

ZONING FAULT DISPLACEMENT HAZARD AROUND CAPABLE FAULTS: A FIRST ASSESSMENT IN ITALIAN URBAN AREAS

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Introduction. Fault Displacement Hazard (FDH) is a component of seismic hazard that focus on the potential of coseismic surface tectonic rupture/deformation.

Although the Italian territory is characterized by a great number of capable faults (i.e., faults able to produce significant ruptures or deformations at or near the topographic surface), nowadays, this hazard is not yet taken into account in official seismic hazard maps and building codes in Italy. Nevertheless this hazard it has been considered in the guidelines and criteria for seismic microzonation (Working Group MS, 2008), and more recently in specific studies (e.g. Peronace *et al.*, 2013) and technical guidelines still under preparation.

This paper aims at providing a general indication of Fault Displacement Hazard in Italy in the 73 most populated urban areas (population > 60,000 inhabitants) with the aim to point out the cities where this hazard does exist and is more relevant (in terms of maximum expected displacements) and what is directly threatened by surface faulting.

This is only a first indication of the areas where this problem is more critical. Of course, a FDH assessment helpful for siting and land planning purposes, will require the delineation of setback areas (i.e. the distance from the fault trace within critical facilities and structures designed for human occupancy cannot be built, Bryant and Hart, 2007) through more detailed site investigations (Quaternary geology and paleoseismology), aimed at characterizing at larger scale the local pattern of capable faults and the age of last movements.

Zoning Fault Displacement Hazard around capable faults. In order to respond to the need of a specific knowledge regarding the Fault Displacement Hazard, the Italian Agency for Environmental Protection (ANPA, later APAT, now ISPRA) in the second half of the 90s started the project ITHACA (ITaly HAZard from CAPable faults). The project is aimed at building a tool for summarizing and making easily available information on capable faults, based on published sources, field checks and ad hoc studies (for more details, see Comerci *et al.*, 2013).

Currently, the ITHACA database is available at the GeoMapView of Geological Survey (<http://sgi.isprambiente.it/GMV2/index.html>) and contains about 2000 records (mapped in Fig. 1) including faults that exhibit at least one evidence of capability among the following: a) historical coseismic surface faulting; b) creep or surficial tectonic deformation; c) Late Pleistocene-Holocene paleoseismic evidence of ground rupture; d) displacement of Quaternary deposits/landforms. Moreover, the faults are classified according to the age of the last ascertained movement.

At the moment, the ITHACA database, although still incomplete and not homogeneous in terms of resolution and reliability of supporting data, is the most reliable tool for a first characterization of Fault Displacement Hazard in the entire Italian territory.

Among previous studies focused on this topic, Guerrieri *et al.* (2009) aimed at estimating the extent of urban areas exposed to surface faulting hazard within the ZS9 seismotectonic zonation of Italy. The analysis was conducted for each seismotectonic zone that was considered homogeneous also in terms of Fault Displacement Hazard, through the intersection of ITHACA and CORINE Land Cover databases. The results of the spatial analysis have been weighted through the introduction of a Fault Class parameter which takes into account the expected maximum displacement associated to capable faults in each zone. For this assessment a standard 300-m wide buffer area around capable faults was considered.

More recently, Guerrieri *et al.* (2013, 2014) proposed a more refined zonation of the area around the mapped capable faults, whose shape and width depend on the seismotectonic behaviour (i.e., type, style and amount of faulting) and the severity of the maximum expected earthquake. These two factors control also the amount of maximum expected surface displacements.

