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Introduction

The Regional Law n. 44/82 ("Norme per la disciplina dell'attività di cava") says:

"La Regione del Veneto disciplina con la presente legge la ricerca e l'attività di cava nel proprio territorio al fine di conseguire un corretto uso delle risorse, nel quadro di una rigorosa salvaguardia dell'ambiente nelle sue componenti fisiche, pedologiche, paesaggistiche, monumentali e della massima conservazione della superficie agraria utilizzabile a fini produttivi."

"La Regione, considerando che i materiali di cava costituiscono risorse non riproducibili, promuove e favorisce sia la ricerca e la sperimentazione di materiali alternativi che quella di tecniche e metodi di utilizzo atti a conseguire il massimo risparmio complessivo soprattutto per i materiali di maggior impatto territoriale o disponibili in riserve più limitate."

As well known, when the work of excavation finishes the quarry loses its function and what remains is a landscape terribly modified. The extracts presented above ratify that it is so important to restore as much as possible the initial landscape in order to minimize the past passage of the humans in that places or, when possible, use other materials that are already present without excavations. The first necessity is related to the notion of the environmental recomposition. With this term according to the mentioned law is intended all the action to be done both during and after the work of cultivation, having the scope of reconstruction in a proper way, orderly and functionally, the area in order to ensure a good protection and the possibility of reuse of the territory itself.

The present work aimed to evaluate the possible recovery of a quarry located in the Province of Treviso that represents the most active Province in this sector (see Figure 1). The material extracted is a cemented gravel; a very precious material that can be used for the building of embankments and for the preparation of concrete.

The cementation phenomenon occurs naturally during a long period of time due to the calcium carbonates present in rocks that are soluble in water. In fact in presence of water the carbonates dissolve until the complete saturation of the liquid itself. Once the equilibrium is reached a small concentration variation of the carbonates, for example due to the evaporation of water, cause the calcium carbonate precipitation leading to a new equilibrium condition. Hereafter the precipitation products set up the cemented bonds sinking around the sand or gravel grains. This material is able to form very steep slope due to the cementation itself; in fact it presents a friction angle of about 35°-45°. If all the extraction were performed in a way to preserve that angle there will not be problems of stability since the cemented soil is able to carry the force exercised. But in most of the cases the mining activity takes advantage of this relevant stability of the materials in order to carry out fronts that are nearly verticals. According to that, the stability analysis performed concerns all the work phases; from the general excavation to the last one regarding the recovery. In particular, the principal material used for that phase is the excavated soils mixed with bentonite that derive from the jet-grouting applied during the building of a system of piles. Due to the low resistance offered by this material, another type of soil will be used to ensure a good stability of the slope.

For what concern the quarry material, the cemented gravel, since it is very difficult to obtain an undisturbed sample, the geotechnical parameters are calculated starting from those identified by several researches on different kind of samples (Previatello and Simonini, 1989; Simonini and Soranzo, 1986).

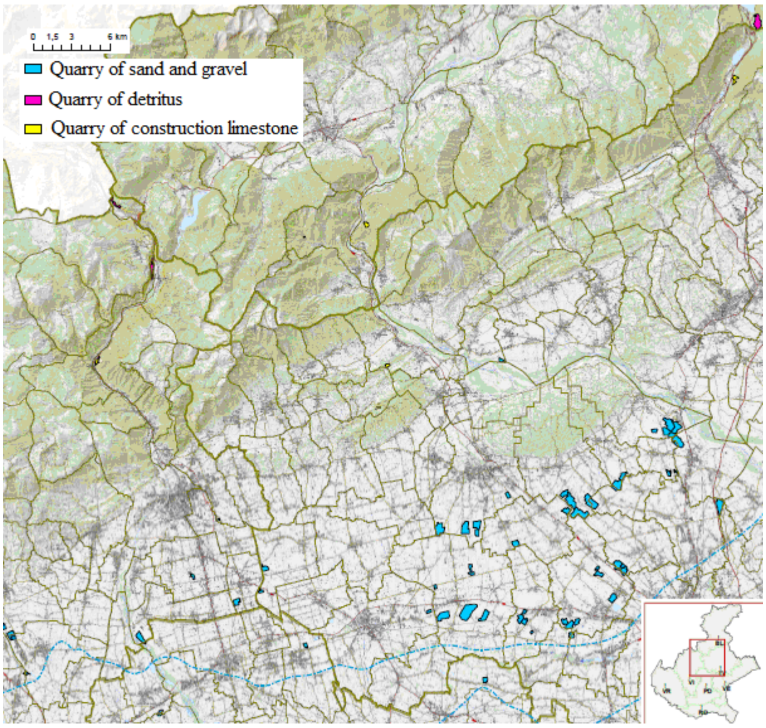


Figure 1 Activity extraction charter for the Veneto Region (Attachment C of the Regional plan for the quarry activity - PRAC)

1. Regulatory framework

1.1 Royal Decree 1443/1927

A first approach to the legislation of the quarry activity took place through the Royal Decree n. 1443 of 29 July 1927 ("Norme di carattere legislativo per disciplinare la ricerca e la coltivazione delle miniere nel regno"). This Decree distinguishes at the second article the activities of minerals extraction from the subsoil in two different categories: mine and quarry.

In particular, in relation with the scope of the present work the materials of the second category which regard precisely the quarries are:

- peat;
- materials for the construction of buildings, roads and hydraulic devices;
- colouring earth, fossil flour, quartz and silica sand, , millstones, whetstones stones;
- other materials industrially available pursuant to and in accordance with Article 1 and not included in the first category.

This Decree establishes in the following articles the right to grant mining defining the subjects involved, the time limit, the way with which transfer to other subjects, the heirs and creditors and the way to give up.

It was then subjected to a revision in the 9th of August of 1999 with the Legislative Decree n. 123. With respect to the previous version the changes were not so significant: some articles were abrogated and some other added or improved. It is noticeable and due to the age of the normative, the absence of specific documents that must be associated with the extraction activity itself. In this way a lot of decisions are freely taken by the manager and also the parts of the law that are not so clear are interpreted by the manager in the manner that prefers. See in the following regional law how this aspect is really well improved.

After this Decree, a Decree of the Republic President (D.P.R.), named "Norme di polizia delle miniere e cave", of the 9th of April 1959 n. 128 was issued. This will not treated in details since its contents go beyond the scope of the present work. In fact it concerns the protection of the health and safety of the workers in order to ensure the correct development of the work activities with respect to the safety of a third party and to the activities of general interest and in order to ensure the good management of the mineral deposits as a State property.

In the '70s, with the D.P.R. n. 2/1972 and the D.P.R. n. 161/1977, carrying out some legislative proxies, the administrative function of the State were transferred to the Regions. As a consequence, the Regions start to make a lot of decree about the quarries introducing new criteria for the management itself. The new aspects give attention not only to the production requirements but also to the prescriptions which regard the protection of the environment. For what concern the Region Veneto, in the 7th of September 1982 was issued the law n. 44 named "Norme per la disciplina dell'attività di cava". See the following section for the details.

1.2 Regional law of 7th September 1982, n. 44 (BUR n. 39/1982)

The Veneto Region, with the law n.44/82 ("Norme per la disciplina dell'attività di cava") says that the quarry materials are resources that are not reproducible. So it promotes and supports both the research and the trials of alternative materials and that of the techniques and the methods of utilization with the scope of the achievement of the total maximum saving especially for what concerns the material with the highest environmental impact or that are available in smaller reserves.

On the other side, the law says that the works made in those places in which there is the building of some activity of public or private interest are essentially works of soil moving. In this way they can't be considered quarries. Not even other type of soil moving can be curve inward the pit definition such as land improvements, all the activities that deal with the utilisation of the material excavated for industrial, construction purposes or for street or hydraulic building. Anyway, the soil moving in a quantity less than 5.000 m3 are not considered inside the quarry field.

The present law, that remained in force for other than thirty years considers the quarry activities as all the works concerning the mining cultivation of those materials, industrially usable, that are contained in the second category (the category that concerns the quarry materials), pursuant to and in accordance with the third clause of the second article of the Royal Decree of the 29th July 1927 n. 1443. That Royal Decree distinguishes, as said before, the cultivation activity between quarry and mine. More specifically the law n. 44/1982 introduced a little improvement in the that distinction. In fact it distinguishes between two groups based on the different degree of environment utilisation related to the excavation activity. The two groups are the follows:

- Group "A": materials whose extraction lead to an high level of utilisation of the territory:
  - sand and gravel;
  - cement limestone.

- Group “B”: materials whose extraction lead to a lower level of utilisation of the territory:
  - clay-brick;
  - polishable limestone and cutting trachyte, marble, quartz, quartizte, molar rocks;
  - limestone, granular limestone, limestone for buildings, for industry;
  - basalts;
  - ferrous clay and volcanic materials;
  - colouring earth;
  - silica sand and foundry soil;
  - gypsum;
  - peat;
  - debris material;
  - all the other materials discovered in any form of natural deposit that belong to the second category discuss before.

It is noticeable that the recent law has adopted a broader classification.

The utilisation degree to which the law refers concerns the utilisation of excavated surfaces and volumes in relation to the resulting amendments to the territory, to the natural landscape and the agriculture area also with respect to the productive aspect.

Even if the law is dated it presents a solid structure since it covered all the aspects related to the cultivation activity, management, reclamation of the quarry as well as to the preserving of the territory and the business protection. In that sense, the Region and the Provinces must refer and plan specific documents; in this way nothing is left to the interpretation of the operator.

The fourth article presents the nominated documents:

- Regional plan for the quarry activity (in Italian PRAC);
- Province plan for the quarry activity (in Italian PPAC);
- Province program for excavation (in Italian PPE);
- Project of cultivation.

See the following paragraphs for a more detailed description.

1.2.1 PRAC

The fifth article defines that Plan as a general instrument for the planning of the mining sector. Its scope is the valorisation of the natural resources with respect to the objectives of the economical scheduling and of the territorial planning. All is done keeping in mind the territory and environment protection and under the necessity of the safeguard of the business and the work.

The present document defines and contains:

- the areas favourably suspected of having some deposits susceptible for the cultivation of materials contained in the group A, described before in the third article, found during geologic, pedologic and hydrologic researches;
- the forecasts, at both regional and provincial level, during all the validity period of the Plan, about the requirements for the material of the group A, made in relation to the statistical elements and to the regional programs that concern the interested sectors;
- the subdivision of the material that belong to the group A to be extracted from the various provinces in order to ensure the fulfilment of the requirements defined in the previous point;
- the general laws for the quarry cultivation that must be followed in all the regional territory, the specific provincial and municipal legislations, the safeguard of the environmental values and also of the economical and productive interests ensuring in any case the final environmental recovery;
- the criteria and the particular modes for the cultivation of the quarries for the material of the group B, specified in the article 3.

In order to follow all the previous points it is necessary to introduce some tools that may help their achievement. For that purpose the law prescribed a report associated with cartography showing the results of the research defined previously, a list of the municipalities having in its territory some area suspected of having some deposits, a report containing the calculation of the foreseeable requirement.

1.2.1.1 Directive 42/2001/EC

This directive is about “the assessment of the effects of certain plans and programmes on the environment” and wants to fix some limits in the definition and draft of the document PRAC. In particular the objectives of this Program can be summarized as follow:

- environment protection: necessity of safeguard the existing environmental heritage limiting as much as possible the impacts that the quarry activity will forcedly produced;

- environmental recovery: the meaning that acquires the interventions directing to the environment recovery, with respect to the principle of the environmental recomposition, exceed the concept until today of the environment restoration (in Italian from “ripristino” to “recupero”);
- rationalize the extraction activity: define a toll able to program some references that help the previsions in the definition of the regional requirements; such well-structured system is define but flexible;
- intensification of the vigilance activity: the Plan must be structured on the base of the principles of control and vigilance in order to make responsible the different hierarchical levels, public or private, even based on the transparency of the actions and of the information.

1.2.2 PPAC

This document specify and define in the provincial territory the characteristics of the document PRAC and is adopted by the Province. The characteristics of the present material are the following:

- recognizes the allocation of the quantity of the material belonging to the group A of which must be ensure the extraction in the regional territory, based on the prescription suggest in the Regional Plan for the quarry activity;
- organizes and verifies the information from the municipalities explained in the previous paragraph in order to ensure the extraction in the provincial territory, of the quantity of material of the previous point;
- stabilizes with respect to the general lines indicated by the PRAC and the lines suggested by the municipalities, the regulation with which control the quarry activity in the provincial.
- Even for this document were defined other reports that must be elaborated according to the scope of the present provincial plan.

1.2.3 PPE

For the realization of the Provincial program for the quarry activity the Province defines every three years a Provincial Program of Excavation. Based on that all the authorizations or concessions are emitted for the cultivation of new quarries or for the amplification of the existing ones. This program is done based on the needs of a more distributed and organized quarry activity in the provincial domain. Doing this the necessity of an environmental recomposition and of the availability of the prescribed material quantities in the PRAC must be taken into account. The

Provincial Program of Excavation is approved by the provincial council, after the opinion of the provincial technique commission for the quarry activity.

1.2.4 Project of cultivation

Anyone who intends to proceed with some cultivation of quarry materials in area available for that purpose must define a project of cultivation, including both the phase of extraction and of the recovery. The project must be edited and subscribed by a professional operator, with respect to the duties suggested by the depositions active in that sector, without neglecting to consider the environment protection.

For that purpose the report that the operator must present are:

- report about the geologic, hydrogeologic, idrographic and landscape characteristics of the intervention area and also on the interference of the extraction activity on them;
- a program of extraction that must provide a documentary evidence of the consistency of the deposit, a qualitative and quantitative valuation of the available material, a clarification about the works of excavation to be done, when possible the localization of the areas of deposition of the extracted materials, the plant for the first manufacturing, the infrastructures and the auxiliary services;
- a project of recomposition for the environment, according to the directives active in that contest;
- an economic-financial program which indicates the utilization and the destination on the market of the material extracted, the potentiality of the plant concerning the extraction activity and its investing programs and finally the forecast about the employment of labour.

All the documents described until now were not put into effect immediately; in fact, they were not jet approved in the year 2004. Only recently they have obtained an important rule in the regulation of the mining activity. This delay was due to the insufficient management present in the quarries; just think about the poor hygiene and safety condition of the workers. If in those days the documents were entered into force probably a lot of sites have closed due to the non conformity to that programs. But is also the inadequate knowledge of the site itself which leaded to the non application of the programs in the sense that it would have been very difficult to define an accurate economic plan, an accurate planimetry or an accurate evaluation of all the material extracted. The last explanation can be associated with the necessity of the planning of a program for the environmental recomposition; it is difficult to think that in the year 1982 there was the attention to the human actions since also nowadays sometimes is not sufficient to prevent some environmental disasters. The regional law n. 44 from this point of view can be considered as a soon of the years 2000 rather than of the 80s.

As is well known, when the work of excavation finishes the quarry looses its function. It is so important to restore as much as possible the initial landscape in order to minimize the past passage of the humans in that places. This necessity is related to the notion of the environmental recomposition. With this term according to the law n.44/82 is intended all the action to be done both during and after the work of cultivation, having the scope of reconstruction in a proper way, orderly and functionally, the area in order to ensure a good protection and the possibility of reuse of the soils itself.

The importance of this Directive is not evident only by the huge quantity of written documents. In fact, at the Title VI are given more specific rules regarding the excavation itself. For example, it is imposed a band of respect of 200 m and a depth of the excavation for the level land lower than a quarter of the characteristic dimension of the excavation itself. This dimension corresponds to the ratio between the surface of the intervention and its perimeter. It is also forbidden to approach the maximum level of the aquifer for a depth about 2 m. At the end of the intervention the closure have to be executed in order to give to the excavation front a slope not lower than 25° with respect to the horizontal plane.

In between the present law and the following one there was a Decree of the Republic President (in Italian D.P.R.) n. 382 dated 18-04-1994 containing some instructions about cultivation concessions, research permits in the national and local sphere. This laws will not be studied in details since concerns things that are out of our area of interest.

1.3 Bill n. 92/2005 "Regulation for the quarry activity"

This bill (in Italian Progetto Di Legge P.D.L) follows in general the same principles of the law n. 44/1982 but for what concern some aspects it generates important modifications. The common aspects regard the hierarchical system of the planning and duties with a particular reference to the proxies to the provinces. Speaking of which the materials are subdivided with respect to the competence; the material under the regional control can be grouped in two types: sand and gravel the first, clay-brick, detritus material, cement limestone, industrial limestone, granular material, "marmorino" and basalts the second. The document PRAC, in accordance to the 5th article, clause 3 continues to control the materials of the group "A". With respect to the previous Directive the documents are reduced in number: there are the Regional Plan for the quarry Activity (in Italian PRAC), the Provincial Plan for the quarry Activity (PPAC) and the Project of organized management of Mining Territorial Setting (in Italian Progetto di gestione programmata di Ambito Territoriale Estrattivo).

In the Article 3 it is described the PRAC structure, defining the contents and the methods of development of the document itself. On the basis of which the innovative aspects of the plan are:

- the definition of the Extractive Contexts (in Italian Insiemi Estrattivi), such as the areas identified on the basis of the presence of deposits of cultivable materials of regional interest belonging to the group "A";
- definition of the Mining Territorial Settings (in Italia ATE) as areas in which it is already prescribed an activity identified inside the Extractive Contexts and that can include active quarries, abandoned or disused;
- the so called Contesti Vocati, such as areal, with characteristics of environmental and territorial compatibility, located inside the Extractive Contexts that are favourable suspected for the opening of new quarries.

In particular the plan is developed on the basis of the forecast of the needs in terms of materials of regional interest with respect to a time frame of twenty years with a time step for the scheduling of ten years.

It is analyzed the themes regarding the safeguard of the environment both concerning the dimensioning of the excavated volumes and the practices for the environmental recovery. All the actions to be taken must be defined during the phase of the project itself and then executed already in the management phase. In this way it is overcome the concept of the territory recomposition defined by the Regional law n. 44/82. It is proposed an instrument that furnish to the quarry activity a new value. The realization of the excavation activity obtains the potentiality of valorisation of the territory giving new opportunities for the territorial transformation that aims at the reuse of places otherwise compromise.

1.4 Resolution of the Regional Junta n. 761/2010

This resolution ("Attività di coltivazione di cave e di miniere di minerali solidi su terraferma. Applicazione del D.Lgs. 30.05.2008 n. 117 sulla gestione dei rifiuti di estrazione. Disposizioni attuative") aims to regulate the quarry activity with respect to the Legislative Decree 20-05-2008 n. 117 about the extraction waste management. Even if it is not our interest to deal with the argument of the waste in this resolution there are also some information about the recomposition of the quarries. In particular in the Decree mentioned there are some rules about the materials that can be used for the recovery of the sites:

- the materials introduced for the purposes of recomposition must be previously authorized and must guarantee the environmental quality. This is ensured if the concentration of chemicals are contained in the A column of the table 1, attachment 5 of the IV part of the Legislative Decree n. 152/06. In this way it is allowed the recovery with adequate materials only if they are not waste;
- the recomposition can be performed also with the by-products ("sottoprodotti") that come from the extraction activity and with the same material extracted in order to maintain a certain equilibrium with the original environment;
- "*L'art. 186 del D.Lgs. 152/2006 individua e consente l'impiego di terre e rocce da scavo provenienti dall'esterno del sito estrattivo quali sottoprodotti utilizzabili per reinterri, riempimenti, rimodellazioni e rilevati. Le terre e rocce da scavo possono essere quindi utilizzate anche per le ricomposizioni ambientali di miniere e cave. Tutto ciò solo previa verifica delle condizioni elencate nel primo comma*[7] *del medesimo articolo del rispetto delle procedure stabilite (DGR 2424/2008/vigenti norme) e, comunque, in presenza di espressa autorizzazione mineraria all'utilizzo nel sito estrattivo";*
- *"Quindi, in una cava nei casi in cui in cui non risulti disponibile sufficiente materiale proveniente dalla medesima cava per eseguire la ricomposizione autorizzata o prescritta e conseguentemente si presenti la necessità di apportare materiale proveniente dall'esterno, potranno di norma essere utilizzati, se ed in quanto ciò è previsto dai provvedimenti di autorizzazione mineraria:*
    - *materiali di cava principali e secondari (utili e associati) provenienti da altre cave;*
    - *sottoprodotti derivanti degli impianti di prima lavorazione nelle cave di materiali di cava o assimilati/sostitutivi, nel rispetto delle condizioni di cui all'art. 183, comma 1, lettera p) del D.Lgs. 152/2006;*
    - *sottoprodotti derivanti dalle sole prime lavorazioni assimilate alla prima lavorazione di cava dei soli materiali di cava o assimilati/sostitutivi*[19]*, ancorché ubicati all'esterno delle cave, nel rispetto delle condizioni di cui all'art. 183, lettera p) del D.Lgs. 152/2006;*
    - *terre e rocce da scavo, quali sottoprodotti, nel rispetto delle condizioni di cui all'art. 186 del codice dell'ambiente e della DGR n. 2424/2008.";*

- *“Il monitoraggio dei rifiuti di estrazione utilizzati ai fini di ripristino e ricostituzione mediante ripiena dei vuoti e volumetrie prodotte dall’attività estrattiva, quando necessario, deve essere previsto nel piano di gestione dei rifiuti di estrazione e deve essere finalizzato ad assicurare, dopo il completamento della ricomposizione, la stabilità fisico-chimica e la riduzione al minimo del rischio di effetti negativi per l’ambiente e per le acque sotterranee e di superficie.”*

It also give the following definition for the recomposition activity:

“ricomposizione (morfologica ed ambientale): attività finalizzata al riuso del sito utilizzando prioritariamente il terreno superficiale di scopertura, i materiali di cava associati (secondari), gli eventuali sottoprodotti del sito e gli eventuali rifiuti di estrazione. Nel caso in cui i precedenti materiali non risultino sufficienti ed idonei, la ricomposizione può essere attuata anche con l’impiego di materiali provenienti dall’esterno: terre e rocce da scavo e/o sottoprodotti secondo quanto previsto dalle disposizioni attuative comuni, lettera C), punti 2) e 3), e a quanto stabilito dall’autorizzazione”

1.5 Resolution of the Regional Junta 9/ Bill n.284/2012

This Regional Resolution (in Italian D.G.R: ”Norme per la disciplina dell’attività di cava”) lead up to a series of innovations with respect to the regional law n. 44/1982. Other than a renewal of the planner documents for the extraction activity the most important part of that bill due to the actualization of the disposition concerning the redefinition/abolition of some Provinces regards the transferring of the administrative function to the municipalities and the subdivision of the authorize power between the Region for what concern the material of the group “A” and the municipalities for the group “B”. The Region anyway maintains its rule of planning, programming and control.

The Regional law n. 44/82 although valid concerning its promoter principles is already dated. This is because it is not aligned with the last legislative and technical developments regarding the environmental sector (think about the Italian procedure of VAS, EIA and VINCA introduced by the European Directive 85/337) and also equipped with too long and complex procedures. In order to solve that things it was decided to present a bill carrying the new sector legislation which on one side wants to be near to the structure and the contents of the Regional law, adopting in this way all the positive aspects that he bring and on the other side inserts in the same a series of simplifications, innovation and modifications. All of them are suggested both due to the legislative, economical, environmental and business evolution and also due to the experiences reached after a thirty-year application. The European Directive mentioned above, implemented in Italy in 1996 ratifies that the quarries and the peat bog with higher than 500,000 m3 material extracted or with an area higher than 20 hectares have to be subjected to the procedure of VIA under the control of the Region. This aspect is anyway not so effective in Italy. This is because from a study conducted by the Bicocca University of Milan in 2012 results that from the 1,574 companies involved in the sector of the mineral extraction 99.5% have dimensions from very small to middle. This leads to the fact that in addition to not fall within the EIA procedure there are less guarantees for the proper management of the sites and the correct environmental recomposition.

Entering into details of the Regional Resolution, the Article 4 reports the new classification of the quarry materials decided on the basis of the strategic importance for the Veneto Region concerning the various types of materials. In this way there are two categories:

- Group "A" materials of regional competence:
    - sand and gravel;
    - detritus material;
    - limestone for industrial and building uses;
    - clay;
    - basalts and volcanic materials;
- Group "B" materials of local competence:
    - ornamental stones (limestone and trachyte, marble);
    - quartz;
    - gypsum
    - silicum sands;
    - molar stones;
    - colour soils and foundry material;
    - peat;
    - other material discovered in any form of natural deposit belonging to the second category in accordance with the article 2 of the Royal Decree n. 1443.

This two categories substitute those of the same name present in the regional law of the previous paragraph. Now they are distinguished by the competence whereas before the distinctive character was the degree of utilization within the territory.

The second item regarding the design report at the 10th article some little modifications with respect to the previous decree. That changes regard the recomposition of the territory after the conclusion of the cultivation works. That procedures, as prematurely have to be done in a way to achieve the correct hydrogeologic arrangement and the landscape reclamation. The originality is introduced by the possibility, other than to return the soil to the agricultural uses, to realize some detention basins, basins to store the water resource or to recover the aquifers in service to periodic inundation or sell to the necessary Regional heritage. It is forbidden the recomposition through the realization of waste landfill.

Since the well organized structure of all the documents the article related to the PRAC and the cultivation project are maintained with the only difference that the bill n. 284 simplifies significantly the global system of planning. In fact the Provincial Plan for the Quarry Activity (in Italian the PPAC) and for the Extraction (in Italian PPE) are no longer provided

Remaining in the field of the planning indications the bill n. 284 preserves with respect to the previous law the scopes of the Plan while it modifies the specific actions of the Plan itself. In particular the Plan have to define:

- the forecasts, at the regional and subregional level for the period of validity of the PRAC for the materials requirements express in relation to the statistical elements and to the regional programs of the development of the interested sectors;
- the technical standards for the cultivation of the quarry able to guarantee in all the regional territory the safeguard of the environmental and landscape values and the support to the economic and productive interests in order to ensure the final recomposition of the environment and of the landscape painting;
- the addresses and the criteria for the planning of the excavation.

It is in this way abandoned the identification of the groups on the basis of the municipal territory.

From the general principles of the PRAC derives the following strategic objectives that the Plan must pursue:

- best utilization of the resource as not reproducible;
- safeguard of the environment in its landscape, territorial and naturalistic components
- safeguard of the economic sector.

These strategic objectives can be largely specified; in fact they can be discern in economic and environment objectives. Sometimes deriving from conflicting requirements the specific objectives have contrary interests and scopes. So it is a duty of the Regional Plan for the Quarry Activity to find a solution.

A scheme of the objectives is presented below:

Table 1. PRAC Objectives

OBJECTIVES	
ECONOMIC	ENVIRONMENTAL
Emphasises the available resource in relation to the foreseeable needs	Reduce the impact of the quarry materials transports
Achieve the progressive equilibrium at least at the territorial level between the demand f inert materials and the availability of the resources	Enhance the remediation of the extractive sites
Reduce the tensions on the costs of the inert materials that derive from the long-range transport	Define the legislation whose scope is the remediation or the reuse of the site
Maintain the economy link to the sector and defend/enhance the occupational levels	Enhance the utilization of alternative materials and of excavated rocks and soils
	Enhance the use of innovative cultivation technology environmental friendly

The present table reveals in advance the scope of the present work. In fact the point "*Enhance the utilization of alternative materials and of excavated rocks and soils*" suggest to use the excavated soils mixed with bentonite in order to remediate the quarry sites. The script would deal with the stability problem of a mining site recomposed with these materials focusing on the particular shape that the new slopes have to be to ensure the stability. The presence of the bentonite, a particular clay, cause the liquefaction of the soil mass itself. In this way specific actions should be taken to avoid stability problems. That problem will be faced with an finite element method that differs from the method of the limit equilibrium since it follow the slope from the origin to the final collapse. In this way it is possible to see the evolution of the deformation of the mass itself.

Returning to the regulatory framework, after the bill n. 284 were defined the Preliminary Document of the Plan (in Italian and *Documento Preliminare di Piano*) and the Preliminar Environmental Report of the Regional Plan of the mining activity (in Italian *Rapporto Ambientale Preliminare del Piano Regionale dell'Attività di cava*) adopted with the Decision n. 1973 dated 2 October 2012. These documents were approved by the Regional Commission for the Environmental Impact Assessment trough the opinion n. 8 dated 24-01-2013. The first document contains synthetically the general and specific objectives that the Regional Plan have to establish in order to follow its scopes which are the promotion of the natural resources coherently with the scope of the economic scheduling and of the territorial planning with the needs of the territory and the environment safeguard and with the necessity of the protection of the work and the companies (Regional law n. 44/82). The document PRAC essentially have to define and program the actions necessary to guarantee to the regional economy a contribution in terms of raw material able to sustain or at least not impede the economic recovery ensuring in the same way the fundamental protection of the environment and the territory. These objectives were evaluated in the Preliminar Environmental Report studying the possible significant impacts on the environment deriving from the fulfilment of the Plan itself.

1.6 The new Regional Plan for the quarry activity- Resolution n. 2015/2013

As said before the PRAC document was defined by the regional law n. 44/1982 but not immediately realized. The Regional Junta, accepting this condition disposed with the provision n. 882 dated 21-06-2011 the start of the activity for the formation of a new proposal for the document itself. Recently, it was proposed a new plan adopted as a first step in the 4th of November 2013 with the decision number 2015 then subjected to a referendum for the presentation of the observations closed in April 2014. It was followed in May by the opinion of the Regional Commission for the Environmental Impact Assessment (in Italian the procedure of VAS), as the Environmental Authority. The recommendations with prescriptive nature and the observations received as considered pertinent were accepted and inserted in the new plan and with these modifications it was approved by the Regional Junta and passed on to the Council.

The strategic objectives of the plan are:

- optimal utilization of the resource as not reproducible;
- protection of the environment in its landscape, territorial and naturalistic components;
- reduce the impact of the transport system;
- favour the environment recovery of the extractive sites;
- define laws about the recomposition or reuse of these sites;
- favour the use of alternative materials and excavated soils and rocks (in Italian “terre e roce da scavo”);
- favour the use of innovative and nature friendly cultivation technologies;
- protection of the economic sector.

Close to this last focus there are other specific objectives:

- development of the available resource with respect to the foreseeable needs;
- achieve the progressive equilibrium, at least at the territorial level, between the inert materials demand and the availability of the resources;
- reduce the tensions on the costs of the inert materials that derive from the long-range transports;
- maintain the economy linked with the sector and defend/develop the occupational and environmental levels.

The new regional plan ratifies that for the materials such as sand and gravel it is possible to excavate only through expansion projects of existing quarries without the possibility of opening new sites. On the contrary, for the construction limestone (in Italian "calcare da costruzione") and detritus, extraction activities through the opening of new quarries and enlargement of those already existing are allowed. In this way the aim is to reduce the use of the territory. Moreover another scope is to favour the recovery of the excavated sites since it will be possible to intervene, on the occasion of authorization, on the actual recovery provisions in order to obtain project solutions more modern and adequate. Particular attention is direct to the protection of the groundwater.

A first proposal occurred in 2008; with respect to this, the new authorizations for the gravel material were reduced of about 70%. In the contest of the extraction activities the main objective was to find the adequate equilibrium between the requirement of improve the economic sector and the protection of the environment.

Entering into details, now the PRAC is composed by several documents that are:

- technical report (attachment A);
- technical enforced laws (attachment B);
- cartography (attachment C);
- environmental report (attachment D);
- non-technical summary (attachment E);
- study for the evaluation of the incidence in accordance with the Decree of the Presidency of the Republic n. 357/97 and its modification (attachment F).

1.6.1 Technical report

In relation to the scope of the present work, the structure of the Regional Plan for the extraction activity is composed by three phases that are closely linked together:

1. cognitive phase: other than the normative aspects it describes the condition of the things through a system of notions that cover all the territorial aspects (geologic and hydrogeologic) and also the condition of things of the sector itself;
2. analysis phase: made by the system of analysis of the cognitive phase composed by the valuation of the available resources, of the requirements that will be the bases of the sequent phase in which the fundamental choices will be realize;
3. proposal phase: elaboration of the plan solution with respect to the objectives, in terms of resource to make available, of allocation of the same and of location of the extractive site. All aspects are then accompanied by the system of technical laws and procedures.

In this document are also reported the objectives described above.

1.6.2 Technical enforced laws

This report can be divided in two parts: the first summarizes the nature, the scopes, the documents, the monitoring and the modifications of the PRAC, the second is essentially about the law. In fact the extractive interventions and the execution techniques are regulated; a series of definitions are also exposed concerning the mining activity. In particular the article 7 poses the sequent definitions that are maintained in the original language:

- *ambito estrattivo: porzione di territorio specifica per ciascuno dei materiali indicati al comma 2 dell'art. 2 (sabbia, ghiaia, detrito e calcare per costruzione) dove è consentita la coltivazione dei relativi giacimenti mediante l'attività di cava;*
- *ambito estrattivo di produzione: ambito estrattivo caratterizzato da consolidata attività di cava individuato per soddisfare in via principale il fabbisogno di un dato materiale;*
- *ambito estrattivo di completamento: ambito estrattivo caratterizzato da debole presenza di attività di coltivazione, destinato a completare il fabbisogno attraverso modeste possibilità di sviluppo e tendendo all'esaurimento della disponibilità;*
- *ampliamento di cava: intervento estrattivo eseguito o da eseguirsi in diretta continuità o in approfondimento rispetto ad una cava esistente, ma non estinta;*

- *coltivazione di cava: insieme delle attività funzionali all'ottimale sfruttamento del giacimento di materiale di seconda categoria di cui al RD 1443/1927 e costituite dalle seguenti principali azioni: escavazioni per scopertura del giacimento; estrazione del materiale principale e del materiale associato; prima lavorazione del materiale di cava; gestione dei rifiuti di estrazione; sistemazione del sito, anche contestuale, mediante il ripristino o ricomposizione ambientale;*
- *comparto estrattivo: insieme consistente di cave, in numero superiore a 15, anche estinte, strettamente vicine tra loro e aventi complessivamente una superficie di scavo superiore a 2.000.000 mq, che occupa una porzione continua e omogenea di territorio, priva di rilevanti elementi fisici di separazione tra le cave (centri abitati, strade principali, ferrovie, fiumi ecc) e interessata da un ampio e intenso sfruttamento estrattivo.*

The document contains also a description of the available maximum volume, the type of cultivation allowed, the specific standards to be observed during the activity itself, the distance to be taken and the technical provisions.

In the paragraph concerning the executive technical regulations, Article 20 and consecutives, there are specific norms about the presence of an aquifer, about the slope of the pit and about the project of the recovery.

In particular for the quarries of sand and gravel:

- *L'escavazione deve essere effettuata mantenendo un'inclinazione delle scarpate perimetrali non superiore a 40° dall'orizzontale, mentre a fine sistemazione le medesime non devono avere inclinazione superiore a 25° dall'orizzontale;*
- *Deve essere prevista nel progetto di ricomposizione la formazione, sulle scarpate di cava, di macchie boscate composte da specie arboree arbustive autoctone adatte alle condizioni climatiche e pedologiche della zona. Tali macchie devono coprire, complessivamente, non meno del 20% della superficie delle scarpate.*
- *Deve essere realizzato, prima dell'inizio dell'attività estrattiva, lungo la recinzione, un arginello in terra alto almeno 50 centimetri in modo da impedire ruscellamenti sulle scarpate di cava.*

Finally, in the attachment of the report are defined a series of rules for the editing of the reports about geologic, geomorphologic, hydrogeologic and hydrographic frameworks, about the management of the wastes and the environmental recovery.

1.6.3 Cartography

This section contains a series of cartographies of the Veneto Region about the geology of the territory, the extractive activities subdivided in quarries of limestone for constructions, detritus quarries, sand and gravel quarries, about the mineral resources still available and the extractive sites.

1.6.4 Environmental report

The contents are defined in the clause 4 of the article 13 of the Legislative Decree n.152/06 (in Italian *Testo Unico Ambientale*) and sequent modifications, which says: *“Nel rapporto ambientale debbono essere individuati, descritti e valutati gli impatti significativi che l’attuazione del piano proposto potrebbe avere sull’ambiente e sul patrimonio culturale, nonché le ragionevoli alternative che possono adottarsi in considerazione degli obiettivi e dell’ambito territoriale del piano stesso”.* This document is closely linked with the procedure of the Environmental Impact Assessment; in fact the report is one of the document that must be present while presenting a EIA procedure.

1.6.5 Non-technical summary

The document contains a description of the previous notions reported in an elementary way, of clear and immediate understanding; there are recalled the economic and environmental objectives of the PRAC, its phases, the law of reference, the persons involved, the requirements valuation and the monitoring plan. Concerning this last aspect are defined the parameters to be monitored and also the deadline; for example, the PM10 concentration in the air are controlled each year.

2. Quarries cultivation

The fundamental aspects and the characteristics of a quarry are, generally, unique and rarely repeatable since the development of a single quarry depends on numerous parameters that are site specific. They also depend on the method of cultivation and the geographic characteristics of the site. The Marche Region defines, in the document PRAE, a limited number of common characters that are sufficient to define univocally the category. The basal elements are:

- the geographic positioning of the quarry;
- the geometric development of the quarry;
- the extraction method;
- the abatement technology.

Since this classification has a general character, it can be considered valid for all the Italian region.

