EXCAVATION OF TUNNELS: SEISMIC METHODOLOGIES FOR THE SOLUTION OF GEOMECHANIC PROBLEMS

РАЗКОПКИТЕ НА ТУНЕЛИ: СЕИЗМИЧНИТЕ МЕТОДИКИ ЗА РЕШАВАНЕТО НА ГЕОЛОЖКИТЕ И МЕХАНИК ПРОБЛЕМИ

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ABSTRACT:
The increasing diffusion of the seismic methodologies has allowed in the last years to resolve some problems connected with the planning and the digging of tunnels. In the note they will be illustrated the contributions for the exploration with the reflection and refraction seismic methods in to define the geomechanical profile of the galleries and the thickness of the rock weakened following the digging. The requirement of to know the geological structure and the lithology of the rocks in progress on the excavation of the tunnels, always has demonstrated like a prevailing element in phase of construction of the same tunnels. To reduce the "geological surprise" in the phase of planning of the galleries are asked researches even more detailed until to the realization of the horizontal perforations long the board of progress or of the "tunnel pilot". The geophysics survey, which more often is used in preliminary phase of research, has gone evolving, species in the employment of the seismic reflection to high resolution and in the different application of the seismic refraction for the study of the geological profile long the board of the tunnel. The text will be documented some applications carried out for the design of tunnels also characterized by a considerable thickness of the overburden.

Keywords: tunnel, seismic reflection, TSP, seismic refraction, inelastic attenuation, tomography.

РЕЗЮМЕ:

Нарастващото разпространение на сеизмичните методологии позволи през последните години да се решат някои проблеми, свързани с проектирането и изкопа на тунелите. В записката ще бъде илюстриран приносът, който сеизмичните методи чрез отражение и пречупване имат при повърхностното и дълбоко изследване при определяне на геомеханичния профил на тунелите и на дебелината на отслабената скала след изкопа.
Необходимостта от опознаването на геоложката конструкция и литологията на скалите по време на изграждането на тунелите винаги е била основен елемент на етапа на строителство на тунелите. За да се намали "геоложката изненада" на етапа на проектиране на тунелите се изисква аналз с още по-големи детайли. Общото геофизичното изследване и по-специално сеизмичното изследване с отражение и пречупване все по-често биват изпозвани в смесен вариант (хибридно сеизмично изследване) не предварителния етап на проектиране, като все повече еволюират, достигайки днес висако степен на надеждност. Текстът илюстрира някои приложения на сеизмични изследвания, изпълнени при проектирането на тунели, които вече са построени, в условия на променлив геоложки състав и определено покритие.

Ключови думи: тунелни, сеизмична размисъл, TSP, сеизмична рефракция, нееластично затихване, томография.

1 INTRODUCTION

The requirement of to know the geological structure and the lithology of the rocks in progress on the excavation of the tunnels, always has demonstrated like a prevailing element in phase of construction of the same tunnels. To reduce the "geological surprise" in the phase of planning of the galleries are asked researches even more detailed until to the realization of the horizontal perforations long the board of progress or of the "tunnel pilot". The geophysics survey, which more often is used in preliminary phase of research, has gone evolving, species in the employment of the seismic reflection to high resolution and in the different application of the seismic refraction for the study of the geological profile long the board of the tunnel. Both methods brought good results as regards the definition of the structural set up present in the area of study. In general the survey with the seismic reflection technique allows us to reach greater depths with substantially similar configurations, while the seismic refraction technique allows us to come to a more precise definition of the portion of the section nearest to the surface, where seismic reflection is less sensitive. However, a verification of the model with the two seismic methods allows us to better relate the geological structures interpreted at a depth with the surface outcrop and to verify the speed analysis adopted for the interpretation of the seismic reflection. The seismic speeds calculated with seismic refraction may also be used directly to estimate the degree to which the rock in the tunnel can be excavated.

