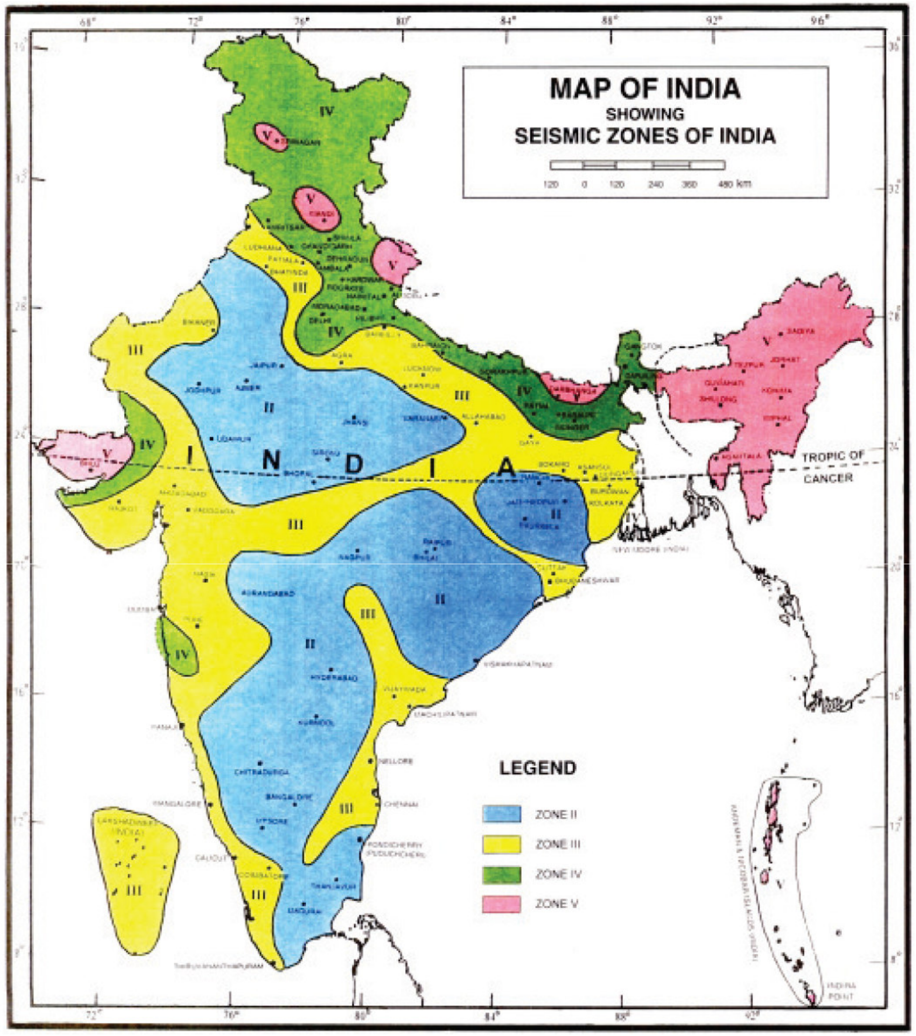
In India:

- IS 1893 Criteria for earthquake resistant design of structures

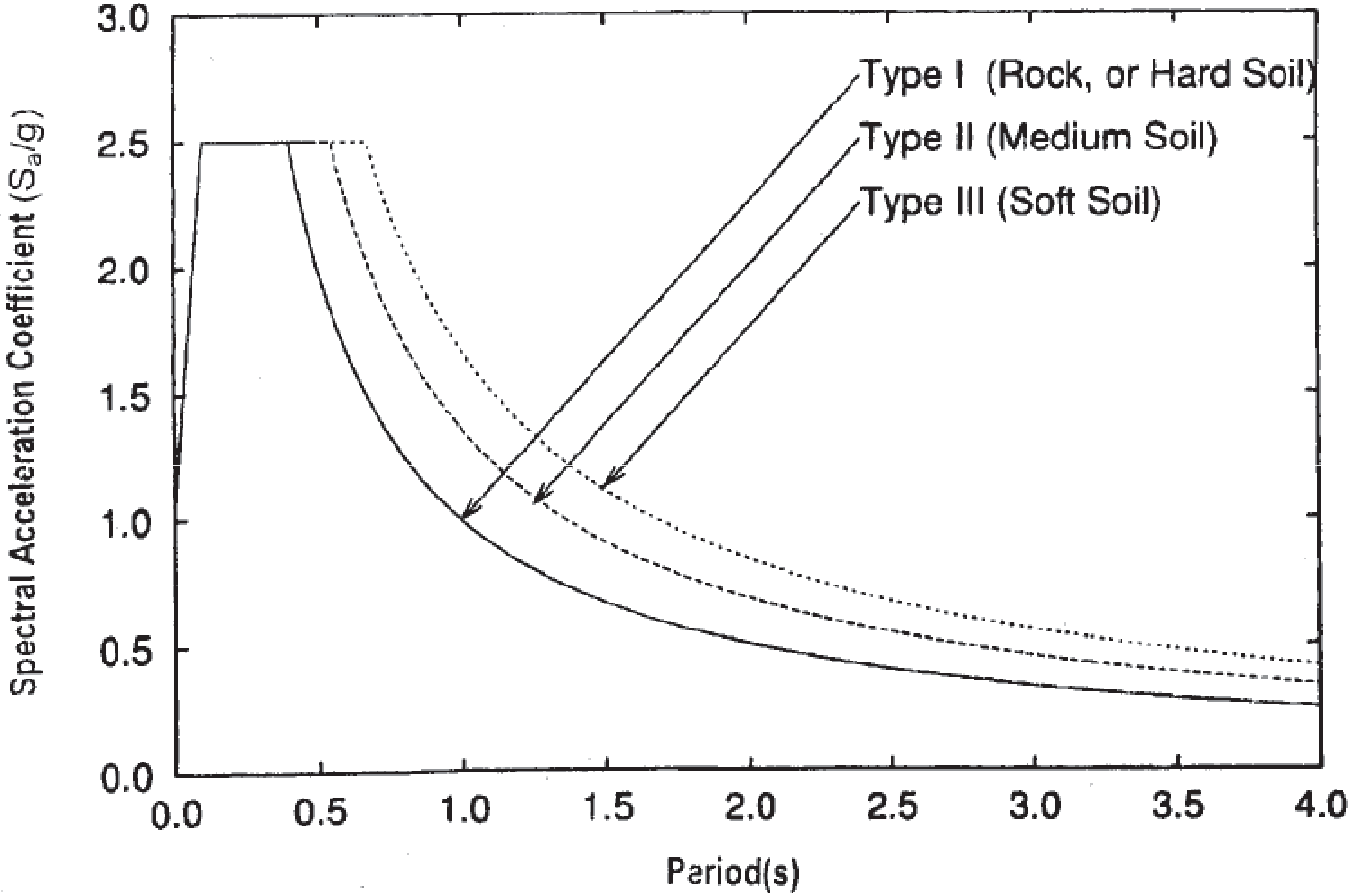
Table 2 Zone Factor, *Z*

(*Clause* 6.4.2)

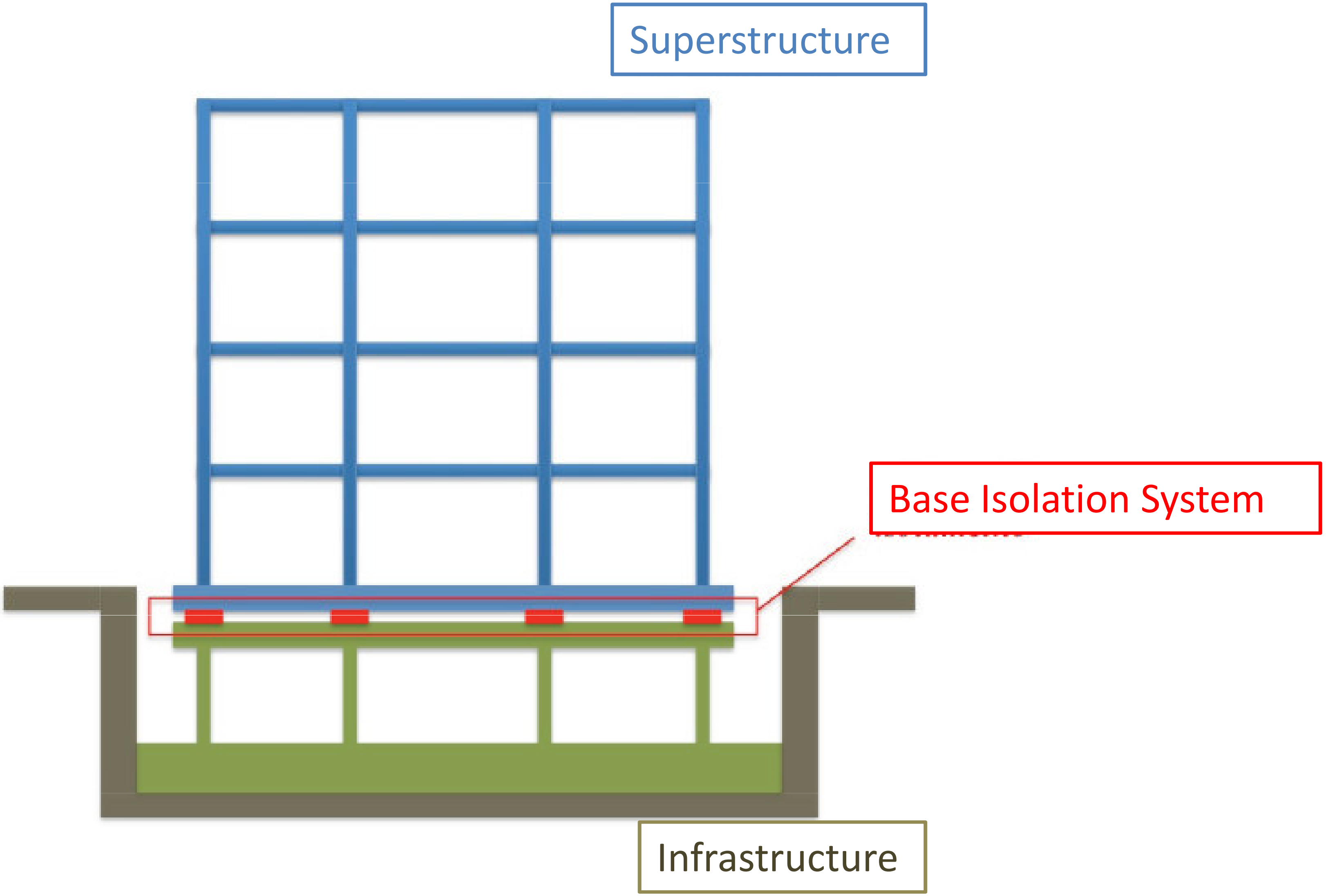
Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36



ACCELERATION SPECTRA ACCORDING TO THE INDIAN CODE



General rules for a base isolated building



RUBBER ISOLATORS OR PENDULUM?

ABOUT THE PERIOD T

For the HDRB the period is a function of:

- M = mass
- K = stiffness
- M may vary (LL may change)
- K can vary in function of Temperature and aging

IN CONCLUSION WITH HDRB THE PERIOD T CAN VARY

- For the Pendulum the period is a function of:
- g = gravity constant: cannot vary
- R = radius: cannot vary

WITH THE PENDULUM THE PERIOD CANNOT VARY

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ABOUT THE STIFFNESS K

- For the HDRB the stiffness is an intrinsecal property.
- For the Pendulum the stiffness is proportional to the mass

$$K = Mg\left(\frac{1}{R} + \frac{\mu}{D}\right)$$

- The centre of stiffness may not be coincident with the centre of mass
- The centre of stiffness is always coincident with the centre of mass

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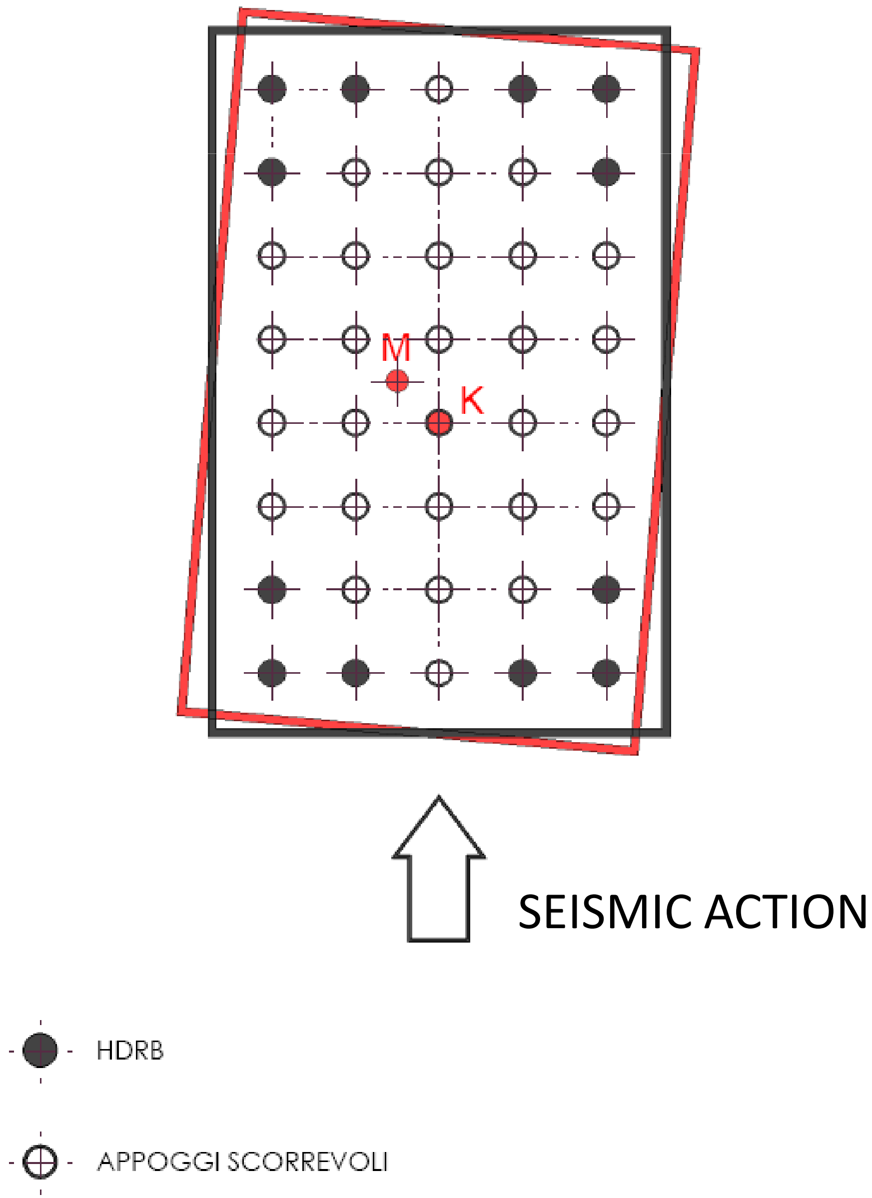

What happens if the mass center is not coincident with the stiffness center

The structure may rotate around the vertical axis, amplifying the displacement at the corners

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RUBBER ISOLATORS OR PENDULUM?

PENDULUM

- Service life ≥ 100 years
- Behaviour independent from aging and environmental conditions

RUBBER

- Service life ≤ 60 years
- Behaviour dependent from aging and environmental conditions

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RUBBER ISOLATORS OR PENDULUM?

PENDULUM

- Fire resistant
- Very high performances in terms of:
  - Period shift
  - Energy dissipation

RUBBER

- May be damaged from fire
- Limited performances in terms of period shift

RUBBER ISOLATORS OR PENDULUM?

