MULTI-HAZARD VULNERABILITY INDICATORS FOR CHURCHES - VERSION 1.0

M. Lazzati[1], S. De Angeli[2], G. Boni[2], S. Cattari[2], and X. Romão[3]

[1] Dept of. Electrical, Electronics and Telecommunication Engineering and Naval Architecture, University of Genoa, Via All'Opera Pia 11, Genoa, Italy. e-mail: marco.lazzati9@gmail.com

[2] Dept. of Civil, Chemical and Environmental Engineering, University of Genoa, Via Montallegro 1, Genoa, Italy, e-mail: {silvia.deangeli, giorgio.boni, serena.cattari}@unige.it

[3] CONSTRUCT-LESE, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465, Porto, Portugal, e-mail: xnr@fe.up.p

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Table 1: Selected churches vulnerability indicators for earthquake

ID	Indicator name	Source	Difficulty level[1]	Description/Notes
EQ.1	Height of the surrounding buildings - interaction with adjacent buildings	Remote and in-situ	1	Cultural heritage buildings are usually centralized in towns and villages, or in high density areas, thus often are close or adjacent to other buildings. In presence of buildings that are independent but not at a certain distance, this indicator become crucial since the collapse of building around the church could damage it. Moreover, when adjacent/connected buildings may interact with the church, their potential effects in altering its seismic response may be accounted for. Such interaction depends on their relative difference in stiffness, mass and strength. The height is here considered as one of the proxies of such more complex phenomena.
EQ.2	Height of the church	Remote and in-situ	1	This indicator assesses the height of the church associated with probable earthquake damage. For example, in contrast to low-rise historical buildings, taller ones may be more vulnerable to the activation of out-of-plane responses associated to high slenderness of walls.
EQ.3	Quality of the masonry	In-situ survey	2	This indicator addresses the church material, by estimating the expected mechanical behaviour of masonry on basis of its physical apparent/visual characteristics.
EQ.4	Roof condition	In-situ survey	2	This indicator aims to evaluate the maintenance conditions of the roof.
EQ.5	Predominance of in-plane or out-of-plane mechanisms	In-situ survey	2	Out of plane mechanism (OOP) and in plane mechanism (IP) are the primary mechanisms for masonry building collapse. The OOP mechanism concerns the response of the masonry walls, induced by orthogonal seismic forcing to their main axis, whose collapse is associated with a condition of loss of equilibrium. The IP mechanisms instead are associated to the attainment of ultimate strength limit at scale of material. The seismic behaviour of churches is usually interpreted by referring to the decomposition in 'macroelements'[2]. Such macroelements may be subjected to both IP and OOP mechanisms; OOP it is the most dangerous between the two.

[1] 1 = non experts can assess / 2 = only experts can assess

[2] A macroelement is a portion of the asset which exhibit an autonomous seismic behaviour. Typical examples are the façade, the apse, the nave, the bell tower etc.

ID	Indicator name	Source	Difficulty level[1]	Description/Notes
				The interaction among macroelements and eventually the occurrence of a box- type behaviour (with a prevalence of IP mechanisms) are also influenced by the role played by the roof. This indicator is achievable only with an in-situ analysis.
EQ.6	Openings of wall façade	In-situ survey	1	The façade is one of most relevant macroelements in a church. It evaluates the effect that the lack of alignment of openings in the different facades of a building has on the seismic behaviour of the facades. Also the dimension of openings is taken into account.
EQ.7	Type of soil	In-situ survey	2	This indicator is relevant for earthquake due to possible site effect (e.g., stratigraphic effect or liquefaction) that may arise in case of an event.
EQ.8	Site morphology	In-situ survey	2	This indicator reflects the importance of factors such as the type of foundation soil, the type of foundations, the elevation differences between the ground and the foundation (Δh), the slope of the terrain (p) and the topography of the building envelope. Depending on the type of foundation ground, the slope of the ground where the building is located and the possible difference Δh between the foundation of the building and the ground, the values in the next table are established.
EQ.9	General external state of conservation	In-situ survey	1	This indicator refers to the external quality of the building, looking for cracks, degradation, and damages on structural elements which may potentially alter the seismic response, making the church more vulnerable.
EQ.10	Bell tower presence	Remote and in-situ	1	The bell tower is one of most relevant macroelements[2] in a church. Usually the bell tower is adjacent to the church with not symmetrical boundary conditions. The main influences include pushing actions that can arise when there is a lack of connection, or a bad connection, between the building and the bell tower. In addition, it is common that the bell tower is higher than the church building, thus there is the risk of the collapse of the tower over the building in case of an earthquake, causing additional damage.

