INNOVATIVE APPROACH TO RETROFIT VULNERABLE SCHOOLS IN PERÚ

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January 2017

Outline

1. School infrastructure vulnerability
2. Retrofitting options
3. Selection criteria
4. Experimental verification
5. Conclusions

1. SCHOOL INFRASTRUCTURE VULNERABILITY

Peru, one of the countries with the highest seismic activity levels and school infrastructure with high vulnerability

NAZCA earthquake (1996)

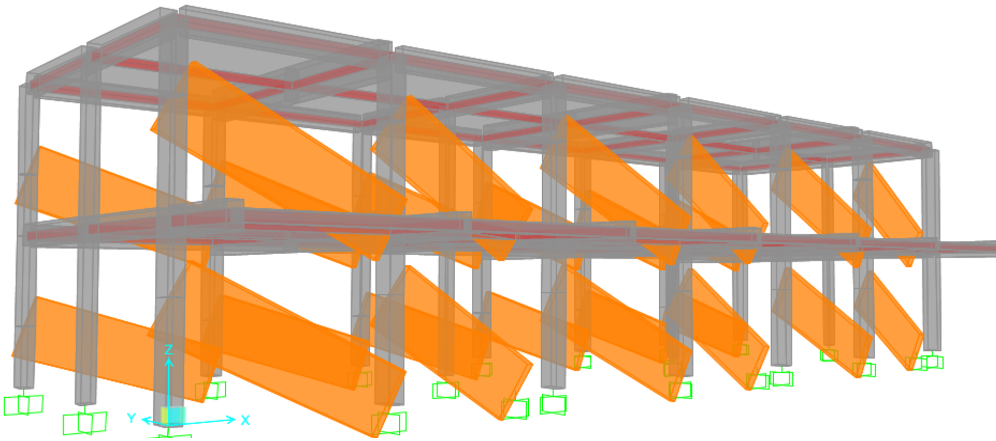
- November 12th, 1996.
- Mw = 7.7
- City of Nazca, between Ica and Arequipa
- Fatal victims = 20
- Injuries= 2,000
- Affected population = 100,000
- Loss estimated = USD$ 43 million

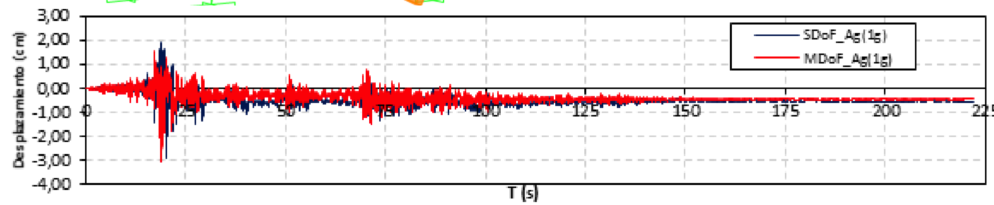
AREQUIPA earthquake (2001)

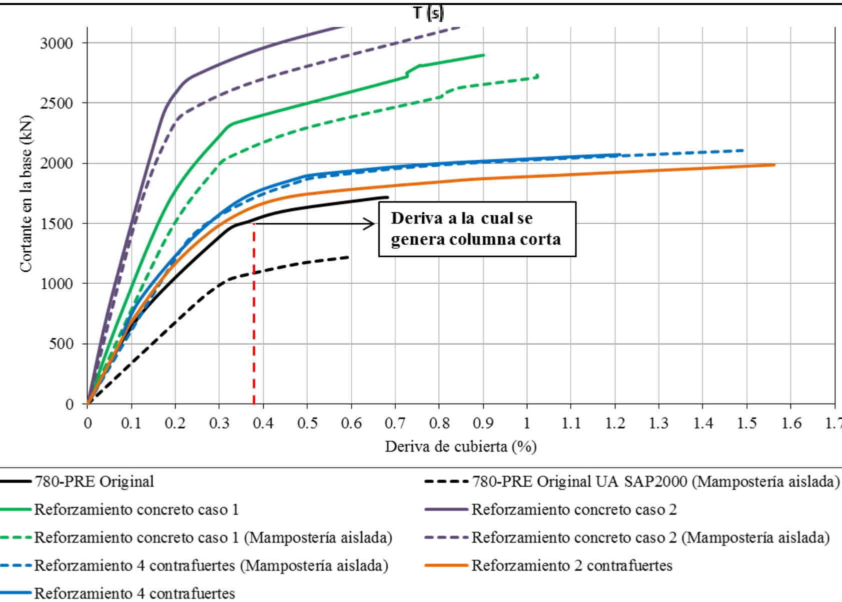
- June 23rd, 2001.
- Mw = 8.4
- Region of Arequipa
- Fatal victims = 102
- Injuries = 2,400
- Missing people =70
- Affected population= 460,000

How to measure vulnerability?

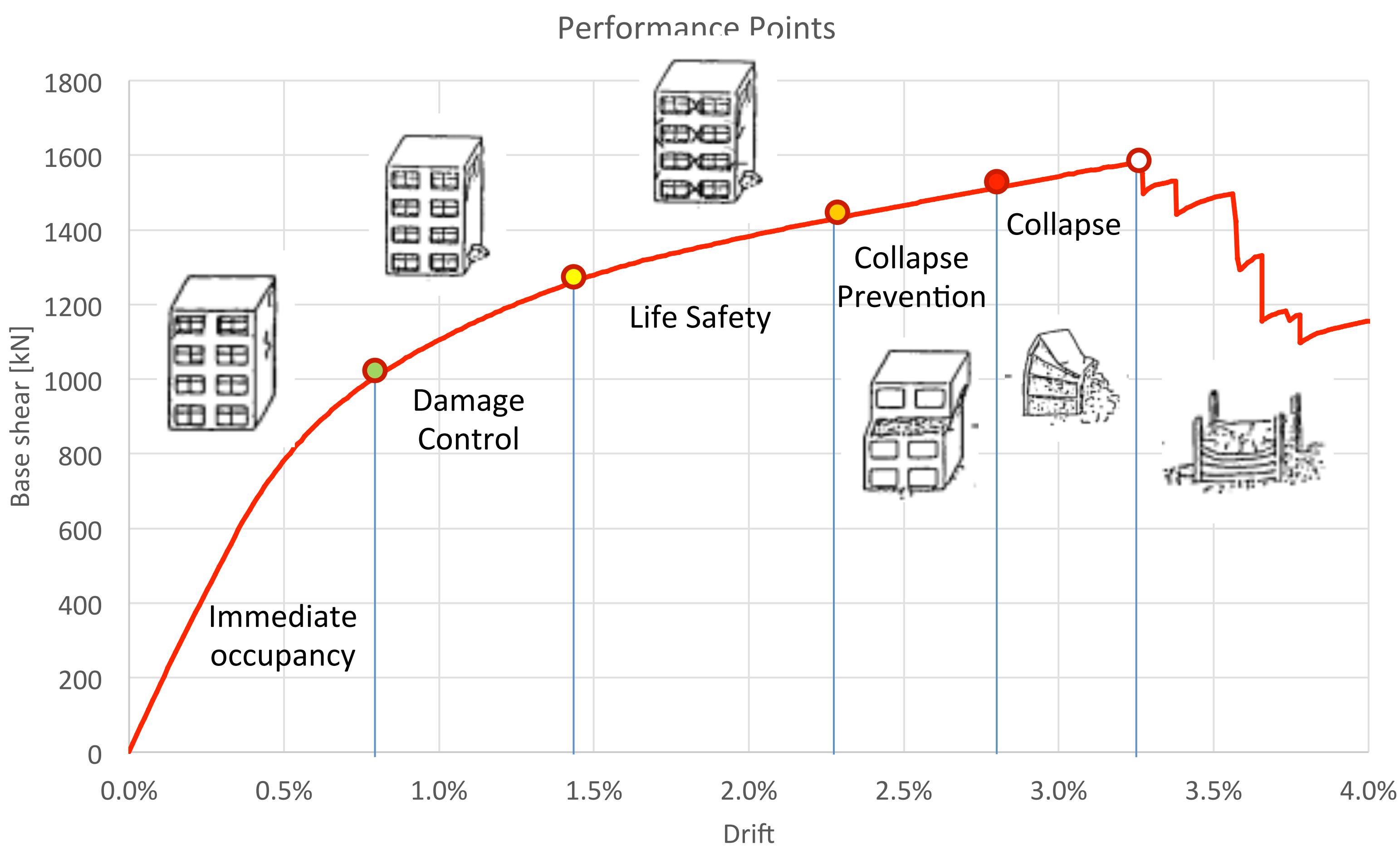
- Computational Model
- Dynamic nonlinear structural Analysis
- Pushover curve for different intervention options