2 SEISMIC SURVEYS – LOW COVERAGE

For the planning of tunnels characterized by low coverage (maximum depth of investigation 150-300 meters) one of the most commonly seismic survey method used is the seismic refraction approach interpreted with GRM and tomographic technique. Figure 2 shows a high-resolution seismic refraction survey 3.000 meter long conducted for the excavation of the new headrace tunnel for the Crevola Toce III hydropower scheme in an area located between the valleys of the Toce and Diveria rivers. From the geological point of view (Figure 1), the area of the headrace tunnel was very complex. In particular the bedrock is composed of a series of gneissic crystalline nappes interlayered by metasediment units originally corresponding to the triassic-cretaceous sedimentary cover of the crystalline crust. The tunnel path runs mainly through gneiss and metasediments (average thickness around 70 meters) composed of a lower gypsum-anhydrite layer locally with micaceous content, fractured marbles and calcschists, and sugary carbonate horizons with characteristics of soil. To better define this complex geologic structure, intersected also by a deep-seated gravitational slope deformation (DSGSD) with a thickness of 180-260 meters, an high resolution seismic refraction profile was executed parallel the tunnel axis, together with VSP tests into some geomechanical holes about 400 meters deep drilled near the alignment.

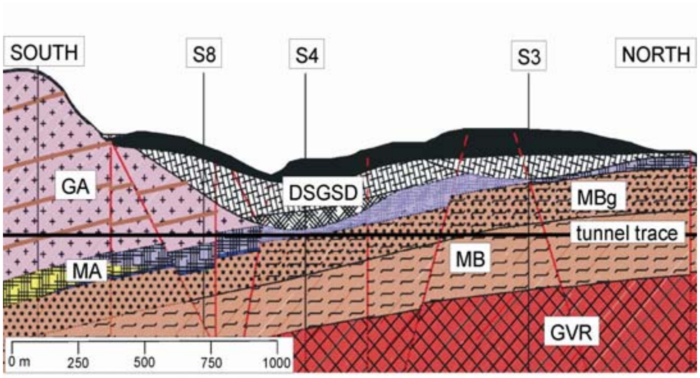


Figure 1. Geological cross section. This interpretation was done before the main geophysical survey was performed DSGSD: Deep Seated Gravitational Slope Deformation (involved terrains: black: moraine deposits,light hatch: Antigorio gneiss; heavy hatch: metasediments) ; GA: Antigorio gneiss; MA: metasediments; MBg: garnet-rich Baceno micaschists; MB: garnet-poor Baceno micaschists; GVR: Verampio gneiss. The location of the three boreholes are also indicated.

Based on the geophysical model, a geological profile of the tunnel was published (Fig. 3), indicating:

a) The DSGSD cover (upper central zone of the section) with discontinuities and/or secondary slip surfaces within it;
b) The lower DSGSD earth flow (or "bed") generally affects the "Gneiss di Antigorio" (GA) and also the metasedimentary sequence over a 200 metre thickness. In any case, this surface never reaches or comes close to the altitude of the tunnel;
c) In the "Gneiss di Antigorio" and in the "metasedimentary sequence" various discontinuities and system of faults have been revealed.