2.1. Geographic contest

The geographic contest allows to distinguish between the so called mount quarries ("*di monte*") and plain ("*di pianura*"). The first are allocated along the slopes of high elevation or hill.

Figure 2. Mount quarry

The two types can be also subdivided in:

- "*culminale*" quarries: sites that in any phases of the activity interest only the highest part of the elevation; not so diffuse since they induce a deep modification of the "horizontal line" leading to high impacts;
- "*mezza costa*" quarries: the extraction is performed in the slope of the elevation and the progression occupies always a portion that is in the middle between the base and the top; the

landscape impact is generally high, but, the allocation along the slopes with decreasing inclination can lowering or annulling the extension of the front “in view”;

- “*pedemontana*” quarries: the extraction is confines at the base of the elevation, involving in part the surrounding level ground and in part the base of the elevation; the excavations are easily hided with the natural elements present in the landscape.

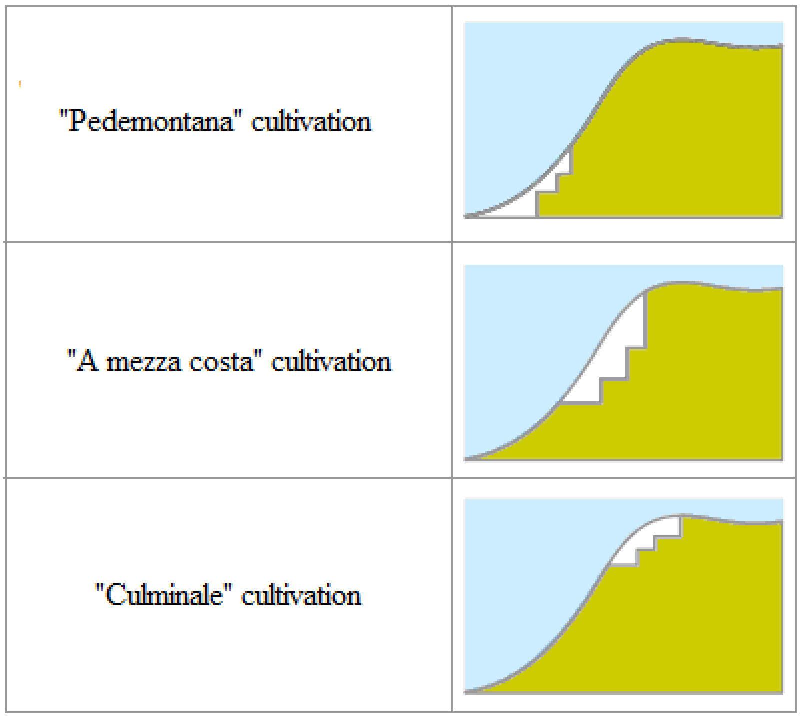


Figure 3. Mount cultivation

They required access tracks to the construction site and service streets that inevitably change the aspect of the slopes through earthworks. The temporal landfill since they need to be located close to the extraction site for economic reasons will impact a lot. The three categories examined can evolve to a cultivation called pit (“*a fossa*”) if the manager wants to reduce the impact (for the “*culminale*” and “*a mezza costa*” cultivations) or if the works are deepen under the ground level (“*pedemontana*” cultivation); in this last case the cultivation will be affected by those impacts that are characteristic of the plain excavation. Anyway, generally in the mount cultivation the ratio between the length and the depth of the pit is never so high since the depth is always relevant contrary to what occurs in the other type of cultivation. This second type, the plain one, develops in nearly flat sites, located to any altimetric level; the quarries can be located close to the foot of the elevation provided that the slope is not touched. For what concern the visual impact, for an observer at the ground level the landscape doesn’t change whereas it is sufficient to move a bit in the height to perceive the entity of the impact. Furthermore it is easily marked by adequately dimensioned wings and suitable directions of the elevation of the excavation fronts.

Figure 4. Plain quarries

The highest problem concerning this type of quarry is the impact caused by the interaction between the excavation and the aquifer since the activity itself can modify the its geometry and eventually leads to the presence of backwater. Even if the cultivation of rocks or soils don’t involve, in general, the groundwater contamination it is a good practice and a law in some regions to maintain the mining activity above the aquifers in order to impede any kind of interference with the groundwater regime. If the laws permit the excavation under the aquifers it must be accompanied by a specific study about the hydrology of the site to account for the contamination risks from external actions with respect the cultivation activities and also having care to impede that some superficial effluents flow inside the quarry. The trench cultivation (in Italian “*coltivazione a fossa*”) used for deposits of loose or incoherent minerals and for coherent stone materials it is convenient in flat zone rather than in the first type described (mount quarries). A particular trench cultivation in this first type is that is called “bottleneck”. This configuration is composed by an horizontal tunnel that collects the slope and the base of the deposit, then the cultivation is made through a series of big steps that give the typical aspect of an bottleneck. See the figure below for a better understanding.

Figure 5. “Bottleneck” configuration

2.2. Geometric development

For what concerns the geometric development the quarries can be grouped in quarries as with open or close geometry. In general the mount quarries can have both the configurations whereas the plain quarries have a close geometry with the exception for those that are located in depressions. For the close geometry there are two categories: pit or well. The first identifies all the quarries having an inclination of the slope that is good for the building of tracks and/or ramps for the connection between the various levels. The second have, on the contrary, plumb walls; in this way the lower service areas are accessible only through vertical transport systems. Both the configurations can be realize at the ground level or on the slope of dome embankments. In this last case the pit quarries can assume the geometric configuration of the funnel described above.

Another geometric classification is based on the distinction between the cultivation at open sky or underground. The fist are applied when the material deposits to be extracted are horizontal or with a little inclination and covered with sediments that can be removed with acceptable prices. The factors that induce to think that this cultivation method is not convenient are: lower number of annually work-days caused by the atmospheric conditions, higher payment for the purchase costs of those soils disturbed by the excavations, higher costs for the recovery works and an higher environmental impact both from the point of view of the landscape and the noise pollution (gunpowder, heavy machine at work, vibration …).

The other type of cultivation is performed when the material to be extracted is located in deep, i.e. when is non economically favourable to work with an open sky and extracted to material that covers the deposit. Once the location of the deposit is identified, it is reached with a system of galleries and tunnels adequately dimensioned. Generally is advisable to proceed from the top to the bottom with the galleries; in this way the load on the underlying galleries is reduced. The waste product can be used to close of eventually stabilize the abandoned site. For these reasons it is a good idea to preferred this technique in the presence of rocky mass having good characteristics of self-lift and in the absence of consistent aquifers.

2.3 Cultivation methods

This argument required a separate chapter; with the term cultivation is intended that "*logic sequence, linked with the temporal rate, with which elementary deposit volume are extracted as well as the resulting technical operation able to transform the minerals in a product ready for the market*". Therefore all the operations, from the research of the mineral to the treatment in order to make it available for the market are intended to be included in the definition of the cultivation.

Among the most important factors there are the form of the surface and the depth of the deposit with respect to the ground plane. The surface is related to the stability analysis whereas the depth of the excavations influences the decision between an open sky or underground cultivation. In the same quarry there could be adopted different kinds of mining activity.

The cultivation methods can be subdivided in:

- unique large steps: the deposit is made by an unique level whose height coincides with the height of the step itself;
- multiple steps: the deposit is made by an unique level that is subdivided in horizontal slabs (in Italian *platea*) that have an height that can varies from some meters to ten meters equals to the height of the step. Each slab is cultivated simultaneously;
- several slabs within an unique step ("*a splateamento su gradone unico*"): the slabs are cultivated sequentially (one at a time) from the highest one;
- several slabs within multiple steps ("*a splateamento su più gradoni*"): the deposit, subdivided in the project in slabs, each been cultivated for the height equal to that of the step, is interested by extraction activity in due or three slabs whose slopes are at a distance that generates due or three squares.

Another category of methods are denominated "with bed" ("*a platea*") when are refereed to deposits of loose materials or weakly coherent, generally from plan deposits, extracted through direct extraction with machine usually used in the movement of the soil. The cultivation is generally performed with a regular scheme through the use of bulldozers and scrapers that extract segment of soils having thickness from some cm to 50 cm, with a length equals to those of the characteristics of the machine.

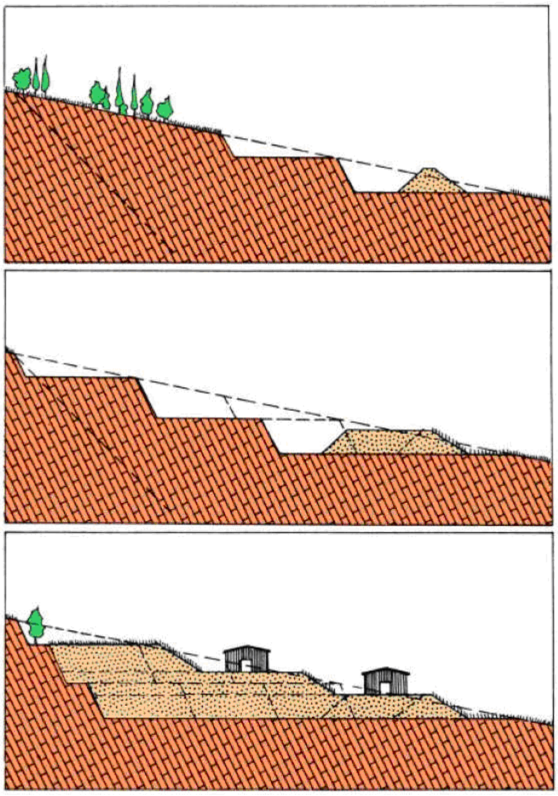


Figure 6. Steps cultivation with the final recovery

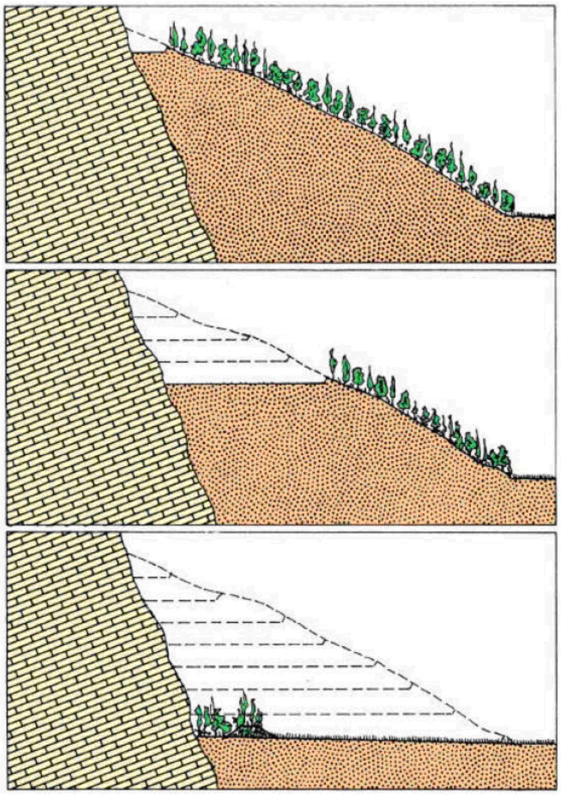


Figure 7. Several slabs within multiple steps cultivation

When the reduction of the visual impacts must be achieve the method of the lots with the slope rotation (*metodo per lotti con rotazione del fronte*) can be performed. It can be applied to all the previous applications. It consists of proceeding with the front with orthogonal directions with respect to the major line of visibility of the quarry. When it is not possible to do this, the quarry can be subdivided in lots and the front is gradually rotates around a fulcrum.

Other methods exist but concern the cut of ornamental rocks or of small blocks or slices that are not of our interest.

2.4 Abatement technology

Among the different technologies that can be adopted there are:

- abatement with perforation or shot;
- abatement with mechanical methods;
- cutting (diamond wire, with chain, with fuse,…).

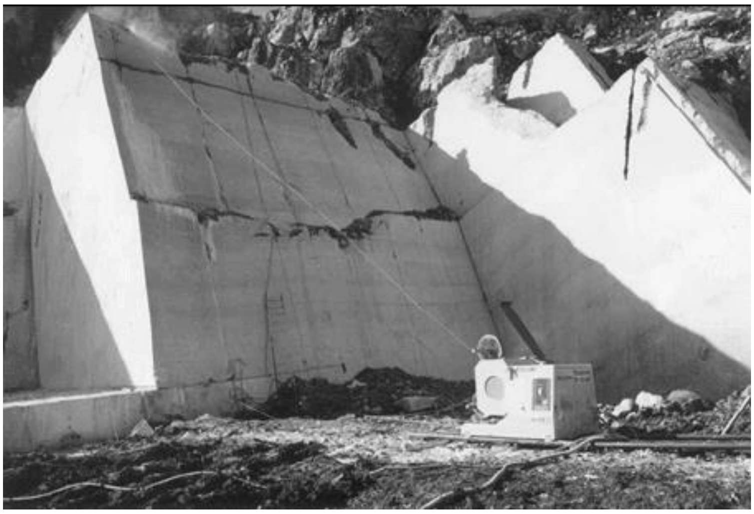


Figure 8. Diamond wire in a marble deposit

2.5 Cultivation phases

Independently from the type of materials extracted and on the site configuration, the cultivation activity is generally subdivided in phases that assumed aspects and operative modalities different with respect to the technology used. Moreover, the principal phases are:

1. rocks abatement: with explosive substances or through mechanical methods; permits the detachment of the materials from its seat and the reduction to the adequate dimensions for the successive works;
2. the so called "*disgaggio*": is the step relative to the making safe the front after the abatement (especially if done with explosive); it is performed removing unstable blocks and making regular the front for the successive work phases;
3. secondary abatement: it is used in order to reduce the excessive dimensions of the blocks for the sequent treatment phase; the use of the explosive or mechanic devices are allowed;
4. clearing out: permits the carry on of the cultivation of the front and the transport of the materials to the sequent productions. The machine used are the hydraulic caterpillar-track and the shovel;
5. internal transport: generally performer with dumper filled by the clearing out machines. The materials load up is then delivered to the primary pounder;
6. primary smashing: there are different types of pounder. It could be of the type called "ad urto" or "a martelli". Another distinction is fix or mobile depending on the cultivation plan of the quarry;
7. transport to the plant: final manufacturing of the material extracted performed outside the mining site itself.

3. Quarries recovery

The progressive development of the interest with respect to the protection of the environment starts to involve also the extractive sector. In particular there is the necessity to answer to the public opinion pressures that interfaces daily with the decline of the quarries site itself. Furthermore the Italian law says that the quarrymen after having gain money from the use of the natural resources of the territory have to take care of the recovery of the site. The environmental problem is closely linked with the type of cultivation in order to properly define the final destination for the extractive area. In this way it must be known before the starting of the mining activity in order to shape the territory until the desired profile. As a consequence the recomposition phase must be an important part of the whole project. Obviously the scope can’t be to rebuild the initial environment but to insert it in the surrounding environment. The choice of the type of recomposition to perform depends on several factors such as the cultivation adopted, its extent and the depth of the excavations, the characteristics of the materials which remain in the site, the presence of water, the proximity to urban sites, to high relevance street or to high interest landscapes. For that purpose it is possible to list a series of “good practices” in order to:

- limit the impacts on the atmosphere: for example through the washing of the trails and the service areas used by the excavators or orienting the slope in function of the site and climate conditions characteristics (wind direction, …);
- limit the impacts on the hydro-environment: maintain the natural original flux lines for the rivers and be sure that the aquifer is not intercepted through piezometric surveys;
- limit the impacts on the soil and subsoil: avoid the hazardous substances contamination or preserve the soil removed in the first phase of the excavation;
- limit the disturbances induced by the noise and vibrations: utilize new machineries or minimize the pressure wave in case of explosions and avoid the use of the explosive near fractures that could lead to some gases release;
- limit the impacts on the landscape and the biodiverstity: foresee solutions that minimize the morphological impact of the excavations and remove the not natural presence of the staircase shape of the excavations;
- limit the impacts on the flora and fauna: evaluate that interventions that may reduce permanently the existing forestry heritage, evaluate the realization of new mobility reducing to the minimum, evaluate the possible damage to the resources.

See the following table for a detailed description of the objectives of the environmental recovery of the quarries. The sequent paragraph is about the most common type of recoveries.

Table 2. Quarries recovery objectives

OBJECTIVE	DESCRIPTION
Site stability	Control of the final morphology; Control of the superficial water through a set of works about the regulation of the water (channels, drainage walls, sewers); Control of the infiltration through adequate drainage systems that favour the flux.
Remould the area and complete it in the context through the use of native plant and the cover material	The not used extracted materials have to be used properly for the recovery operations; The slopes have to be modelled in order to create surfaces adequate for the roots of the vegetal species that will be used for the recovery.
Establish and enhance the habitat with particular attention to the water cycle	Maximum possible biologic and morphologic diversity in order to optimize the inserting of the site in the territorial context. For that purpose it is convenient to operate some experiments to find some limiting factor for the success of the recovery itself.
Appraise the recovered water	Return the area to the community through some educational, scientific, naturalistic, athletic recoveries and also with the purpose of the energy production from renewable sources.

Figure 9. Example of naturalistic recovery

Table 3. Types of environmental recovery

TYPE OF RECOVERY	DESCRIPTION
Naturalistic	Also called ecologic recovery since it tends to rebuild the original landscape altered by the mining activity. It considers the reforestation, the becoming green again (in Italian "rinverdimento"), body of water with naturalistic management, faunistic oasis, …
Recreational	The idea is not to rebuild the natural landscape but an environment with club facilities for the community and for the recreation. Generally they are zones near the urban cities, cardinal for the connection with the rural area. there could be planned athletic area, natural park, camps, luna park,…
Productive	The scope of that recovery is to produce something that is different from the extraction activity. In this way the area have to be adequate for the proper new scope. For example the agriculture, fish culture or livestock holdings,…
For civil emergences	This recovery answers to the requirement of sites that can be used during emergences situations caused by natural disasters. The abandoned quarries could be used as assistance area, container area, heliport, deposit area for the first aid operations,…
For residential scope	Territorial replanning due to the fact that it is not allowable another subtraction of land to the agricolture in order to satisfy the residential requirements

Figure 10. Quarry in the province of Vicenza before and after the recovery

Consecutively to that description are presented two types of recomposition for the specific cases of a plan quarry and mount quarry.

3.1 Recovery of a plan and trench quarry

For the trench quarries with a large depression, whose level is higher than the aquifer and with an adequate drainage system of the superficial water it is sufficient to cover the bottom with the vegetal soil removed during the first part of the extraction. The slope must be of the order of 2-3% towards the side in which there is the drain for the meteoric water. The same can be said for the lateral slopes that will be modelled with inclination higher than 15° in order to facilitate the sequent agriculture with mechanical devices. Such soils present an agricultural productivity lower than the undisturbed soil and will be places for pasture, grasslands or grain cultivations. In case of low permeability of the soil which cause stagnation it is possible to plan a poplar culture since this type of tree highly sustain the presence of water.

3.2 Recovery of a mount quarry

This recovery is much more complex since the high impact that it generates on the environment, but a good cultivation phase could help the recomposition of the quarry. The main problem concerns the stability of the fronts of the excavations; in fact they have to be modelled according to the geomechanic and geostructural property of the soils itself. Sometimes, in presence of an high elevation the recovery is made by large steps (in Italian “a gradoni”) that have a slightly inclination towards the mount. But it may cause a stagnation of the water that could negatively influence the stability. Once the final arrangement is defined the vegetation plan must be defined with seed plants that are able to guarantee the consolidation in short time of the slope and the mitigation of the erosive phenomena. Frequently the local administrations request to use the quarry as landfill since the high degradation that regulates that zone and the good accessibility. Moreover this option have to be maintained as the last possibility in order to face with the hostility of the population.

Finally is not simple to make a prevision of the cost related to the recovery actions since each interventions differs from the others and foresees operations that could change every time. Obviously the cost have not to be higher than the that of the extracted materials otherwise the extraction itself become useless.

3.3 Recovery with excavated material mixed with bentonite

The excavated material (in Italian “materiale da scavo”) are from long time cause of discussions since for a long period were considered as wastes and were deposed in landfills. That leads not only to the uselessly occupancy of space but also to the wastefulness of a resource that could be used again. Over the years this material loses the qualification of waste passing to the qualification of by-product (in Italian "*sottoprodotto*"). See the following figure which reports the legislative path.

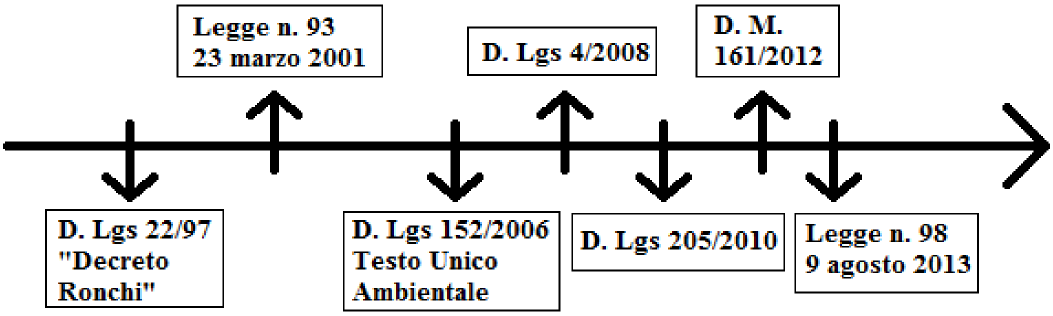


Figure 11. Regulatory framework for the excavated soils and rocks

In the sequent table will be present the main legislative passages.

Table 4. Legislative excursus: part 1

Law	Characteristics
D. Lgs 5 Febbraio 1997 n. 22 - "Decreto Ronchi"	Risk criterion: the soils and rocks as not hazardous materials obtained from the excavation activity are excluded from the waste regime (art. 8, comma 2, lett. c). Decision immediately contested by the European Commission that leads to an interpretative debate. It concludes with the fact that some operators excluded the contested materials from the waste regime and other not.
D.M. 25 ottobre 1999 n. 471	Attachment 1: definition of the concentration limits that have to be respected by the materials in order to be excluded from the waste regime (table 1, colums A and B as mg/kg of dry substance).
Legge 23 marzo 2001 n. 93	Article 10: exclusion from the application of the waste laws of *"le terre e rocce da scavo destinate all'effettivo utilizzo per reinterri , rilevati e macinati, con esclusione di materiali provenienti da siti inquinati e da bonifiche con concentrazione di inquinanti superiore ai limiti di accettabilità stabiliti dalle norme vigenti".*
Legge del 21 dicembre 2001 n. 443 nota come "Legge Lunardi"	Article 17: conditions that have to be respected in order to exclude the S&R from the waste regime: respect of the limits impose by D.M 25 ottobre 1999 n. 471 for the polluting substances and ensure that the use have to be performed without preliminary transformations and through the modalities expected in the EIA project or, if not undergo to the EIA through the modalities approved by the Administrative Authority prior to the ARPA opinion.

Table 5. Legislative excursus: part 2

Law	Characteristics
D. Lgs del 3 aprile n. 152 del 2006	Article 184-bis: by-product definition: any kind of substances that satisfy the sequent conditions: *"-la sostanza o l'oggetto è originato da un processo di produzione, di cui costituisce parte integrante, e il cui scopo primario non è la produzione di tale sostanza od oggetto;* *-è certo che la sostanza o l'oggetto sarà utilizzato, nel corso dello stesso o di un successivo processo di produzione o di utilizzazione, da parte del produttore o di terzi;* *-la sostanza o l'oggetto può essere utilizzato direttamente senza alcun ulteriore trattamento diverso dalla normale pratica industriale;* *-l'ulteriore utilizzo è legale, ossia la sostanza o l'oggetto soddisfa, per l'utilizzo specifico, tutti i requisiti pertinenti riguardanti i prodotti e la protezione della salute e dell'ambiente e non porterà a impatti complessivi negativi sull'ambiente o la salute umana."*
D. Lgs 4/2008	Article 186, clause 1 says that "le terre e rocce da scavo: *-siano impiegate direttamente nell'ambito di opere o interventi preventivamente individuati e definiti;* *-sin dalla fase di produzione vi sia certezza del'integrale utilizzo;* *-l'utilizzo integrale della parte destinata a riutilizzo sia tecnicamente possibile senza necessità di preventivo trattamento o di trasformazioni preliminari;* *-sia garantito un elevato livello di tutela ambientale;* *sia accertato che non provengono da siti contaminati;* *-le loro caratteristiche chimiche e chimico-fisiche siano tali che il loro impiego nel sito prescelto non determini rischi per la salute e per la qualità delle matrici ambientali interessate ed avvenga nel rispetto delle norme di tutela delle acque superficiali e sotterranee, della flora, della fauna, degli habitat e delle aree naturali protette;* *-la certezza del loro integrale utilizzo sia dimostrata."*
Decreto del Ministero dell'Ambiente e della tutela del Territorio e del Mare 10 agosto 2012, n. 161	*"I materiali da scavo possono contenere, se la composizione media dell'intera massa non presenta concentrazioni di inquinanti superiori ai limiti previsti dal decreto, anche: calcestruzzo, bentonite, polivinilcloruro (PVC), vetroresina, miscele cementizie e additivi per scavo meccanizzato."*

Table 6. Legislative excursus: part 3

Law	Characteristics
Legge n 98 2013 “Disposizioni urgenti per il rilancio dell’economia”	Article 41: *“i materiali derivanti dallo scavo, intesi come sottoprodotti, ricavati da opere soggette a VIA e AIA, sono gestiti secondo il D.M. 161/12 al di là delle quantità prodotte. Viceversa, i restanti materiali (cioè derivanti da opere non soggette a VIA e AIA) andranno trattati secondo il D.L. 69/13 indipendentemente dalle quantità prodotte.”*
DPCM 29 agosto 2014 “Sblocca Italia”	Article 7, clause 2: for the use of the soils and rocks the following conditions must be considered: *“-il materiale non deve provenire da siti contaminati o sottoposti ad interventi di bonifica ai sensi del titolo V della parte IV del decreto legislativo n. 152 del 2006;* *- l’utilizzo nel sito prescelto deve avvenire nel rispetto dei limiti alle emissioni in atmosfera, nonché delle norme di tutela delle acque superficiali e sotterranee, della flora, della fauna, degli habitat e delle aree naturali protette, e deve essere dimostrata la compatibilità del materiale da utilizzare con il sito di destinazione.”*

This type of material was presented because as said before it represents the soils that will be used for the recovery of cemented gravel and sand quarry of the Province of Treviso, that is the most active in the Veneto Region. Obviously, as occurs frequently, the material used for the recomposition differs a lot from the point of view of the resistance from the original material that as described following have an high capability to form very steep slopes. In fact the cemented materials can be considered as a fortune whereas the soils mixed with bentonite give to the soils the characteristics typical of a poor clay. Consequently a slope composed by cemented gravel is more stable considering the same inclination angle; so it is necessary when dealing with the recovery materials to adopt gentler slope.

3.3.1 The bentonite

The bentonite is a fillosilicate ($Al_2O_3 - 4SiO_2 - 4H_2O$), a natural clay that derive from the alteration of the vitreous effusive rocks, composed almost by montmorillonite, calcium or sodium. It can be found in volcanic soils as a product of the decomposition of the volcanic ashes. It presents a particular crystalline structure composed by thin layer, it is not toxic and chemically inert. The principal deposits can be find in the North of America, in particular in Montana, near, Fort Benton from which derives the name of the mineral.

The water has a high impact on it; in fact the bentonitic material become an impermeable gel and waterproof when enters in contact with water. The phenomenon is always accompanied by a consistent increase of the volume (15-20 times higher than the initial one) and by an adsorption that leads to an increase of the mass five times higher than the same dry quantity of material. The main variables that control this behaviour are the granulometry and the temperature. Thanks to that the material mixed with bentonite shows high potentialities in the construction sector. More specifically the principal properties of that material are:

- it becomes plastic and adhesive when mixed conveniently with water;
- it becomes hard and rigid when subjected to a drying operation, but remains plastic if it has not experienced an high heating;
- at very high temperature there will be the process know as "*calcinazione*" and the water lost can't be reintroduced;
- has a fusion temperature that is lower with respect to that of the silicon dioxide, SiO2 and so it has a limited fire-resistance;
- benefits of the property of "tixotropy": it obtains a certain stiffness at rest whereas becomes fluid if agitated;
- in the construction sector it is used as waterproofing, for the containment of the walls of excavation in narrow sections, as containment of the walls for poles works;
- in the building site (in Italian "*cantiere*") it is used as a liquid additive for the excavation of galleries, underground micro tunnel od for the process of jet- grouting.

The waterproffing properties of the bentonite arise when the material is subjected to a pressure that contrast the expansion as occurs normally. The material in fact hydrates and increases in volume with respect to the available space (it could close fissure until 3 mm). Entering into details the bentonite structure refers to a series of layers composed by cations having an tetrahedral or octahedral coordination. The minerals that make that layers have a flat shape and form fine grained aggregates. The active ingredient of the bentonite used for example for the production of the geosynthetic barriers is the montmorillonite, an hydrate silica of aluminium and magnesium, morphologically made by alumina octahedral imprisoned between two layers of tetrahedral silica (structure 2:1: see figure below). It represents the mineral with the best qualities; in fact it has an high specific surface (800m2/g) which implies the presence of finer particles and the subsequent availability of cationic changes and reactions. As an example, 1 g of montmorillonite corresponds to an area of 800 m2 of conditioned water; it is a value very high also if compared with that of other minerals such as Caolinite and Illite. Its elementary units are linked together by Van der Waals forces that exercise through the inter-layers cations. They can be exchanged with those present in the solution that hydrates the clays. The water molecules and the exchangeable ions could enter and separate the layers. See the following figure reporting the structure of the discuss minerals:

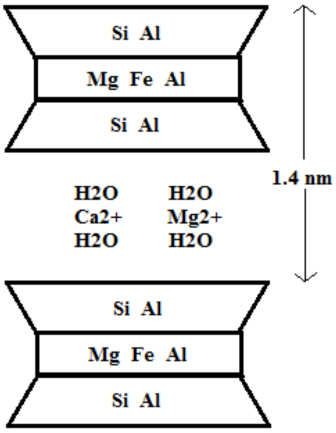


Figure 12. Montmorillonite structure

In this mineral the isomorphic substitutions in the crystalline lattice produced a net negative charge on the surface of the minerals and a sequent relevant capacity of cationic exchange (CEC=80-120meq/100g). In relation to the chemical composition of the solution with which the mineral enters in contact there can be different type of bentonite. For example it is possible to talk about calcium bentonite, potassium bentonite and sodium bentonite when the cations exchange occurs with Ca2+, K+, Na2+. Finally is important to distinguish between the natural bentonite and the activated one. The first has the proper characteristics of the clay find in nature while the second is obtained through a chemical processes that artificially increase the presence of a cation with respect to the others.

Operatively, in this work the recomposition material is taken from the construction of piles (in Italian “diaframmi”) in a place not so far with respect to the quarry. In particular the material results from the excavation after the phase of the sedimentation. The excavated materials have the sequent properties:

Table 7. Recovery material properties the so called “Recovery material 1”

Parameter	Value
Unit weight γ	17 kN/m3
Cohesion c	2 kN/m2
Stiffness E0	70,000 kN/m2
Friction angle ϕ	30°

According to the norm UNI 1006 the material is geotechnically classified as a sandy-clayey-silty gravel, medium to high in dimension coloured grey (classification: A-2-7). The unit weight is obtained from the AASHTO modified test (reference norm ASTM D 1557) that gives a value for γdry of 1.87 Mg/m3 to which corresponds an optimum water content of 12.4%. Another test performed is the CBR one that allows to define the stiffness through the following formula of conversion:

$$E_{dyn} = E_0 + 700$$

with the stiffness expressed as kg/cm2. Considering a typical value of Edyn for a sandy soil equals to 1,500 kg/cm2, E0 will results 800 kg/cm2 that is converted to kN/m2 and taken in order to be in favour of safe equals to 70,000 kN/m2. It is important to remember that all the coefficients assumed come from assumptions to be in favour of safety.

Once it is posed in field it is well compacted in order to improve the stability of the material itself.

4. The quarry material: cemented sand and gravel

The cementation is a process that occurs naturally during a long period of time due to the calcium carbonates present in rocks that are soluble in water. In fact in presence of water the carbonates dissolve until the complete saturation of the liquid itself. Once the equilibrium is reached a small concentration variation of the carbonates for example due to the evaporation of water, causes the calcium carbonate precipitation leading to a new equilibrium condition. The carbonation reaction is the following:

$$Ca(OH)_2 + CO_2 \Leftrightarrow CaCO_3 + H_2O$$

Hereafter the precipitation products set up the cemented bonds sinking around the sand or gravel grains. On the contrary, when the solution is not saturated the effect is the opposite, i.e. the carbonates and the relative bonds tend to melt in water leading to the degradation of the gravelly medium. The carbonatic film that is created establishes some weak attraction forces between the particles and also stops the grains among them as they are wedge. Its thickness and hardness influence the mechanic characteristics of the cemented medium. Obviously this process doesn’t complete in an hour or a day since the time is its best supporter. The “youngest” bonds will give rise to the cemented gravels while the “grandfathers”, after have experienced the geologic time and the tectonic movements will give rise to the sedimentary rocks.

4.1 Researches on the cemented materials

In this paragraphs the geotechnical properties of the cemented soils will be studied. At the weaker end of the spectrum, the cemented materials behave neither completely as a soil or a rock, often with the characteristics of both. Thus they provide their own set of challenges with regard to slope stability assessment and engineering design due both to the often weak nature of the contributing cementation bonds and the possibility of cementation degradation due to environmental factors such as groundwater seepage. A series of studies were conducted upon this arguments in order to better understand the behaviour of this natural material. In particular, a study performed in the eroding coastal cliff of central California distinguishes between weak and moderately cemented sand. The first has a unconfined compressive strength (UCS or qu) of less than 100 kPa whereas the second type in between 100 and 400 kPa. This strength generally reflects the shear resistance of soils.

All cemented sands show the tendency to form steep natural and cut slopes (Figure 13) and the tendency to fail in a dramatic brittle collapse upon excessive loading.

Another additional important feature is that cemented granular soils are capable of resisting compression and shear force similar to uncemented sands but also withstand at least some minimum tensile stress due to cohesion (cementation and/or interlocking) effects (Collins et al. (2009)).

Triaxial testing shows that both the materials fail in a brittle fashion at low confining stresses and at low strain levels (on the order of 0.5-2%) with increasing ductile response at higher confinement. Also Clough et al. (1981) identified this property and in addition to that they found that a rapid volumetric increase appears upon shearing. The two materials could be modelled effectively using linear Mohr-Coulomb strength parameters, although for weakly cemented sands, the curvature of the failure envelope is more evident with decreasing friction and increasing cohesion at higher confinement. In particular the friction angles are similar to those obtained from uncemented sand materials whereas cohesion is generally a function of both the cementing agent and the angularity of the particles that provide bonging surfaces.

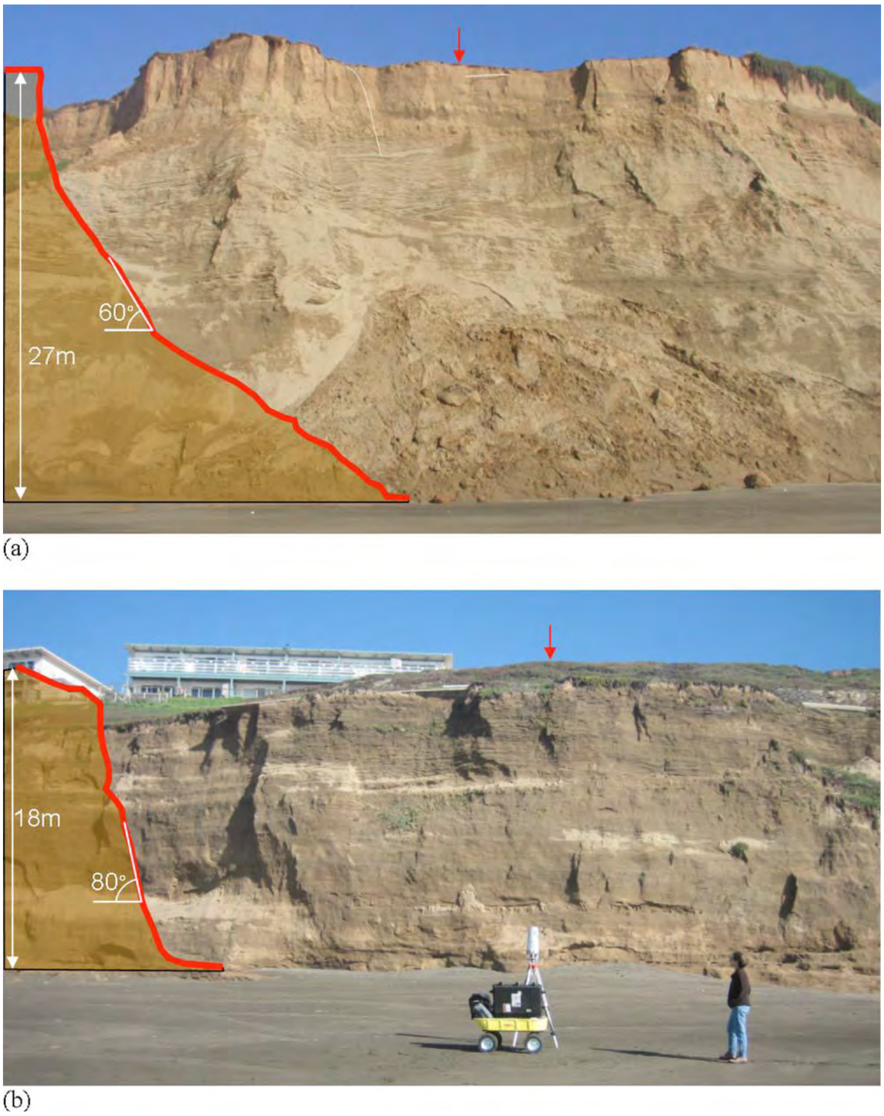


Figure 13. Examples of. (a) weakly cemented sand cliff; (b) moderately cemented sand cliff (Collins et al. (2009))

For what concern the laboratory testing the geotechnical sampling of cemented sands can be very difficult since it undergoes to extensive disturbance. This disturbance lead to higher densities and water content, a more ductile stress strain response and a lower shear-strength envelope. On the other side, reconstituted samples are generally not acceptable for strength testing since the original fabric can’t be replicated and hence the apparent cohesion differs from the in situ material. Because of these limitation, a lot of studies were performed about this argument. As an example, the mathematical model of Fernandez and Santamarina (2001) obtains a positive results in the analysis of the mechanic behaviour of these materials prepared with lime. In the figure below (Figure 14) it is reported a microscope picture of an artificially cemented sand. It is noticeable that the calcium carbonate $CaCO_3$ which is placed in between the sand grains increases the superficial roughness.