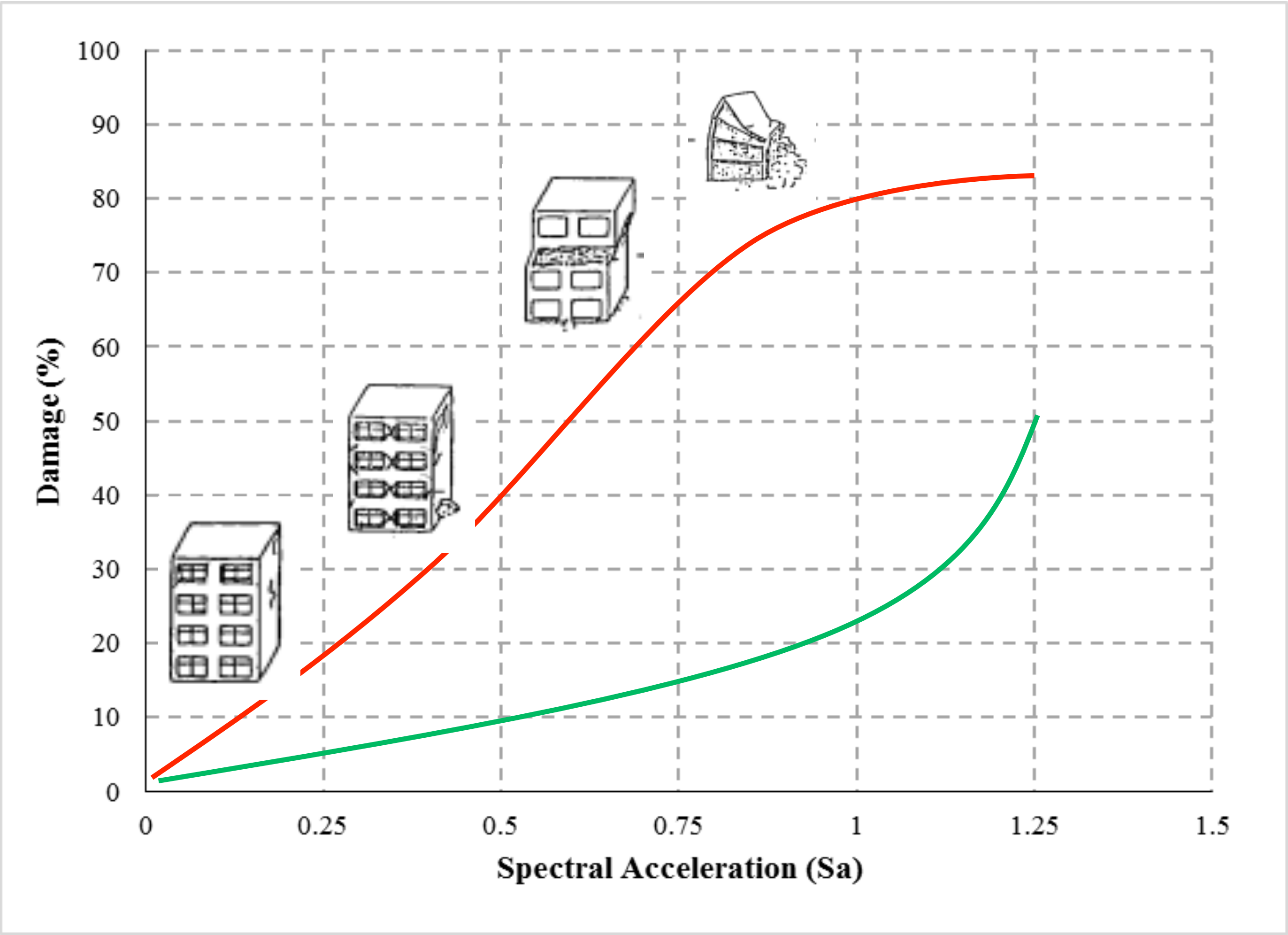




Incremental retrofitting: Performance points

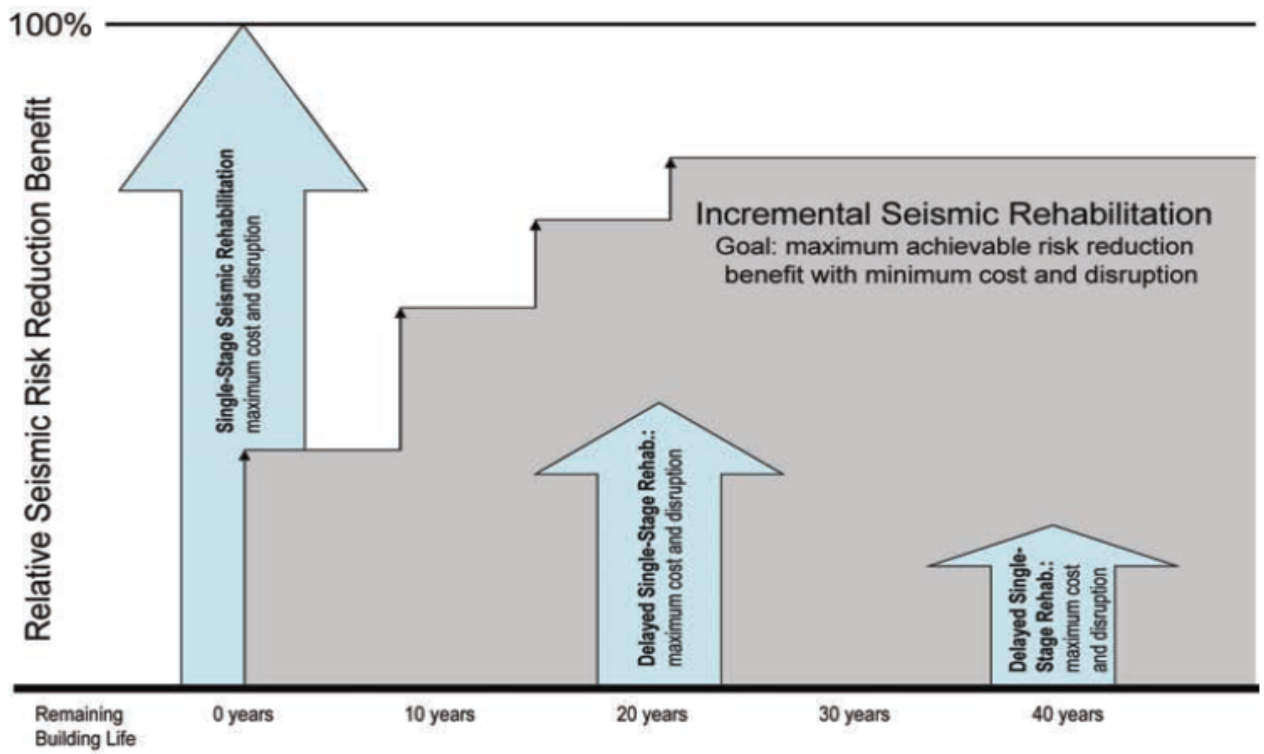


Incremental retrofitting: Performance points



INCREMENTAL RETROFITTING: CONCEPT

Incremental retrofitting: discrete steps over a period of time → Acceptable risk reduction with less initial resources



Source: FEMA P-420

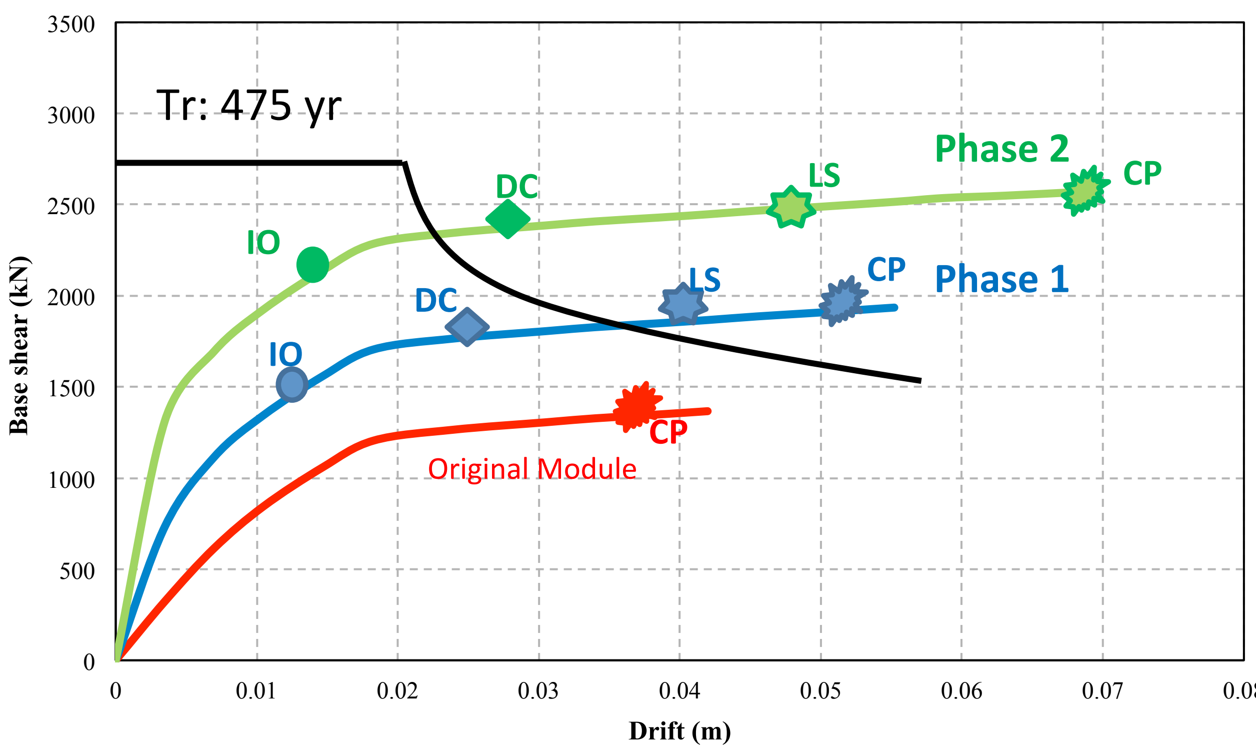
Incremental retrofitting: Acceptance Criteria for capacity and demand

Tr = 475 Earthquake – PGA: 0.4g

Performance objective (ASCE 41-13):