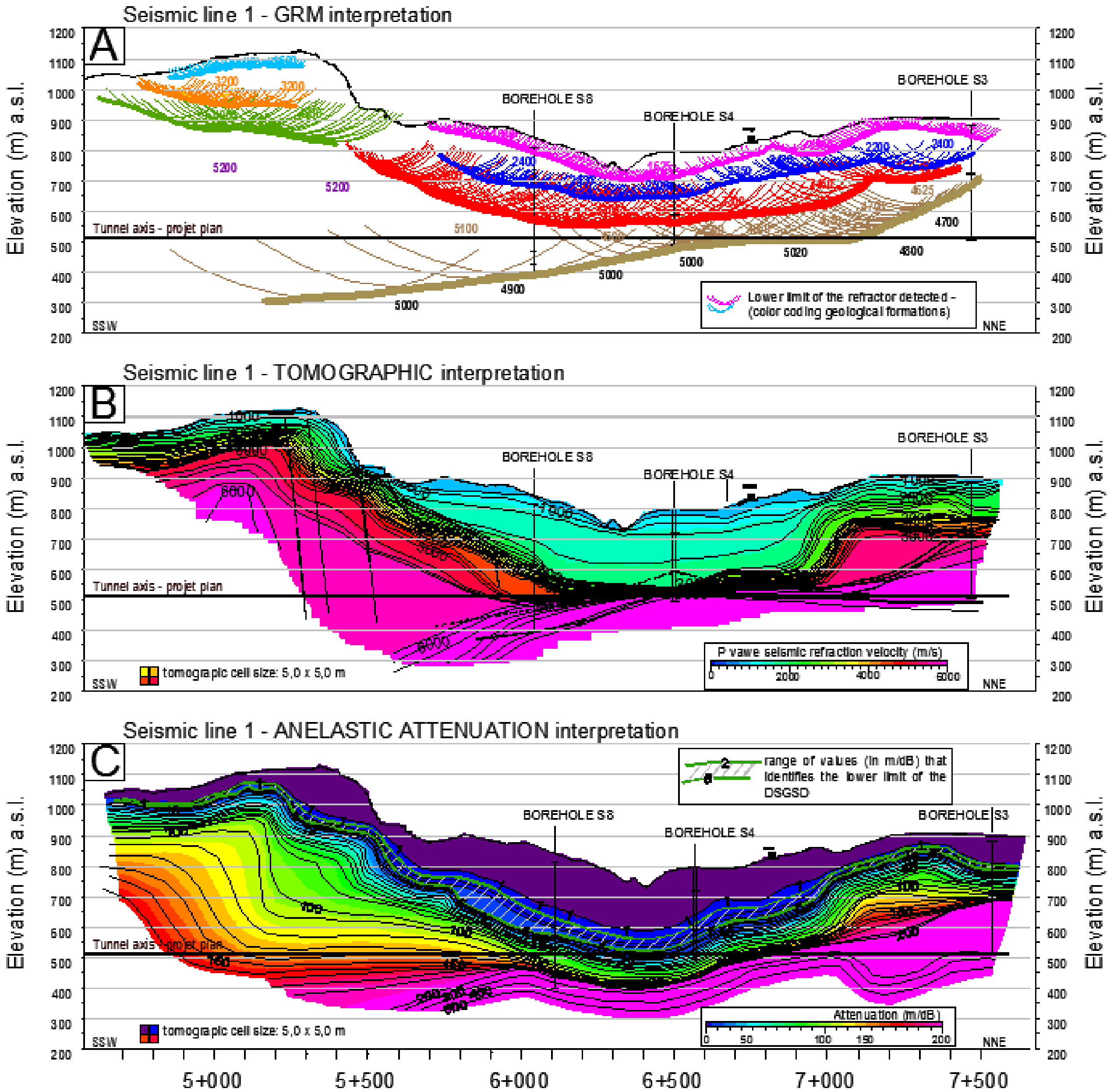


Figure 2. Seismic line 1: A Interpretative Section GRM, B Seismic refraction tomographic section, C Anelastic attenuation elaboration. In the refraction technique only the initial arrivals of the P or S waves are studied. The transit times are associated with the mechanical characteristics of the rocks, more tenacious a rock is, then higher the seismic speed of the lithotype involved in the passage of the seismic wave. About the tomographic method, this approach involves the sub-division of the bi-dimensional space into cells, according to a pre-established grid, with the attribution of a determined seismic value to each grid section. The interpretation of the seismic refraction was aimed at characterising the soils by means of the parameter of seismic speed, defining seismic speed ranges for the various lithotypes with reference to the geological knowledge of the site in question. Referring to anelastic attenuation, in this case is analysed the attenuation of the amplitude values, that at the end carry out a parameter describing the rock qualities.

3 SEISMIC SURVEYS – HIGH COVERAGE

For the planning of tunnels characterized by high coverage (maximum depth of investigation 300-600 meters or more) the most commonly seismic survey method used is the seismic reflection technique (Assida Y. 2001). Figure 4 shows a high-resolution seismic reflection profile done for the planning of the connecting road of the A4 with the Lumezzane (BS) industrial area. The territory in question is essentially part of a valley floor area within the southern pre-Alpine zone of Brescia, slightly north of the border with the upper Pianura Padana.

