World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

an initiative of
Earthquake Engineering Research Institue (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Rubble-stone masonry house

Report#	58
Last Updated	
Country	Slovenia
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Important

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General Information

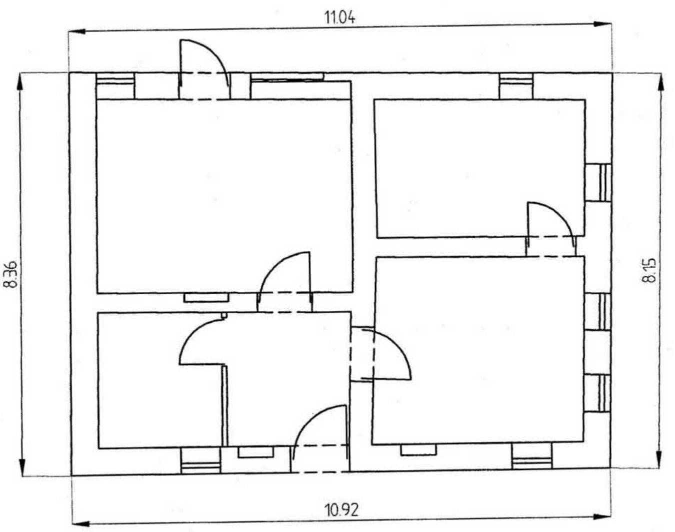
Building Type:	Rubble-stone masonry house
Country:	Slovenia
Author(s):	Marjana Lutman Miha Toma#evic
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in the area of Upper Posocje. The residential housing stock built before the World War II in that area is generally 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.
Summary:	Rubble-stone masonry houses are still found throughout Slovenia. This housing type is special because of its history. It 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 the buildings that were demolished). 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 after the earthquakes.
Length of time practiced:	51-75 years
Still Practiced:	No
In practice as of:	
Building Occupancy:	Single dwelling
Typical number of stories:	2-3
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	This type of construction was practiced between the World War I and the World War II.

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	Typical shape of building plan is usually rectangular.
Typical plan length (meters)	13
Typical plan width (meters)	10
Typical story height (meters)	2.7
Type of Structural System	Masonry: Stone Masonry Walls: Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)
Additional comments on structural system	Lateral load-resisting system: 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. 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. Gravity load-bearing system: The gravity-load bearing system 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.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	10-15%
Typical wall densities in direction 2	10-15%

Additional comments on typical wall densities	The typical structural wall density is up to 10 %. 9% to 12 %.
Wall Openings	Average area of a window opening in front exterior wall is 1.2 m.sq. in the rural area and 1.7 m.sq. in the urban area. The door opening area in exterior and interior bearing walls is approximately 2.0 m.sq.. 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.sq.).
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	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.
Type of Foundation	Shallow Foundation: Wall or column embedded in soil, without footingShallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	
Type of Floor System	Other floor system
Additional comments on floor system	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.
Type of Roof System	Roof system, other
Additional comments on roof system	Timber: wood planks or beams that support clay tiles. 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.
	When separated from adjacent buildings, the typical

Additional comments section 2	distance from a neighboring building is 10 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.



Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Wall: rubble stone mortar masonry	Characteristic Strength- rubble stone:compressive strength 150 MPa mortar: low strength masonry: compressive strength 0.98 MPa, tensile strength 0.06 MPa - 0.08 MPa Mix Proportion/Dimensions- mortar: lime/mud sand 1:9 rubble stone: local lime stone, partly cut at corners mortar: mud mortar with a little lime masonry: two outer layers of bigger stones
Foundations	Rubble stone mortar masonry	compressive strength: 150 MPa; low strength compressive strength: 0.98

		MPa; tensile strength: 0.06 - 0.08 MPa
Floors	Timber	
Roof	Timber	
Other		

Design Process

Who is involved with the design process?	Other
Roles of those involved in the design process	Engineers and Architects play a role during the renovating, repair and strengthening.
Expertise of those involved in the design process	

Construction Process

Who typically builds this construction type?	OwnerBuilder
Roles of those involved in the building process	The houses of the presented type were mainly built by local builder or by owners themselves, with the assistance provided by neighbours. The houses were built to be used by the owners; in some cases the builders live in the houses as well.
Expertise of those involved in building process	Construction of this type of houses is nonengineered and it is based exclusively on the builder's experience.
Construction process 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.
Construction issues	Poor quality of masonry, Lack of structural integrity, Poor wall-to-floor connections, Weak supports of new reinforced concrete floor structures which replaced old timber ones. The new reinforced concrete slabs are supported only with the interior wythe of the wall and is not attached to the exterior wythe.

