Agreement INGV-DPC 2007-2009

Project S4: ITALIAN STRONG MOTION DATA BASE

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Appendix B

NTC topoghraphic classification of ITACA recording station

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1. Topographic classification

Morphometric analyses of high resolution digital elevation models (DEM), with the support of Geographic Information Systems (GIS), have been implemented to provide a practical tool for the identification of recording stations on topographic sites possibly affected by relevant seismic amplification effects.
Analysis havs been applied to 691 recording stations of the RAN (Italian National Accelerometric Network) with the aim to collect information for the ITACA database.
European and Italian seismic codes suggest topographic aggravation factors in the 1 – 1.4 range to be applied to seismic actions, depending on simple morphologic parameters (average slope angle, width and height of the relief), on the type of relief (isolated cliff or ridge) and on the location of the site relative to the relief.
According to the Italian Technical Norms (NTC, 2008), reflecting the same prescriptions as in the Part 5 of the EC8 (CEN, 2004), a simplified classification of landforms is identified into four categories:

1. T_1: flat surfaces, isolated slopes or reliefs with average inclination $i \leq 15°$
2. T_2: Slopes with average inclination $i > 15°$
3. T_3: Reliefs with ridge top width much smaller than the base, and average inclination $15° \leq i \leq 30°$
4. T_4: Reliefs with ridge top width much smaller than the base, and average inclination $i > 30°$

1.1 GIS method

Simple GIS functions are used to calculate slope parameters and to classify critical ranges of inclination, while the identification of ridges or reliefs with significant elevation gradients requires to devise more complex procedures, described in this work.
To this end, critical slope and ridge detection maps have been elaborated for the whole national territory, based on the 30x30 m resolution Global Digital Elevation Model GDEM (ASTER instrument developed jointly by METI (Japan) and NASA (USA); available on the site http://www.nasa.gov/topics/earth/features/aster-20090629.html). The original files are GeoTIFF format with geographic lat/long coordinates and a 1arcsecond grid and with estimated accuracy of 20 m at 95% confidence for vertical data. The files covering the whole Italian territory are 95 and, after to be downloaded, they have been made available, for internal use of the project, at the ftpsite: ftp.mi.ingv.it/download/Pessina_ASTER.
Standard procedures exist nowadays in any GIS software for the production of slope maps that can subsequently be classified in three slope ranges according to the building code requirements ($i < 15°$, $15° \leq i < 30°$ and $i \geq 30°$). The identification of crests and ridges, that is critical for a proper identification of the topography class, requires instead more complex procedures.
Once the critical conditions are synthesized into GIS layers, their proximity to strategic structures are checked. Analysis were performed at national scale: into a 100 m ray of the station the simultaneous presence of zones of potential topographic amplification has been detected (Figure 1).

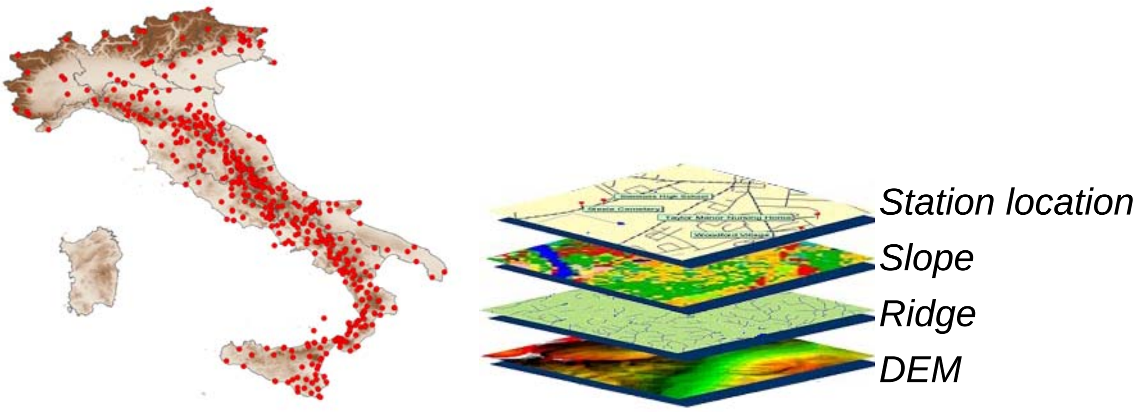

Figure 1. RAN station distribution and synthesized overlay process.