Table 2: Selected churches vulnerability indicators for flood

ID	Indicator name	Source	Difficulty level[3]	Description/Notes
FL.1	Number of floors	In-situ survey	1	This indicator assesses the number of floors of the building, which would allow or not people to escape from the flood and the presence of basements. Thus, this indicator has an opposite influence with respect the same indicator relative to earthquake hazard, since in case of flood hazard it is positive to have an escape route from the ground floor.
FL.2	Dry feature of the masonry	In-situ survey	2	This indicator addresses the current conditions of the church construct material, with a focus on the masonry features which can influence the drying capacity. For instance, volcanic rocks (e.g., ignimbrites) will present lower absorption values than sedimentary rocks (e.g., lime stones). In case of a flood, the material can absorb the water that may affect the integrity not only in structural resisting systems (loss of strength, e.g., due to drying cycles, volumetric variations, etc.) but also the coatings due to the damaging effects (i.e., leaching, hydrolysis, sulphate attack) that chemical components of the floodwater may contain.
FL.3	Opening of wall facade on the first floor	Remote and in-situ	1	The openings on the ground floor can facilitate water entering the building and flooding the ground floor and the basement, if present.
FL.4	Quality of the drainage system	Remote and in-situ	2	This indicator measures the actual conditions of the drainage system that surround the church, accounting also the distance between the system and the building. This may influence the depth and duration of flood.
FL.5	Number of exposed facades	Remote and in-situ	1	This indicator accounts for how many facades are potentially directly exposed to flood hazard, to understand which facades could be damaged and/or weakened more than the other during a flood event.
FL.6	Protection by vegetation	Remote and in-situ	1	Vegetation play an important role in case of flood: the type of vegetation can assume a protective role constating a physical barrier to the water flow or, on the contrary, if transported by the flow, may increase the damage.
FL.7	Type of soil	In-situ survey	2	The soil type influences the ground's capacity to absorb water, influencing infiltration, runoff and then duration of the flood.

[3] 1 = non experts can assess / 2 = only experts can assess

ID	Indicator name	Source	Difficulty level[3]	Description/Notes
FL.8	Slope of the ground	Remote and in-situ	1	This indicator considers the slope of the ground in the area surrounding the church and the presence of retention basins, factors that may impact flow speed and flood maximum depth and duration.

Table 3: Selected churches vulnerability indicators for fire

ID	Indicator name	Source	Difficulty level[4]	Description/Notes
FI.1	Electric installations	In-situ survey	2	This indicator measures the actual conditions of the electrical components of the building, accounting also the deterioration that an event before a fire may produce, thus deficiencies to mitigate the impact of future damages.
FI.2	Gas installations	In-situ survey	2	This indicator measures the actual conditions of the gas components of the building, accounting also the deterioration that an event before a fire may produce, thus deficiencies to mitigate the impact of future damages.
FI.3	Distance of the surrounding buildings	Remote and in-situ	1	This indicator aims to evaluate the distance between the church and the surrounding buildings, in order to take into account the possibility that a fire started in the buildings around the case study, can overrun the building under examination, and vice versa.
FI.4	Exterior hydrants	Remote and in-situ	1	This indicator evaluates the distance between the church and the nearest hydrants. Such indicator is an indirect measure of how quickly firefighters can activate suppression actions during a fire. The time response on the firefighters can in its turn significantly influence the severity of the damages.
FI.5	Automatic extinguish system	In-situ survey	1	This indicator addresses the existence and the actual conditions of automatic extinguish systems (e.g., sprinklers).
FI.6	Active suppression system	In-situ survey	1	This indicator takes into account the presence and the actual conditions of fixed or portable active fire suppression systems installed at appropriate indoor or outdoor locations to facilitate firefighter response.
FI.7	Presence of vegetation	Remote and in-situ	1	The presence of vegetation near a building can increase the fire load in case of a fire, and then propagate the fire to surrounding buildings. We evaluate such indicators looking at the distance between the vegetation and the church.
FI.8	Security cameras for intentional fires	In-situ survey	1	The presence of security camera outside and inside the building can decrease the possibility of intentional fire, acting as a deterrent.
FI.9	Average occupancy	Remote and in-situ	1	This indicator takes in consideration the amount of people that the building usually guest, to evaluate how much would be easy the evacuation in case of fire.

