Analysis of the decompression state of a landslide side in urban environment.

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ABSTRACT: the execution of the geological researches pertinent to the reorganization and the reinforcement of a public building called Villa Immacolata, pointed out the existence of a complex system of subsurface fracturing in line with the morphology of the neighbouring polygenic scarp. The subsequent geophysical inquiries allowed to map such fractures up to a depth of about 30 m, enough to cause the breaking of the foundation grade beams with horizontal displacements of 4 centimetres. Finally the result of the geotechnic analyses, which required numerical models with finite elements, brought to advise against the restoration interventions of the building, element totally non applied by the contracting station. After three years from the end of the works the building is damaged again.

1 Introduction

In searching the reasons which had produced the damaging of a public building of multi-floor, called Villa Immacolata (Figure 1), object of reorganization and reinforcement for the Jubilee of 2000 and situated in San Silvestro (Pescara - Italy), from the beginning the existence of a system of subsurface fracturing, which had determined the growth of plastic hinges to the structural nodes of the first floor system and of a diffuse fissured picture, has been clear. A series of morphologic steps corresponded to such fracturing on the topographic surface, represented by a densely urbanized morphologic level and connected to the valley floor through a largely deformed side.
The geomorphologic analysis of the territory pointed out the existence of a landslide of creep type along the slope, under a remarkably steep scarp with a high of 25 m, remodelled by subsequent phenomena of meteor degradation. The fractures found on the soil, supposed to be deep on the geomorphologic basis and confirmed by the execution of geophysical prospectings, appeared, for direction and towards some associated traction efforts, suitable to the tension field induced by the collapse conditions of the slope.
The researches carried out on the complex soil-structure showed the existence of a tension field of prevalent traction and cut-off, with zones affected by a pure traction able to produce cracks on a portion of the grade beam foundation and associated horizontal displacements of 4 cm (fig. 2), to

which supplementary moments of 78 kNm that act on the foundations-pillars nodes and pillars-beams of the 1° floor system correspond.

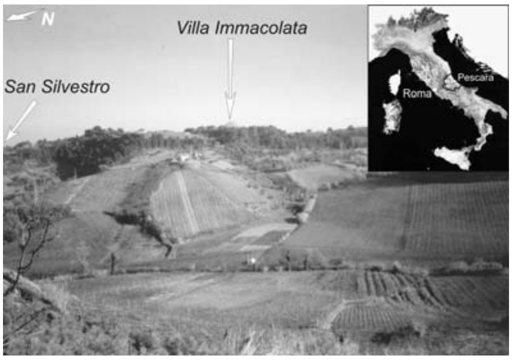

Figure 1. Territorial scheme

The hypothesis is that the fractures , organized in at least two differently oriented system, still now in an evolutive phase and responsible for the structural deformation of the building, are due to the tensional effluent associated with an active dynamics of the slope, as testified by the presence, at the bottom of the slope, of a well developed and probably recent alluvional fan.

Figure 2. Crack passing on foundation of grade beams, with a horizontal translation of 4 cm.

The geometry of the principal fractures is lightly curved, with tracts which reflect the trend of the above described scarp (Fig. 3a), while some of them can be followed across the entire building. In order to obtain predictions of the static integrity of the building in post-interventation conditions, numerical modellings with finite elements were executed, able to weigh the salient aspects of the problem.
The starting point was necessarily convergent on the observed ad measured physical processes, whose complexity depended on the constituent laws adopted for the various geomaterial, on the

utilization of elasto-plastic elements of contact with the function of simulating the presence and evolution of the fractures and on the use of viscoelastic laws able to describe the time-dependent evolution of the described phenomenon.
The results of the FEM analyses induced to advise against the restoration interventation of the building, which was totally not applied by the contracting station and the planners.
After three years from the end of the works, the building, in spite of the use of underpinning micropiles, is damaged again and present a cracks in line with the orientation of the soil fracturation systems.