PENDULUM

- No maintenance requirements after an earthquake
- Very good cost/efficiency ratio

RUBBER

- Possible maintenance after an earthquake

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QUALITY CERTIFICATES

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IQNet®
THE INTERNATIONAL CERTIFICATION NETWORK

CERTIFICATE

IQNet and
CQC
hereby certify that the organization

WUHAN HIRUN ENGINEERING EQUIPMENT CO.,LTD.
(WUHAN HIRUN ENGINEERING EQUIPMENT CO.,LTD. GUANGZHOU RUBBER FILIALE)

No.9 Wudong Street, Qingshan District, Wuhan, Hubei, China
(Northeast Side of 7431 Factory, Western Side of Guang Hua Road, White Cloud District, Guangzhou, Guangdong, China)

For the following field of activities

Design, Production and Service of Bridge Bearing, Building Bearing, Damper, Anti-seismic Devices, Expansion Joints, Pre-stressing System, Rotational Spherical Hinge, Rubber Goods

Has implemented and maintains a
Management System
Which fulfils the requirements of the following standard

ISO9001:2008

Issued on: May. 05, 2015
Validity date: May. 04, 2018
Registration Number: 00115Q23978R2M/4200

Michael Drechsel
President of IQNet

Wang Kejiao
President of CQC

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CQC

QUALITY MANAGEMENT SYSTEM
CERTIFICATE

Certificate No.: 00115Q23978R2M/4200

We hereby certify that

WUHAN HIRUN ENGINEERING EQUIPMENT CO.,LTD.
(WUHAN HIRUN ENGINEERING EQUIPMENT CO.,LTD. GUANGZHOU RUBBER FILIALE)

Organization Code Certificate: 27193144-8

No.9 Wudong Street, Qingshan District, Wuhan, Hubei, China
(Northeast Side of 7431 Factory, Western Side of Guang Hua Road, White Cloud District, Guangzhou, Guangdong, China)

by reason of its
Quality Management System
has been awarded this certificate for compliance with the standard
ISO9001: 2008 GB/T19001-2008
The Quality Management System Applies in the following area:

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Certified since: Aug. 06, 2009 Valid from: May. 05, 2015 Valid until: May. 04, 2018

After a surveillance cycle, the certificate is valid only when used together with an Acceptance Notice of Surveillance Audit issued by CQC. Please access www.cqc.com.cn for checking validity of the certificate.
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CNAS
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CNAS C001-Q

IAF

Signed by: Wang Kejiao

IQNet

CHINA QUALITY CERTIFICATION CENTRE 中国质量认证中心

CHINA QUALITY CERTIFICATION CENTRE
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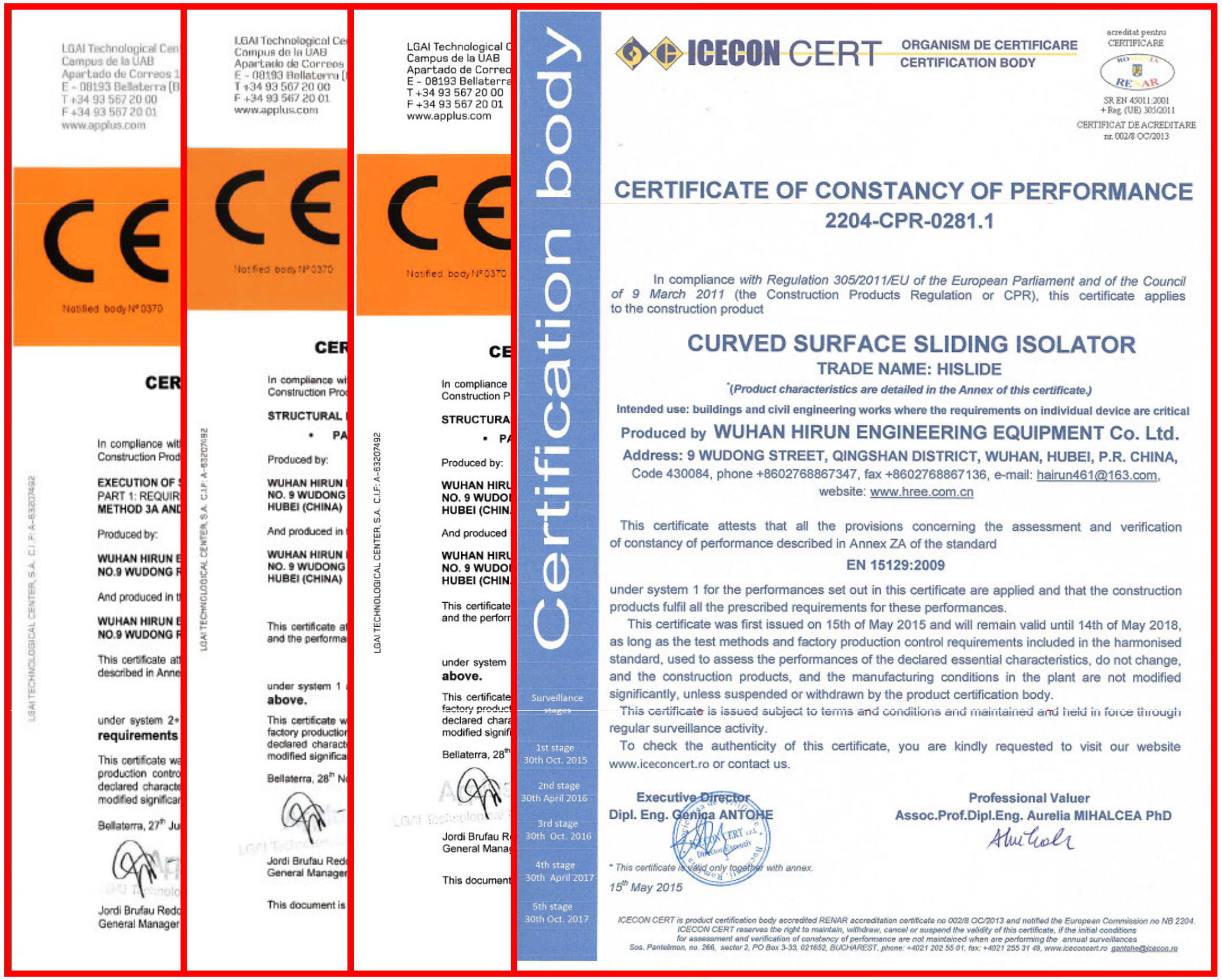

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acreditat pentru CERTIFICARE — RENAR — SR EN 45011:2001 + Reg. (UE) 305/2011 — CERTIFICAT DE ACREDITARE nr. 002/8 OC/2013

Certification body

CERTIFICATE OF CONSTANCY OF PERFORMANCE
2204-CPR-0281.1

In compliance *with Regulation 305/2011/EU of the European Parliament and of the Council of 9 March 2011* (the Construction Products Regulation or CPR), this certificate applies to the construction product

CURVED SURFACE SLIDING ISOLATOR
TRADE NAME: HISLIDE
(Product characteristics are detailed in the Annex of this certificate.)

Intended use: buildings and civil engineering works where the requirements on individual device are critical

Produced by WUHAN HIRUN ENGINEERING EQUIPMENT Co. Ltd.
Address: 9 WUDONG STREET, QINGSHAN DISTRICT, WUHAN, HUBEI, P.R. CHINA,
Code 430084, phone +8602768867347, fax +8602768867136, e-mail: hairun461@163.com, website: www.hree.com.cn

This certificate attests that all the provisions concerning the assessment and verification of constancy of performance described in Annex ZA of the standard

EN 15129:2009

under system 1 for the performances set out in this certificate are applied and that the construction products fulfil all the prescribed requirements for these performances.

This certificate was first issued on 15th of May 2015 and will remain valid until 14th of May 2018, as long as the test methods and factory production control requirements included in the harmonised standard, used to assess the performances of the declared essential characteristics, do not change, and the construction products, and the manufacturing conditions in the plant are not modified significantly, unless suspended or withdrawn by the product certification body.

This certificate is issued subject to terms and conditions and maintained and held in force through regular surveillance activity.

To check the authenticity of this certificate, you are kindly requested to visit our website www.iceconcert.ro or contact us.

Surveillance stages: 1st stage 30th Oct. 2015; 2nd stage 30th April 2016; 3rd stage 30th Oct. 2016; 4th stage 30th April 2017; 5th stage 30th Oct. 2017

Executive Director
Dipl. Eng. Genica ANTOHE

Professional Valuer
Assoc.Prof.Dipl.Eng. Aurelia MIHALCEA PhD

* *This certificate is valid only together with annex.*

15th May 2015

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- CE marking certificates

HIRUN Production line

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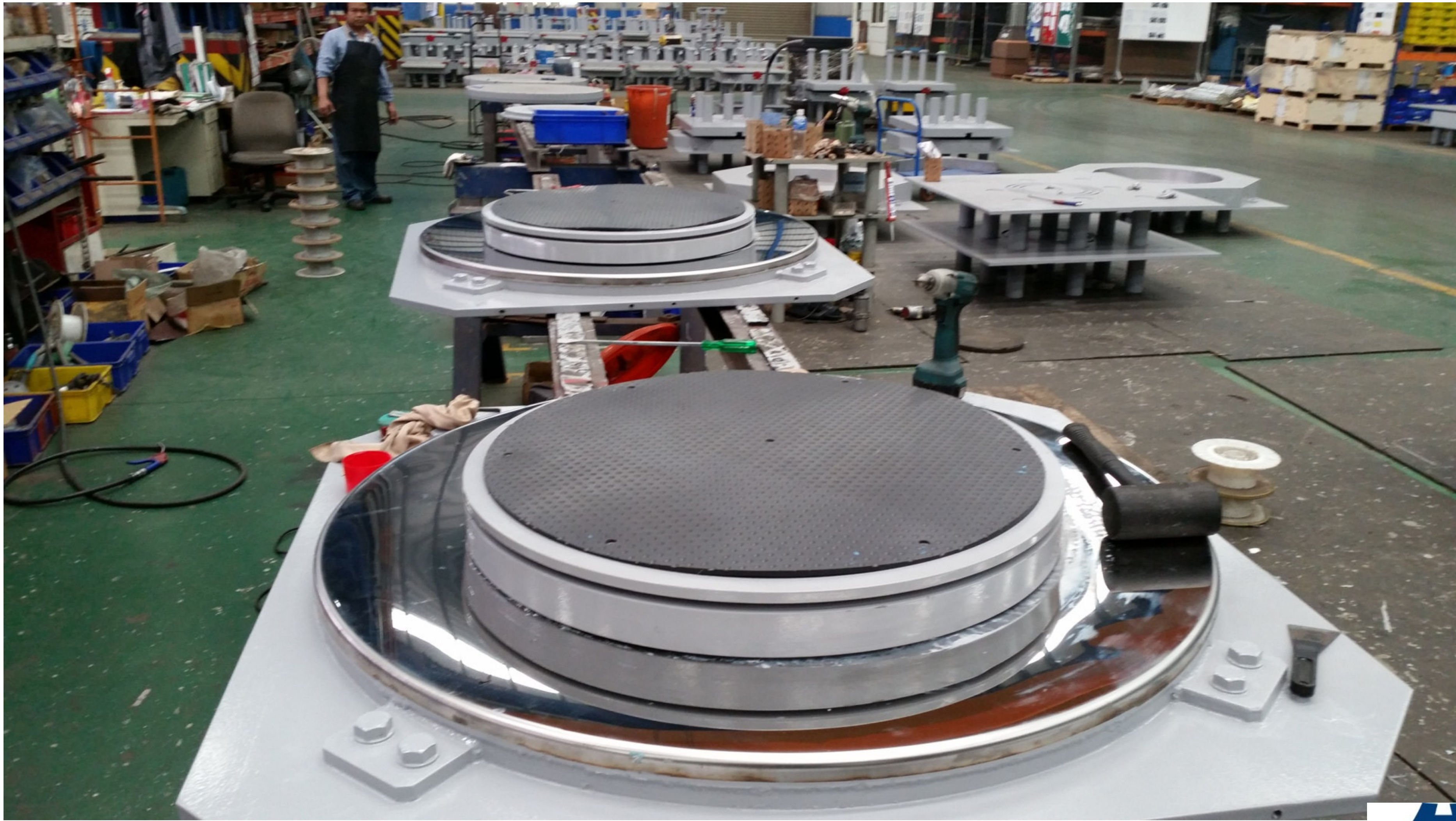
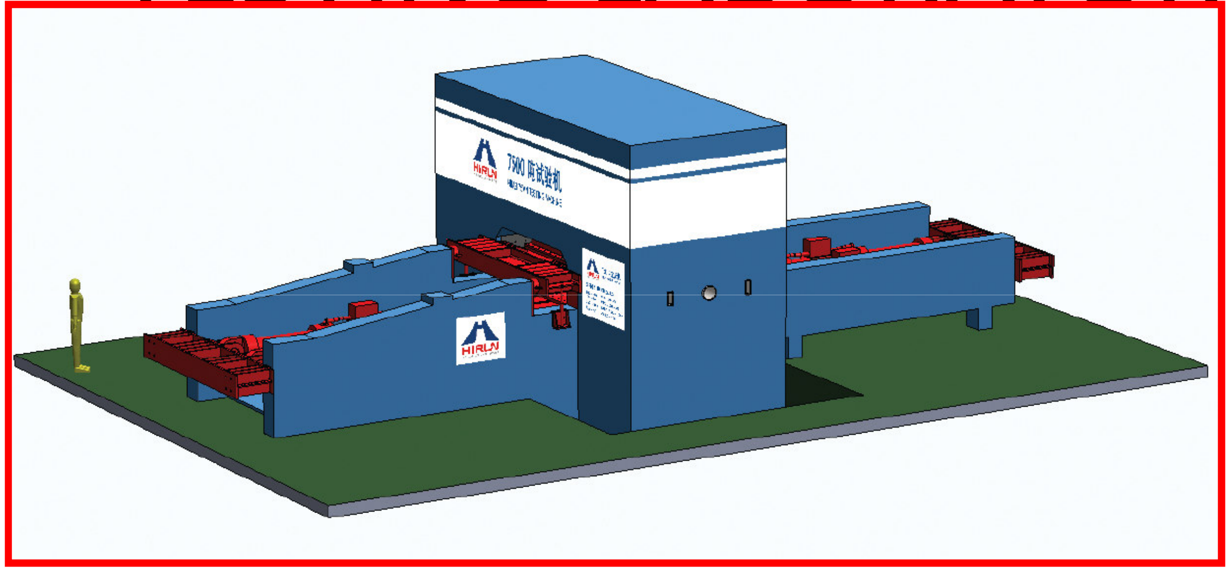
HIRUN Production line

HIRUN Production line



HIRUN Production line

TESTING LABORATORY



HIRUN MAIN TESTING EQUIPMENT

- Vertical load, dynamic, 75 MN
- Vertical displacement 120 mm (dynamic)
- Horizontal load, dynamic, 6000 kN
- Horizontal displacement 1200 mm
- Horizontal peak velocity 1000 mm/sec

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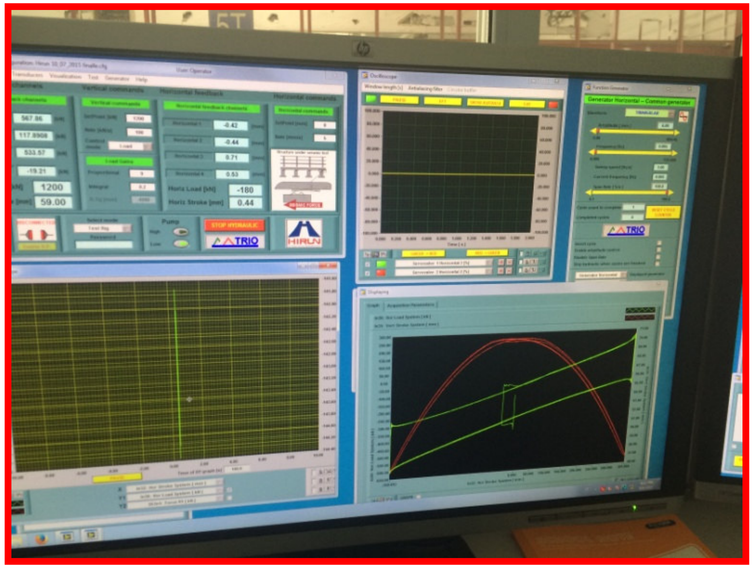
TESTING LABORATORY