The ArcMap procedure *ad-hoc* implemented with "Model builder" application for the evaluation of critical slope, ridge and elevation gradient maps is shown in Figure 2 and 3, instead, illustrate the results of the ridge detection procedure applied in the Cental Appennine area, close to the stations of Colfiorito, Cesi and Serravalle di Chienti.

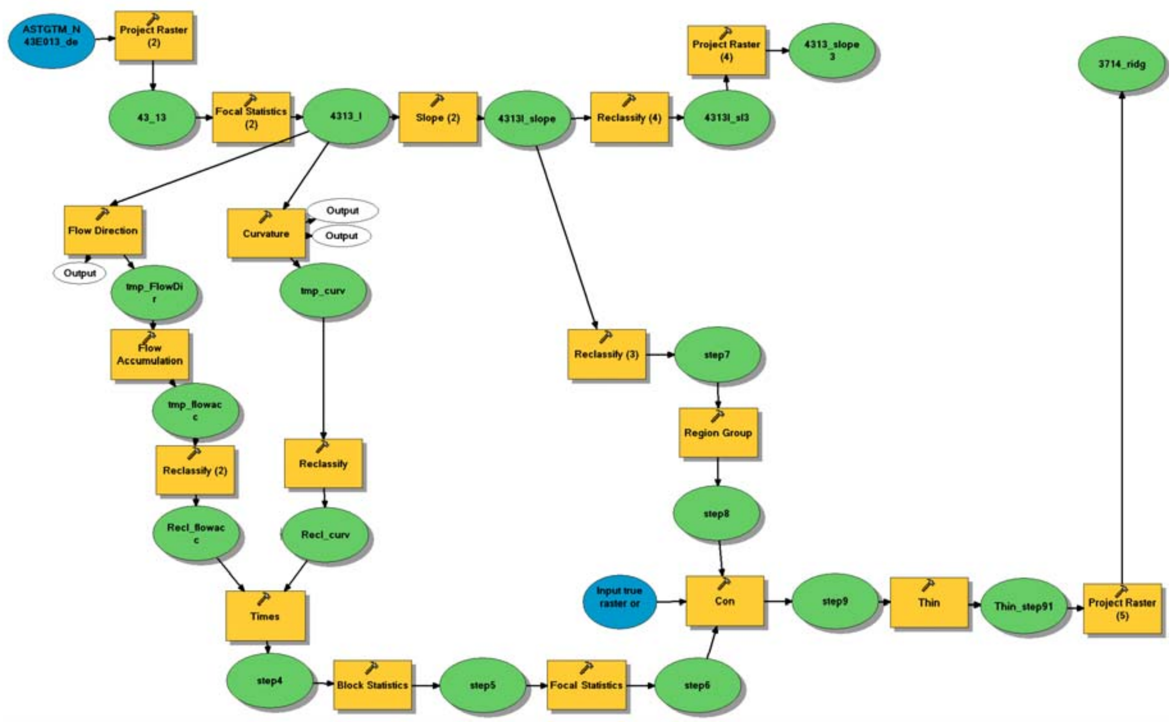

Figure 2. ArcGis model building structure developed for ridge detection: input data are in bleu, produced data in green and geoprocessing tools in yellow.