Phase 1:
Life Safety — LS

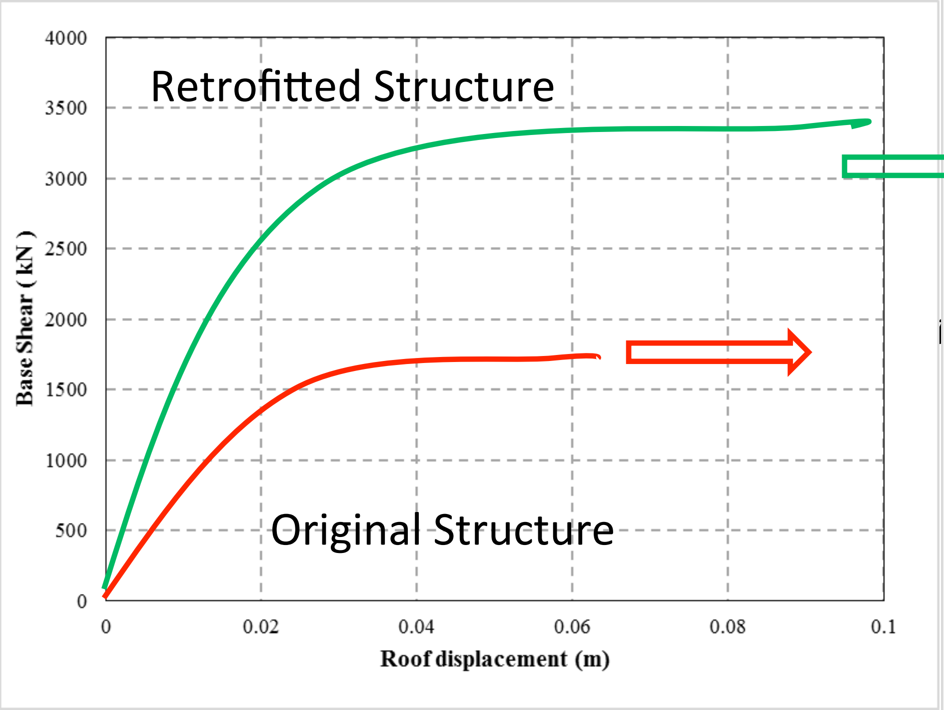
Phase 2:
Damage control — DC

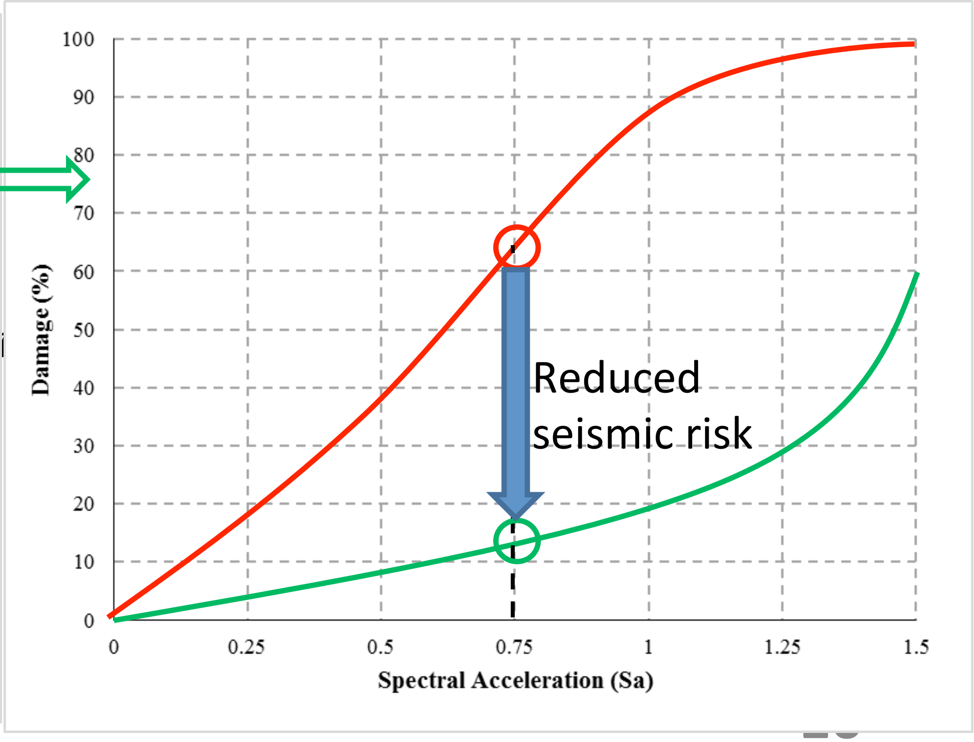


Methodology - Risk assessment

Probabilistic – Average Annual Loss

Risk Reduction in mitigation plans is calculated as the difference in the AAL between the original structure and the retrofitted one.





2. RETROFITING OPTIONS

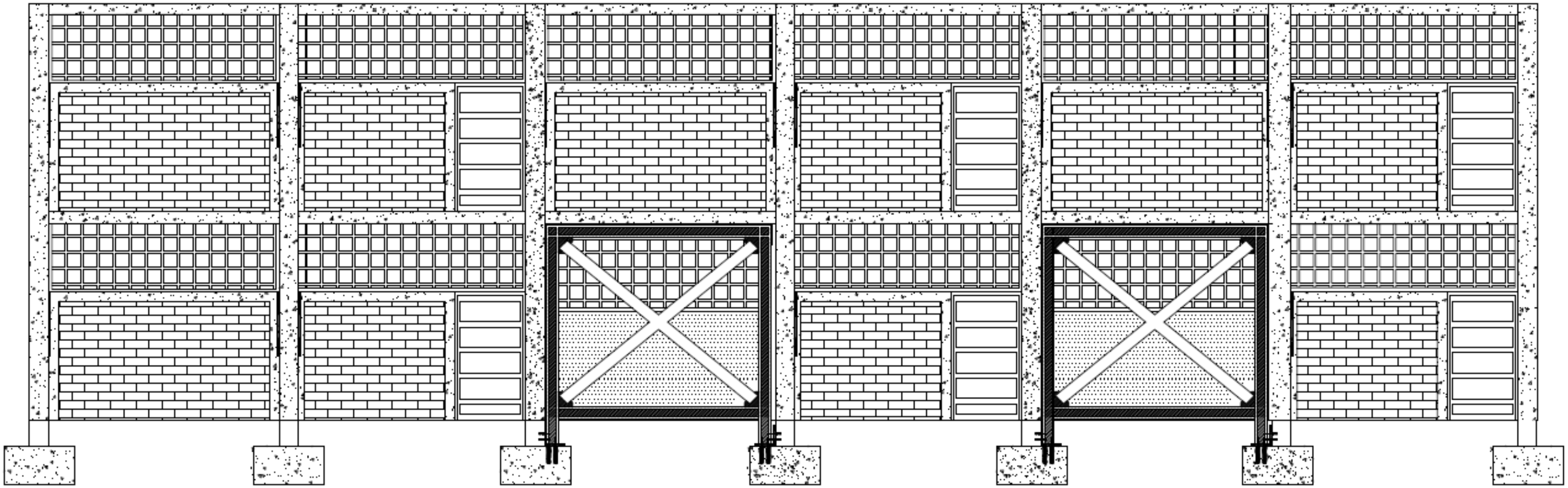
Incremental retrofitting solutions

General criteria for the solutions:

1. Minimize intervention time to avoid interruption of classes/activities
2. Minimize intervention costs and complexity of the construction process
3. Minimize the area and number of elements intervened
4. Minimize impacts in the functionality of the classrooms (maintain lighting, door location)
5. Avoid intervention to the foundation
6. Phase 1 should achieve a performance level of immediate occupancy or higher

1) Steel Braced Option

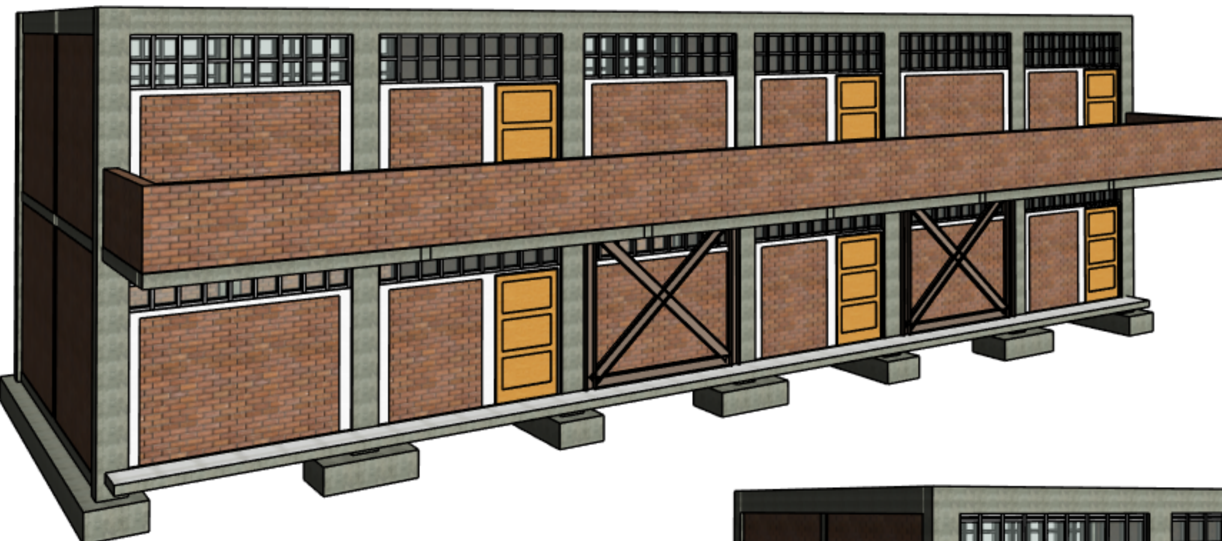
- Braced steel frames: Steel frames (beams + columns) with braces placed, anchored to the concrete frame.



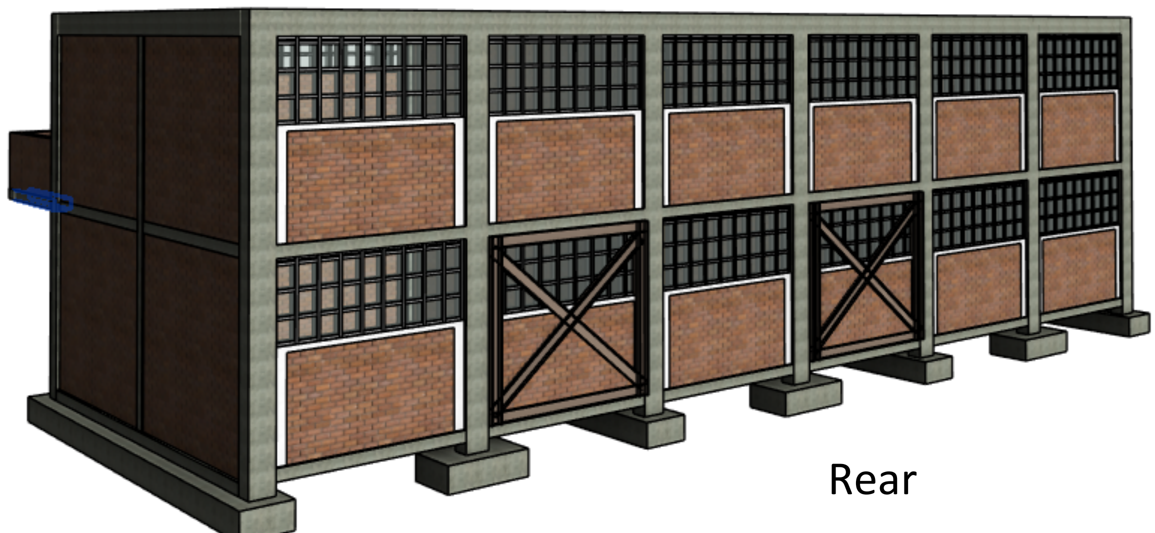
In 2 selected spans in 1st floor on each façade