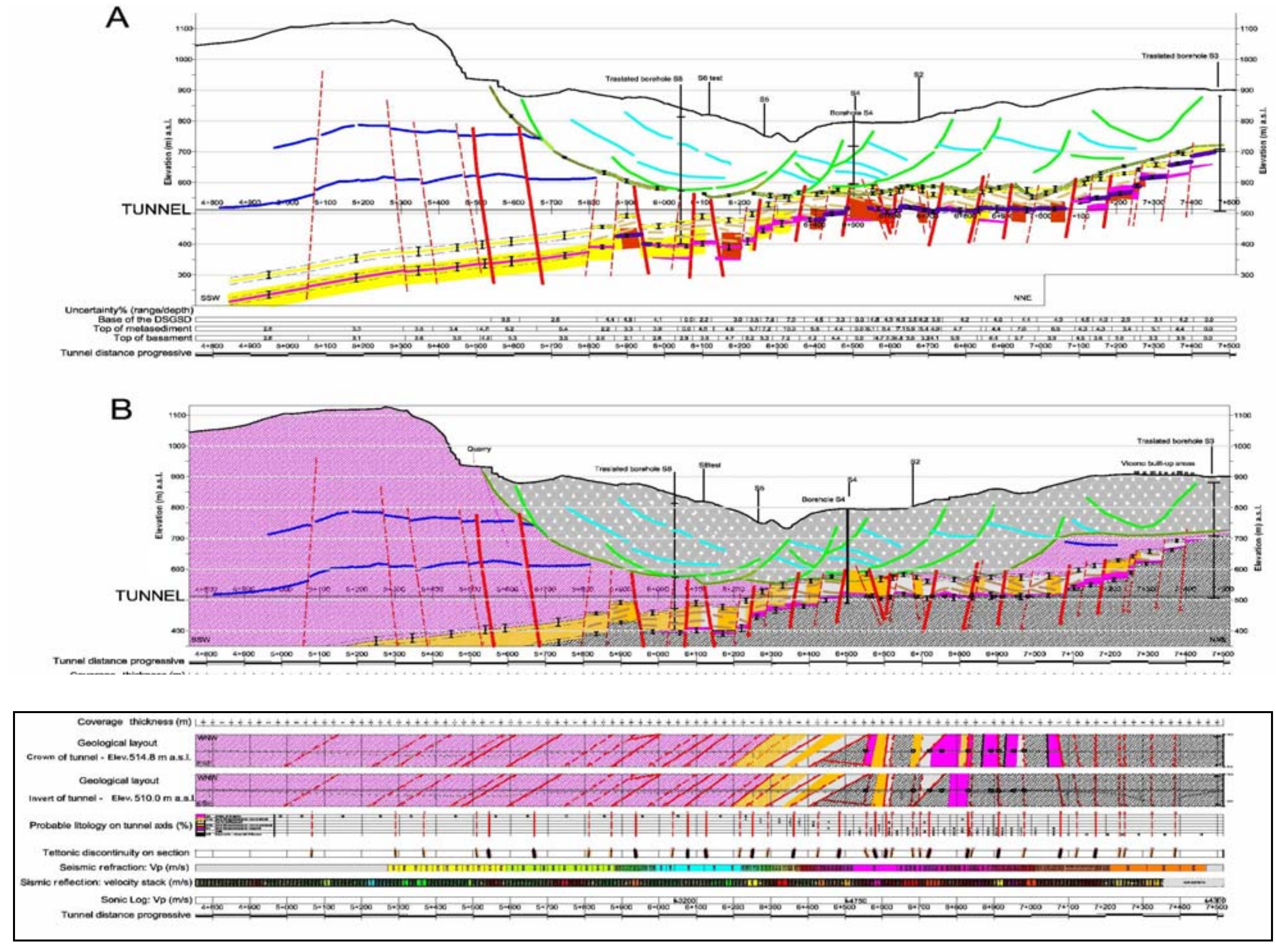


Fig. 3. Geophysical (A) and geological-structural (B) models of the tunnel profile. The lower part of the figure from top to bottom shows the following elements: 1)Thickness of the tunnel cover (in meters); 2)Layout of geological structure at the tunnel crown; 3)The probable lithology on the tunnel axis. 4)The tectonic discontinuities identified in the section; 5) Seismic velocity Vp; 6)Seismic stacking velocity obtained from seismic reflection; 7)Sonic velocity values, in m/sec, recorded ;during the three deep geognostic surveys.