Building Codes and Standards

Is this construction type address by codes/standards?	No
Applicable codes or standards	
Process for building code enforcement	

Building Permits and Development Control Rules

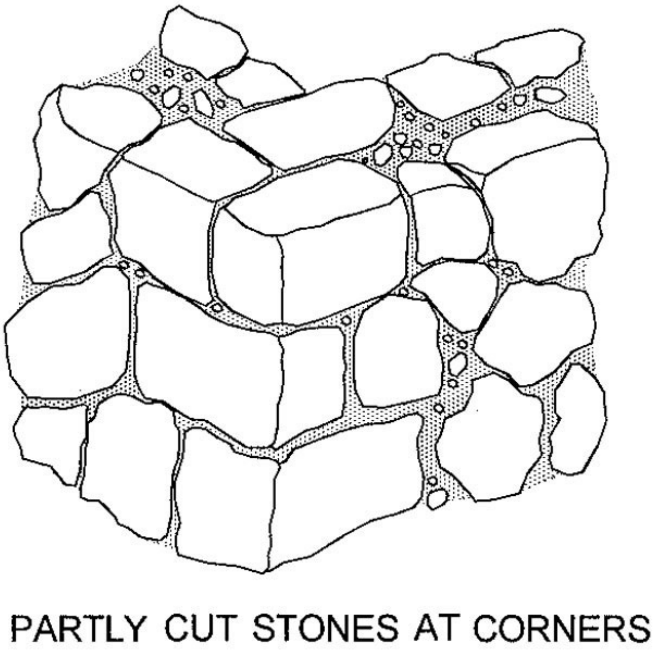
Are building permits required?	Yes
Is this typically informal construction?	Yes
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and development control rules	Building permits are required nowadays, when any structural invention is planned. Building permits are required to build this housing type.

Building Maintenance and Condition

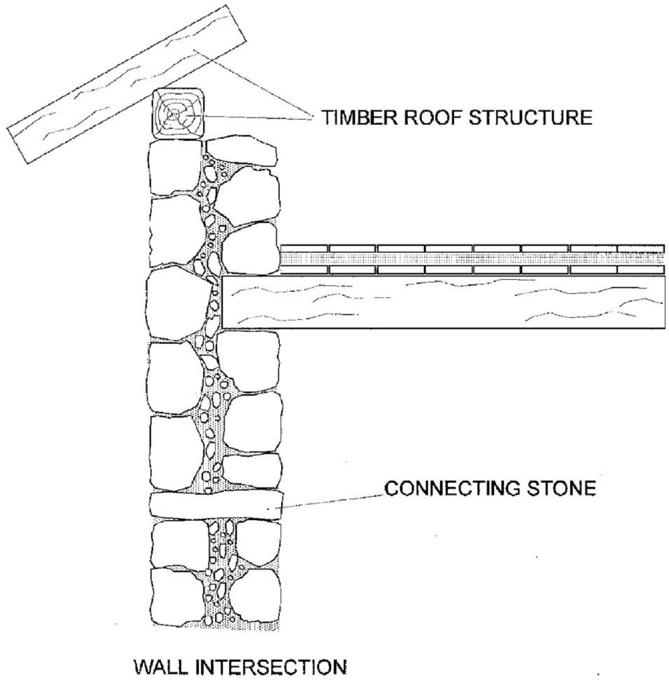
Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	Since houses of this type were constructed approx. 80 years ago, the costs can not be estimated.
Labor requirements	N/A
Additional comments section 3	National and European Codes are applied for structural modifications, including repair and strengthening.



Critical Structural Details - wall intersection



Typical structural details - wall to-floor connection

An Illustration of Key Seismic Deficiencies - lack of structural integrity results in wall dislocation and corner damage

Seismic deficiency: pier failure

Socio-Economic Issues

Patterns of occupancy	Houses of this type are mostly occupied by one family and in some cases by two families. Each building typically has 1 housing unit(s). Buildings of this type have two units sometimes.
Number of inhabitants in	

a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	<5
Additional comments on number of inhabitants	
Economic level of inhabitants	Low-income class (poor)Middle-income class
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 1:1 or better
Typical Source of Financing	Owner financedPersonal savings
Additional comments on financing	
Type of Ownership	Own outrightOwn with debt (mortgage or other)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	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 Poso#je 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.
Are premium discounts or higher coverages	

available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	Yes
Additional comments on premium discounts	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.
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1976	Friuli, Italy*
1998	Bovec, Slovenia**

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	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, closed openings and in corner zones; - Heavy damage to walls, partial collapse of corners, delimination and disintegration of masonry.
Additional comments on earthquake damage patterns	Overall damage patterns observed in past earthquakes for this type of construction included: - Cracking: heavy damage of structural walls. Delamination and disintegration of masonry. Dislocation of walls and vertical cracks at corners; partial collapse of wall corners. -Horizontal cracks along the wall-to-floor joints.