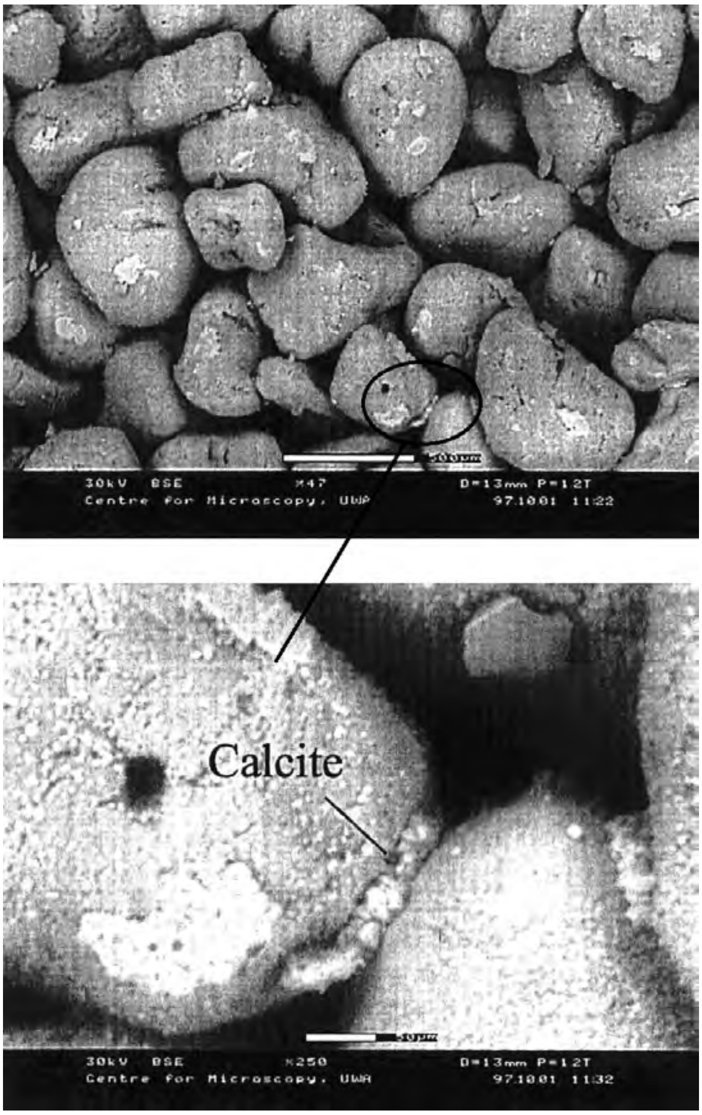


Figure 14. Microscope picture of an artificially cemented sand (Fernandez and Santamarina, 2001)

For what concern the test results the decrease in void ratio in the moderately cemented sand is thought to be the primary factor for the increase strength if compared with the weakly cemented sand. Moreover the larger surface area of the particles allows more contacts for cementation. In the first table presented below (Table 8) a series of geotechnical index properties are reported which allow to classify the material according to the USCS classification. The unit weight, the in situ moisture content and the specific gravity are typically equal to those of the uniform sands. In fact the unit weight of a sand is in between 14-17 kN/m3 whereas for a gravel is in between 18-20 kN/m3.

Table 8. Geotechnical index properties of weakly and moderately cemented sand from California (Fernandez and Santamarina, 2001)

Material	USCS desig.	Unit weight γ (kN/m3)	In situ gravimetric water content	Void ratio e	Specific gravity Gs	D50 (mm)	%<#200 sieve
Weakly cemented	SP	17.0	8.9	N/A*	0.64	0.21	1.4
Moderately cemented	SM	18.7	12.6	22.1	0.60	0.15	12.1

*N/A=not applicable

In the Table 9 the Mohr-Coulomb strength parameters discuss above are reported:

Table 9. Engineering strength properties of weakly and moderately cemented sand from California (Fernandez and Santamarina, 2001)

Material	UCS (kPa)	Friction angle ϕ (°)	Cohesion c (kPa)	Tensile strength σt (kPa)	Elastic modulus at 20 kPa confinement (kPa)
Weakly cemented-in situ wc*	13	39	6	0	23,000
Moderately cemented-in situ wc	340	46	69	32	115,000
Moderately cemented-wetted wc	124	47	34	6	50,000

*wc=water content

Note that there are some differences for what concern the cohesion c; typical value for sandy soils are close to 1 kPa. The values found during this experience suggest that the weakly cemented sand is the most close to the uncemented material itself. Moreover increasing the water content for a moderately cemented sand the cohesion value decreases obviously. So it could be confirmed that cohesion plays an important rule in the shear strength of a cemented soil.

The friction angle is close to those of the wet sands and the sandy gravel that are around 30-35° and 35°-50°. The slightly difference can be ascribed to the dilatancy phenomenon (i.e. increasing of the volume) which occurs upon shearing at low confinement. Thus result in an higher shear strength in terms of the friction angle (Ponce and Bell 1971).

Conventional triaxial test were also performed including unconfined tests (ASTM 2004g), conventional compression tests and field stress path tests. The last one differs from the others since the soil element is subjected to σ1, the major principal stress, and to a decreasing confinement but in a direction opposite to conventional triaxial tests to reach the state of failure described by a linear envelope with intercept "a" and inclination Φ that can be easily converted in the Mohr-Coulomb c and φ. Further, tests on weakly sands were only performed at the in situ water content since they would collapse when introduced to water. Graphical results are reported below (Figure 15, Figure 16, Figure 17, Figure 18).

The first explains the general difference between the two types of failures: brittle and ductile. The first failure occurs at a high confining pressure, an low strain rate and happens suddenly whereas the second occurs after an high strain rate and with an medium confining pressure. In this way the first is the more hazardous since it can't be predicted and no alarm signs are shown.

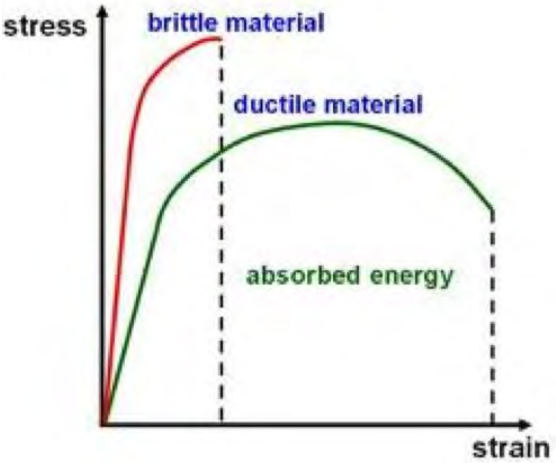


Figure 15. Failure criterion

The second and third figures report the results of the tests performed; they indicate an initial steep, near linear increase of stress, such as for the brittle material behaviour in the figure above, followed then by a slight ductility until the failure that occurs in the range between 0.2 and 1.2% axial strain. This brittle behaviour is accentuated in the FSP test results with failure at only 0.05-0.3% axial strain.

An average Poisson ratio (i.e. the ratio between the cross and longitudinal strains) of 0.295 was obtained from moderately cemented stresses and volume measurements and it was found to be consistent with that for typical sands (0.2-0.45). The elastic modulus E (i.e. the ratio between the tension σ and the strain ε) is an order of magnitude larger between weakly and moderately cemented sand. The cementation leads to an increase of the stiffness of the soil whereas the increase of the water content causes a decrease of the stiffness itself (see Table 9).

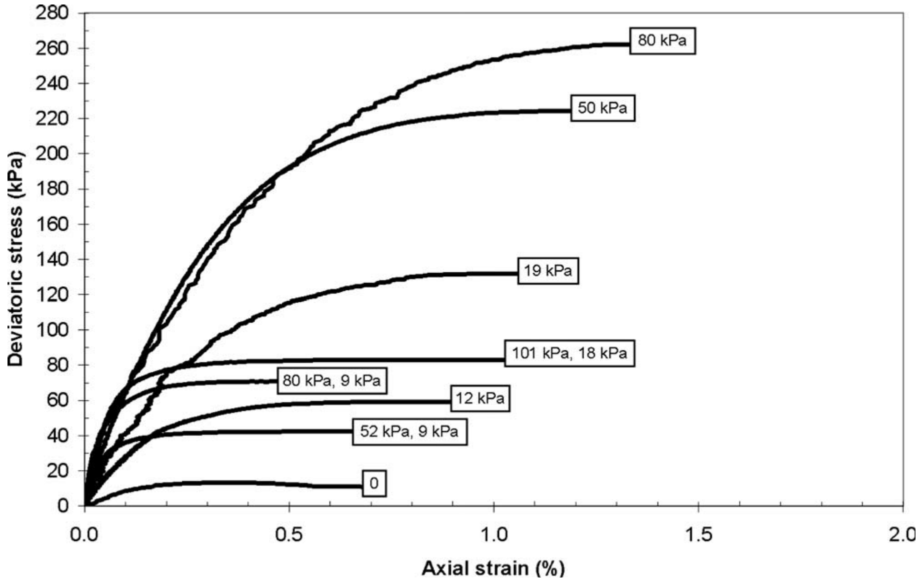


Figure 16. Typical weakly cemented sand tests at in situ moisture content for unconfined (UNC) and triaxial (TRX) compression anf FSP loading. XX kPa=σ3 (UNC and TRX), XX kPa, YY kPa=constant σ1, σ3 at failure (FSP) (Collins et al. 2009)

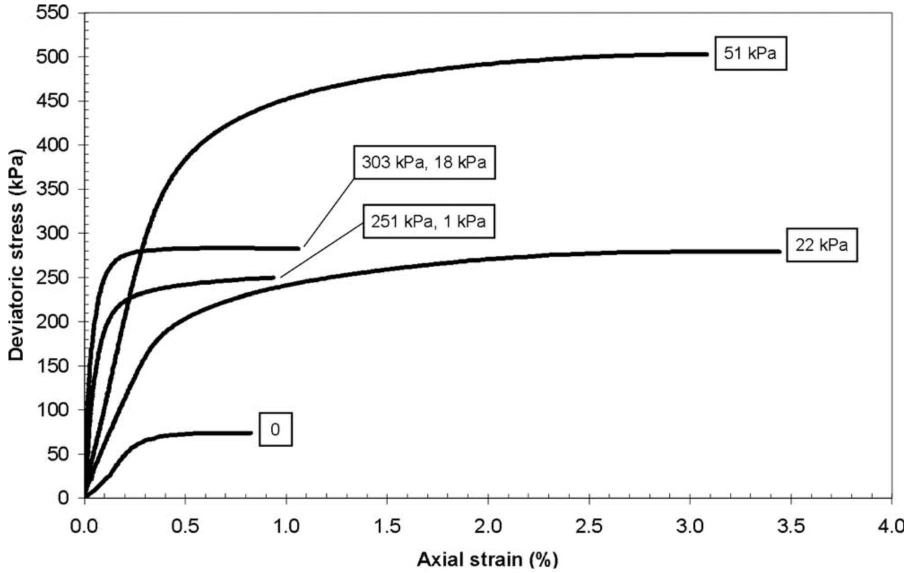
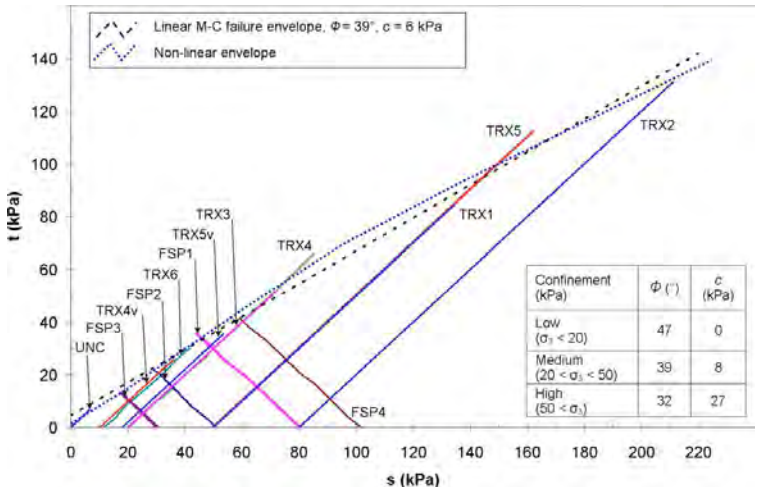


Figure 17. Typical moderately cemented sand tests at wetted moisture content for unconfined (UNC) and triaxial (TRX) compression anf FSP loading. XX kPa=σ3 (UNC and TRX), XX kPa, YY kPa=constant σ1, σ3 at failure (FSP) (Collins et al. 2009)

Wetting has a pronounced effect on both soils. In the weakly cemented sand, complete disaggregation occurred upon wetting causing a tensile shear strength value of zero. In moderately cemented sand saturation increases from 55% to 96% leading to a 60% decrease in the value of UCS, 50% decrease in cohesion, 55% decrease in elastic modulus and more than 80% decrease in tensile strength. Note that the friction angle remains nearly unchanged as expected (Table 9).

Linear Mohr-Coulomb effective shear-strength parameters can be well-fit to both materials, although the weakly cemented sand shear-strength envelope is more obviously steeper and curved at low stresses. See the following figure (Figure 18) that report a test result example in the strain-tension stresses space for weakly cemented sand.



Confinement (kPa)	Φ (°)	c (kPa)
Low (σ_3 < 20)	47	0
Medium (20 < σ_3 < 50)	39	8
High (50 < σ_3)	32	27

Figure 18. Stress path failure data and envelope plotted in s-t stress space for weakly cemented sand. UNC=unconfined, TRX=conventional triaxial, TRXv=traixial with vacuum, FSP= field stress path triaxial. Nonlinear Mohr-Coulomb strength parameter are shown in table

A more recent study on the triaxial shear behaviour of a cement-treated sand-gravel mixture (2014) says that there are a series of parameters which control the mechanical behaviour of the soil such as the cement content, cement type, relative density and grain size distribution. The soil investigated is something new because until that moment only the well graded gravely sands were investigated. This innovation concerns a poorly graded sand-gravel mixture containing 30% of gravel and 70% of sand; it was investigated both under drained and undrained conditions. Portland cement is used as cementing agent in the quantity of 0%, 1%, 2% and 3% (dry weight). Furthermore samples were prepared at 70% relative density and tested under confining pressure of 50 kPa, 100 kPa and 150 kPa. They were also compared with uncemented samples to better capture the behaviour of the cementation phenomenon.

What is found, according to the previous study, is that cementation can increase brittleness, shear strength and dilative behaviour of sands (Amini Y. and Hamidi A. 2014). After the samples preparation in terms of addition of the cement agent and relative compaction they were consolidated up to the desired confining pressures. Shear loading was applied at an axial strain rate of 0.1 mm/min for drained tests (DC) and 0.3 mm/min for undrained ones (UC). These triaxial compression test allowed to measure the cell pressure, volume change, pore pressure, load and displacements through electronic transducers. As found by Collins et al. (2009) the UCS increases with increasing cement content.

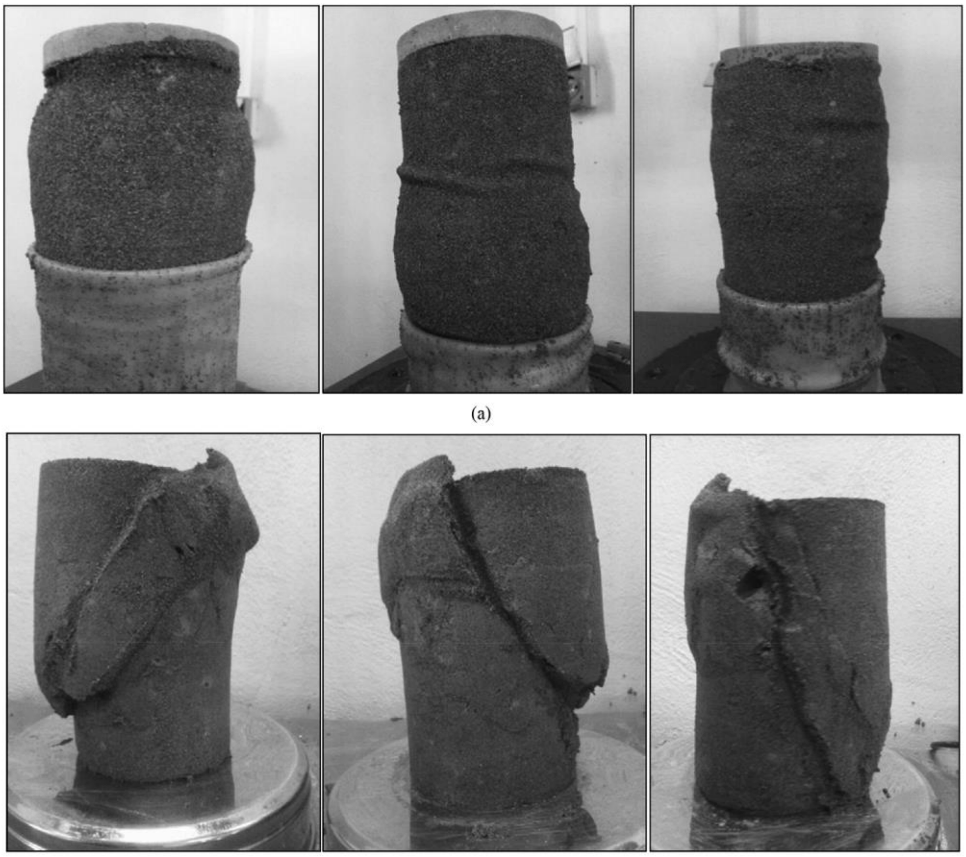
To analyze and well interpret the results it is important to present the following parameters:

$$q = \sigma_1' - \sigma_3'$$

$$p' = (\sigma_1' + 2\sigma_3')/3$$

$$p = 1 + e$$

σ'1 is the major effective principal stress, σ'3 is the minor effective principal stress and e is the void ratio. The figure below shows the typical failure modes of the uncemented and cemented samples.



(a)

(b)

Figure 19. Failure modes of tested sampes: (a) barreling mode in the uncemented samples, (b) shear zone failure in the cemented ones (Amini Y. and Hamidi A. 2014).

As can be seen all uncemented samples in the drained and undrained test showed barrelling mode without shear plane formation. Despite adding the cement agent (CC=1%) the failure mode will result in a combination between barrelling shape and shear plane, although shear band was not obvious and barrelling was the predominant mode. Increasing the cement content the thickness of the shear plane increased and the samples experienced a brittle failure and underwent significant dilation with apparent peak point in the stress-strain curve. In both drained and undrained situations, cemented soils showed a shear band with a thickness in between 3 and 6 cm. The corresponding inclination with respect to the horizontal axis decreased from 70° to 55° with increase in confining pressure from 50 kPa to 150 kPa.

For what concern the stress-strain behaviour, which theoretically is represented in the Figure 20, the volume changes and the pore pressure see the following figures (Figure 21, Figure 22, Figure 23, Figure 24). As suggested before the drained test are indicated by the letter "D" whereas the undrained ones by the letter "U". They are also followed by a number that represents the value of the confining pressure expressed in kPa. In order to check the repeatability of the experiments the tests were repeated twice and the average stress-strain diagram is plotted below. As can be seen in all the figure with the letter (a), the drained and undrained situations showed an apparent peak point associated with the failure. After that the slope of the stress-strain curve decreased to its residual value in an axial strain of about 20%. For the uncemented samples under undrained condition, the peak stress was not obvious and the softening behaviour was not as clear as the drained tests. Differently from the figure of the previous study (Figure 16, Figure 17) the increase in cement content and the reduction in confining pressure caused more softening in stress-strain curve.

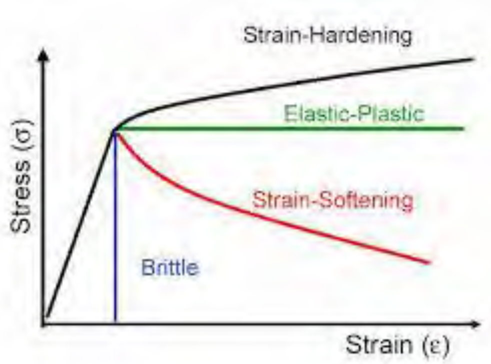


Figure 20. Strain-stress behaviour

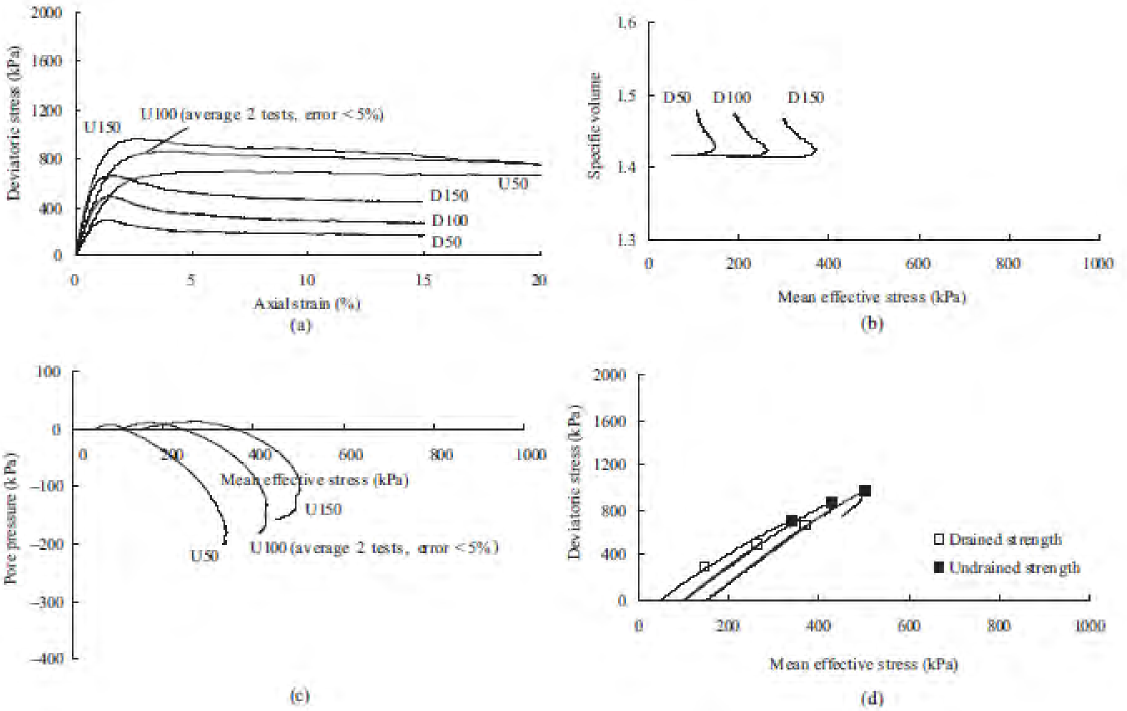


Figure 21. Trixial test results of uncemented samples

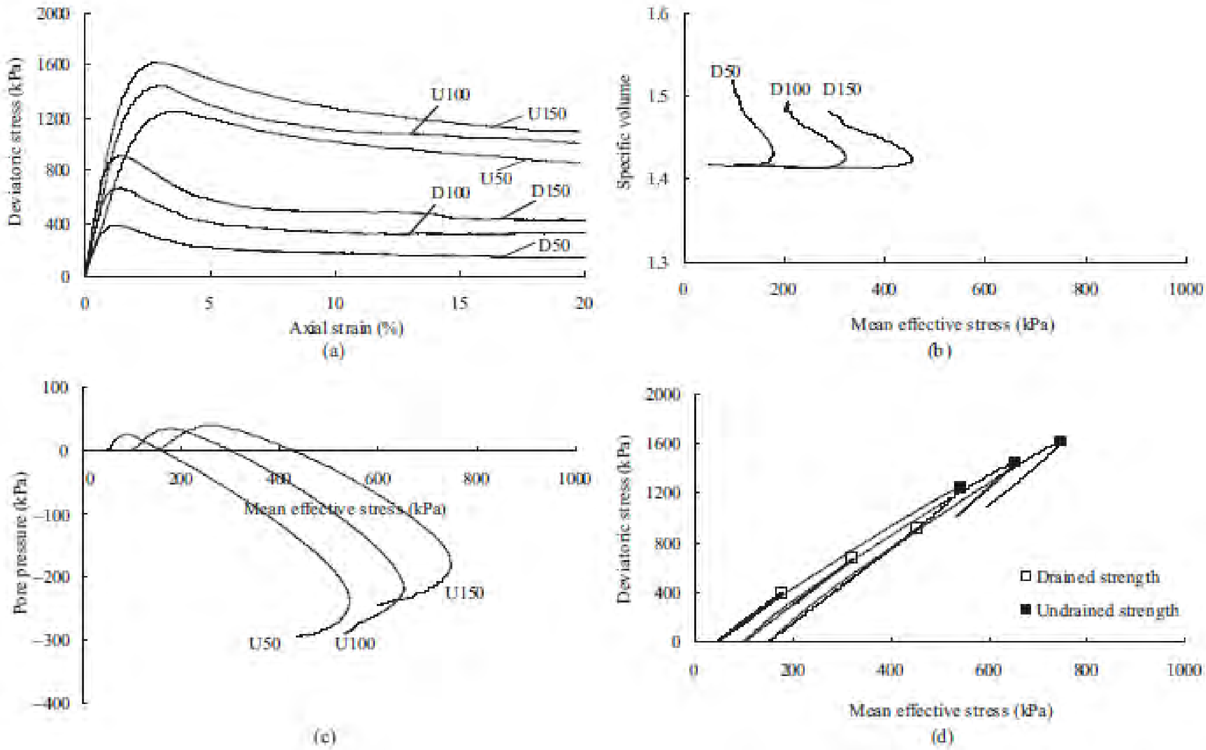


Figure 22. Triaxial test results of cemented samples with 1% Portland cement content

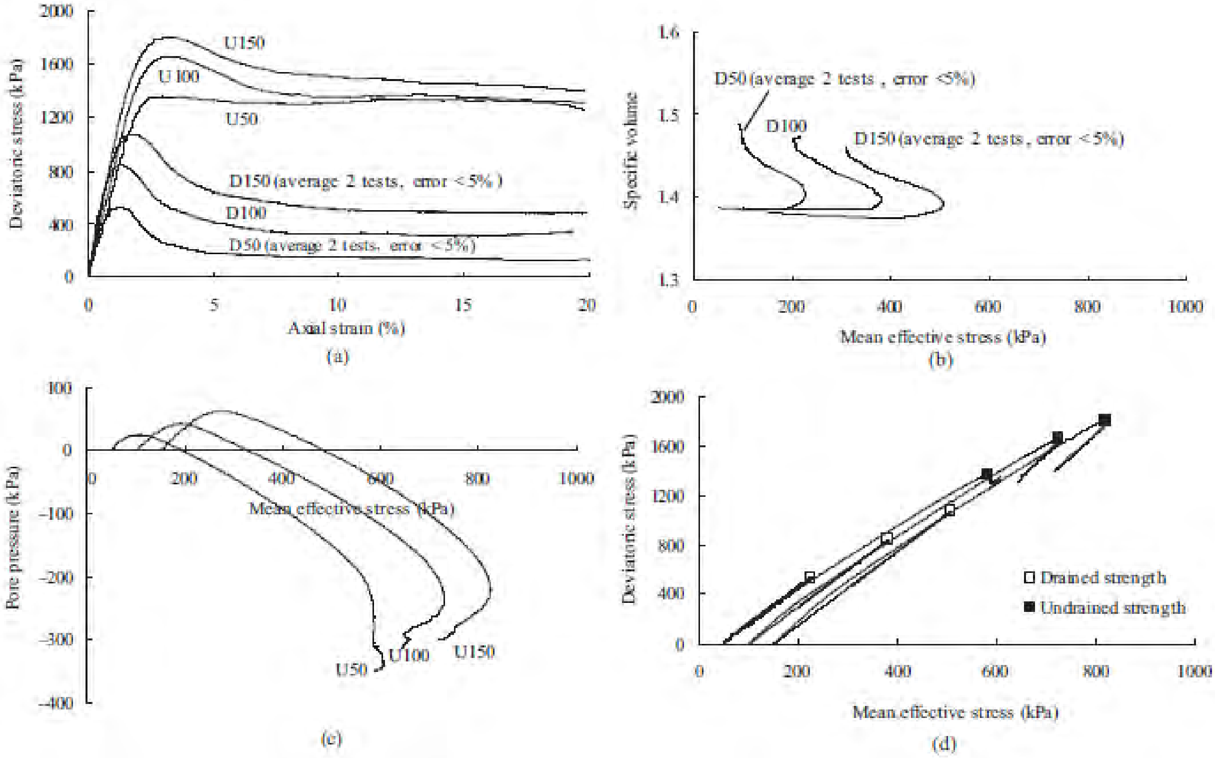


Figure 23. Triaxial test results of cemented samples with 2% Portland cement content

For the case of cemented samples, the strain associated with the peak strength is larger in undrained condition tests than that in drained ones. It can be concluded that the cement soils behaviour is more brittle in the drained condition and bond degradation occurs easier when volumetric strains can freely occur in soil (Malandraki and Toll, 2001).

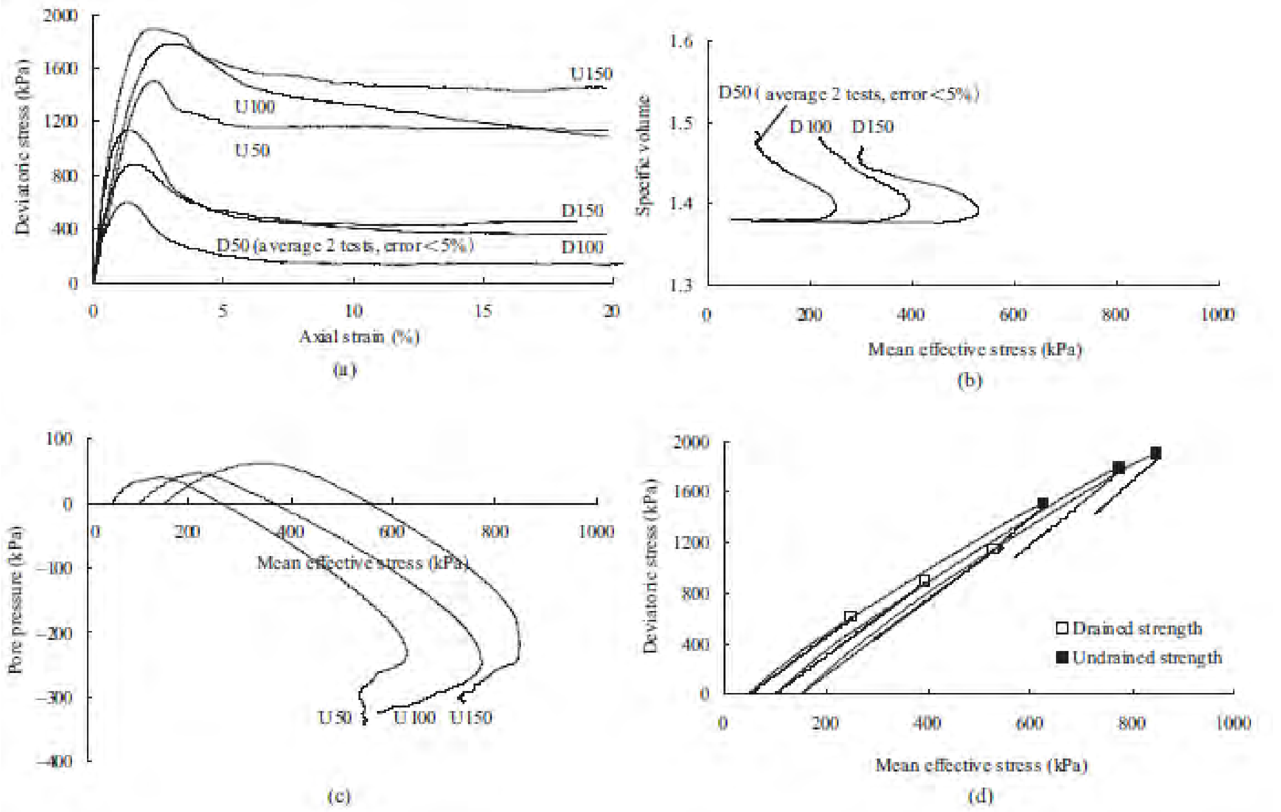


Figure 24. Triaxial test results of cemented samples with 3% Portland cement content

From the figure of the letter (b) it can be understand the contractive behaviour at the start of shearing that is then followed by a large dilation. Increasing the confining pressure increased contractive behaviour at the start of the test. Concerning the pore pressure (figure with letter (c)), positive pore pressure occurred at the beginning of the loading followed by significant negative pore pressure at the final state. This behaviour is the reflection of that of the volume: when a compression occurs the pore water pressure is positive (first phase) whereas on the contrary it is negative when expansion occurs (second and last phase). Furthermore as for the volume, increasing the cement content and decreasing in confining pressure increased the negative suction at the end of the loading process.

The stress paths are depicted in the letter (d). They moved linearly with a slope of 3:1 in q-p' space in the consolidated drained tests. In these cases they reached a peak point which has been marked on the figures. After that, softening caused reversal of the stress path with the same slope until residual stress state is reached. In undrained condition the peak point of the stress path was higher due to the highly negative pore pressure.

This study also showed that the increase in the cement content doesn't particularly influence the relation between shear strength parameters in the drained and undrained conditions. Finally the authors find that, as suggested by Collin at al., the brittle behaviour of cemented soils is more obvious in drained condition than in undrained state. The axial strain at the peak shear strength was smaller in drained condition than in undrained state. Moreover the failure envelopes were lower in the drained situations rather than the undrained ones.

All the information given with these two studies where almost found by the experiments conducted in the year 2002 in the Tehran alluvium by E. Asghari, D.G. Toll and S. M. Haeri. In fact triaxial compression tests were performed on uncemented, artificially cemented and destructured samples in order to understand the mechanical behaviour of the cemented coarse-grained alluvium in a vast area of Tehran city. This because the stability in this deposit was often attributed to the cementation effects that produce an increased shear strength in the material. In fact as showed by the Figure 25, the Teheran alluvium is characterized by very steep cut which has been stable for a long period of time.

Figure 25. Stable deep trench in the cemented coarse-grained alluvium of Tehran (E. Asghari, D.G. Toll and S.M: Haeri, 2002)

The cement agent used for the laboratory tests was an hydrated lime $Ca(OH)_2$ with a content of 1.5, 3 and 4.5 % of the weight of dry soil. Cementation effects were studied in three main series of drained and undrained triaxial tests on cemented, uncemented and destructured samples. The last one was prepared by breaking down the artificially cemented soil by hand; in this way it may well perform differently from the uncemented soil.

Concerning the results, as said before, the authors found almost the same behaviour described above. All uncemented samples showed barrelling failure modes during shear and underwent contraction except the sample tested at the lowest confining stress i.e. 25 kPa. The same can be said for the destructured samples with the exception of the lowest confining stress of 55 kPa. These two exception showed the presence of a shear zone in the sample and demonstrated a clear peak in shear stress. On the other side cemented samples showed a brittle failure mode accompanied with a shear zone at low confining stresses with a transition to a barrelling failure mode at higher confining stresses. That fact poses something new with respect to the study of Amini Y. and Hamidi A. (2014) since it investigated the behaviour of the soil based on the confining stresses rather than the degree of cementation. In fact in cemented samples with confining stresses lower than 110 kPa, shearing was accompanied with a shear zone without significant barrelling. At higher confining stresses, the samples undergo considerable barrelling but still showed a shear zone. In addition to the mentioned study the brittle behaviour not only increases with increasing cementation but also decreases with an increase in confining stress. The experiments also suggest and confirm that the thickness of the shear zone in the cemented samples varied between 2 and 5 cm; this characteristic is found to be not only dependent on the amount of cementation but also on the confining stress level of testing. In this way the degree of cementation and the effective stress level are thought to be the major variables examined.