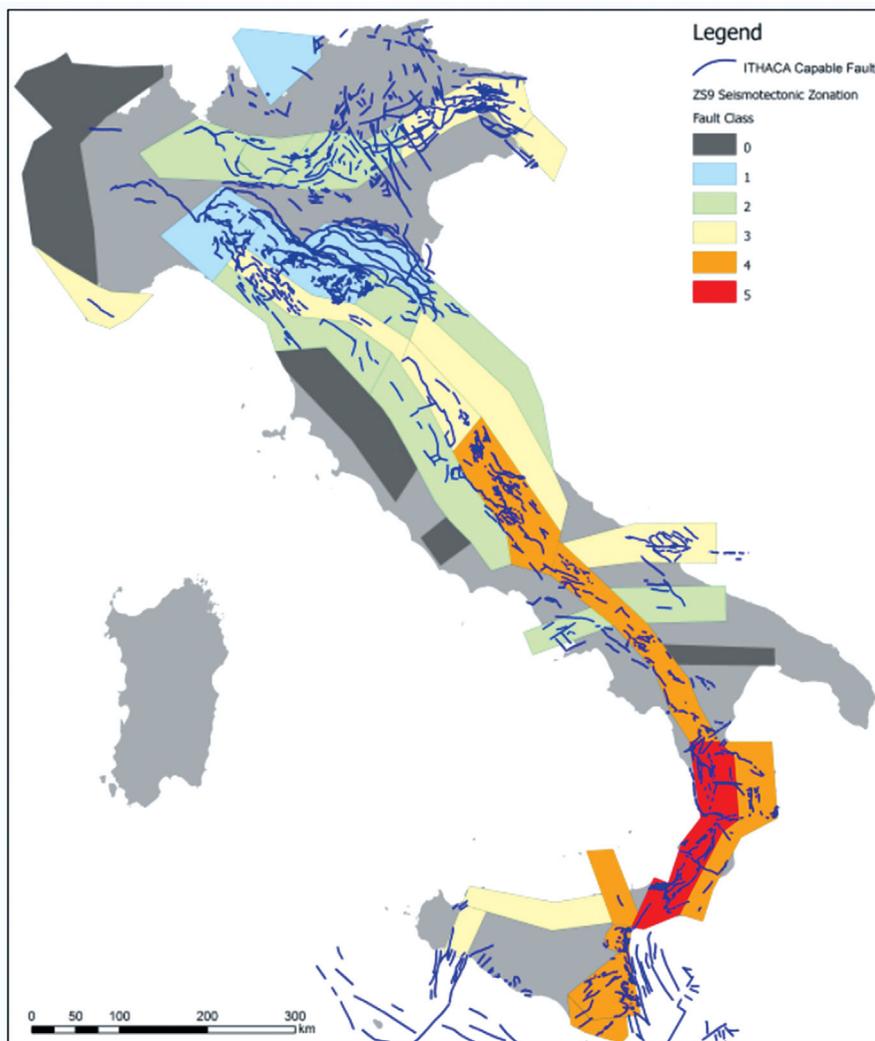


Fig. 1 – The ITHACA database over the ZS9 seismotectonic zonation (Meletti and Valensise, 2004). According to the Fault Class parameter (Guerrieri *et al.*, 2014), it is possible to evaluate maximum expected offsets: 1: 0-5 cm; 2: 5-20 cm; 3: 20-50 cm; 4: 50-150 cm; 5: up to 250 cm.

Five Fault Classes have been proposed in this model: for each class, the maximum expected offsets and typical widths of the hazard zone in the footwall and in the hanging-wall of the master capable fault are provided. To this end, the capable faults recorded in ITHACA have been split into three main groups according to the prevalent fault kinematics (normal, reverse or strike-slip) and classified into different classes identified by specific maximum magnitude ranges (Fig. 2).

In order to take into account the uncertainties affecting the location of capable faults recorded in ITHACA, a standard minimum width value equal to 30 m has been introduced on both the side of the fault trace (of course, in some cases it could be convenient to consider a larger uncertainty, if the resolution of original data sources is very scarce).

For normal faults (Fig. 2, above) these relationships result from a careful review of the documented normal surface faulting pattern caused by several modern and historical events occurred in the Italian territory (cfr. Boncio *et al.*, 2012 and bibliography therein). Since in an

Fault Class (with M_{max} ranges)	Normal faults		Examples
	Maximum expected offset (vertical)	Hazard zone width	
1 ($5.5 < M_{max} < 6.0$)		HW: 50 m FW: 30 m	
2 ($6.0 < M_{max} < 6.3$)		HW: 150 m FW: 30 m	
3 ($6.3 < M_{max} < 6.6$)		HW: 200 m FW: 40 m	
4 ($6.7 < M_{max} < 7.0$)		HW: 250 m FW: 50 m	
5 $M_{max} > 7.0$		HW: 300 m FW: 100 m	

Fault Class (with M_{max} ranges)	Reverse faults		Strike-slip faults	
	Maximum expected offset (vertical)	Hazard zone width	Maximum expected offset (horizontal)	Hazard zone width
1 ($5.5 < M_{max} < 6.0$)		HW: 100 m FW: 30 m		HW: 30 m FW: 30 m
2 ($6.0 < M_{max} < 6.3$)		HW: 300 m FW: 30 m		HW: 60 m FW: 60 m
3 ($6.3 < M_{max} < 6.6$)		HW: 400 m FW: 40 m		HW: 100 m FW: 100 m
4 ($6.7 < M_{max} < 7.0$)		HW: 500 m FW: 50 m		HW: 150 m FW: 150 m

Fig. 2 – ITHACA capable faults have been classified into five classes according to the maximum magnitude range values. For each class, the following data are provided: the maximum expected offsets and typical width of the hazard zone in the hanging-wall (HW) and in the foot-wall (FW) of the master capable fault. Above: parameters for normal faults with some examples of documented surface faulting events. Below: the same parameters for reverse and strike-slip faults.

extensional environment, surface primary ruptures (i.e. principal faulting, sensu Youngs *et al.*, 2004) are expected to occur mainly in the hanging wall of the master fault, we have considered an asymmetric zone located mainly on the downthrown block, and width proportional to the maximum surface offset. For example, for capable faults with maximum magnitude equal to 6.0 and maximum offsets lower than 5 cm, the hazard zone width is at least 50 m in the hanging wall but not more than 30 m in the footwall. Indeed, for capable faults with $M_{max} > 7.0$ and maximum offsets larger than two meters (e.g. Calabria) the hazard zone width is in the order of 400 m (100 m in the footwall and 300 m in the hanging wall).