The pre-alps of Brescia in particular are part of the Lombardy Basin, a subsident sector identified in the Late Triassic period and active throughout the entire Tethyan rifting period, in which imposing sedimentary successions were deposited within the sub-basins controlled by a lively distensive tectonic activity. The purpose of this study was the definition of the tectonic and stratigraphic model of an area characterized by high thickness rocky mainly of limestone. The seismic reflection method was implemented to obtain a picture of the structural setting of relevant layers, and therefore their geometrical relationships. This method is mostly used in petroleum exploration, and it is credited of a detailed insight capability due to data acquisition redundancy, as compared to other geophysical techniques. To achieve good results with this method, a 3-steps procedure must be implemented: a) it is mandatory to carefully plan the seismic acquisition field layout, as a function of target depth, 3D structural setting, relevant petro-physical parameters and surface morphology; b) a complex data analysis sequence, referred to as "Data Processing" must be performed on field data, in order to get a final seismic section which is the output of this survey technique; c) the final seismic section, which is a distance to two-way-traveltime section, must be interpreted, to get a geological distance to depth section. The results of the interpretation phase depends largely on the interpreter's experience and on the availability of other information, like surface rock outcrops and borehole stratigraphy, to get a proper tie with the geological setting. Interpretation normally is carried out on Two-way-time migrated seismic section, with the aid of average and interval velocity plots. Lateral variations of velocity were especially used to confirm faults interpretation and fault blocks imaging. Interpreted horizons were based on surface geology and controlled by parallelism with the relevant marker. Depth conversion was done for each section with a constant velocity function.

The seismic section shows a progressive upcoming of layers northwards, that causes the progressive subcrop of deeper and older stratigraphic terms. Interpreted faults appears to be concentrated mostly in two tracts of the profile, in the middle part e near the north end. Velocity data shows the presence of a low velocity zone near the northern end of the profile, having a thickness of about 150 m from surface, a feature that could evidence the presence of a highly fractured rock assemblage.

