World Housing Encyclopedia
an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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HOUSING REPORT
Rubble-stone masonry house

Report #	58
Report Date	05-06-2002
Country	SLOVENIA
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
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Summary

Rubble-stone masonry houses are still found throughout Slovenia. This housing type with its special history represents a typical, older residential building in the northwestern part of Slovenia. After their destruction during World War I, these houses were rebuilt, mostly with the recycled stone material from demolished buildings. Many houses of this type were subsequently damaged during the last two earthquakes in Slovenia (1976 Friuli and 1998

Bovec). In order to preserve the country's architectural heritage, about 66% of these houses were strengthened following these earthquakes.

1. General Information

Buildings of this construction type can be found in the area of Upper Posocje. The residential housing stock built before the World War II in that area is generally of this type. It represents 24 % of dwelling stock in that area. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for less than 75 years.

Currently, this type of construction is not being built. This type of construction was practiced between the World War I and the World War II.


Figure 1A: Typical Building


Figure 1B: Typical mountain village - Drezniske Ravne, Slovenia

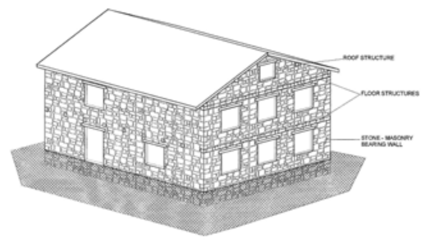

Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.

2.2 Building Configuration

Typical shape of building plan is usually rectangular. Average area of a window opening in front exterior wall is 1.2 m^2 in the rural area and 1.7 m^2 in the urban area. The door opening area in exterior and interior bearing walls is approximately 2.0 m^2. Maximum opening area is approximately equal to 16% of the front exterior wall area. The back exterior walls are usually not perforated with openings at all or in some cases there are smaller window openings (approx. area 0.5 m^2).

2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. The additional back entrance door is rare, usually there is no additional door besides the main entry. There is no additional exit staircase besides the main staircase. The only means of escape from the building is through the main staircase and the main entry and/or in some cases through the additional back door.

2.4 Modification to Building

After the 1976 Friuli earthquake certain modifications on the buildings of this type were carried out, mainly combined with the repair and strengthening. Some examples are: construction of new R.C.. slabs above the basement and ground floor, addition of balconies and exterior staircases, and new bathrooms. The replacement of existing interior stone masonry walls with brick masonry walls or reinforced concrete columns are rare. The extensions are usually built close to original buildings, however the old and the new parts have not been adequately connected together in the structural sense.

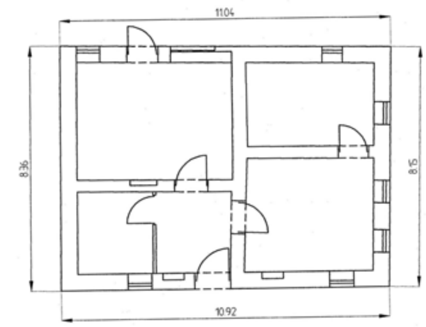

Figure 3: Plan of a Typical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☑
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
			Dual system – Frame with	

Structural concrete		21	shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). The gravity-load bearing structure consists of roof, floor structures and structural walls. Original or new roof structures are made out of timber and roofs are covered with ceramic tiles. In many cases original wooden floor structures have been replaced with reinforced concrete slabs.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). The lateral load-resisting system consists of exterior and interior stone walls. The walls are generally uniformly distributed in both orthogonal directions, and the building plan is generally regular. In general, with a few exceptions, the walls are not connected by means of wooden or iron ties. The thickness of walls varies from 40 to 70 cm, with spacing ranging from 3.0 m to 6.0 m. The walls are supported by foundation walls (strip foundations) made out of rubble masonry or there are no footings at all. Lateral load transfer to bearing walls is accomplished through roof and floor structures. The weakest links in this structural type are usually: weak inner infill between exterior wythes of masonry, vertical joints between walls, and connections between roof

/floors and walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 13 and 13 meters, and widths between 10 and 10 meters. The building has 2 to 3 storey(s). The typical span of the roofing/flooring system is 6 meters. Typical Plan Dimensions: Length ranges from 9 m to 13 m, width ranges from 6 m to 10 m. Typical Story Height: Story height varies from 2.5 to 2.7 meters. Typical Span: Typical span is 3 - 6 meters. The typical storey height in such buildings is 2.7 meters. The typical structural wall density is up to 10 %. 9% to 12 %.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

Wood beams with ballast and wood planks. The existing wooden floor/roof structures are not considered to be a rigid diaphragm unless they are tied with diagonal ties and connected to the walls.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☑
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑

	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

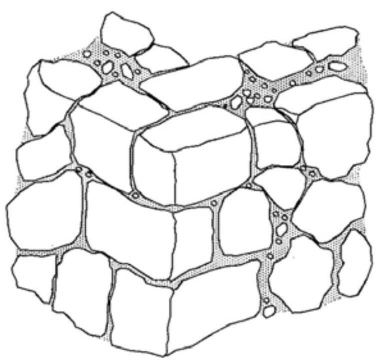

Figure 4A: Critical Structural Details - wall intersection

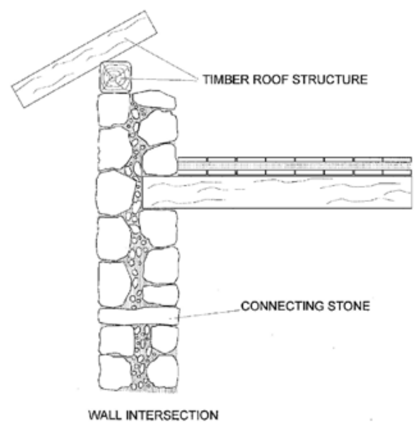

Figure 4B: Typical structural details - wall to-floor connection


Figure 5A: an Illustration of Key Seismic Deficiencies - lack of structural integrity results in wall dislocation and corner damage


Figure 5B: Seismic deficiency: pier failure

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. Buildings of this type have two units sometimes. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is less than 5.

4.2 Patterns of Occupancy

Houses of this type are mostly occupied by one family, or in some cases by two families.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☐
1:1 or better	☑

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☐
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

One or two bathrooms or latrines per housing unit. The bathrooms were added when the building renovations were performed. .

4.4 Ownership

The type of ownership or occupancy is outright ownership and ownership with debt (mortgage or other).

Type of ownership or occupancy?	Most appropriate type
Renting	☐
outright ownership	☑
Ownership with debt (mortgage or other)	☑
Individual ownership	☐

Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☐	☑	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☑	☐	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐

Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	The walls are built with two exterior wythes using larger stones with a stone rubble infill in poor mud mortar with a small amount of lime. In general, there are many voids in the middle portion and the connecting stones (through stones) are rare. This type of masonry is characterized with low tensile strength. The walls are not tied by means of steel or wooden ties.		Cracking: heavy damage of structural walls. Delamination and disintegration of masonry. Dislocation of walls and vertical cracks at corners; partial collapse of wall corners.
Frame (columns, beams)	Not applicable.		
Roof and floors	Timber floor joists are supported only by the interior wall wythe and are not attached to the exterior wythe.	Timber floor and roof structures are not heavy.	Horizontal cracks along the wall-to-floor joints.
Other			

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is A: HIGH VULNERABILITY (i.e., very poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☑	☐	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1976	Friuli, Italy*	6.5	IX-X (EMS)
1998	Bovec, Slovenia**	5.5	VII-VIII (EMS)

The epicenters of the main shock on May 6, 1976 (M= 6.5 , focal depth 20-30 km) and the strongest aftershock on September 15, 1976 (M=5.9) were in Friuli, Italy, 20.5 km from the border between Italy and Slovenia. In Italy 965 people died and an enormous damage was caused. In Slovenia, the maximum intensity was VIII EMS. Out of 6,175 damaged buildings, 1,709 had to be demolished and 4,467 were retrofitted. The strongest earthquake with the epicenter in Slovenia in the 20th century occurred on April 12, 1998. The epicenter was approx. 6.3 km South-East from the town of Bovec, and the focal depth was between 15 and 18 km. No building collapses were reported, however out of 952 inspected buildings, 337 were found to be unsafe, out of which 123 beyond repair. The effectiveness of strengthening methods applied in 1976 was analyzed. Typical patterns of earthquake damage to traditional stone-masonry houses are: - Cracks along the joints between walls and floors; - Vertical cracks at the corners and wall intersections, separation of walls, collapse of gables; - Cracks in structural walls, falling out of masonry at lintels, dosed openings and in corner zones; - Heavy damage to walls, partial collapse of corners, delimination and disintegration of masonry.

Figure 6A: a Photograph Illustrating Typical Earthquake Damage in the 1998 Bovec earthquake

Figure 6B: Out-of-plane gable collapse

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Rubble stone mortar masonry	compressive strength: 150 MPa; low strength compressive strength: 0.98 MPa; tensile strength: 0.06 MPa - 0.08 MPa	lime/mud sand 1:9	Local lime stone, partly cut at corners mud mortar with a little lime two outer layers of bigger stones.
Foundation	Rubble stone mortar masonry	compressive strength: 150 MPa; low strength compressive strength: 0.98 MPa; tensile strength: 0.06 - 0.08 MPa		
Frames (beams & columns)				
Roof and floor(s)	Timber			

6.2 Builder

The houses of the presented type were mainly built by local builders or by owners themselves, with the assistance provided by neighbors. The houses were built to be used by the owners; in some cases the builders live in the houses as well.