Conversely, a clear documentation of surface faulting pattern occurred in compressive and strike-slip environment is quite scarce: only for the reverse 1976 event in Friuli some local surface ruptures have been interpreted by some authors as surface faulting (cfr. Bosi *et al.*, 1976; Aoudia and Suhadolc, 2000 based on Martinis and Cavallin, 1976). Moreover, a paleoseismic evidence in a compressive environment (secondary surface faulting) has been clearly documented at Monte Netto (south of Brescia) (Livio *et al.*, 2012). Anyway, considering these cases but also the available cases of documented reverse surface faulting events around the world (cfr. Lettis *et al.*, 1997), it is clear that in a compressive environment surface faulting features typically occur not only in correspondence to the main thrust but also at the hinge of the growing anticline, even with normal displacement ((e.g., 1980 El Asnam M 7.3 earthquake; Shan and Bertero, 1980; Meghraoui *et al.*, 1988; Meyer *et al.*, 1990). This zone may be located in the hanging wall of the main thrust at a variable distance from the thrust front (up to some km). During the 1980 El Asman event, extensive fissures and normal faulting occurred on the upthrown block of the primary thrust as far as 2 km from the trace of the primary thrust producing, in most places, most pronounced scarps than those along the primary thrust fault (Shan and Bertero, 1980). Thus, the hazard zone width in the hanging wall of reverse faults has to be significantly larger than in the hanging-wall of normal faults, at least twice the corresponding width for normal faults. Of course, secondary ruptures cannot be excluded even at larger distance (up to some km from the thrust front) in case of growing near-surface anticlines.

For strike-slip fault systems (e.g. in the Gargano area, Puglia), a relevant role is played by surface ruptures occurring along faults located off the principal fault trace and in response to an earthquake along the principal faults (concept of distributed faulting; cfr. Petersen *et al.*, 2011). Such faults may be linked in depth to the major structure (e.g. flower structures, pull-a-part basins, etc.), but might be also located at a distance of several hundreds of meters up to several km. Therefore, each fault segment has been managed as an independent source of FDH, locally with normal or reverse component.

Fault Displacement Hazard in Italian urban areas. We have applied the illustrated model on the administrative territory of 73 Italian cities with population > 60,000 inhabitants, and in particular on the 45 cities that, according to ITHACA, are crossed by capable faults (Fig. 3 left).

Taking into account the maximum expected offsets, it is possible to state that Fault Displacement Hazard is very relevant

- in four cities (Reggio Calabria, Messina Catanzaro and Cosenza), where offsets even larger than one meter are expected (class 5);
- in six cities (Siracusa, L'Aquila, Ragusa, Benevento, Catania and Potenza), where maximum offsets are in the order of several decimeters up to one meter (class 4);
- in five cities (Trieste, Udine, Perugia, Treviso and Venezia) where maximum displacements can reach 50 cm (class 3);

In the other 30 cities, Fault Displacement Hazard does exist but is much less relevant, as maximum displacements are in the order of some centimeters (19 cities) or lower (the remaining 11 cities).

The total area exposed to FDH in the 45 cities is equal to about 2.5 % of the study area. In particular, the total area of Fault Class 5 is about 52 km², with a large contribution of those

