Japan-Italy Joint Research Final Presentation

Gerard J. O'Reilly

13 December 2019

IUSS
Scuola Universitaria Superiore Pavia

ROSE Centre
Centre for Training and Research on Reduction of Seismic Risk

Overview

- The joint research had several objectives:

1. Look at the differences between base isolation implementation
   - Number and types of buildings
   - Types of isolotars used
   - Typical design scenarios
2. Examination of a case study design example
   - Design a building with base isolation using Italian and Japanese building codes (compare methods)
   - Compare performance generally (size of device, design displacement)
   - Sensitivity studies
3. What can be transferred/learned between Japan-Italy

Tokyo, Japan

13 December 2019

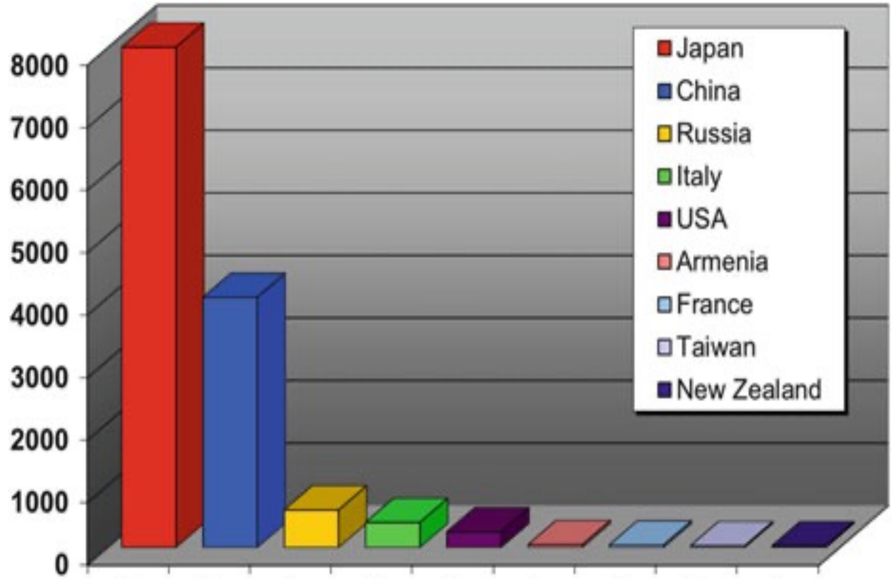
Base isolation in Japan and Italy

IUSS
Scuola Universitaria Superiore Pavia

Japan-Italy Joint Research Final Presentation

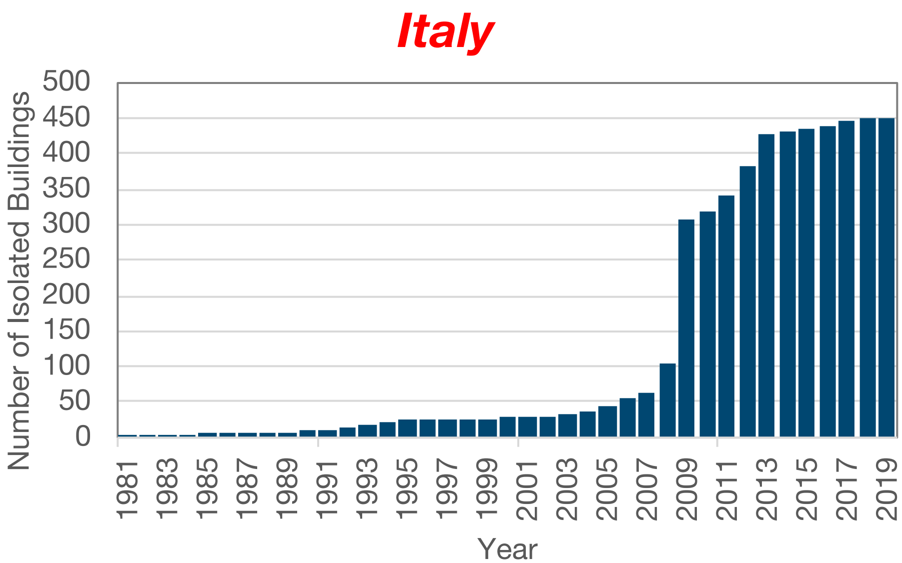
Gerard J. O'Reilly

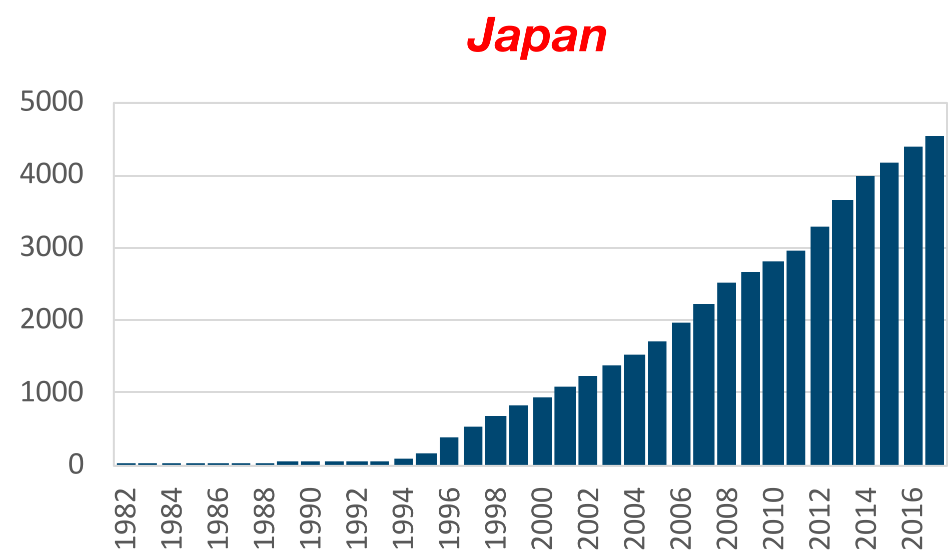
A brief overview



- An extensive database has been maintained by the *Japanese Society of Seismic Isolation* (JSSI)
- In the case of Italy, such documentation is rather scarce and much less organised
- Martelli *et al.* [1] provided a global picture of the relative engagement with seismic isolation systems
- Japan is clearly very far ahead of most other countries in terms of relative usage.

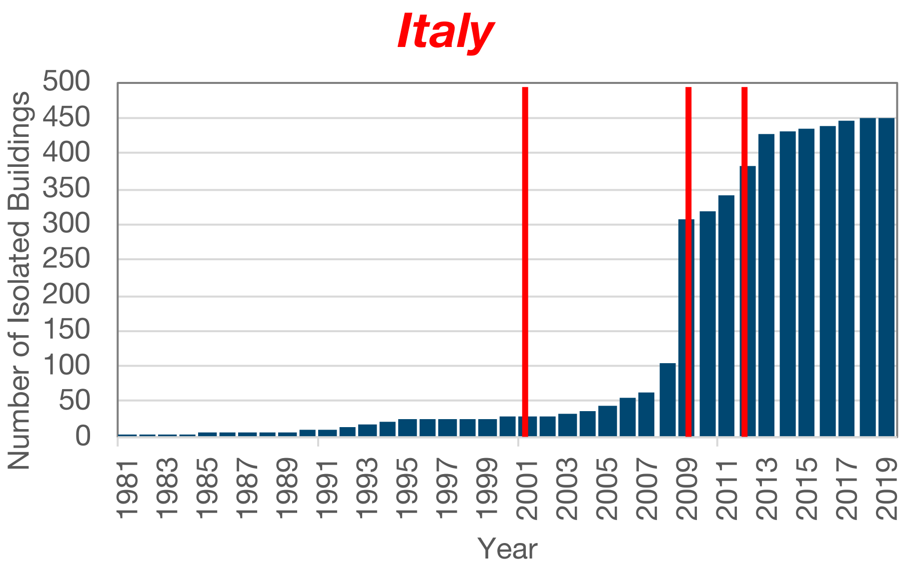
Base isolation over the years

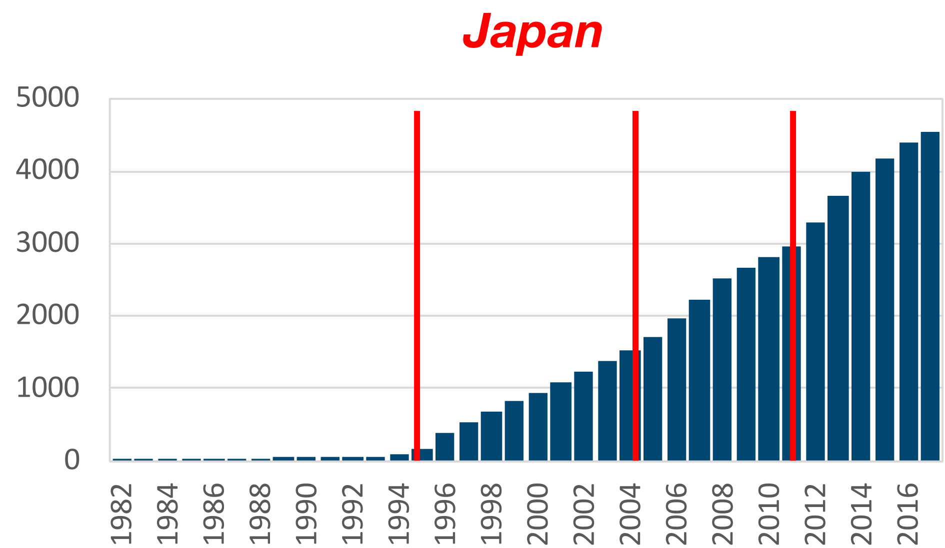




- If we look at the data, we may see some trends
- Base isolation was introduced in Italy in 1981
- Was difficult to use because of code restrictions (long an costly process)
- In Japan, not so many buildings with base isolation before 1995 - Why?