6.3 Construction Process, Problems and Phasing

The houses were built traditionally with the local construction materials: local lime-stone, sand and timber from local forests. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

Construction of this type of houses is non-engineered and it is based exclusively on the builder's experience. Engineers and Architects play a role during the renovating, repair and strengthening.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

National and European Codes are applied for structural modifications, including repair and strengthening.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

Building permits are required nowadays, when any structural invention is planned. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s).

6.8 Construction Economics

Since houses of this type were constructed approx. 80 years ago, the costs can not be estimated. N/A.

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is available. The whole area of Slovenia has been divided into the two "seismic insurance zones". The residential buildings are divided into two categories depending on the age of construction: older buildings, built before or in 1965, and the newer buildings, built in 1966 or later. For the higher seismic zone, the annual insurance rate is 0.105 % of the building value for older buildings and 0.07 % for the newer buildings. For the lower seismic zone, the annual insurance rate is 0.07 % and 0.045 % of the building value for older and newer buildings respectively. The area of Upper Posoèje is situated in the higher seismic zone and this type of houses have been built before 1965. The usual insurance rate is therefore 0.105% of the building value. Houses with large cracks are sometimes refused for earthquake insurance. In the case of fine cracks the insurance company previously makes a copy of the cracks. However, in the case of complete seismic strengthening with all permits, these houses may be insured with discount: the annual insurance rate is 0.07% instead of 0.105% of the building value.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
The walls are built with two exterior wythes using larger stones with a stone rubble infill in poor mud mortar with a little lime. There are many voids in the infill and connecting stones (through stones) are rare. Masonry has	Strengthening by systematic filling the voids with injected cementitous grout. The grout is injected into the wall through injection tubes and nozzles, which are built into the joints between the stones uniformly over the entire surface of the wall. Low pressure is used to inject the grout. The injected grout has the purpose to bond the loose parts of the wall

low tensile strength.	together into a solid structure.
The walls are not tied by means of steel or wooden ties.	Tying all walls with steel ties at each floor level. Steel ties are placed symmetrically on both sides of all bearing walls, just below the floor structures, in horizontal notches, which have been cut in the plaster up to the wall surface. Ties are threaded at the ends and bolted on the steel anchor plates. Ties are usually of diameter 16 - 20 mm.
Floor structures are supported only by the interior wall wythe and are not attached to the external wythe.	Floor structures (old wooden or newer reinforced concrete slabs) are anchored to the exterior wall surface by means of steel elements.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?
The design of strengthening measures are performed when a house is planned to be reconstructed or renewed or after an earthquake in the process of repair and strengthening.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Both - as a mitigation effort and combined with the repair after an earthquake.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
Yes.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
An architect and an engineer were involved in the retrofit design. The construction is carried out by a contractor. After the 1998 Bovec earthquake, all contractors who were performing repair and strengthening were additionally trained.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Many buildings have been adequately repaired and strengthened after the 1976 Friuli earthquake. The walls were grouted, the old timber floor structures were replaced with new reinforced concrete slabs in many cases and houses were completely tied. The effectiveness of these measures was confirmed during the 1998 Bovec earthquake.
Adequately repaired and strengthened structures suffered almost no damage in the earthquake.

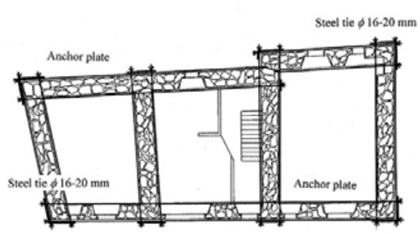

Figure 7A: Illustration of Seismic Strengthening Techniques

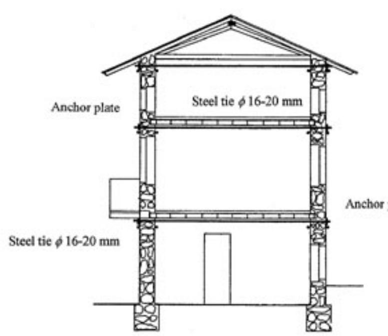

Figure 7B: Typical building elevation with seismic strengthening

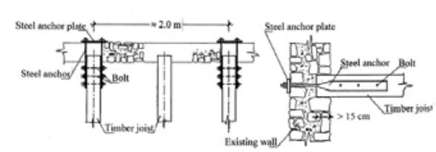

Figure 7C: Seismic strengthening of floor-to-wall connection

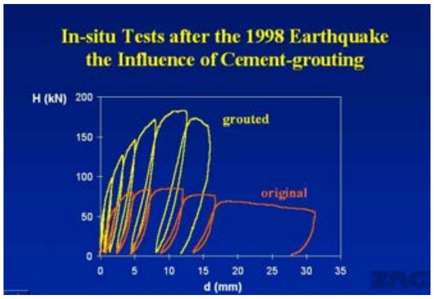

Figure 7D: Seismic strengthening by injection grouting: strengthened vs. unstrengthened specimen


Figure 7E: A building strengthened after the 1976 Friuli earthquake remained undamaged in the 1998 Bovec earthquake

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