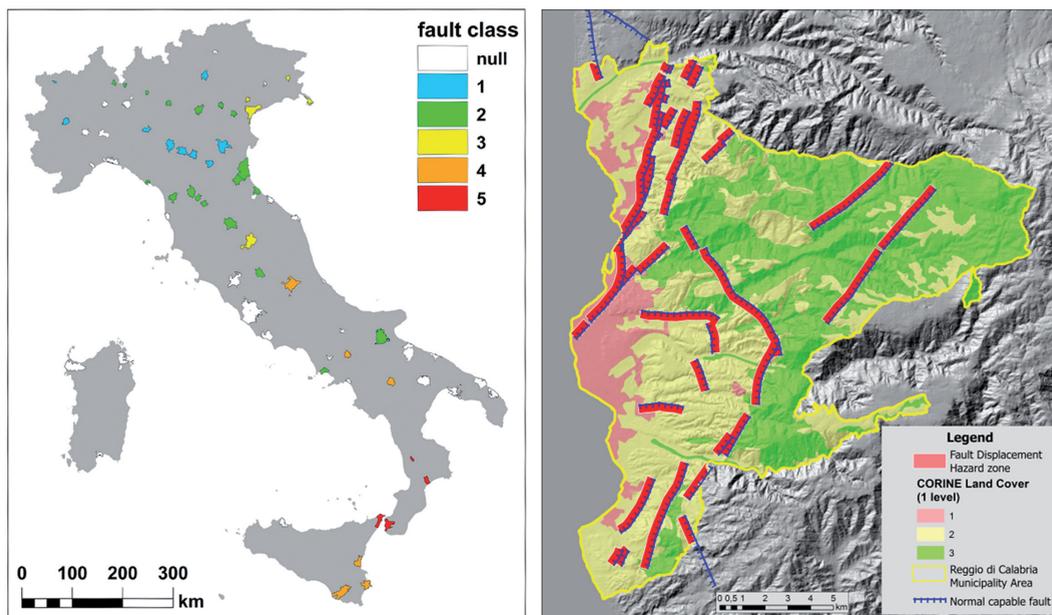


Fig. 3 – Left: Fault Displacement Hazard in the administrative territory of 73 Italian cities with population > 60,000 inhabitants. More than 60% of such cities are affected by capable faults: maximum expected offsets are different according to the fault class (see text for more details). Right: Fault Displacement Hazard areas at Reggio Calabria, mainly located in the hanging-wall of normal capable faults. Land Cover distribution and FDH areas; the FDH areas occur in urban (code 1), agriculture (code 2) and natural (code 3) zones.

affecting Reggio Calabria (31 km²; 12% of the entire territory, see detail in Fig. 3, right) and Messina (14 km²; 7% of the entire territory).

Considering the land cover/use of FDH areas (source: CLC 2006, EEA (2007), only 17 % is already urbanized. Conversely, most of the FDH areas (83 %) still affect agricultural and natural areas, but might be theoretically affected by urban development in the next future (see

Tab. 1 - Fault Displacement Hazard in the administrative territory of 13 Italian cities with population > 60,000 inhabitants, crossed by capable faults with relevant expected offsets, ranging from tens cms up to more than one meter (Fault Class 3, 4 and 5) Areas are expressed in km². Land cover in FDH areas is based on CLC 2006 and points out urban (class 1), agriculture (class 2) and natural (class 3) areas.

City	Fault Class	Total Municipality Area	FDH area	FDH% area	Land cover of FDH areas (CLC class 1)	Land cover of FDH areas (CLC class 2)	Land cover of FDH areas (CLC class 3)	FDH% Urban area
Catanzaro	5	112,7	4,7	4,2	0,6	3,2	1,0	12,3
Cosenza	5	37,9	2,0	5,3	0,0	1,3	0,7	0,3
Messina	5	213,8	14,3	6,7	2,7	4,8	6,8	19,1
Reggio di Calabria	5	239,0	30,9	12,9	3,8	18,6	8,5	12,3
Benevento	4	130,8	2,7	2,1		2,7	0,1	0,0
Catania	4	182,9	0,3	0,2		0,3	0,1	0,0
L'Aquila	4	473,9	37,6	7,9	1,2	5,7	30,7	3,2
Potenza	4	175,4	0,3	0,2		0,3		0,0
Ragusa	4	444,7	9,6	2,2	0,2	8,1	1,3	2,6
Siracusa	4	207,8	17,2	8,3	2,9	13,3	0,9	17,1
Perugia	3	449,5	7,2	1,6	0,4	5,5	1,3	6,1
Treviso	3	55,6	0,4	0,7	0,0	0,4		3,5
Trieste	3	85,1	5,6	6,6	1,6	0,8	3,2	28,3
Udine	3	57,2	1,8	3,1	0,6	1,2		34,3
Venezia	3	415,9	0,0	0,0		0,0		0,0

map for Reggio Calabria in Fig. 4, right). The land cover affected by FDH areas for cities where FDH is relevant (Fault Class 3, 4 and 5) is reported in detail in Tab. 1.

Of course, these results cannot be taken as a Fault Displacement Hazard zonation, due to the large uncertainties introduced in the analysis by the low-resolution in the spatial location of some ITHACA capable faults and in the CORINE Land Cover (scale 1:100,000).

Conclusions. Despite the uncertainties in the location of the FDH areas, this study contributes to identify the Italian cities where Fault Displacement Hazard does exist and is relevant, in terms of areal extension and maximum expected offsets.

The hazard is particularly evident in some cities located in Calabria and Sicily, in the inner sector of the Apennines and in Friuli. More detailed seismotectonic and paleoseismic investigations are recommended in the municipality territory of these cities for a more precise FDH zonation in order to i) adopt mitigation measures for strategic settlements located in the FDH areas and ii) to take into account the existing FDH in the areas that could be characterized by urban expansion in the next future.

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