Base isolation over the years



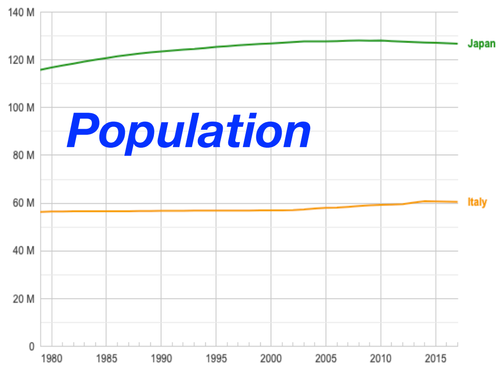


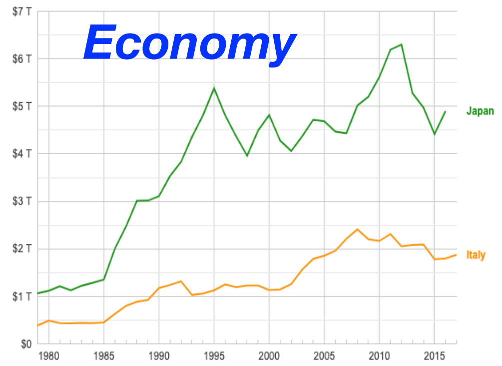
Japan			Italy		
Year	Name	Mw	Year	Name	Mw
2011	Tohoku	9.1	2012	Emilia-Romagna	5.8
2004	Chuetsu	6.9	2009	L'Aquila	6.3
1995	Great Hanshin	7.3	2002	Molise	5.9

- Major earthquakes in both countries had an obvious impact
- Created more awareness and pro-active society (also damaged buildings)

Relative comparisons

- But still comparing the differences, Japan has many more buildings with base isolation – why?
- Not easy to say, but some could be:





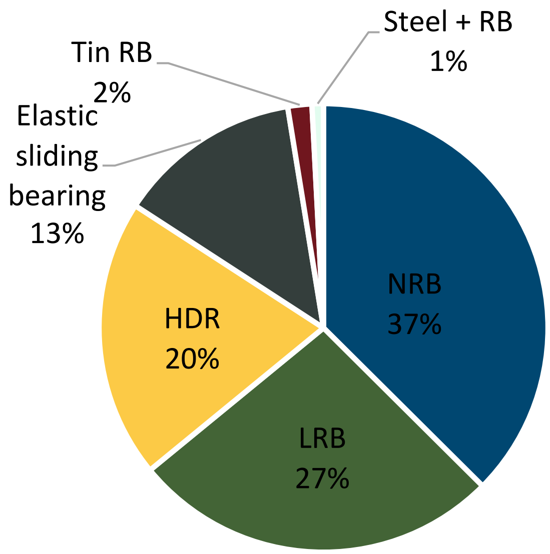
Italy

Year	Name	Mw
2012	Emilia-Romagna	5.8
2009	L'Aquila	6.3
2002	Molise	5.9

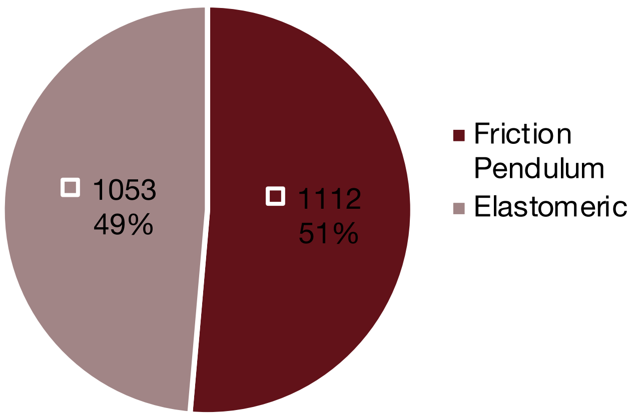
Japan

Year	No. of Events > Mw = 6.0	Notable Events
2019	7	
2018	5	
2017	3	
2016	10	Kumamoto
2015	4	
2014	5	
2013	8	
2012	13	
2011	60	Great Tohoku
2010	5	
2009	4	
2008	11	Iwate-Miyiga
2007	5	Niigata Chuetsu-oki
2006	1	
2005	11	
2004	12	Niigata Chuetsu
2003	12	Tokachioki
2002	2	
2001	3	Geiyo

Types of devices



Japan



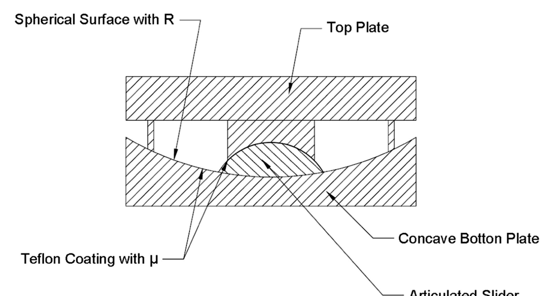
Italy

- In Japan, elastomeric bearings are very popular (many types)
- In Italy, friction pendulum devices gaining popularity
- Feedback from an Italian manufacturer said that the market today is about 60:40 for friction pendulum bearings

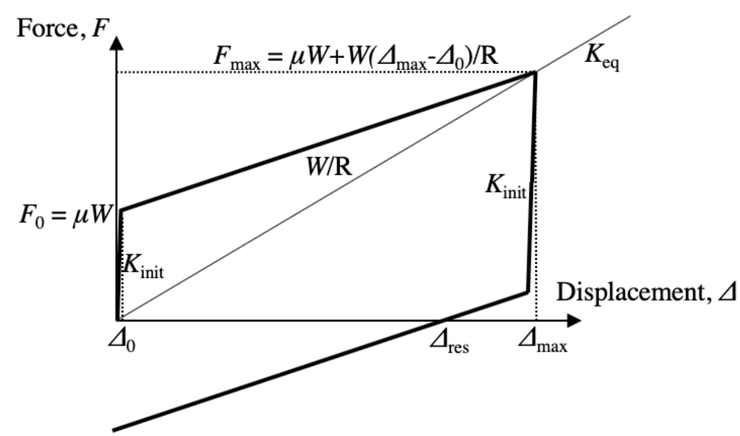
Why friction pendulum?

- Speaking with practitioners in Italy, some reasons for recent rise in friction pendulum popularity:
  - Easier to reach the isolation period (properties are controlled by device dimensions and friction coefficients)
  - Because device properties are easily customisable, can help with problems with eccentricities for torsional issues (retrofitting)
  - Lastly, friction pendulum isolators are cheaper – for displacements greater than 15cm, the cost ~50% of elastomeric isolators

(a)

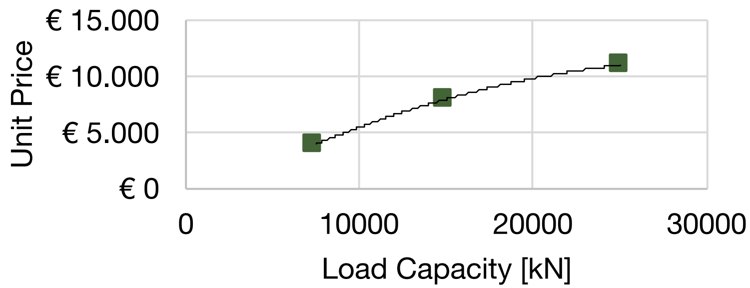


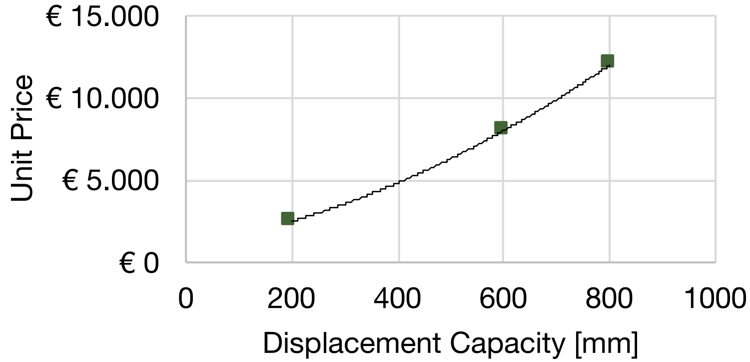
(b)



What about the costs?

	Displ. Capacity [mm]	Load Capacity [kN]	Radius, R [m]	μ [%]	Unit Price (EUR)	Unit Price (JPY)
1	200	15000	4.5	4.3	€ 2,500	¥300,000
2	600	7500	4.5	4.3	€ 4,000	¥480,000
3	600	15000	4.5	4.3	€ 8,000	¥960,000
4	800	15000	4.5	4.3	€ 12,000	¥1,440,000
5	600	25000	4.5	4.3	€ 11,000	¥1,320,000



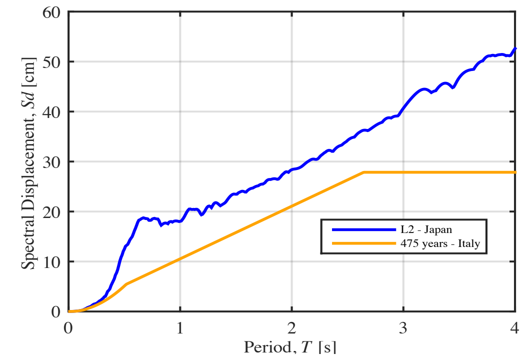


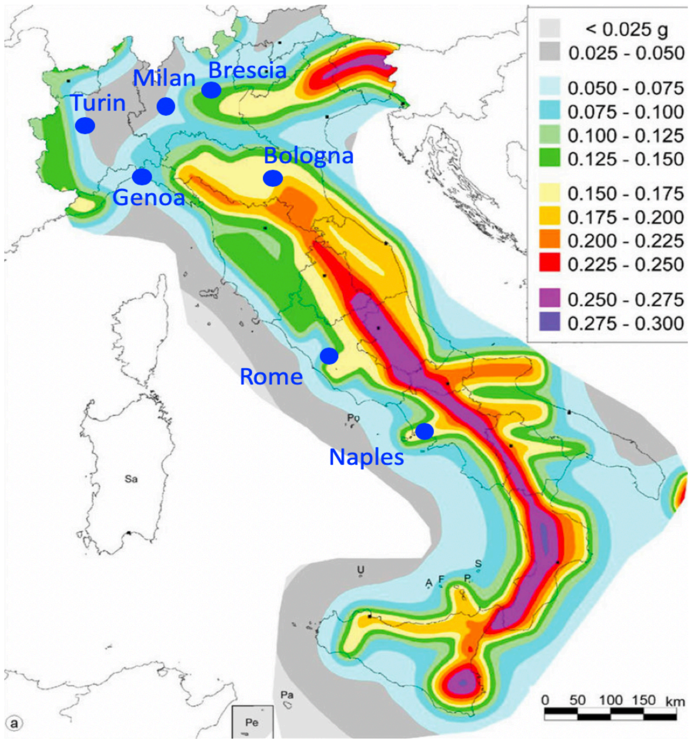
$$\text{Price} = -1.333e-5L^2 + 0.8333L + 0.0104\Delta^2 + 5.4167\Delta - 8500$$

- We asked a manufacturer in Italy to provide the costs for several devices
- Saw that the cost essentially depends on axial load capacity and displacement capacity of device
- Prices appear reasonable compared to Japanese elastomeric devices

Which kind of buildings?