For what concern the stress-strain behaviour nothing is new: there is no clear peak in deviatoric stress for uncemented samples but the presence of a peak for all cemented samples is evident. For a given confining stress the strain associated with peak strength decreases with an increase in cementation. In cemented samples the peak strength is followed by strain softening. See as an example the following figure (Figure 26, Figure 28, Figure 27) reporting the volumetric strain, the deviatoric stress-axial strain and the stress ratio-axial strain for the 1.5% cemented sample.

The volume changes, which in the previous study was reported for a poorly graded and a well graded soil, referred here to the different types of soil (cemented, uncemented and destructured) with respect to the axial strain. In particular at the lowest confining stresses, both cemented and uncemented samples undergo dilation during shear and at the highest confining stress (1,000 kPa) both soil samples showed contraction. As can be seen from the following figure, more cementation induces a greater amount of compression.

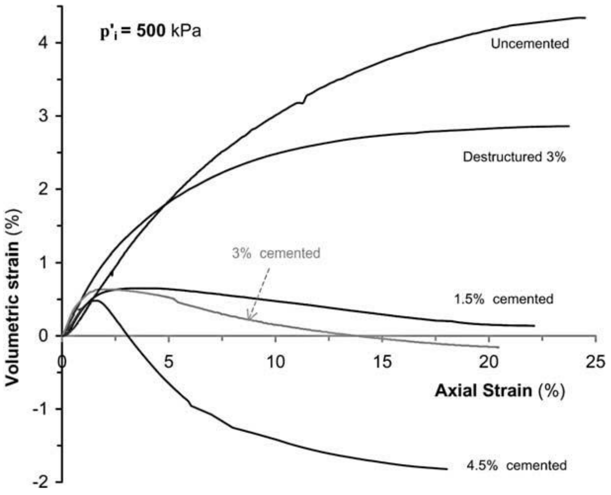


Figure 26. Cementation influence on volume changes during shear (drained test with p' = 500 kPa) (E. Asghari, D.G. Toll and S.M: Haeri, 2002)

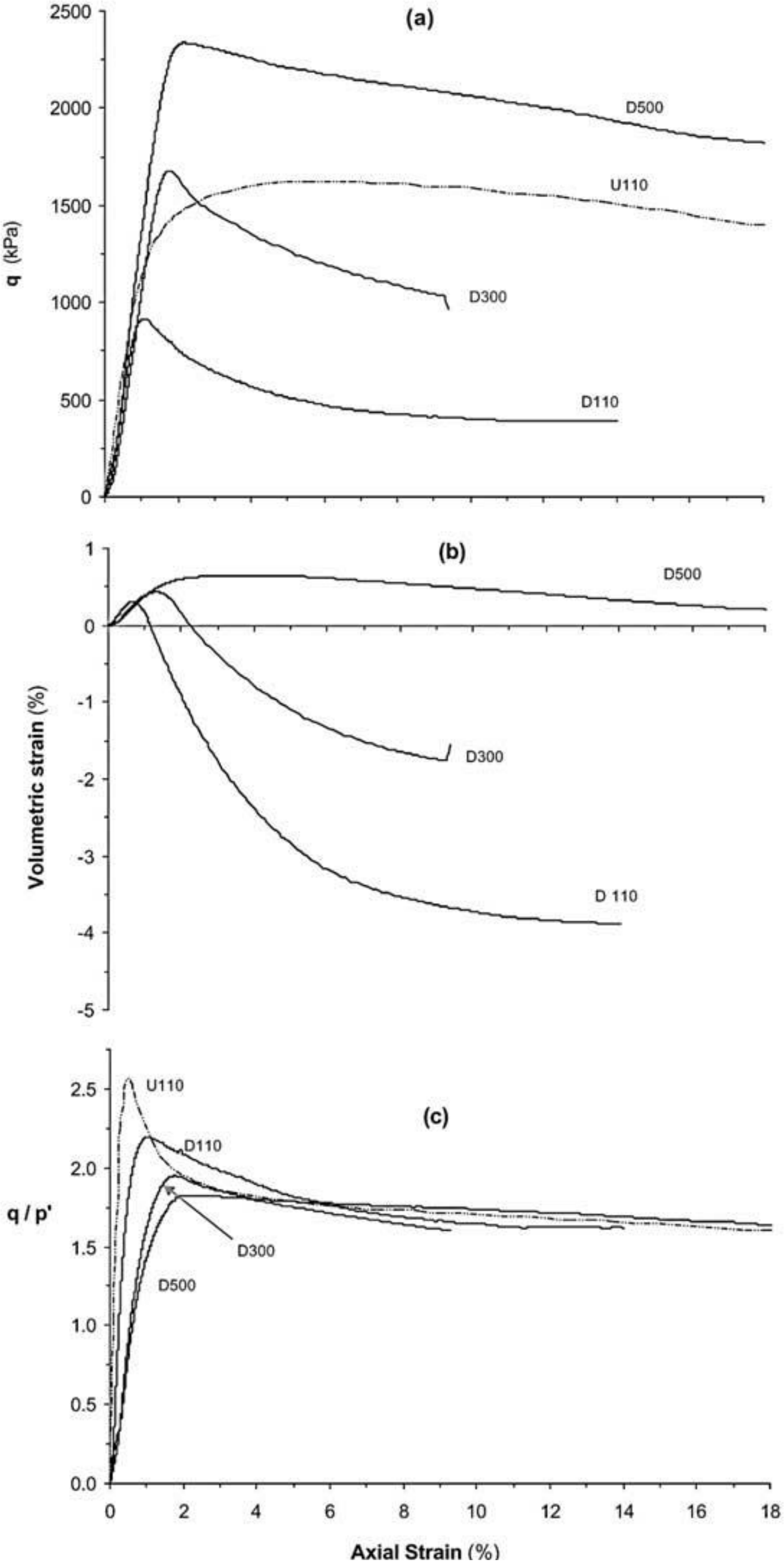


Figure 27. Behaviour of 1.5% cemented samples during shearing at various confining stresses: (a) deviatoric stress-axial strain, (b) volumetric strain-axial strain for drained tests, (c) stress ratio-axial strain (E. Asghari, D.G. Toll and S.M: Haeri, 2002)

Finally the failure envelope was investigated showing the following result:

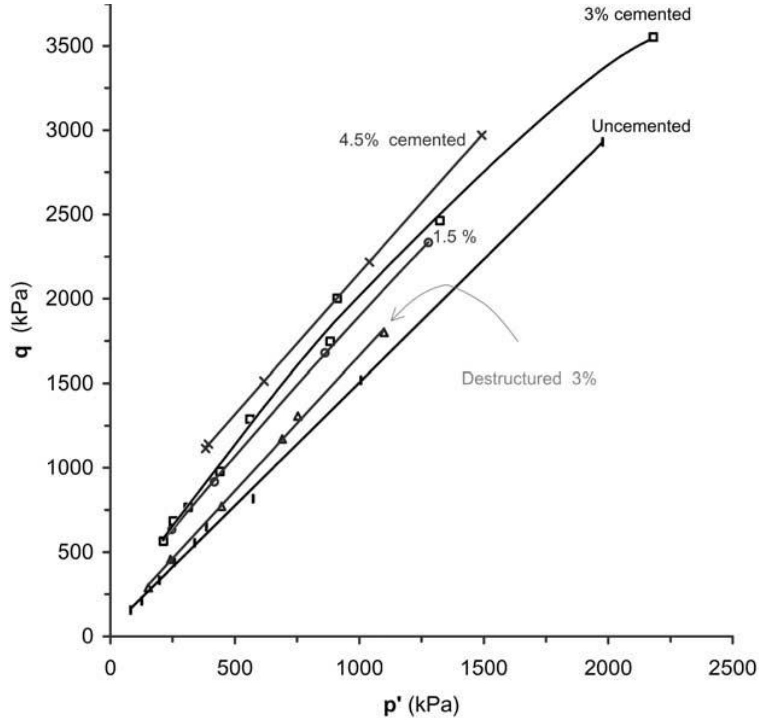


Figure 28. Failure envelope of samples in q-p' space (E. Asghari, D.G. Toll and S.M: Haeri, 2002)

The envelope is almost linear for uncemented and destructured samples whereas is curved for cemented samples contrary to what was found for the cemented-treated sand-gravel mixture for which the envelope was linear too (Figure 21, Figure 22, Figure 23, Figure 24). But as can be seen from the Figure 28 the curvature is not so evident so the two results can be considered almost equivalent. The results of the tests on the cemented samples suggest an apparent cohesion which increases as cementation increase.

4.2 Researches on the stability problems

For what concern the stability different experiments were conducted on the strength characteristics of the cemented material, the seepage forces effect and the liquefaction resistance but the adequacy of the existing analysis techniques to accurately predict failure has not be satisfactory addressed. There are a lot of aspects which may influence the type of failure; for example the surface weathering, toe erosion, slope modification and inertial forces due to high seismicity. In this way the proper identification of the failure mode dictates the degree of certainty that the slope stability analysis can be performed. Further it must be carefully identified in concert with the actual slope geometry and local material properties.

Brian D. Collins and Nicholas Sitar presented in 2011 a study on weakly cemented and moderately cemented sand slopes. In 2008 they have found that the cliff geometry of a coastal site in northern California and the failure mode are directly dependent on cliff material strength. In particular the present study found that the weakly cemented sand collapsed in parallel-sided planar failure due to toe erosion from wave action whereas cliffs formed in moderately cemented sand experienced exfoliation slab-type failure as a result of groundwater seepage and resulting tensile-strength loss (see Figure 29, Figure 30).The analysis of the cliffs takes 6 years through the collection of a terrestrial lidar (Light Detection And Ranging) data of the cliff face. The use of this technology allow the collection of detailed pre and post geometry of evolving cliffs in space and time through the measure of the distance by illuminating a target with a laser and analyzing the reflected light. Typical cross sections generated indicate the key differences in failure mode on the basis of various degree of cementation. In weakly cemented sand erosion-induced geometric conditions are required for failure. As presented in the table of the Figure 30, failure occurred with cliff-slope inclination upward of 60° and with vertical cliff-toe heights of between 0.7 and 1.4 m. For the case of moderately cemented the geometric signature differs from the previous case; in fact the slope inclinations are nearer to vertical and the cliff does not undergo appreciable changes at the toe as a result. The measured slope inclinations make the case for the dependence and requirement of a stress-related failure condition. As can be seen in the figure below the role of cementation on failure mode is important to any study of slope stability in these materials.

The choice of the method to be used for the stability analysis depends on several factors in particular on the nature of the failure mode and the material properties. For slopes that collapse suddenly with minimal strain potential such as those cemented, limit equilibrium techniques are preferred. Among the methods presented by the study of B. D. Collins and N. Sitar one is based on the known work of Coulomb (1773) and aimed to evaluate the maximum depth H in steep cut slope at angle β. The value for H is calculated considering a static solution for a rigid body of soil moving along a Mohr-Coulomb type shear plane. This parameter can be then expressed in terms of a factor of safety Fs as follow:

$$\frac{c}{F_s} = \frac{\gamma}{2H}\left(\frac{H^2}{\tan\alpha} - \frac{H^2}{\tan\beta}\right)\left(\sin^2\alpha - \sin\alpha\cos\alpha\frac{\tan\phi}{Fs}\right)$$

where c is the cohesion, ϕ the soil friction, γ the soil unit weight, β the angle of the slope and alpha the shear plane inclination angle expressed as:

$$\alpha = {(\beta + \phi)}/{2}$$

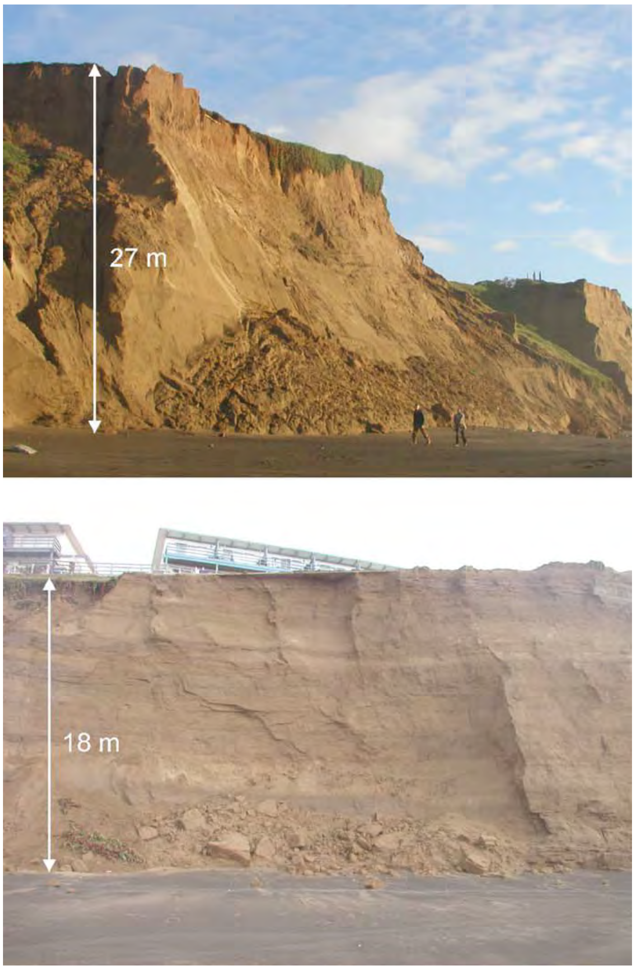
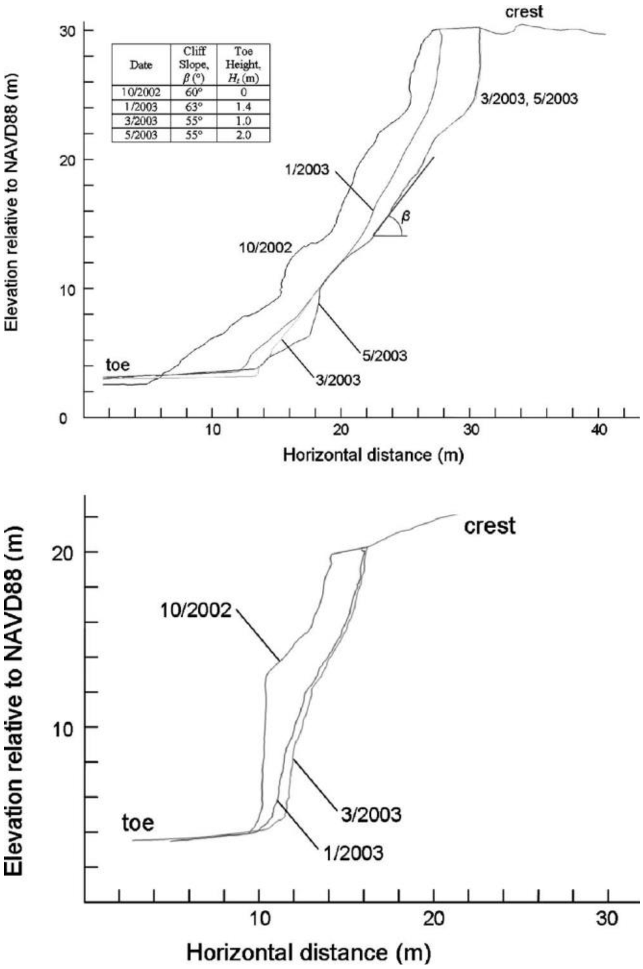


Figure 29. Weakly and moderately cemented sand cliffs in northern California (B. D. Collins, N. Sitar, 2011)



Date	Cliff Slope, β (°)	Toe Height, H_t (m)
10/2002	60°	0
1/2003	63°	1.4
3/2003	55°	1.0
5/2003	55°	2.0

Figure 30. Topographic expression of cliff in weakly cemented sand and moderately cemented sand from selected data of terrestrial lidar data collection (B. D. Collins, N. Sitar, 2011)

Note that Fs is presented twice in the formula; this required an iterative method in order to find the final value for the factor of safety Fs. It is correct when the (n-1) solution is nearest the n solution itself. Moreover this method is thought to be reasonable when the slope angle is steep especially for cohesive soils as the slope approaches vertical. Anyway the magnitude of crest retreat is grossly overestimated by up to five times its expected value and the failure inclination is underestimated by up to 10° (Collins 2004).

The second type of method investigated regards a more accurately method which describes the evolving cliff geometry and in particular the presence of a vertical toe. It was studied by Carson (1971) and later reviewed by Sunamura (1992). The methods assumed a variable vertical toe height Ht and adjusted the standard Culmann expression; the height H is composed by two measure: the slope height (Hs) and Ht. Thus the Sunamura's (1992) formula can be expressed in the same format as the method presented before:

$$\frac{c}{F_s} = \frac{\gamma}{2H}\left(\frac{H^2}{\tan\alpha} - \frac{H^2}{\tan\beta}\right)\left(\sin^2\alpha - \sin\alpha\cos\alpha\frac{\tan\phi}{F_S}\right)$$

where

$$\alpha = \frac{1}{2}\left[\phi_N + \tan^{-1}\left(\frac{H^2}{H_S^2}\tan\beta\right)\right]$$

$$\phi_N = \tan^{-1}\left(\frac{\tan\phi}{F_S}\right)$$

Even if this expressions provide a good improvements of the actual crest retreat and better simulate the true geometric conditions of evolving scope, it still be not adequately accurate for the type of slope analyzed herein especially considering predictions of the slope and failure plane angle. To overcome this problem, Darby and Thorne (1996) successfully introduced the use of variable pore pressure and a failure plane that is not constrained to pass through the toe. The drawback concern the use of the relative formula for the stability analysis; in fact it is applicable only to cohesive soils that undergo a magnitude of crest retreat greater than the shear plane surface depth (i.e. $\alpha \leq \beta$).

In this way it is also most applicable to weakly cemented deposits where a clearly identifiable shear plane develops at depth over the length of the slope. In moderately cemented materials (i.e. those with an UCS>30 kPa) increased cementation and cohesion results in steeper slopes than weakly cemented sands an altogether different failure mode may dominate. Generally the type of failure that dominates is a shallow, discontinuous brittle failure. Sometimes it can be used for the stability analysis those methods developed for rock mechanics rather than for soil mechanics. However this type of analysis is still overly complicated with respect to the required material parameters needed for case-study application (Cai et al. 1990).

The figure presented below represents the geometric assumption made using the conventional Culmann-Coulomb method and the modified one. Note that in the second type the quantity H is made by two contributions: Hs and Ht leading to ah higher surface of sliding.

The study as said before distinguishes between the weakly and moderately cemented sands; this distinction is also maintained when the authors described the type of stability methods used. In fact for the first type of material a limit equilibrium analysis method is presented that allows for modelling variable cliff toe height, midslope inclination angle and vertical crest with tension crack. The key assumption is that the failure plane inclination is parallel to the slope inclination (i.e. infinite slope assumption).

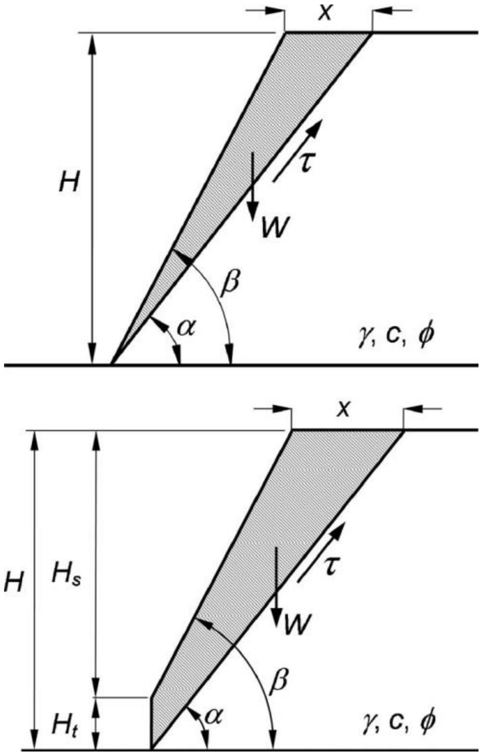


Figure 31. Geometric configuration using conventional Culmann method and modified Culmann method for vertical toe (B. D. Collins, N. Sitar, 2011)

In particular from the combination of the conventional infinite slope stability concepts and the finite slope method and from the use of variable toe and crest heights the force equilibrium leads to the following expression:

$$Fs = \frac{2c\left[\dfrac{H_S + H_t}{H^2 - (H_S + H_{tc})^2}\right] + \gamma\cos^2\beta\tan\phi}{\gamma\sin\beta\cos\beta}$$

This equation can be used to identify the critical slope geometric condition required for failure. That is, if Ht, Hs or β change for whatever reason the factor of safety can be explicitly computed. It was applied to a specific case study of the sea-cliff area of California whose soil parameters were selected from those presented by Collins and Sitar (2009) and were a cohesion of 8 kPa, unit weight of 17 kN/m2, an angle of internal friction ϕ of 39°, a midrange confining stress of 20-50 kPa.

The equation allows for the study of the evolution of the stability envelope through the value of the factor of safety. It is obtained changing the toe heights (Hs) and the slope angles (β). The shape of the envelope obtained is pseudo-parabolic; this highlights the interplay of the tangential stress and strength components in the previous equation. Increasing the slope angle, the normal stress component decreases whereas the shear strength component increases. The formula provides both a method for the relative stability to be assessed and for the slope conditions required for failure to be identified. For the case study it was found that the cliff failed when the toe reached about 2 m in height and midslope reached an inclination of about 60° (B.D. Collins, N. Sitar, 2011). Making a comparison with other type of stability analysis methods shows that there is a good agreement between the proposed method and the method of the slices (Spencer); in fact they give a failure plane inclination for the given geometry for Fs=1 of 57° for the proposed method and 59° for the slices one. Also the crest retreat is similar: 1.3 m for the first and 1.2 m for the second approach. However, comparisons with other methods (such as conventional Culmann and modified one) show their limitations by predictions of excessive crest retreat and shallower than observed shear-plane inclination angle. Furthermore the proposed method is thought to be good for evaluating the stability of weakly cemented sand cliffs subject to changing geometric conditions (B.D. Collins, N. Sitar, 2011).

For the moderately cemented sands the slope steepness and the tensile strength reduction caused by wetting can be the primary causes of failure differently from the shear failure of the weakly cemented sands. In this way the two materials must be treated separately. The analysis method developed for this type of materials compares the tensile stress distribution (σ3 here taken as a negative value for tension) of a given slope with respect to the soil's tensile strength parameters σt. If the in situ tensile strength (σt) is higher (i.e. more negative) than the tensile stress, the slope is considered stable:

$$|\sigma_t| \geq |\sigma_3|$$

As said before two are the possible causes of failure: changes in slope geometry such that the tensile stresses increase or the material tensile strength decreases for example as a result of wetting. Linear elastic finite element method (FEM) analyses can be used to evaluate such stresses; despite that the method is still considered a limit equilibrium analysis and it provides an explicit explanation of the observed failure mode. Entering into details, a three-material, finite elements analysis (Geo Slope 2009) was performed to model the distribution of the tensile and compressive stresses. The soil parameters used were taken from geotechnical testing (Collins and Sitar 2009) and are summarized in the following table.

Table 10. Material properties FEM tensile stress modeling

Moderately cemented sand				
Elastic modulus E (kPa)	Poisson's ratio ν	Unit weight γ (kN/m3)	Void ratio e	Tensile strength σt (kPa)
1.15*10^5	0.295	18.7	0.6	32 (dry), 6 (wet)

At the cliff face, the predicted tensile stresses are approximately -2 kPa but increase up to -12 kPa at the bottom of the cliff. Thus using the tensile stress mechanism approach the slope is determined to be stable under the dry condition since 32 kPa is higher than 2 kPa. On the contrary, upon wetting, the tensile strength (6 kPa) is less than the tensile stresses and the failure is predicted to occur according to the equation presented before.

As a conclusion of this study, due to the low shear strength of the weakly cemented sands, the details of the evolving site-specific geometry must be considered in order to mitigate the possible instability. For that category of materials the failure is caused by geometric changes such as toe erosion or slope steepening so particular measures should be taken to prevent such facts. On the other side, the high cementation strength of the moderately cemented sands lead to the formation of steeper slopes and the consequence failure due to tensile stresses rather than shear ones.

Even if this research is based on the cliff of the state of California it can be anyway used as a reference for the general description of the methods for the stability analysis. In fact although the methods were applied to specific in situ materials they are universally valid and applicable.

5. The quarries of moderately cemented gravel and sand

One of the most strategic materials extracted in the regional territory is that identified with the denomination sand and gravel. Its trend has a decreasing behaviour from the year 1990 (close to 12,000,000 m3/y) to the year 1994 (close to 6,800,000 m3/y) and then an opposite tendency in the two-year period after with an extraction until 9,000,000 m3/y. During the long period from the year 1997 to the year 2007 a nearly constant production is registered of about 8,500,000 m3/y. The five-years period between 2008 and 2011 is characterized by a decreasing trend which shows a progressive contraction of the extracted volume of sand and gravel materials: from less than 7,500,000 m3/y to 5,400,000 m3/y in the year 2010 then followed by a small increase in the last year during which the total extraction was about 5,850,000 m3. This general tendency reflects the market global crisis which has interested also the quarries activity.

Considering the single provinces, the major productive are Verona, Vicenza and Treviso; on the other side, Padova and Rovigo have a negligible extraction activity. No-one active quarry is present in the territory of the remaining provinces of Belluno and Venezia. The following figure summarized all the trend for the sand-gravelly material from the year 1990 until 2011 for all the active provinces. Note that the Province of Treviso, as said in the introduction, is the most active.

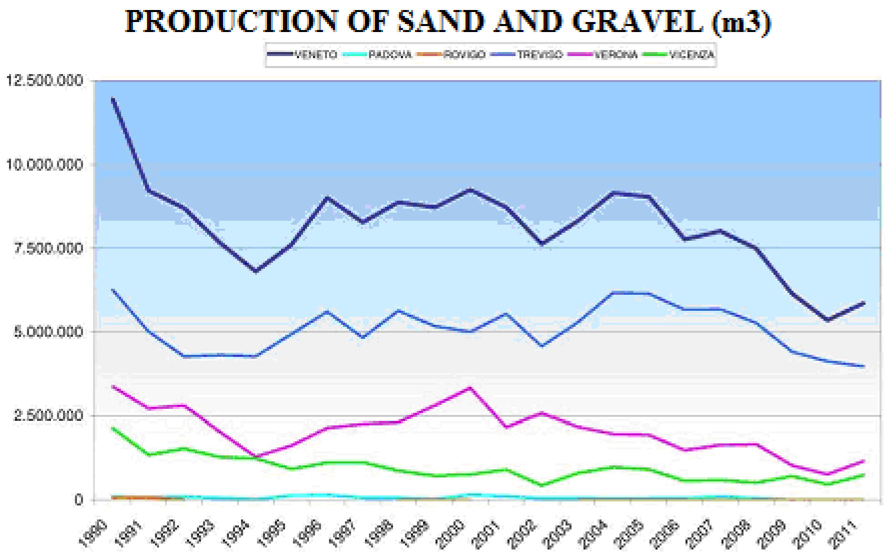


Figure 32. Sand and gravel production trend in the Veneto region

The volumetric quantity of available sand and gravel, under the control of the Region, has in the long period an increasing behaviour. From the year 1990, with less then 66,000,000 m3 as reserves, is recorded in the following six years a certain stability of the deposit volume with averages near 68,500,000 m3. In the three-years period 1997-1999 this average trend decreases to 66.000.000 m3 followed then by an high increase in the year after (higher then 77,700,000 m3) and then contracted again until the year 2003 (close to 63,000,000 m3). During the two-years after it was observed a new development of the reserves which approach in the year 2005 94,500,000 m3 that was then followed by a decrease of about 10,000,000 m3. The year 2007 was similar to the year 2004 with 88,500,000 m3 which then definitely stabilizes close to 85,000,000 m3 until 2011.

The quantity of materials extracted is obviously linked with the available materials present in the territory and also with the number of active quarries. Considering this last concept, the Veneto Region indicates that in 1990 the active quarries were 118. It was then followed by the same fluctuating trend described for the quantity of materials extracted and for the available deposits leading to the 49 active sites in 2011. For more details about the years in between them see the figure below.

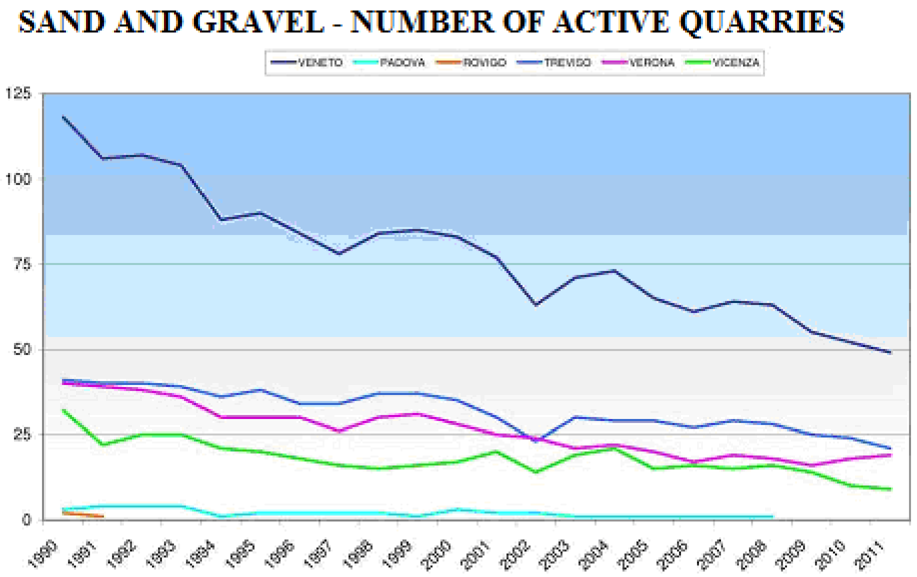


Figure 33. Active quarries trend in the Veneto region

The present work aimed to analyze the geotechnical properties of a typical gravel of the alluvial zone of the rivers Piave and Brenta. This type of material can be found in the most part of the territory of the region and in particular in the provinces of Treviso, Verona and Vicenza at the foot of the Dolomiti. In these zones the erosive action of the water and of the glaciers produced wide alluvial site crushing, breaking up and transporting the rocky material downstream. Close to the mother rock in fact there are coarse materials. In the level ground, where the river velocities decrease and don’t have enough energy to transport the heavier particles, there are the deposits of the finer and lighter particles. As a consequence near the mother rocks the materials are mainly composed by cobblestone and gravel whereas getting away from these rocks the materials become finer from the gross sands to the silts and clays.

For what concern the chemical composition, the Veneto gravel presents the same composition of the Dolomiti district that are composed by sedimentary rocks modelled during the Alpine orogenis and then subjected to the erosion. The Dolomiti rocks are made chiefly by carbonates and are also rich in fossils. As well known, this link between the carbonates and the fossils is very narrow since the shellfish and the mollusk shell contain a huge quantity of calcium, that represents the principal element of the carbonation. If also the great dimension of the fossilized shell are considered it is easy to understand the rule that they play in this process.

5.1 The site under study

From the exam of some quarries in the alluvial basin of the river Piave, Previatello and Simonini (1989) found a certain homogeneity in the soil composition; it concerns both granulometry and the chemical structure. This implies that the origin of that quarries is common and takes place from a wide and well spread erosive process. The material examined turn out to be a gravel with a sand fraction in the range of 9%-27%. The fraction that passes the sieve number 40 shows a non plastic behaviour and the fraction lower that the sieve number 200 is comprised between 3% and 10%. Moreover, the gravelly fraction has a nature mainly carbonatic as the most part of the rocks which compose the *Dolomiti*. Anyway, there are also other the so called "*litotipi*" such as porphyry, granite, sandstone, flint and schist (in Italian *porfidi, graniti, arenarie, selci e scisti*). The finer fraction confirms that characteristic. For the fraction between the sieves number 40 and 200, the 60% is composed by carbonates (limestone and dolomie) and the percentages of carbonates decreases up to 54% for the material passing the sieve number 200. The determination of the carbonates content is made through the volumetric gas method. It was conducted on the fine fraction between the sieves n. 40 and 200 giving the following characterization:

Table 11. Carbonates content determination

Fraction passing between the sieve n. 40 and n. 200			
% calcite	% dolomite	% others	Ratio calcite/dolomite
21	39.9	38.1	0.53
Fraction passing the sieve n. 200			
% calcite	% dolomite	% others	Ratio calcite/dolomite
13.2	40.7	46.1	0.32

In the finer fraction it is always found, near the other minerals, the so called pirosseni.

Some density tests carry out in situ indicate a unit weight of 22.5 kN/m3. All the analysis have been performed considering the constitutive bond for the material of Mohr-Coulomb: $\tau=c+\sigma\tan\varphi$ as already said. The quarries under study are of the type called pit quarry (in Italian "*in fossa*").

5.2 Slope geometry of the quarries

To understand which is the most common geometry that achieves a slope of a quarry of cemented gravel, Previatello and Simonini (1989) studied 10 quarries located in the Treviso Plan. The extraction activity that may influence the shape itself has been done with mechanical diggers that excavated from the toe of the slope itself. Due also to the moderate cementation of the material the cultivation is performed with high height and an inclination in the range of 75°-85°. As said before, the cementation phenomenon plays the most important rule in the definition of the final shape of the slopes. In fact, both natural causes (such as the precipitation) and the change in tensions due to the excavations may cause the decay of the cementation of the material. The presence of water can have both stabilizing and destabilizing effects. What is decisive is the path that it follows and the materials that it encounters; generally in a cube of undisturbed gravel the water is a destabilizing agent and permeates from the top and exits from the bottom more or less in the same quantity. In this way two are the possible consequences:

1. a certain amount of carbonates, contained in the flushing water and/or incoming from the mass of gravel above, enters in contact with the gravel and precipitates in the solid form in that cube of gravel;
2. the solid carbonates that already link together the gravel particles, due to the chemical equilibrium, will enter in the water solution substituting by those who precipitate and will be flushed in the mass of gravel below it.

In this way the cemented gravel are form.

Returning to the characteristics of the slope, due to the high inclination of the excavated slope and the water action it was observed an annual evolution of the geometry itself that leads to the final, stable shape of the slope. In fact the scarp collapses or single elements are detached from the slope. This material accumulates at the toe of the slope forming a deposit that enlarges in time and that tends to be cemented again due to the precipitation of solution containing carbonates mobilized by meteoric agents (Figure 34).

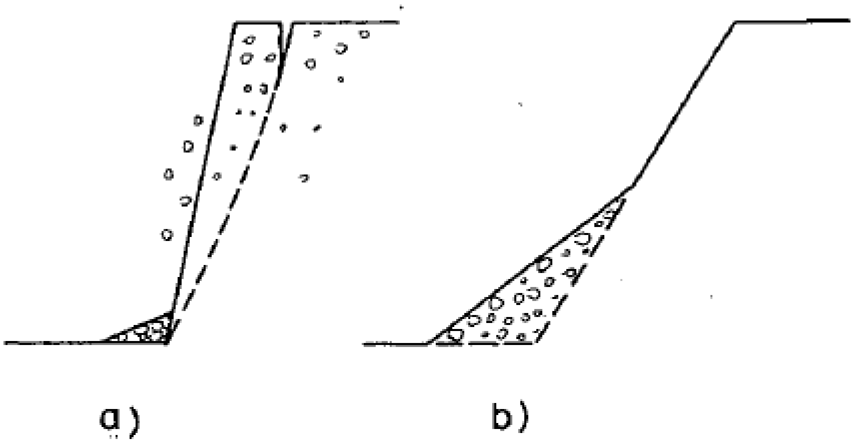


Figure 34: Scarp evolution in time: a) beginning of the phenomenon; b) end of the phenomenon (Previatello and Simoninil, 1989)

Previatello and Simonini (1989) studied 300 sections of quarries referring to the parameters depicted in the Figure 35.

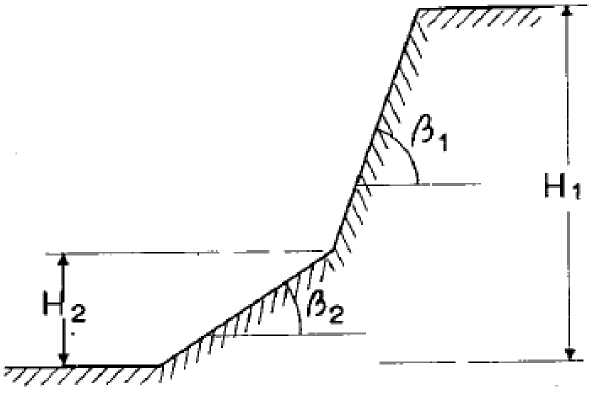


Figure 35: Geometry of the excavation fronts: H1: total height of the front, H2: height of the toe deposit, β1: angle between the front and the horizontal line, β2: angle formed by the toe deposit and the horizontal line (Previatello and Simoninil, 1989)

The graphical results are presented below. For what concerns the angle β1 it is observed a decreasing behaviour that is more emphasizes in the first 24 months after the mining activity. The values of that angle descend to 75°-85° during the excavation until 60°-70° after 6 years. The relation between the angle and the time is thought to be of logarithmic type; through a minimum squares interpolation, expressed as:

$$\beta_1 = 85° - 5 \ln t$$

with t expressed as months it is possible to obtain the follow graphical result.

