SASPARM 2.0

EUCENTRE European Centre for Training and Research in Earthquake Engineering

IUSS Scuola Universitaria Superiore Pavia

Support Action for Strengthening PAlestine capabilities for seismic Risk Mitigation

SASPARM 2.0

2014 PROJECT FOR CIVIL PROTECTION FINANCIAL INSTRUMENT PREPAREDNESS AND PREVENTION SCHEME

RETROFIT MEASURES
PRACTITIONERS (advanced retrofitting measures)

Pavia – Nablus
May 25, 2016

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Advanced Rehabilitation Techniques

The measures mentioned in this part cover the current state-of-the-art. They are more complex and demanding than the ones shown before.

The tables and the chapters referenced here can be found in Deliverable D.C.1, just like before.

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Rehabilitations Techniques made with FRP

Rehabilitation Techniques made with FRP

✓ Fiber-Reinforced Polymer Composite

Fibre Type	Density (kg/m³)	Tensile strength (MPa)	Young modulus (GPa)	Ultimate tensile strain (%)	Thermal expansion coefficient (10^{-6}/°C)	Poisson's coefficient
E-glass	2500	3450	72.4	2.4	5	0.22
S-glass	2500	4580	85.5	3.3	2.9	0.22
Alkali resistant glass	2270	1800-3500	70-76	2.0-3.0	-	-
ECR	2620	3500	80.5	4.6	6	0.22
Carbon (high modulus)	1950	2500-4000	350-650	0.5	-1.2...-0.1	0.20
Carbon (high strength)	1750	3500	240	1.1	-0.6...-0.2	0.20
Aramid (Kevlar 29)	1440	2760	62	4.4	-2.0 longitudinal 59 radial	0.35
Aramid (Kevlar 49)	1440	3620	124	2.2	-2.0 longitudinal 59 radial	0.35
Aramid (Kevlar 149)	1440	3450	175	1.4	-2.0 longitudinal 59 radial	0.35
Aramid (Technora H)	1390	3000	70	4.4	-6.0 longitudinal 59 radial	0.35
Aramid (SVM)	1430	3800-4200	130	3.5	-	-
Basalt (Albarrie)	2800	4840	89	3.1	8	-

Property	*Matrix*		
	Polyester	Epoxy	Vinyl ester
Density (kg/m³)	1200 - 1400	1200 - 1400	1150 - 1350
Tensile strength (MPa)	34.5 - 104	55 - 130	73 – 81
Longitudinal modulus (GPa)	2.1 – 3.45	2.75 – 4.10	3.0 – 3.5
Poisson's coefficient	0.35 – 0.39	0.38 – 0.40	0.36 – 0.39
Thermal expansion coefficient (10^{-6}/°C)	55 - 100	45 - 65	50 - 75
Moisture content (%)	0.15 – 0.60	0.08 – 0.15	0.14 – 0.30

- FRP for structural strengthening are available as precured strips or uncured sheets;
- Sheets: improving shear capacity and confinement (fibers parallel to shear forces);
- Strips: strengthening flexural capacity (fibers parallel to longitudinal axis of element).

Uddin, N. (Ed.). (2013). *Developments in fiber-reinforced polymer (FRP) composites for civil engineering*. Elsevier.

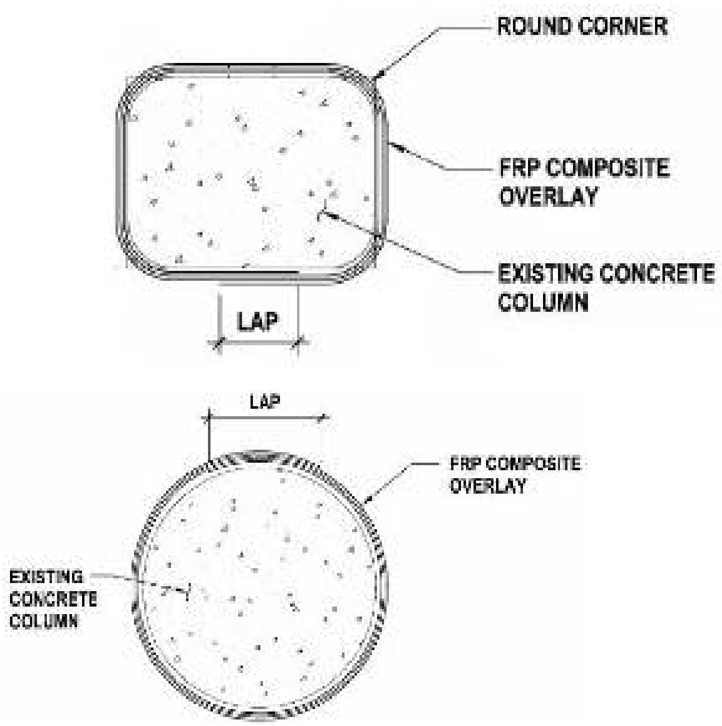
Rehabilitation Techniques made with FRP

✓ Fiber-Reinforced Polymer Composite

Advantages	Disadvantages
Higher ratio of strength to self weight (10 to 15 times greater than steel)	Higher raw material cost
Carbon and aramid fibre reinforcement have excellent fatigue characteristics	Lower elastic modules (except some Carbon FRPs)
Excellent corrosion resistance and electromagnetic neutrality	Glass FRP reinforcement suffers from stress corrosion
Low axial coefficient of thermal expansion	Lack of ductility
Fast-track application	Low fire resistance
Insignificant increase of member-dimensions	Highly trained workforce

Rehabilitation Techniques made with FRP

✓ 9.4 - FRP for columns



FEMA 547, 2006.

- Overlay with unidirectional fibers in a horizontal orientation provides shear strengthening and confinement;
- Confinement enhances the concrete compression characteristics;
- Confinement provides a clamping action to improve lap splice connections
- Confinement provides lateral support for column longitudinal bars.