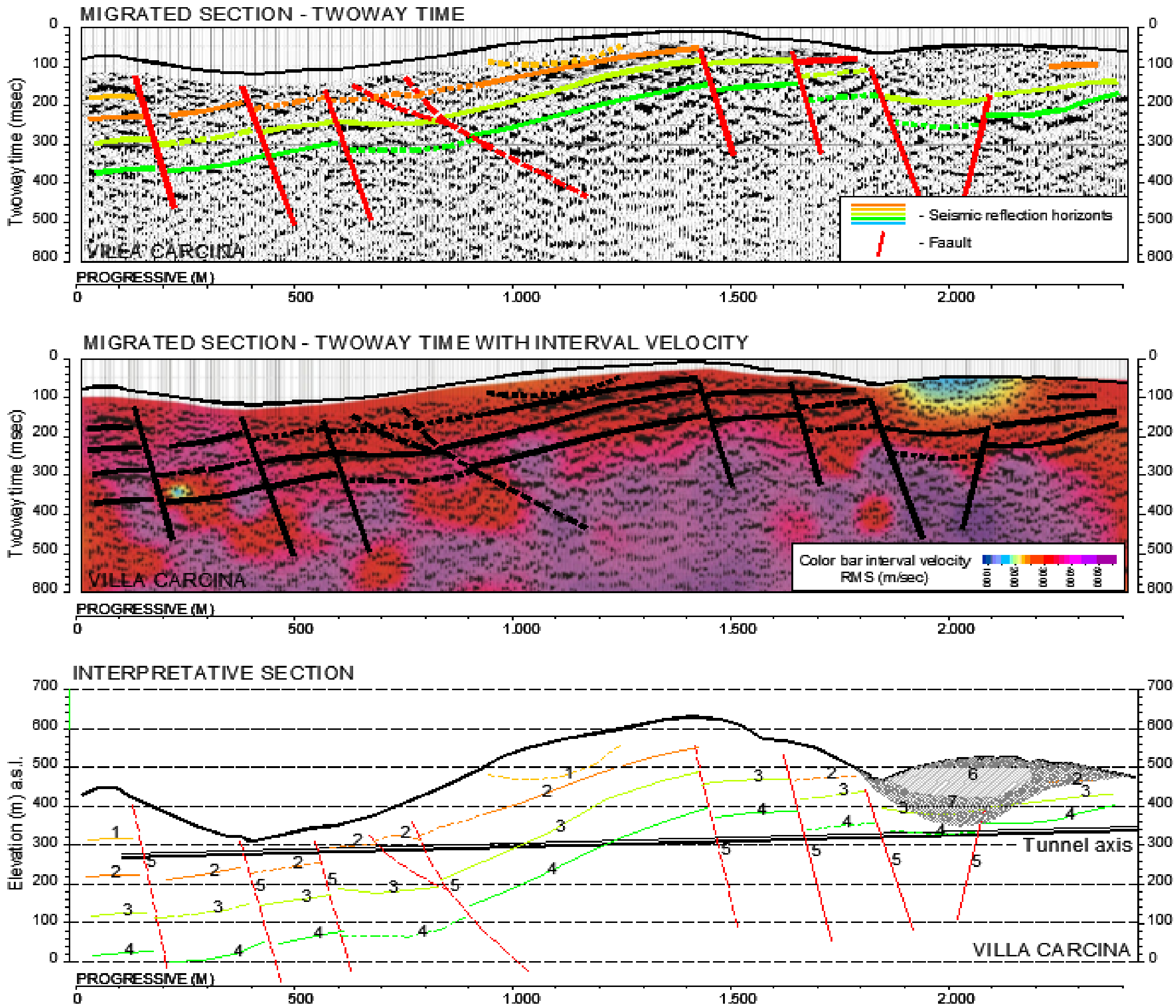


Figure 4. Villa Carcina Tunnel: seismic reflection profile and interpretative section. Legend: 1) 2) 3) 4) - seismic horizons; 5) - faults; 6) 7) - velocity anomaly. Villa Carcina Tunnel : This profile is characterized by a large depth from surface of the planned tunnel position.

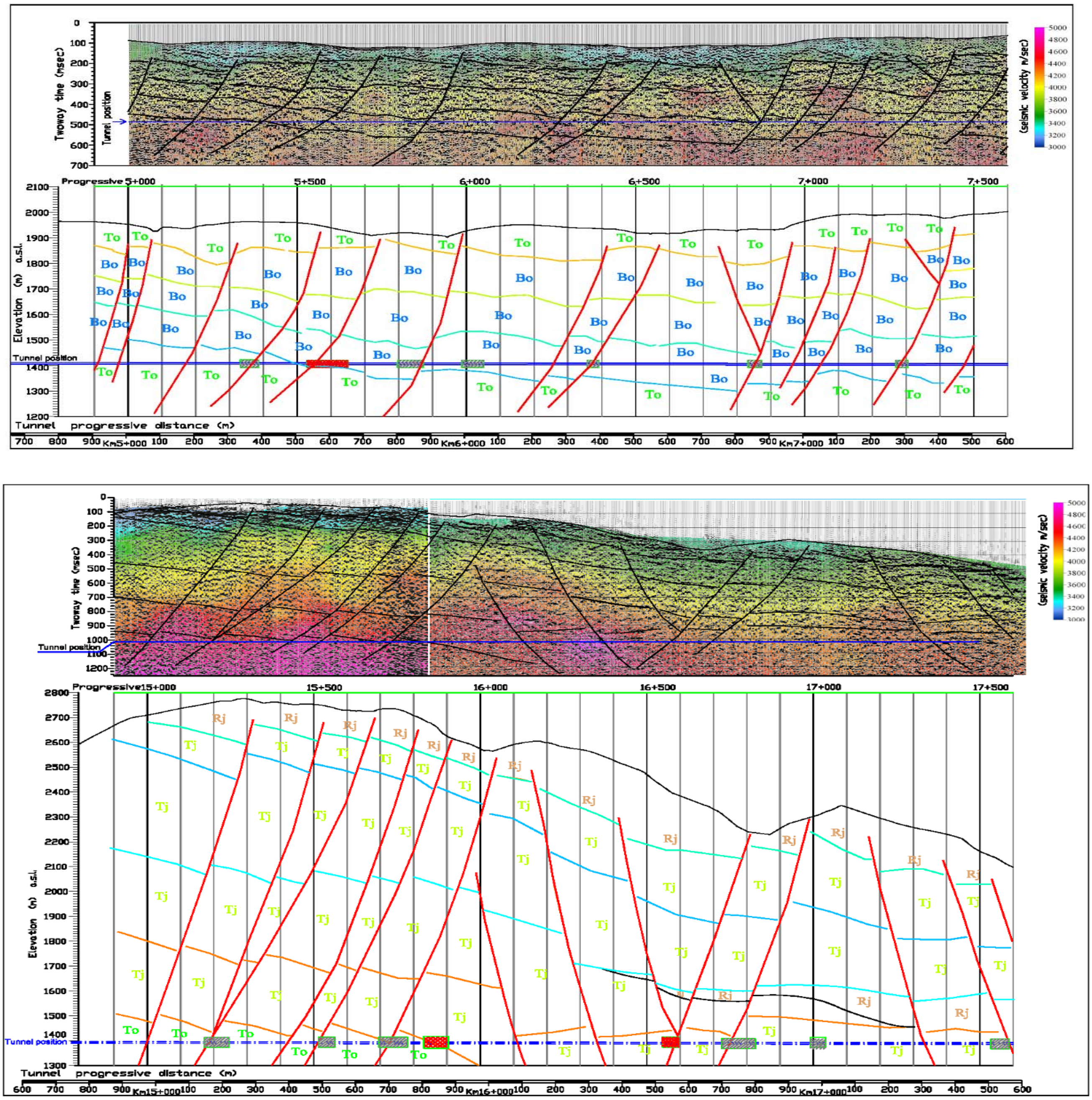
For the analysis of seismic reflection data, the following process was adopted:

PHASE 1
Pre-processing
-conversion format
-geometry input
-trace killing

PHASE 2
Shot data processing
-RMS gain
-Spectral analysis
-Band pass pre-filtering
-Resampling
-Band pass filtering
-Exponential gain
-Mixing
-"spiking" deconvolution
-AGC gain
-Muting
-Band pass filtering
-Sorting

PHASE 3
CDP data processing
-Pre-stack phase
-aerated static corrections
-analysis of velocity
-Normal Moveout correction
-residual static corrections
Stack
-C.D.P. summation (stacking)
-reduction to common datum
-RMS gain
-Post-stack phase
-Migration
-mixing

PHASE 4 :
-Complex attributes



FORMAZIONI	*Lithologies reference*	Code		AGE
VULCANITI DI OMO (OF)	– *Basalts* – *Basalts and* – *trachiti* – *Trachiti*	Bo BTo To	1,2,3,7,8,1 0 4, 9 12, 13	Miocene Oligocene inf.
VULCANITI DI JIMA (JF)	– *Rhyolites* – *Trachiti* – *ASH*	Rj Tj Aj	14, 15, 17 12, 13 5, 6	Miocene Oligocene sup.
DICCHI E LACCOLITI (VI)	– *Dolerti* – *Dicchi*	Dol D	11 16, 18	Miocene sup.
VULCANITI DI WOLLAGA (WF)	– *Basalts* – *Basalts and trachiti*	Bw Bt	1 9	Miocene sup. Pliocene inf.
IGNIMBRITI DEL RIFT	– *Rhyolites* – *Andesite trachite*			Pliocene Quaternario inf.

Table 1: Sequence stratigraphy of the area. Abbreviations and numbers have been used for the identification of lithologies in the following tables and in the figures.

VULCANITI DI OMO (OF)		VULCANITI DI JIMA (JF)	
Hard Basalt	1	Rhyolite	14
Fractured Basalt	2	Breccia rhyolitesca	15
Basalt amigdaloide	3	Breccia rhyolitesca with tufi	17
Compact Clay	7	Trachite	12
Basalt scoriaceo	8	Trachite with clay	13
Basaltic fills and alteration	10	Tufi compact	5
B.O. + T. Basalt	4	Priclastiti tufacee	6
Basalt / breccia trachitica	9		
Trachite	12		
Trachite with clay	13		
DICCHI E LACCOLITI (VI)		**VULCANITI DI WOLLAGA (WF)**	
Dicchi doleritici	11	Hard Basalt	1
Rhyolite porfiridica / micro granite	18	Basalto / trachite	9
Sienite	16		

Table 2. lithologies encountered in the excavation of the tunnel, related with the formation of belonging (Table 1).