- Some other differences that were noticed between Italy and Japan:
  - Japan uses additional oil dampers, Italy doesn't
  - Japan has many tall buildings with isolation, but Italy doesn't
- Oil dampers not needed since displacements demands in Italy are not that high compared to Japan
- Tall buildings in Italy are few and mostly built after introduction of base isolation
- Located in regions of low seismicity



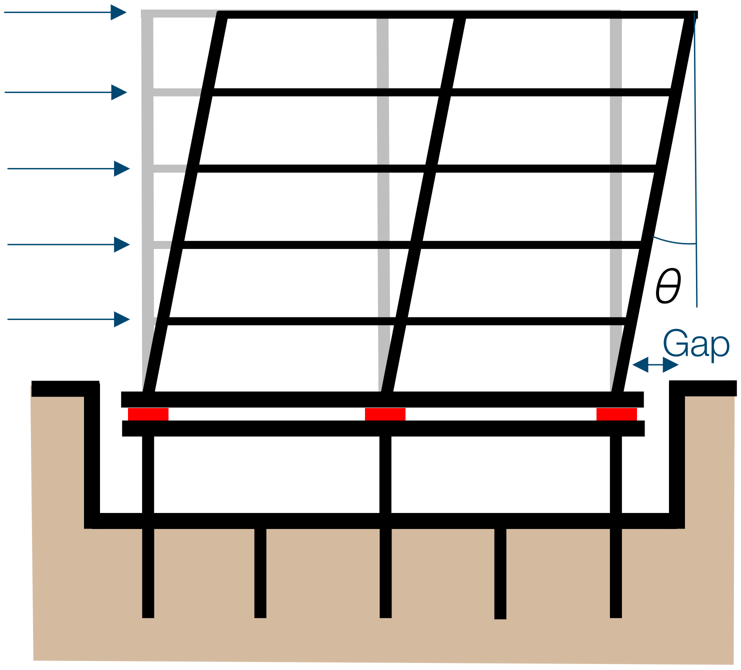


Case Study Building

Design for Japanese and Italian design codes

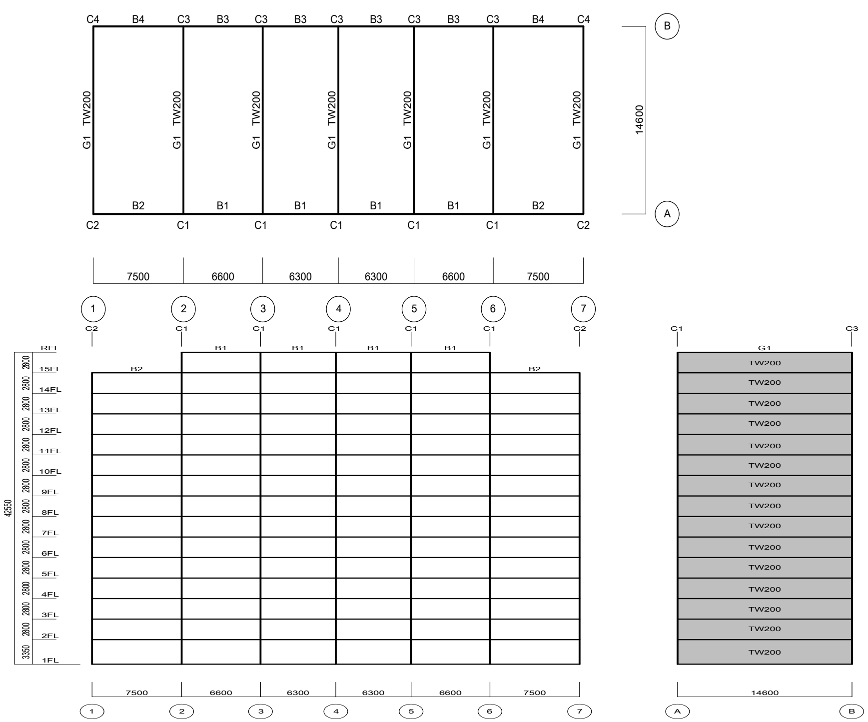
Objectives

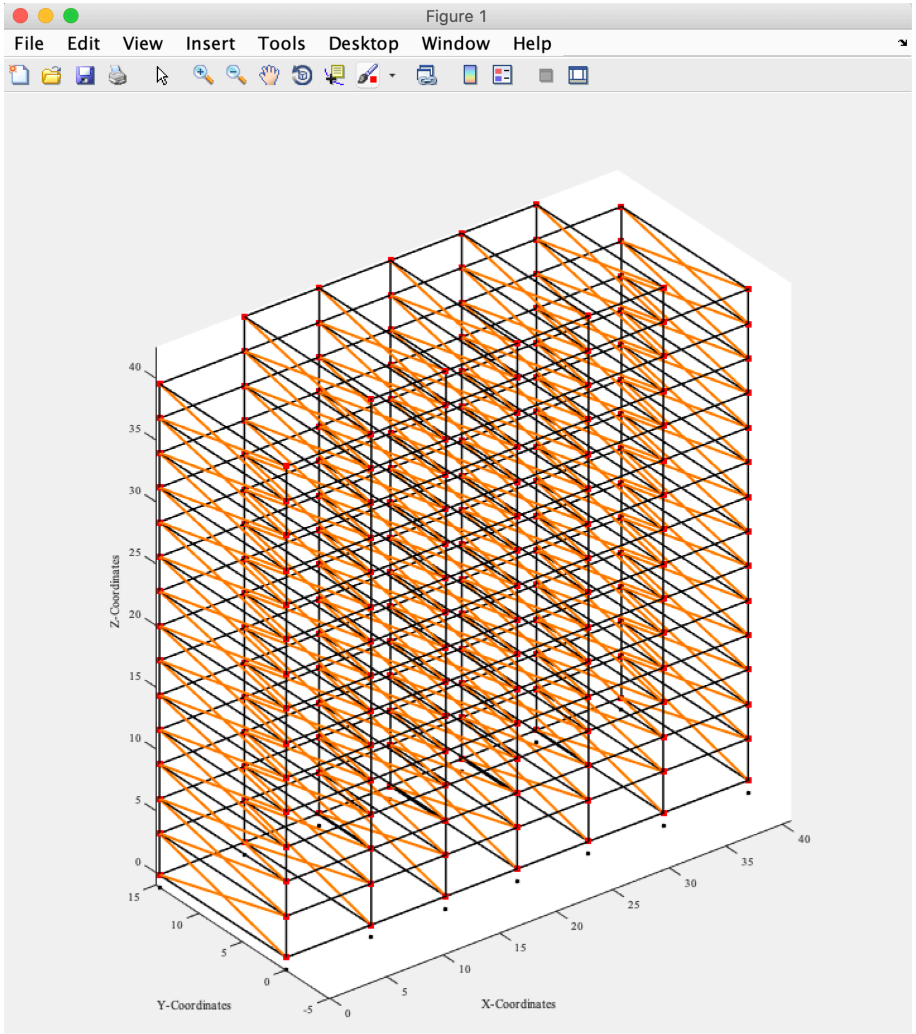
- Design the building:
  - Using the Italian building code for Italian seismic hazard
  - Using the Japanese building code for Japanese seismic hazard
  - Compare
- Investigate:
  - Can Italian friction isolators be used in Japan?
  - How do they compare to elastomeric bearings?
  - What is the impact of potential collision with retaining wall?
  - What are the expected losses?
- General conclusions



Numerical Modelling of Case Study Building

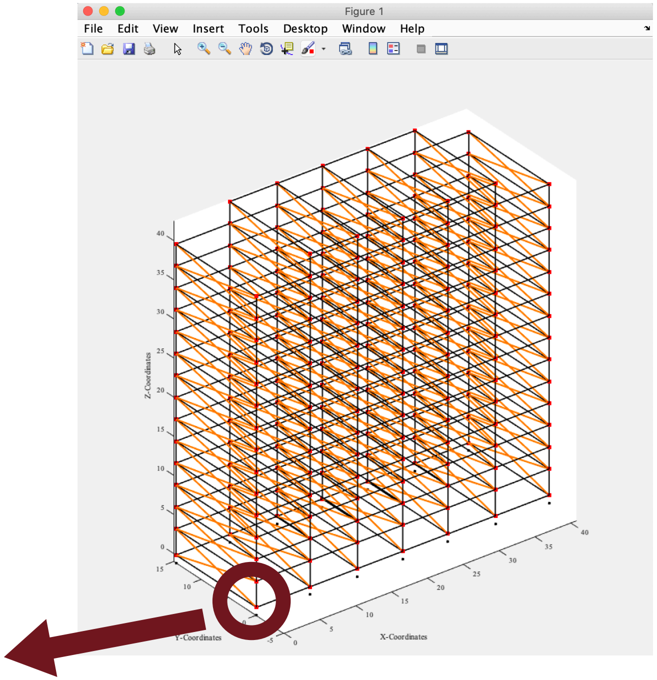
- Numerical model wascreated in OpenSees
- Efforts were made to ensure Japanese and Italian modelling assumptions are compatible