2 Construction of the physical model of the problem.

Considering the complexity and the purpose of the consultation work and the choice or necessity to turn to geotechnical analyses with finite elements, it has been necessary to rebuild preliminarily the physical model of the problem.
Such procedure has required the execution of a detailed geologic and geomorphologic relief, directed to the study of the subsurface fracturation system, of the side dynamics and to the planning of a correct campaign of geophysical prospectings.
With reference to figure 3a and 3c the subsurface is made up of gravelly-sandy deposits organized in strata of lenticular and tabular geometry which, when they emerge, they show a level of variable chemical cementation. The basis of such a depositional unit is made of cracked and over consolidated pleistocenic clays and silts (structurally complex clays), typically organized in centimetric strata and bands (Casnedi, 1991).
The processes linked with the rapid evolution of the hydrographic reticulate responsable for the present morphological configuration, have determined a tensional effluent linked with the removal of the lithostatic load on the site, giving rise to structural scarps, also of remarkable height and in continuous evolution.
The different rheologic behaviour of the described soils gives rise to the formation of a system of traction fractures of prevalent orientation NE-SW, in line with the trend of the described scarps, and in a subordinate way NW-SE. The length of some fractures reaches 250 m, with variable rejection along the axis, up to the maximum of about 1 meter.
The geophysical prospections consisted of the execution of a seismic line of High Resolution reflection in SH waves and of 5 profiles GPR (Ground Probing Radar). The two typologies or researches have been carried out in order to rebuild the subsurface structure, the presence and the orientation of the discontinuity surfaces and also their detail in proximity to the topographic surface and, however, of the support plane.
As regards the interpretation of the seismograms (Fig. 3b), the possibility of subjecting the acquired data in digital form to an appropriate sequence of processing, allowed to improve the obtained results in an evident way. Therefore, with the “stacking” which greatly improves the signal-noise relation, the interpretation has required the execution in sequence of a “filtering in frequency”, of the “deconvolution” and the “F-K” filtering.
The geophysical researches, adequately set by drilling perforations, have actually confirmed the hypotheses emerged from the geomorphologic analysis of the territory, permitting to locate three fractured and displaced reflectors and four seismostratigraphis units, from the top to the bottom, defined as (Fig. 3b):
- unit “A”, made up of sandy silts with a propagation velocity of the cut-off waves V_{SH} = 120 m/s;
- unit “B”, made up of slimy sands with generally thickened gravels and velocity V_{SH} = 220 m/s;
- unit “C”, laterally confined and referred to sandy gravels, with V_{SH} = 330 m/s
- unit “D” with V_{SH} = 410 m/s and corresponding to the most powerful reflector.

The delineated picture has therefore been complicated by the presence of variously inclined and sometimes subvertical different discontinuities, able to interrupt and to displace towards the bottom the single specific units as well as to produce topographic steps with the highest rejections of about 1 metre. The main ones of such discontinuities have been followed up to the deepest investigation (about 30 m).

All the researches have been finally summarized in the geological section of Figure 3c, used as a basis for the construction of the numerical model with finite elements.