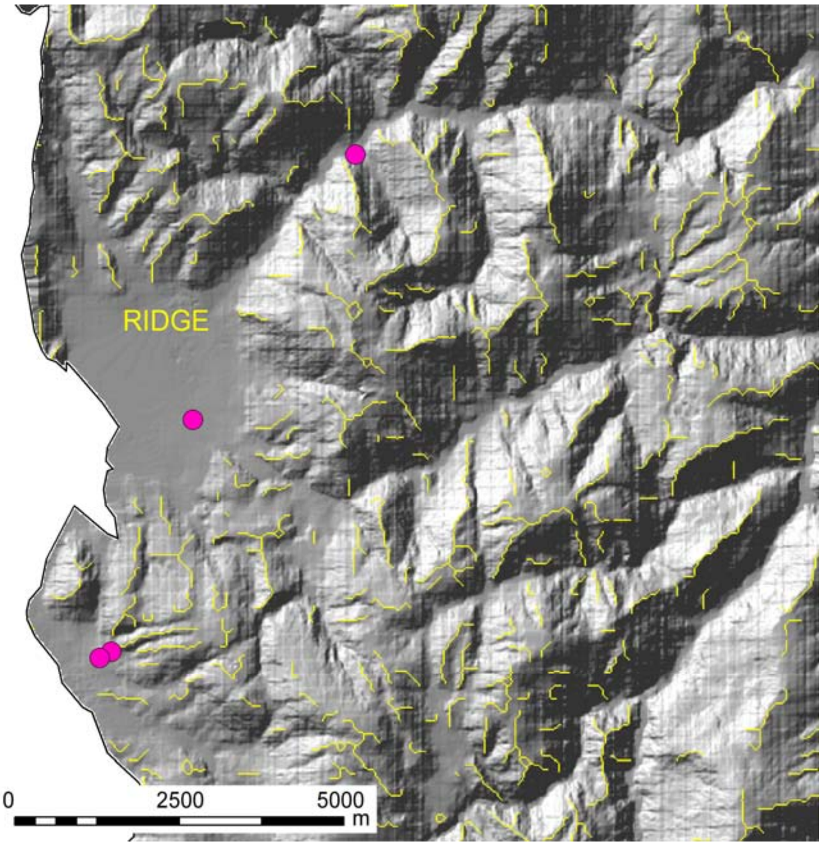

Figure 3. Results of ridge detection (yellow lines) in the Appennine mountains; circles represent the recording station position.

The GIS analysis has shown that the proper identification method depends on the resolution of the Digital Elevation Model (DEM) and on the morphological features of the terrain. For these reasons, sensitivity analysis were carried out referring to different Italian regions characterized by mountains with relatively low height and gentle morphology (Central Italy) and by high mountains and sharp topographic features (Alps or South Appennine zones) (Pessina *et al*., 2010).

1.2 Analysis on slope and ridge features

Each station was characterized according to the *slope* and *ridge* features.
Data are collected not in the exact position of the station, but in a 100 m buffer in order to reduce errors due to the inaccurate location of the station and to the shift of the grids after the mosaic operation. Through a *Zonal Statistic Analysis* values of a raster (in this case slope angle and ridge presence) are summarized within the zones of another dataset (the 100 m buffer station). Within the polygon of each recording station the software calculates various statistics of the slope and ridge maps, such as minimum and maximum value, mean, median, sum, majority, median, minority or variety. By combining the different values it is possible to identify the localities that can be affected by topographic amplification effects.

1.2.1 Slope

The slope map is reclassified into three classes with values ranging between 0 and 2 ($\boldsymbol{i} \leq 15$, $15° \leq \boldsymbol{i} \leq 30°$ and $\boldsymbol{i} > 30°$ respectively). The considered Zonal Statistic values are the minimum (MIN), maximum (MAX) and SUM; according to their combination, a *slope code* is assigned to each station, as shown in Table 1.

Table 1. Table statistical analysis parameters and their combination in the slope-code assessment.

MIN	MAX	SUM	N. of cases	description	*Slope_code*
0	0	0	410	No slope, flat area	0
0	1	1-46	169	If SUM < 4, small part of the area around the station is slope in the [15°-30°] range	0
				If 4 ≤ SUM < 35, significant part of the area around the station is slope in the [15°-30°] range	0.5
				Se SUM ≥ 35, all the area around the station is on slope in the [15°-30°] range	1
0	2	20-76	29	Presence of flat zone, slope in the [15°-30°] range and slope >30°	2
1	1	41-42	8	Full slope in the [15°-30°] range	1
1	2	51-77	14	Full slope > 15°	3
2	2	96	1	Full slope > 30°	4
		Total:	**631**		

1.2.2 Ridge

The ridge map is characterized by values of 0 (no ridge) and 1 (presence of ridge).
Assuming, as in the case of slope characterization, the same MIN, MAX and SUM parameters of the zonal statistical analysis, is the SUM value that fully identify the presence of ridge. Most of the cases in which SUM is > 10 (in a buffer station of 100 m) indicates that the ridge is diameter of the buffer and the station is very close to the ridge. Lesser value of SUM points out the presence of ridge near the station. Table 2 illustrates the combination of the zonal statistic parameters in the assignation of *ridge code* process

Table 2. Table statistical analysis parameters and their combination in the ridge-code assessment.

MIN	MAX	SUM	N. of cases	description	*Ridge_code*
0	0	0	477	No ridge	0
0	1	1-12	153	If SUM < 10, the ridge is closet o the station	0.5
				If SUM ≥10 the station is presumably on the ridge	1
1	1	1	1	Station on the ridge	1
		Total:	**631**		

1.2.3 Buffer overlay

Station with buffer partial or total overlay (see Figure 4) can not be discriminated during the zonal statistical analysis and need to be checked one by one; they are 60 stations.