PHASE ONE

1) Steel Braced Option



Front



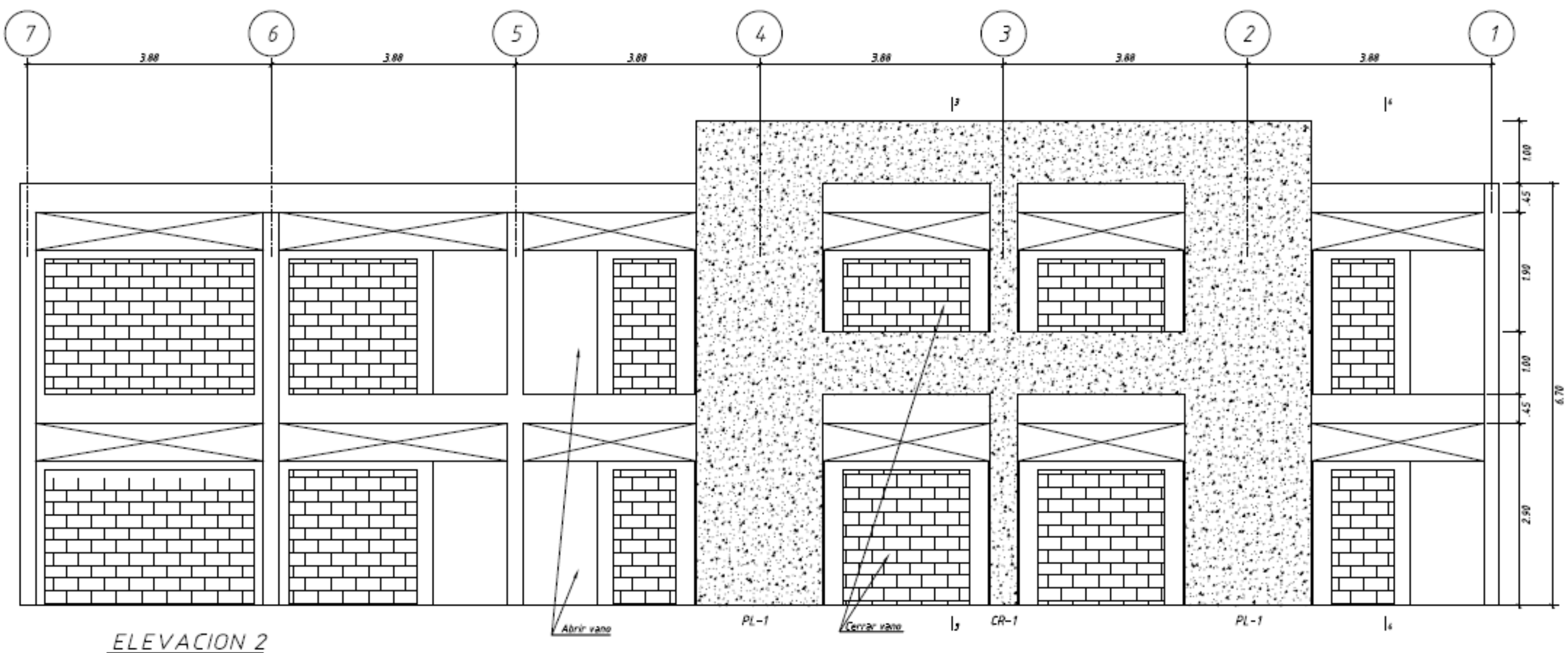
Rear

In 2 selected spans in 1st floor on each façade

PHASE ONE

2) Concrete Shear Walls

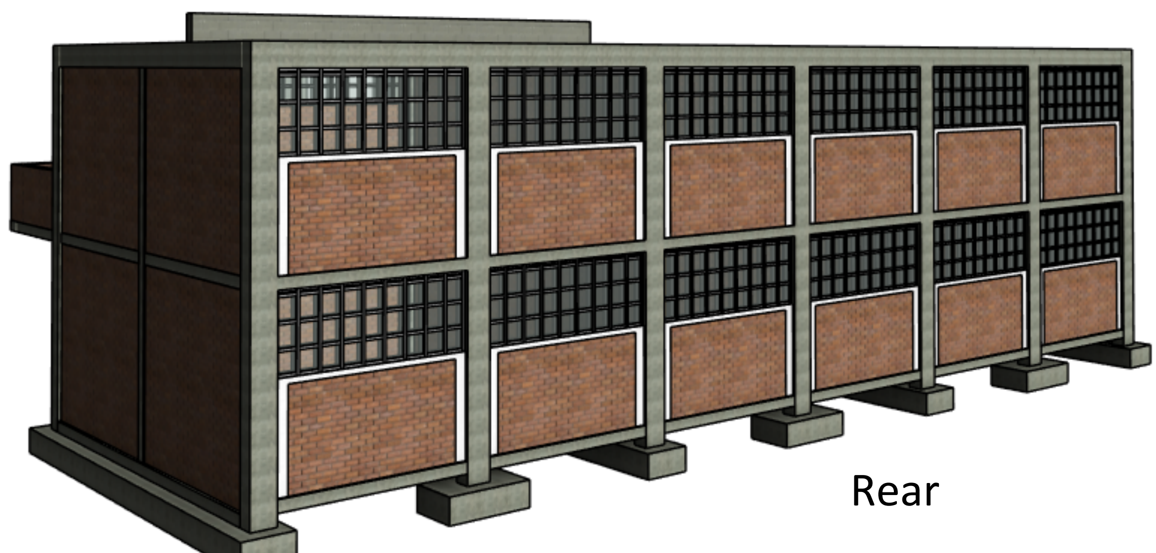
Concrete walls: Add 2m long concrete walls along two existing columns, separated by a third column which is also intervened. The walls are connected by retrofitted beams.



Concrete shear walls on principal façade
PHASE ONE

2) Concrete Shear Walls

Front



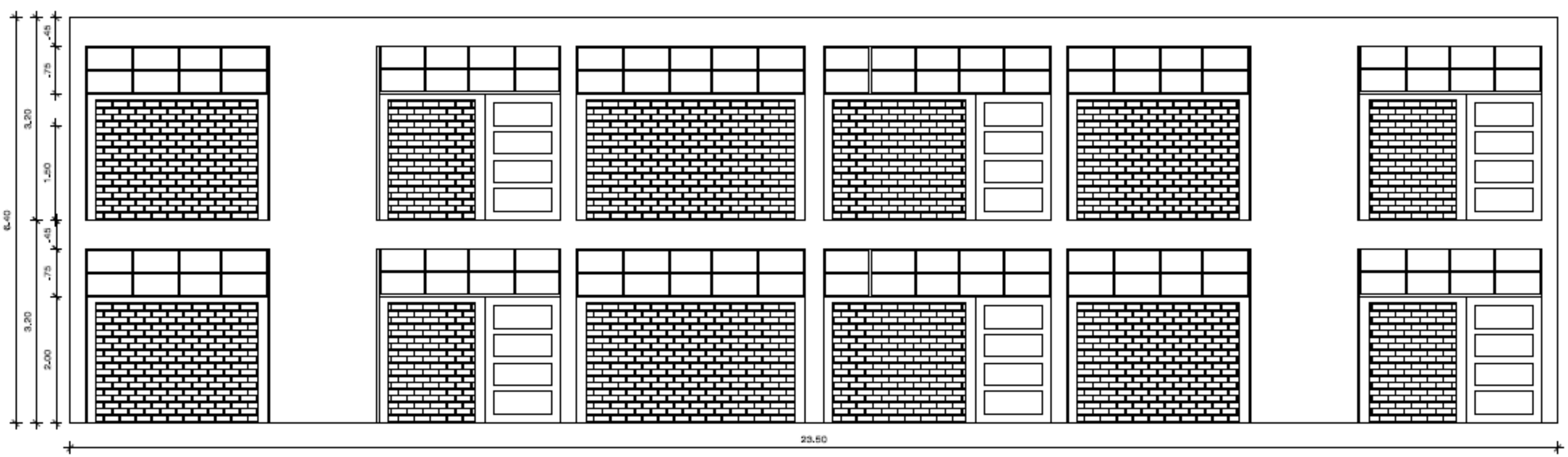
Rear

Concrete shear walls on principal façade

PHASE ONE

3) Confined Retrofitted Masonry Walls

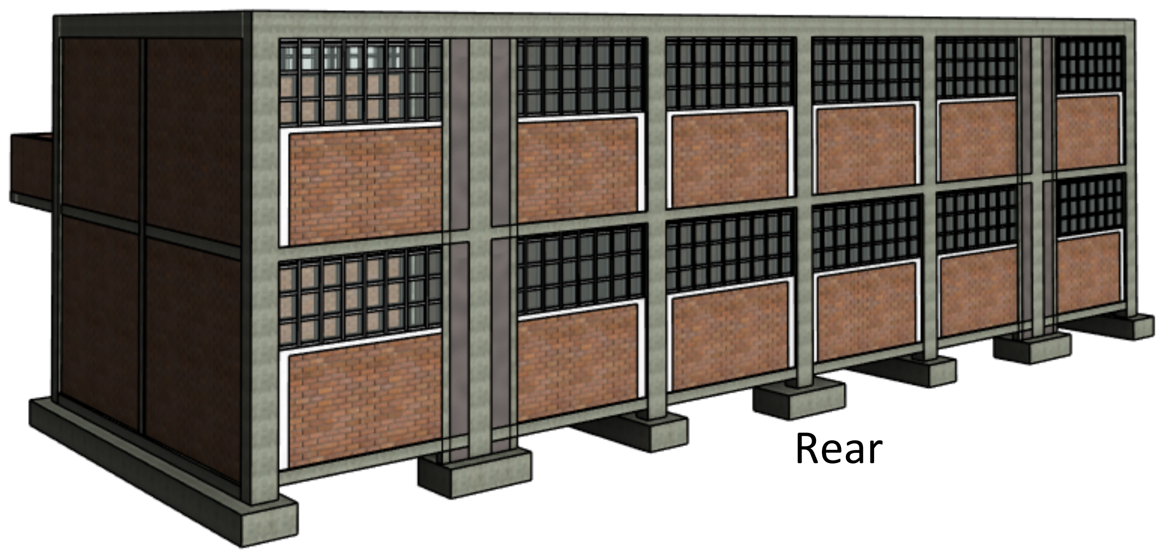
Masonry walls: Add a masonry wall 50 cm long above the infill, next to an existing column to fill the gap and form a confined masonry wall.