Rehabilitation Techniques made with FRP

✓ 9.4 - FRP for columns

www.MAC-MBT.com (MAC spa - Modern Advanced Concrete)

Rehabilitation Techniques made with FRP

1) fibers

2) Epoxy resin

Courtesy of Prof. G. Manfredi, Dr G. Verderame
(University Federico II, Naples)

Rehabilitation Techniques made with FRP

Video ▶

www.frpcolumn.com

Rehabilitation Techniques made with FRP

Video ▸

STATIS LLC, Greece

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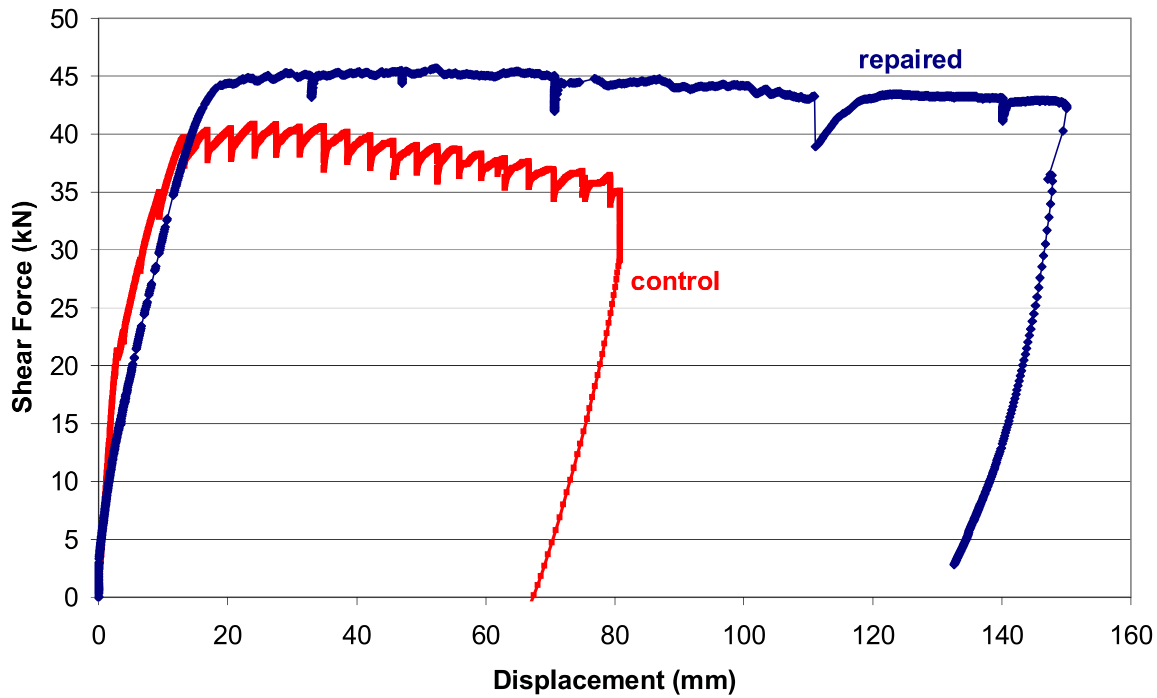
Rehabilitation Techniques made with FRP



Courtesy of Prof. G. Manfredi, Dr G. Verderame
(University Federico II, Naples)

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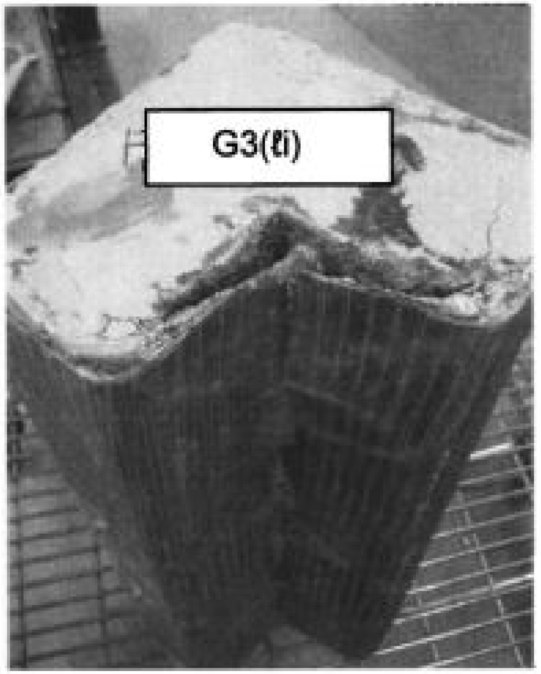
Rehabilitation Techniques made with FRP

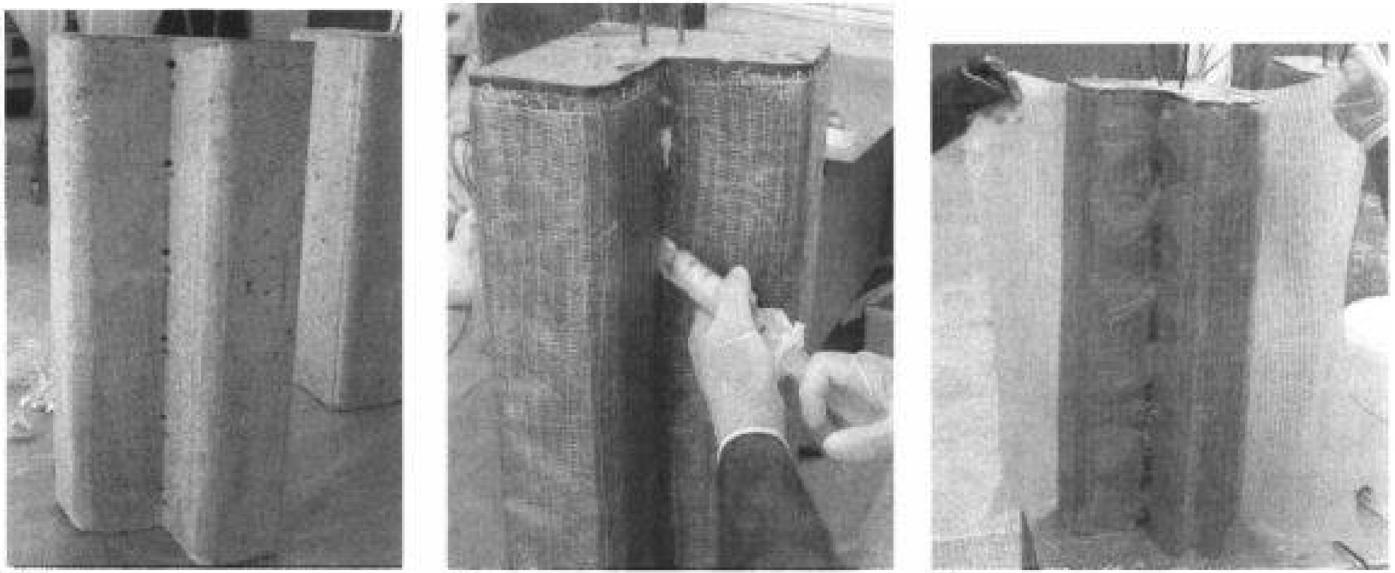
Anchorage issues in L shaped columns or walls



M. Karantzikis, C. Papanicolaou, C. Antonopoulos, T. Triantafillou, *Experimental Investigation of Nonconventional Confinement for Concrete Using FRP*, Journal of Composites for Construction, 9(6), 480-487, 2005.