1.3 Topographic classification

By combining the slope codes [0, 0.5, 1, 2, 3 and 4] with the ridge ones [0, 0.5 and 1] it is possible to assign the topographic index $T_1 \div T_4$ to the stations, as defined in NTC2008. The following situations have been classified (see also Table 3):

T1 Localities without amplification effects, with average slope $\boldsymbol{i} \leq 15°$, corresponding to the T_1 class of the NTC2008. In this group, 381 stations (~ 60% of the stations automatically detected) are located in area without ridges in the nearest 100 m, and 96 stations have presence of ridges but on very gentle hills or very elongated elevations, without significant 2D amplification effects. There is a single noteworthy case in which the station of Vagli is located close to a ridge on a steep slope, and the automatic procedure gives an erroneous topographic classification. Indeed, the station is located in the proximity of an artificial lake and the average slope $\boldsymbol{i}$ estimation is affected by the flat surface, while the morphological profile is really different. This situation deserves to go into more depth.

T2 Stations on slopes with average inclination $\boldsymbol{i} > 15°$, without presence of ridge (62 stations) or, when the ridge is close, there is no the simultaneous presence of accentuate slope ($\boldsymbol{i} > 30°$) (46 stations). Most of these cases refers to stations located on a slope or close to a flat morphological platform. According to the NTC2008 they are classified as T_2. Prescriptions indicate that the amplification is null at the base of the slope and maximum at the top: in this stage of analysis it is impossible to effective position of the station on the slope.

T3 Only very few stations (less than 10) were classified as T_3, being characterized by average inclination $15° \leq \boldsymbol{i} \leq 30°$ and presence of reliefs with ridge top width much smaller than the base.

T4 Finally, 4 stations were classified as T_4.

Some combinations of slope and ridge codes do not permit a firm classification in T_1 – T_4 class. For instance, 93 stations, about 15% of the total, are not directly classified (NC): most of them are station with no ridge and presence of medium slope within 100 m, generally located at the base of slope and belonging to T_1 or T_2 class. In these cases, a one-by-one classification was performed by the support of GoogleEarth and ArcGis data (checked data √ in Table 3). For instance, Figure 5 illustrates the case of MCR station, classified as T_1. Most of these cases are classified as T_1/ T_2, but T3 and even T4 cases has been recognised.

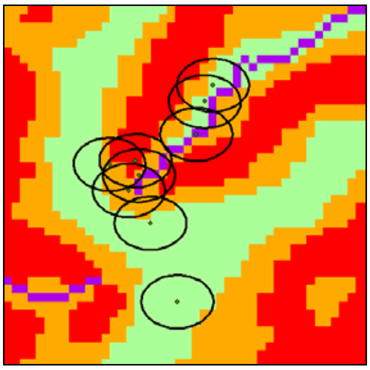

Figure 4. Stations located on the hill of Cerreto di Spoleto. When the 100 m buffer (black perimeters) are not circle because the map is projected in geographic coordinates. When the buffers overlay, it is not possible to extract useful information by the statistic analysis.

Figure 5. Example of visual inspection trought GoogleEarth for the topographic classification (the case of Macerata Feltria MCR station).

Some other combination can be doubtful. These cases are enlighten in Table 3 were all the combinations of slope and ridge codes and the final T_i (i=1,2,3) classification. For these cases a visual check (√) has been performed, by sample, and the prevalent T_i class has been attributed to the combination.

Table 3. Combination of ridge _code and slope_code in the assignment of EC8 topographic classes.