2 Confined Retrofitted Masonry Walls for each façade
PHASE ONE

3) Confined Retrofitted Masonry Walls

Front

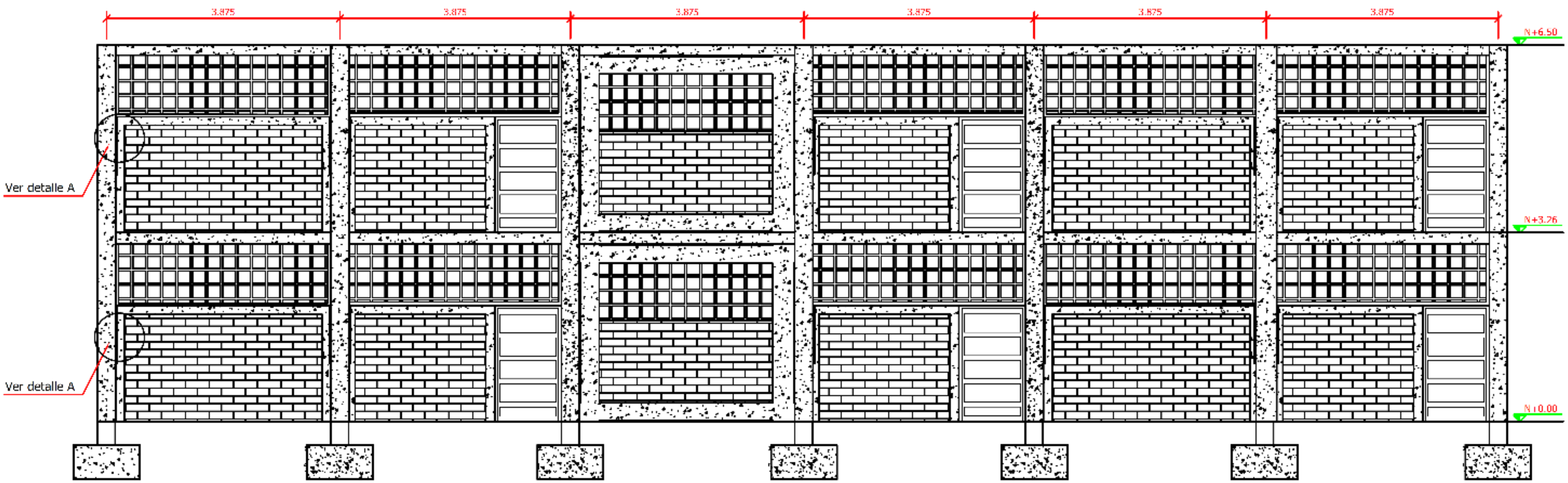


2 Confined Retrofitted Masonry Walls for each façade

PHASE ONE

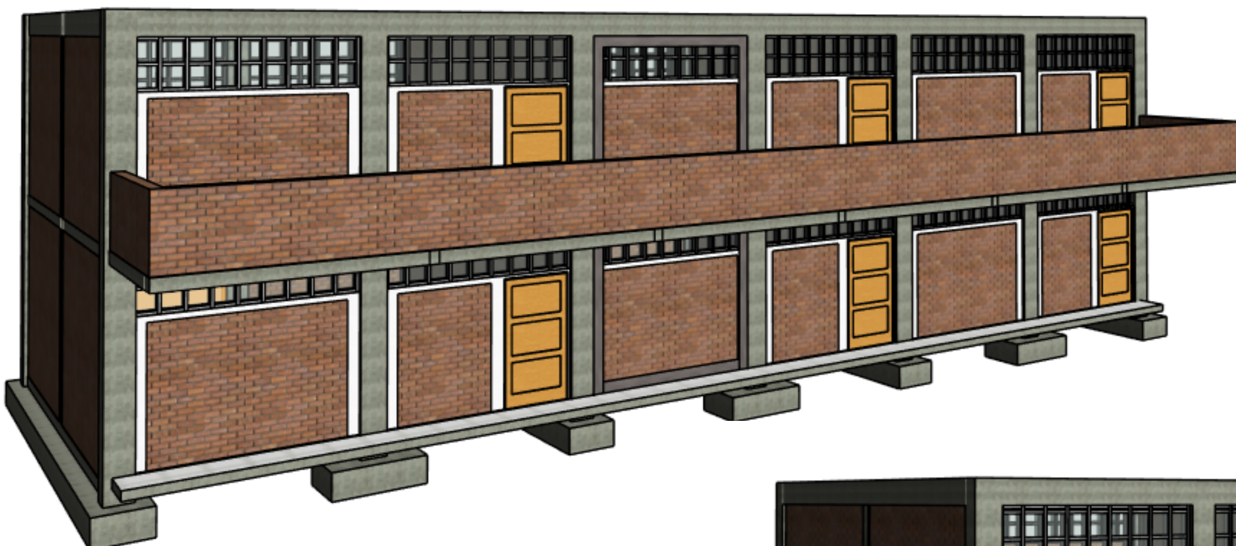
4) Additional Concrete Frames

Additional Concrete Frames: Add an internal additional concrete frame connected to the original structure in frame corners.

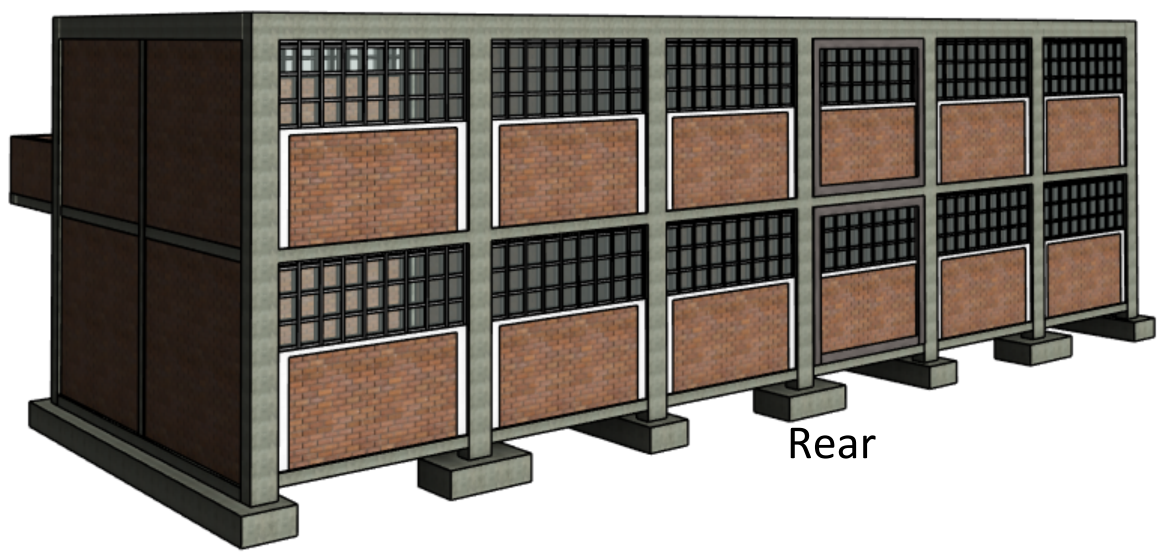


4 Additional Concrete Frames
PHASE ONE

4) Additional Concrete Frames



Front



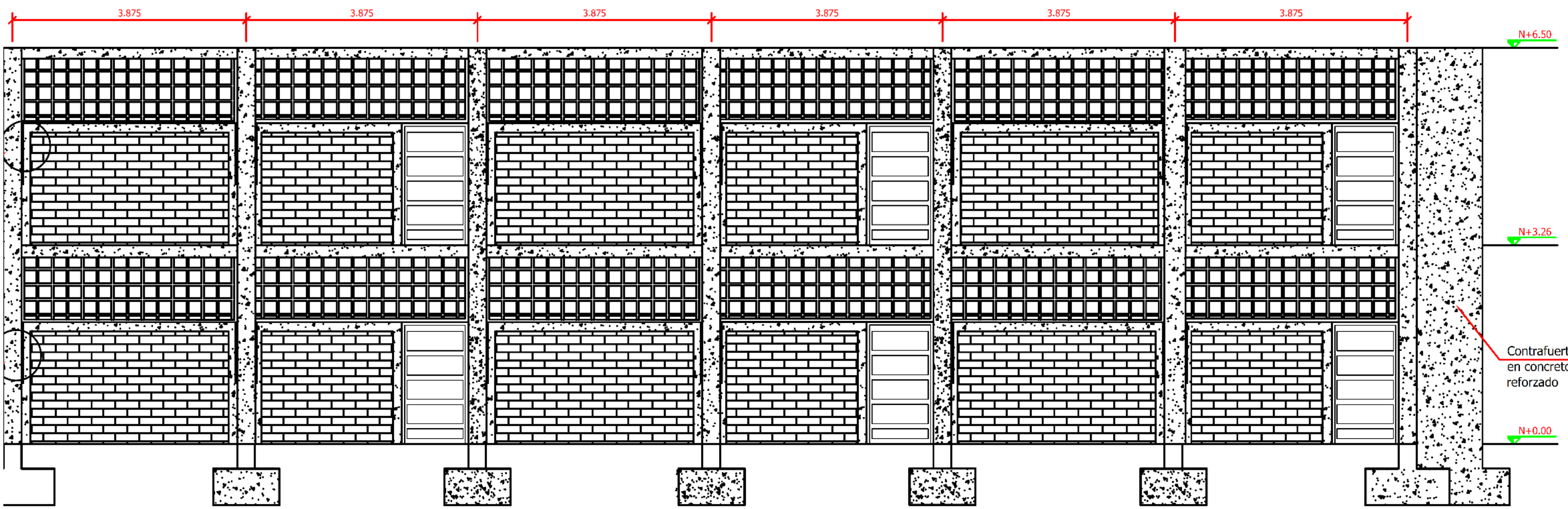
Rear

4 Additional
Concrete Frames

PHASE ONE

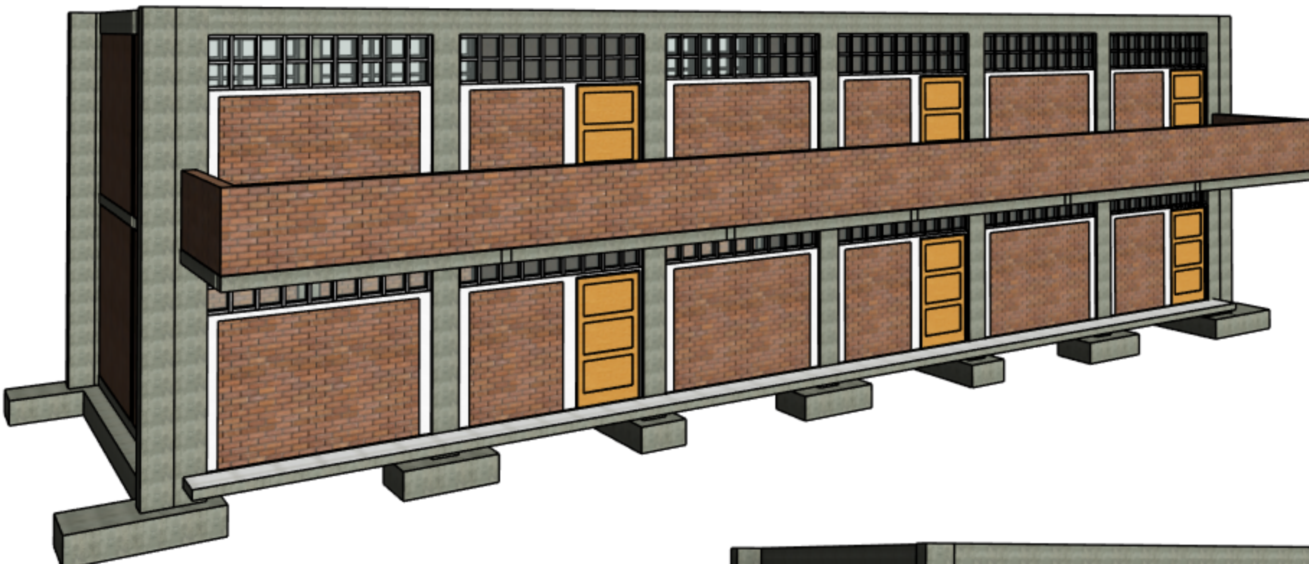
5) Buttress Walls

Additional Concrete Frames: Add an internal additional concrete frame connected to the original structure in frame corners.

