CASSAS Landslide - Susa Valley, Piedmont, Italy

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1 INTRODUCTION

The “Cassas” landslide extends on the right hydrographic slope of the middle Susa Valley in the Cottian Alps (Piedmont, Italy), about 10 km SW from Susa town. The valley is drained by the Dora Riparia river. The landslide is located inside the territory of Salbertrand (Turin County), in the Gran Bosco Natural Park and it affects the overall right slope in Cassas locality.

The Susa Valley has always been an important line of communication between Italy and France. In the studied area, the highway A32 (Turin-Frejus tunnel), the international railway line Turin-Modane and the National Road SS24 run across the Salbertrand flood plain. The highway A32 service station “Gran Bosco” is located close to the landslide toe.

It seems interesting to remember that the landslide name comes from the French word “Casser” meaning “to break”.

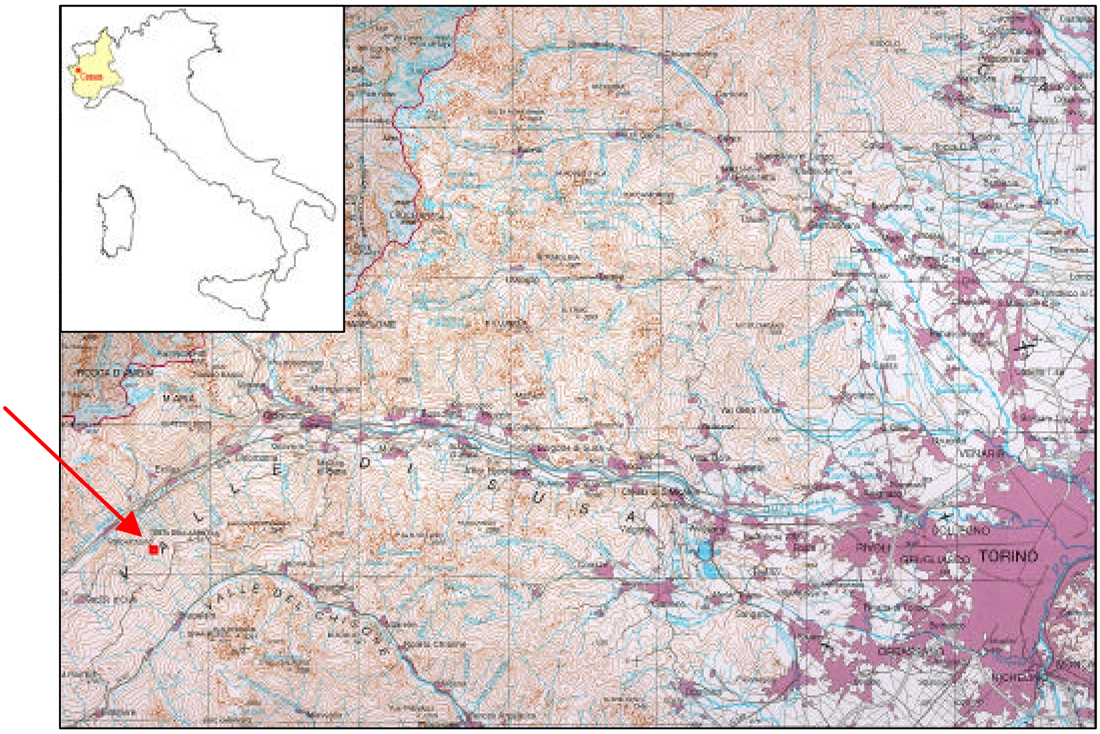

Figure 1. Location map of "Cassas" landslide , Susa Valley

2 REGIONAL FRAMEWORK

2.1 *Climate*

The climate of the considered area is characterised by a Pre-alpine regime (type "c"). According to Thornthwaite classification, this area can be classified as B4B1'rb3', Region: cold axeric; Subregion: cold temperate (BIANCOTTI & BOVO, 1998a e b; BROVERO et al.,1996; ECOPLAN, 2000).

The annual average rainfall (period 1951-1986) is 869 mm, with 94 raining days per year and an average intensity of 9.2 mm/day. Rainfall peaks have been recorded in Salbertrand in May (86 mm) and October (85 mm).

As regards thermometric regime, these are the monthly mean temperatures [°C] recorded by the station of Salbertrand-Le Selle (alt. 1950 m amsl – period 1991-1999): Jan -1,25; Feb –0.99; Mar 0.72; Apr 1.89; May 6.6; Jun 9.37; Jul 12.42; Aug 12.66; Sep 7.86; Oct 4.7; Nov 1.1; Dec –1.74.

Mean snow covering [cm] measured at the Salbertrand-Le Selle station (alt. 1950 m amsl – period 1991-1999): Jan 56.4; Feb 67.3; Mar 65; Apr 33; May 5.7; Jun 11.9; Jul 8; Au 6; Sep 2.4; Oct 3.2; Nov 8.4; Dec 32.2.

2.2 *Regional Morphology*

The upper Susa Valley is mainly characterised by fluvial and glacial morphogenesis and by landslide activity.

Salbertrand plain was originally a lake generated by the valley damming due to old landslides (in correspondence of Serre La Voute locality) and the Susa-Chisone watershed is characterised by bilateral extension of top ridges. Geological evidences indicate that the regional geodynamic stress field and the gravity slope deformations are interactive systems (CAPELLO, 1941; see references in BROVERO *et al.*, 1996).

2.3 *Regional Geology and Structural Setting*

This slope is located in correspondence of the contact between the Ambin Massif (Briançonnais Domain, Middle Pennine Units) and Piedmont Domain (Undifferentiated calcschists and ophiolite units - Piedmont-Ligurian ophiolite nappe system).