Rehabilitation Techniques made with FRP

Solution: use FRP «tuft» anchors along the corner



(a) (b) (c)

Fig. 2. Photographs of L-shaped specimens tested: (a) six pairs of holes at anchorage locations; (b) filling of holes with resin; and (c) anchors in position and wrapping of last glass fiber reinforced polymer layer

M. Karantzikis, C. Papanicolaou, C. Antonopoulos, T. Triantafillou, *Experimental Investigation of Nonconventional Confinement for Concrete Using FRP*, Journal of Composites for Construction, 9(6), 480-487, 2005.

Rehabilitation Techniques made with FRP

Use of FRP «tuft» anchors also ensures fibers can reach larger strain and strength values.



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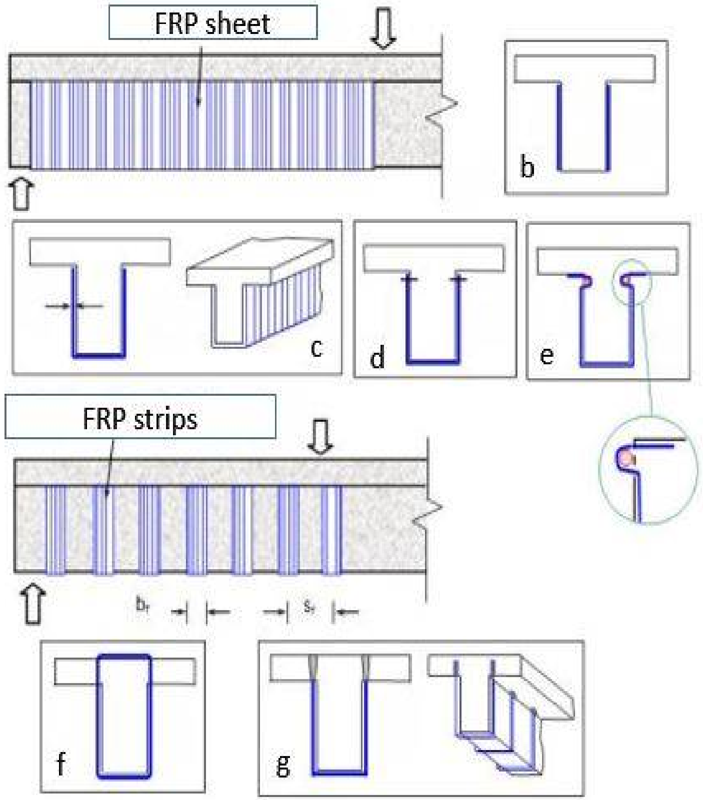
Rehabilitation Techniques made with FRP

✓ 9.4 - FRP for beams



- Sheets and laminates of FRP applied on the faces of beams to increase shear resistance;
- Jackets **fully anchored** to make composite material reaching much larger values of strain without bondage early failure.

T.C. Triantafillou, *Shear strengthening of RC beams using epoxy-bonded FRP composites*, ACI Structural Journal, 95(2), 107-115, 1998.

Rehabilitation Techniques made with FRP

✓ 9.4 - FRP for beams

- Strips applied along the longitudinal direction of beams improve flexural capacity;
- **Proper anchorage is key.**

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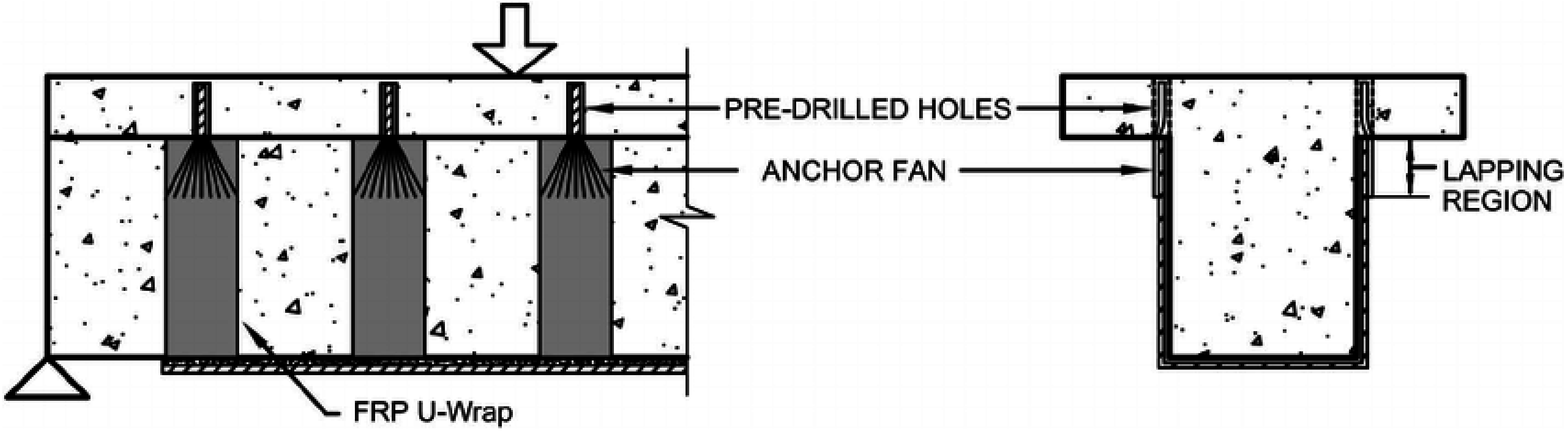
Rehabilitation Techniques made with FRP

✓ 9.4 - FRP for beams

Use of “tuft” FRP anchors eliminates chances of early de-bonding ensuring that the maximum strain of fibers can be reached.