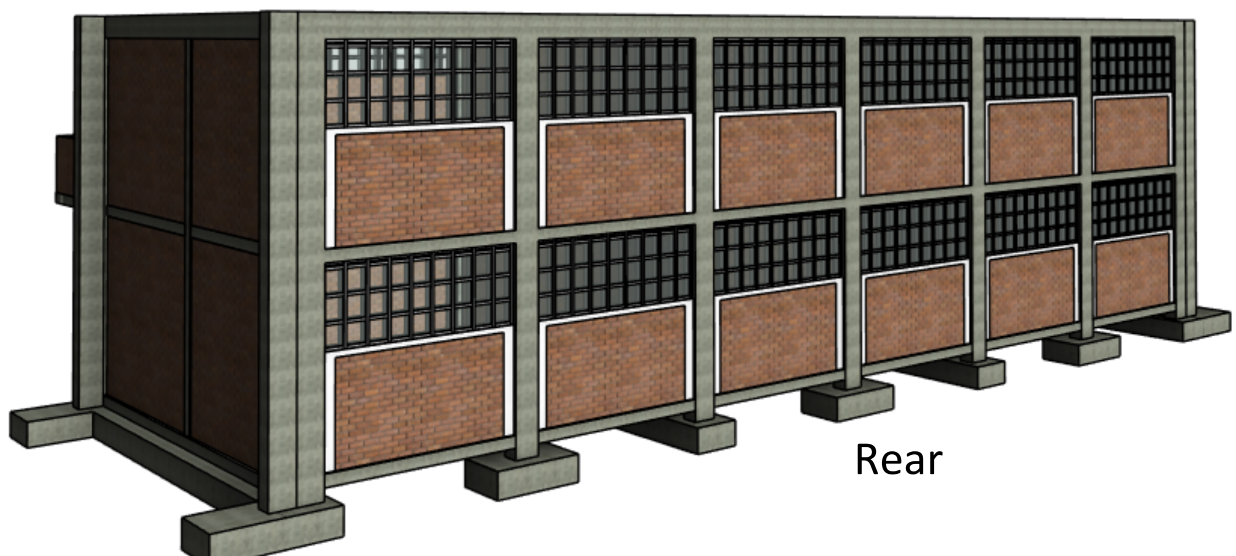


2 Additional Buttress Walls
PHASE ONE

5) Buttress Walls



Front



Rear

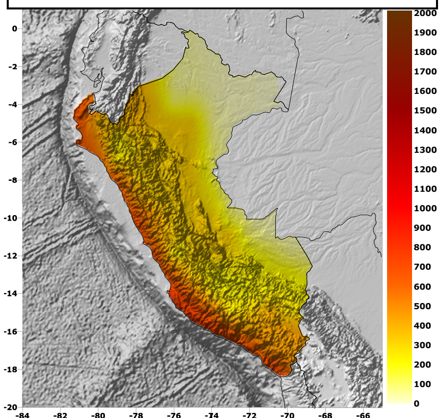
2 Additional
Buttress Walls

PHASE ONE

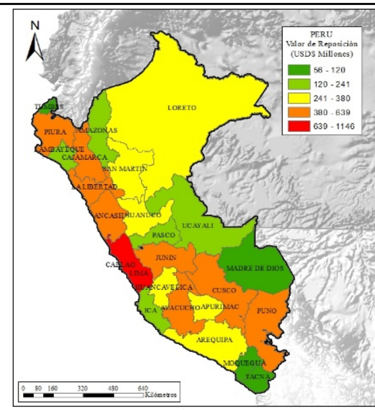
3. SELECTION CRITERIA

Probabilistic risk assessment: general methodology

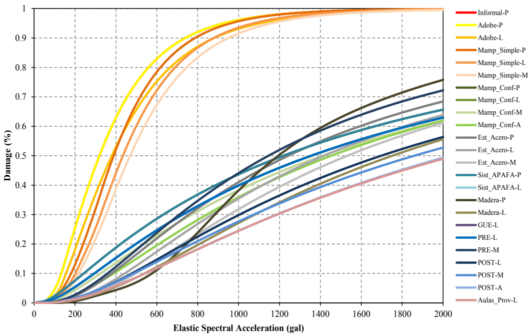
Hazard



Exposed Assets



Vulnerability



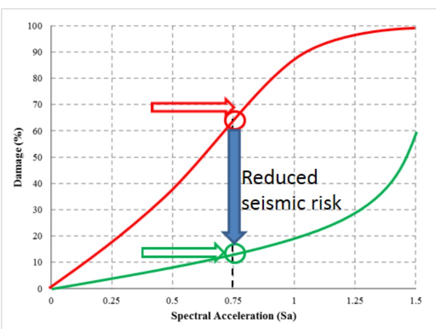
Probabilistic risk assessment

Average Annual Loss (AAL) for each building

SELECTION OF THE BEST MITIGATION OPTION

B/C = Benefit / Cost Assessment

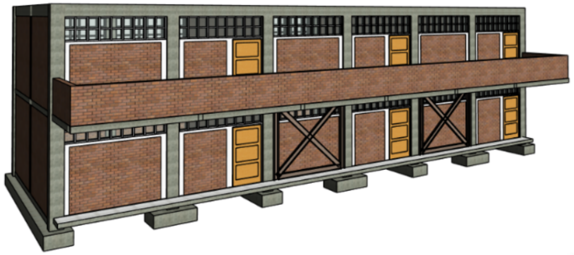
$$B/C = AAL\,\$\downarrow before\ damage - AAL\,\$\downarrow after\ intervention\ /Cost\ of\ intervention * i\downarrow discount\ rate$$



- ✓ Risk Reduction (Vulnerability Curves)
- ✓ Downtime reduction
- ✓ Indirect losses reduction
- ✓ Reduction in maintenance costs

- ✓ Nominal cost of intervention
- ✓ Bussiness interrumtion during intervention

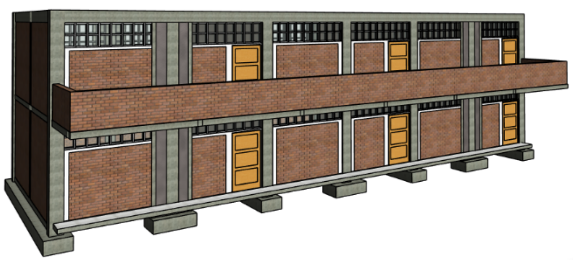
1) Steel braces



B/C = 2.5

Additional considerations:
- Very simple intervention
- Short installation time
- Better performance
- Limited functional impact

2) Confined Masonry walls



B/C = 2.0

Additional considerations:
- Intermediate seismic performance
- High availability of materials
- Standard qualified personal to implement
- Foundation intervention

3) Concrete shear walls

B/C = 1.5

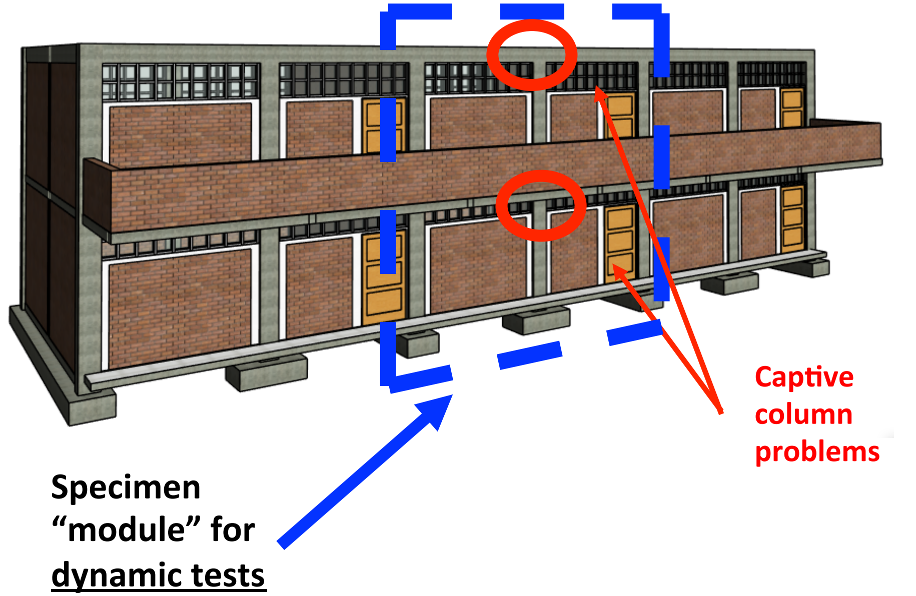
Additional considerations:
- Longer intervention time
- More complex procedures
- Significant reduction in window areas
- Foundation intervention

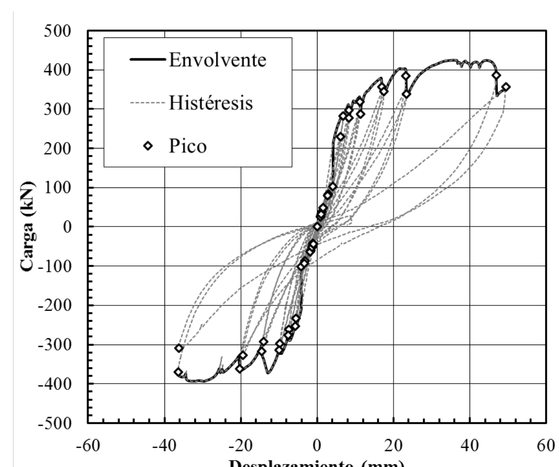
4. EXPERIMENTAL VERIFICATION

Original structure for benchmark

- Experimental tests for calibrating vulnerability
  - Experiment setup & analysis model
  - Laboratory test full scale, specimens test, etc.