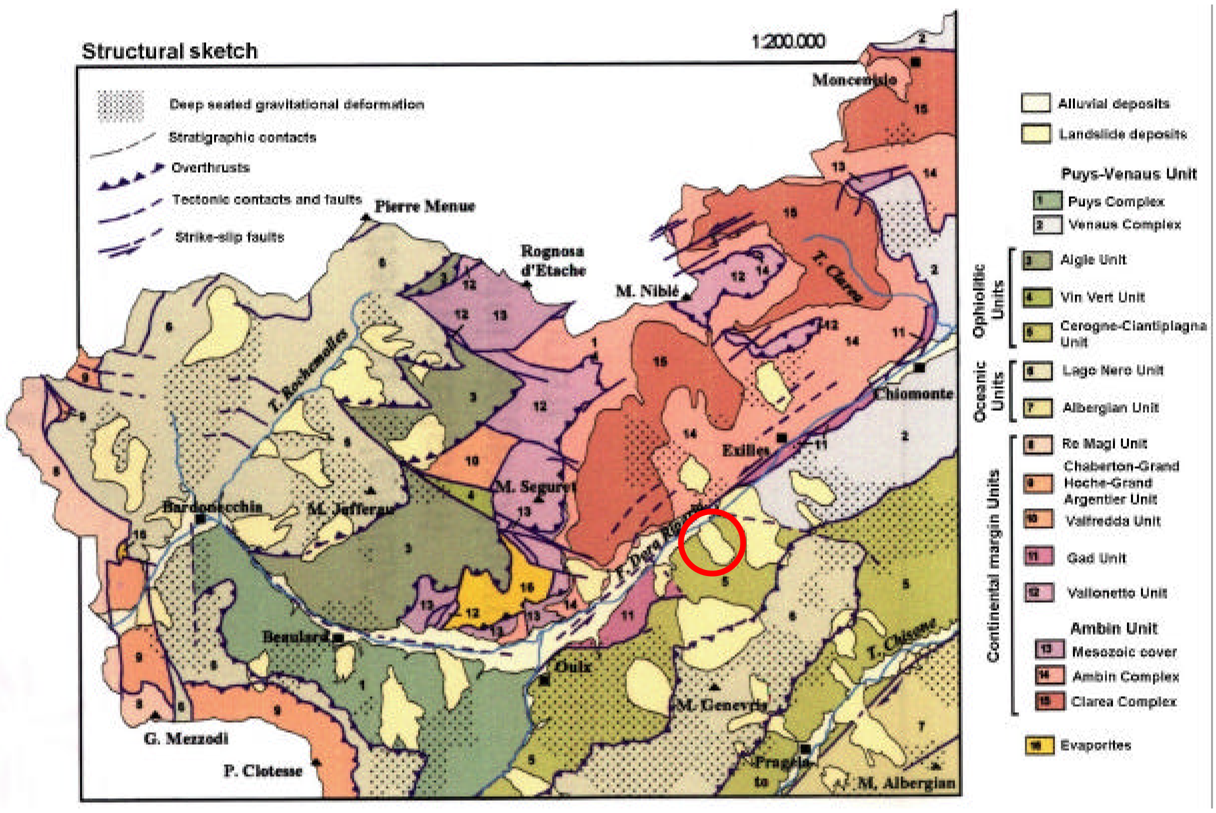

Figure 2. Geological-structural map of the Bardonecchia sheet n. 153 of the CGI 1:50000 scale and legend of the tectonostratigraphic units (red circle: Cassas landslide) [AA.VV., 1999].

The Ambin tectonostratigraphy is represented by:

- Clarea Serie (micaschists and fine-grained gneisses, pervasively albitized, re-equilibrated to blueschist-facies),
- Ambin Serie (metacomglomerates with quartz pebbles; quartzose micaschists and quartzites; glaucophane-, white mica- and chlorite-bearing micaschists with rare marbles in decimetric levels; quartzose micaschists with chlorite and rare glaucophanic schist boudins.
- Mesozoic cover (carbonate-rich micaschists; grey marbles, dolomite and subordinates micaschists; micaceous quartzites layers, green-white, locally quartz-micaschists at chloritoid levels; quartzitic conglomerates).

The Ambin Massif outcrops on the left slope of the valley and, subordinately, at the bottom of the right one.

Piedmont Domain outcrops on the right slope and is represented by:

- Gad tectonostratigraphic unit (lawsonite - phengite - chlorite bearing calcschists; carbonatic breccias with dolomitic and quartzic clasts; grey massive dolomitic limestones with subordinate levels of carbonatic breccias).
- Cerogne-Ciantiplagna tectonostratigraphic unit (calcschists with glaucophane and epidote)
- Chiomonte-Venaus complex, pertaing to the Puys-Venaus tectonostratigraphic unit (glaucophane and epidote bearing blackish schists and massive carbonate calcschists and interlayers of mica and chlorite bearing quartzites and gneiss).

Quaternary deposits are represented by: glacial deposits (lodgment, ablation and undifferentiated till), landslide deposits, mixed origin deposits, scree, alluvial deposits. Recent eluvial-colluvium deposits are represented by heterogeneous and incoherent mass of soil material and rock fragments.

The regional synmetamorphic deformation is characterized by a tectonic foliation (S1) that overgrew on the pre-Alpine layering with development of folds P1 (first folding phase); S1 is refolded by a second folding phase P2 that gave origin to crenulation cleavage S2. The S2 foliation corresponds to the main Alpine regional schistosity (SR). P2 folds are refolded by a third folding phase (P3 folds) with associated crenulation cleavage S3; decametric folds P4 and schistosity S4 (related to the fourth phase) are also observed.

The regional brittle tectonic deformation is characterized by:

- N60 normal and left-lateral strike-slip conjugated fault systems;
- N100-120 normal and right-lateral strike-slip fault systems;
- N-S dip-slip fault systems.

These brittle structures are recognizable at all scales (from kilometric to outcrop scale).

3 LOCAL FRAMEWORK

3.1 *Local Geology and structural setting*

The landslide site is located in the Cerogne-Ciantiplagna tectonostratigraphic unit (Undifferentiated calcschists and ophiolite units) that is characterized by several Alpine ductile deformation phases followed by intense brittle deformation.

At local scale, bedrock exposures belonging to the Cerogne Complex are constituted by undifferentiated calcschists into blueschist-facies at glaucophane and epidote with interlayers of carbonatic calcschists with ochre alteration patina; metabasites more or less layered with locally basaltic metabreccias; quartzites with Mn mineralization; micaceous quartzites at Na-anphibole; phyllitic micaschists and blocks of serpentinite.