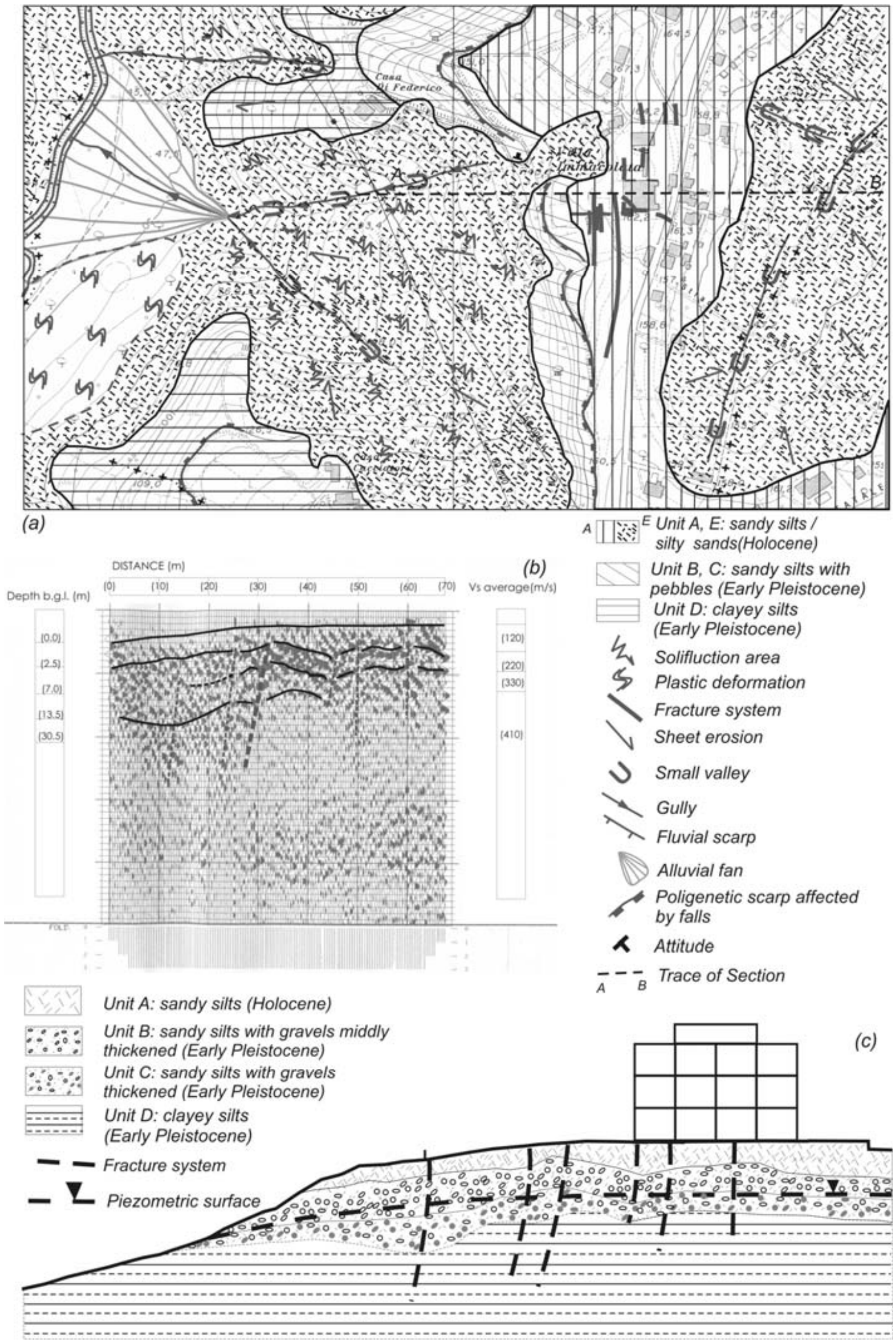

Figure 3. a) geomorphologic map; b) interpretative scheme of the seismic with High-Resolution reflection; c) geological section.

3 Numerical analyses

As stated in the introduction the complexity of the problem has required complex numerical models with finite elements, able to gather the salient aspects of the dealt problem. In their calibration, the use of an interactive procedure has been imposed (Doležalovà et al., 2001), since the study of the real behaviour of geotechnic structures cannot be limited to the pure prediction and/or verification through back analysis, but must evolve through calibration steps among the numerical solutions, the environmental and structural monitorings, the tests in site and the laboratory.
All the soils have been modelled as non linear-perfectly plastic means (table 1), characterized by the Drucken-Prager yielding surface and by a rule of defector flux ($\psi = 0$), with breaking criterion (Nova R., 2002):

$$\sigma_1'^2 + \sigma_2'^2 - \sigma_1'\sigma_2' - \sigma_1'\sigma_3' - \sigma_2'\sigma_3' - \left[\mu\left(\sigma_1' + \sigma_2' + \sigma_3'\right) + k\right]^2 = 0 \tag{1}$$

$$\mu = \frac{2\sin\phi}{\sqrt{3}\left(3 \pm \sin\phi\right)} \tag{2}$$

$$k = \frac{6c'\cos\phi}{\sqrt{3}\left(3 \pm \sin\phi\right)} \tag{3}$$

which represents, in the space of the principal stresses, the equation of a cone whose axis is the trisetrix of the first octant. Choosing in a appropriate way μ and k (Equations 2 and 3) it is possible to make the cone inscribe or circumscribed to the Mohr-Coulomb pyramid or to approximate the latter going over the points of mathematic peculiarity.

Table 1. Principal mechanic parameters

Soils	γ [kN/m^3]	c' [kPa]	ϕ' [°]	E' [MPa]	ν
Covering Soils	18.2	30	32	24	0.33
Base silts and clays	20.2	20÷200	27	18	0.25

The formulation of non linearity has been solved adopting the Newton-Raphson modified iterative scheme, which allows a minor computational charge. In fact, the use of the function of the same out standing for every iteraction, in the linearization allows us to avoid rebuilding the matrix of the Jacobian and to operate its factoring at each step.
For the convergence with the measured displacements and the subsequent execution of predictive analyses, it has been necessary to implement in the calculation the presence of the traction-cut-off fractures, so as appeared from the geophysical prospectings. The same ones have been modelled through elasto-plastic interface elements (contact elements) characterized by a proper normal (k_n) and tangential (k_t) rigidity:

$$k_n = E/h \qquad ; \qquad k_t = G/h \tag{4}$$

where h is the thickness of the interface and E and G are respectively the elastic and cut-off module of the soils affected by the fracturation.