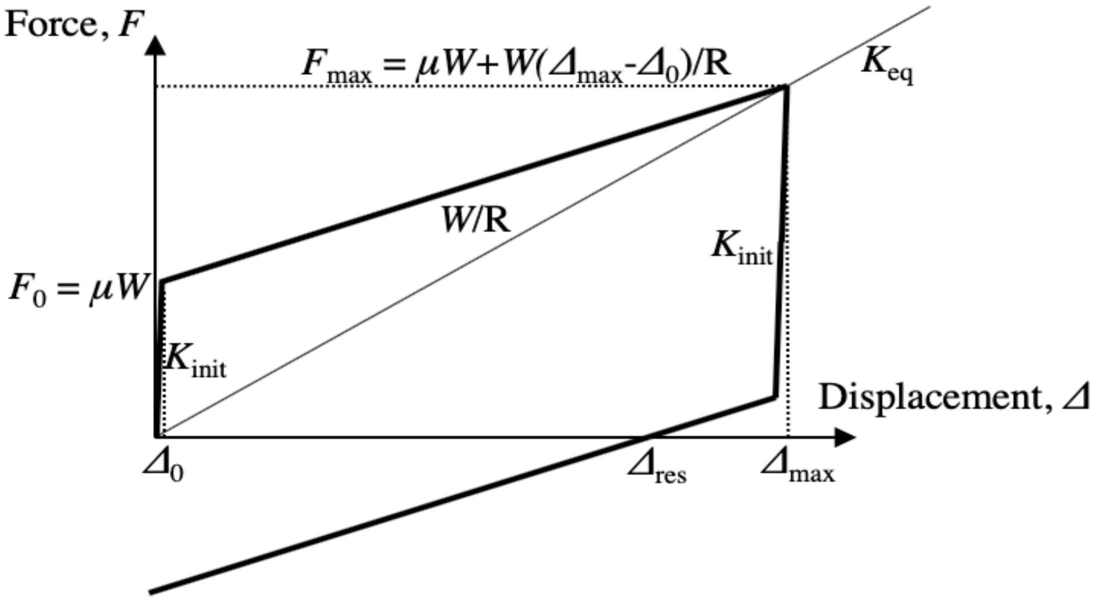


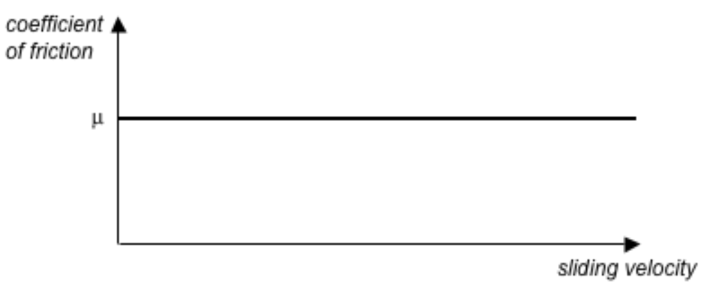


Numerical Modelling of Isolation System

- Single friction pendulum isolators were placed at base of each column
- Standard Coloumb friction model used







Design Limit States

Not checked for base isolation

Italy

Limit State		T_R [years]
~~Operational~~	~~SLO~~	~~30~~
Damage Limitation	SLD	50
Life Safety	SLV	475
Collapse Prevention	SLC	975

Japan

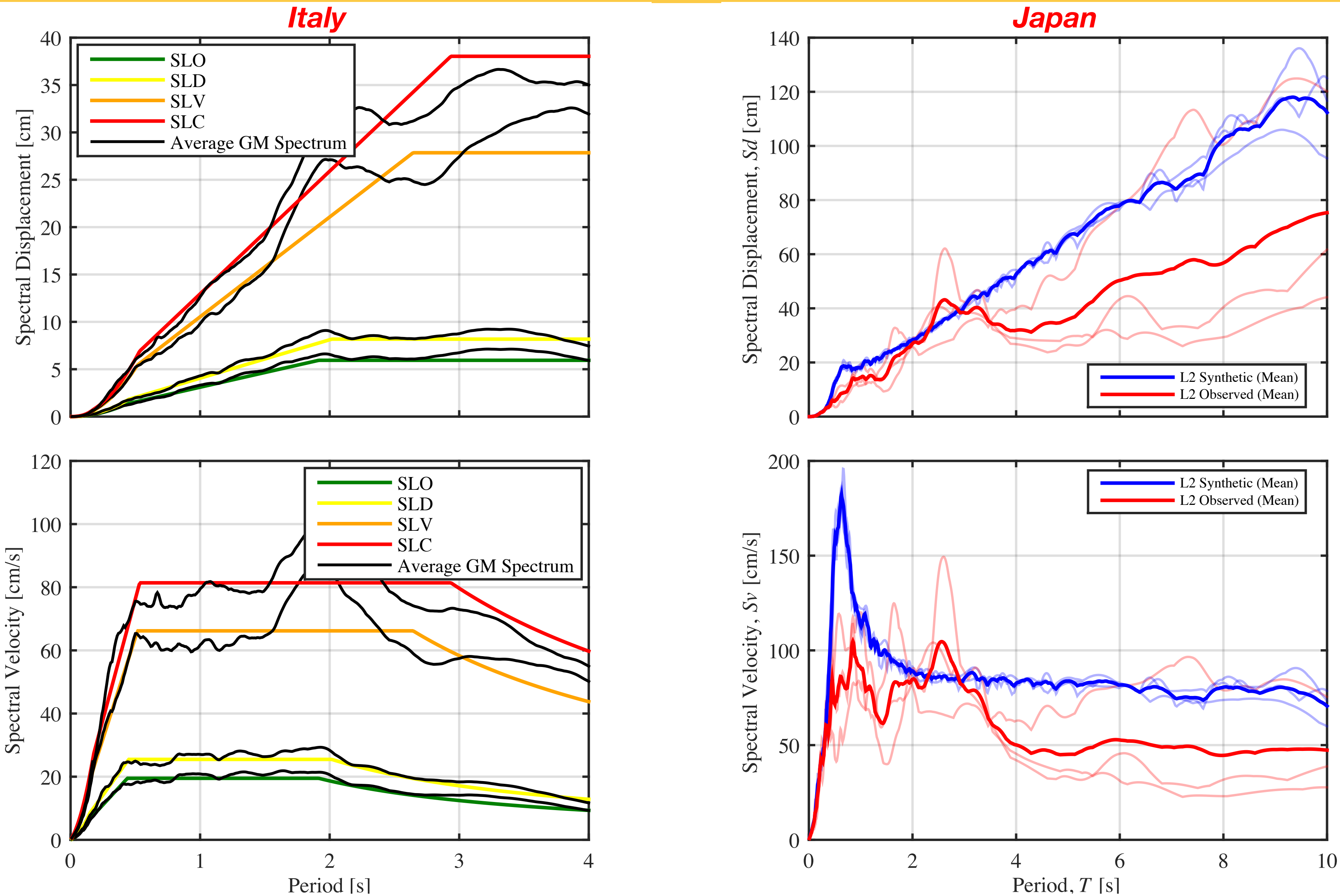
Limit State		T_R [years]
Rare	L1	~50
Extremely Rare	L2	~500
Very Extremely Rare	L3	>1000

- Italian limit state intensities defined using hazard analysis (PSHA)
- Japan limit state intensities defined with reference to L2 shaking

Design Requirements

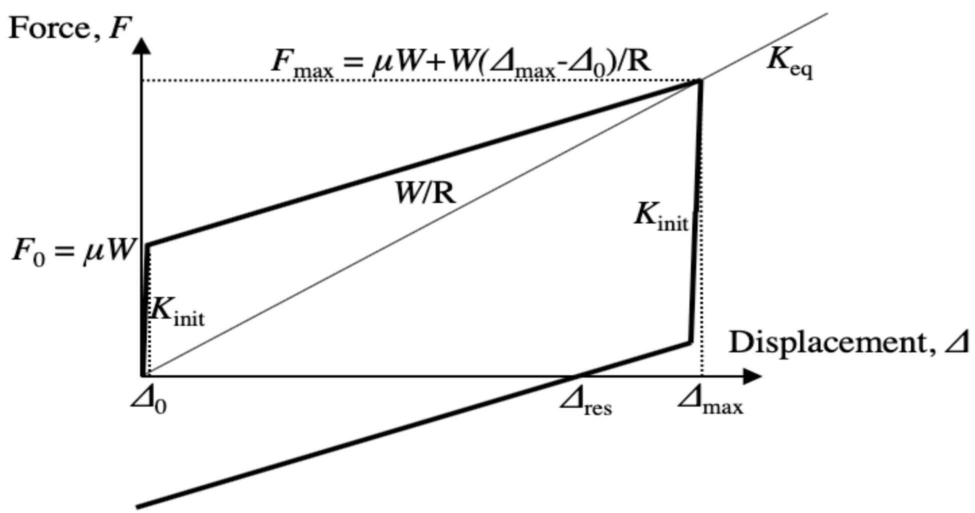
		Italian Code			Japanese Code		
		SLD	SLV	SLC	L1	L2	L3
Building-Specific	Peak Storey Drift	0.5%	-	-	1/300 (0.33%)	1/200 (0.5%)	1/100 (1.0%)
	Peak Floor Acceleration	0.2g	0.3g	-	0.2g	0.3g	-
	Perimeter Gap	-	Not exceeded		-	Not exceeded	
Device-Specific	Maximum Compression	Less than device's rated capacity			Less than device's rated capacity		
	Minimum Compression (Uplift)	No uplifting allowed unless it can be experimentally shown to not be an issue			Not allowed		
	Maximum Displacement	Less than device's displacement capacity			20cm	50cm	< Capacity
	Residual Drifts	Maintain functionality	-	-	Designer choice		
	Vertical GM				Should be considered (+/-0.3g)		-

Ground Motions



- The following are the two isolators chosen for both case studies

	Italy	Japan
Curvature Radius, *R*	3.1 m	4.5 m
Friction Coefficient, *μ*	4.5%	4.3%
Displacement Capacity	20 cm	75 cm
Axial Capacity	17,500 kN	20,000 kN



Design Verification

- For both countries, the limit state requirements were checked using dynamic analysis

Italy

		SLD	SLD	SLC	
θ_{max}	X	0.11%			*Storey drifts*
	Y	0.02%			
a_{max}	X	0.21g	0.35g		*Floor accelerations*
	Y	0.16g	0.35g		
Δ_{gap}			15.2cm	19.7cm	*Perimeter gap*
P_{max}			14,134kN	14,341kN	*Maximum isolator load*
P_{min}			756kN	434kN	*Isolator tension*
Δ_{max}			15.2cm	19.7cm	*Isolator displacement capacity*
Δ_r		0.7cm	1.8cm		*Residual displacement*