- HIRUN MAIN TESTING EQUIPMENT

TESTING LABORATORY



- HIRUN TESTING EQUIPMENT: control room

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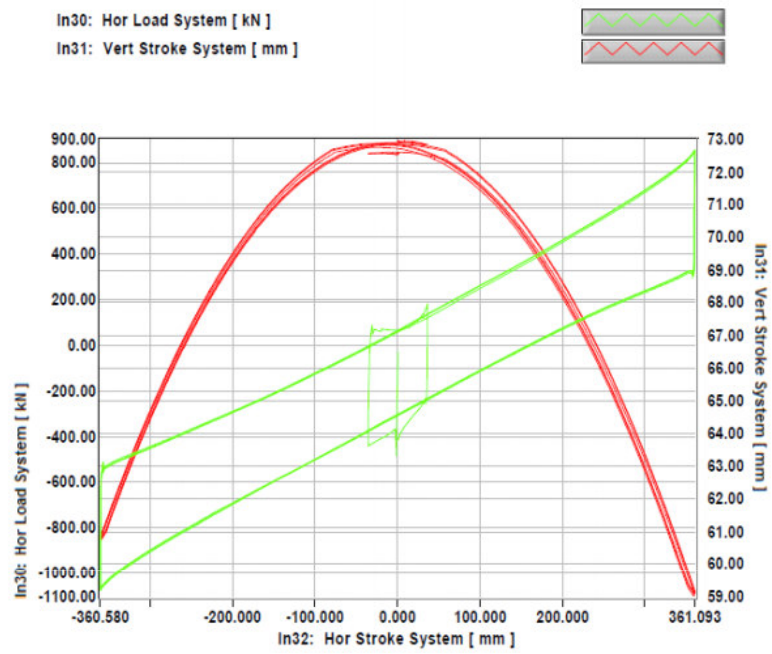
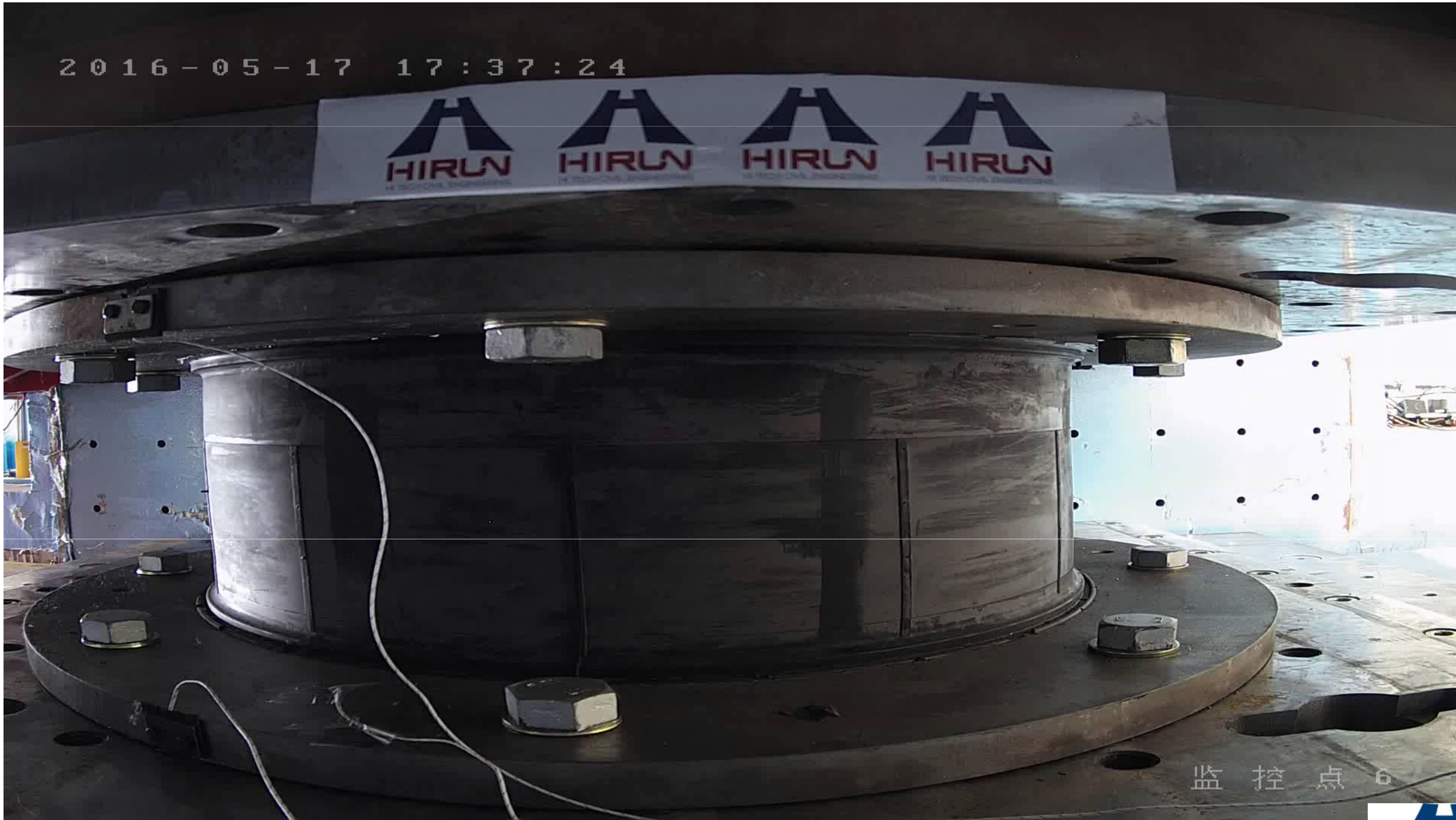
TESTING LABORATORY



horizontal load VS *horizontal stroke plot*
Vertical stroke VS *horizontal stroke plot*

- Test execution and output

Dynamic test on LRB with:
Vertical load 7540 kN; Stroke ±486 mm; Velocity 1000 mm/s



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Dynamic test on Sliding Pendulum with:
Vertical load 8000 kN; Stroke ±360 mm; Velocity 594 mm/s

PREFABRICATED BUILDINGS

- They are very suitable to be base isolated with sliding pendulum for the following reasons

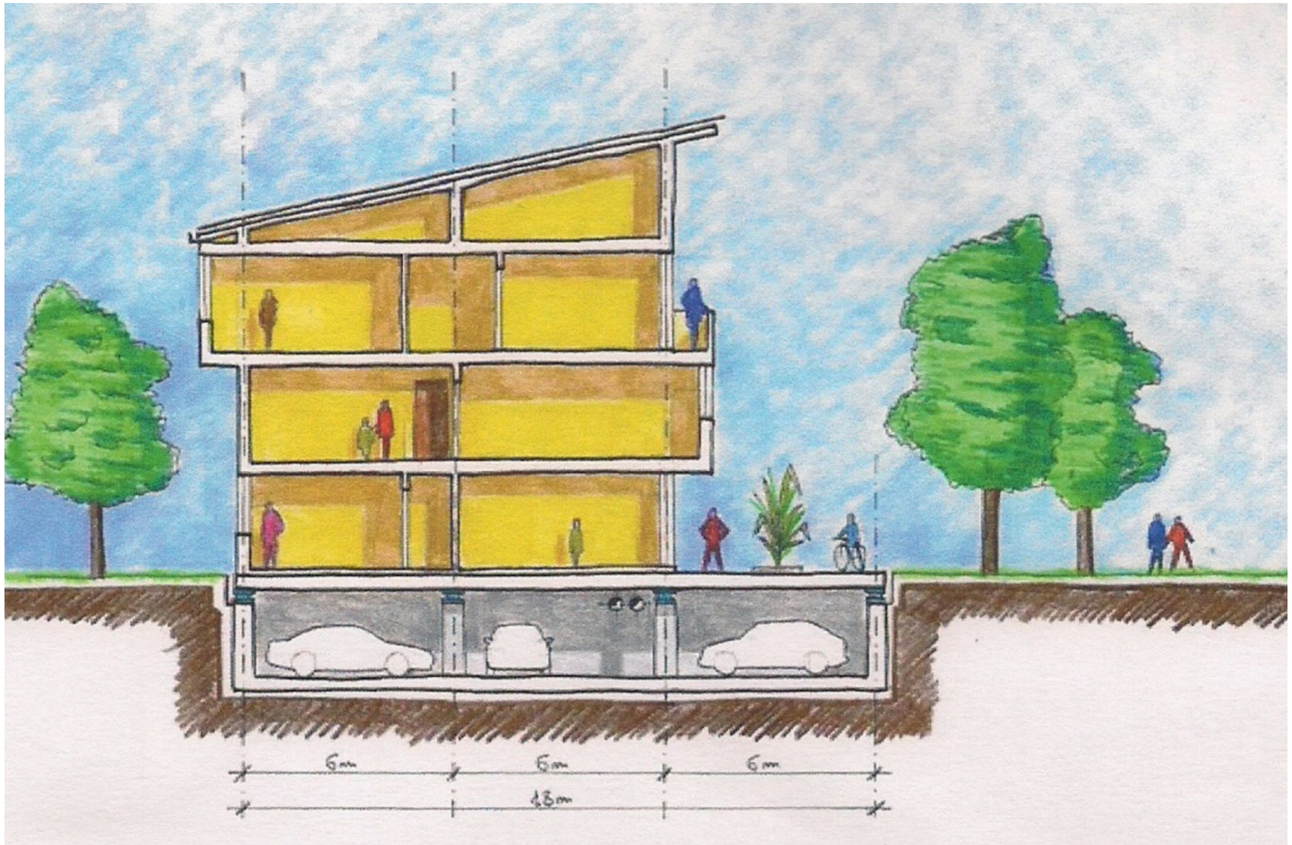
1. They are very rigid and therefore can be easily modeled with the single degree of freedom scheme
2. The pendulum provides an efficient base isolation independently from the type of structure and the mass distribution

- THIS TECHNOLOGY HAS BEEN USED IN ITALY IN THE LARGEST BASE ISOLATION PROJECT EVER BUILT: THE C.A.S.E. PROJECT

The C.A.S.E. Project in L'Aquila

185 apartment buildings on 7400 Sliding Pendulum Isolators: the largest base isolation project of the world, completely built in 6 months only

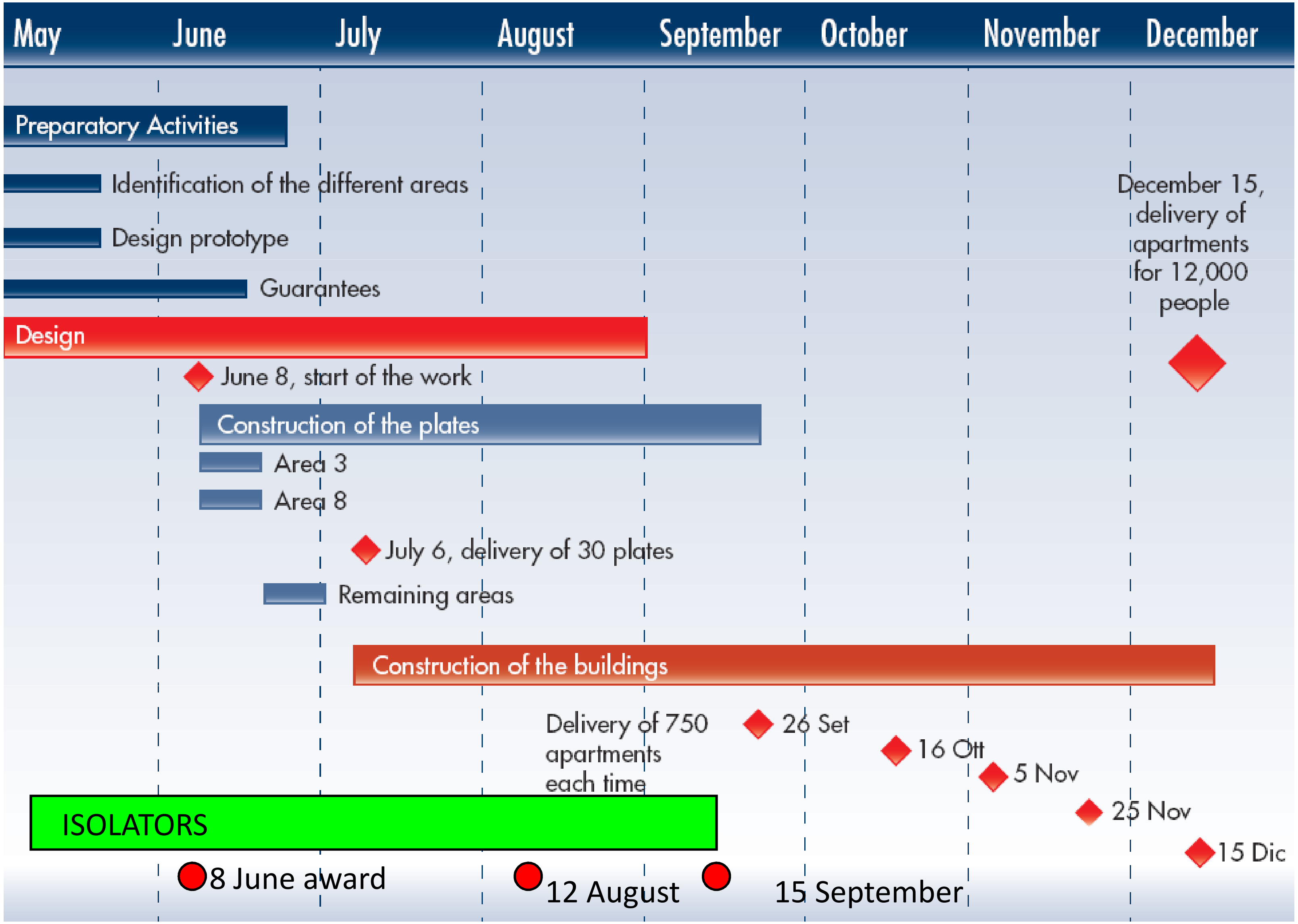
The C.A.S.E. Project in L'Aquila



The conceptual design:

- A foundation slab in reinforced concrete of 18 x 54 x 0,5 m
- Supporting 40 columns in steel or reinforced concrete
- Supporting 40 isolators
- Supporting a concrete slab of 18 x 54 x 0,5 m
- Supporting an apartment building

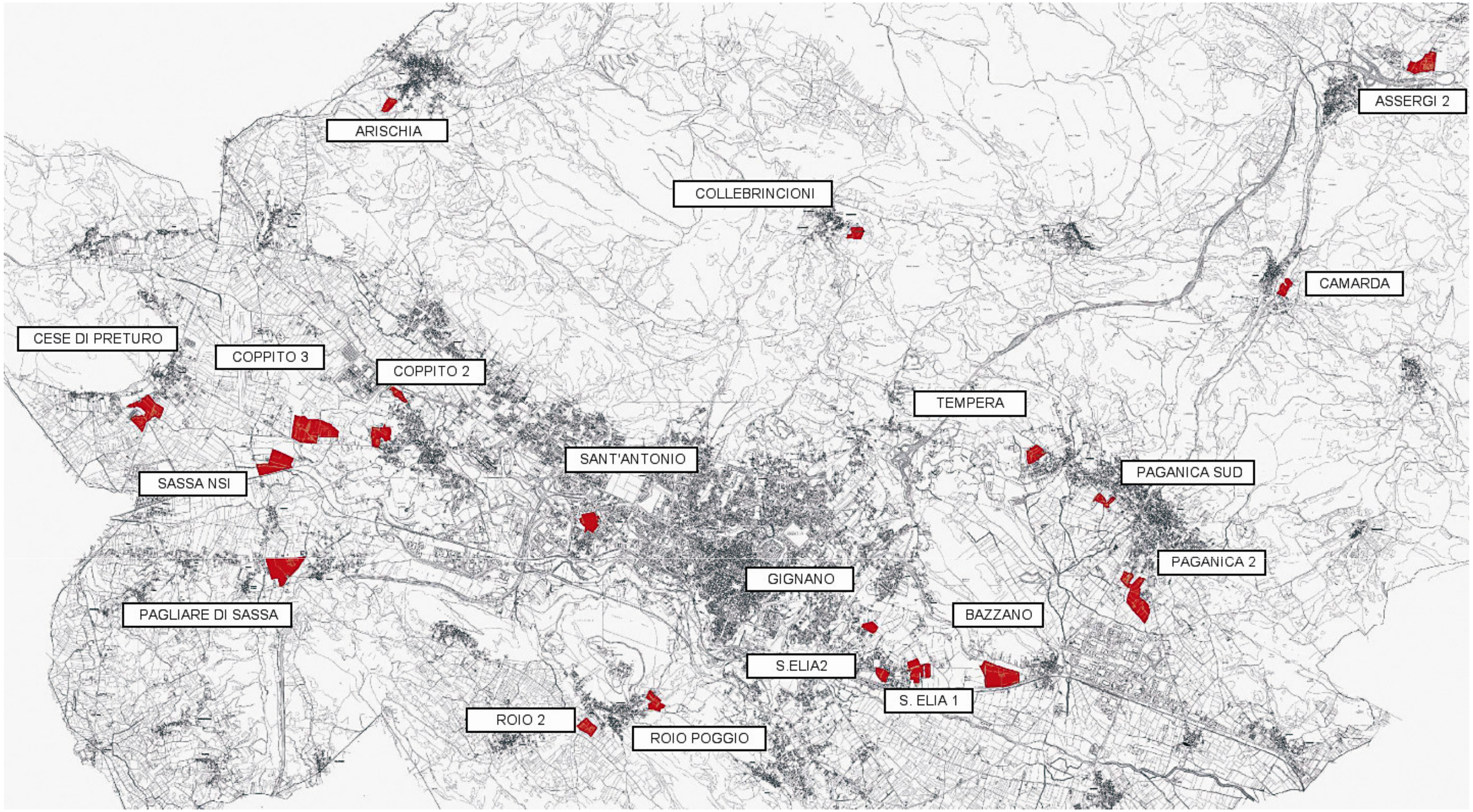
The C.A.S.E. project in l'Aquila – Time Table