The main discontinuities observed (with dip-direction and dip), mainly carried out from field investigation (1991, 1996, 2000), are listed below:

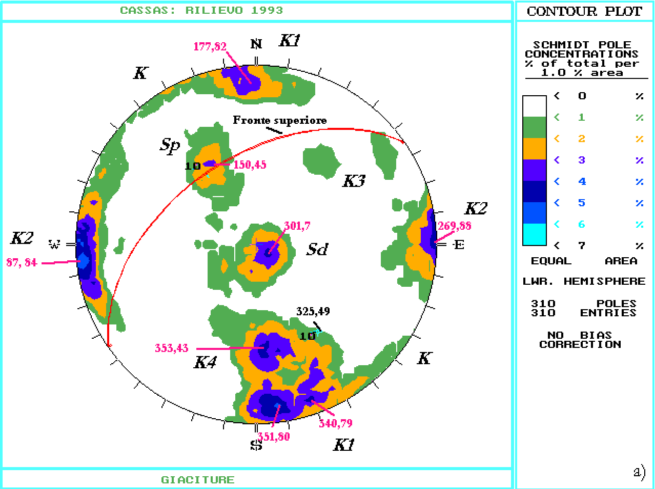

Figure 3. Stereographic representation to the discontinuity systems (Sp=SR, Sd=SL) [BROVERO *et al.*, 1996].

SR - (150°/45°): Regional schistosity, sub-parallel to the tectonic contact between the Ambin tectonostratigraphic unit and undifferentiated calcschists and ophiolite units.

SL - (301°/15°): Local schistosity foliation with variable orientation near the main scarp.

K1 - (351°/80°): Main fracture system: sub-vertical joint system N and S dipping, generally highly persistent; generally low alteration with rare presence of soft filling of cataclasite and breccia.

K2 - (269°/88°) - Main fracture system: E and W dipping sub-vertical fracture systems partially sub-parallel to sub-meridian regional dip-slip fault system; generally low alteration with rare presence of soft filling.

K3 (230°/60°) - This system is well distributed and less persistent and pervasive than K1 and K2; generally low alteration with rare presence of soft filling (microbreccia, silt and gouge).

K4 (350°/45°) - This system is less persistent and pervasive than K1 and K2; carbonatic striae (dipping 40°-45° to WNW) have been observed on some K4 joints in the detachment zone; generally low alteration with rare presence of soft filling (calcite, cataclasite and microbreccia).

K (330°/90°) – Sub-vertical joint system striking NE and SW; generally low alteration with rare presence of soft filling (microbreccia and silt).

3.2 *Water Conditions*

No surface waters have been observed on landslide area; some drainage lines correspond to the external margins (starting approximately at 1250 m amsl). Flow regime is related to seasonal cycle, fading during dry periods. Aquifer is represented by very permeable landslide debris cover. The basic level corresponds to the underlying calcschists bedrock. Groundwater level varies according to rainfall regime. Main infiltration zone (rain and snow melting) is located in the upper part of Cassas accumulation zone. Highly fractured bedrock enables deep water circulation.

Two springs are present in the lower part of landslide (estimated flow on July 1997: from $2 \cdot 10^{-4}$ to $8 \cdot 10^{-4}$ m^3/s). There are also some springs along the scarp crossing the displaced mass between 1350 m amsl and 1550 m amsl. (EPIFANI, 1991; BROVERO *et al.*, 1996; PARO, 1997; ECOPLAN, 2000).

4 LANDSLIDE

4.1 *Landslide Identification*

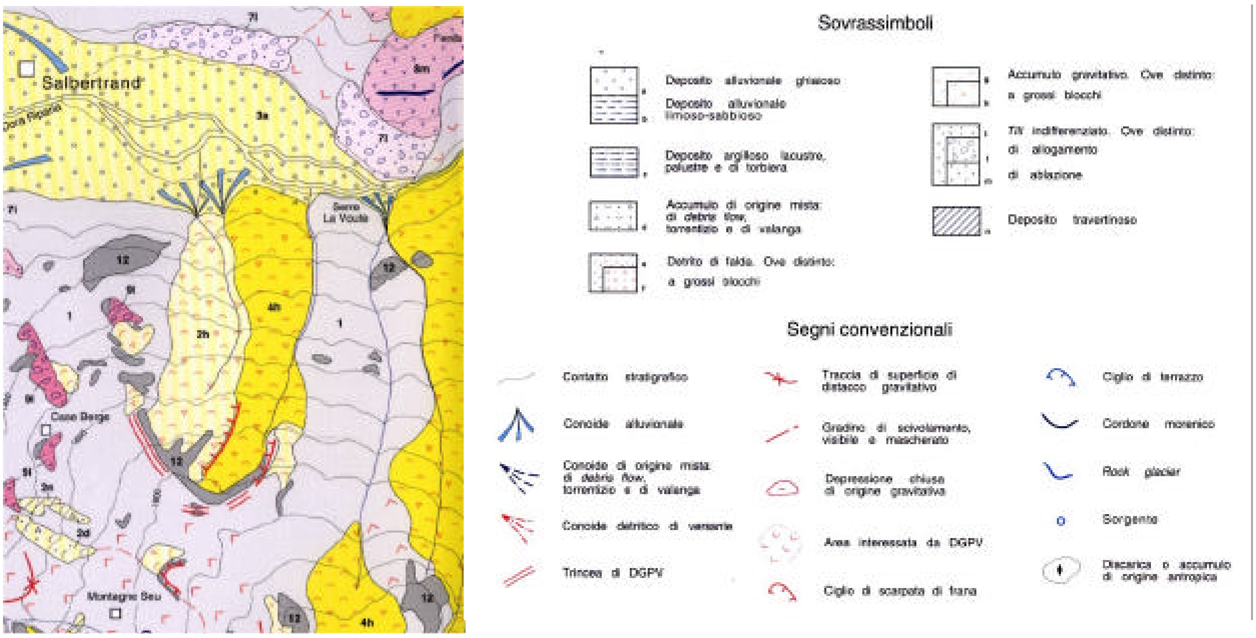

Figure 4. Extract from superficial formations map of Susa Valley [GIARDINO & FIORASO, 1998]
Legend. 1: eluvium-colluvium; 2, 4: landslide acc.; 3: alluvial dep.; 7,8,9: glacial dep.; 12: bedrock.