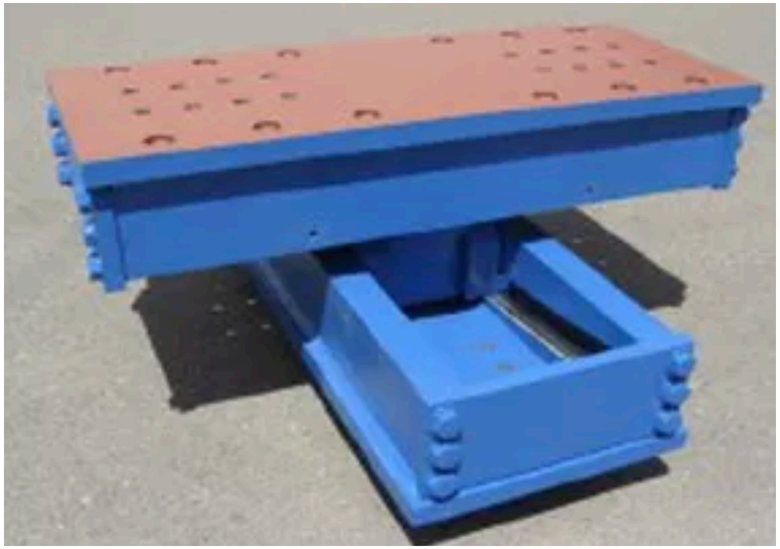
Japan

		L1	L2	L3
θ_{max}	X	0.13%	0.27%	0.37%
	Y	0.02%	0.04%	0.06%
a_{max}	X	0.19g	0.60g	
	Y	0.15g	0.60g	
Δ_{gap}			30.2cm	77.4cm
P_{max}			17,031kN	17,302kN
P_{min}			-3,247kN	-3,626kN
Δ_{max}		4.2cm	30.2cm	77.4cm

Storey drifts
Floor accelerations
Perimeter gap
Maximum isolator load
Isolator tension
Isolator displacement capacity
Residual displacement

Tension in the devices?

- One important problem was the possibility of tension in the devices for the Japanese design
- Japanese code does not allow tension in friction devices
- Italian code allows if experiments can show that tension will not be a problem
- One solution is a tension bearing device
- Offers no lateral resistance but prevents uplifting

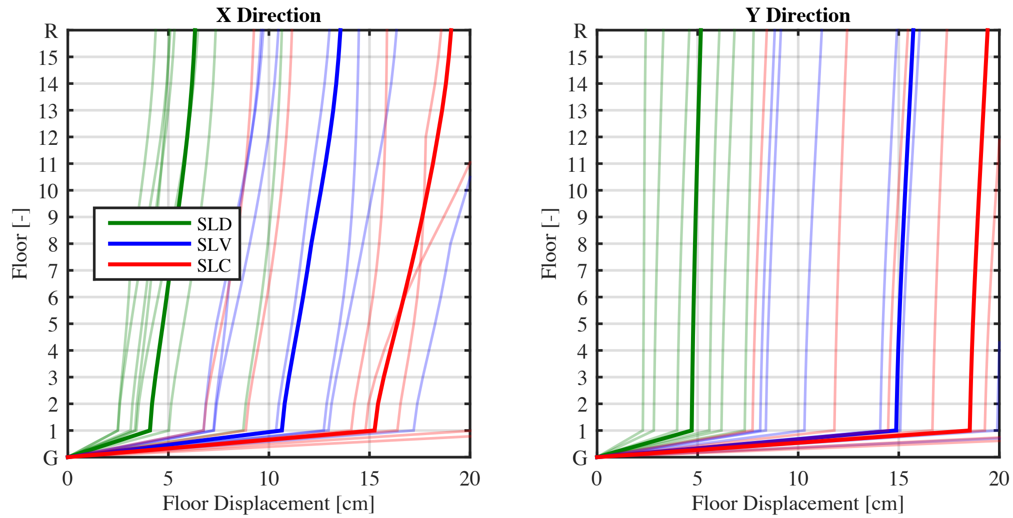


(Photo: Earthquake Protection Systems, USA)

Dynamic Analysis Results

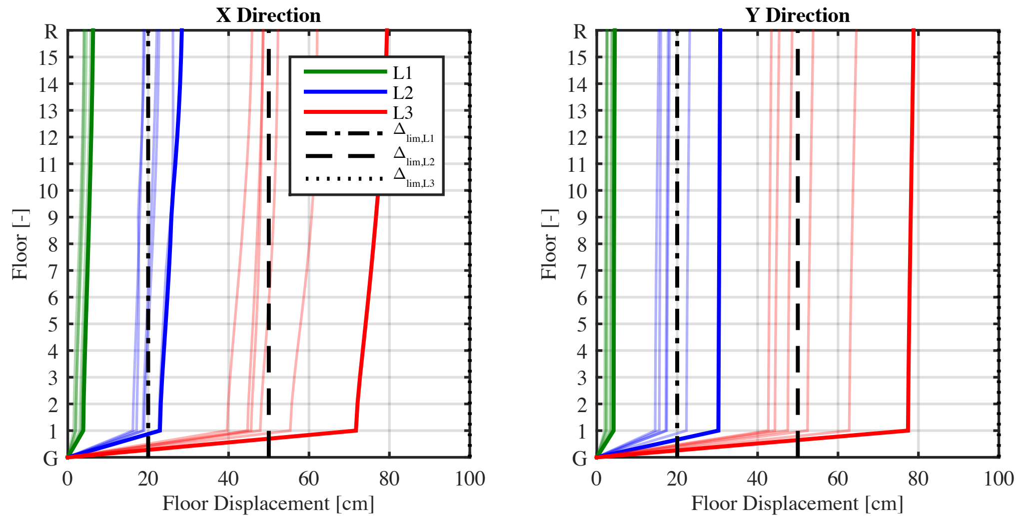
Floor Displacements

Italy



Italian analysis: Take the <u>average</u> response

Japan

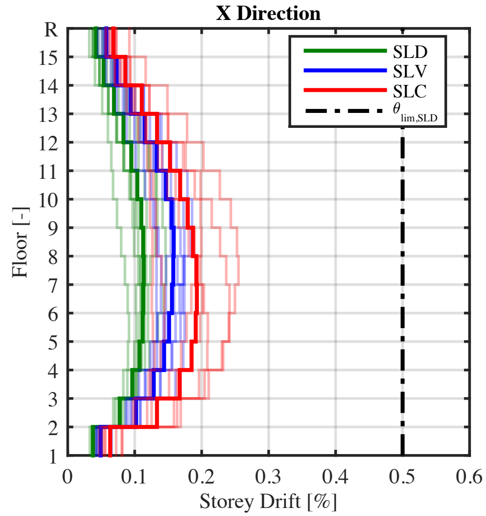


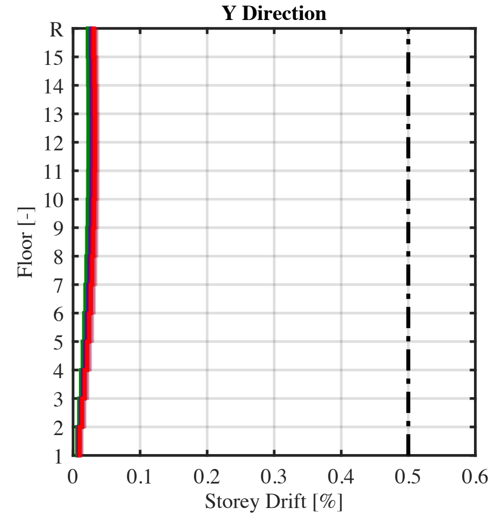
Japanese analysis: Take the <u>maximum</u> response