First 4000 isolators delivered

3400 additional isolators delivered

The C.A.S.E. project in l'Aquila
The location of the 19 sites where the 185 buildings have been erected

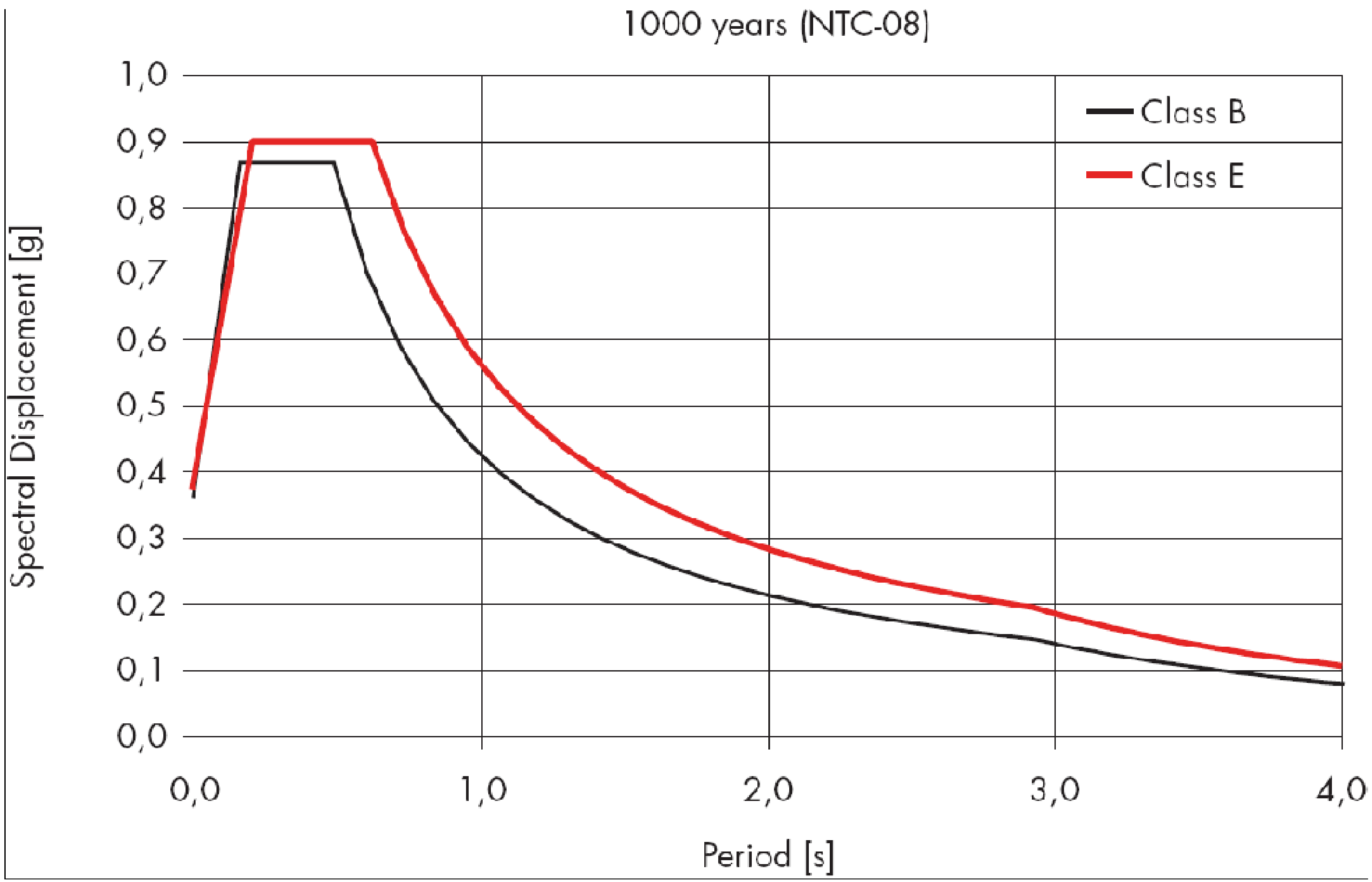


The C.A.S.E. project in l'Aquila

One of the sites:

Cese di Preturo with 20 buildings

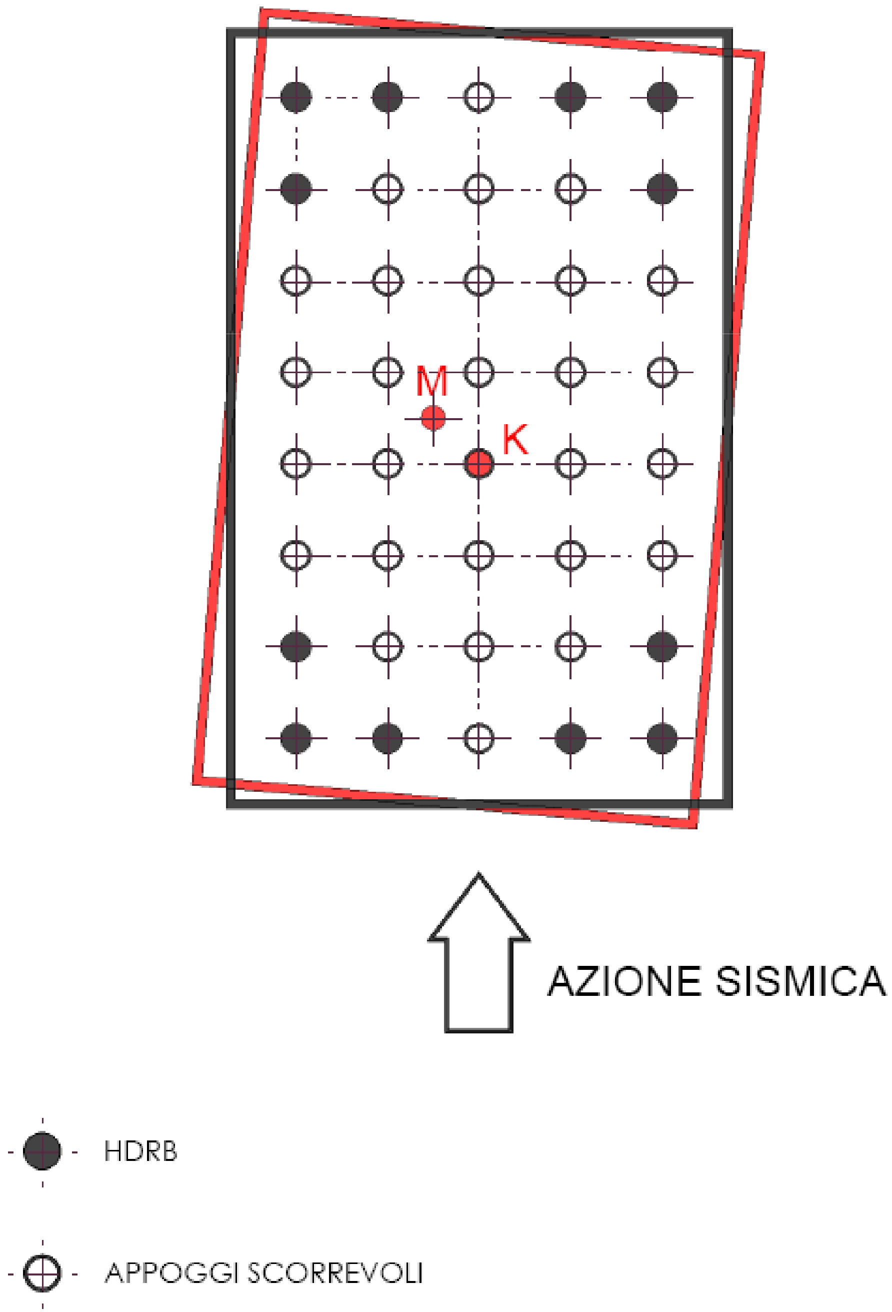
The C.A.S.E. project in l'Aquila
The design response spectrum



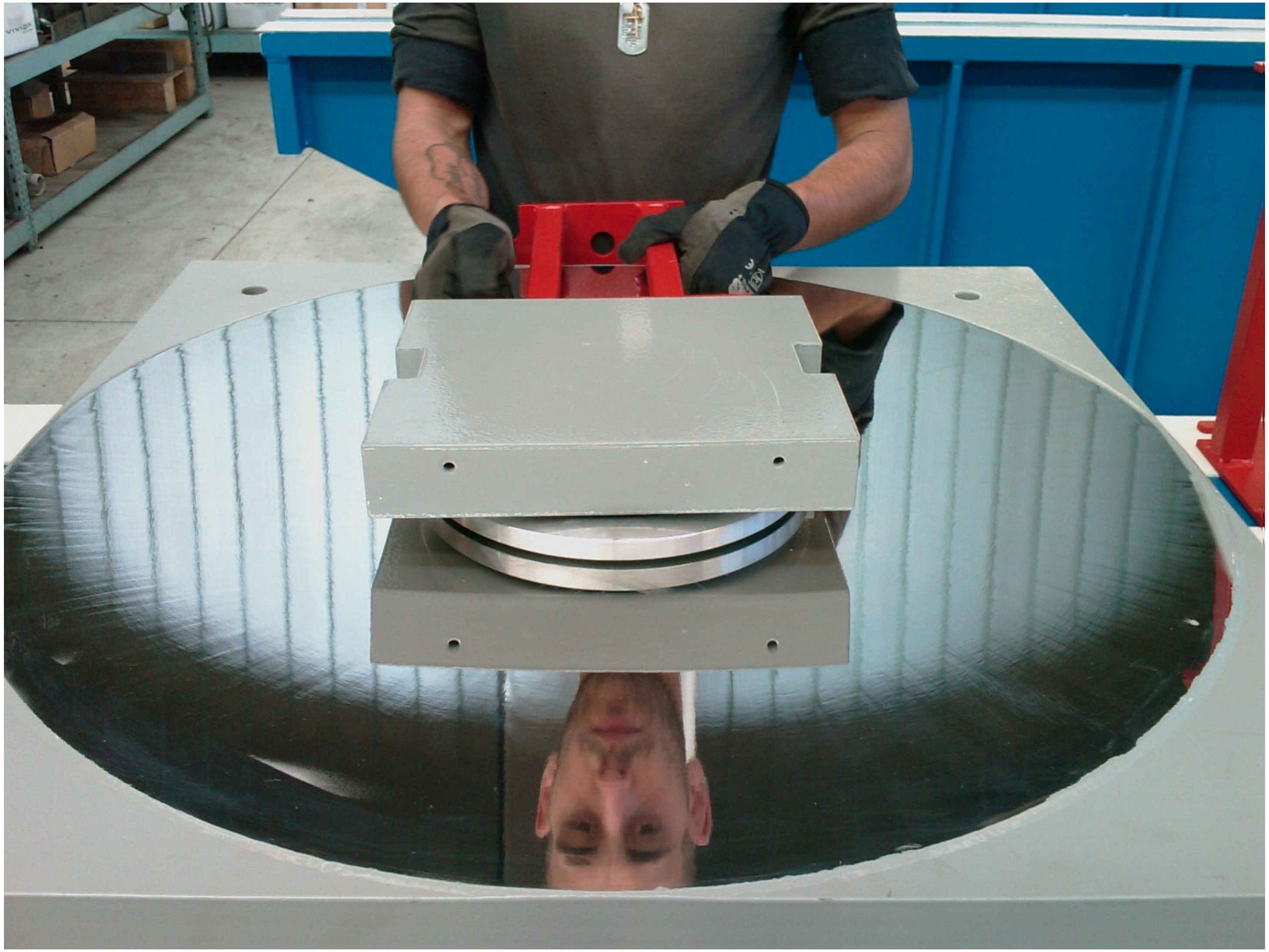
DESIGN OF THE BASE ISOLATION SYSTEM

- Requirement given by the client
  - Natural period of the base isolated structure 3,2 s
  - Design displacement for HDRB ± 360 mm
  - Design displacement for Pendulum ±260 mm
  - Vertical load at ULS 2820 kN

The CASE Project in L'Aquila



- Why the sliding pendulum requires less displacement.
- Rubber isolators require an additional displacement due to the unforeseen excentricity
- Sliding pendulum isolators provided a uniform base isolation independently of the mass distribution.
- This allowed to adopt multiple types of prefabricated buildings, involving more supplyers and allowing the reduction of the construction time



Manufacturing of the sliding pendulum isolators

Assembling chain for the sliding pendulum.
The production reached over 100 isolators per day

The sliding material HOTSLIDE

The sliding pendulum isolators on top of the 40 steel columns supporting the concrete slab

Detail of an isolator on top of one column. All fixing are mechanical in order to speed up the installation

The CASE Project in L'Aquila

One of the 185 buildings completed.