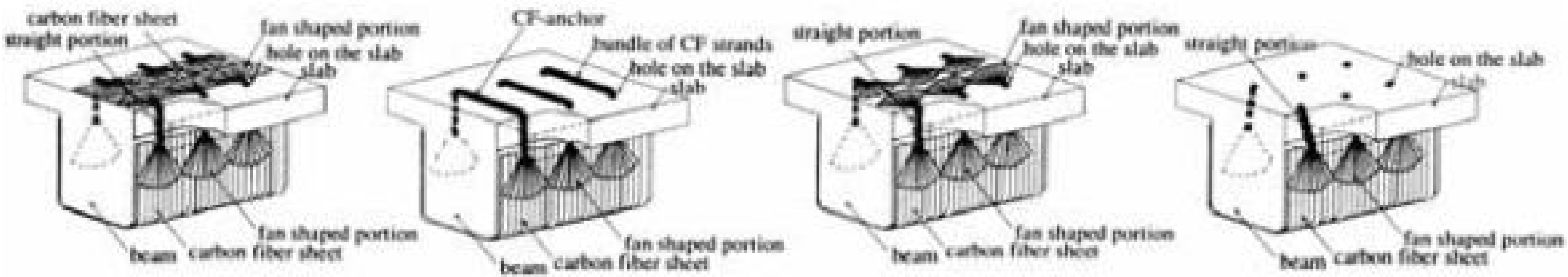


Kalfat, R., Al-Mahaidi, R., & Smith, S. T. (2011). *Anchorage devices used to improve the performance of reinforced concrete beams retrofitted with FRP composites: State-of-the-art review.* Journal of Composites for Construction, 17(1), 14-33.

Rehabilitation Techniques made with FRP

✓ 9.4 - FRP for beams

Different ways of connecting the anchors:



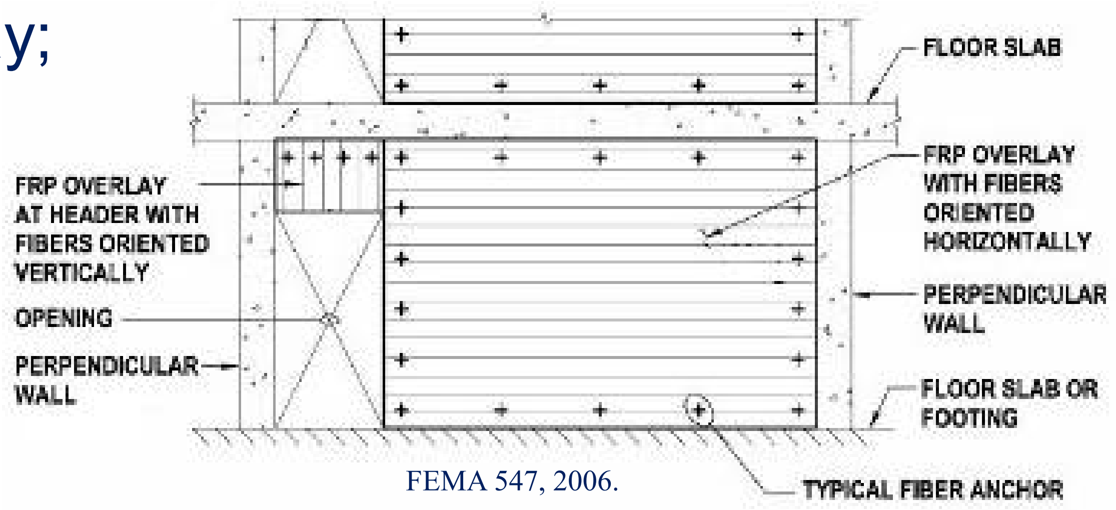
Y. Jinno, H. Tsukagoshi, Y. Yabe, *RC Beams with Slabs Strengthened by CF Sheets and Bundles of CF Strands, Proceedings of FRPRCS-5*, London, United Kingdom, 2001.

- First two methods are the optimal ones;
- Last one to the right is the least effective.

Rehabilitation Techniques made with FRP

✓ 9.4 - FRP for shear walls

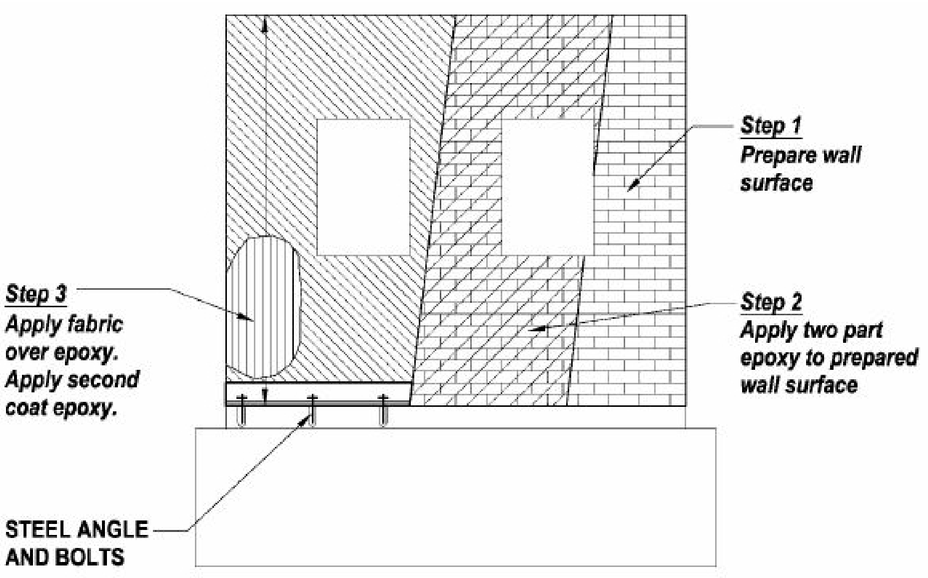
- Enhancing in-plane shear capacity of the shear wall;
- Overlay applied to one or both sides of a wall and should be wrapped around the ends of the wall to aid in anchoring the overlay;
- Horizontal-oriented fibers: enhance shear capacity, creating a flexural post-yield response;
- Vertically-oriented fibers in bidirectional layouts: limit vertical strains, inhibiting the ductile behavior.