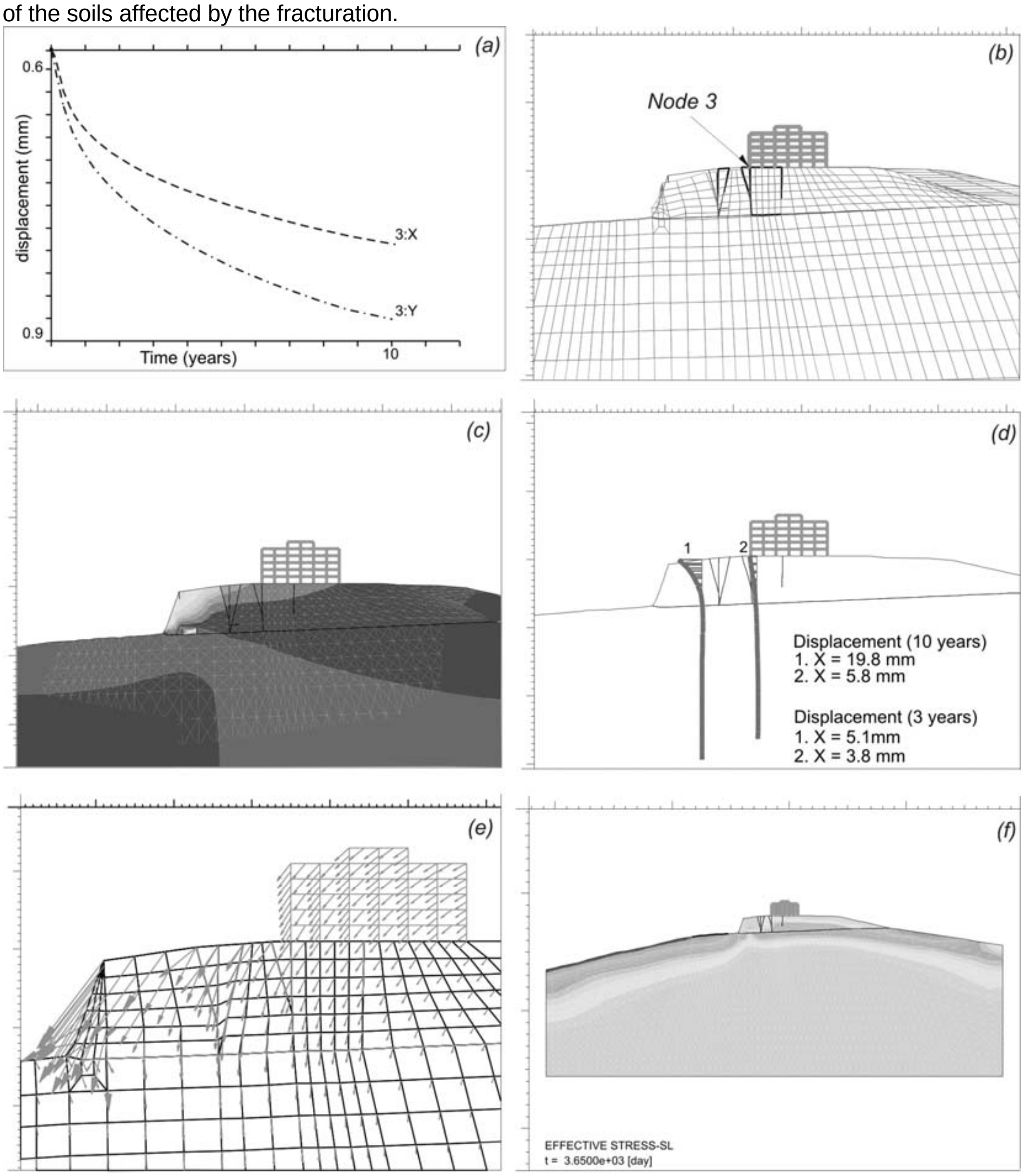

Figure 4. a) time-displacements curves (X → horizontal, Y → vertical) of knot 3; b) deformed mesh; c) horizontal displacements; d) numerical inclinometers; e) displacement vectors; f) effective stress-level.