Dynamic Analysis Results

Storey Drifts

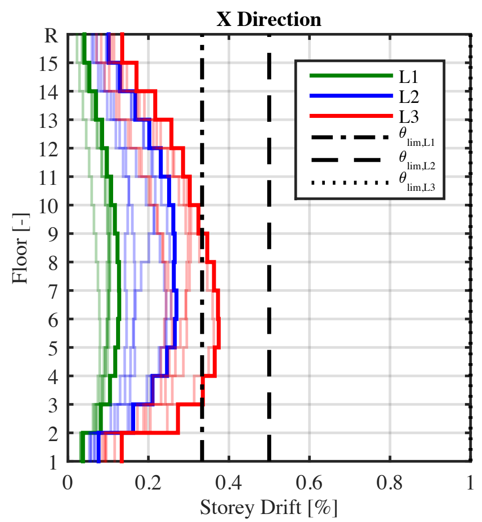
Italy

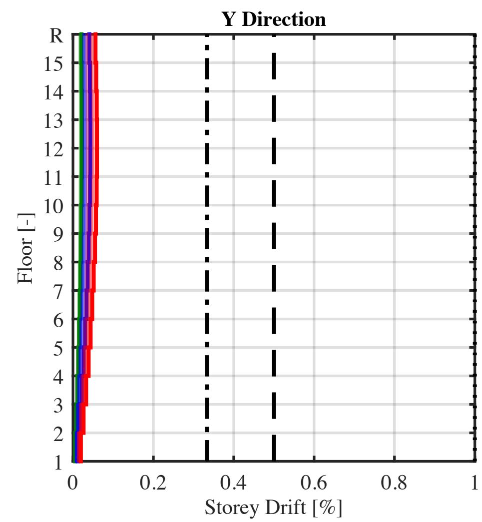




Italian analysis: Take the **average** response

Japan





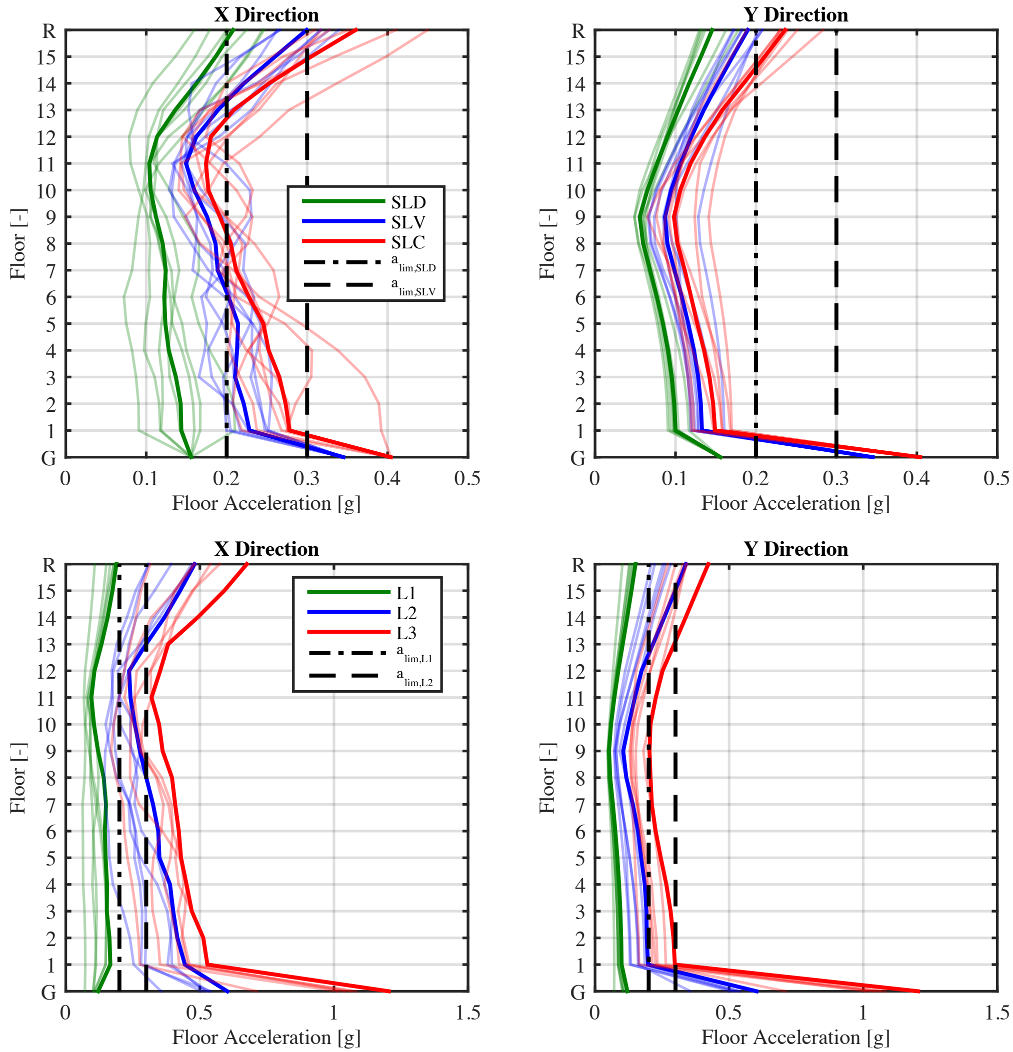
Japanese analysis: Take the **maximum** response

Dynamic Analysis Results

Floor Accelerations

Italy

Japan



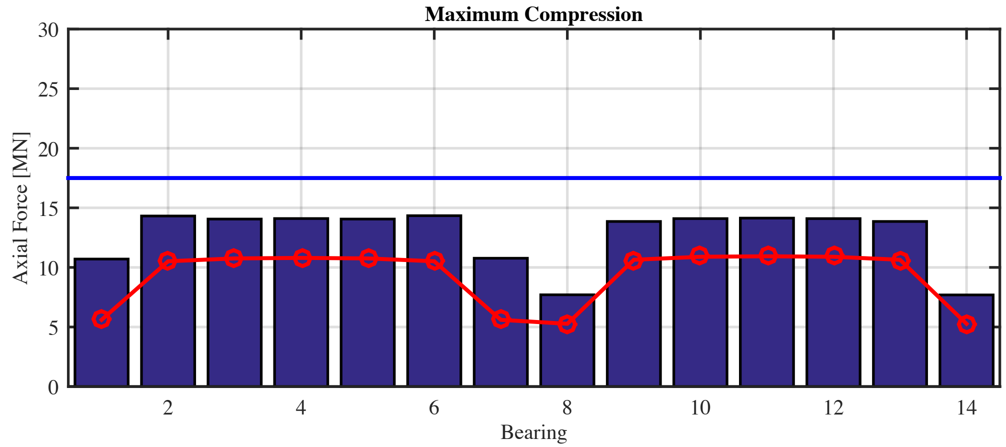
Italian analysis: Take the <u>average</u> response

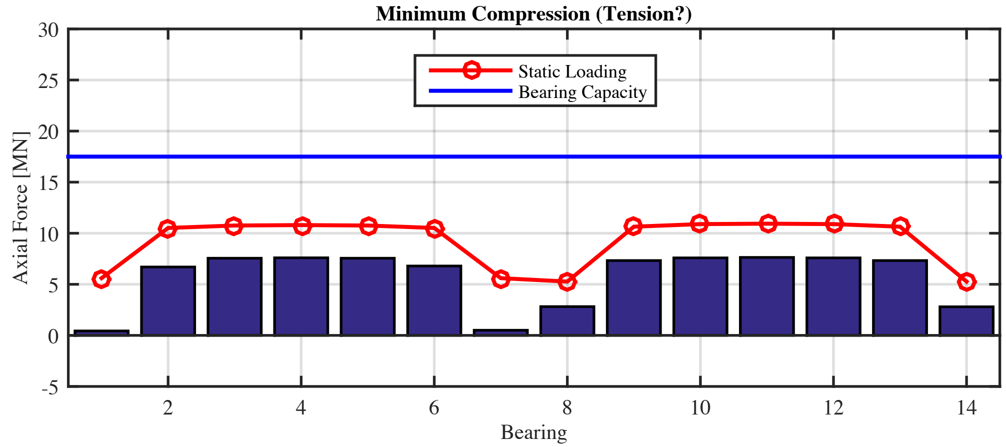
Japanese analysis: Take the <u>maximum</u> response

Dynamic Analysis Results

Isolator Axial Forces

Italy

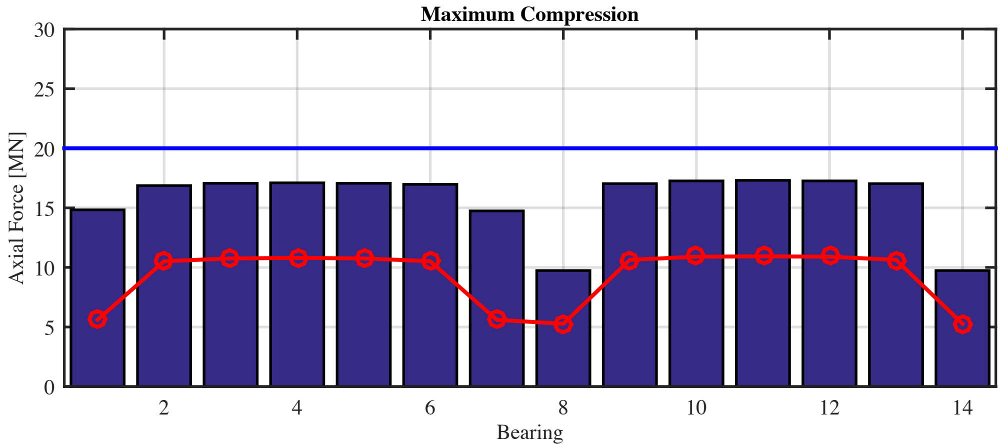


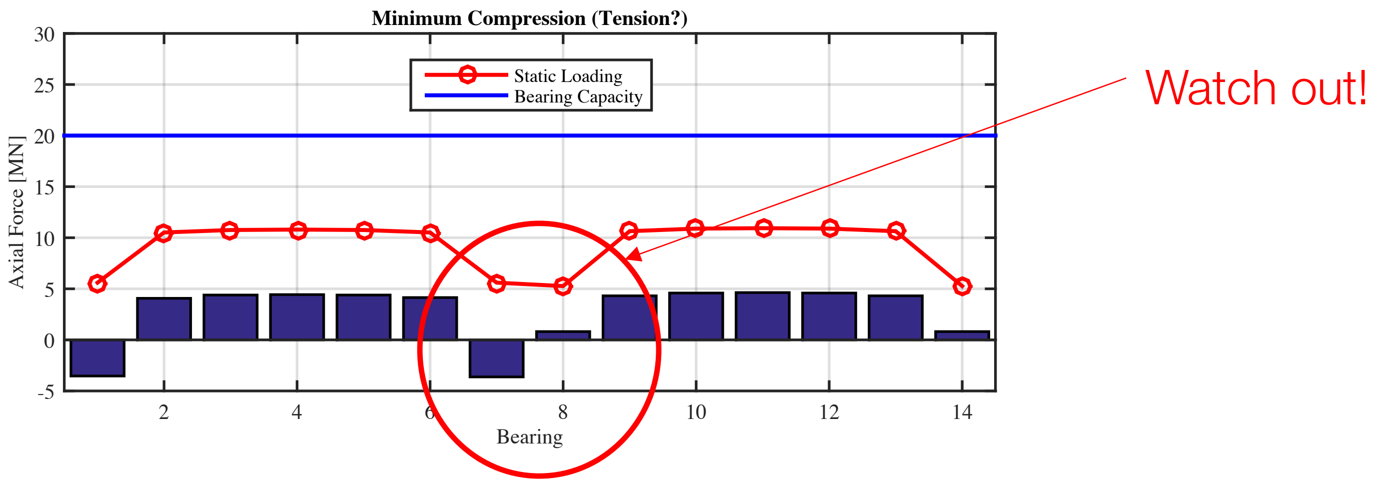


Dynamic Analysis Results

Isolator Axial Forces

Japan





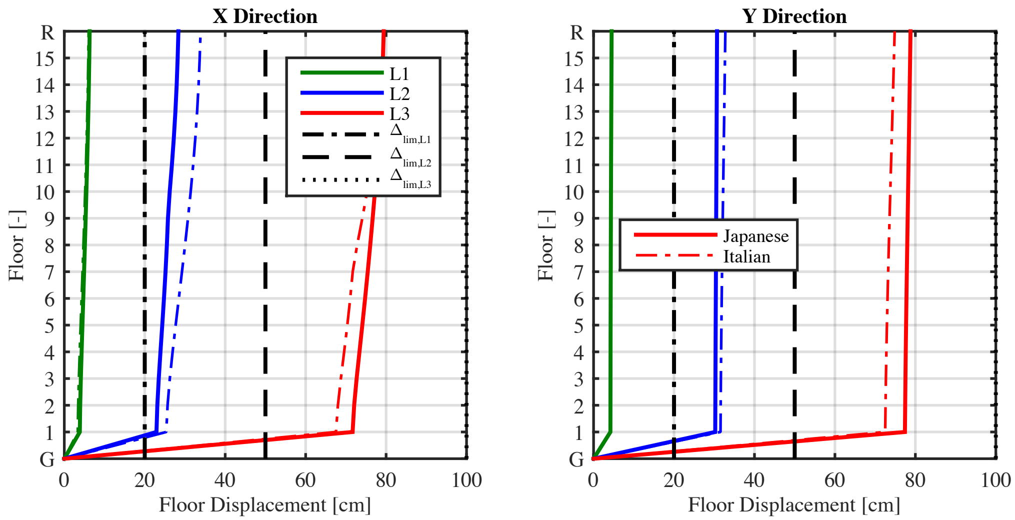
Main takeaway points?