Type 780 PRE (Source: PUCP, Sismid)





- Original structure behaviour

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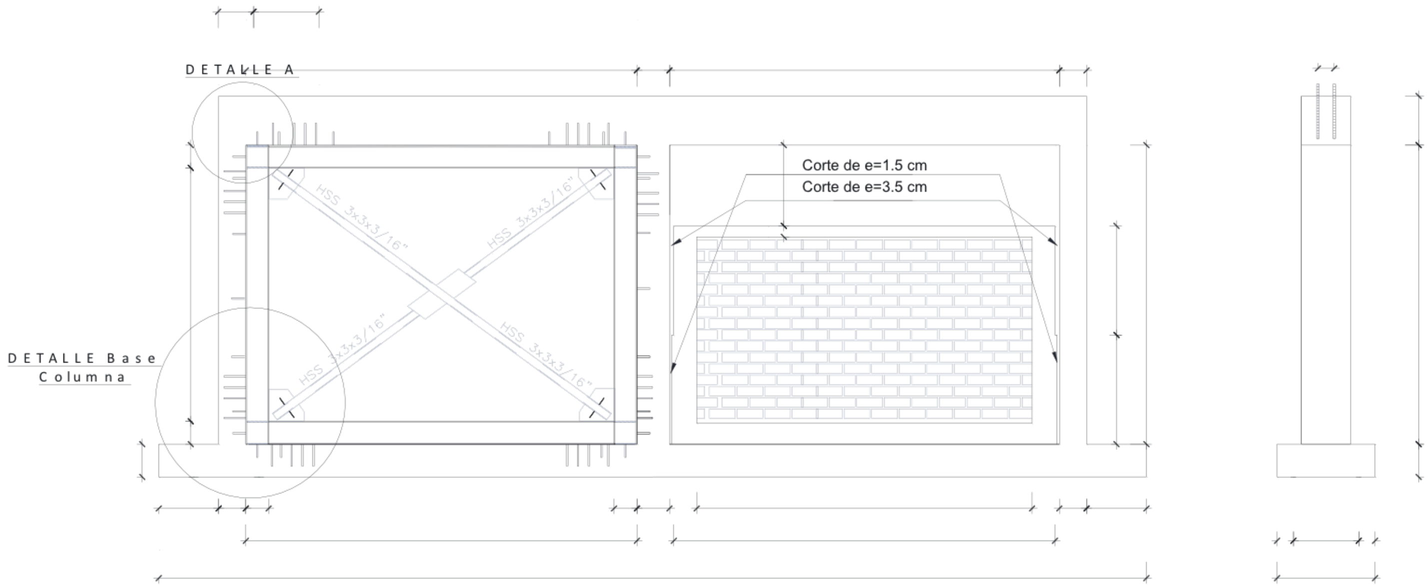
1) Steel Braces



1) Steel Braces

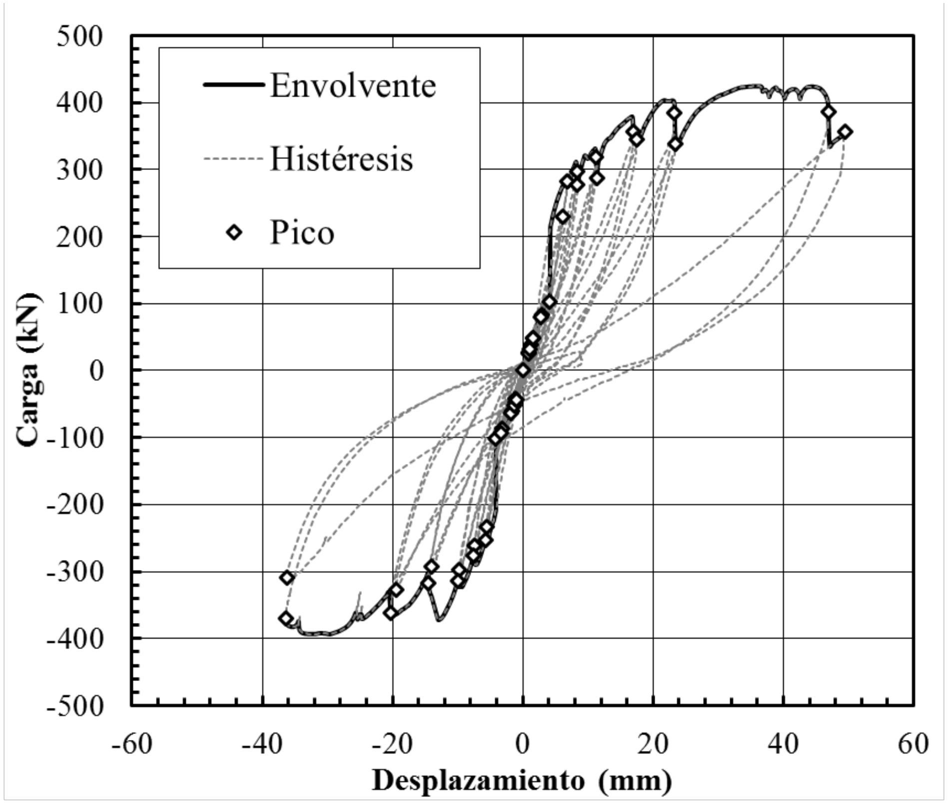
B/C = 2.5

GLOBAL EXPERIMENT VIEW
(Steel brace retrofit)

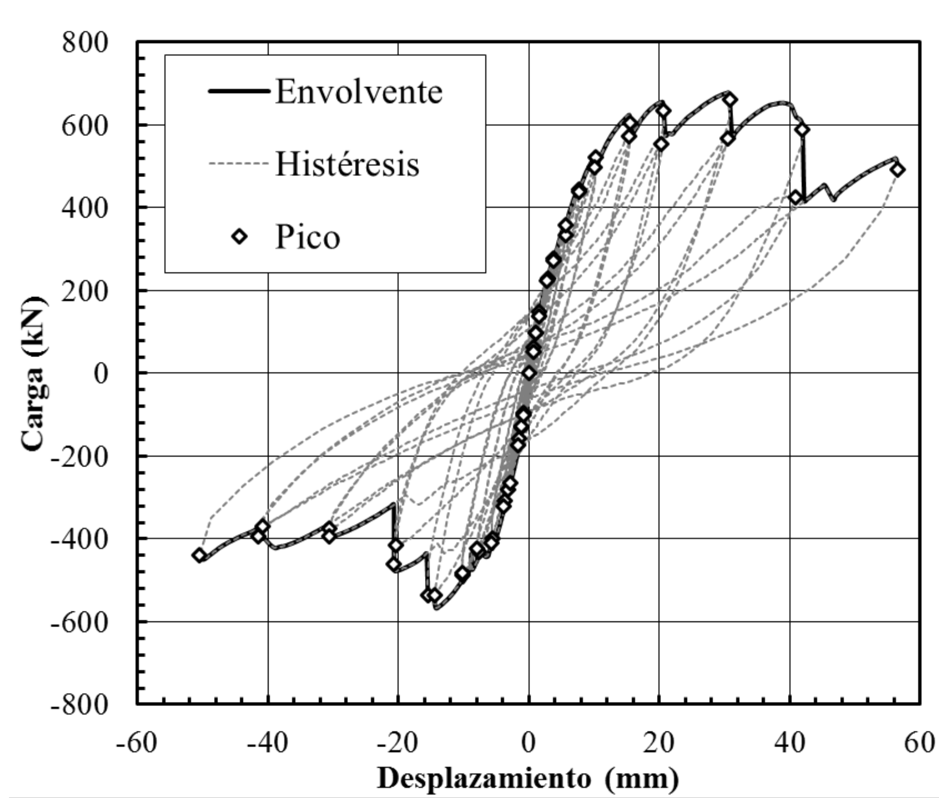
DETAILED VIEW
(Junction between Steel and concrete frames)