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e.	FALSE

	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.	TRUE
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
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);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	FALSE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		TRUE

Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	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.
Earthquake-resilient features in walls	
Seismic deficiency in frames	Not applicable.
Earthquake-resilient	

features in frame	
Seismic deficiency in roof and floors	Timber floor joists are supported only with the interior wall wythe and are not attached to the exterior wythe.
Earthquake resilient features in roof and floors	Timber floor and roof structures are not heavy.
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the [Seismic Vulnerability Guidelines]()

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class	o	-|				

A Photograph Illustrating Typical Earthquake Damage in the 1998 Bovec earthquake

Out-of-plane gable collapse

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
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 low tensile strength.	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 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.

Additional comments on seismic strengthening provisions	
Has seismic strengthening described in the above table been performed?	The design of strengthening measures is performed when a house is 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 a repair following earthquake damages?	Both - as a mitigation effort and as repair after an earthquake.
Was the construction inspected in the same manner as new construction?	Yes.
Who performed the construction: a contractor or owner/user? Was an	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

architect or engineer involved?	contractors who were performing repair and strengthening were additionally trained.
What has been 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.
Additional comments section 6	

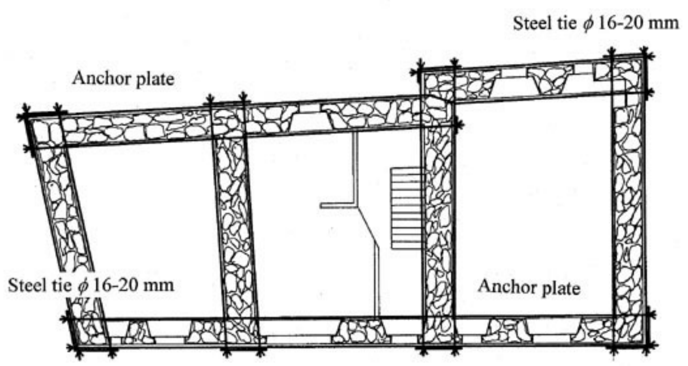
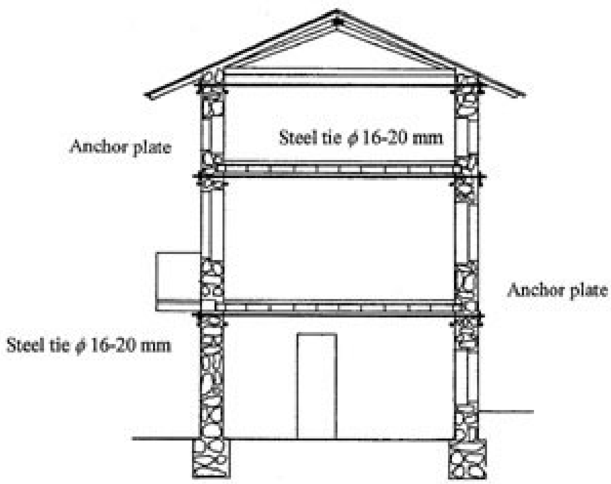
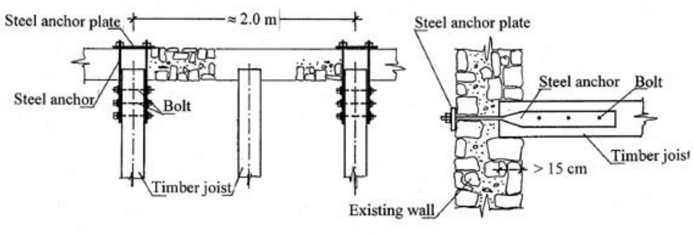


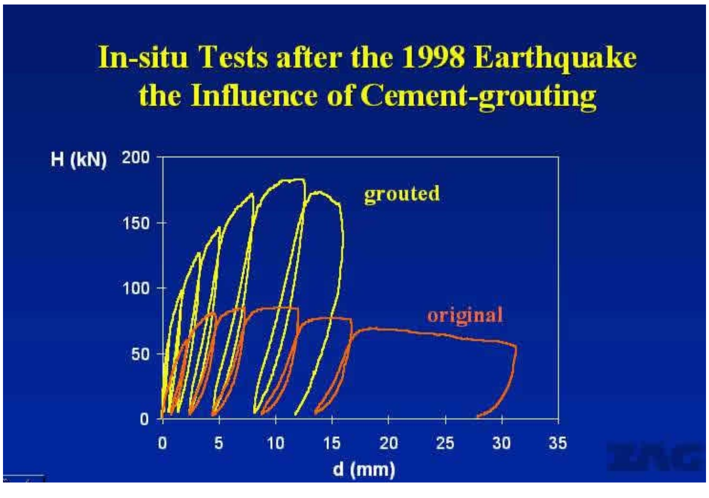
Illustration of Seismic Strengthening Techniques



Typical building elevation with seismic strengthening



Seismic strengthening of floor-to-wall connection



Seismic strengthening by injection grouting: strengthened vs. unstrengthened specimen

A building strengthened after the 1976 Friuli earthquake remained undamaged in the 1998 Bovec earthquake

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