Moreover, as appeared from the geomorphologic models and confirmed by the laboratory tests, it has been necessary to simulate the softening of the base silts and clays linked with the evolution of external processes (softening). We think that such process can be increased by the infiltration waters and by the groundwater flow, both supported by the geometry of fractures.

After identifying the resistance features of the base soils and their variation for the content of waters

(from direct cut-off tests), a variation of the cohesion in time but not in space has been imposed, in order not to bring a “forced convergence” to the numerical model.
Therefore a law of softening has been applied (Figure 5), using an inverse hyperbolic function set by the laboratory tests able to reproduce the described phenomenon:

$$Y = T^{-0.3} - 1.4985 \qquad (5)$$

where T represents time, variable from 0 to 10 years (width of the predictive analysis) and Y the cohesion.

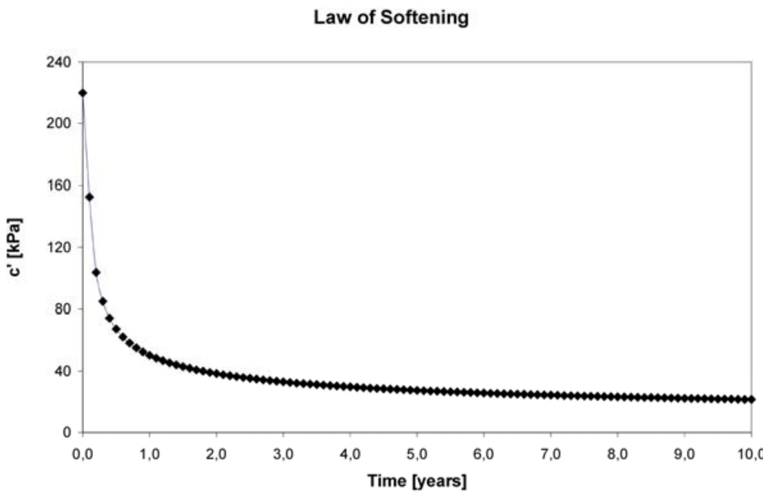

Figure 5. Law of softening deduced through an experimental way .

4 Description of the result and conclusions.

Since the geotechnic analyses have been used with predictive purposes, it is necessary to compare the obtained results to the initial data: the fracture of the foundation grade beams with horizontal displacement of 4 cm, distributed in the 35 years from the date of the building (ca 1965) to the date of the analyses execution (2000). Therefore the medium rate of the reference translation is of 1,14 mm/year.
The analyses with finite elements, set for a length of 10 years, have actually confirmed the work hypotheses, or the elements arisen from the supplemented analysis of the set soil-structure, also with the right limitations of a numerical model which, even if it is complex, it never will be able to object the real processes. During the analyses some significant model points have been monitored, of which the horizontal displacements of the structural nodes pillars-foundations (Figure 4a/4d - knot 3) and the superior border of the scarp are summarized (Figure 4d – inclinometer 2): respectively 5,8 and 19,8 mm after 10 years, with an annual medium rate of 0,58 mm/y for knot 3 of reference. After extrapolating the datum in the space of the three years, equivalent to the passed time from the end of the works up to now, the displacements appear to be of 3,8 and 5,1 millimetres.
The discrepancy between the values deduced from the surveys and calculations can be explained also because of the presence of subfoundation micropiles, which even if they could not prevent the phenomena of structural deterioration, have actually slackened such processes and apparently reduced the extension of the fessures picture.
The result of the FEM analyses, which have originated from physical model rebuilt according to geomorphologic relieves and geophysical prospections, advised the contracting station and the

planners to adopt technical expedients in order to safeguard the static integrity and the future functionality of the building, such as carrying out jet-grouting pushed to the depth of 30 metres.
Since the existence of an organized system of fracturation of the surface, responsable of the side decompression phenomena was difficult to perceive for the planners, they chose to adopt the subfoundations micropales 9 m long, incapable in our opinion, to offer the right degree of safety to the building, to renovate and consolidate.

Figure 6. Cracks for a flexion cut-off combined action of a new handwork used as an electric cab, next to the principal building.

In other words, the geotechnique analyses, as final step of a widen multidisciplinary research, advised against the restoration interventions of the building which was absolutely not applied by the contracting station and the planners. After three years from the end of the works, the building is cracked again; it shows a cracks in line with the orientation of the subsurface fracturing system.
Moreover, as Figure 6 shows, the state of the site decompression is such as to produce the appearance and widening of cracks also on new building built in the last three-years period.

5 Reference

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