1) Steel Braces

BEFORE INTERVENTION

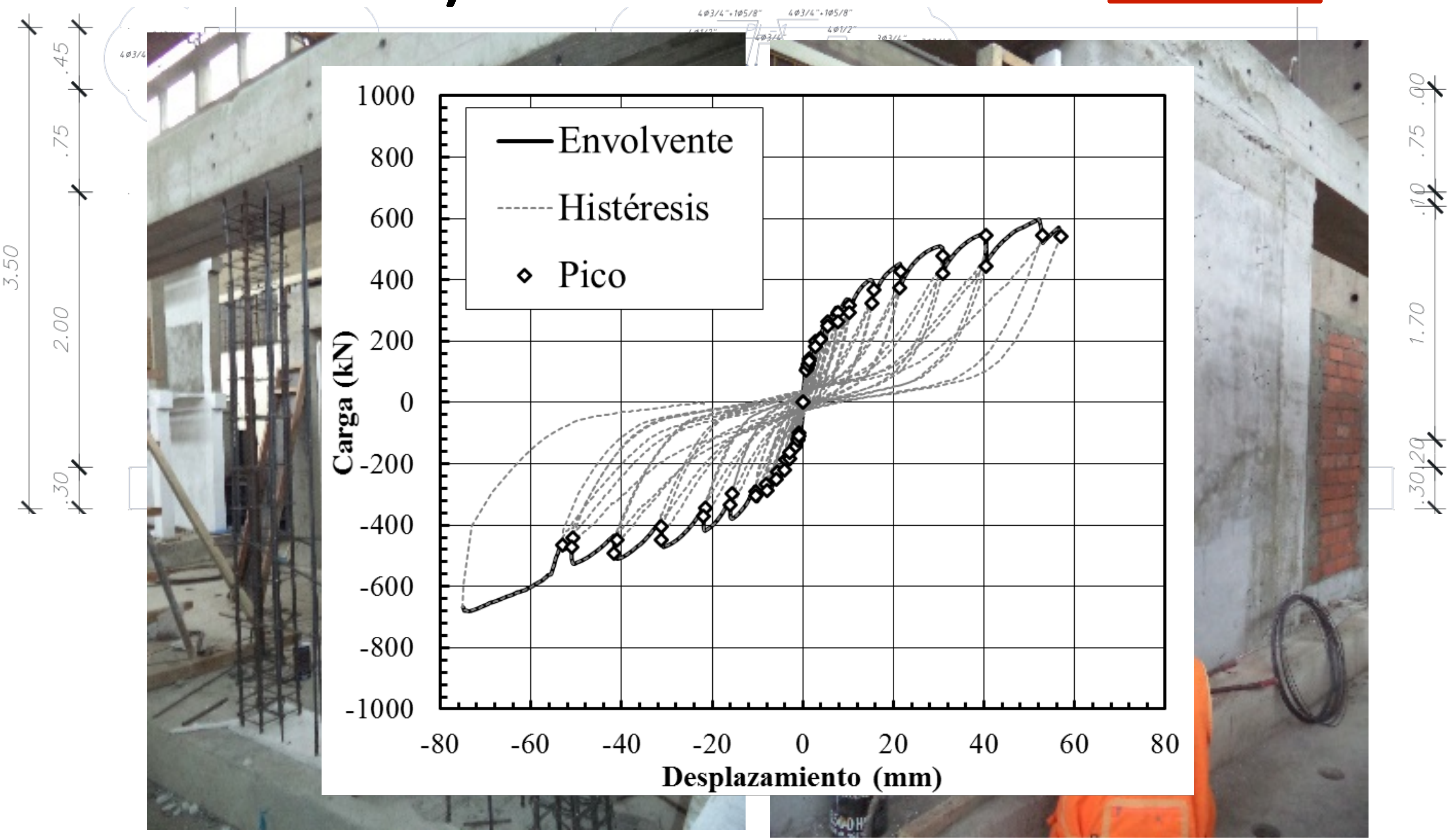


AFTER INTERVENTION



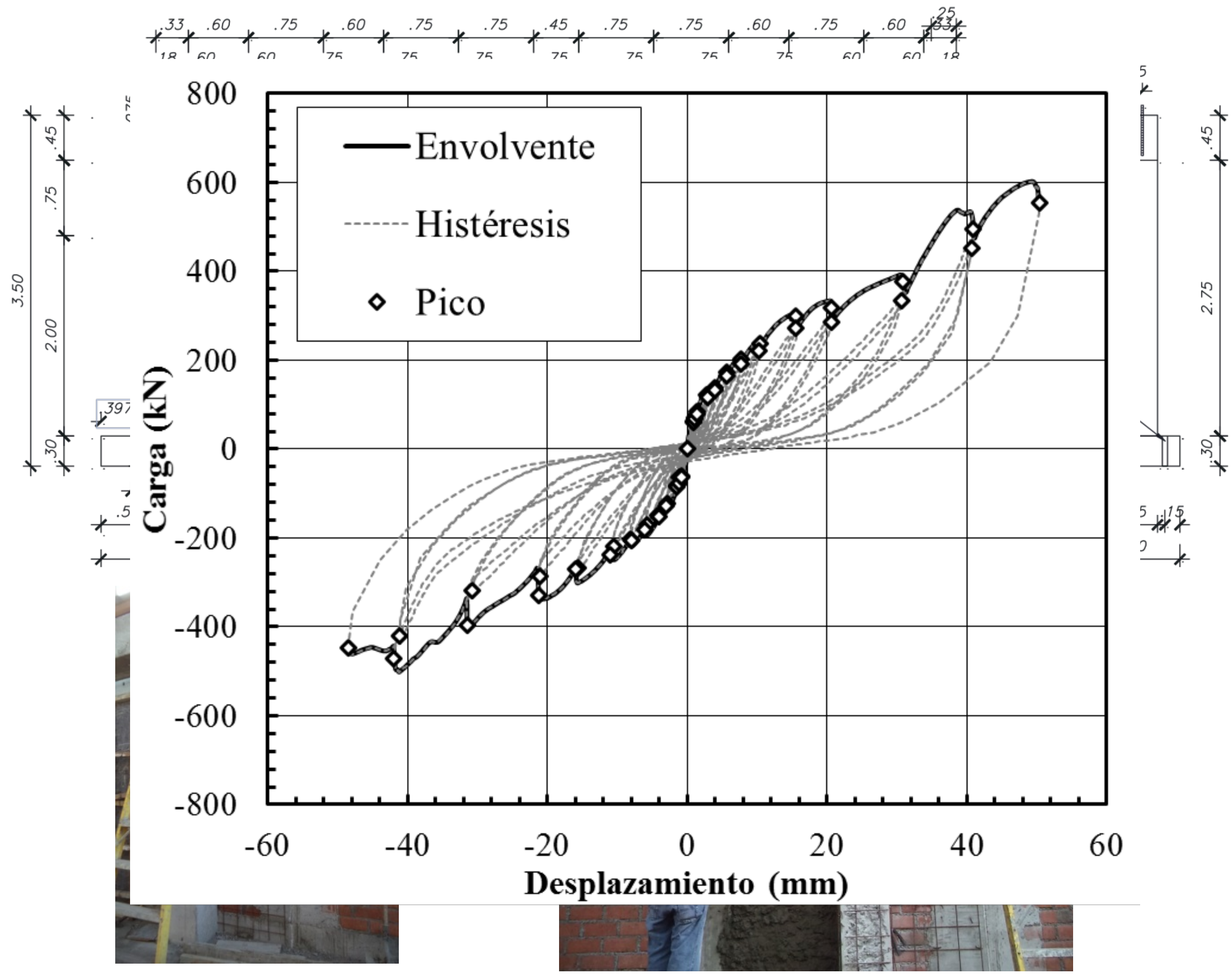
2) Concrete Shear walls

B/C = 1.5

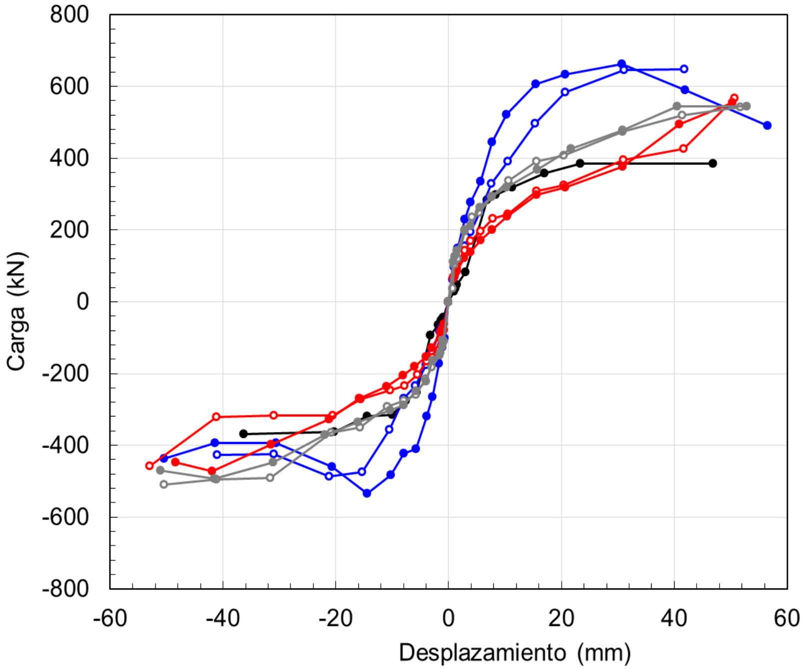


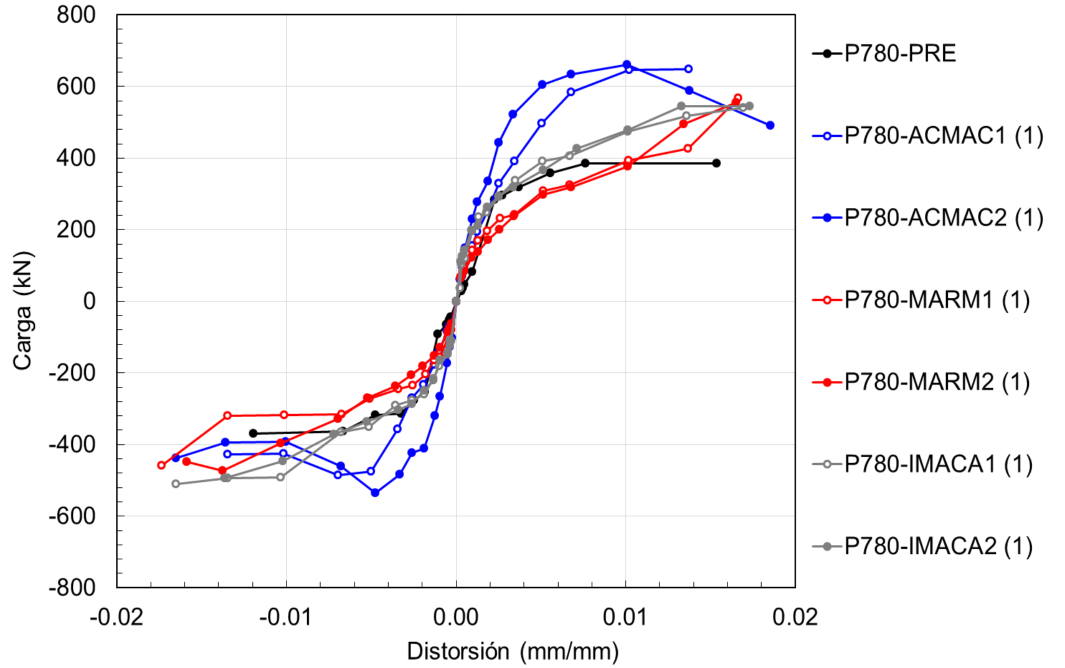
3) Confined masonry walls

B/C = 2.0



Comparison of the three retrofitting techniques and the original PRE780





5. CONCLUSIONS

1. Reliable **vulnerability assessment** is possible through computational and physical modelling
2. Vulnerability is measured by means of the **expected damage or economic loss** of each building typology for different earthquake scenarios
3. Optimal mitigation options can be selected using **disaster risk assessment** and **benefit/cost analysis**.
4. **Innovation and technology** allows the optimization in the design of retrofitting options.
5. An **optimal risk reduction option**, will reduce total intervention costs **significantly!!**


Nota Técnica

Estrategia de Reducción del Riesgo Sísmico de Edificaciones Escolares Públicas del Perú[1]

Noviembre de 2016

Proyecto dirigido por El Banco Mundial y elaborado por:

[1] Foto: "Institución educativa emblemática Alfonso Ugarte, construida en 1927, reforzada estructuralmente en 2010"


Nota Técnica

GUÍA TÉCNICA PARA EL DISEÑO DEL REFORZAMIENTO SÍSMICO INCREMENTAL DE EDIFICACIONES ESCOLARES

Diciembre de 2016

Proyecto dirigido por El Banco Mundial y elaborado por:

Thank you