The slope morphostructural characteristics of the Cassas landslide sector are connected to deep-seated gravitational slope deformations phenomena. Two different zones of accumulation can be recognized, adjacent and partially overlapping. Displaced mass volume has been estimated in 20÷30 millions m^3 (estimated volume of the most active sector not less than 10 millions m^3).

The right slope involved by Cassas landslide extends for about 1550 m in altitude, with an average gradient of 50%÷55% and exposure to NW.

Slope profile is characterized by cambering and slope bulging with closed subsidences and trenches. The main scarp, developed as an arcuate pattern, is modeled in very fractured carbonate schists.

At the present moment four main movements are recognized: two involving the metamorphic bedrock (as extremely slow deep-seated gravitational slope deformation-DSGSD and as seasonally rock fall) and two involving deposits (debris) as very slow slide and as flow towards the bottom of the valley.

Displacements were recorded in 20/05/1728 (probably in surrounding areas), 1920÷1930, 1954, 1955, 06÷14/12/1957, 02/1958, but the last paroxistic event occurred on June 1957, when there was a rainfall of about 150 mm in 3 days. The 1957 landslide has been characterized by four different kinematic mechanism: as toppling and rock fall in the upper part of the landslide body and as debris slide-debris flow which reached the Dora Riparia river.

4.2 *Landslide Detail*

Inside the “Cassas” area three distinct sectors are recognizable:

Cassas landslide s.s. 1, corresponding to the upper part of landslide (about 1350 m to 1950 m of altitude);

Cassas landslide s.s. 2, corresponding to the lower part of landslide (about 1350 m of altitude to floor valley - about 900 m)

Pietragrossa, corresponding to the oriental border of Cassas landslides (s.l.), whose instability is related to post-glacial event, while displacement dates are not known.

A wide bedrock outcrop can be observed at the left side of Cassas landslide, just above the highway service station. Woody scree is present at the outcrop bottom.

4.3 *Landslide Morphometry*

The affected slope has an extent of 1.8 km in length (total area about 0.8 km^2), a total height of 900 m (from 1900 m to 1000 m of the talweg) and a supposed total volume of the mobilised mass involved of $20 \cdot 10^6$ $m^3 \div 30 \cdot 10^6$ m^3 (more active sector supposed volume not less than $10 \cdot 10^6$ m^3).

Measurements referred to a campaign of seismic profiles and drillings (GEODATA, 1996) estimated a width of 550-600 m and a depth of rupture surface of 60 m about (see fig. 9).

4.4 *Landslide Morphology*

Figure 5. Cassas landslide (photo of the 1965)

The main landslide features were observed in different aerial photos of 1954, 1963, 1978 and 1990.

On aerial photos of 1954 in the upper part of western landslide (about 1350 to 1950 m asml - Cassas landslide s.s.1) were recognizable transverse cracks of recent formation, as well as zones of accumulation of recent debris falls,

On aerial photos of 1963 the maximum extension of Cassas landslide in the last paroxysmal event of June 1957 has been delimited, with slide as main movement and subordinate falls; minor scarps related to recent (June 1957); arcuated slide surfaces were also evident.

In the lower part of landslide (about 1350 m amsl to floor valley-900 m amsl- Cassas landslide s.s. 2) debris flow movements prevail and the zone of accumulation in the floor valley, on the preexistent fan, is evident.

On aerial photos of 1978 minor scarps related to 3 plain slide surfaces are visible.

After field mapping and aerial photointerpretation, evident morphological features (PUMA *et al.*, 1989) seem to point out recent movements in the Pietragrossa sector, corresponding to the lower part of oriental border of Cassas landslides (s.l.).

4.5 *Landslide History*

First historical data concerning instability processes in this area are referred to the May 1728 flood event, which heavily affected all the Susa Valley. At the end of the 19th century the general instability of this area caused a lot of problems to the constructions of railway tunnels between Chiomonte and Salbertrand.

Afterwards, in the first half of the 50's of the 20th century, a sequence of localized movements were recorded and then, during the June 1957 flood event, a paroxysmal phase interested the western part of the slope, determining the actual morphological pattern.

Recent monitoring techniques recorded a movement rate of 100/120 mm/y in the youngest part of accumulation.