- The designs have similar responses
- Japan design has much larger displacements (normal)
- Building response (drift and acceleration the same)
- Uplift needs consideration in Japan

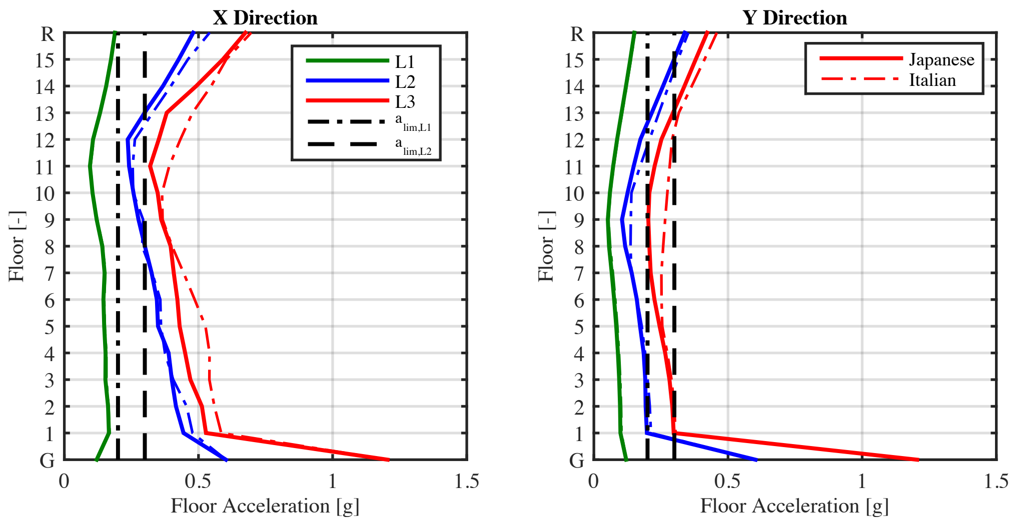
- Now what if we looked at:
  - Italian building subjected to Japanese ground motions
  - Japanese designs (elastomeric vs. friction pendulum)