FEMA 547, 2006.

Rehabilitation Techniques made in FRP

✓ 9.10 - FRP for URM wall



- Increase shear strength of the wall;
- After application, FRP must be protected against ultraviolet rays;
- Vertical strips: improve out-of-plane resistance;
- Diagonal strips: resist diagonal tension stresses from in-plane shear.

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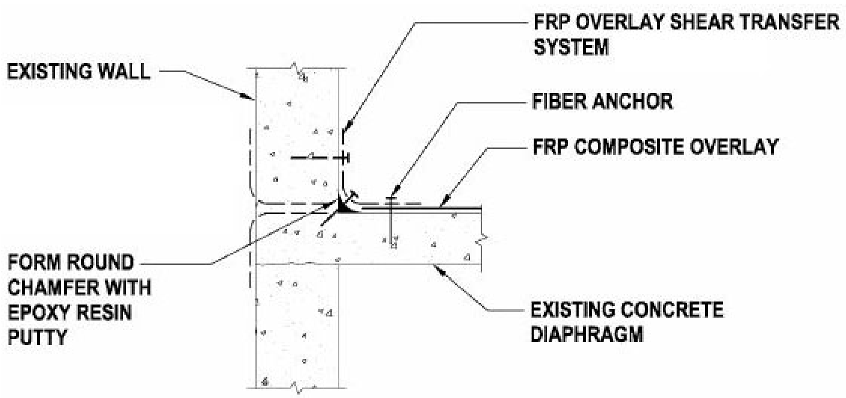
Rehabilitation Techniques made in FRP

✓ 9.16 - FRP for concrete diaphragms

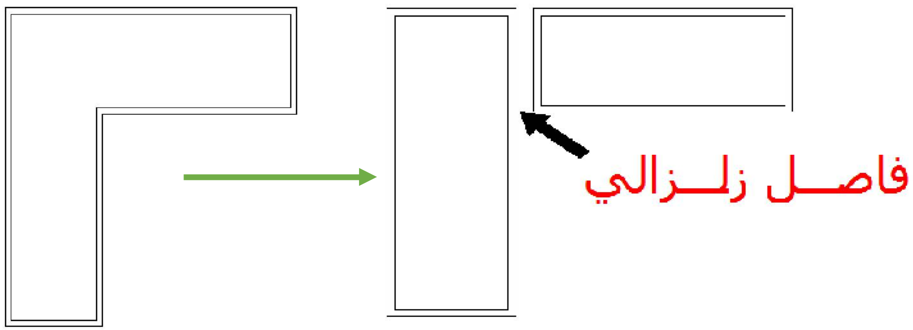


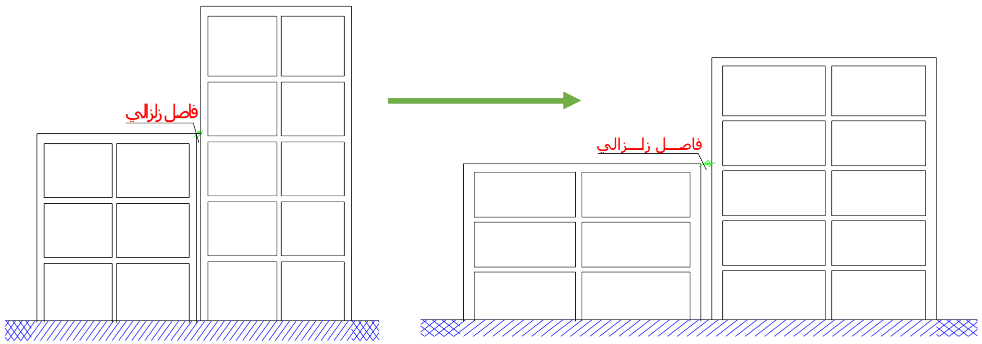
FEMA 547, 2006.

- Increase in-plane shear strength;
- Fibers oriented parallel to the applied shear direction;
- Bi-directional fibers orientated at 45° to the shear plane for strengthening joint.

Advanced Rehabilitation Techniques

✓ 9.10 – Seismic Joint





- Transformation of a single irregular building into multiple regular structures;
- Independent movement during dynamic response;
- Locations where differential movement is likely or where different materials come together;
- In reentrant corner of L, U or T-shaped building;
- Maximum drift of the two units must be calculated.

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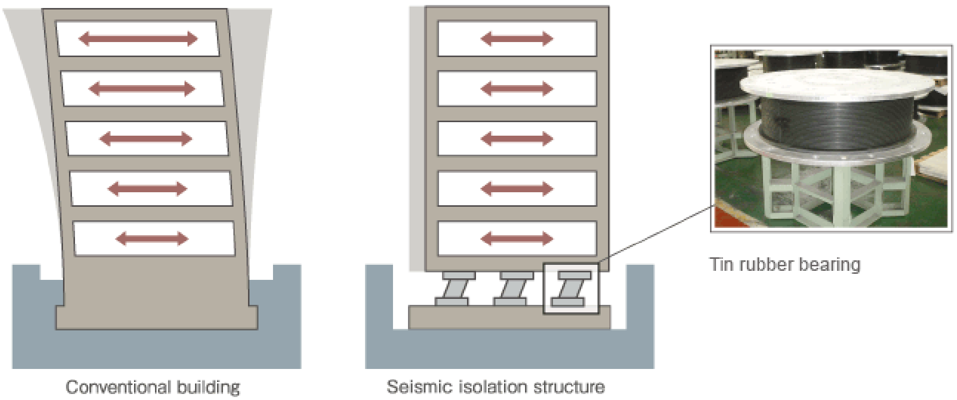
Advanced Rehabilitation Techniques