Ridge code	Slope code	N. of cases	Description	EC8	Check
0	0	381	Flat zone	T1	
	0.5	79	Close to slope with 15°< *i* <30° (T1, T2, T1/T2)	NC	√
	1	29	On slope with 15°< *i* <30°	T2	
	2	18	No ridge, contemporary presence of flat area and slope *i* > 15°. Stations **generally** classified as T2, it is impossible detect if they are at the base of slope, in the middle of slope, near terraces or in narrow valley).	T2	
	3	14	On slope with with *i* > 15°	T2	
	4	1	On slope with with *i* > 30°	T2	√
0.5	0	92	Flat zone (the presence of ridge evidences small morphologic discontinuities on a territory generally flat). Some visual inspections leat to a T1/T2 classification for stations located at the base of a slope	T1	
	0.5	41	Close to the ridge and presence of slope with 15°< *i* <30°	T2	
	1	5	Close to the ridge and on slope with 15°< *i* <30°	T2	
	2	8	Close to the ridge and contemporary presence of flat area and slope *i* > 15°. Some situations refers to hill as the case of San Marino, Cerreto di Spoleto and Pollina. (T2, T3, T4)	NC	√
	3	4	Close to the ridge and on slope *i* > 15°.	T4	√
1	0	4	Elongated hills with very gentle slope (*i* < 15°), not affected by 2D amplification	T1	
	0.5	6	Elongated hills with gentle slope (*i* < 30°), not affected by 2D amplification, but neither flat (T1/T2, T2, T3)	NC	√
	1	6	Ridge and slope with 15°< *i* <30°	T3	√
	2	2	Rridge and contemporary presence of flat area and slope *i* > 15°. (hill)	T3	√

1.4 How to use the topographic information

Within the ITACA database, the topographic classification can be used with the opportune criteria. At the first step, the automatic attribution of T1 can be assumed with a high level of confidence: they represent about 69% of all the stations (see figure B6).

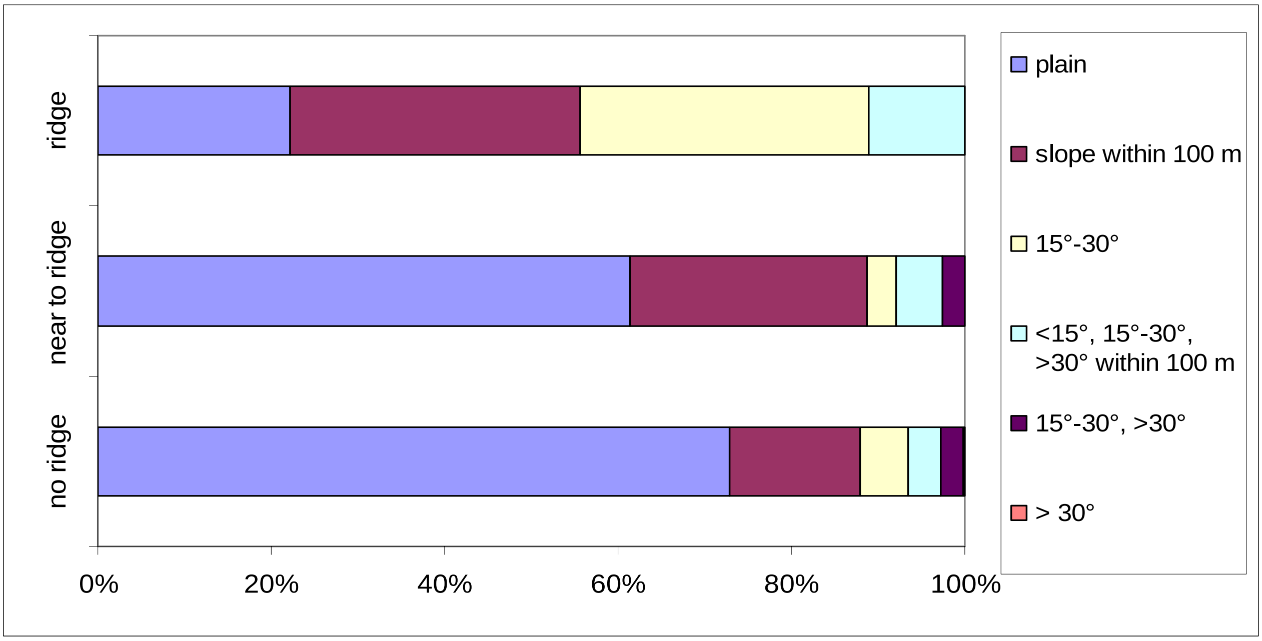

Figure 6. Distribution of the classified stations, accordino to the slope and closeness to ridge.