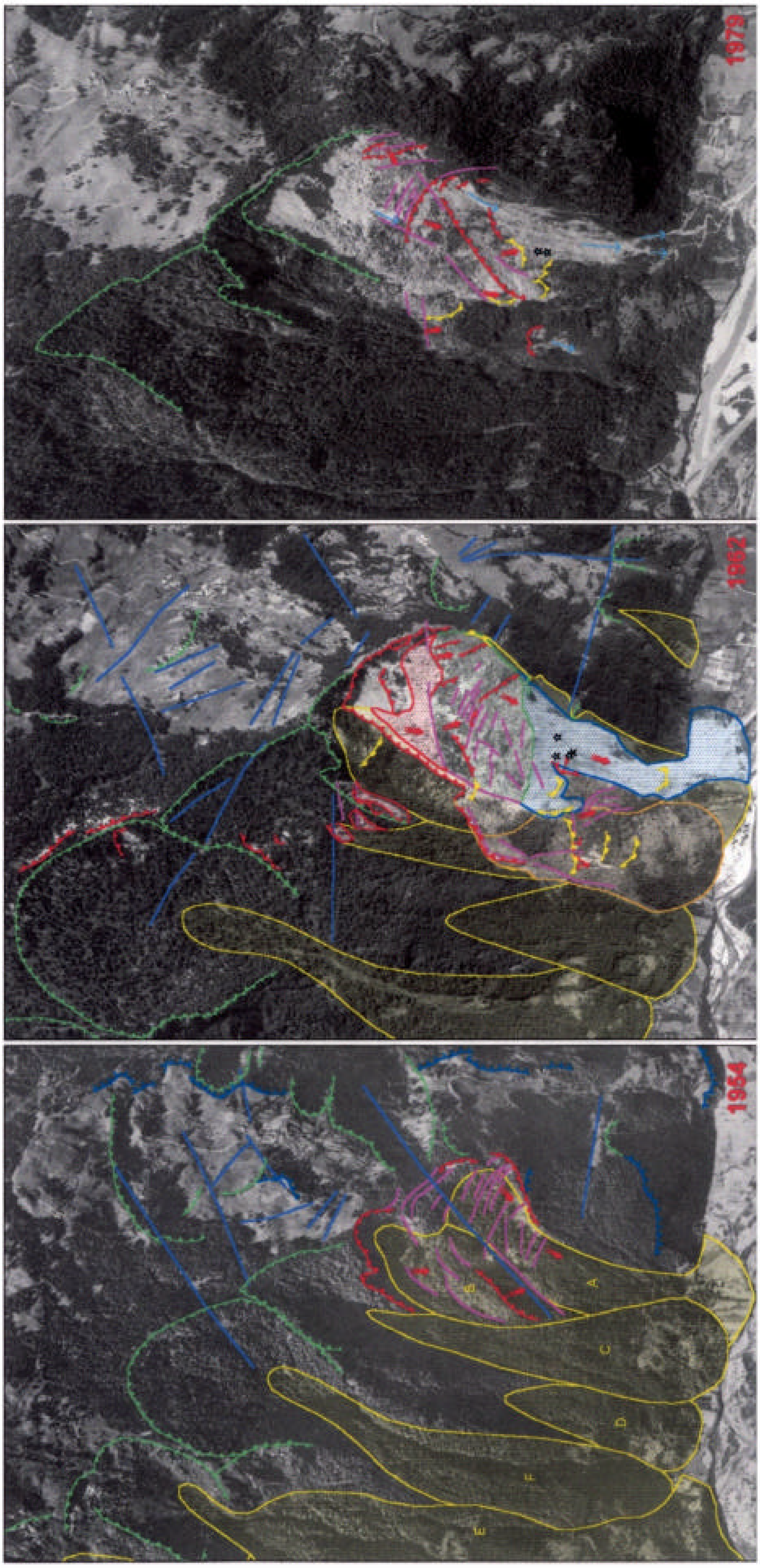

Figure 6. Cassas slope evolution trend by photo-analysis (1954, 1962, 1979) [CITIEMME *et al.*, 2000]

5 INVESTIGATION AND MONITORING

Several studies related to historical analysis, field works and deep investigations of Cassas landslide have been carried out since 1980.

In order to preserve the important transportation infrastructures (international highway and railway) laying at the bottom of the investigated slope, a monitoring system and a series of protection works have been designed and installed.

The organisation of geological-structural data and the subsequent realisation of a geological model are necessary to understand the instability phenomenon evolution. Thus, it is relevant to link the different data sets referring to a proper local tectonic and/or kinematic model and to construct geologic profiles and 3D models.

Mechanical, hydraulic, hydrogeological information are then needed to build up and run geotechnical models.

Last, but not least, displacement measurements and deformation monitoring allow to control the landslide evolution which is important for prevention as well as for calibrating the models prediction.

5.1 *Survey and monitoring of landslide activity*

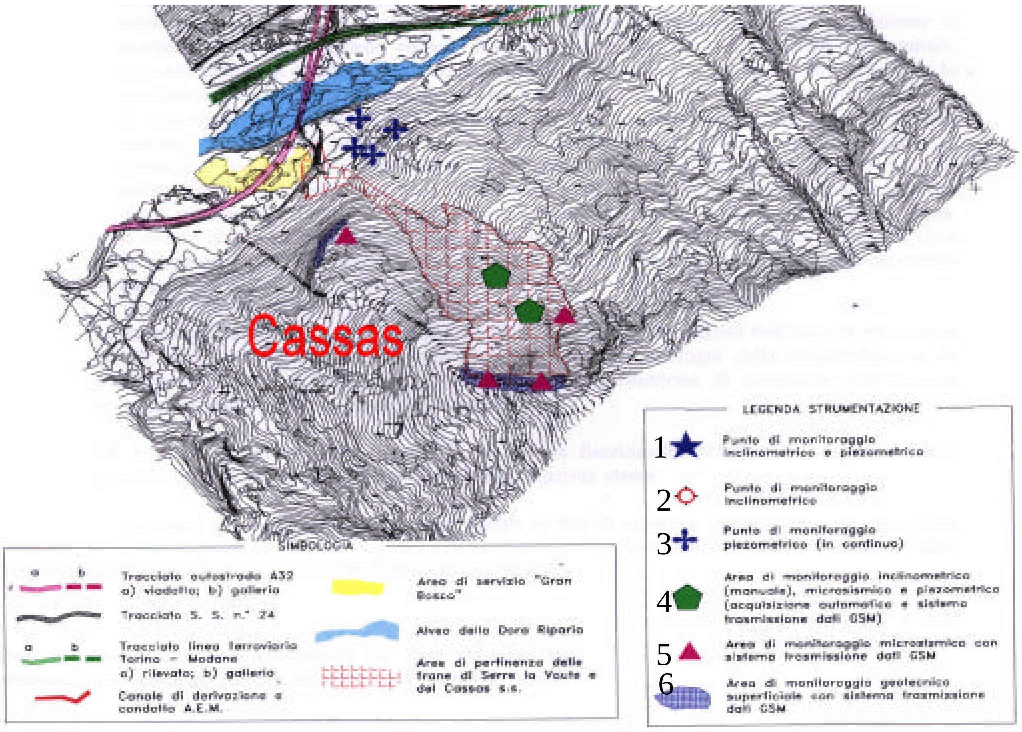

Figure 7. Monitoring devices location map [CITIEMME *et al*., 2000].

1) inclinometer and piezometer ; 2) inclinometer ; 3) piezometer; 4) inclinometer, piezometer, micro-seismic monitoring (automatic acquisition data and transmission system by GSM); 5) micro-seismic monitoring area with transmission by GSM; 6) surface geotechnical monitoring area equipped with data transmission by GSM.

17 boreholes (15 with continuous coring) have been drilled since 1991 (BROVERO *et al*., 1996; CITIEMME *et al*., 2000):

- 14 in the landslide body (50÷80 m deep);
- 3 at the landslide crown (25÷30 m deep);
- some of the boreholes house piezometers, inclinometer casings, geophones.