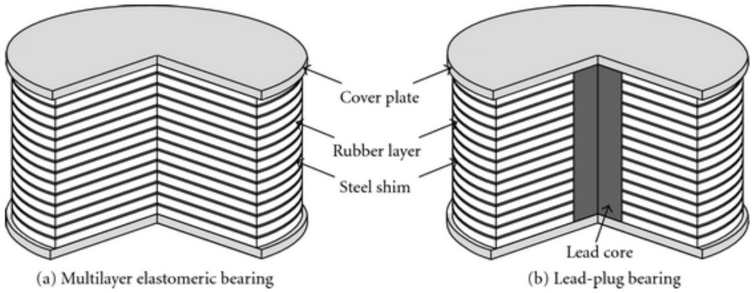
✓ Seismic Isolation

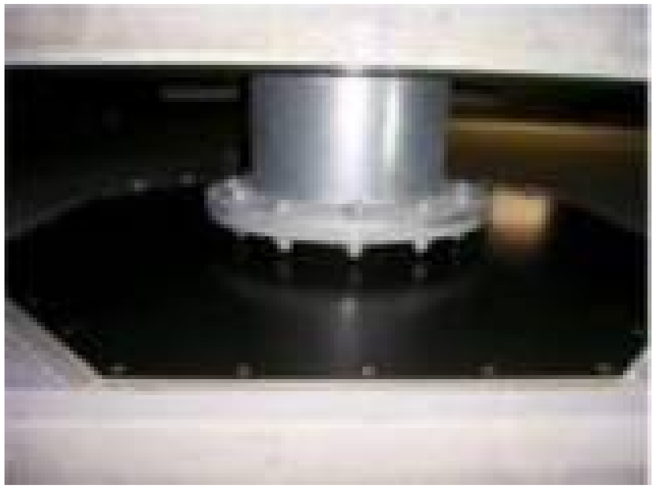


- Flexible approach for isolating the structure from the ground, reducing seismic shock propagation into the structure;
- Lengthening building's fundamental period of vibration to reduce the seismic demand;
- Minimizing also secondary damage to equipment;
- Buildings on very soft soils, very tall and flexible may not achieve much benefit from isolation.

Advanced Rehabilitation Techniques

✓ Seismic Isolation

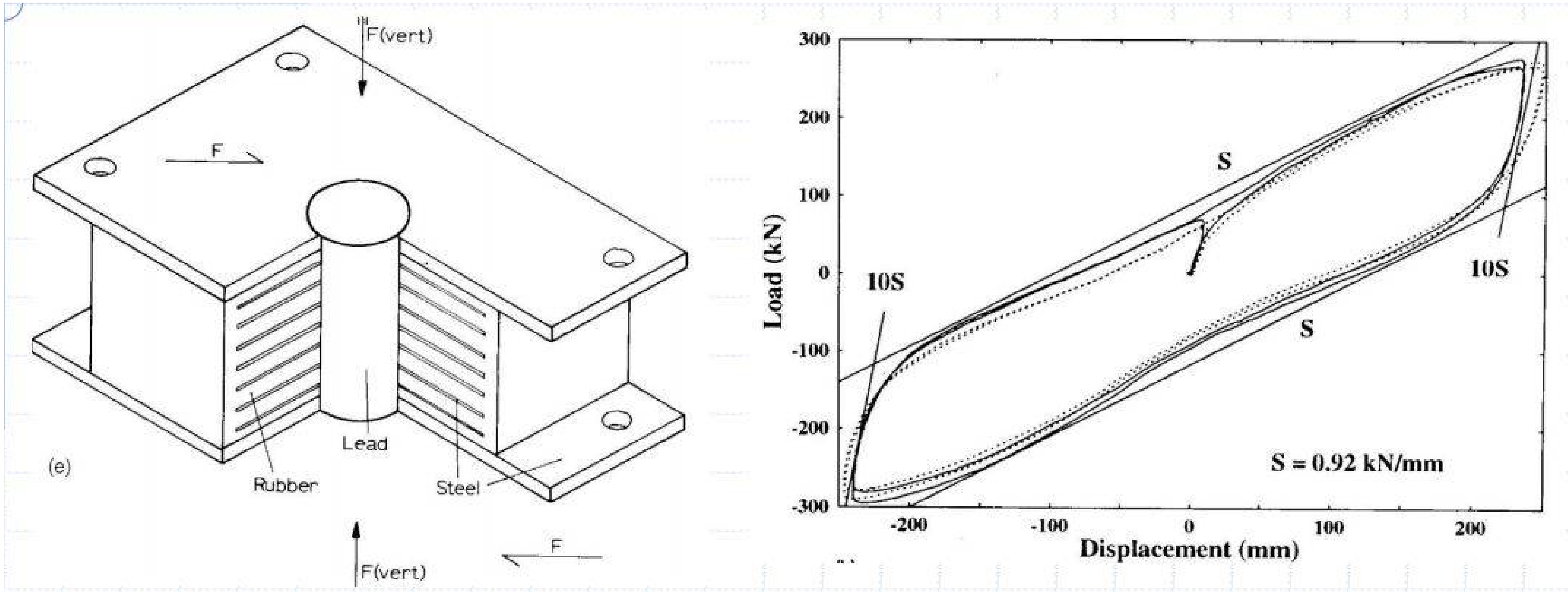




- Elastomeric isolator: sandwiches of soft rubber sheets and hard steel;
- Soft rubber reduces the building vibration to slow shaking and hard steel plate contributes to sustain the weight of building;
- Slider: PTFE (Polytetrafluoroethylene) and a stainless steel plate finished with smooth surface as a mirror;
- Sustainment of the building and movement it laterally with a certain amount of friction.