[4] 1 = non experts can assess / 2 = only experts can assess

ID	Indicator name	Source	Difficulty level[4]	Description/Notes
FI.10	Building content	Remote and in-situ	1	The furniture and the content inside the church can be made by wood; thus, such indicator considers this contingency as a further vulnerability element in case of a fire.
FI.11	Open flames	Remote and in-situ	1	Open flames, such as candles, are almost always present in churches and play an important role in fire protection, also in case of intentional fire.

Table 4: Earthquake vulnerability indicators and description of the different levels they can assume

ID	Indicator name	Vuln. level	Description
EQ.1	Height of the surrounding buildings - interaction with adjacent buildings	0	No one buildings are close enough and tall enough to potentially collapse on the church. The interaction with adjacent/connected buildings is considered negligible in altering the seismic response of church.
		1	At least one side of the church can be damaged by the collapse of a neighbourhood building. The interaction with adjacent/connected buildings is considered small to moderate in negatively altering the seismic response of church.
		2	At least two sides of the church can be damaged by the collapse of a neighbourhood building. The interaction with adjacent/connected buildings is considered moderate to high in negatively altering the seismic response of church.
		3	At least three sides of the church can be damaged by the collapse of a neighbourhood building. The interaction with adjacent/connected buildings is considered very high in negatively altering the seismic response of church.
EQ.2	Height of the church	0	The height of the building is less or equal than 6 meters
		1	The height of the building is between 6 and 9 meters
		2	The height of the building is between 9 and 12 meters
		3	The height of the building is greater than 12 meters
EQ.3	Quality of the masonry	0	Prevalence of squared or hewn elements or parallelepiped bricks or bricks on both faces of the wall. Horizontal rows over a large part of the wall, without interruptions of continuity on both faces of the wall. Mortar in good condition and well preserved, with joints not too large in relation to the stones or bricks or with large joints and mortar of excellent quality. Masonry with large square elements and no mortar or with a very thin layer of mortar.
		1	Presence of irregularly shaped elements or pebbles and square-shaped blocks or bricks. Walls with one face of irregularly shaped blocks or bricks and the other face of pebbles or irregularly shaped elements. Intermediate situation between compliance and non-compliance, including the case of horizontal rows only on one face of the wall. Intermediate quality mortar with not excessively eroded joints. Walls with irregular elements and degraded mortar but with effectively wedged between the spaces of the elements.
		2	Presence of irregularly shaped elements or pebbles and square-shaped blocks or bricks. Walls with one face of irregularly shaped blocks or bricks and the other face of pebbles or irregularly shaped elements. Intermediate situation between compliance and non-compliance, including the case of horizontal rows only on one face of the wall. Intermediate quality mortar with not excessively eroded joints. Walls with irregular elements and deteriorated mortar but with effectively wedges between the spaces of the elements. Prevalence of elements with their largest dimension under 20 cm. Vertical or vertically aligned joints on two or more elements in large portions of the wall. Wall of solid brickwork.