- 50% of the buildings were in prefabricated wood
- 30% of the buildings were in prefabricated concrete
- 20% of the buildings were in steel

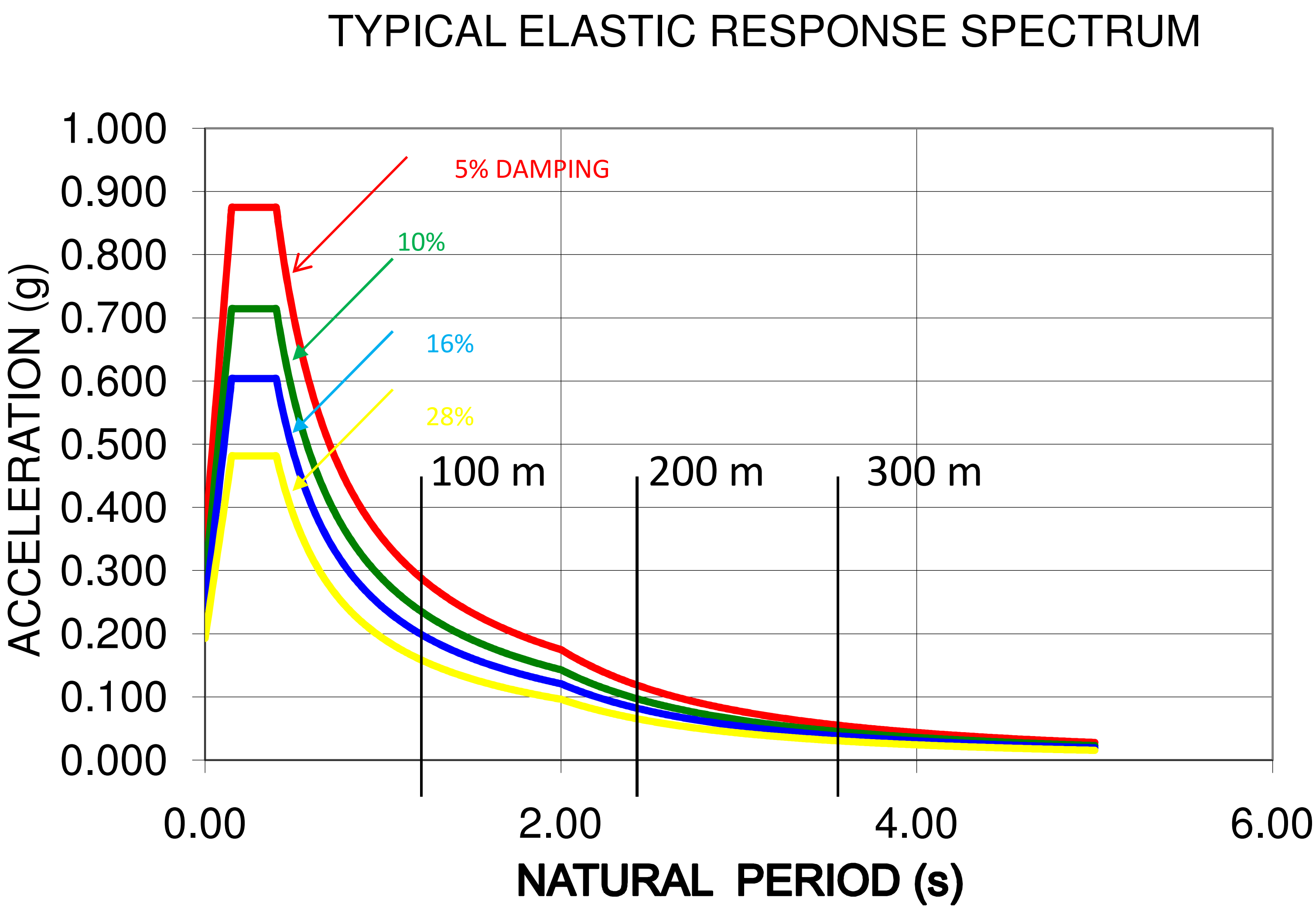
Seismic and wind actions in a tall building

- In a building the seismic action decreases in direct proportion to the height
  - Seismic action may be reduced by increasing the period or the damping
- The wind action increases in direct proportion to the height
  - Wind action may be reduced utilizing suitable devices like TMD
- The displacement of the building may be reduced in both cases utilizing TMD

ACCELERATION IN A STRUCTURE IN FUNCTION OF:

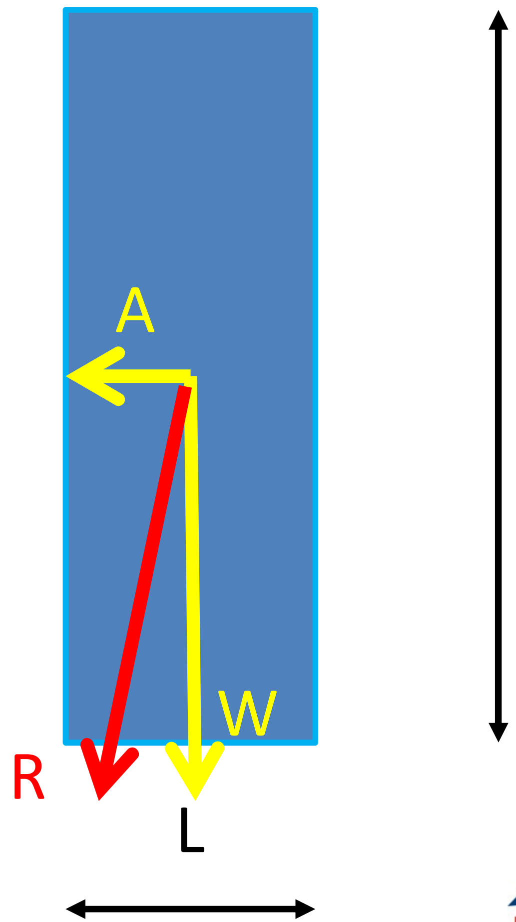
- NATURAL PERIOD
- DAMPING

TYPICAL HEIGHT OF BUILDINGS ARE SHOWN

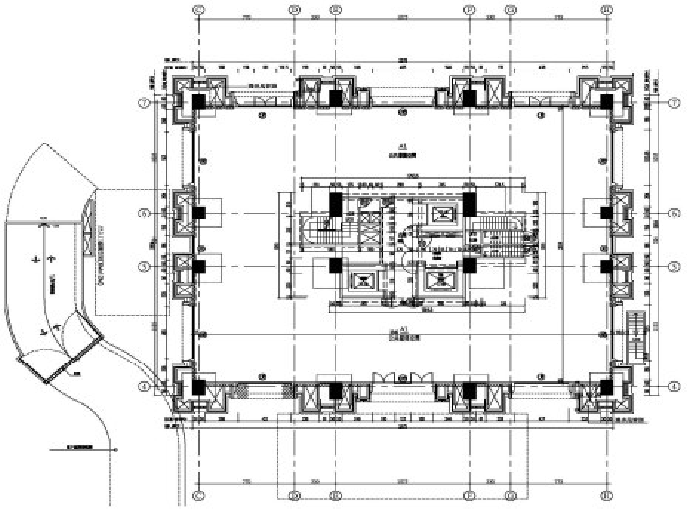


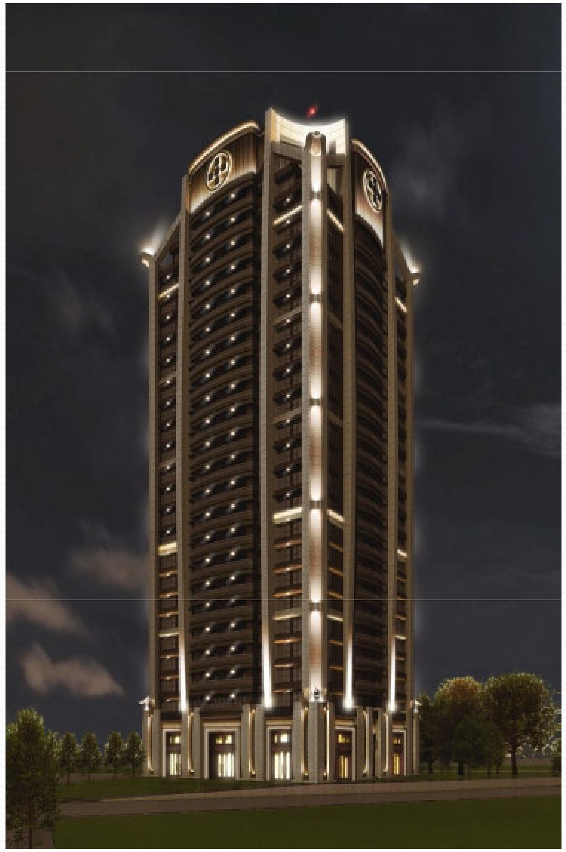
IS BASE ISOLATION SUITABLE FOR TALL BUILDINGS?

- No problem if the ratio H/L is smaller or equal to 5 or 6 (the exact value depends on the seismicity grade of the area)



Exemples of tall buildings base isolated
DINTAI apartment building, 25 floors TAIWAN 2013





Shang Guan Development Co., Ltd. - Changsha Street New Construction Project (15 Floors)

(Structure Examined by: Taipei Structure Engineering Association (TSEA) and the Professor of NCREE)

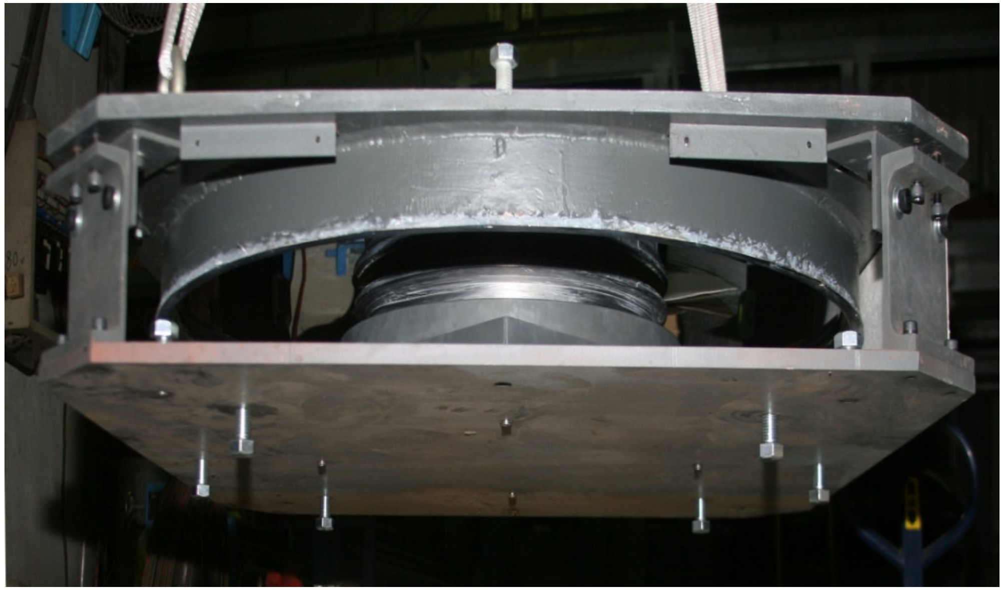
This construction uses Pendulum Isolation System.

Pendulum Bearings: 8 sets

High Damping Dampers: 4 sets

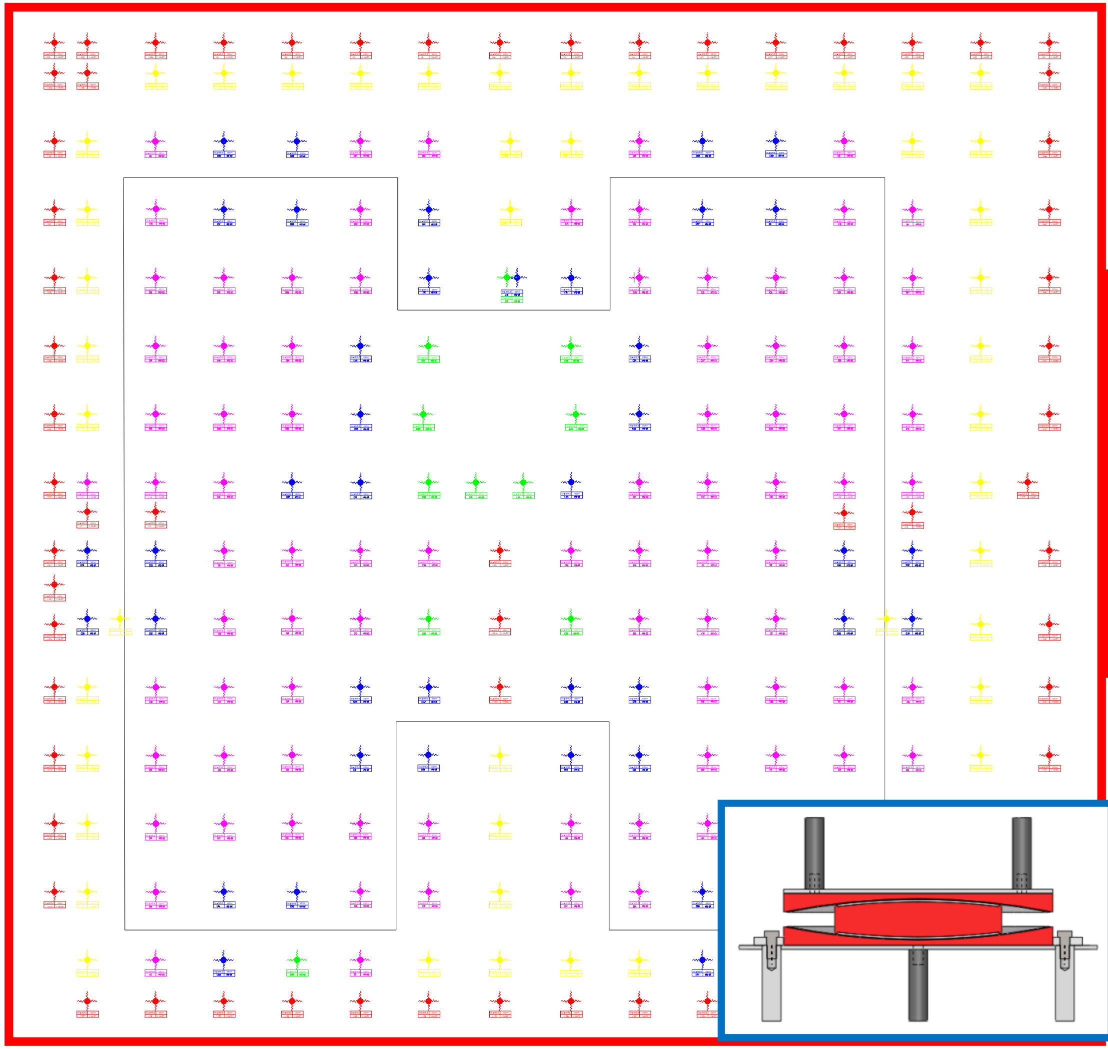
Structure System Characteristics: height to width ratio H/W≒10

Huang Long Development 15 F Installation 2015.1.27



Examples of base isolated buildings in India

- SEZ - IT/ITES BUILDING GURGAON



The design is based on:

HP2: friction pendulum with double sliding surface (5 types)

HISLIDE-FRICITION PENDULUM						
Technical Characteristics						
Symbol	Abbreviation	Mark	Vertical Load[kN] Seismic	Displacement[mm] Seismic	Rotation [rad]	N°Pieces
(red)	HP2-1	HP2 1500/424	1500	¡ À80~¡ À12	0.01	67
(yellow)	HP2-2	HP2 4000/424	4000	¡ À80~¡ À12	0.01	51
(magenta)	HP2-3	HP2 5500/424	5500	¡ À80~¡ À12	0.01	90
(blue)	HP2-4	HP2 8500/424	8500	¡ À80~¡ À12	0.01	42
(green)	HP2-5	HP2 12000/424	12000	¡ À80~¡ À12	0.01	11

Location MAP of sliders and isolators for the IREO SEZ - IT/ITES BUILDING I

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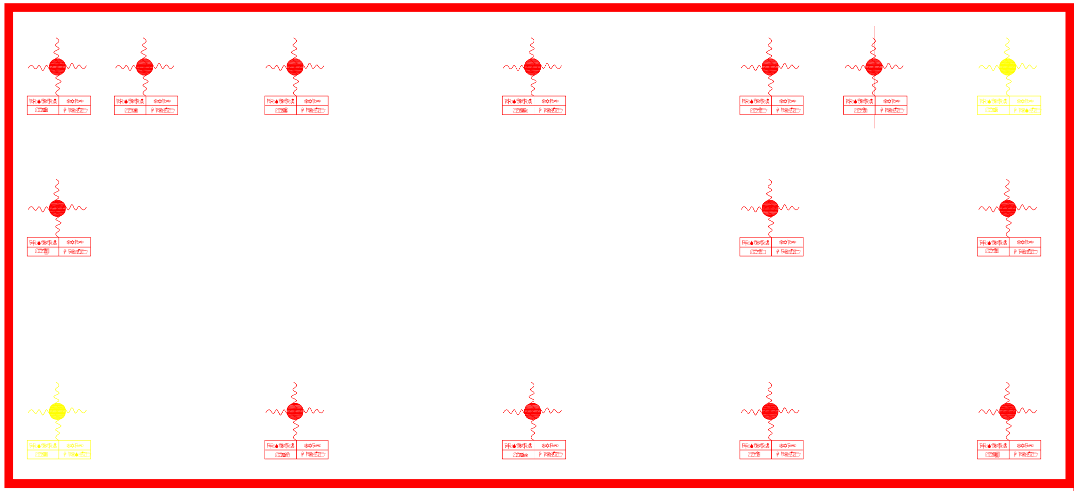
Examples of base isolated buildings in India

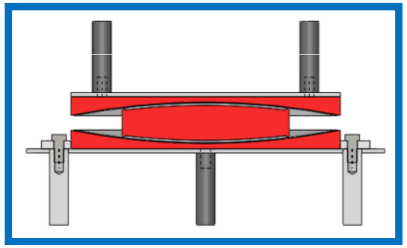
- SHOW CASE BUILDING NEW DELHI



The design is based on:

HP2: friction pendulum with double sliding surface (2 types)

HISLIDE-FRICITION PENDULUM						
Technical Characteristics						
Symbol	Abbreviation	Mark	Vertical Load[kN]	Displacement[mm]	Rotation [rad]	N°Pieces
			Seismic	Seismic		
(red)	HP2-1	HP2 4000/430	4000	±180 ~ ±215	0.01	13
(yellow)	HP2S-1	HP2S 4000/430	4000	±180 ~ ±215	0.01	2



Location MAP of sliders and isolators for the IREO SEZ - IT/ITES BUILDING PROJECT

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IF THE BUILDING IS TOO TALL

There are the following possibilities:

1. To increase the damping of the building utilizing
   - Energy dissipating bracings, or:
   - Visco-elastic shear walls
2. To apply a TMD on top of the building

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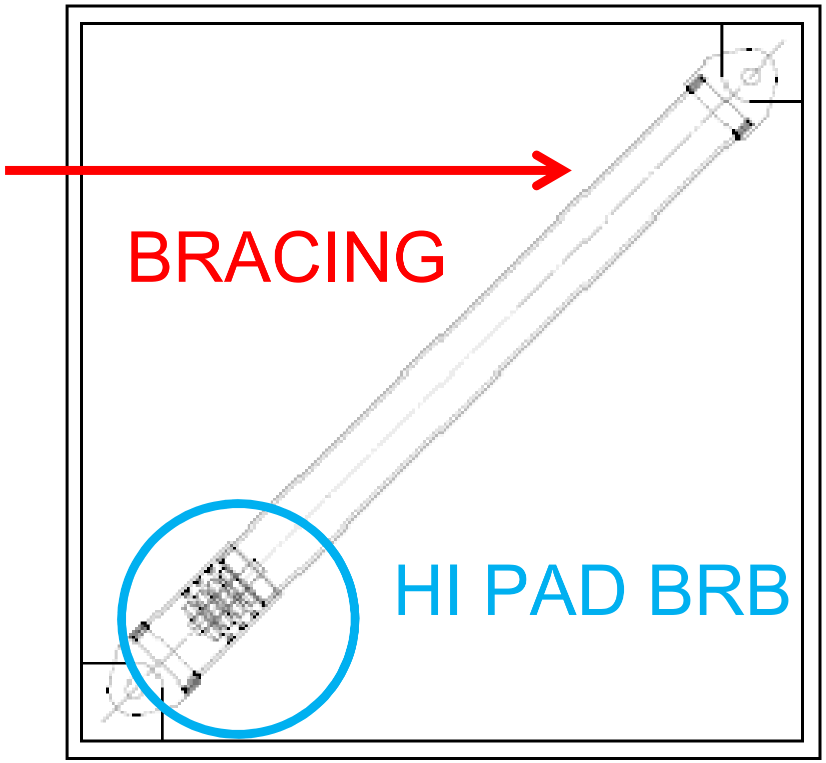
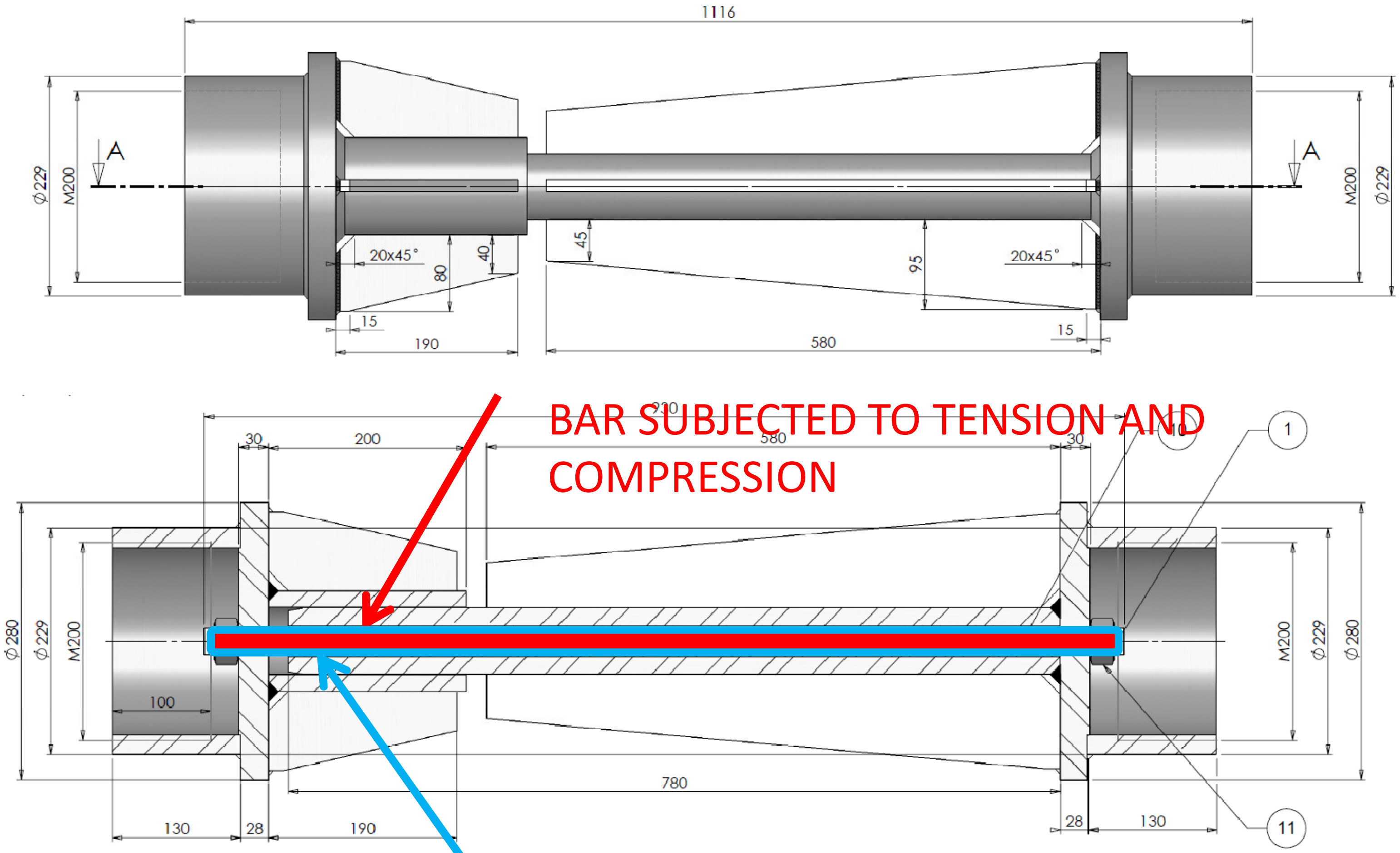
A buckling restrained bracing consist in a steel member subjected to tension and compression.
A portion of the member (HI PAD BRB) is subjected to yield.
The buckling in compressen is restrained by a special device



HI-PAD BUCKLING RESTRAINED BRACING



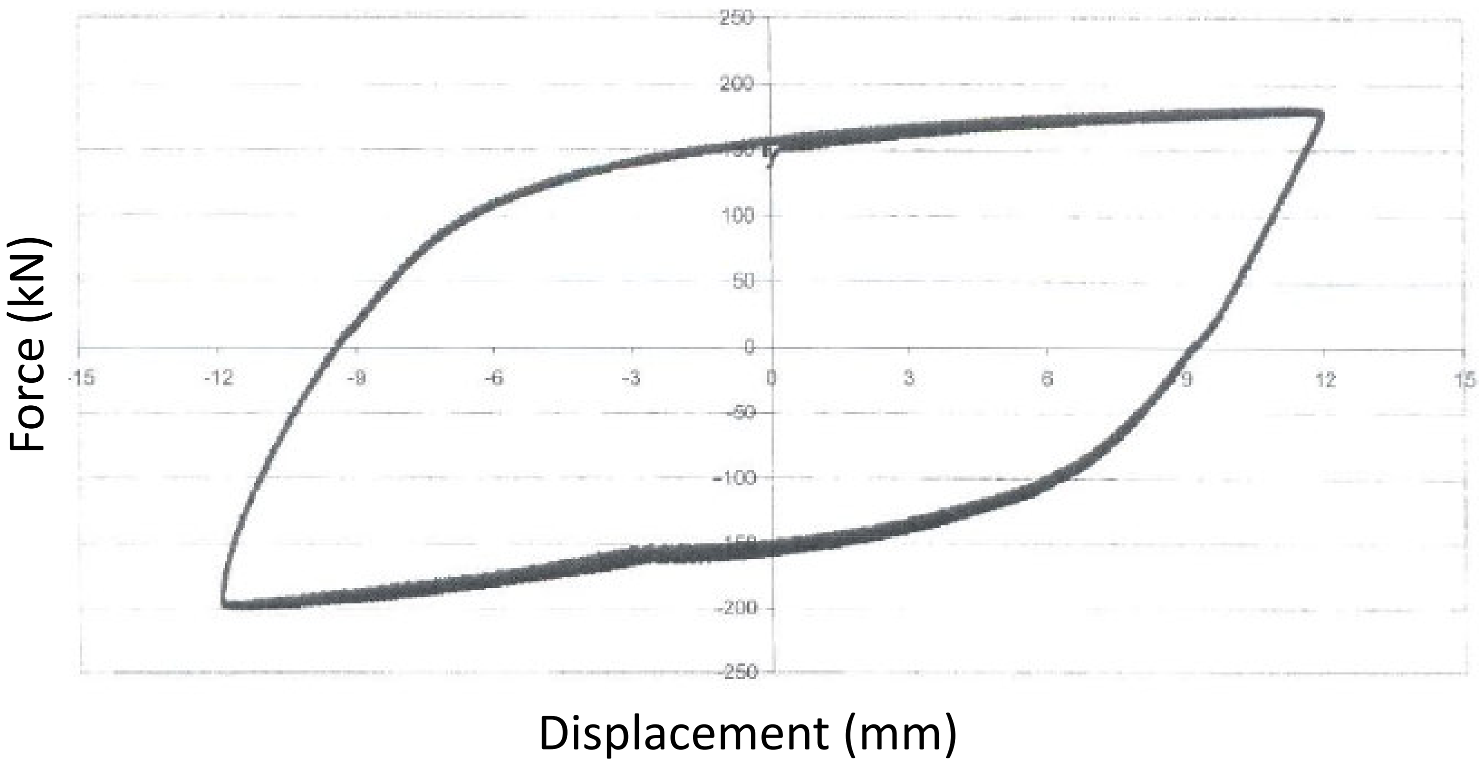
HY- PAD TYPICAL FEATURE

HI-PAD

Buckling Restrained Bracings

Dynamic testing

HI-PAD BUCLING RESTRAINED BRACINGS



Typical load – deflection plot

HI PAD BRB Design Criteria

- HI – PAD BRB are designed, manufactured and tested in accordance with EN 15129 Part 6
- They are characterized by 2 parameters:
  - Fy the force at yield
  - Sy the elastic displacement
- They may be modelled in a non linear analysis as bi-linear as shown in the following slide.
- They dissipate energy by yield

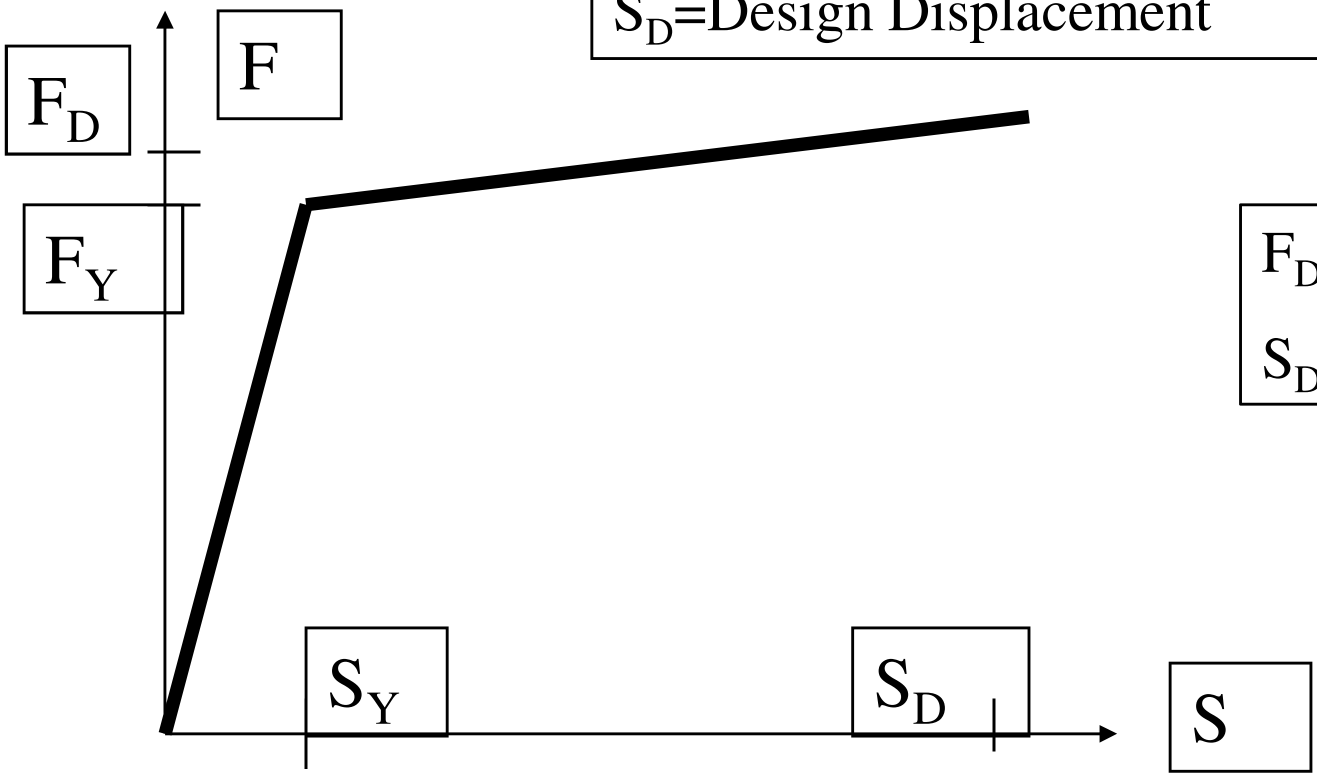
MATHEMATICAL MODEL OF A HY-PAD BRB BRACING

F_Y=Yield Force

F_D=Force at design displacement

S_Y=Displacement at yield

S_D=Design Displacement



F_D= 1.15 F_Y

S_D= 15 S_Y

MAIN ADVANTAGES USING BRB

- Service life ≥ 100 years
- Very limited maintenance requirements
- Limited space requirement
- Activation stroke of the order of 1 mm
- Suitable for any kind of structures
- Very good performance/cost ratio

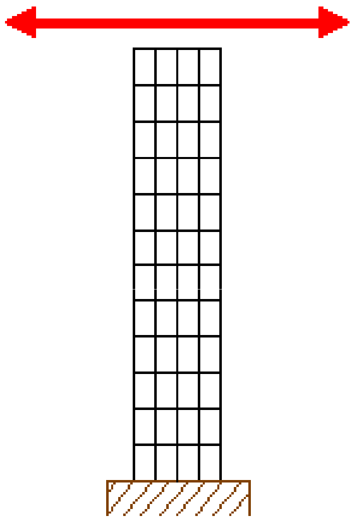
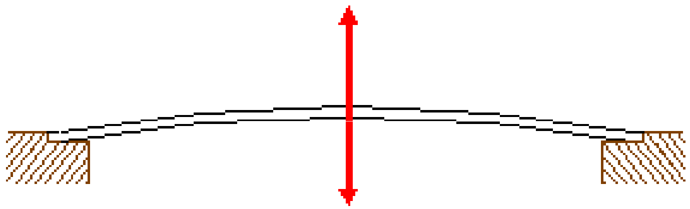
WHAT IS A TMD

- TMD is a mass that is connected to the structure by a spring and a damping element without any other support, in order to reduce the vibration of the structure
- The frequency of the TMD is tuned to a particular structural frequency so that it will resonate out of phase with the structure