Drilling logs confirm a 50-60 m thick landslide body made of chaotic materials (boulders, pebbles, clasts) in sandy and/or silty matrix. The hypothesis of a failure surface located at about 60 m depth is supported by the presence of breccias and a fine silt level.

The 4 seismic refraction profiles survey (EPIFANI, 1991; BROVERO *et al.*, 1996) reveals the following layers, in agreement with boreholes information:

- cover (shallow unit): seismic velocity 0.5-0.7 km/sec,
- cover (bottom unit): seismic velocity 1.6-1.7 km/sec,
- chaotic layer of debris in sandy/silty matrix: seismic velocity 3.0-3.8 km/sec,
- fractured rock substratum: seismic velocity 4.0-4.4 km/sec.

Geotechnical laboratory tests performed (BROVERO *et al.*, 1996), measured a compressive uniaxial strength respectively of 58 MPa for massive schists and of 36 MPa for phyllitic schists.

The “ROCK NOISE” micro-seismic monitoring network (GEOENGINEERING, 1996, GEODATA, 1996, BROVERO *et al.*, 1996; CITIEMME *et al.*, 2000) consists of 5 surface and 2 deep (installed inside boreholes) uniaxial geophones in the crown area; 3 surface and 2 deep uniaxial geophones besides 2 deep triaxial deep geophones in the landslide main body. One triaxial surface geophone is located near the toe, but out of the recognised landslide area. Since installation (summer 1994 – spring 1995), the network has been recording micro-seismic activity; routine signal processing have been carried out in order to distinguish “local” and “far” events (CITIEMME 2001a).

Two 50 m deep inclinometers (Cassas3 & Cassas4) were installed in 1995 in the main body area (GEOENGINEERING, 1996; GEODATA, 1996; BROVERO *et al.*, 1996). Data recorded since October 1998 (when boreholes have been recovered after damage and drilled to 80 m depth) up to July 2001 are briefly summarised hereafter (CITIEMME, 2001d):

- Cassas3: max deformation between 47 and 50 m depth, max integral displacement about 120 mm (1st June 2001) along NNW direction;
- Cassas4: max deformation between 61 and 63 m depth, max integral displacement about 145 mm (1st June 2001) along NW direction.

In the period June-July 2001, displacement magnitude in the most deformed sections has increased so that at the moment measures are only possible in the upper portion of the boreholes, to 47.5 m and 62.0 m depth respectively (CITIEMME, 2001e).

Two sectors of the main body were instrumented with 14 joint extensometers and 1 tiltmeter; a sector near the toe (out of the recognised landslide area) was instrumented with 12 tiltmeters and 12 joint extensometers in 1996 (GEOENGINEERING, 1996; BROVERO *et al.*, 1996). No significant displacements nor rotations have been recorded, according to the last measures available (GEODATA, 1996; CITIEMME, 2001c).

Two geotechnical tests were performed on massive schists, measuring uniaxial compressive strength (58 Mpa) and on phyllitic schists, measuring uniaxial compressive strength (36 Mpa).

5.2 *Monitoring of meteorological and Hydraulic conditions*

Meteorological conditions in the considered area are monitored through 2 stations of Regional Meteorological Service, active since 1990 located at Salbertrand-Graviere (1032 m amsl) and Salbertrand-Le Selle (1950 m amsl).

Considering the 1991-1999 period, the main recorded values for Graviere (BIANCOTTI & BOVO, 1998a; BIANCOTTI & BOVO, 1998b) are:

- max monthly precipitation: 280 mm (October 1992),

- average max monthly precipitation: 100 mm (October),
- max monthly height of snow covering: 168 cm (February 1994),
- average max monthly snow covering height: 233 cm (February),
- annual average annual temperature: 7.6 °C (ECOPLAN, 2000).

For the same period at Le Selle station (BIANCOTTI & BOVO, 1998a; BIANCOTTI & BOVO, 1998b):

- max monthly precipitation: 232 mm (June 1992),
- average max monthly precipitation: 119 mm (May),
- max monthly snow covering height: 124 cm (January 1997),
- average max monthly snow covering height: 67 (February),
- average annual temperature: 4.5 °C (ECOPLAN 2000).

Two electrical resistence strain gauge piezometers (Pz3 and Pz4) were installed in the main body; three electrical resistence strain gauge (Cas1, Cas2, Cas3) and the Cas4 absolute pressure transmitter (since an artesian water table was encountered) were installed near the landslide bottom (GEOENGINEERING, 1996; GEODATA, 1996; BROVERO *et al*., 1996; CITIEMME *et al*., 2000).

In the period June 1999 – June 2001, Pz3 has shown a discontinuous and rising trend with water level between 34 and 25 m depth, while Pz4 has shown a discontinuous and deepening trend with water level between 33 and 40 m depth (CITIEMME, 2001c).

In the period April 1998 – June 2001, Cas1 has shown a constant water level at about 31 m depth, Cas2 a smooth rising trend with water level between 20 and 17.5 m depth, Cas4 has measured pressure oscillating probably due to the meteoric events, while Cas3 has been out of order since September 2000, after a substantially constant water level between around 30 m (CITIEMME 2001c).