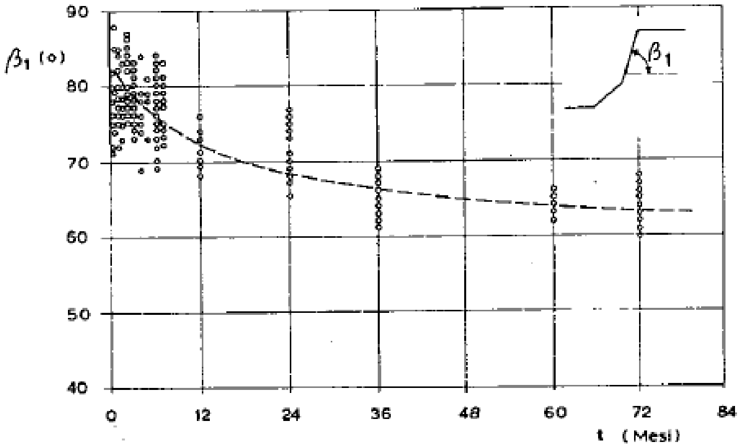


Figure 36. Relation between the time and β1 (Previatello and Simoninil, 1989)

For what concerns the other angle β2 the evolution differs from the previous one. In fact the toe deposit is linked to the type of excavation machinery used and to the height and the mechanism of collapse. Considering the long range, the slope tends to arrange to values close to 35° (Figure 37). The figure suggests also that at the beginning the slope was characterized by a collapse activity (first year) then followed by a stable phase.

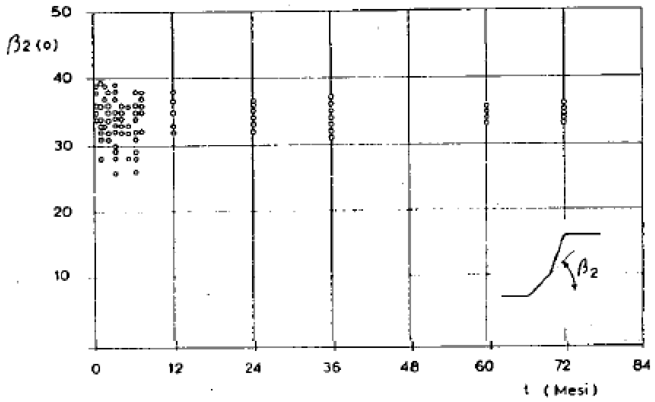


Figure 37. Relation between the time and β2 (Previatello and Simoninil, 1989)

The last one parameter analyzed is the ratio between H2 and H1 (Figure 38).

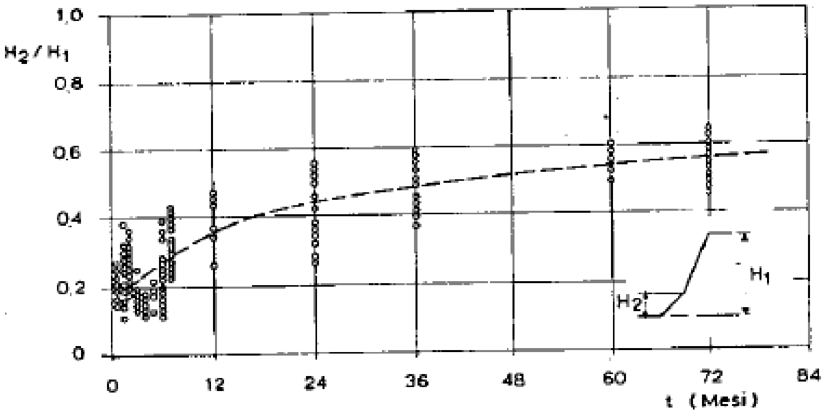


Figure 38. Relation between the time and the ratio H2/H1 (Previatello and Simonini, 1989)

As for the case of the angle β1 the data distribution was analyzed through the minimum squares interpolation with the following formula:

$$H_2/H_1 = 0.08 + 0.11 \ln t$$

with t expressed in months. It is evident that H2 tends to increase in time and it leads to a characteristic geometric configuration in which the height H2 represents the 50% of the total height (see also Figure 34).

Analyzing the stability problem of that configuration of a quarry slope, Previatello and Simonini (1989) find out that the evolution of that slope after the end of the excavation activity can be interpreted in terms of the decay of the resistant parameter “cementation” c. Through the hypothesis of a sliding surface which intersect the summit point of the toe deposit H2, the authors carry out a series of “back analysis” whose results, in terms of cementation c, are reported in the following figure.

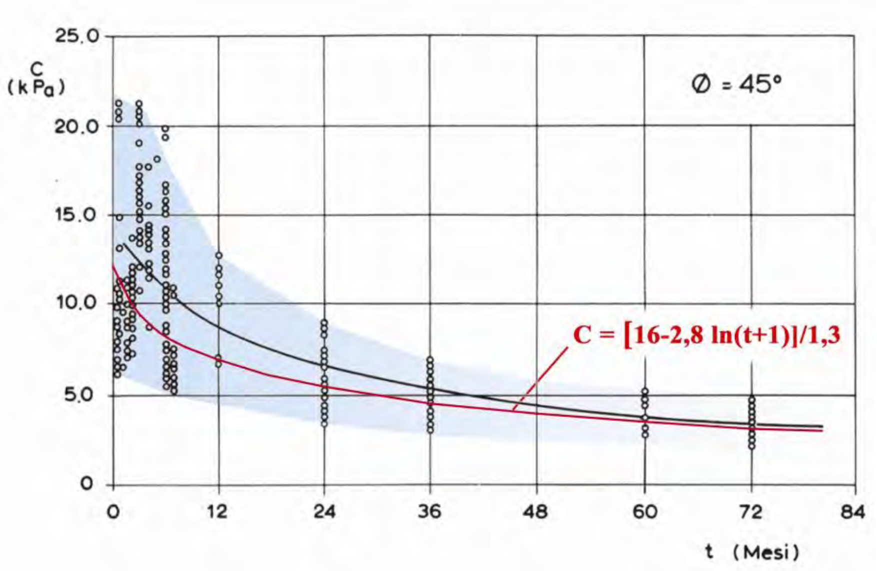


Figure 39. Behaviour in time of the cementation ”c“ parameter (Previatello and Simonini, 1989)

As can be observed the parameter c decreases in time from values between 5 kPa and 22.5 kPa to values between 2 kPa and 5 kPa. The variance between the maximum and the minimum value is higher for time of the order of 12 months. Progressively it is achieve at the long range a stable situation as said before. Also here the interpolation is done as follows:

$$c(kPa) = 16 - 2.8 \ln t$$

with t as months. The cementation, even after 72 months is not null indeed it helps to maintain stable the deposit at the toe whose height is H2.

Another study, conducted three years before by Simonini and Soranzo on four quarries in the alluvial Plan of the Brenta river (Bassano del Grappa) find out the that the minimum value for β1, for abandoned quarries (more than 5 years of no activity) is 45° whereas the angle β2 increases until 35°. They also find out some relation for the shear stress resistance depending on the type of quarry: active or abandoned. The criterion adopted is the same as before, i.e. Mohr-Coulomb and gives:

- for active quarries: $\tau(kPa)=\frac{(7.5\div 22.5)}{F_c}+\sigma\frac{\tan 45°}{F_\phi}$ with Fc=Fϕ=1.0-1.2 (the last case for c=7.5 kPa);
- for abandoned quarries: $\tau(kPa)=\frac{(0.0\div 17.5)}{F_c}+\sigma\frac{\tan 45°}{F_\phi}$;generally it was observed (150 sections) that the cementation parameter varies from 0.0 to 2.5 kPa. As a consequence, the term related with the cementation could be neglected (i.e. the first one). For the value of the Factor of safety Fϕ it depends on the nature of surrounding properties: if there are cultivation a value of 1.15 could be sufficient whereas in case of buildings a value of 1.3 could be adopted.

The article concludes saying that the parameter cohesion could be the one that is reduced in time leading to the decay of the shear resistance of the slope material. Moreover the criteria introduced about the mechanical parameters (τ, ϕ, c) could be used for the determination of the angle β for example from the following abacus:

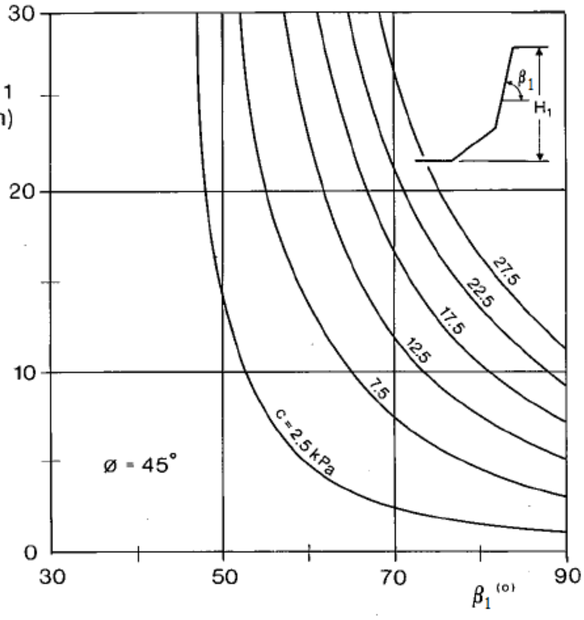


Figure 40. Abacus for the evaluation of the angle β1 (Simonini and Soranzo, 1986)

6. Slopes stability problems

The term landslide sometimes is not adequate to the natural or artificial phenomena since many types of slope movement do not involve sliding. Moreover, Cruden (1991) has suggested a simple definition of landslide: *"the movement of a mass of rock, debris or earth down a slope"*. In this way the term can cover all slope movements that occur from natural to man made with the exception of the ground subsidence.

The slope stability is indicated at the letter m) of the article 10 of the Legislative Decree n. 624/96 *("Attuazione della direttiva 92/91/CEE relativa alla sicurezza e salute dei lavoratori nelle industrie estrattive per trivellazione e della direttiva 92/104/CEE relativa alla sicurezza e salute dei lavoratori nelle industrie estrattive a cielo aperto o sotterranee")* as one of the aspects for which, before the start of the extraction activity itself, the risks assessment must be done and the consequent identification of the operative measures and modalities specifying the solutions adopted or the risks absence. For the open quarries (in Italian "cave a giorno") the stability analysis and the necessity of its annual revision is recalled in the article 52 of the same Decree.

In particular this article says:

"Prima dell'inizio dei lavori di coltivazione, il datore di lavoro predispone una relazione sulla stabilità dei fronti che prenda in considerazione i rischi di caduta di massi e di franamento; in tale relazione, in conformità alle vigenti normative tecniche, devono essere definite, in funzione della natura e dello stato del terreno nonché dei macchinari impiegati, l'altezza e la pendenza dei fronti di coltivazione e dei terreni di copertura nonche' il metodo di coltivazione impiegato; la relazione e' aggiornata annualmente"

The specific laws of the extraction sector identify only for the open quarry the necessity to carry out an analysis of the stability before the beginning of the cultivation and then annually update this preliminary valuation (see article 52 of the Legislative Decree n. 624/96). However, referring to the article number 10 of the same Decree (the contents of the document "*Documento di Sicurezza e Salute*") the site stability analysis is required for all the cultivation types, considered as the risk assessment with respect to the possible instabilities of the rock mass or of the soil under cultivation.

Based on that, the best technical setting for the stability analysis is surely that referred to the well known "probabilistic approach". This approach takes into account the variability in time and space of the strength parameters of the materials, of the uncertainties associated with the instability mechanisms, of the impact to the environment and to the humans and of the conceptual and geotechnical model chosen for the analysis. The probability to see a landslide is defined as the probability that the ratio between the unstable forces and those stable is higher than a certain value, fixed with respect to the forecast conditions and the design scheme adopted.

In this way, being the parameters for the analysis associated to a certain probability, also the degree of safety of the quarry slope is a function characterized by a probability distribution. That function allows to evaluate the risk degree to which are exposed the workers and the environment. Moreover, sometimes, this approach is not simple to be adopt due to the high number of tests required in order to obtain significant distributions, to the high intrinsic variability of the data, to the complexity of the elaborations and to the number of uncertainties that have to be considered. To overcome the problem is important to implement the analysis through experimental observations and surveys to be conducted on the site or in lab in order to quantify the characteristic values of the materials. This procedure must be done according to the degree of complexity or risks and the interest of the site since higher is the degree of detail higher are the costs. Due to the inevitable uncertainties that affect the analysis the designer have to take all the necessary measures to be in favour of the safety. This implies that the values of the parameters have to be as preventive as poor are the experimental observations.

More generally, the stability analysis of the mineral excavations, of their slopes or embankments have to be based on an adequate:

- geologic knowledge of the site and in particular of the volume geotechnically significant;
- evaluation of the geotechnical parameters of the soil and rocks;
- choice of the calculation methods for the stability in relation to the in situ soils and rocks, to the structural arrangement of the whole mass, to the actions and the presence of buildings;
- accordance with laws and regulations.

Entering into details, the geometry of a landslide can be summarized in the following figure. Note that there are two principal zones: the zone of depletion and that of accumulation. The landslide is composed by a crown (the top of the slide), the head, the main body, the foot and the toe that encompass both these parts.

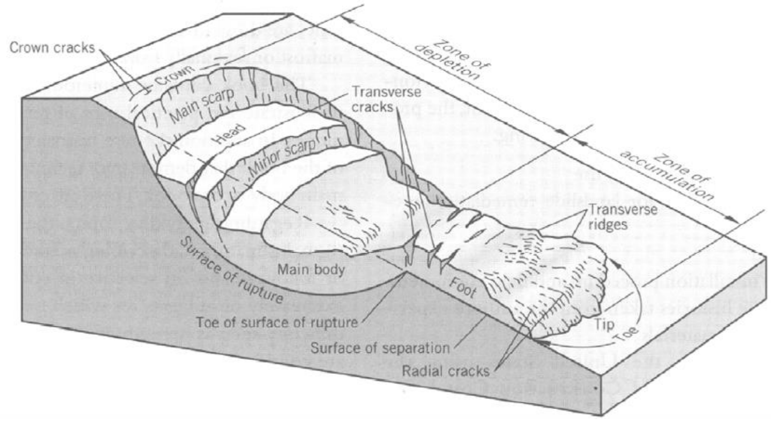


Figure 41. Landslide geometry by Varnes (1978)

Starting from that the International Association of Engineering Geologists (IAEG) created a Commission on Landslides in order to produce a more detailed description of that phenomenon. The result is shown in the figure below:

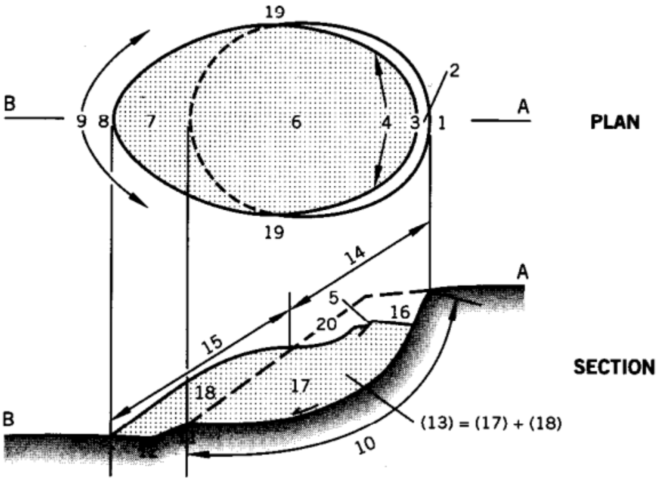


Figure 42. IAEG landslide classification

In which the points are:

1. Crown: practically undisplaced material adjacent to the highest part of the main scarp;
2. main scarp: visible part of rupture surface at the upper edge of the landslide;
3. top: highest point of contact between the displaced material and the main scarp;
4. head: upper parts landslide along contact between displaced material and main scarp;
5. minor scarp: steep surface on displaced material of landslide produced by differential movements within displaced material;
6. main body: part of displaced material of landslide that overlines the surface of rupture;
7. foot;
8. tip;

9. toe: lower, usually curved margin of displaced material of a landslide, most distant from the main scarp;
10. surface of rupture;
11. toe of surface of rupture intersection, usually buried, between the lower part of the surface of rupture and the original ground surface;
12. surface of separation: part of original ground surface overlain by the foot of the landslide;
13. displaced material: material displaced from its original position composed by both the depleted mass and the accumulation;
14. zone of depletion;
15. zone of accumulation;
16. depletion: volume bounded by main scarp, depleted mass and original ground surface;
17. depleted mass;
18. accumulation;
19. flank: undisplaced material adjacent to sides of surface of rupture;
20. original ground: surface of slope that existed before landslide took place.

The original work by Varnes (1978) has been updated and partly revised by Cruden and Varnes in 1996. They divided the slope movements into six categories:

1. falls;
2. topples;
3. slides- rotational and translational;
4. lateral spreads;
5. flows;
6. combination of types.

Graphically:

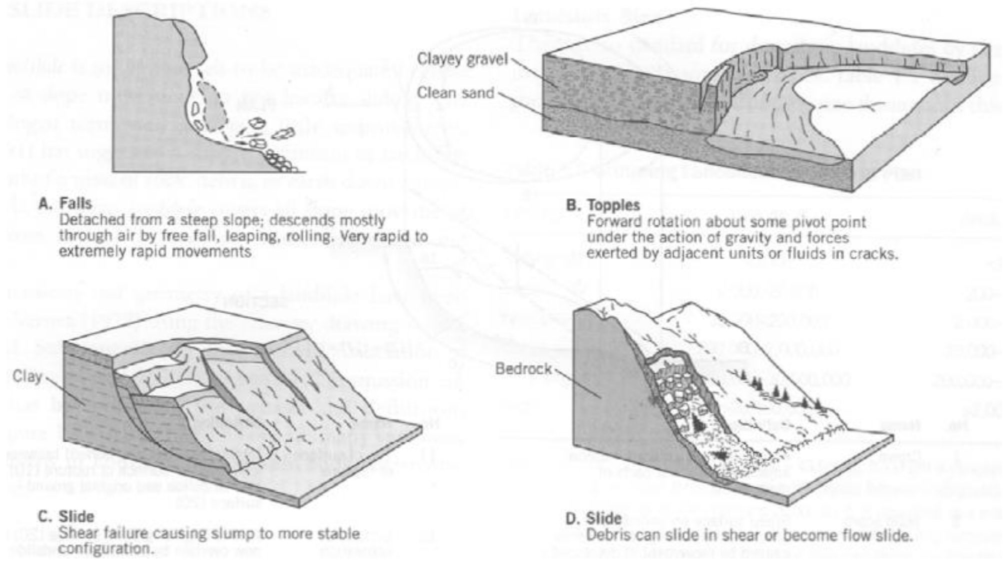


Figure 43. Types of landslide (from point 1 to 3)

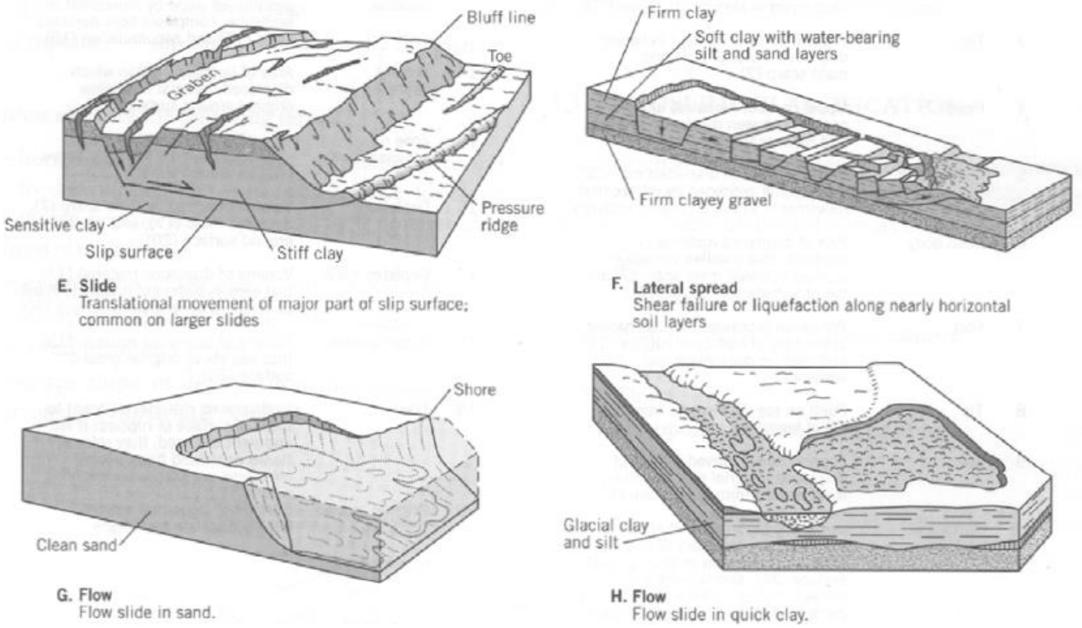


Figure 44. Types of landslide (from point 3 to 5)

Slope failure are usually due to a sudden or gradual loss of strength by the soil (this is the case: we pass from a very good strength material-cemented soil- to a poor one- excavated soil mixed with bentonite) or to a change in geometric condition (steepening of an existing slope). The modes of failure consequently can be different; they can interest the whole soil body or a little amount of it. For more details see the following figures.

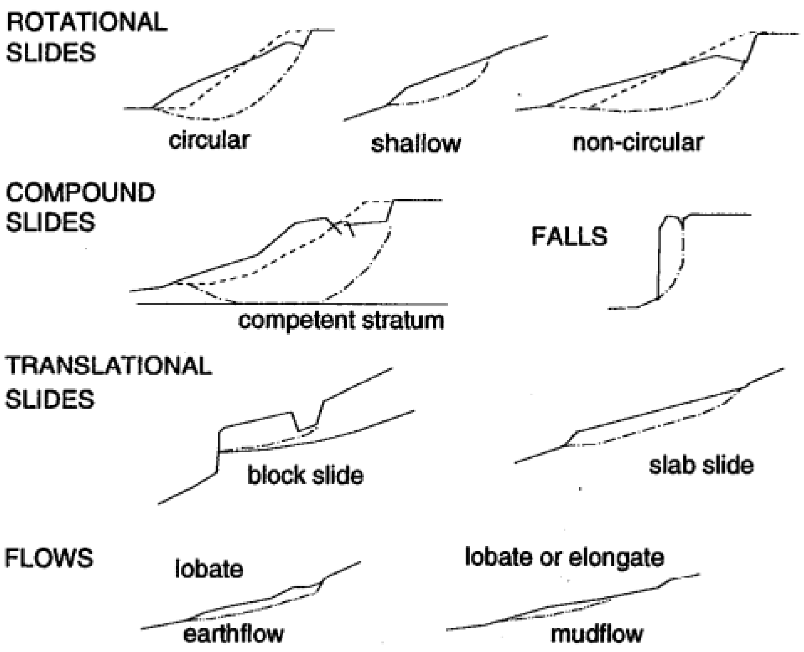


Figure 45. Types of failure

6.1 Quarry's slopes stability

Entering into details the main items required to evaluate the stability of the slope concern the shear strength of the soils, the slope geometry, pore pressures or seepage forces and the loading and environmental conditions. To account for the stability as said before it is necessary to evaluate the Factor of Safety (FOS or Fs) which varies with the material type and the performance requirements. Generally lower the quality of the site investigation, the higher the desired FOS should be. For the Italian case it is possible to distinguish between two phases: before the ministerial decree of the 18th of January of 2008 and after the decree itself. Before that document the safety was guarantee through the allocation of certain precautionary parameters to the soil itself after having performed some surveys. After the decree to be sure of the stability of a structure it is necessary to increase the actions (called design actions) or decrease the resistances (called design resistances). There are several definitions of the factor of safety; the first, according to the suggested Italian law, is given by the ratio between the available shear strength and the required shear strength just to maintain the stability.

$$F_s = \frac{\tau_f}{\tau_{req}}$$

where τreq is equals to τ mobilized that represents a percentage of the overall shear resistance. In particular, the Italian "*Norme Tecniche per le Costruzioni*" defined Fs as equals to 1.1 to consider a slope stable. Furthermore, depending on the type of analysis performed:

- $\tau_{req} = \frac{C_u}{F_s}$ for short-undrained terms or total stresses;
- $\tau_{req} = \frac{C'}{F_c} + \frac{\sigma' \tan\phi'}{F_\phi}$ for long-drained effective stresses terms.

See the following table for the values of Fc and FΦ and other partial coefficients for the geotechnical parameters of the soil.

Table 12. Factor of safety for the soil geotechnical parameters

Parameter	Symbol*	Factor of safety
Effective cohesion	c’k	1.25
Friction angle	tanΦ’k	1.25
Unit weight	γ	1
Undrained cohesion	cuk	1.4

*note: k=characteristic; they refer to the combination 2 (A2+M2+R2) of the first approach defined in the Italian NTC ‘08

The FOS is considered to be constant for the entire failure surface. Another definition of FOS often considered is the ratio of total resisting forces to total disturbing forces for planar surfaces of the ratio of total resisting to disturbing moments as in the case for circular slip surfaces. See the following figure for a more detailed description.

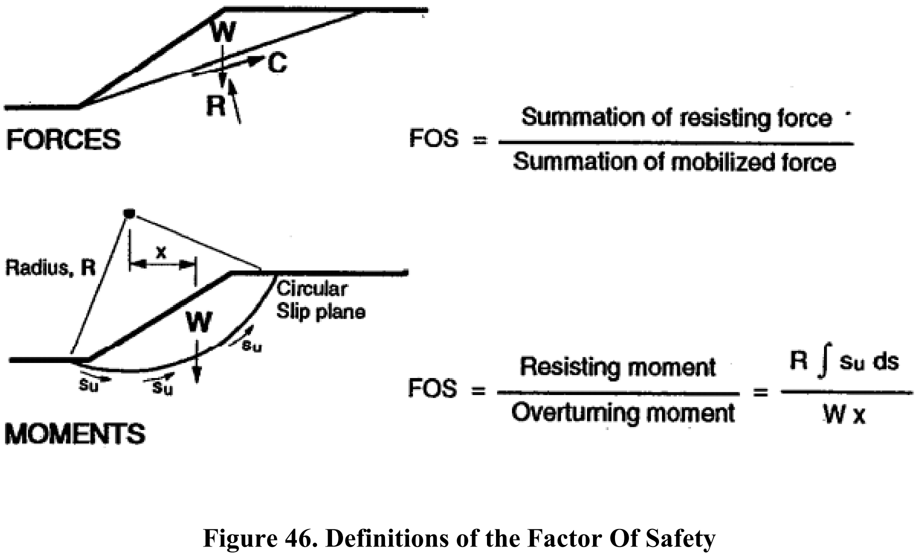


Figure 46. Definitions of the Factor Of Safety

7. Analysis through the program PLAXIS

PLAXIS is a finite element package that has been developed specifically for the analysis of deformation and stability in geotechnical engineering projects. The calculation itself is fully automated and based on robust numerical procedures. The program allows to reproduce real situations linked with plain strain of axisymmetric conditions. In order to simulate the tensional behaviour and the deformation of the geotechnical materials investigated an hardening-soil model is assumed (in Italian "*Elasto-plastico incrudente*"). In reality a model which perfectly simulates the behaviour of the cemented materials doesn't exist. This is because as can be seen in the figures of the section 4 (Figure 16, Figure 17, Figure 22, Figure 23, Figure 24) the cemented gravel presents a tension-deformation graph with an initial linear elastic phase followed by a peak strength that leads to the final constant value of the ultimate residual strength. For that purposes see the figure below which compare the theoretic behaviour with the real one:

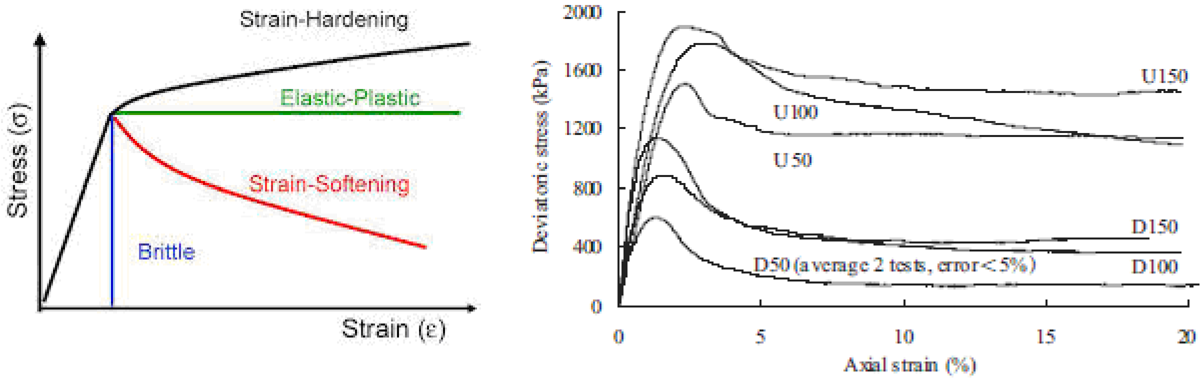


Figure 47. Comparison between the theoretical behaviour of the soils and the real one of the cemented gravel

Since none of the models contained in PLAXIS take care of the peaks the hardening- soil model is considered to be the best one. It is an advanced method for the simulation of the soil behaviour; with respect to the simpler Mohr-Coulomb approach the stress state continues to be described by the friction angle φ, the cohesion c and the dilatancy angle psi but the stiffness is described by three components: the triaxial loading stiffness E50, the triaxial unloading stiffness Eur and the oedometer loading stiffness Eoed (see figure below). Generally the code computes Eur~3 E50, Eoed~E50 . This model also accounts for stress-dependence stiffness moduli meaning that all stiffness increases with pressure.

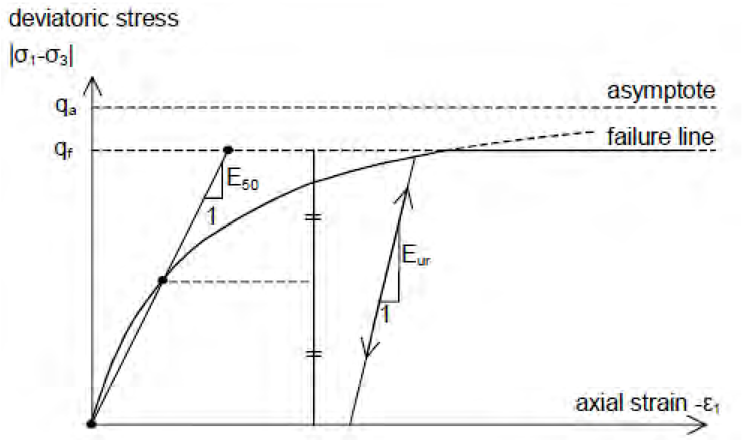


Figure 48. Hyperbolic stress-strain relation for PLAXIS

Concerning the goal of the present work, to simulate at best and prevent failure the quarry site is cultivated through different phases that are:

- phase 1: general excavation (in Italian "*sbancamento generale*");
- phase 2: abatement of the excavation front (in Italian *"abbattimento del fronte di scavo*");
- phase 3: final recomposition.

During the first phase the excavation is performed through horizontal layers and the fronts have an inclination equal to 45° that is the minimum slope considered stable for the cemented material (Simonini et all, 1986 and 1989). This is due to the fact that the first phase it not the final one and also it is the longest one so is important to ensure the stability of the fronts. Furthermore the excavation is stopped more or less at 5 meters with respect to the maximum limit for the concession. This distance is sufficient to avoid excessive erosive action of the meteoric water that will weaken the cemented bond. From a level to the following 5 meters of space are left free for the passage of the excavators. The height of each step is defined according to the norm n. 128/59 which says that the height has to be lower with respect to the maximum height reachable from the working machine. This not only for safety reason of the workers but also because it allows a better control of the front instabilities. For all the details see the Figure 49 and the section 7.1.

The second phase regards the stage in which the quarry is almost consumed. During that period the workers used the particular property of cementation of the gravel to optimize the inclination of the slopes. In fact, until the maximum limit of the concession the fronts are set to be almost vertical. But the lowering of the cohesion of the remaining material and the possible atmospheric agents dictate that this phase has to be as fast as possible to avoid failure or landslide. In this way the recovery material is also used to secure the front. The investigated quarry as a front of 30 m; the related stable inclination for a weak cohesion is set to 50°.

Anyway to increase the use of the particular property of that material three different slope inclinations are used:

- for the first 6 m 72°;
- until 14 m of depth 53°;
- until the bottom of the quarry (30 m) 49°.

A lower distinction with only two inclinations would cause an high release of this precious material in the quarry whereas a distinction with four of more inclinations is practically impossible to be performed.

Since during this phase the atmospheric conditions could lead to a decrease of the cementation, different values of the parameter cohesion c will be used according to the number of days in which the material is exposed to that agents:

- initial cohesion (0 days): c=12 kN/m2;
- cohesion between 1 and 30 days: c=11 kN/m2;
- cohesion between 21 and 60 days: c=10 kN/m2;
- cohesion between 61 and 180 days: c=8 kN/m2;
- residual cohesion (other than 180 days): c=3 kN/m2.

Note that they differ from the value that could be obtained with the formula presented in the chapter 5.2 because since the cohesion plays the most important rule in the stability of the slope it is important to be in favour of safety to prevent any kind of instability phenomena so the values obtained with the mentioned formula are reduce of about 1.25 as wanted by the Italian law "*Norme Tecniche per le Costruzioni*" (Table 12). Since the period of time is not daily but is based on a period of time that varies the cohesion c is consequently reduced to take into account of also this fact.

The recovery phase is in a certain way defined by the regional law n. 44/82 which says that the final slope has to be 25° but nothing is said about the type of material to be used for the recomposition. Obviously such material can't have very good quality because of economic reasons. In most of the cases excavated materials made of some residual silt are used. According to our aim, the quarry is recomposed with excavated material that come from the pile construction. As shown in the following figure the recovery is not made by horizontal layers as is done in the first phase but is performed through elements called "trance" in order to make this last phase as fast as possible. In fact with this technique the excavated front is immediately make safe since the degradation of the cementation is limited. Note the difference between the slope of the first and last phase: the white zone represents the first one and in fact the slope is more steep than the white portion that is visibly gentle. The figure also clearly described the type of excavation performed: as it moves forward, the recovery advances too in order to prevent the degradation of the cemented soil. This type of conduct have to be performed also according to the law that suggest to perform the recovery at the same time of the excavation to preserve also the natural characteristics of the site itself and to reduce the impact of the mining activity.

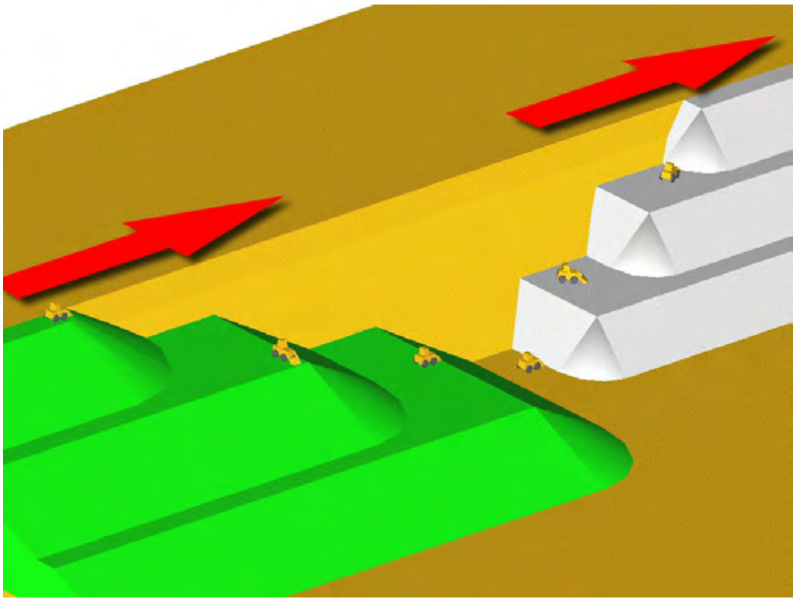


Figure 49. Three-dimensions representation of the excavation phases: white colour for the first stage, green colour for the recovery stage

The Figure 50 described graphically the three phases of a general section of the quarry; note the different slope designed which varies from the 45° of the general excavation to the 25° of the recovery and also the different type of activity carried out: horizontal excavation first, inclined layers for the recomposition.