Italian Isolators in Japan

Floor Displacements

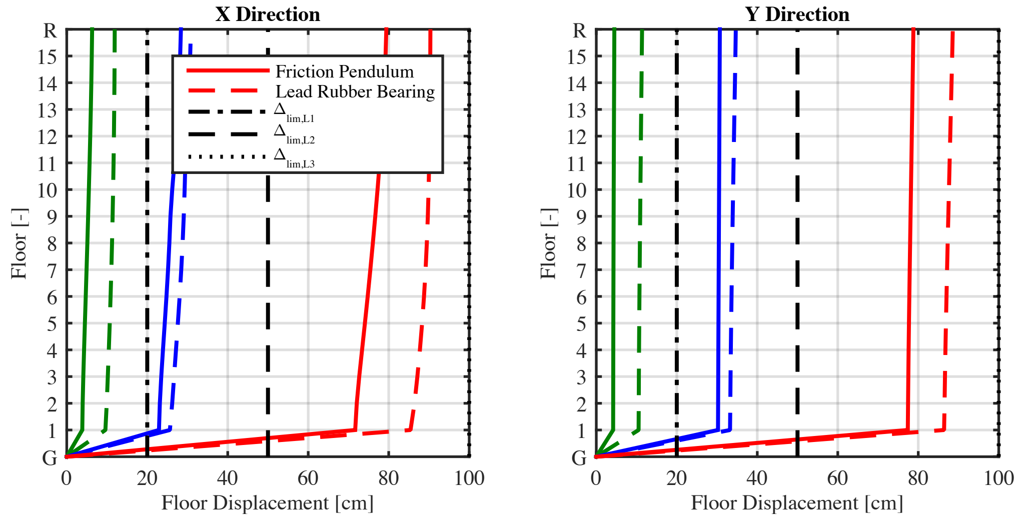


Floor Accelerations

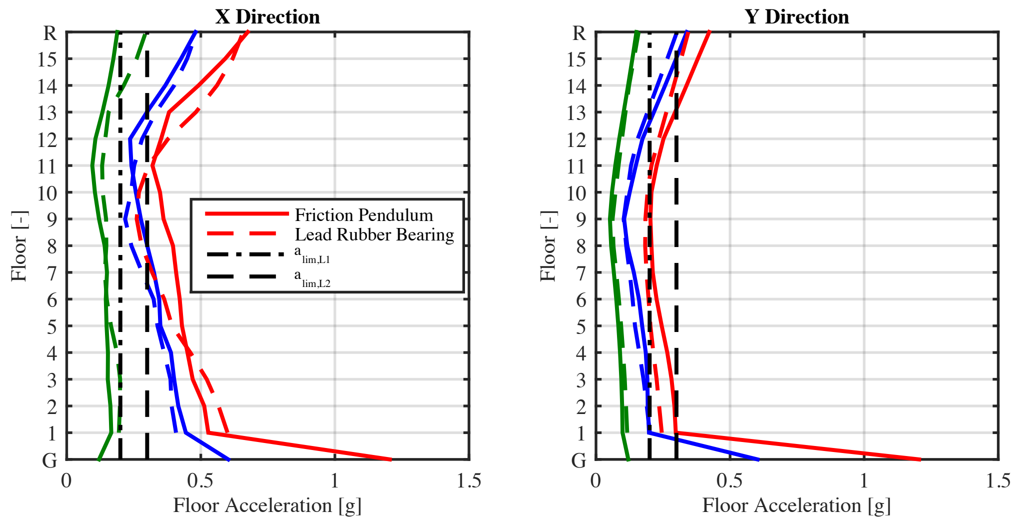


Elastomeric vs. Friction Pendulum in Japan

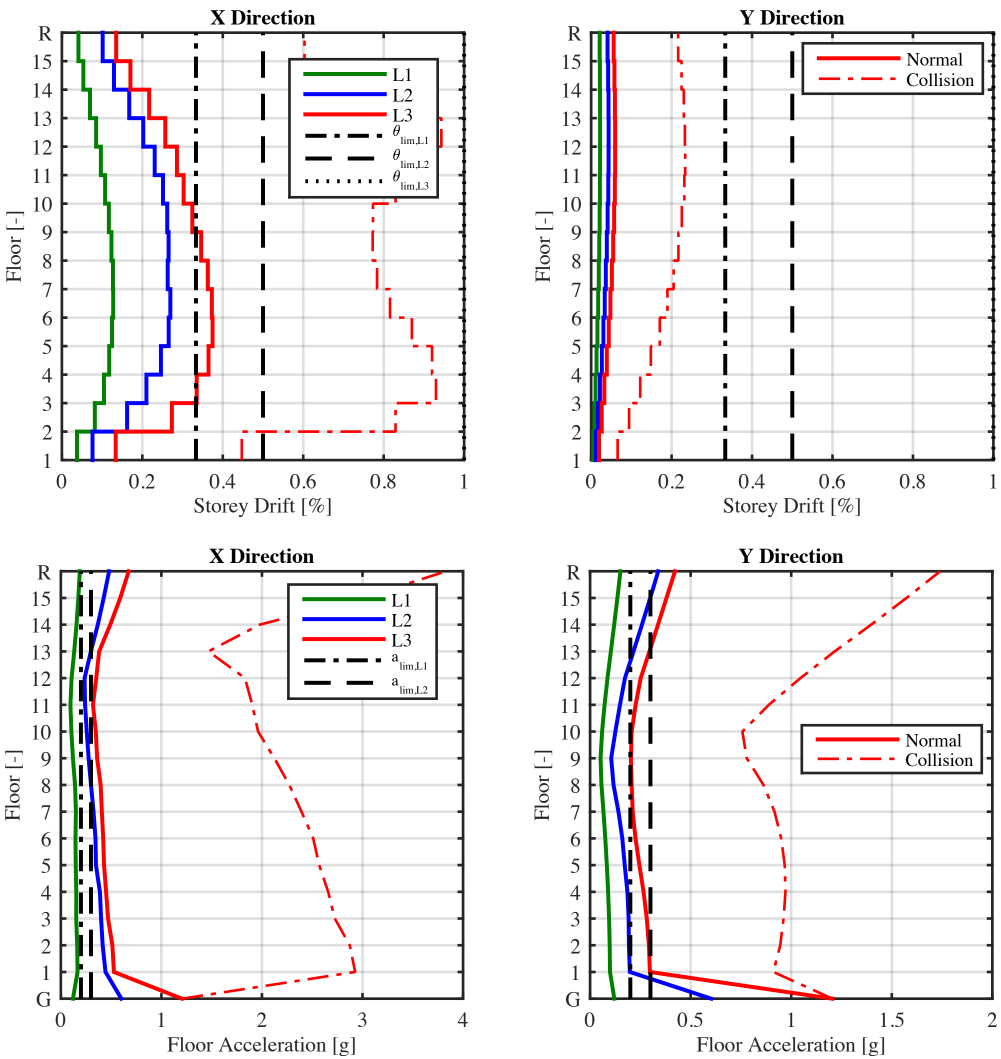
Floor Displacements

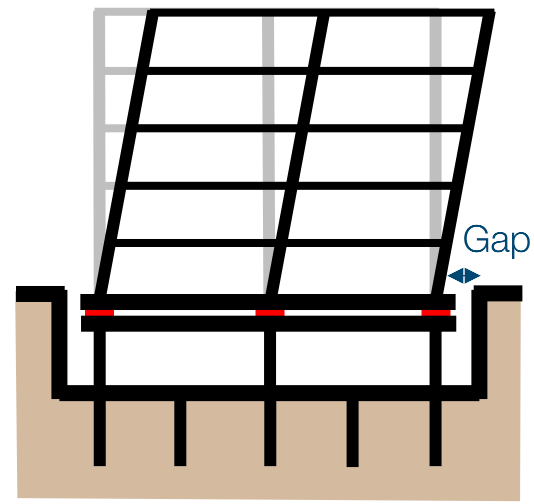


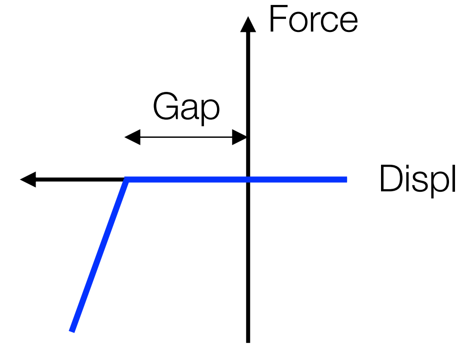
Floor Accelerations



Impact with Retaining Wall





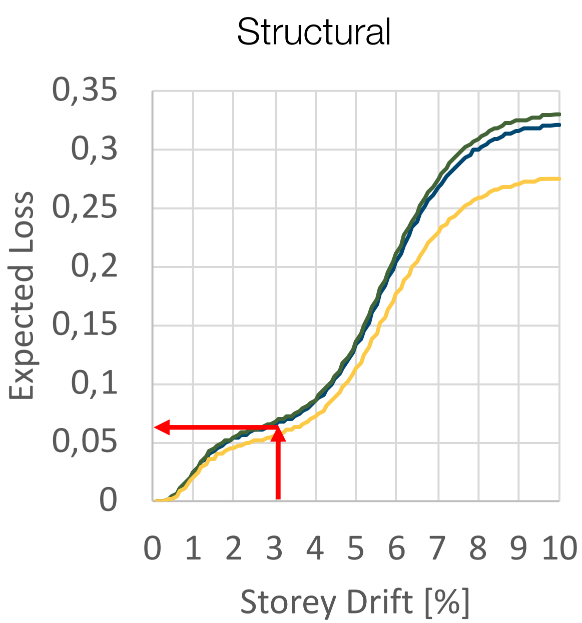


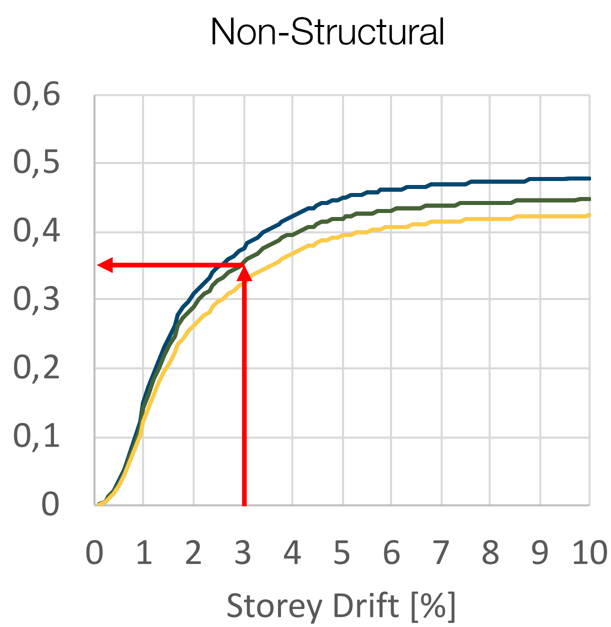
Impact with retaining wall was modelled by inserting a gap element in OpenSees model

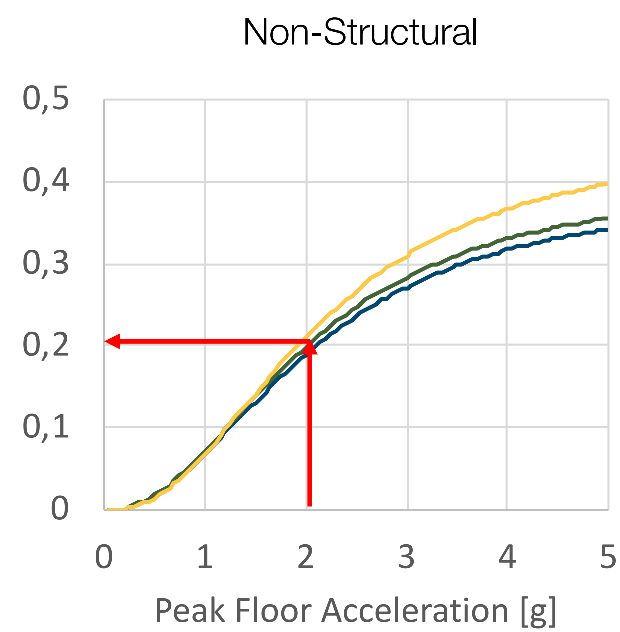
Loss Assessment

- How would the different considerations compare if we estimated the losses?
- Follow approach developed by Ramirez and Miranda
- Using storey-loss functions, the losses at each storey-based on drift or acceleration can be computed

$$E[L|LS] = \sum_{i=1}^{n} E\left[L_{PSD,i}|LS\right]/n + \sum_{i=1}^{n+1} E\left[L_{PFA,i}|LS\right]\Big/(n+1)$$

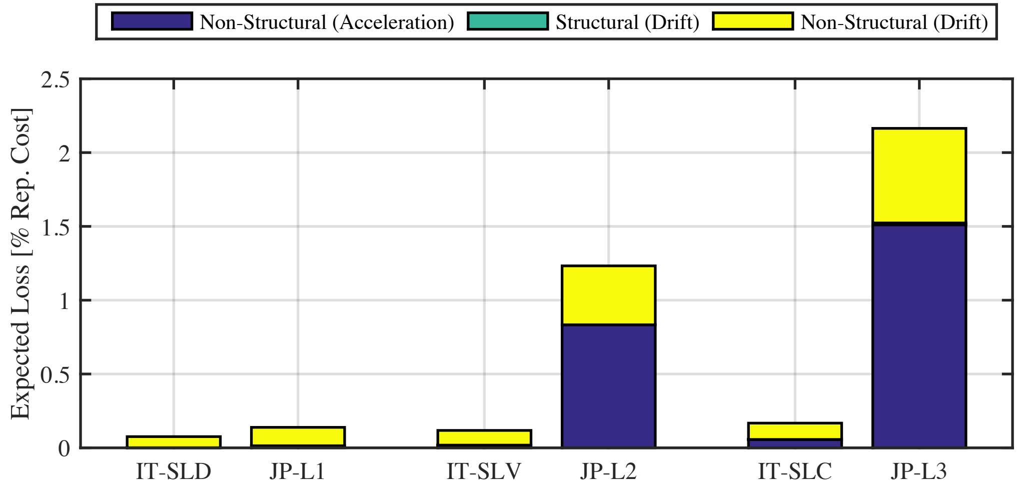




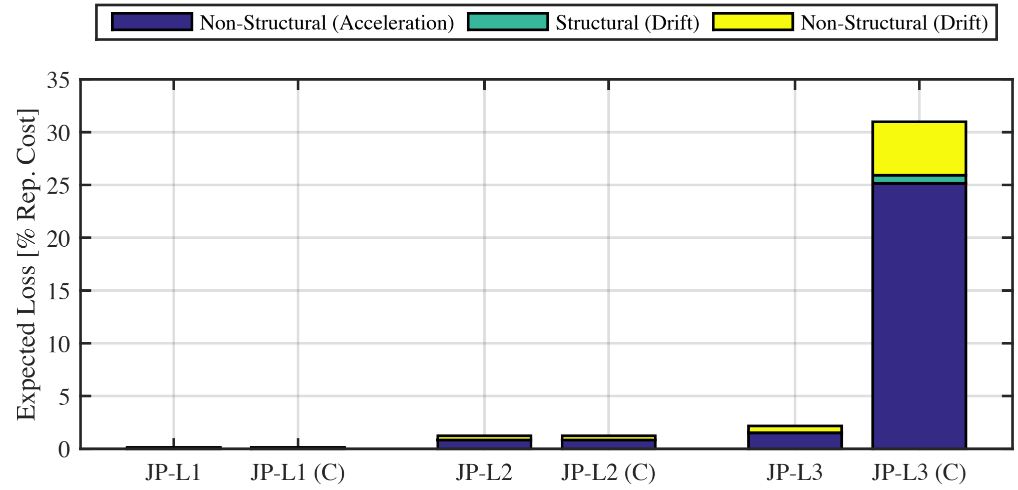


Loss Assessment

Japan vs. Italy



Japan (with Collision Analysis)



To Summarise… (1/2)

- Differences or similarities between Japan and Italy?
  - Main difference is the extent to which base isolation has been utilised - Japan much more
  - What is similar is how significant earthquakes have resulted in a rise of base isolation implementation
  - Differences were examined from an economic and social point of view
    - Japan's population double Italy's
    - Much more sustained economic growth when Italy in economic difficulty

- Elastomeric versus friction-based pendulum systems?
  - Japan likes elastomeric, but Italy is liking friction pendulum more recently
  - In Italy, friction pendulum has more flexibility and advantageous

To Summarise… (2/2)

- Problems faced in seismic design with base isolation?
  - Japan needs bigger displacement devices
  - Japan has to be more careful of uplifting
- What about losses?
  - Losses are quite low for both countries
  - Japan's losses much higher than Italy (normal)
  - If collision with the retaining wall occurs, large losses but not so much structural damage
- In a single sentence, we found:
  - Japan is not using friction pendulum isolators as much as they could
  - They offer more simplicity and customisable
  - Italian devices are compatible to use in Japan
  - Can be much cheaper!

Thank you