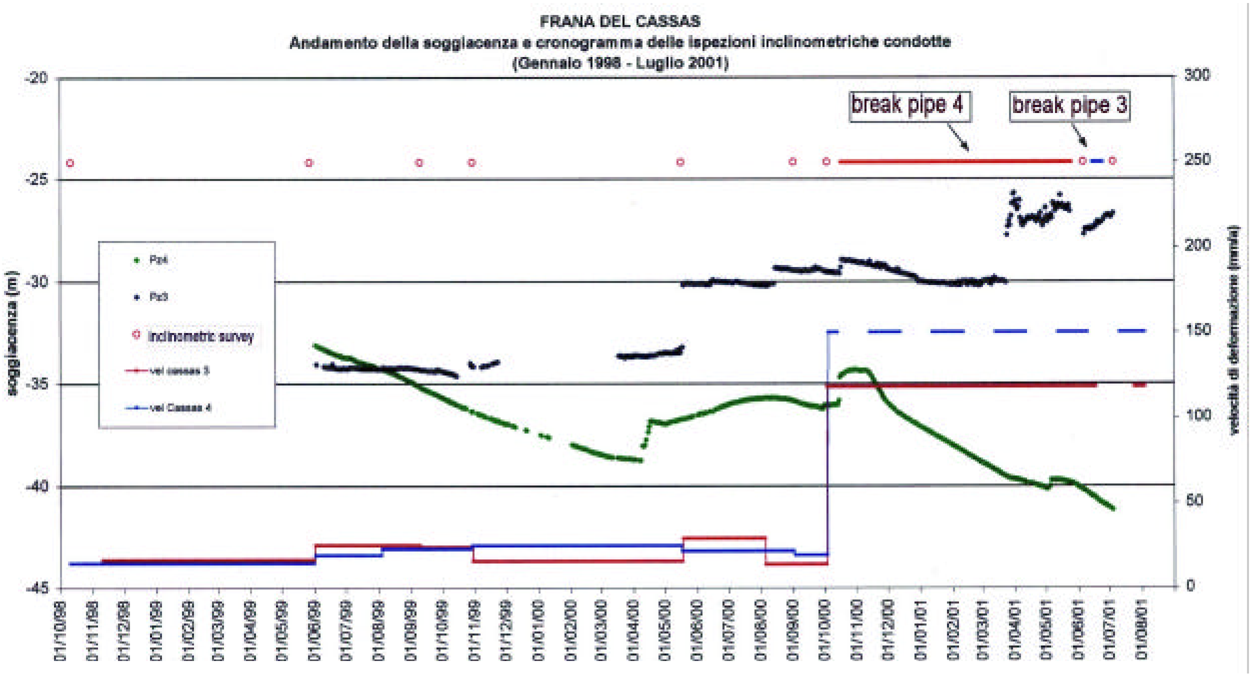

Figure 8. Chronology (1998, Jan.÷2001, Jul.) of inclinometric survey and groundwater level trend in the Cassas Landslide [CITIEMME et al., 2000].

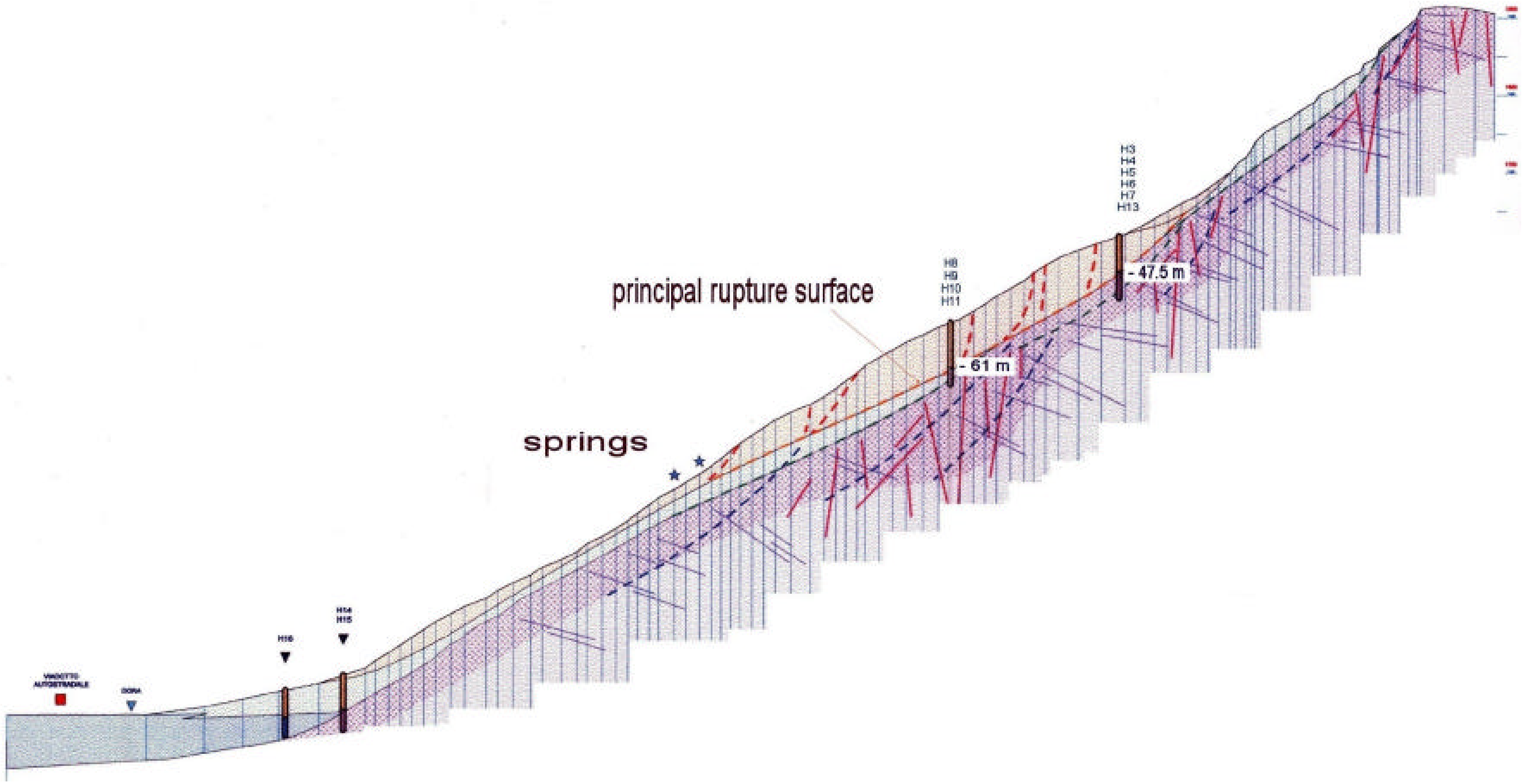

Figure 9. Cassas landslide cross section [CITIEMME *et al.*, 2000]

6 MODELLING

Two different approaches have been followed to model "Cassas" landslide behaviour and evolution.

Landslide triggering has been studied by means of a method which couples probabilistic and deterministic approaches (OBONI & BOURDEAU 1983). A stochastic evaluation of mechanical parameters (shear strength angle, cohesion, water table position have been defined by mean value and standard deviation) and forces has been carried out, while local failure is analysed through markovian approach, in order to point out the landslide mechanism (OBONI & RUSSO 1986).