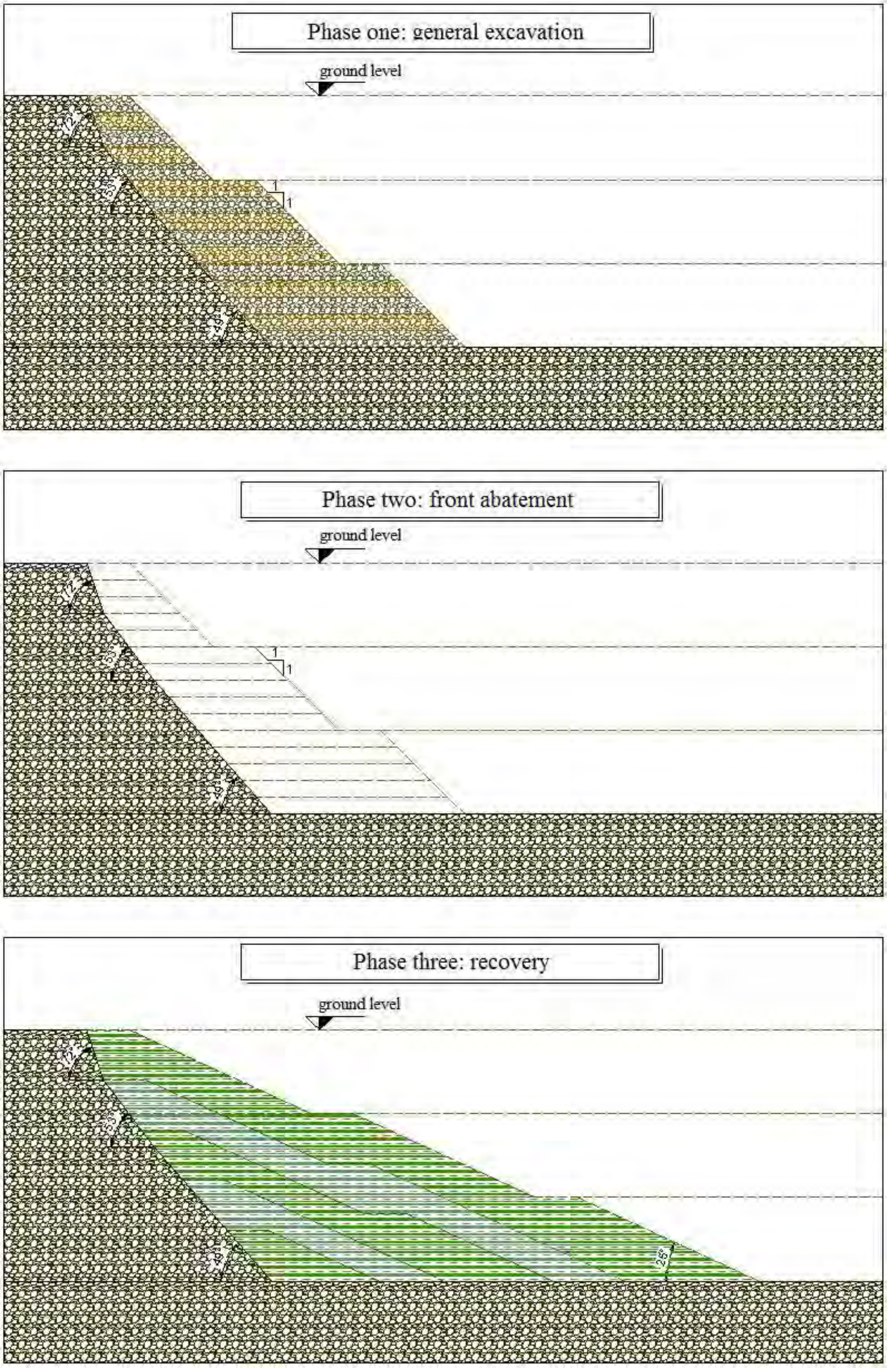


Figure 50. Section view of the three excavation phases

7.1 Stability analysis with the finite elements method

In the definition of the project with the program PLAXIS several are the stages that have to be followed:

- definition of the geometry of the problem: i.e. the scheme of the quarry itself;
- definition of the materials (see the table below);
- definition of the proper mesh: the meshing is important to define the degree of accuracy of the study itself. Higher is the density of the mesh higher will be the accuracy of the results;
- definition of the boundary conditions: for the case under study the two vertical limits of the quarry have the property of horizontal fixity whereas the line that determine the bottom of the quarry have both horizontal and vertical fixity;
- definition of the water pressures: the quarry is not interested by the water table;
- definition of the initial stresses: determine according to the hardening-soil method (OCR=1, k0=0.304);
- definition of the stage construction: each steps predict the activation of a specific part of the quarry itself according to the excavation plan.

Table 13. Characteristics of the cemented gravel

Cemented gravel		
Parameter	Symbol	Value
Unit weight	γ	22.5 kN/m3
Initial elastic stiffness	E50	100,000 kN/m2
Elastic unloading stiffness	Eur	300,000 kN/m2
Friction angle	φ	45°
Dilatancy angle	psi	10°
Poisson's modulus	n	0.2
Initial cohesion	c	12 kN/m2
cohesion between 1 and 30 days	c	11 kN/m2
cohesion between 21 and 60 days	c	10 kN/m2
cohesion between 61 and 180 days	c	8 kN/m2
residual cohesion (other than 180 days)	c	3 kN/m2

Table 14. Characteristics of the recovery material called "Recovery material 1"

Recovery material		
Parameter	Symbol	Value
Unit weight (compacted and dry)	γ	17 kN/m3
Initial elastic stiffness	E50	70,000 kN/m2
Elastic unloading stiffness	Eur	210,000 kN/m2
Friction angle	φ	30°
Dilatancy angle	psi	0°
Poisson's modulus	n	0.25
Cohesion	c	2 kN/m2

The material used for the recomposition is obviously less good with respect to the cemented one. In fact it has a lower elastic stiffness which would lead in a higher deformability, a lower friction angle and cohesion which lead to the necessity of a lower inclination of the slope.

7.1.1 Simulation of the first phase

As said before, during this phase the inclination of the slope is maintained 45° to preserve the cementation of the material. Running the model, after 30 days of excavation (assumed to be necessary to conclude the first phase) the simulation gives the following results:

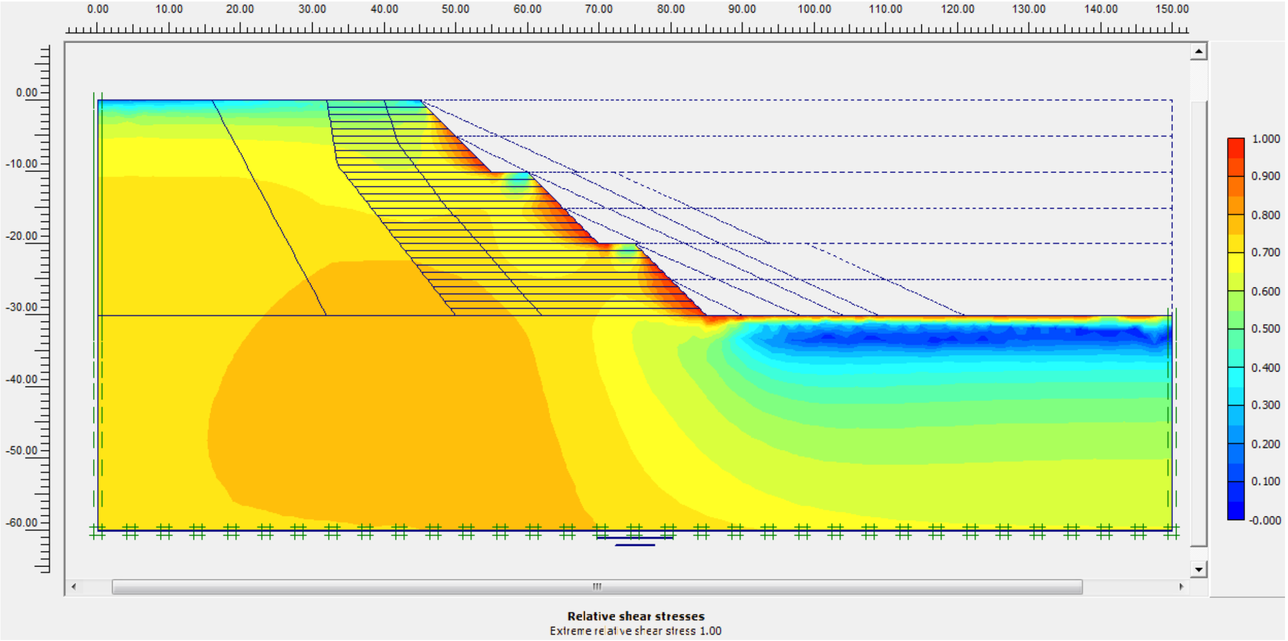


Figure 51. Output of the program PLAXIS: relative shear stresses (ratio between the point tension and the failure tension) after the first phase

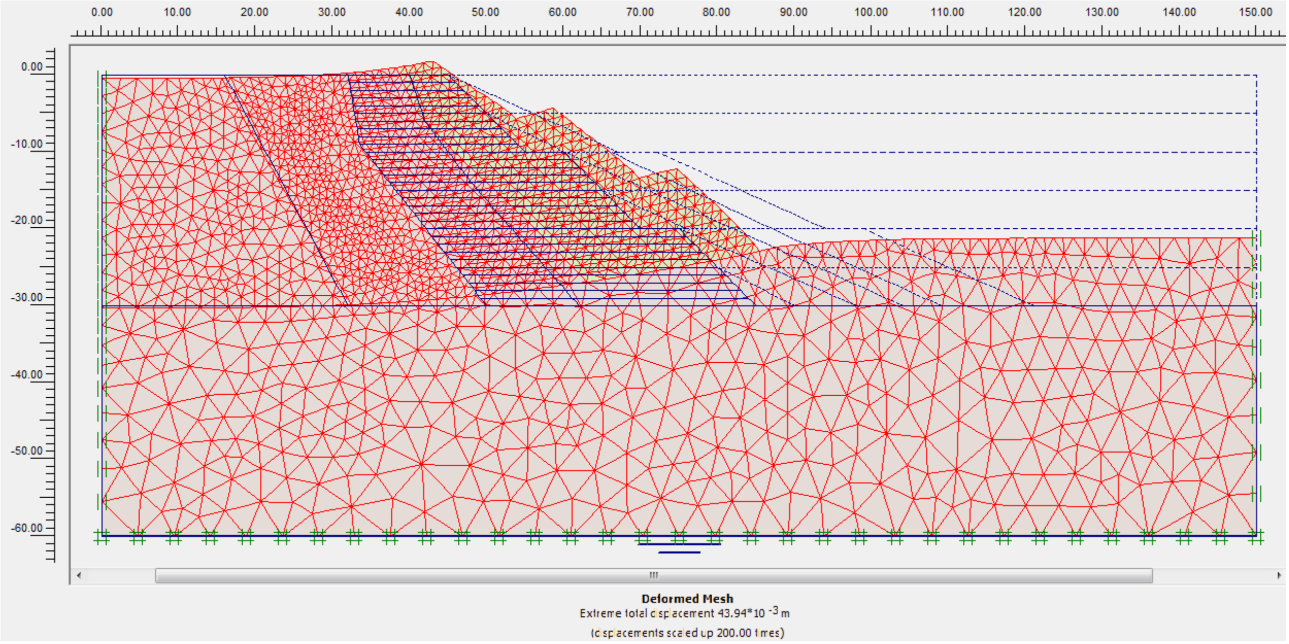


Figure 52. Output of the program PLAXIS: deformed mesh (scaled up to 200 times) after the first phase

The Figure 51 confirm that the decided inclination of 45° is sufficient to maintain the stability; in fact the relative shear stress that govern the slope stability approaches the value 1 in a limited surfaces (1-2 meters in depth). Note that obviously the bottom of the quarry is perfectly stable. This relative shear stress is the ratio between the effective tension which acts in a point and the stress at failure (the maximum achievable). It corresponds to the inverse of the Factor Of Safety Fs introduced in the paragraph 6.1; the difference is:

$$F_s = \frac{\tau_f}{\tau_{req}} \qquad\qquad F_{rel} = \frac{\tau_{acting}}{\tau_f}$$

where τreq is equals to τ mobilized that represents a percentage of the overall shear resistance, τf is the failure shear stress and τacting is the tension that acts in the site investigated. The difference concerns also the value that the two factors must achieve to ensure the stability: the Factor Of Safety has to be higher than 1.1 whereas the relative shear stress has to be lower than 1. In this sense they are one the inverse of the other since the shear stress at failure is at the numerator for the first case and at the denominator in the second.

For what concern the deformed mesh, illustrated in the Figure 52, note the little swelling (deformations scaled up to 200 times higher) which characterizes the base of the quarry. The bottom of the quarry after this first phase is set to the option “Reset displacement to zero” in order to take into account the unloading phase that is characterized by the absence of motion. In fact the following step, representing the first stage of the second phase has the following graphical output.

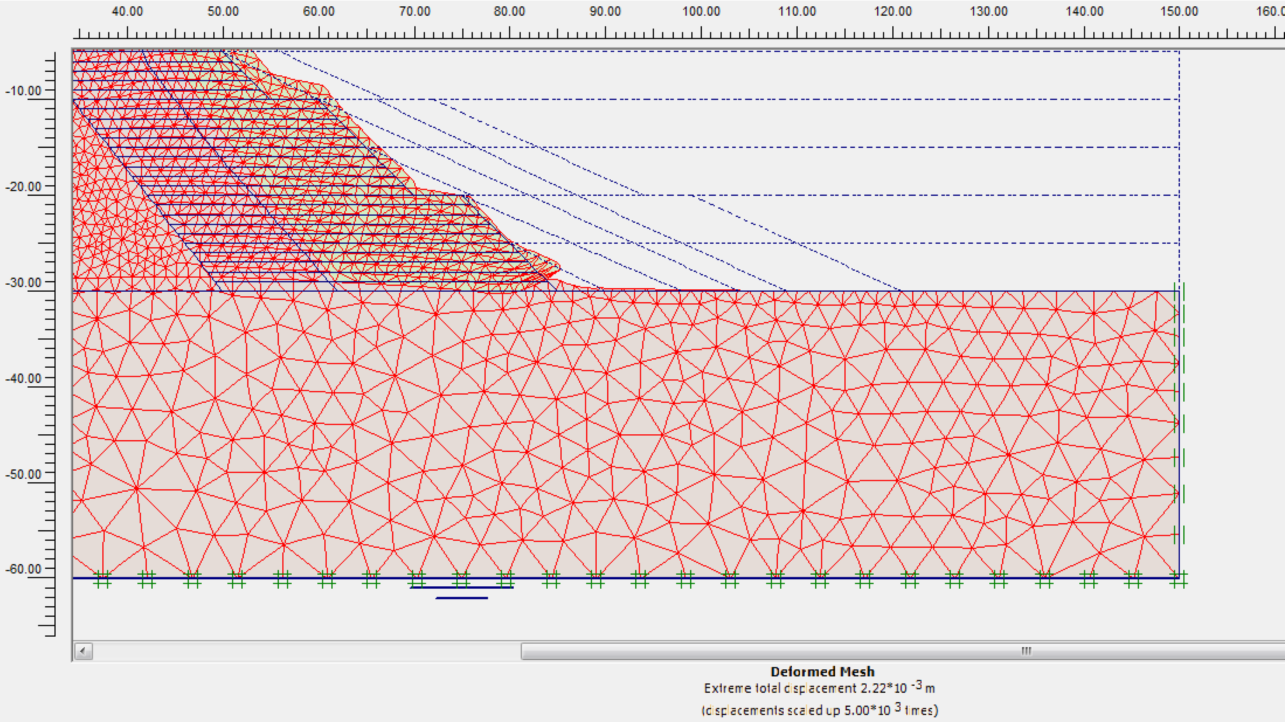


Figure 53. Particular of the bottom of the quarry after the first phase of excavation (scaled up to 500 times)

The correspondent displacement at the step before the start of the second phase is presented below:

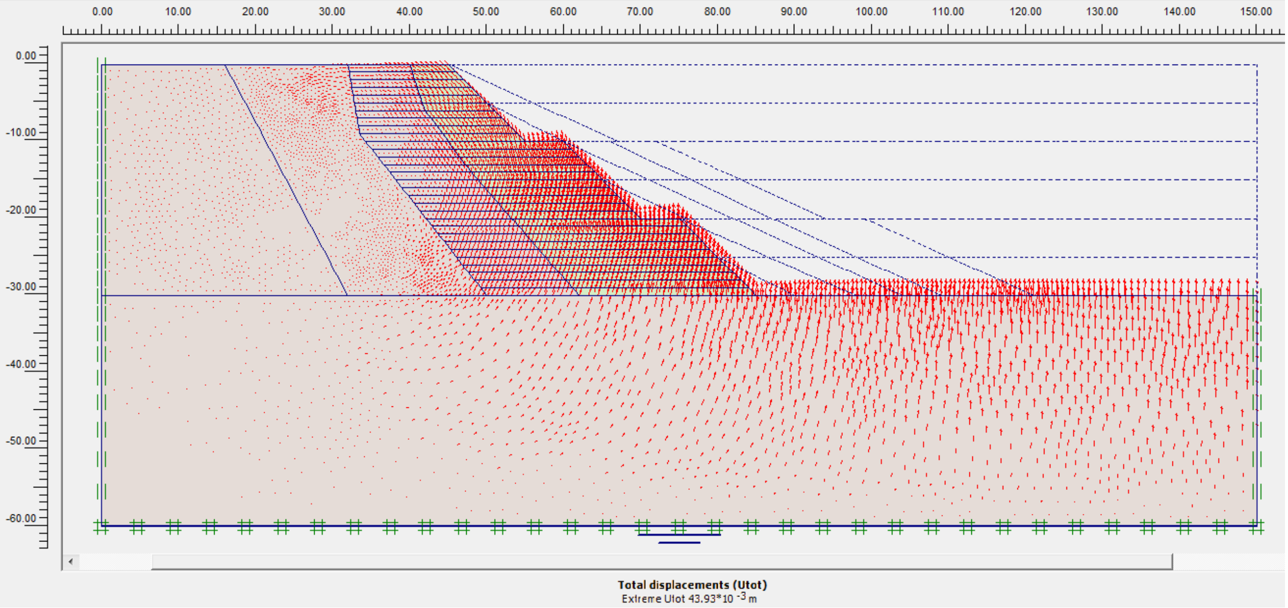


Figure 54. Output of the program PLAXIS: total displacement after the first phase (scaled up to 50 times)

The arrows which represent the displacements confirm the elastic behaviour of the material in the unloading phase as foreseed in the hardening-soil method description (see Figure 53); remember that the displacements are scaled of about 50 times so in reality the displacements would be invisible. This is due to the cohesion which characterized the in situ gravel and to the high stiffness of the material caused by the cementation itself; it will expand more if the own stiffness will be decreased. In particular the extreme total displacement is about 0,044 mm.

7.1.2. Simulation of the second phase

During the abatement of the front the slopes are excavated in order to approach the critical inclination for the stability. This is done because the manager wants to obtain the highest quantity of material so he plans to dig until the limit imposed by the geotechnical characteristics of the cemented gravel. As a result the area characterized by the failure tension is more extended than the case before so this phase has to be fast in order to prevent some failure to occur.

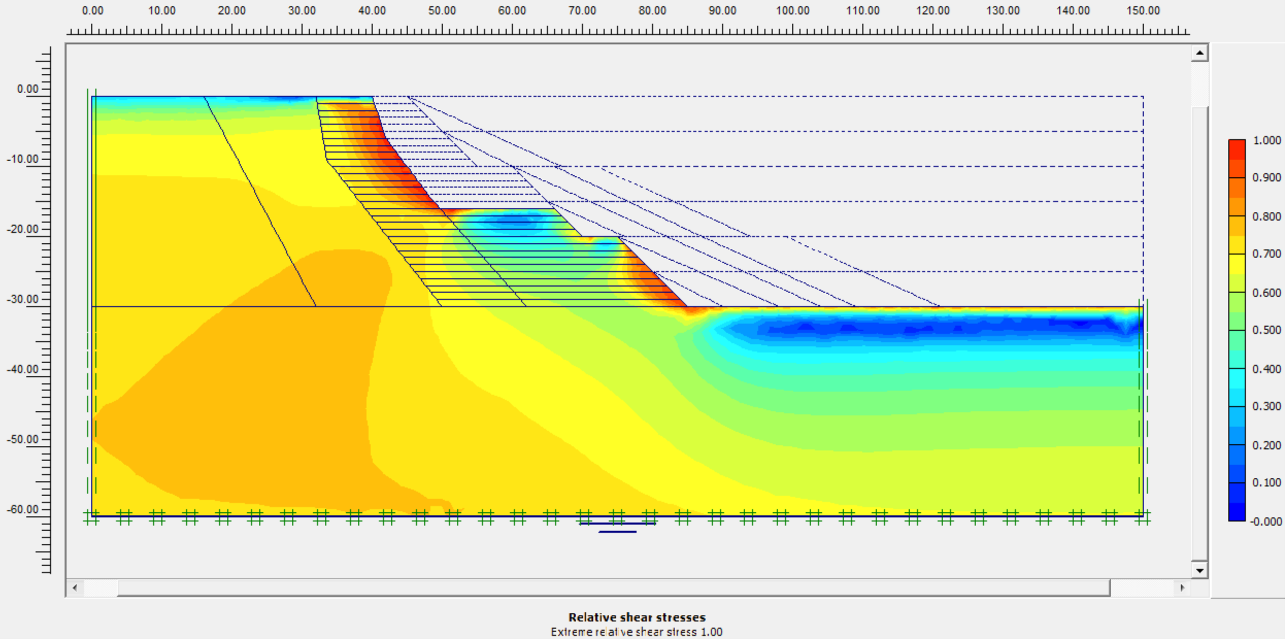


Figure 55. Output of the program PLAXIS: relative shear stresses (ratio between the point tension and the failure tension) during the second phase

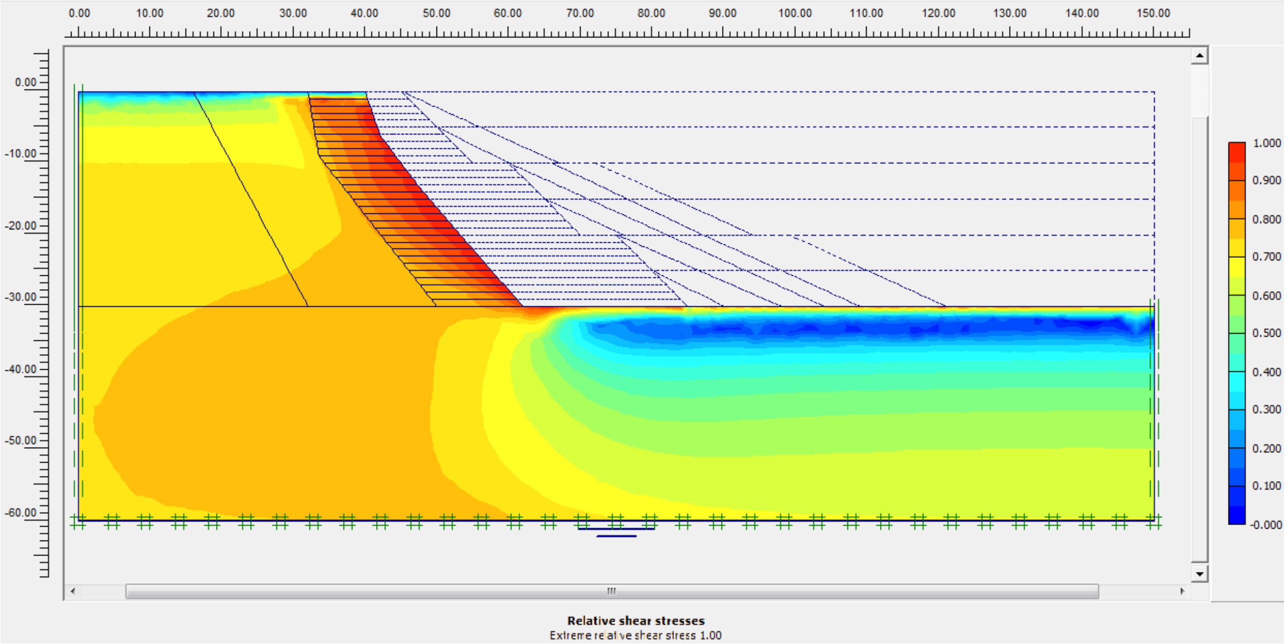


Figure 56. Output of the program PLAXIS: relative shear stresses (ratio between the point tension and the failure tension) after the second phase

Note that initially (Figure 55 compared with Figure 51) the extension of the risk area, the red one, is not so high with respect to the end of the first case but after some steps (each step is made by two layers and represents 3 days of working activity) the area under risk is close to 10 m extended. This necessary required a fast beginning of the recovery phase in order to block the cemented material and to prevent collapses since the exposition to the atmospheric agents could lead to the breaking up of the cemented bonds. In fact, the excavation activity has been designed in order to perform the excavation simultaneously to the recomposition (Figure 49) for two reasons: extract as much as possible the cemented material and guarantee the stability through the confinement offered by the recovery material and prevent to high visual impact performing an immediate recomposition of the quarry.

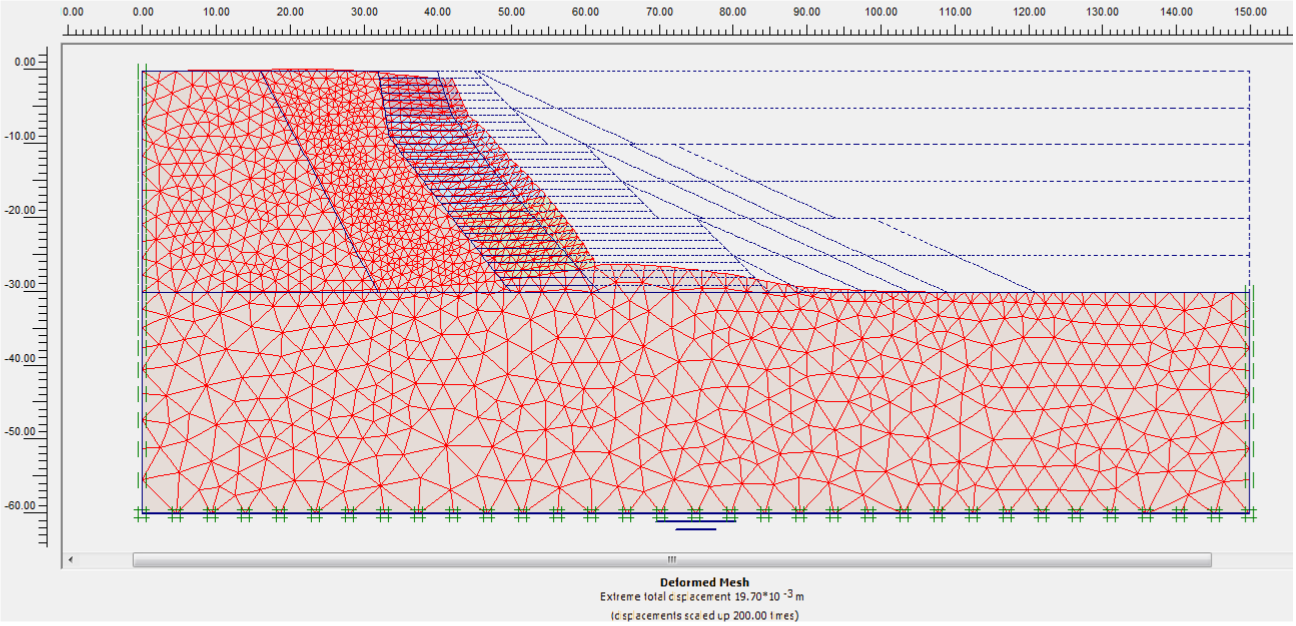


Figure 57. Output of the program PLAXIS: deformed mesh (scaled up to 200 times) after the second phase

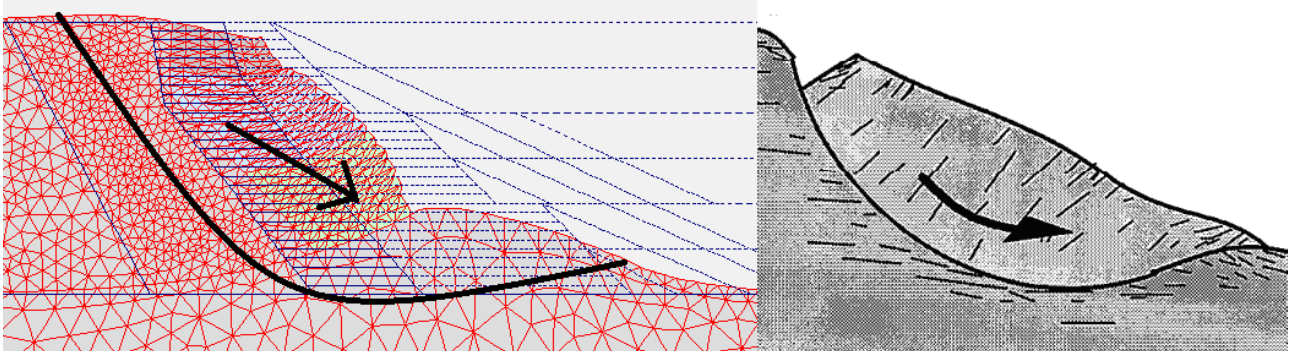


Figure 58. Particular of the failure mode of the slope quarry: the circular slip surface (scaled up to 500 times)

Notice the swelling of the lower portion of the slope reported in the Figure 57. This behaviour also here is related to the unloading phase that causes the release of the tension. In the Figure 58, thanks to the high scale adopted (500 times higher), is represented the type of failure that would occur and a comparison with the theoretical failure: in the figure taken from the output of the current analysis, the portion of soil on the left side is pushing the excavated slope which lead to the uprising of the bottom of the quarry and the swelling of the above part (the so called “circular slip surface” failure represented in the figure on the right). As can be seen the two figures are very similar. The failure mainly occurs through the rotation of the unstable volume of soil. Also for that figure is possible to see that the portion of the slope interested by a failure risk is more extended than before due to the increased inclination adopted.

The drawback of the cohesion change for each step is that the instability could be caused either by the decrease of cohesion or by the soil volume that push the part below it. To assess which is the cause a further analysis could be performed maintaining the cohesion fixed and comparing the results but in this way it is implicitly supposed that the cemented material remain the same during all the excavation activity that in the long range is not so real. So it is possible to say that in the short range (with c fixed) probably the cause is the volume of soil that pushes the part below it whereas considering a longer period of time the failure is related to the change of cohesion and so to the atmospheric conditions. We decided to analyze the problem changing the cohesion because as described in the chapter 4 the water controls the equilibrium which rules the cementation phenomenon.

7.1.3 Simulation of the recovery phase

The law prescribed to use an inclination of about 25° for the recovery. But as said before it doesn’t take into account the type of material used so further analysis are necessary. Also due to the fact that the excavated material is mixed with bentonite and contrary to the general thinking that this additive gives not the characteristic of stability to the soils itself it is mandatory to study the behaviour of that configuration to assess if 25° are enough to guarantee the stability of the quarry. The recomposition will be performed with the technique called “*per fette ascendenti*” in order to conserve as much as possible the stability of the slope; in fact this method considers not to expand the material horizontally but to develop in height (Figure 61). In particular this phase will be organized as follow:

- first simulation with 25°;
- second simulation with 20°;

As will be presented in the following sections these two configurations lead to the collapse of the slope so it was decided to introduce, other than the excavated soil, another type of material called “Recovery material 2” whose characteristics are presented in the proper chapter. Maintaining the configuration with a slope inclined of 20°, two possible configuration are analyzed. The first with the “Recovery material 2” placed closed to the cemented one and the “Recovery material 1” used to fill the core of the slope (Figure 67); the second considers the slope as divided in two part: the bottom is filled with the “Recovery material 1” and the part above it with the second type of material (Figure 71).

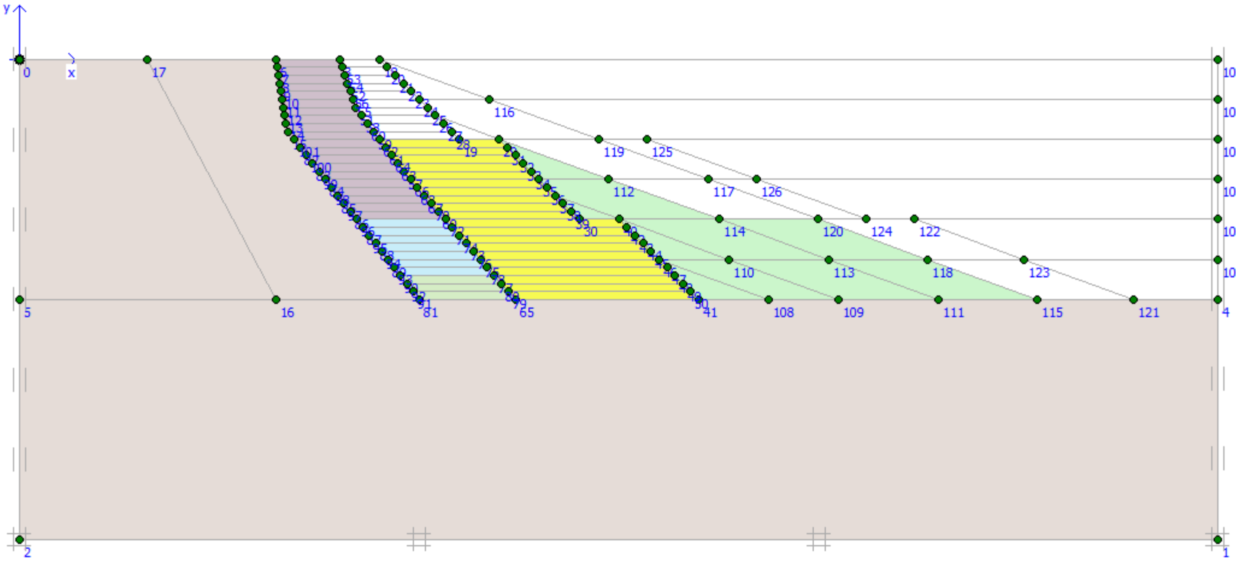


Figure 59. Recovery phase: particular of the technique used

7.1.3.1 Fist simulation with 25° slope

The final configuration with 25° slope is the following:

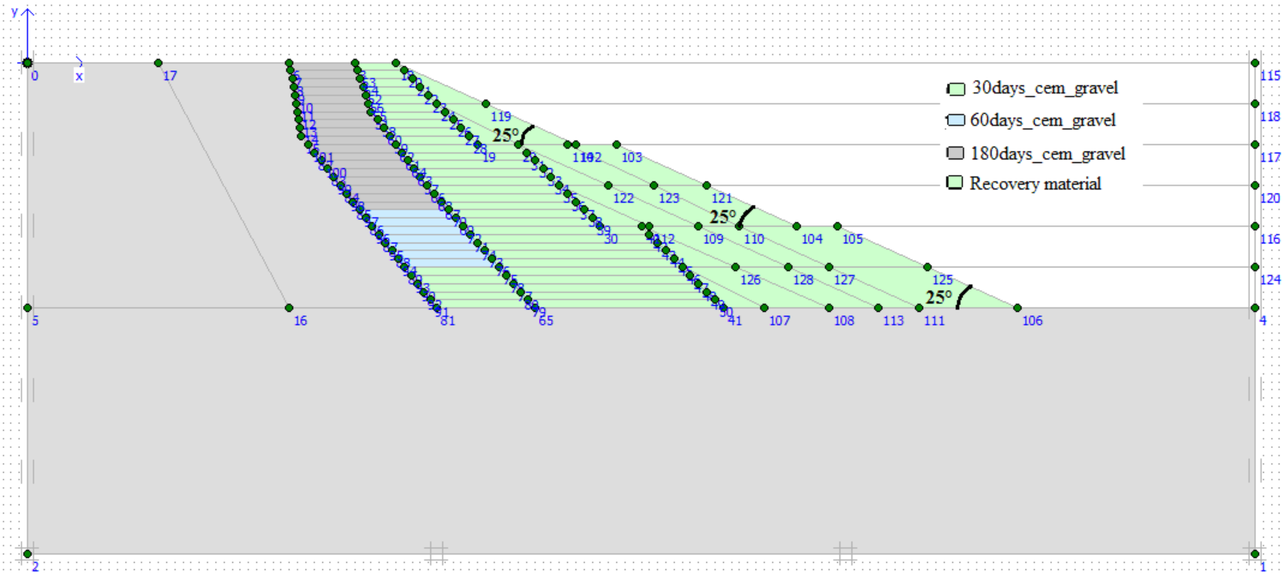


Figure 60. Shape of the slope of the quarry after the recovery

Even if the material is well compacted when place in the site at the end of the recomposition the soil collapses.

So looking at the Figure 62, reporting the deformed mesh (scaled up only to 2 times), it is possible to localized the failure surface that is on the top of the quarry. As the quarry is recomposed starting from the bottom the cemented material on the top starts to loose the strength due to the high slope imposed causing the final collapse with an extreme total displacement of about 4.37 m. If before the displacements were of the order of the millimeters, now the extreme displacement is of the order of the meters; three order of magnitude higher. The program stops working at the penultimate stage in correspondence to the failure. Since the characteristics of the recovery soil are fixed it is necessary to change the angle pose. If it would not be enough some arrangements such as membranes or nets have to be used to contain the material.