The remaining 31% of the stations can be deal with caution:

- the manual inspection (√) assures a medium level of confidence, largely for T2, T3 and T4 classification;
- but the one-by-one visual check is not convinced when stations are classified NC (Not automatically Classifiable), indeed, most of the NC cases, even if they are visually detected, can not be univocally classified and they present a large margin of uncertainties. For instance, the PGL (Peglio) station is located close to a ridge of a relief with slope from null ($\boldsymbol{i} \leq 15°$) to moderate ($15° < \boldsymbol{i} \leq 30°$) inclination (see Figure B7): the ridge top width is not much smaller than the base and it can be difficultly classified as T3. Moreover, the inclination of the slope is low and again the station can be difficultly classified as T2. At the end a T1/T2 class was attributed to the PGL station
- Moreover, most of the T2 cases refer to station located on slope, without further indication on the relative position of the slope (at the base, in the middle or at the top of the slope). EC8 and NTC08 norms indicate that the amplification is null at the base of the slope and maximum at the top, varying uniformly along the slop.

Operatively:

1. One third of the stations not classified as T1 could be affected by amplification phenomena and deserve a deeper investigation.
2. In the ITACA characterization form, T2, T3 and T4 stations that have not been investigated (√) can be proper marked to indicate a lower level of confidence in the attribution of topographic classification.

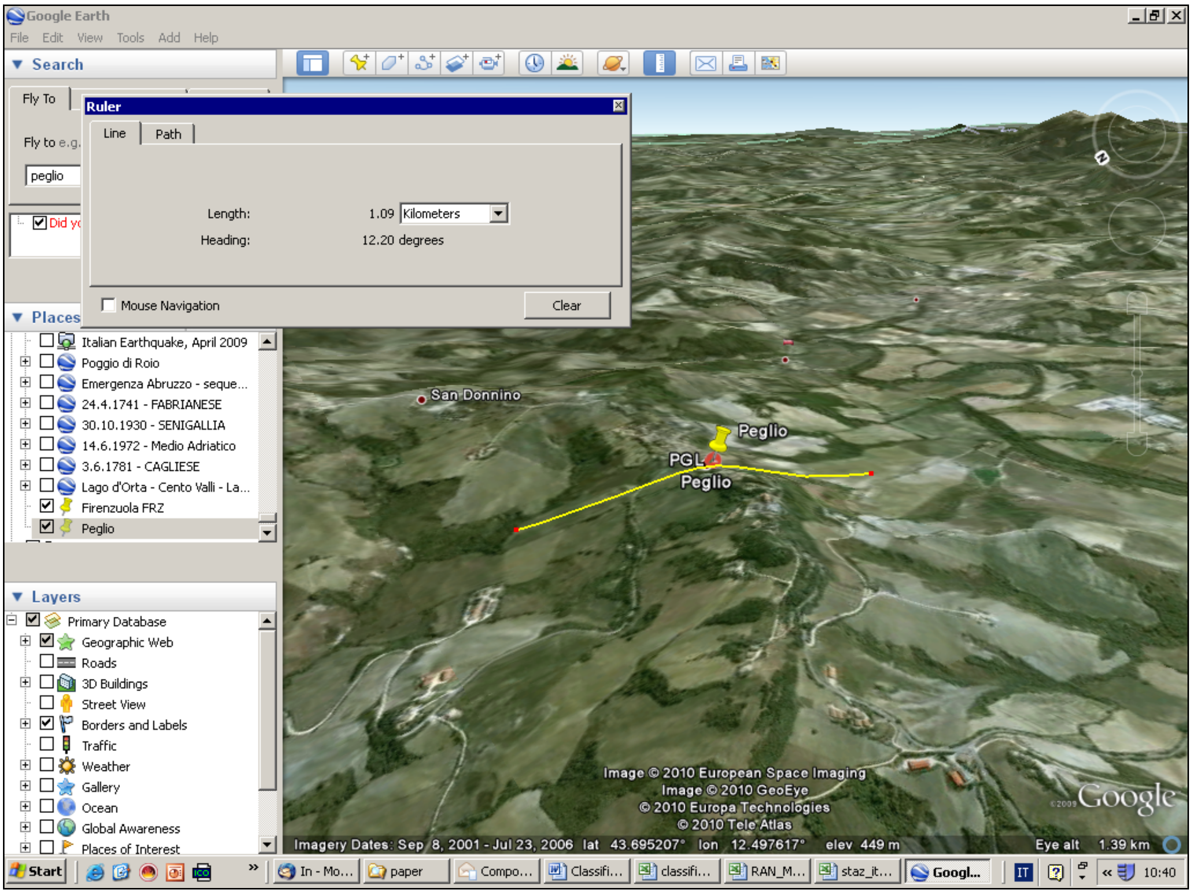

Figure 7. Peglio station, located in proximity of a ridge of a "large" relief, represents one of the cases of doubtful classification.

References

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