Two slope sectors, 1957 landslide (2 profiles) and west mountain spur have been considered (CITIEMME *et al*. 2000). The output consists of transition diagrams that represent failure probability vs. slope foot distance.

A runout scenario, concerning rockfall, has been outlined according to the lumped mass theory. Blocks have been represented by material points defined by mass and velocity; sliding has been characterised by a friction coefficient; rebound by normal and tangent reaction coefficient. The output is represented by path, stop probability area and kinetic energy of blocks (CITIEMME *et al*. 2000).

7 STABILIZATION AND PROTECTION WORKS

Catch fences and attenuators, Woven wire-rope nets covering an area of 1650 m^2 were realized, as well as scaling of very unstable small to middle rock portions and surface drainage (EPIFANI, 1991).

8 LAND USE AND RISK ASSESSMENT/MANAGEMENT

8.1 *Land Use*

Land use of the landslide involved area is represented by:

- artificial/urbanized area in correspondence of the slope toe (fan),
- forest at the external borders of 1957 landslide (deciduous in the lower portion of slope, coniferous in the middle-upper part),
- shrub scattered on the landslide accumulation zone.

8.2 *Elements at Risk*

Near the gravitative phenomenon of Cassas there are the highway A32 (Turin-Frejus tunnel-France), the service stations “Gran Bosco”, the National Road SS 24 “del Monginevro”and the international railway line Turin-Modane.

With the Monte Bianco tunnel closure and the 2006 winter Olympic Games that will take place in this alpine sector, these infrastructures will hold a strategic role.

The evolution of the gravitational process, slow but continuous, can produce accelerations in the western sector of the Cassas landslide with potential involvement of the flood plain and the infrastructures. Some rural buildings are located in the floor valley at Graviere.

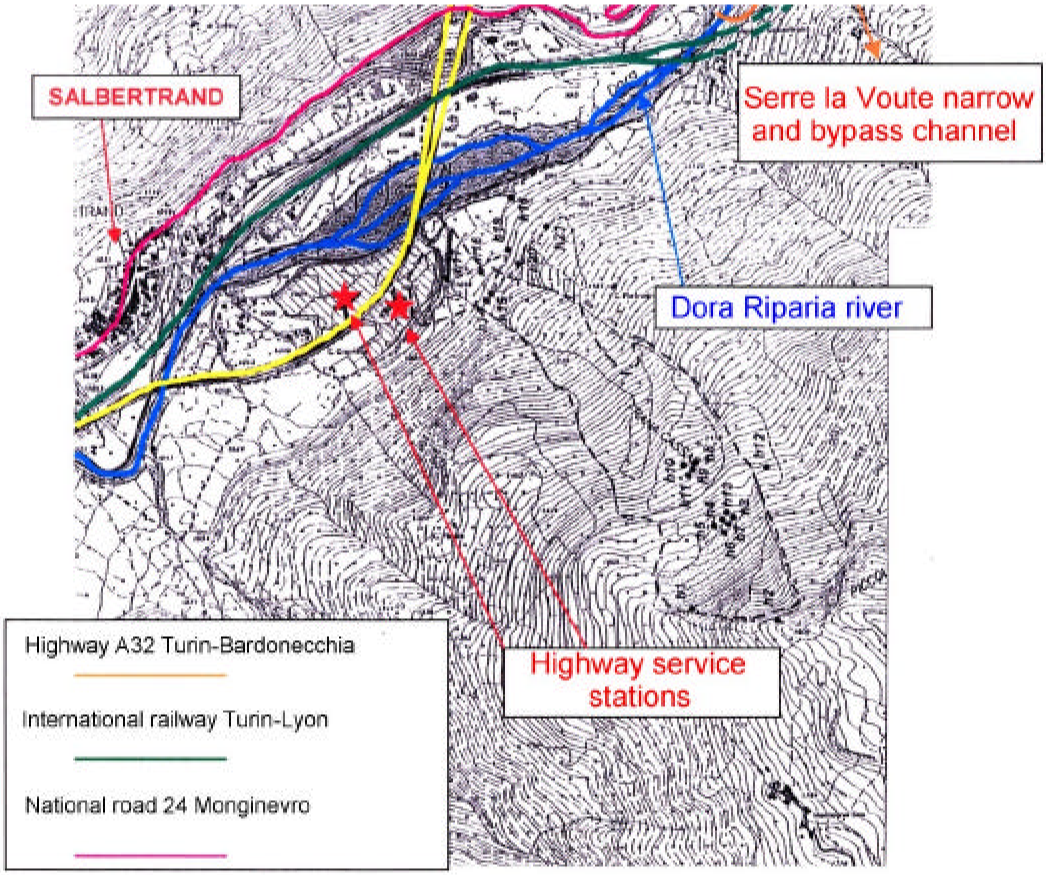

Figure 10. Main elements at risk [CITIEMME *et al.*, 2000]

9 FIRST SCENARIOS

Some different scenarios corresponding to different process typology and intensity can be supposed.

A portion of the slope toe could be involved by reactivations of 1957 landslide portions with debris flows, with rockfalls from Cassas western slope, due to intense rainfall. As a consequence small thickness debris accumulations on motorway and service station area could occur. To prevent this situation only monitoring systems and debris removal could be carried on (occurrence probability of medium grade).

A landslide phenomenon comparable to 1957 Cassas landslide would involve the slope toe and a portion of floor valley, with destruction of about 600 m of motorway, total destruction of the closest slope station area and partial destruction of the other one.

Remedial and protection works should include: monitoring systems, station areas evacuation plan and road-railway traffic closing, besides debris removal and rebuilding (occurrence probability of medium grade).

A disastrous landslide of the entire slope would involve most of floor valley, causing destruction and damages as far as Salbertrand hamlet. Destruction of about 1,5 km motorway and about 1,8 km of railway. Remedial works should include monitoring, floor valley evacuation (near

Salbertrand) and road-railway traffic closing. Debris removal and rebuilding (occurrence probability of low grade).

The risk analysis has been extended to the western portion of Cassas slope (CITIEMME *et al.*, 2000), out of landslide area, but the results appear unreliable due to the lack of information about the general slope assessment.

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