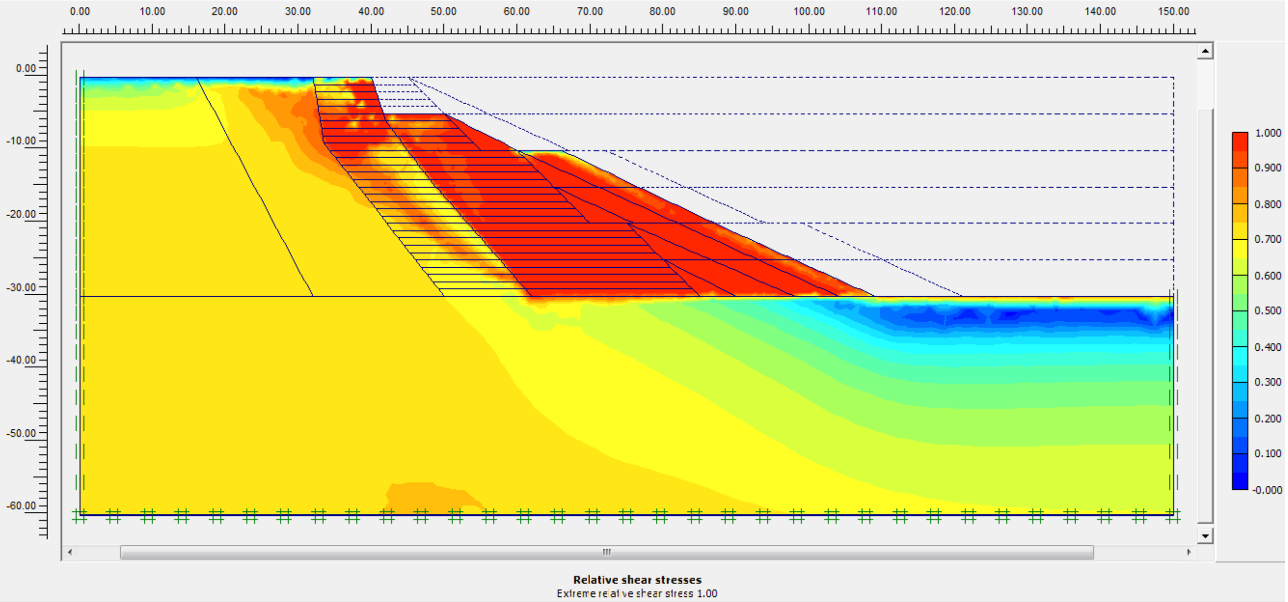


Figure 61. Relative shear stresses close to the end of the recovery

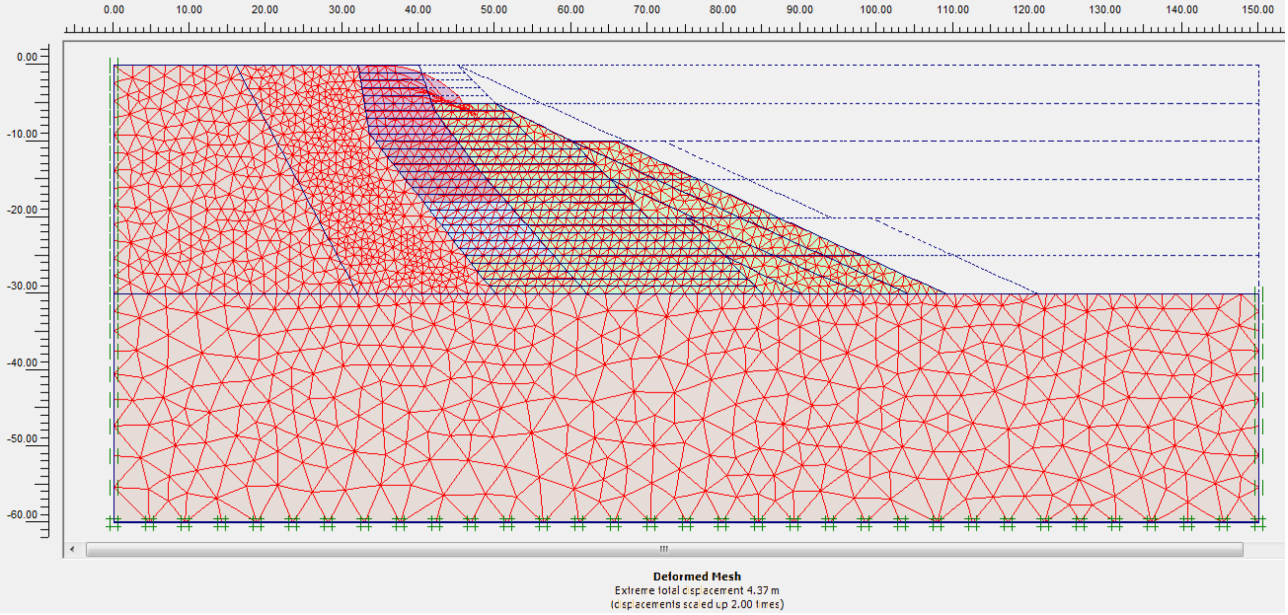


Figure 62. Deformed mesh of the recovery phase; see the particular of the collapse

7.1.3.2 Second simulation with 20° slope

Imposing a new value for the inclination, 20°, the slope doesn't collapse but as presented in the figure below is characterized by a wide unstable area. Since this phase is the final one it is not possible to accept a situation that is so hazardous. The law prescribed a value for the Factor Of Safety higher than 1.1; in our case the portion that directly lay on the original soil is at risk of collapse since it has a Fs that is not higher that 1. Whereas the portion far from the centre of the quarry, on the right side, is safer: the Fs is in the range between 1.1 (1/0.9) and 1.25 (1/0.8).

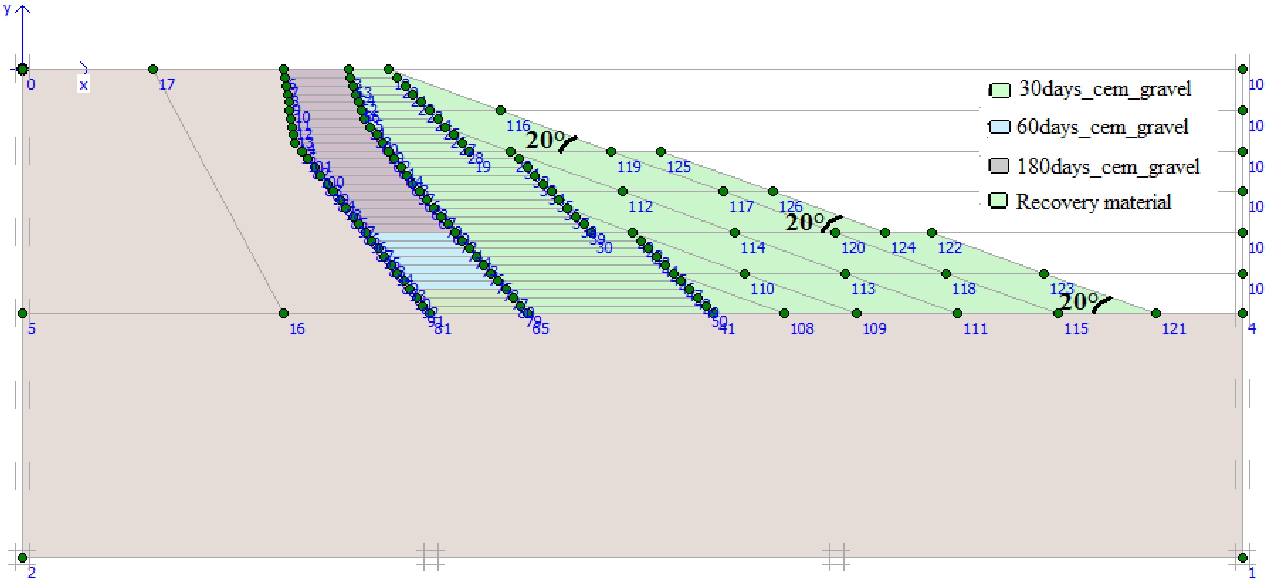


Figure 63. Shape of the slope of the quarry after the recovery

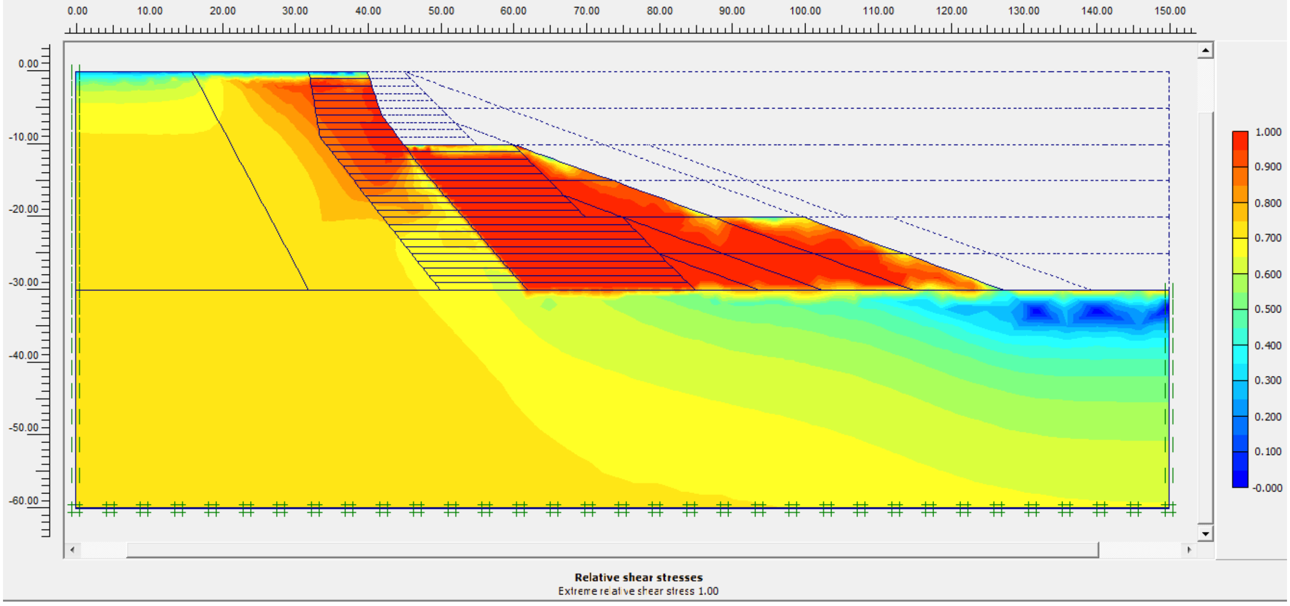


Figure 64. Output of the second simulation with 20° slope

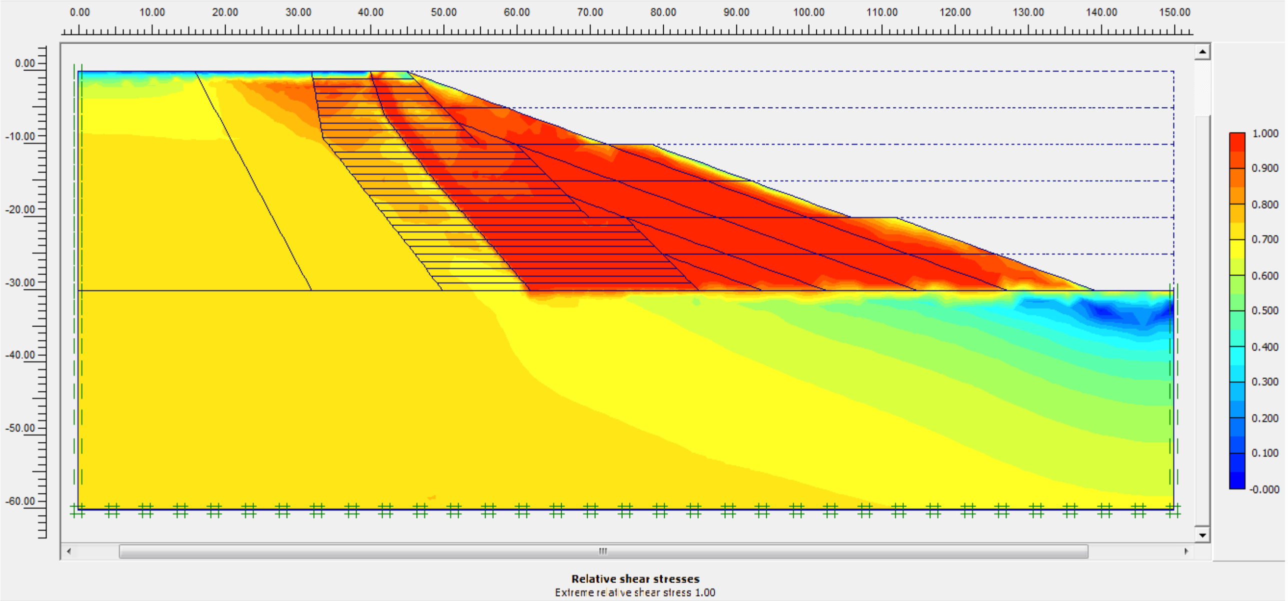


Figure 65. Output of the second simulation with 20° slope

The deformed mesh is presented in the figure that follows: as can be seen the quarry sinks. This behaviour may be a result of the compaction that occurs when the several layer are superposed. But the site doesn’t simply sinks vertically; the original gravel tends to be trailed to the centre of the quarry itself. This problem only occurred with that kind of program that works with finite element in which each point is linked to the other through the continuity law; so if a point is moving those who are close to it move too. In this way the influence carry by the stiffness is neglected. This law in reality is not respected and probably the friction between the two parts and the different response to the tension due to the different stiffness (70,000 vs 120,000 kN/m2) will lead to the detachment or a fracture between the two contact surfaces. To limit this relative motion is sufficient to increase the degree of compaction of the recovery material in the proximity of the front, in this way the elastic stiffness is increased.

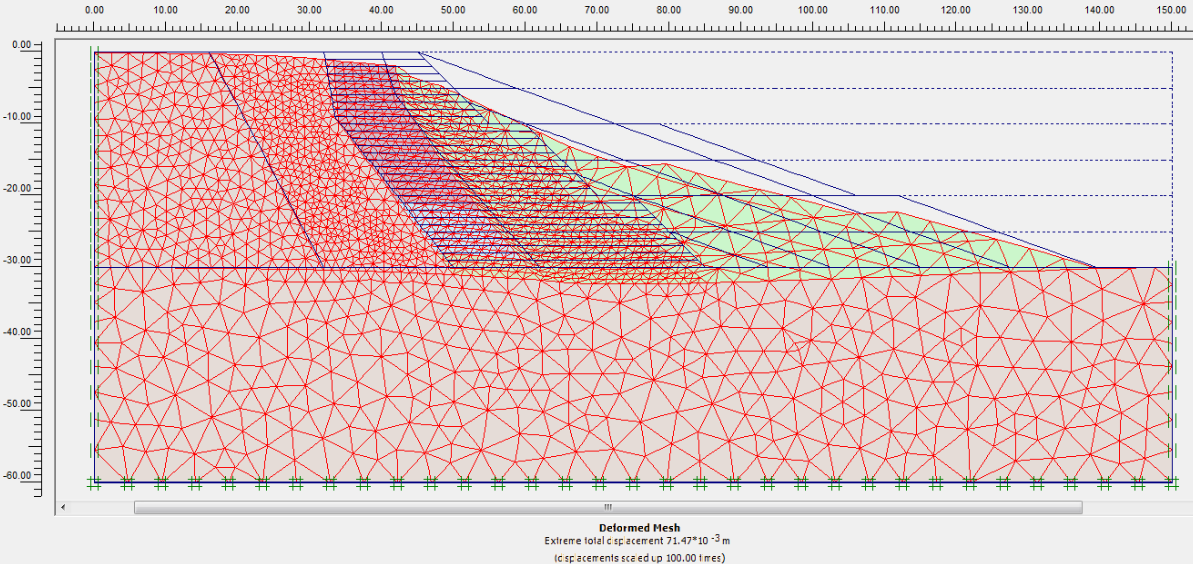


Figure 66. Deformed mesh of the second simulation

So the possible solutions to that situation of instability are:

1. adopt some arrangements such as an higher compaction, membranes, cages (in Italian "*gabbie*");
2. use another type of material with an higher cohesion to increase the shear resistance;
3. decrease further the inclination of the front;

The last may be the simplest one since doesn't involve other materials or technique but considering the high risk of instability of the configuration with 25° and 20° a slope of 15°-10° would not reduce so much the problem. The second possibility, that is the one adopted, is to include another type of material, for example with an higher cohesion. A previous study (2003) was conducted in the same quarry considering a material with the following characteristics:

Table 15. Geotechnical properties of the material "Recovery material 2"

Washing silt		
Parameter	Symbol	Value
Unit weight	γ	17 kN/m3
Initial elastic stiffness	E50	10,000 kN/m2
Elastic unloading stiffness	Eur	30,000 kN/m2
Friction angle	φ	25°
Dilatancy angle	psi	0°
Poisson's modulus	n	0.2
Cohesion	c	12 kN/m2

That material was placed in a slope with an inclination of 25° and results to be stable. The study conducted concerns the stability of the front such as our case but without specifying the type of material used. In fact the author simply said that he chose a material with poor quality in order to be in favour of safety. In our case, on the contrary the aim is to investigate the stability of the slope of a quarry but the type of material is specified since we want to find a final arrangement for the excavated material that differs from the landfill. The excavated material in fact, as said in the paragraph 3.3, is no more considered as a waste but as a by-product with some residual and appreciable potentiality.

7.1.3.3 Simulation with the introduction of the "Recovery material 2"

Considering the second type of solution from the list presented in the section 7.1.3.2, a new material (the so called "Recovery material 2") was introduced in two ways that will be described later.

Remember that the recovery configuration will not change: the slope near the original cemented gravel is inclined of 45°, that on the right side of 20° and the steps construction follows the sequence presented before.

Comparing the different soils, the second new one can be used for the construction of a slope with slower inclination since the friction angle is 25° (30° for the excavated material) but considering that the recovery is made in a way to be as far as possible and that the material is characterized by an high cohesion (12 kN/m2), the inclination of 45° assumed for the part filled with that material is considered anyway to be stable. Concerning the cohesion it directly affects the shear resistance: higher is its value higher will be the strength. So from that point of view the excavated material is less stable than the new one. Finally the two material will have no the problem related to the difference in stiffness since the continuity hypothesis between the nodes assumed by the program itself.

Once the comparison is well understand, the two types of arrangement introduced at the beginning of the paragraph can be described:

1. the material with the highest resistance ("Recovery material 2") is placed closed to the original one and on the right side whereas the worst soil is used to fill the core of the slope (Figure 67);
2. the slope is divided in two part: the bottom is filled with the worst material and the part above it with the best soil (Figure 71).

First configuration

Starting with the first, the configuration is the one presented in the Figure 69. Remember that the composition is done with the method called "*per fette ascendenti*"; in this way the same type of material is place once at all on the cemented gravel to anchor the original material itself and also to prevent the atmospheric condition altering the cemented bonds.

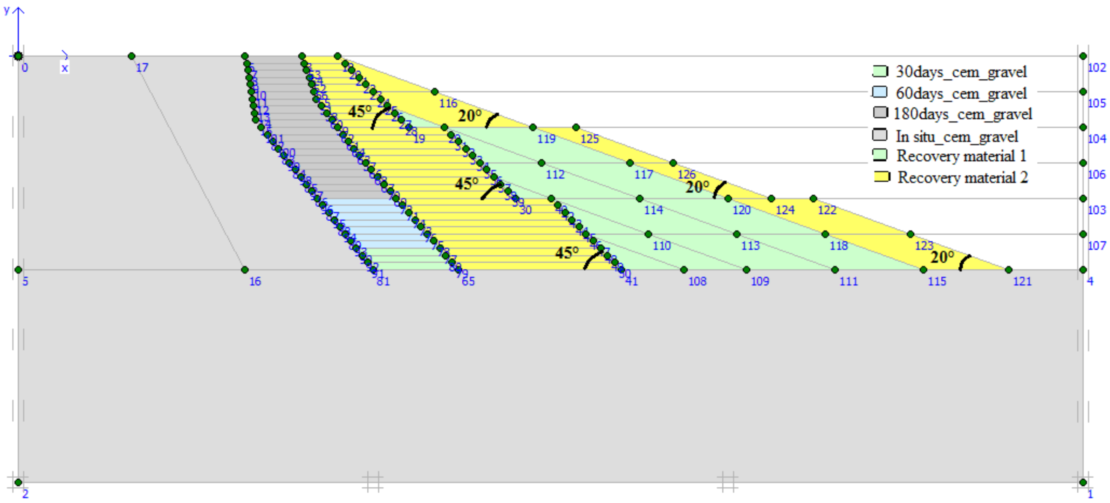


Figure 67. Second configuration for the recovery

The finite element analysis leads to the following relative shear stresses that represents the inverse of the Factor Of Safety:

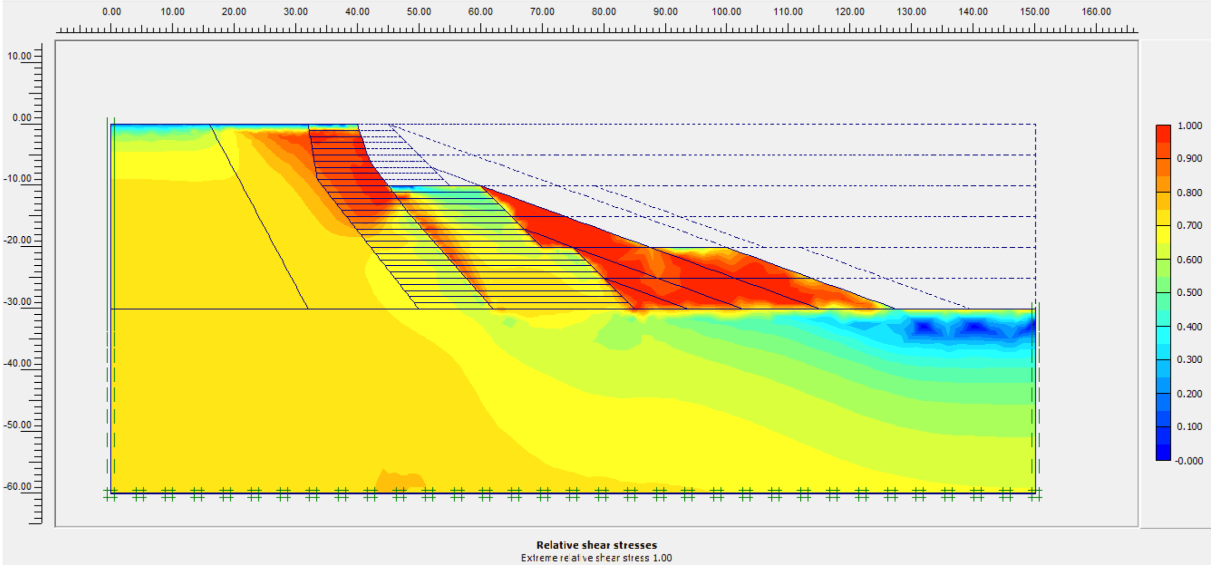


Figure 68. Relative shear stresses of the new configuration

The new material introduced has a very lower stiffness than the original one which leads to the red zone in correspondence to the surface in between the two soils. In this portion the soil tensions approach that of failure due to the difference in stiffness. In particular the recovery material is more deformable. In fact the elastic stiffness is defined as the ratio between the force applied and the consequent deformation ($E=\sigma/\varepsilon$); considering the value of the tension σ as a constant, higher will be

E lower will be the deformations. The figure below clarified this behaviour: the original soil is visibly less deformed than the recovery material.

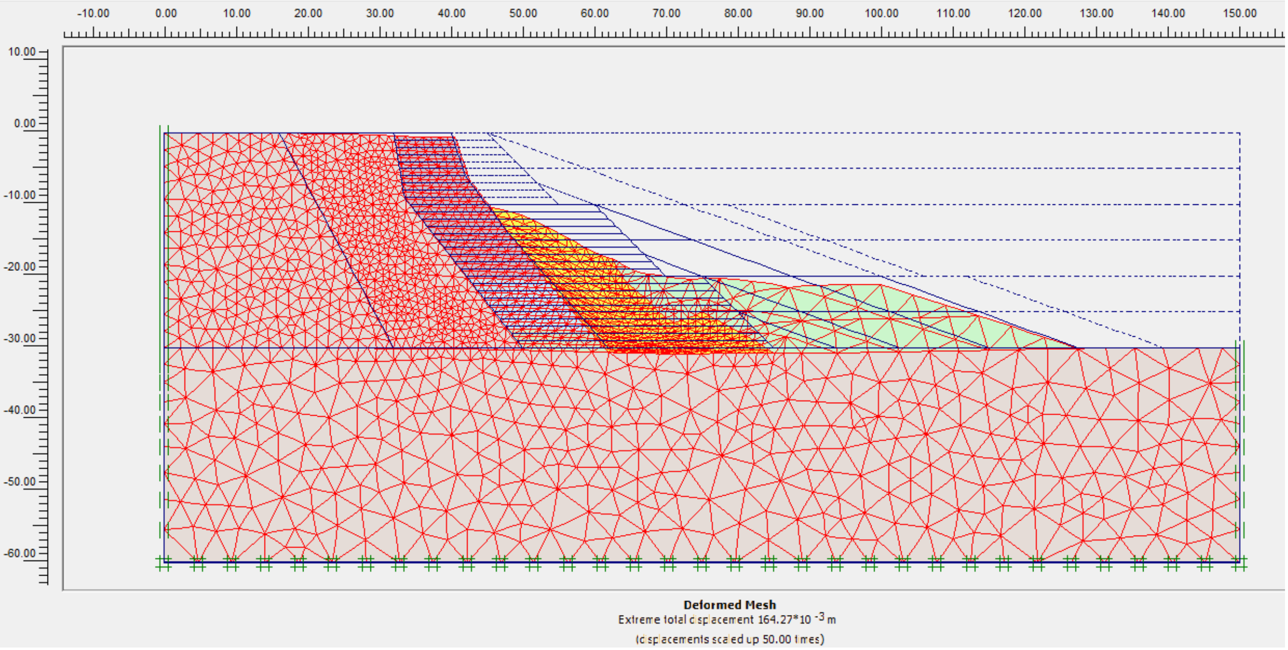


Figure 69. Deformed mesh of the new configuration

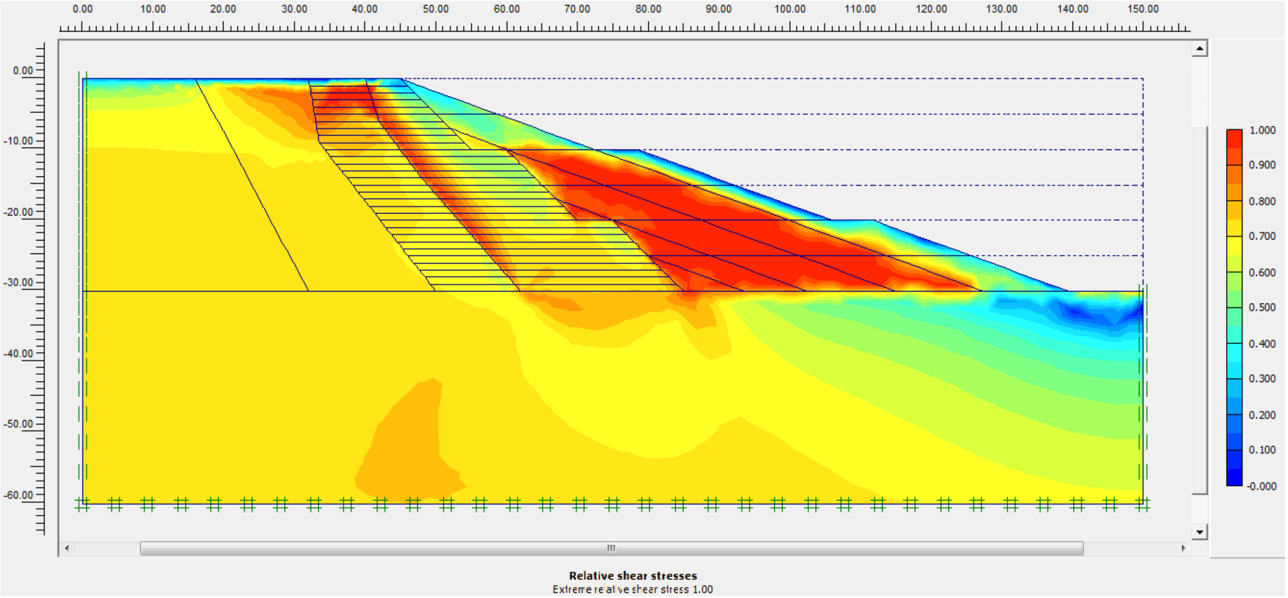


Figure 70. Relative shear stresses of the final step of the recomposition

The slope doesn't collapse but is not to safe as wanted. As said before the reason of the red zone in the surface between the two different materials is the difference in stiffness; whereas the other red zone is the excavated material. This zone is really instable due to the low cohesion which characterized the soil.

Second configuration

The second configuration considers the more unstable material placed close to the original slope and the more stable in the lateral part and on the top of the slope close to the original cemented gravel. In this way the more stable material could help the other one to achieve an higher degree of stability; in a certain way it serves as anchor. The graphical solution is presented following.

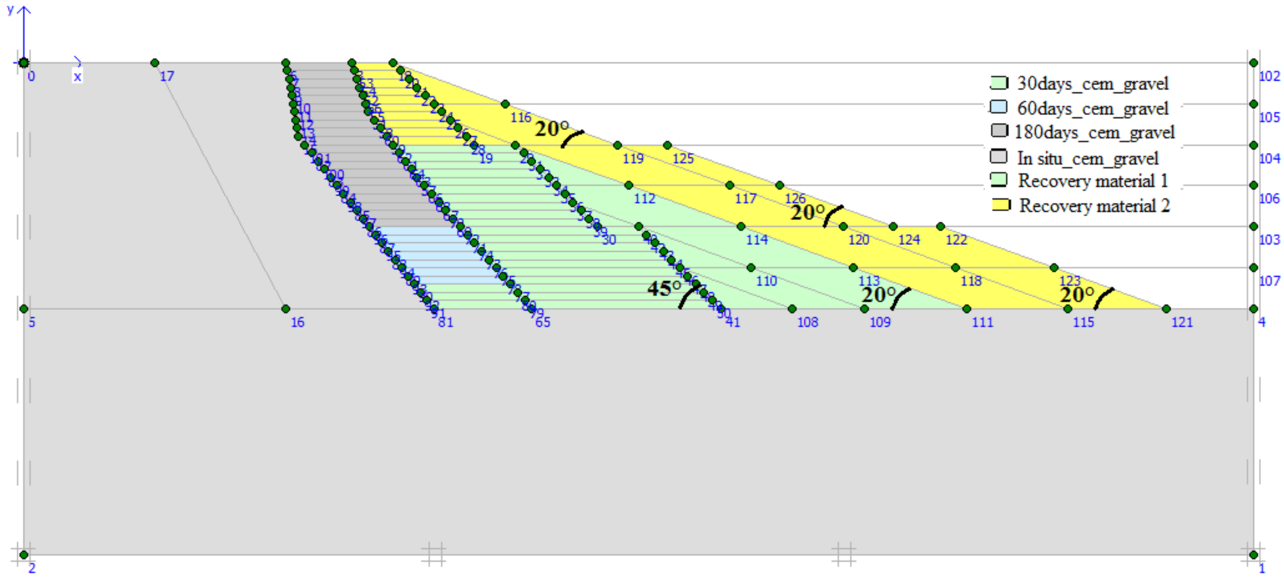


Figure 71. Second solution: the "Recovery material 1" close to the slope and the "Recovery material 2" as anchor

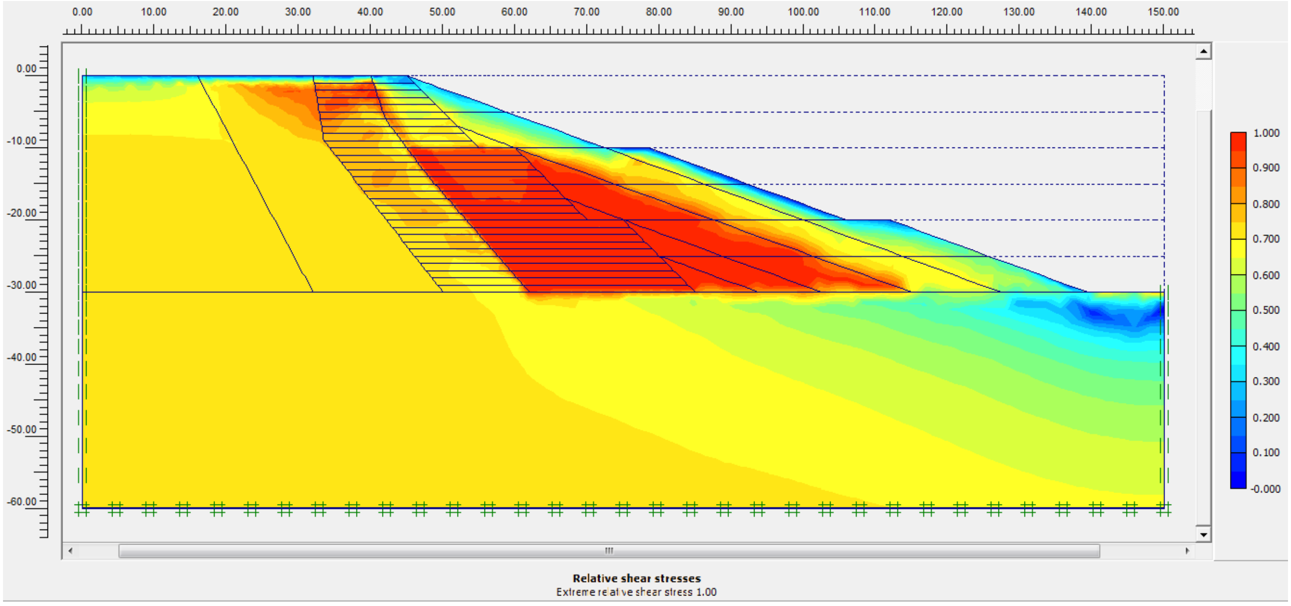


Figure 72. Shear relative stresses with the worst material ("Recovery material 1") in the core

Obviously the result is the inverse of the previous. But in this case the unstable part considering a long period of time, could be stopped and anchored by the second type of recovery material. This fact would lead to a more stable configuration than the previous case. Remember that the factor of safety have to be higher than 1.1. In this way the red portion having a relative shear stress equals to 1 implies a unitary Fs that is not sufficient to guarantee the stability whereas the zones having a relative shear stress of 0.9 refers to a Fs equals to 1/0.9=1.11 that can be considered acceptable. The deformed mesh of that case is presented in the Figure 74: the extreme displacement is lower than the case before; in fact in the current case at the end of the recovery is 0.1 m whereas in the past case was about 0.25 m (see the comparison presented below).