Advanced Rehabilitation Techniques

✓ Seismic Isolation

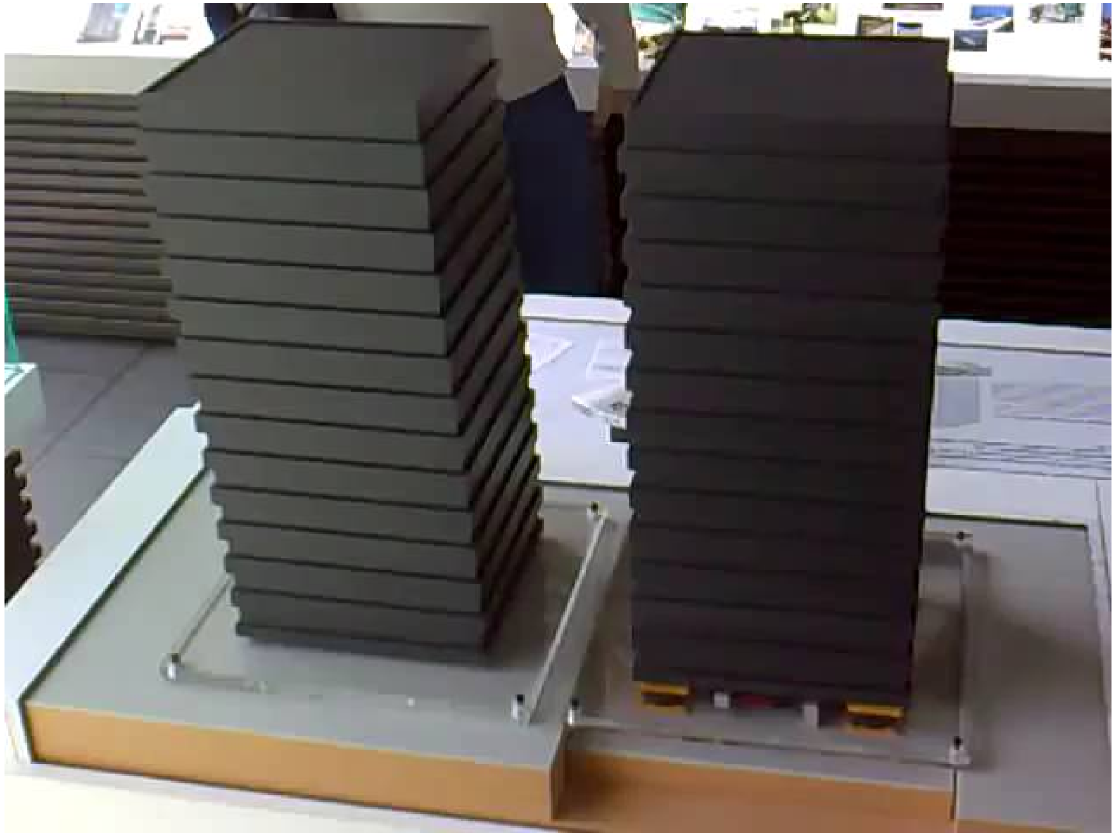


Lead-Rubber bearing devices have become the most popular base isolation devices. They require minimal maintenance, are very reliable and are covered by several design strategies.