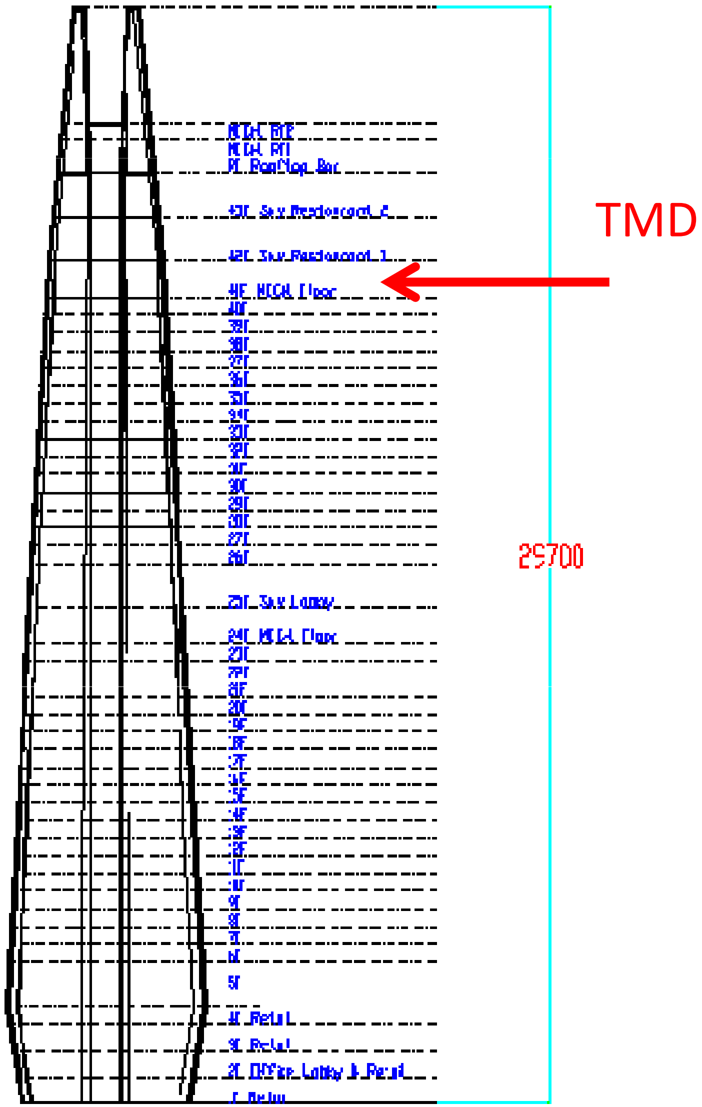
MAIN USES OF TMD DEVICES

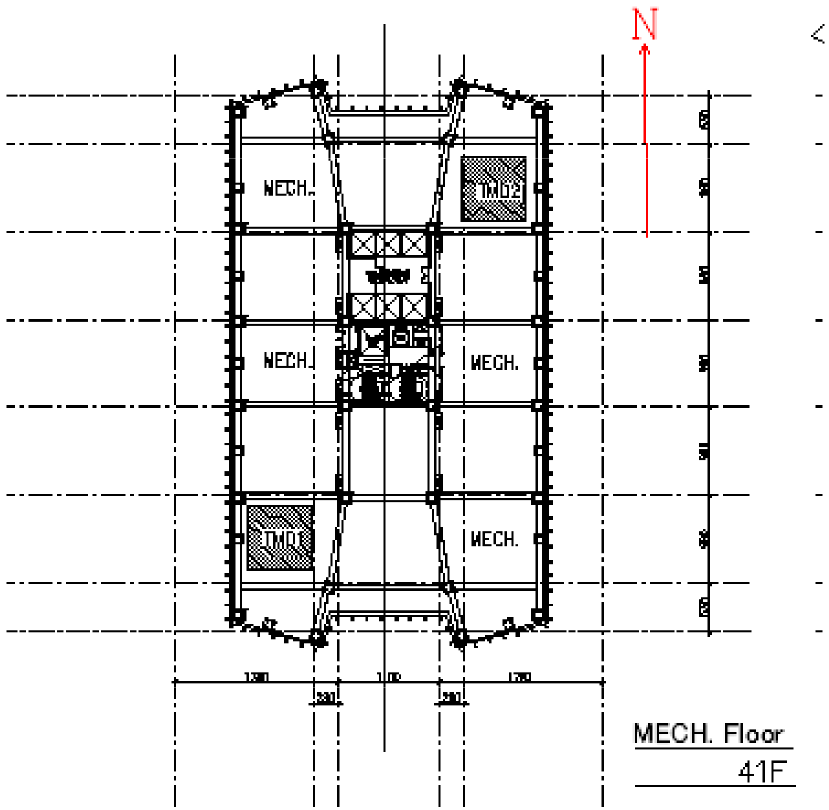
The TMD devices are used in tall or flexible structures in order to prevent structural problems due to the vibration of the structure

TYPICAL CASES:

1) High buildings	2) Flexible bridges or viaducts
	

TMD FOR NANSAN PLAZA





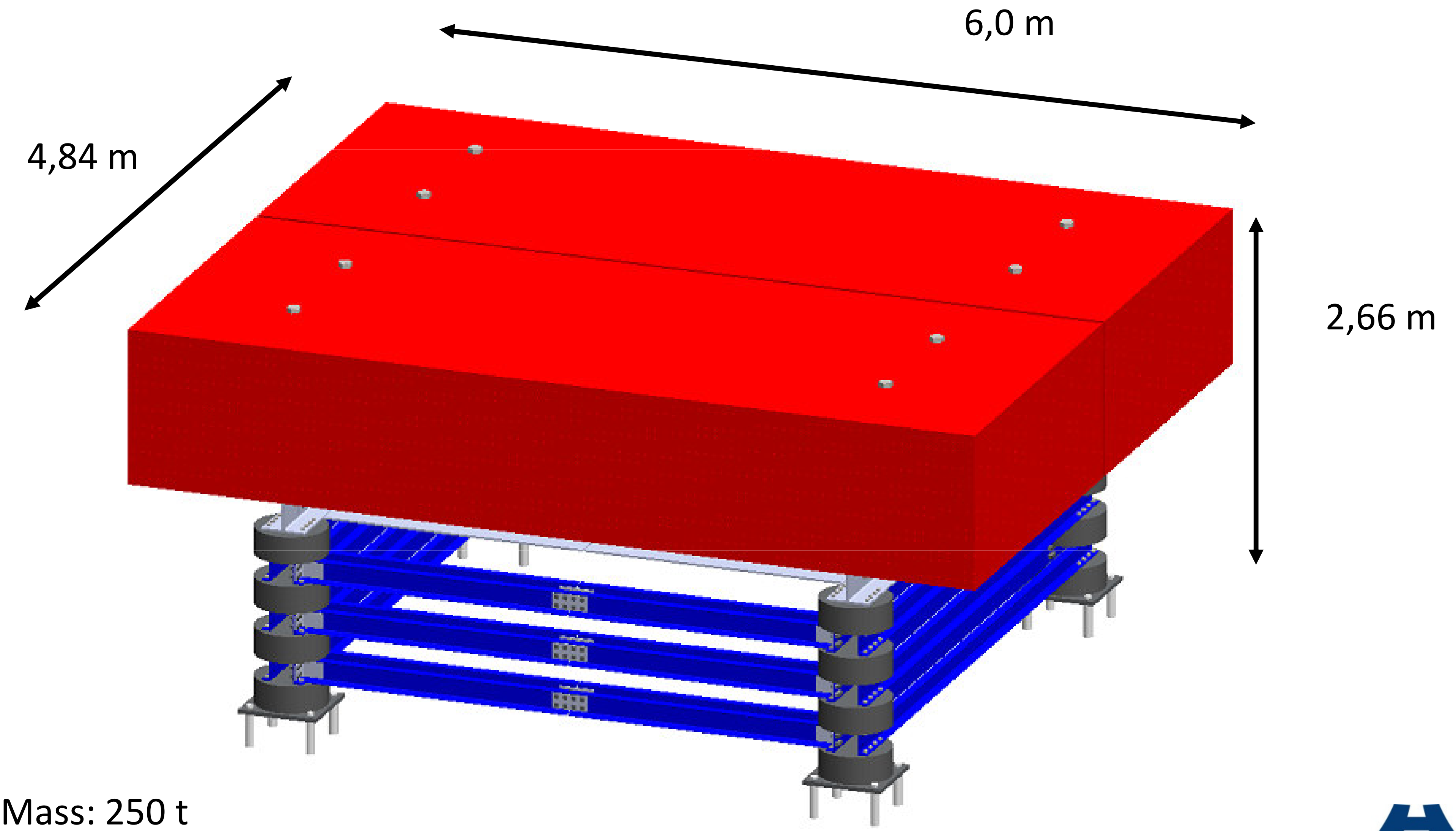
41F MECH. Floor

TMD FOR NANSAN PLAZA

TECHNICAL PROPERTIES

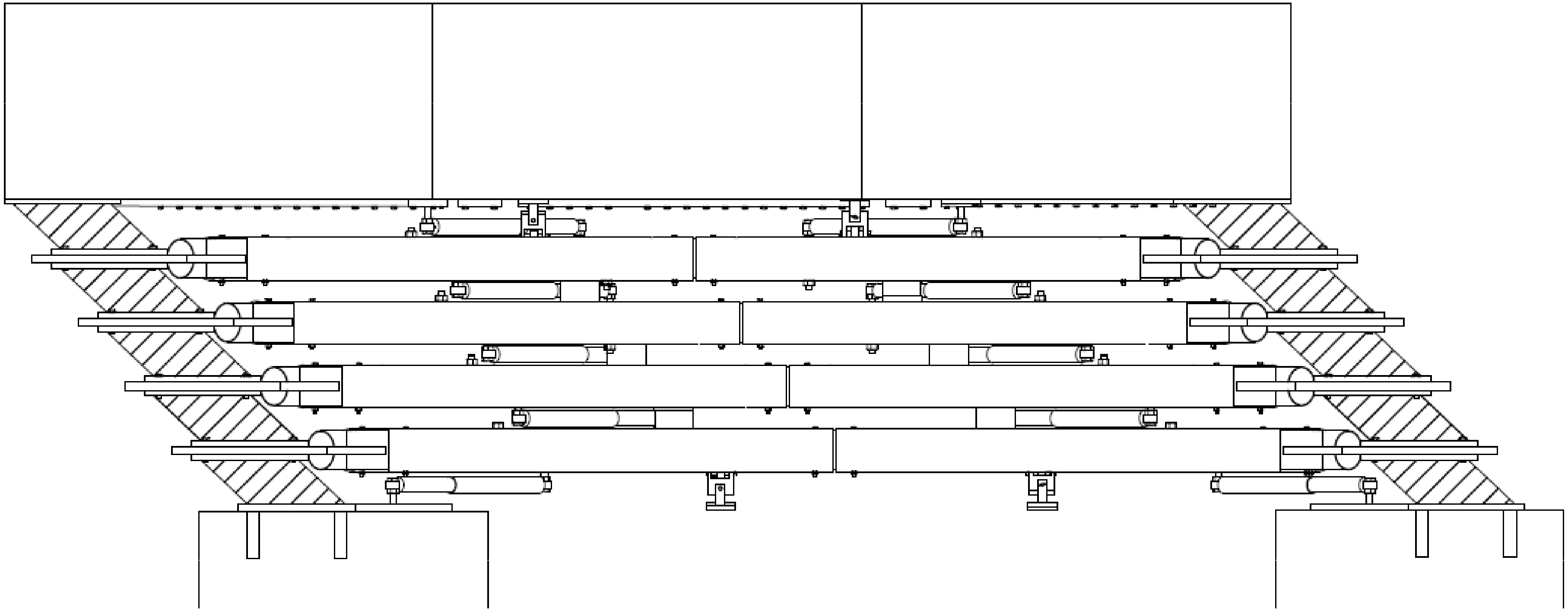
- Mass: 250 t (0,005 of the reference building mass). Adjustable ±10%
- X-direction stiffness 744 kN/m
- Y-direction stiffness 765 kN/m
- X-direction period 3,64 s ± 5%
- Y-direction period 3,59 s ± 5%
- Displacement ± 780 mm
- Equivalent viscous damping 10%

TMD FOR NANSAN PLAZA (STEEL MASS)



Mass: 250 t
Weight: 2500 kN

TMD AT MAXIMUM DISPLACEMENT



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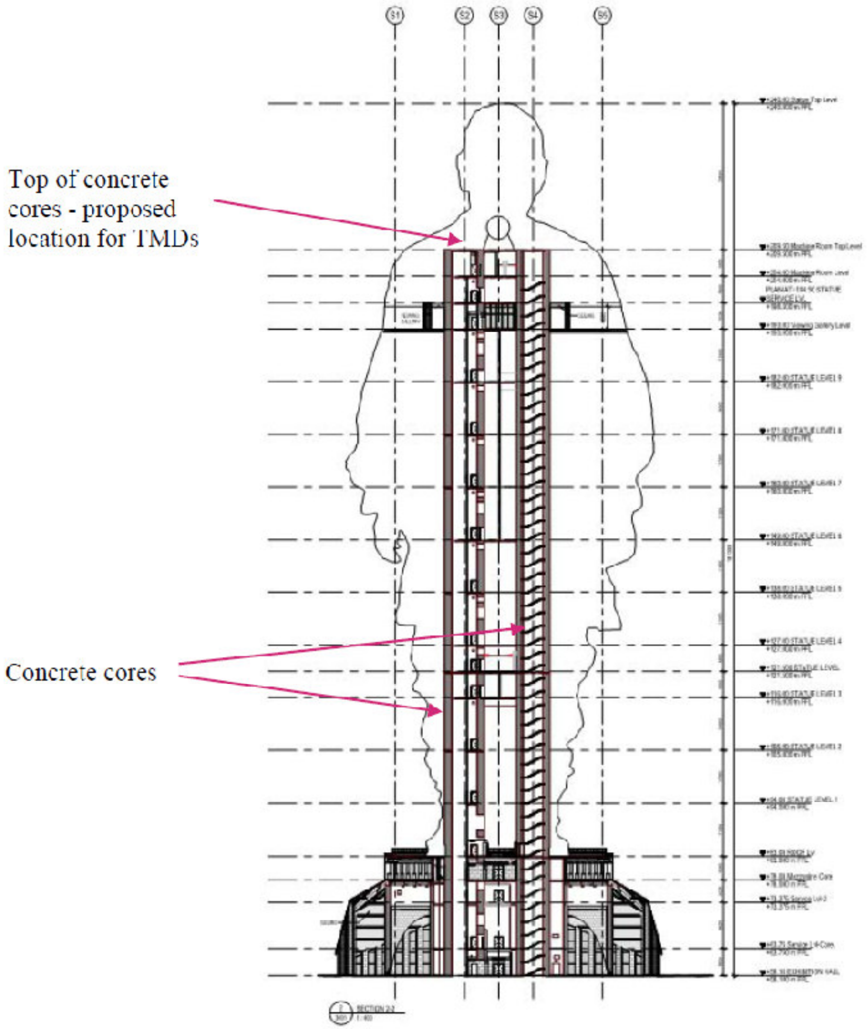
Study for the TMD of the Statue of Unity in Gujarat



2. Performance requirements of the TMD

Each TMD shall provide the following performances

Nominal mass M = 200 t

Frequency in X direction F_X = 0,25 to 0,40 Hz

Frequency in Y direction F_Y = 0,45 to 0,65 Hz

Max displacement in X direction

- At 0,25 Hz D_{1X} = ±1000 mm
- At 0,30 Hz D_{2X} = ±750 mm
- At 0,40 Hz D_{3X} = ±330 mm

Max displacement in Y direction

- At 0,45 Hz D_{1Y} = ±180 mm
- At 0,55 Hz D_{2Y} = ±130 mm
- At 0,65 Hz D_{3Y} = ±100 mm