ID	Indicator name	Vuln. level	Description		
		3	Vertical or vertically aligned joints on two or more elements in large portions of the wall. Solid brick wall. Small stones in relation to the thickness of the wall, absence of stones clearly arranged transverse to the wall. Horizontal sections are interrupted or clearly offset across the entire wall face. Prevalence of elements with their largest dimension under 20 cm. Wall of only solid brick diatoms. Vertical or vertically aligned joints on two or more elements in large portions of the wall. Solid brick wall. Poor or deteriorating and dusty mortar with no cohesion. Absent mortar. Excessively large mortar joints, comparable to that of the elements if the mortar is not of very good quality.		
EQ.4	Roof condition	0	The roof is in good conditions. It effectively connects macroelements[2] and doesn't provide pushing actions.		
		3	The roof presents permanent deformations or signs of water infiltration. It doesn't connect macroelements and potentially provide pushing actions.		
EQ.5	Predominance of in-plane or out-of-plane mech.	0	No presence of vulnerability factors		
		1	Predominance of vulnerability factors associated to IP mechanisms		
		2	Predominance of vulnerability factors associated to of OOP mechanisms		
		3	Both mechanisms IP and OOP are strongly vulnerable		
EQ.6	Openings of wall façade	0	Openings have regular dimensions and are vertically aligned		
		1	Openings with regular or irregular dimensions, that are horizontally misaligned for more than half of their opening		
		2	Openings with regular or irregular dimensions, that are vertically misaligned for more than half of their opening		
		3	Openings with irregular distribution or covering large spans		
EQ.7	Type of soil	0	The type of soil does not magnify the resonance of the seismic waves		
		1	Topographic or basin effects: the first one is related to the focusing of the waves at the crest of a topographic irregularity, the second one the waves focus on the edges of a basin creating also surface wave generation		
		2	Stratigraphic effect: a layer of low resistance soil over a layer of higher resistant soil/rock		
		3	The soil is susceptible to have the pores full of water, this cause liquefaction. Liquefaction may occur if the expected value of ground accel. is greater than or equal to 0.1*g* and the dominant magnitude is greater than or equal to 5		
EQ.8	Site morphology			*Dh*	*Inclination of the terrain*
		0	Rock with or without foundation	-	$p \leq 10$
		1		-	$10 < p \leq 30$
		2		-	$30 < p \leq 50$
		3		-	$p > 50$

ID	Indicator name	Vuln. level	Description		
		0	Melted without impulse with rock foundation	Dh = 0	p ≤ 10
		1		0 < Dh ≤ 1	p ≤ 10
		1		Dh ≤ 1	10 < p ≤ 30
		2		Dh ≤ 1	30 < p ≤ 50
		3		-	p > 50
		3		Dh > 1	-
		0	Melted without impulse without foundation	Dh = 0	p ≤ 10
		1		0 < Dh ≤ 1	p ≤ 10
		1		Dh ≤ 1	10 < p ≤ 30
		2		Dh ≤ 1	30 < p ≤ 50
		3		-	p > 50
		3		Dh > 1	-
		2	Melted with and without impulse with foundation	Dh ≤ 1	p ≤ 50
		3		-	p > 50
		3		Dh > 1	-
		2	Melted with impulse without foundation	Dh ≤ 1	p ≤ 30
		3		-	p > 30
		3		Dh > 1	-
EQ.9	General state conservation	0	The external masonry shows perfect conditions, without any cracks or others visible signs of degradation		
		1	The building show superficial cracks that do not affect the behaviour of the building, the outside details are degraded, but there are no signs of damaging on the structure		
		2	There are signs of degradation, maintenance is absent, presence of cracks or other sings of degradation on the main elements of the building		
		3	The masonry is clearly visible, the edges of the building are not present and structural damages are present		
EQ.10	Belltower	0	The bell tower is not present		
		3	The bell tower is present		

Table 5: Flood vulnerability indicators and description of the different levels they can assume

ID	Indicator name	Vuln. level	Description
FL.1	Number of floors	0	The building has more than one floor and has no basement
		1	The building has only the ground floor and has no basement
		2	The building has more than one floor and has a basement
		3	The building has only the ground floor and has a basement
FL.2	Dry feature of the masonry	0	The masonry is in good condition and shows clearly fast-dry features
		1	The masonry is not in condition but shows fast-dry features
		2	The masonry is not in good condition and do not show fast-dry features
		3	The masonry can be disassembled by the water and do not show dry-fast features
FL.3	Opening of wall facade on the first floor	0	No openings on the ground floor that are greater than or equal to the 10% of the total area
		1	No openings on the ground floor that are greater than or equal to the 25% of the total area
		2	No openings on the ground floor that are greater than or equal to the 50% of the total area
		3	Openings that are 50% or more of the area of the total area
FL.4	Quality of the drainage system	0	The system is present, active and has received some maintenance recently
		1	The system is present and active
		2	The system is present but it is not clear if it is currently working or not
		3	The system is not present
FL.5	Number of exposed facades	0	Only one facade is directly exposed
		1	Two facades are exposed
		2	Three facades are exposed
		3	All the building is exposed