Advanced Rehabilitation Techniques

✓ Seismic Isolation

Video ▸

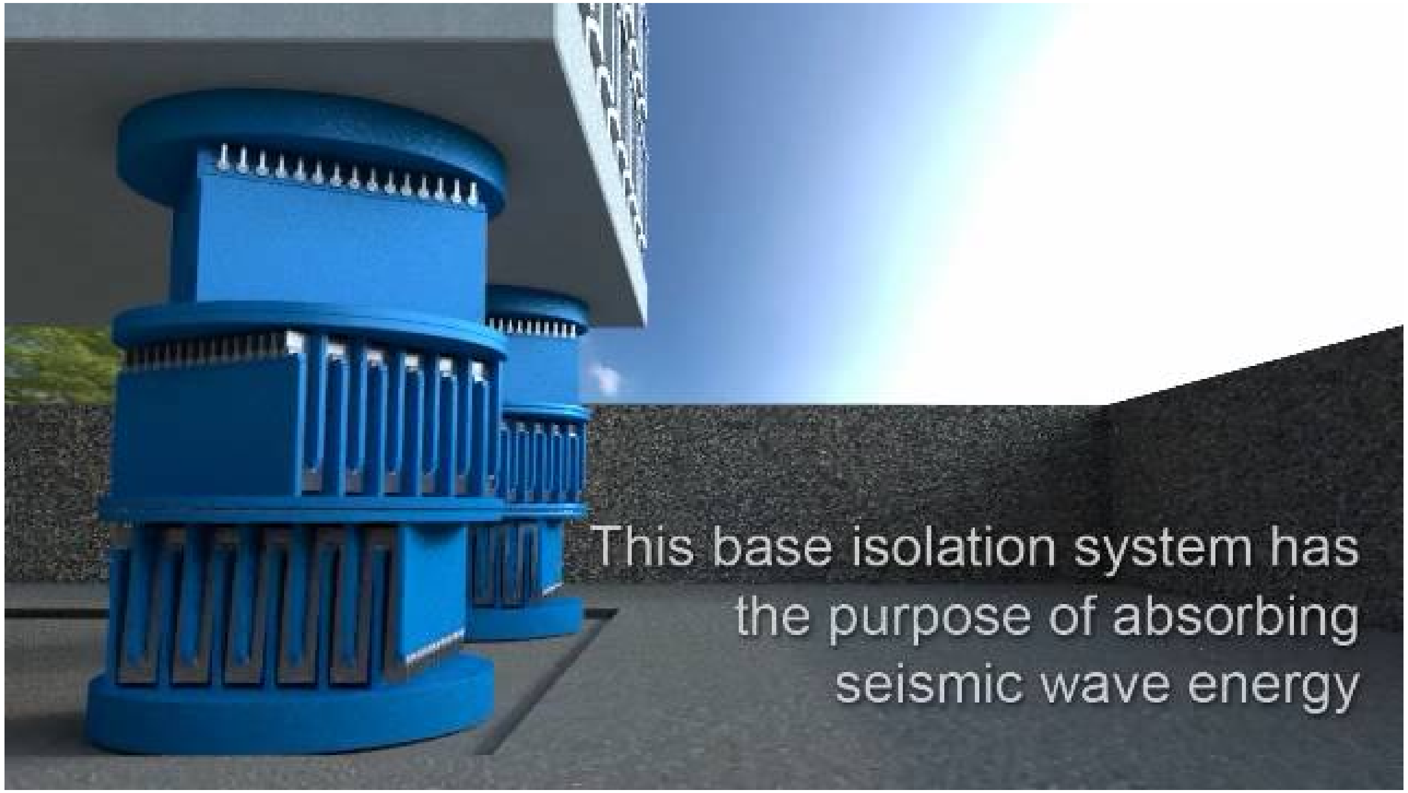


https://www.youtube.com/watch?v=Fw7aQwMmBNM

Advanced Rehabilitation Techniques

✓ Seismic Isolation

Video ▸



www.straddlingpendulum.com

Advanced Rehabilitation Techniques

✓ Energy Dissipation

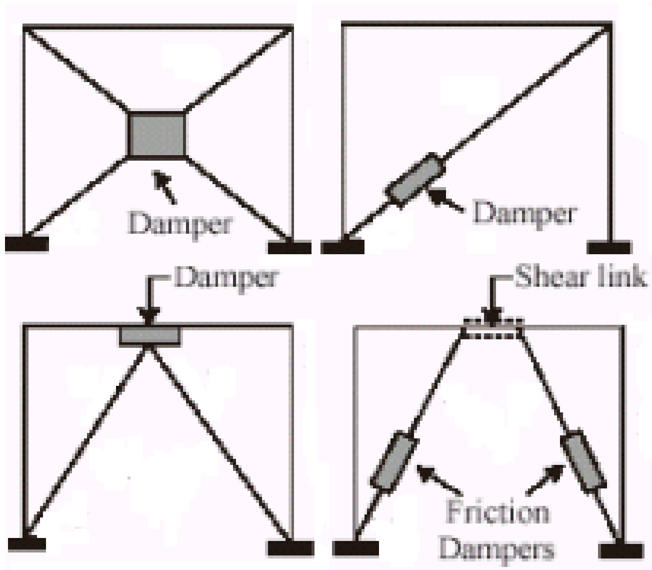
- Dissipation of much of the earthquake-induced energy in disposable elements;
- Limit damaging deformations in structural components;
- 3 categories of damping: hysteric, velocity-dependent and others;
- Adding damping is most relevant in flexible buildings, such as steel or concrete moment frames;
- Damping needs to accommodate very large displacements.

Advanced Rehabilitation Techniques

✓ Energy Dissipation

Courtesy of Prof. G. Manfredi, Dr G. Verderame (University Federico II, Naples)

- Displacement – dependent devices: rigid-plastic (friction devices), bilinear (metallic yielding devices) or trilinear hysteresis.



Advanced Rehabilitation Techniques

✓ Energy Dissipation

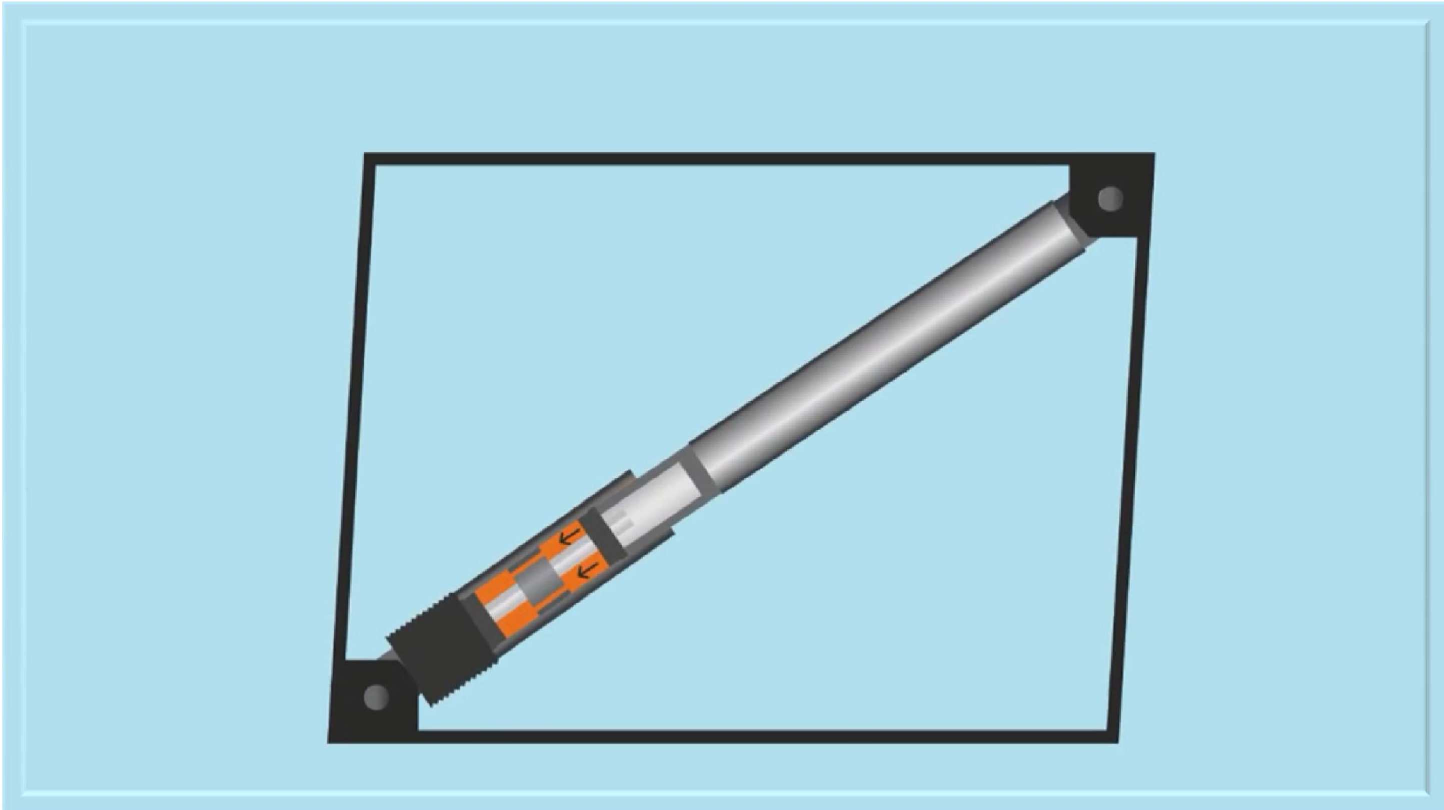
- Velocity – dependent: solid and fluid viscoelastic devices and fluid viscous devices.

Courtesy of Dr M. Forni (ENEA)

Advanced Rehabilitation Techniques

✓ Energy Dissipation

Video ▸



Miyamoto International

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Implementation in Palestine

✓ Evaluation of applicability of proposed techniques.

Retrofitting schemes	Availability of the Material	Familiarity	Low Demand for Specific Training	Simplicity of Structural Analysis
RC	✓ ✓ ✓	✓ ✓ ✓	✓ ✓	✓ ✓
Steel	✓ ✓	✓ ✓	✓	✓ ✓
Masonry	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓	✓ ✓
FRP	✓	✓	✓	✓ ✓
Seismic Joint	✓ ✓ ✓	✓	✓ ✓	✓ ✓
Seismic Isolation	✓	✓	✓	✓
Supplemental Damping	✓	✓	✓	✓

Do you agree with these estimates? Your feedback is always welcome

Thank you for your attention!

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