Equivalent viscous damping ξ = 15 – 19%

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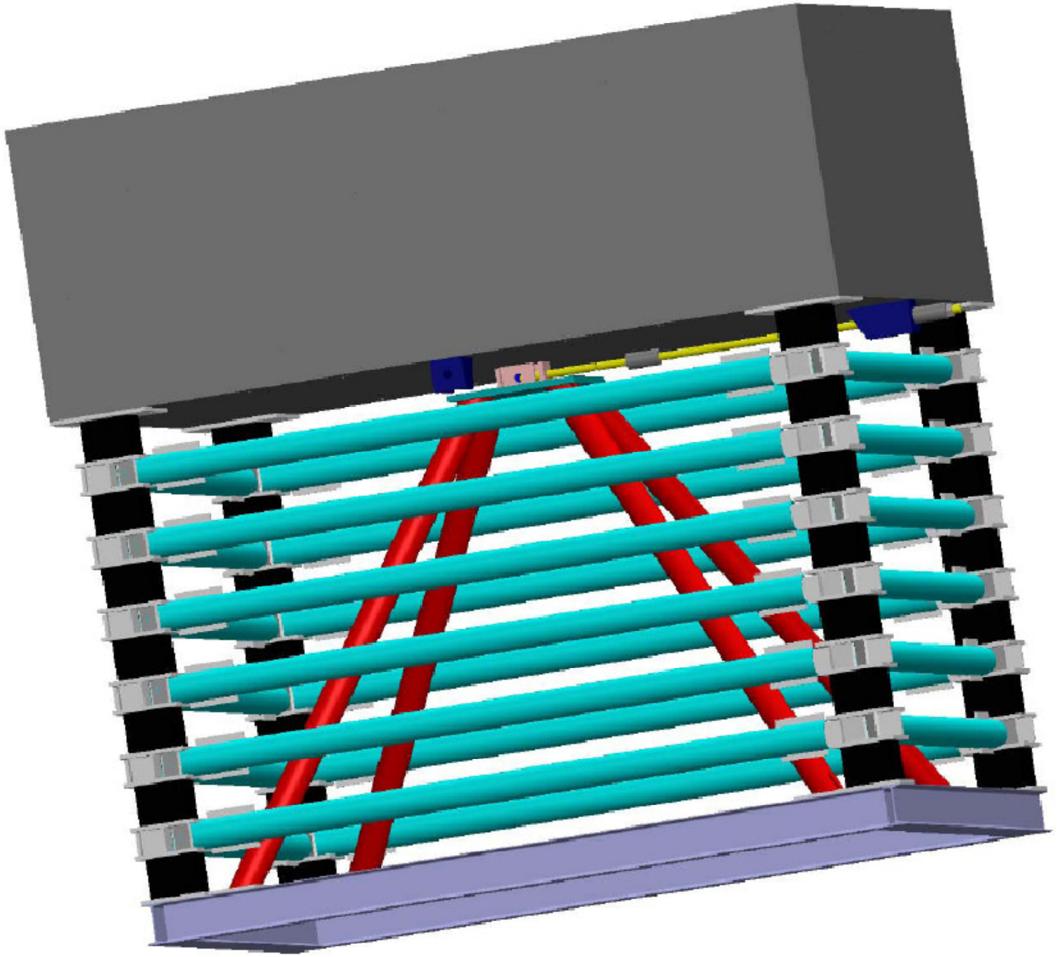
Study for the TMD of the Statue of Unity in Gujarat



TMD with electro-inductive damper for a chimney in Morocco

PERFORMANCE REQUIREMENTS	
Mass	10 t
Frequency	0,25-0.35 Hz
Max displacement	400 mm
Equivalent viscous damping	3 – 10%
Frequency adjustment tolerance	≤0,005 Hz
Service life	> 50 years

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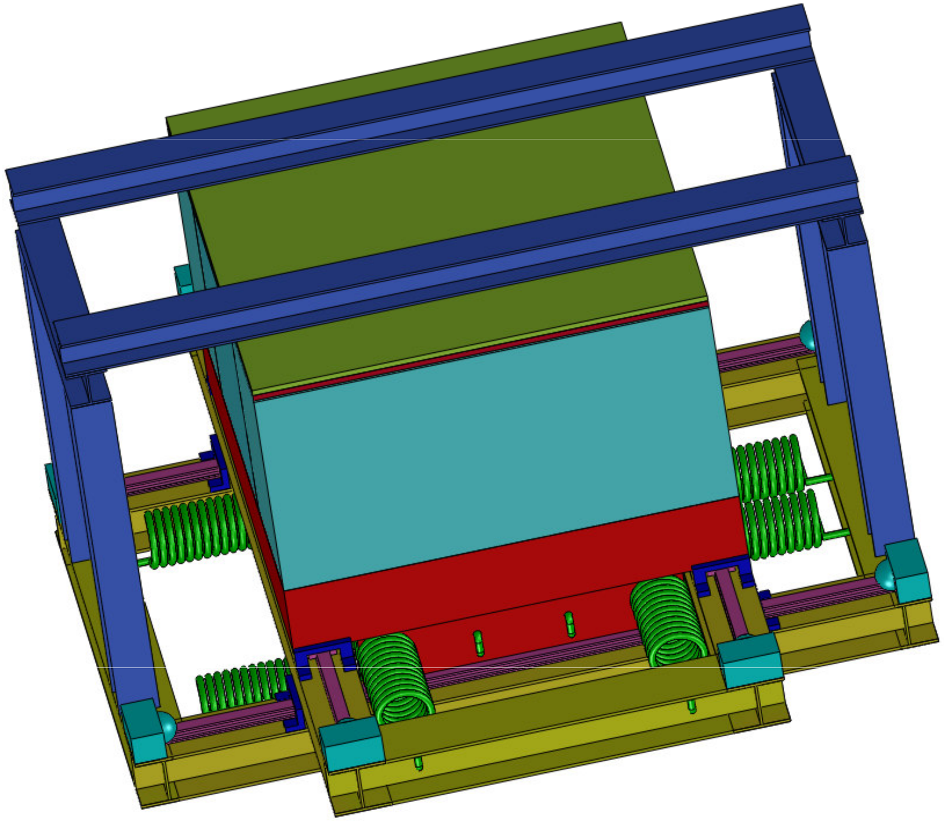
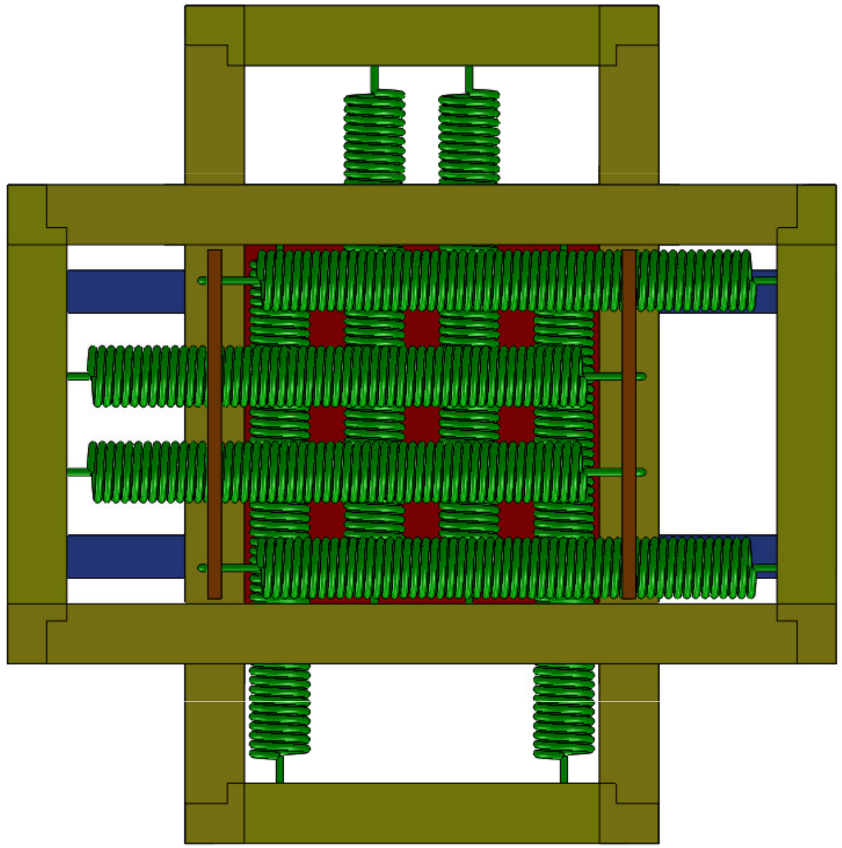
TMD with electro-inductive damper for a chimney in Morocco





3D views

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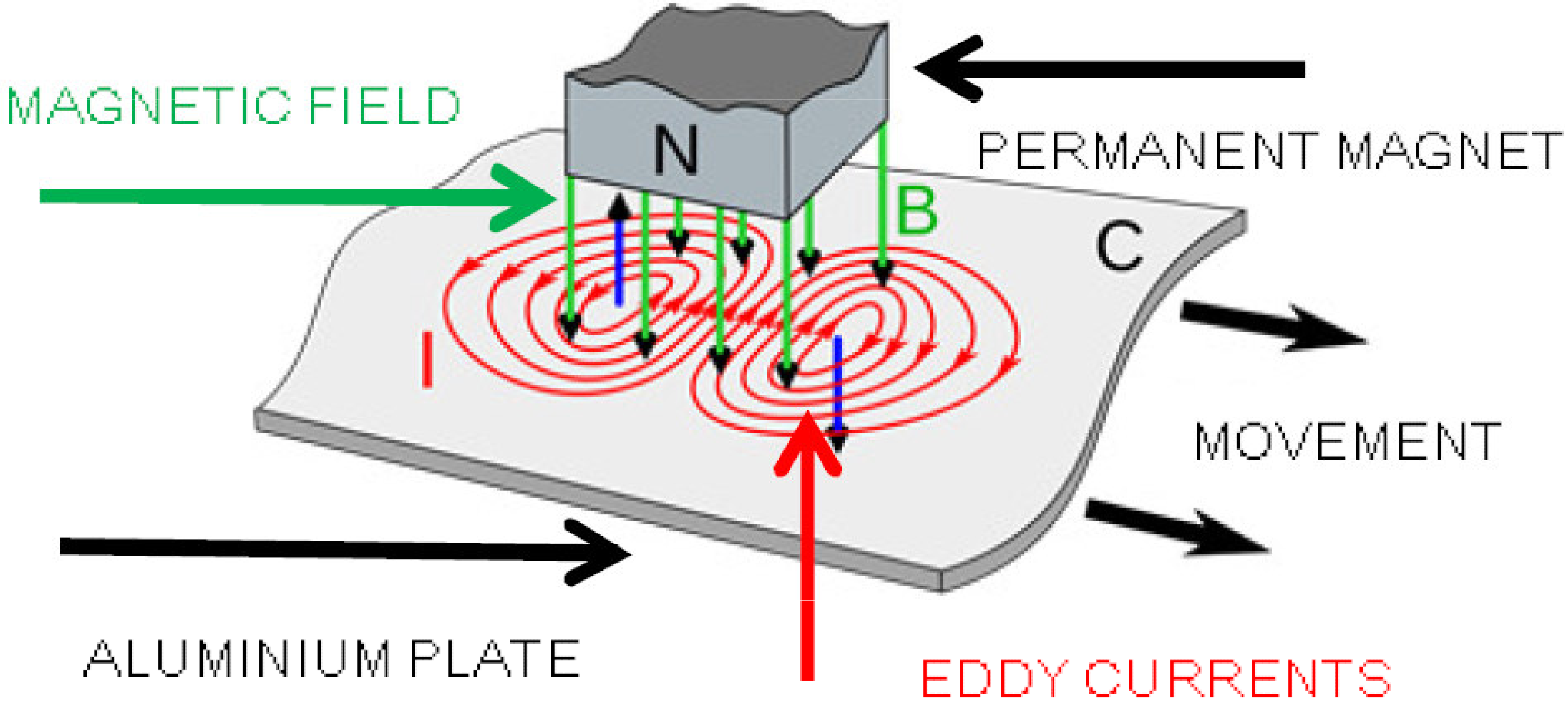
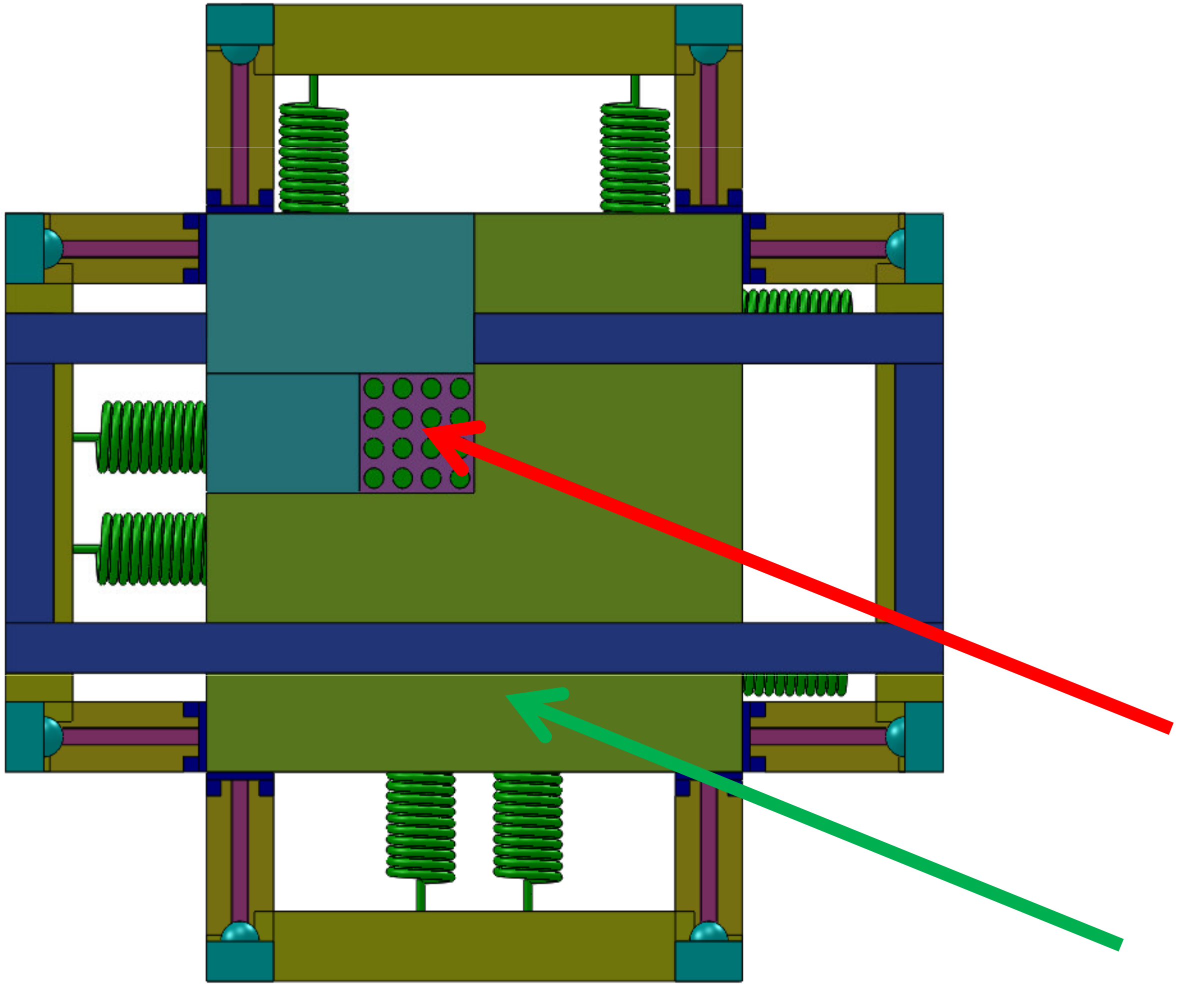
TMD with electro-inductive damper for a chimney in Morocco



- The damping is given by the eddy currents (Foucault currents) generated by the relative movement of permanent magnets in an aluminium plate

TMD with electro-inductive damper for a chimney in Morocco



- Detail of the permanent magnets in cobalt samarium

Conclusion

- Base isolation is a mature and well proven technique to protect buildings from the earthquake.
- When applicable is the best possible solution to reduce the seismic action.
- Sliding pendulum isolators can grant a very high efficiency/cost ratio
- For tall buildings energy dissipating bracings and/or TMD represent a very good alternative solution

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THANKS FOR YOUR ATTENTION

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