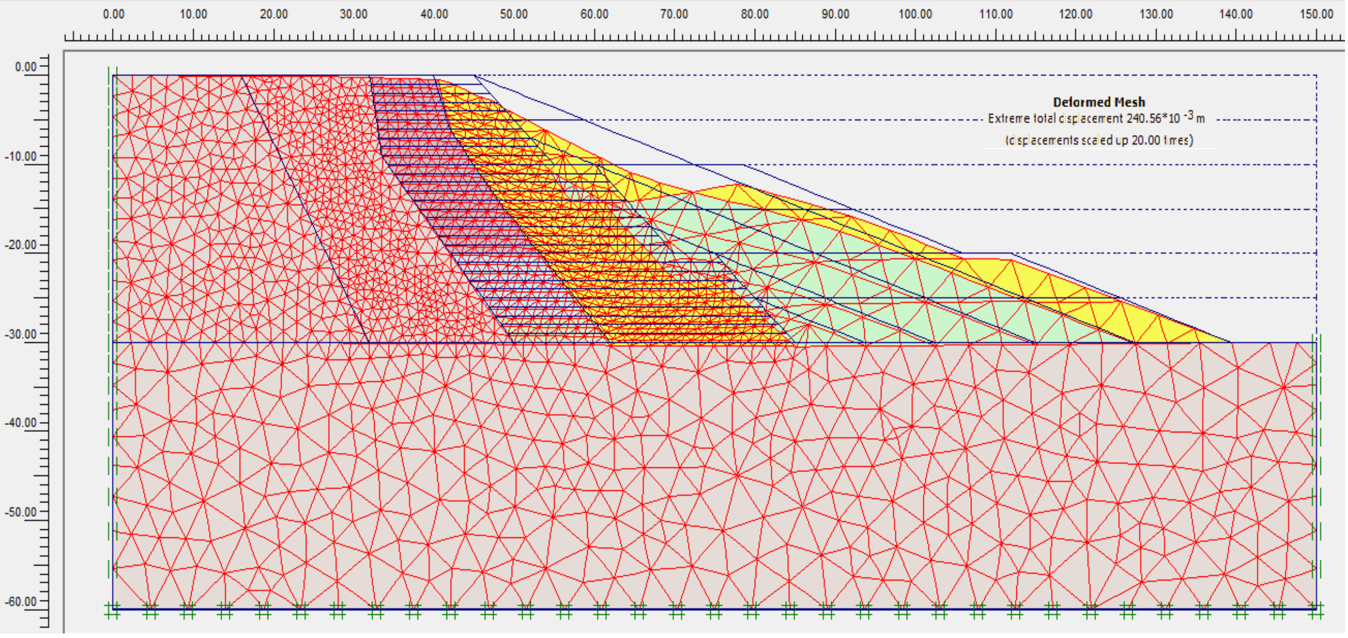


Figure 73. Total deformed mesh of the previous case - First configuration

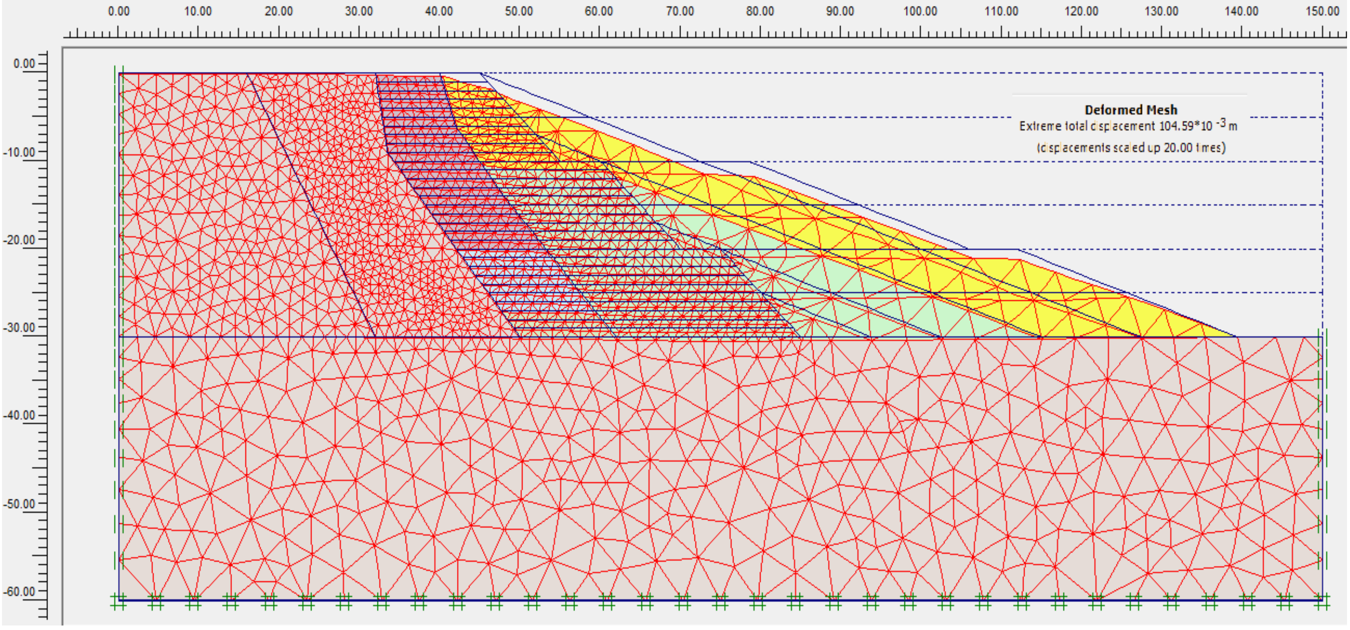


Figure 74. Total deformed mesh of the present case – Second configuration

This fact can be linked with the elastic stiffness: the excavated soil has higher stiffness which leads to lower deformation. Moreover since the two close materials, the original and the excavated, have similar stiffness they behave in a equal manner leading to a more stable situation.

Another difference between the two cases is that the surface between the two type of material in the first case is horizontal so the excavated soil is directly push down by the above portion. On the contrary, in the second case that surface of contact is inclined of 20° so the compaction is harder than the other case. Taking into account of all these aspects the final configuration is presented in the following chapter.

Final configuration

So the best solution seems to be a mix of the two previous case: it takes the advantage of the inclined slope of the second solution and of the placement of the more stable material closed to the original one from the first configuration (Figure 77 and Figure 78).

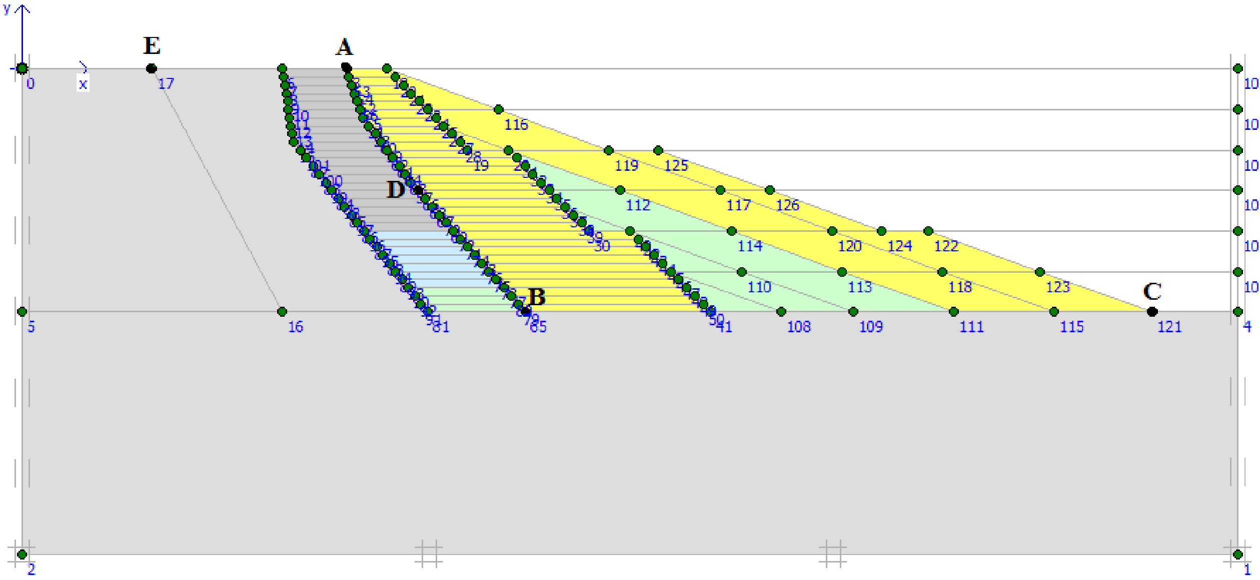


Figure 75. Final configuration for the quarry recovery

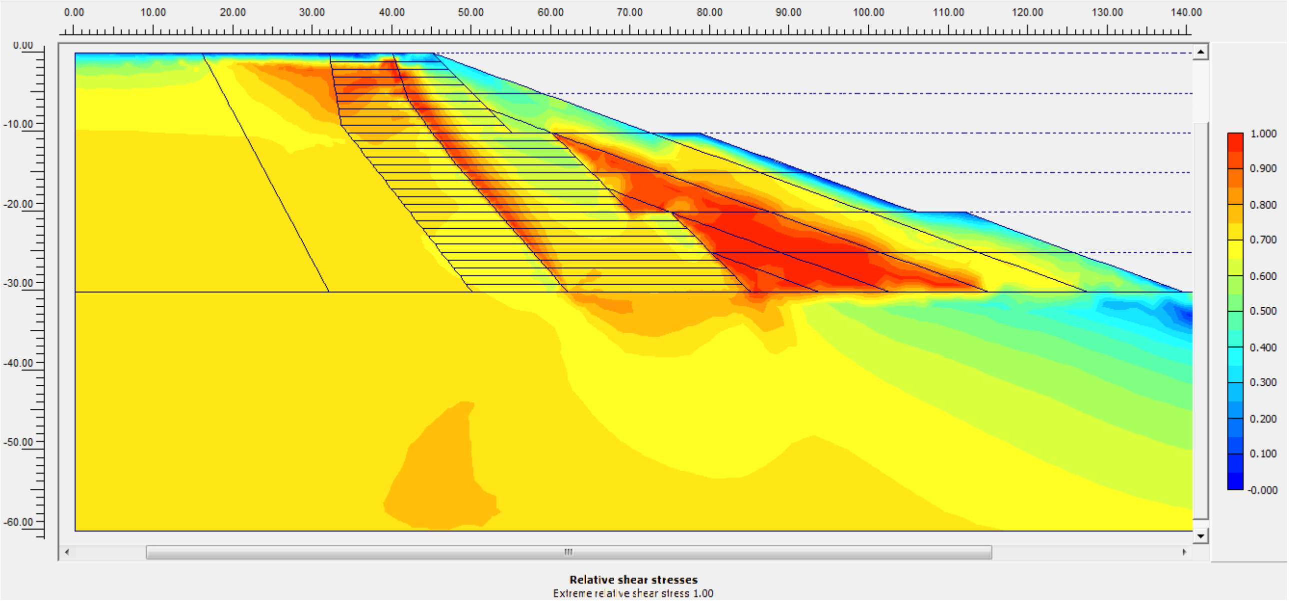
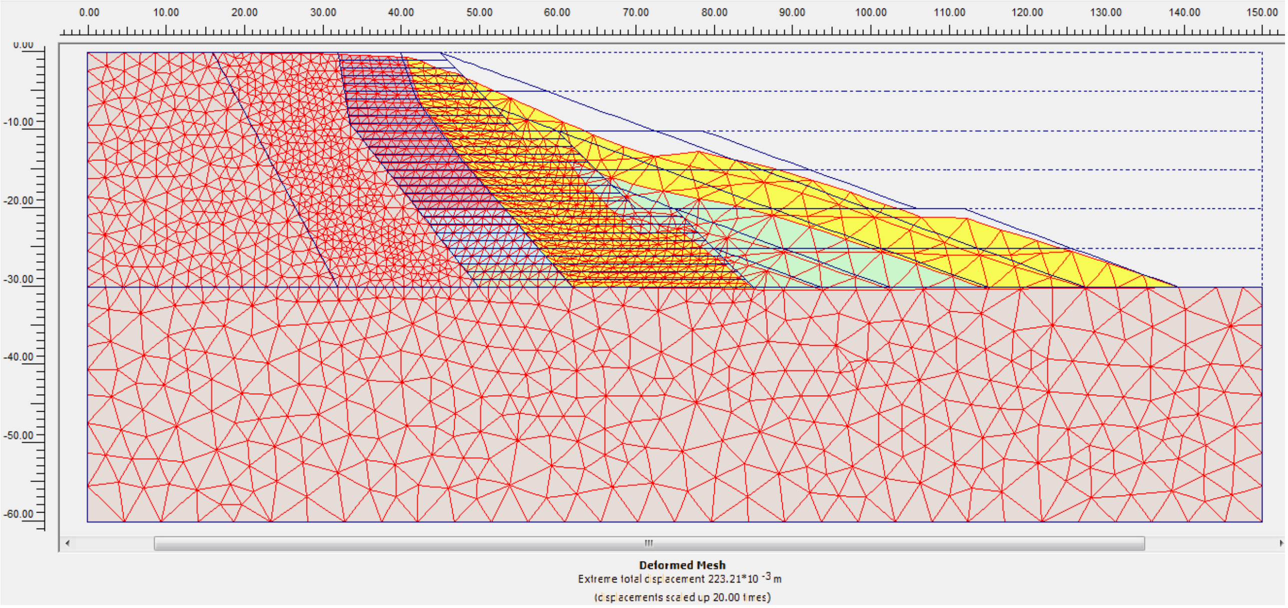


Figure 76. Relative shear stresses of the final configuration

The presence of a red zone between the "Recovery material 2" and the original excavated soil is linked with the difference in the elastic stiffness that caused a not equal behaviour when the two material are in contact.

As can be seen from the Figure 77, the extreme total displacement is not in between the previous two cases (0.223 m) but is anyway lower than the first case. Also the mesh is not so deformed as the first case; in fact it tends to the behaviour of the second case due to the inclination assigned to the excavated material used for the recovery.



Deformed Mesh
Extreme total displacement $223.21 \cdot 10^{-3}$ m
(displacements scaled up 20.00 times)

Figure 77. Deformed mesh of the final configuration

Graphical results of the final configuration

The potentiality of the program PLAXIS doesn't concern only the possibility to show the tension with different degree using the degradation of the red colour but it also allows to make some graph about the behaviour of the soil during all the working phases. As shown in the figure below it is possible to represent the displacements of some characteristics points (A, B, C, D, E in the Figure 75). The points are chosen considering the place of major interest from the view of the soil behaviour; in fact for example the point A is located in correspondence of the surface characterized by the passage from the original material to the recovery one.

The figure below reports the displacements in modulus for each steps used to run the analysis. It is also possible to represents the displacement in a particular direction, horizontal or vertical with the correct sign.

From the first figure it is possible to see how the displacements increase during the first phase of the "general excavation through horizontal layers"; in particular the point C shows the highest degree of |U|. The possible explanation to that phenomenon can be find in the allocation of the point itself: in fact it is located at the bottom of the base of the quarry. This implies that during the excavation, since the thought type of failure mode is the circular slip surface (Figure 58), all the left part of the quarry push the right part at the bottom; as a consequence the point C, followed, obviously, by the point B are forced to move up. See for that purpose the zoom presented in the Figure 79.

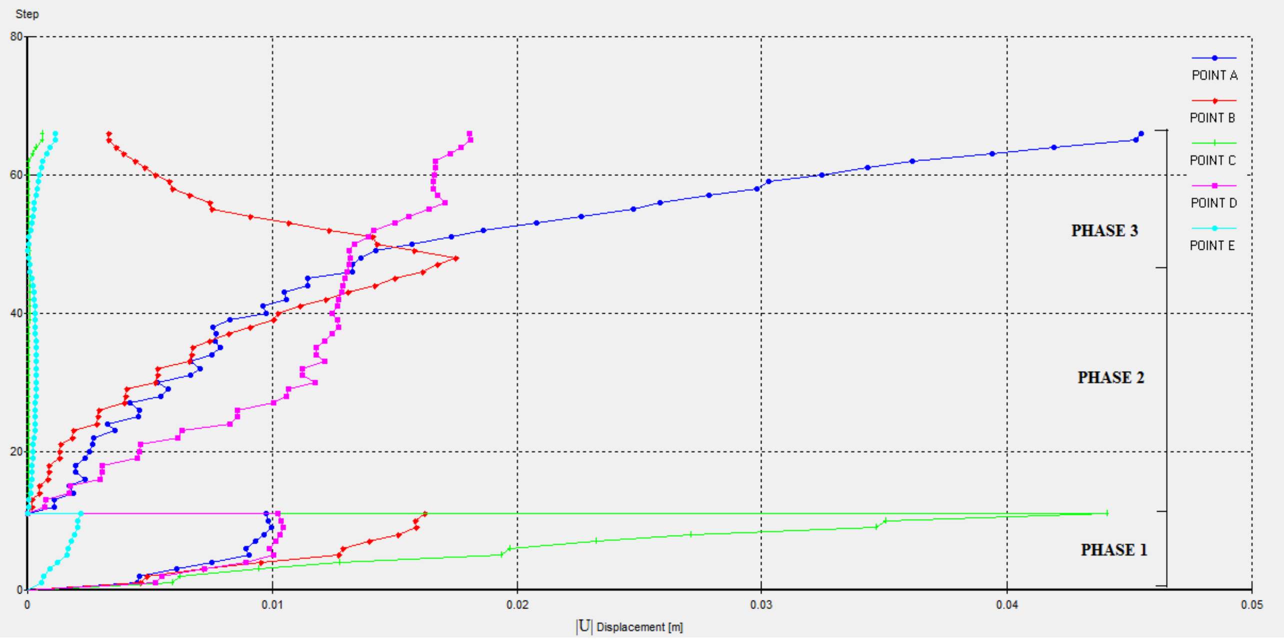


Figure 78. Graph of the displacement |U| for several characteristic points of the quarry. Note the particular of the phases characterization

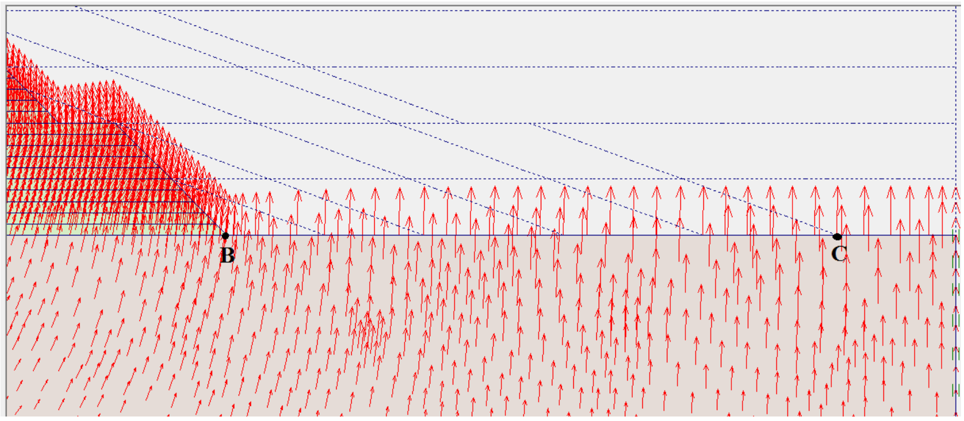


Figure 79. Particular of the total displacement of the point C and B (scaled up to 100 times) at the end of the first phase. Note how the displacements are higher than the left part

Obviously the point E is the place less subjected to the influence exercised by the excavation itself so it shows the lowest displacements. Generally in correspondence of the centre of the quarry the points are subjected to swelling (up-rise); then gradually moving inside the slope of the quarry the points tend to display the opposite behaviour: the so-called subsidence (Figure 80). The displacements in this way decrease increasing the distance with respect to the centre.

Note also the fact that after the first phase all the displacements approach the zero value; this is imposed, through the command "reset displacements to zero", in order to separate the two phases in order to consider them separately and avoid mutual influences.

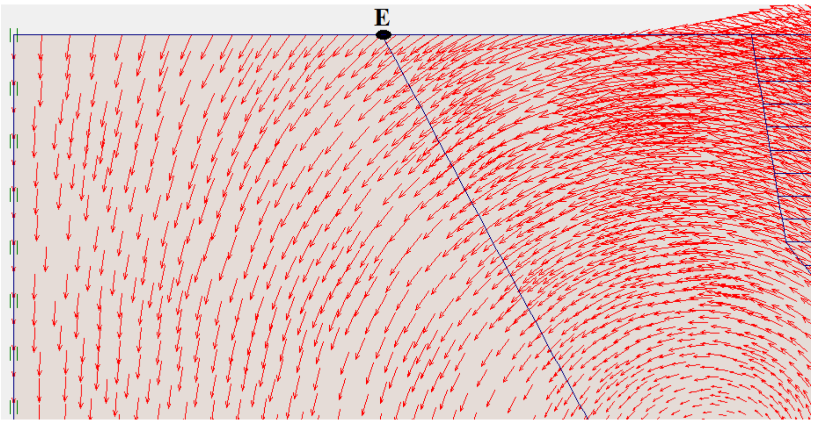


Figure 80. Particular of the subsidence phenomenon (scaled up to 100 times)

During the second phase the displacements maintain more or less an increasing monotonic behaviour for all the points; the point B and C continue to be subjected to swelling, but with a lower rate. The point A since it is located at the top of the quarry slope starts to show some sinking (Figure 81, Figure 82). This behaviour is reflected with a minor magnitude also by the point E.

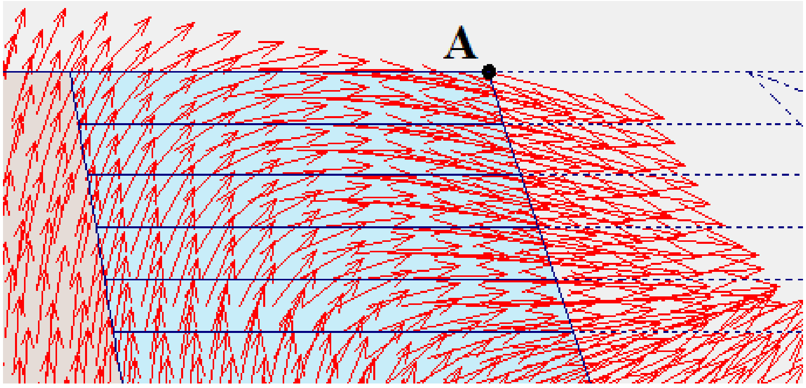


Figure 81. Sinking of the point A during the first part of the second phase (scaled up to 200 times)

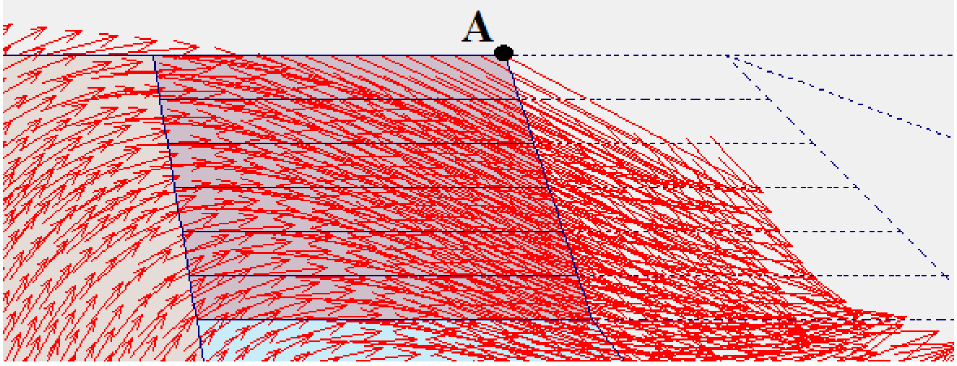


Figure 82. Sinking of the point A during the last part of the second phase (scaled up to 200 times)

Finally, concerning this second phase, the point D shows a particular behaviour: until it is blocked by the front material the swelling phenomenon prevails, in fact the |U| increases, then once the cemented soils is excavated the support fails and the material behind the point D start to relax leading to the behaviour shows in the Figure 80.

In the last phase, the recovery, the point A sees an evident increase of the displacements due to the fact that the soils of the slope is in a relax phase as said in the previous paragraph. The dragging phenomenon here is clear: already in the first step of the recomposition is it possible to see an evident swelling of the material, then followed by a further increase of the displacements.

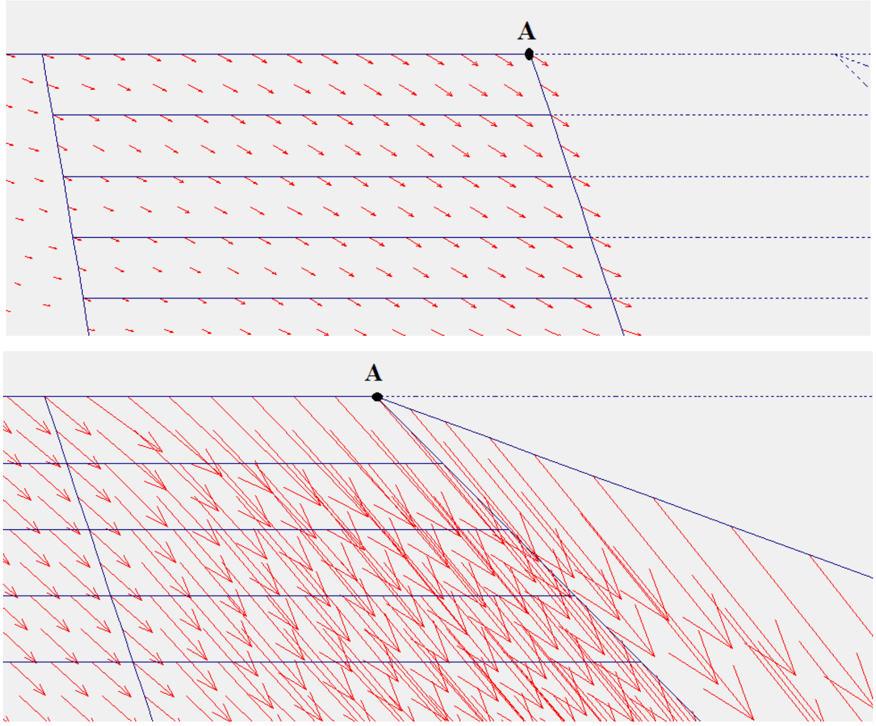


Figure 83. Comparison between the first and the last step of the recovery phase (scaled up to 20 times)

The following figures represent respectively the horizontal and vertical displacements, Ux and Uy. The Figure 86 representing the horizontal displacements, allows to understand and see clearly the distinction between the swelling and subsidence phenomenon. The right part of the graph with respect to the zero value represents the extension of the material whereas the left part the compression. Note the opposite behaviour of the point D described before: compression until 15 m in correspondence to which the original soil is anchored by the front material and then expansion until the phase of the recovery in which the material return to be block by the recovery material. The points E and C are too much far from the centre of the quarry to display horizontal displacements.

The graph of the vertical displacements shows the distinction between the subsidence (up-rise) and the swelling (in Italian *"rigonfiamento"*).

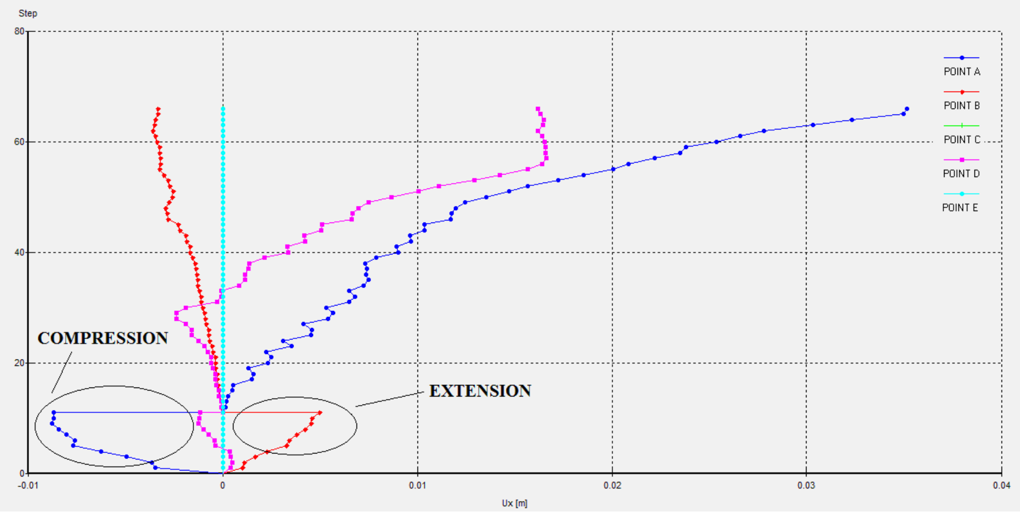


Figure 84. Graph of the displacements Ux

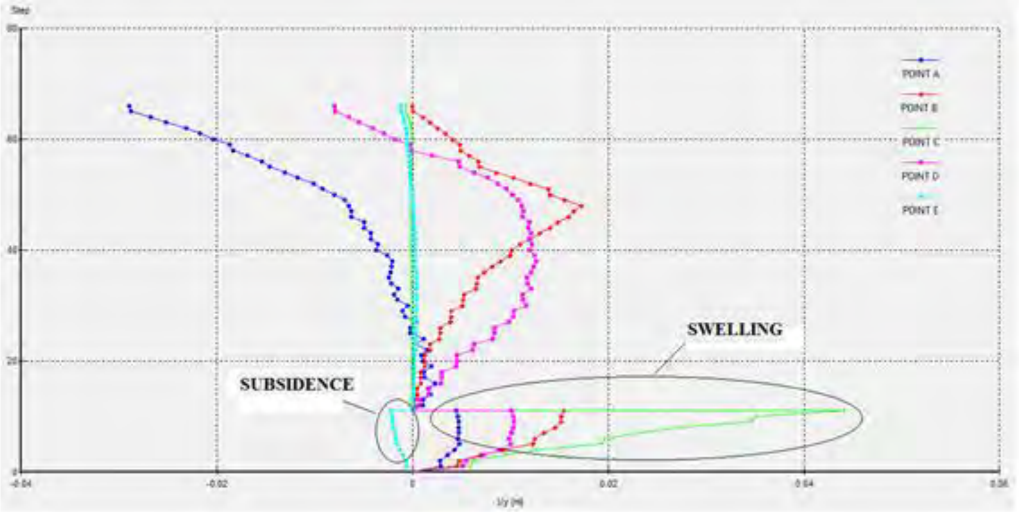


Figure 85. Graph of the displacement Uy

For example, during the first phase all the points, due to the fact that the excavation remove the soils on the right part, undergo to the circular slip failure mode since the left part (represented by the point E which obviously swells) pushes up the soil of the slope. The point B sees an increase of the subsidence until the end of the second phase then when the operator start to recompose the quarry the point B decreases the subsidence until a little swelling at the end. Finally the point A and D show a similar behaviour: first subsidence then swelling. Looking only at the points on the front (A, B and D) it is possible to say that in the complexity they have a similar behaviour and in particular the displacements never overpass the value of 2 cm. Since they represents the cemented material (the points are located on the front composed by the original gravel) it is possible to compare the value obtained with those coming from the experiments (Paragraph 4). In this way it may confirm the strength of the cemented bond or not. Both Asghari et al (2002) and Collins et al. (2009) explain that to achieve the rapture of that bond the axial strains have to be higher than the 2% (see Figure 16, Figure 17, Figure 27). So the stability analysis performed with this last solution is in favour of safety.

8. Conclusions

Summing up the results of the study performed it is important to highlight the following aspects:

- the excavated material mixed with bentonite is not so stable: but since it is not polluted and it helps the recovery of the quarries prevents the disposal in the landfill with the label of waste;
- the idea of the introduction of the “Recovery material 2”, placed externally with respect to the excavated material, seems to be good since it acts as an anchor and prevents collapses;
- the two material compensate each other: the high deformability of the “Recovery material 2” is filled by the low deformability of the excavated material whereas the low shear resistance exercised by the excavated material is filled by the high cohesion of the other soil which leads to higher shear strength;
- the law is perfectly followed: the excavated material is used as a by-product for the recomposition of the quarries, the slope as an inclination lower than 25° and the recovery is performed simultaneously to the excavation ;
- the final solution preserve the precious characteristic of the cemented bond: the grains continue to be linked together without showing some collapse; in this way the peculiarity of the material is used to preserve the stability even after the mining activity when the place will be used for recreational purpose;
- the numerical solution seem to be better than the calculation made by hands with some theoretical formulation since more details could be introduced. Moreover the simplification made by the use of a 2D representation, due to the infinite depth with respect to the other dimension, make the method not so difficult to be implemented. However the finite element method has also some drawbacks such as the one related to the continuity law applied to the nodes of the mesh: if a node moves all the others move too, causing the dragging of the cemented material (phase 3), but in reality a detachment is more probable. In this way the use of numerical modelling have to be done taking care of the following aspects:
    - the natural variability of the characteristics (such as the cohesion which we try to vary according to the atmospheric condition) and the factor that may influence the soil behaviour can’t be determined deterministically. The local behaviour could differ with respect to the assumed average conditions;
    - a better solutions could be achieve if it is possible to compare the values obtained through the finite analysis and those obtained from the observations made in the site but this would imply

to wait and observe until 180 days after the closure of the site and also simulate the action of the atmospheric conditions; since at this step the site is closed, the manager spends money for that controls without gains money so he will do it with not so much care;

- the change of the slope and materials (so cohesion and stiffness) with which the recovery was performed is called "parametric analysis" which help to understand which are the parameters that control the phenomenon studied; in fact the values used for the parameters can't be considered exact value. In particular, higher is the cohesion better will be the shear strength on equal slope angle, higher will be the stiffness, lower will be the deformation and the instabilities.

Another aspect to underline is the importance of the interchange of information between different sectors: the project of a construction work, approved by the competent Authority, must contain also the final deposition of all the excavated soils. In this way the customer have to obtain the permit to dispose such material in a quarry or allotments so have to move in order to find the proper site in terms of distance from the point of production, capacity of the site, related costs and so on.

The recovery of a quarry with excavated material is an operation performed nowadays; so the work aimed also to favour the practice described since, as prescribed by the law, the soils is previously analyzed to prevent the presence of contamination so is something safe and in a certain way environmental friendly.

Further analysis that could be suggested are based on one of the most important step in the modelling of a project: the calibration step. During this phase in fact the model parameters are change in order to ensure that it behaves as close as possible to the experimental data. To do this is important to have a certain number of data that come from the measurements made in the field of interest. This process is also based on the timing because to be sure of the goodness of the data is important to capture the variability of the system.

Another practice concerns the excavated material used for the recovery; since this material was for several year considered as a waste and so forbidden for the recovery of the quarries further controls should be suggested to ensure the zero sign with respect to the environment. In fact even if the law dictates the control of the absence of contaminants, the recovery technique is something that developed recently so some controls during the period after the intervention should be carried out. For example, if the soil was used for agriculture purpose control the quality of the crops or if for recreational purpose control the quality of the flora and fauna present.

Finally, is important to underline that with this kind of recovery activity the following article of the Regional Law n. 44/82 was perfectly fulfilled:

“La Regione del Veneto disciplina con la presente legge la ricerca e l’attività di cava nel proprio territorio al fine di conseguire un corretto uso delle risorse, nel quadro di una rigorosa salvaguardia dell’ambiente nelle sue componenti fisiche, pedologiche, paesaggistiche, monumentali e della massima conservazione della superficie agraria utilizzabile a fini produttivi.”

9. Attachments

9.1 Procedure for the gas-volumetric test

This test is one of the official test used in the soil chemical analysis. The aim is to calculate the carbonates content through the CO2 volume release from the sample treatment with the chloridric acid (HCl). The total carbonates content is express in terms of equivalent CaCO3.

The reaction that govern the process is defined as:

$$CaCO_3 + 2HCl \rightarrow CO_2 + H_2O + CaCl_2$$

In this way, knowing the CO2 formed it is possible to know the CaCO3 content; in fact for each mole of CaCO3 that reacts, one mole of CO2 is produced.

What is required to perform this analysis is:

- dry sample (dried in open air);
- the so called *"calcimetro"* with water saturated with CO2;
- thermometer to measure the environmental temperature;
- barometer.

The device used to perform the test is reported below:

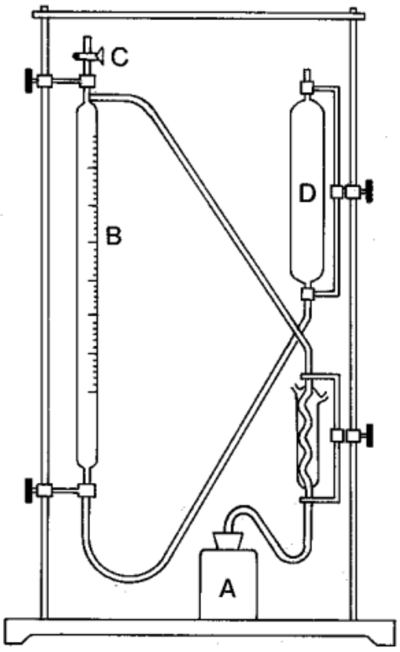


Figure 88. Dietrich-Fruhling device: A: sample container, B: graduated tube, C: valve, D: level tube

In the container A in which there is the soil sample, fine and dried place a test-tube containing the proper dilute solution of HCl. Collect this container with the calcimeter and reset the pressure by making equal the internal and extern pressure through the valve C. By moving the test-tube the chloridric acid enters in contact with the soil sample; the CO2 produced will decrease the water level in the tube B. After that produce a little depression by lowering the level tube D in order to achieve the complete formation of the CO2 by shaking the container A (the time depends on the specific type of soil studied). Finally make equal the pressures, internal and external, in order to achieve the same level in the tube D and B; consequently read the value of the CO2 volume produce

The CO2 volume must be standardized to the temperature of 0°C and to the pressure of 760 mm as Hg (101,325 kPa), i.e. standard condition. To do this the variables to be considered are: the CO2 volume determined, the atmospheric pressure, the temperature and the water vapour tension correspondent to that temperature derived from a table. The formula is:

$$V_0 = \frac{V_t(P_t - \varphi)273}{760(273 + t)}$$

where V0 is the volume of CO2 under standard condition expressed as ml, Vt the volume of the CO2 at the temperature and pressure of the analysis (ml), Pt the atmospheric pressure as mm of Hg under the condition of the analysis itself, t the temperature as °C of the analysis, φ the water vapour tension as mm of Hg. Typical value for φ are reported in the table below.

The equivalent calcium carbonate is measured from the this volume of CO2 and is then compared to the mass of the analytic sample. In fact the total carbonate content is expressed as g/kg through:

$$C = \frac{V_0 * 0.0044655 * 1000}{M}$$

where C is the total carbonate content, Vo the volume of CO2 formed under the standard conditions (ml), 0,0044655 is the equivalent gas-volumetric and M the mass of the fine soil sample used for the analysis (as g).

Obviously the method described is not perfect: some negative aspects exist about the dependence of the solubility of CO2 in HCl from the temperature which leads to a underestimation of about 10-20% for the soils with a carbonates content of 40-60%, 2% respectively. Another drawback concerns the fact that the production of the CO2 can take place also from the treatment with HCl of the organic compounds.

Table 16. Water vapour tension for different temperature

Temperature °C	Water vapour tension mm of Hg	Temperature °C	Water vapour tension mm of Hg
10	9,2	23	21,1
11	9,8	24	22,3
12	10,5	25	23,7
13	11,2	26	25,2
14	12,0	27	26,7
15	12,8	28	28,4
16	13,6	29	30,0
17	14,5	30	31,8
18	15,5	31	33,7
19	16,5	32	35,7
20	17,6	33	37,7
21	18,6	34	39,9
22	19,8	35	42,1

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