ID	Indicator name	Vuln. level	Description
FL.6	Protection by vegetation	0	The building is surrounded from vegetations that, in case of flood, will decrease the velocity of the water and block the transported materials
		1	No presence of vegetation around the building / the building is surrounded from an irrelevant density of vegetation
		2	The building is surrounded by low vegetation/bushes that, in case of flood, can be carried together with the flow slightly increasing the damage to the building
		3	The building is surrounded by tall vegetation that, in case of flood, can be carried together with the flow significantly increasing the damage to the building
FL.7	Type of soil	0	The soil shows good absorption characteristics
		1	The soil shows good absorption characteristics, even if it is commonly wet
		2	The soil shows poor infiltration characteristics
		3	The soil is impervious or susceptible to have the pores full of water
FL.8	Slope of the ground	0	The building is on a hill (so no chances of flood)
		1	The building is on a slope (water does not accumulate, but the fast water and debris may carry can cause damage)
		2	The building is in a flat area and there is a retention basin nearby (so there is a buffer to retain excess water)
		3	The building is in a flat or depressed area and there is no retention basin nearby (so water can accumulate)

Table 6: Fire vulnerability indicators and description of the different levels they can assume

ID	Indicator name	Vuln. level	Description
FI.1	Electric Installation	0	System always active and in good conditions
		1	System not always active and in good conditions
		2	System always active and in bad conditions
		3	System not always active and in bad conditions
FI.2	Gas installations	0	The system is present, active and has received some maintenance recently
		1	The system is present and active
		2	The system is present but it is not clear if it is currently working or not
		3	The system is not present
FI.3	Distance of the surrounding buildings	0	There are more than 4 meters between at least one side of the building and a surrounding building
		1	There are 2-4 meters between at least one side of the building and a surrounding building
		2	There are less than 2 meters between at least one side of the building and a surrounding building
		3	At least one side of the building is connected with a surrounding building
FI.4	Exterior hydrants	0	At least one hydrant presents at a distance less or equal to 10 meters
		1	At least one hydrant presents at a distance between 10 and 25 meters
		2	At least one hydrant presents at a distance between 25 and 50 meters
		3	Hydrants are not present
FI.5	Automatic extinguish system	0	The system is present, active and has received some maintenance recently
		1	The system is present and active
		2	The system is present but it is not clear if it is currently working or not
		3	The system is not present
FI.6	Active suppression system	0	The system is present, active and has received some maintenance recently
		1	The system is present and active
		2	The system is present but it is not clear if it is currently working or not
		3	The system is not present
FI.7	Presence of vegetation	0	There is not vegetation that can increase the fire load in the surrounding area
		1	There is presence of vegetation far than 4 meters either from the building or a surrounding building
		2	There is presence of vegetation between 2 - 4 meters either from the building or a surrounding building
		3	There is presence of vegetation closer than 2 meters either from the building or a surrounding building

ID	Indicator name	Vuln. level	Description
FI.8	Security cameras for intentional fires	0	Presence of cameras outside and inside the building
		1	Presence of cameras only outside
		2	Presence of cameras only inside
		3	There are not security cameras
FI.9	Average occupancy	0	The church is nor active for church service neither for visiting
		1	The church is active both for visiting and for service, but does not attract several visitors who are mainly locals
		2	The church is active both for visiting and for service, and attracts both tourists and locals
		3	The church is one of the main attractive buildings of the city, the touristic attendance is very high
FI.10	Building content	0	The content is not flammable
		3	The content is flammable
FI.11	Open flames	0	no open flames
		1	If the a flame fall down on something that cannot burn
		2	If the a flame fall down on something that I don't know if it can burn or not
		3	If the a flame fall down on something that can burn