Figure 5. Homogeneous traits of the seismic profile: between the progressive 2 + 7 + 500 and 900 km (top), and between the progressive 14 + 750 and 17 + 600 km (bottom). Above, the "seismic section migrated in times" with superimposed by means of colorimetric scale, the trend of the speed of the stack; in the lower section interpreted in depth are highlighted where the tectonic lineations identified, the contacts lithological (abbreviations are those of Table 1 and 2) and also shows the position of the tunnel under construction. highlighting the critical areas generally associated with detensioning rock (rectangles) caused by the intersection of tectonic lineations and intersection lineations with lithological contacts with unfavourable arrangement.

Figure 5 shows a high-resolution seismic reflection profile done for the planning of the headrace tunnel with very high coverage (700 to 1200 meters) of a hydropower scheme placed in Gilgel Gibe II in Ethiopia. The hydraulic tunnel was realized through the advancement of two TBM and affected only the effusive volcanic soils due to various events that have characterized the magmatism of the "Ethiopian Rift." The profile seismic reflection performed in correspondence of the 'axis of the tunnel has allowed us to reconstruct the structure of the subsoil and the position of the tectonic discontinuities that could affect the advancement of the two TBMs. The systematic execution of seismic testing TSP in progress on the excavation face has allowed then to validate the model inferred from seismic executed surfaces. The comparison of the predictive phase and the results of the excavation, the tunnel being now completed, has allowed us to effectively evaluate the seismic reliability of these methodologies. The use of this seismic survey for the reconstruction in the depths of the geological profile of a tunnel (Cravero et al., 2000), it appeared quite innovative in the panorama of investigations for tunnels, because, very often, you advance the TBM having a little information available and addressing problems after they have occurred.
For the reconstruction of the geological profile of the hydraulic tunnel Gilgel Gibe II hydroelectric plant, in relation to the large thickness of the overburden, was used seismic reflection; extreme accuracy in the experimental recordings and the subsequent processing of the data, has allowed us to give to the new geological profile, a decidedly high precision. The combination of the results of stratigraphic and tectonic elements, obtained with the usual interpretation, with the values of the "speed interval", obtained from seismic reflection profile through special processing, has allowed us to produce a new model in which the areas have been highlighted characterized by detensioning rock. These areas of potential criticality have also been investigated systematically, when the front was located in the vicinity of the same, with the seismic methodology TSP. Subsequent excavation of the tunnel has always allowed the verification of the exact location of the discontinuity identified and assessed in relation the high number of tests, the reliability of this new seismic methodology. The verification, with the subsequent advancement of the excavation face, the discontinuities identified by the TSP (an example in figure 7), allows to infer, both for those classified as "certain" both for those deemed more "uncertain" in relation to the reflection of the seismic signal, that 75% of the scheduled events was actually encountered during excavation. Events actually occurred 50% fell within the tolerance range (± 5 meters for the near and ± 10 meters to more distant ones), while about 20-25% had a gap of a few meters with respect to the above-mentioned range accuracy. These findings testing have also pointed out, in the case of effusive volcanic rocks, a propensity methodology TSP to identify discontinuities related to variation index RMR of the rock against faults and lineations. The excavation works were completed in June 2009 and the hydroelectric plant was started October 1, 2009.

4 TUNNEL SEISMIC PREDICTION (T.S.P.)

Knowledge about rocks characteristics beyond the excavation face of tunnels has always been part of underground engineering research (Ashida 2001). The seismic reflection technique known as T.S.P. (Tunnel Seismic Prediction) used for exploration on the excavation face of tunnels, is the evolution of the original V.S.Pp. technique (Vertical Seismic Profile prediction), used in wells for hydrocarbons (Figure 5a). The T.S.P technique reduces "geological surprises" to a minimum, allowing for detailed prior verification of critical zones, previously identified by standard geotechnical and geomechanical tunnel profiles (Kneib 1999 ; Kneib et al. 2000; Baldi et al. 1999; Baldi et al. 2006). Briefly, the aims of the T.S.P. method are:

- To provide advanced geological prediction for 100 meters ahead of the tunnel face and up to 150 m in hard rock masses;
- it also reduces to a minimum the need for sub-horizontal drilling,
- To provide an evaluation of the mechanical properties of the rock ahead the face;
- To avoid entrapment of TBMs.

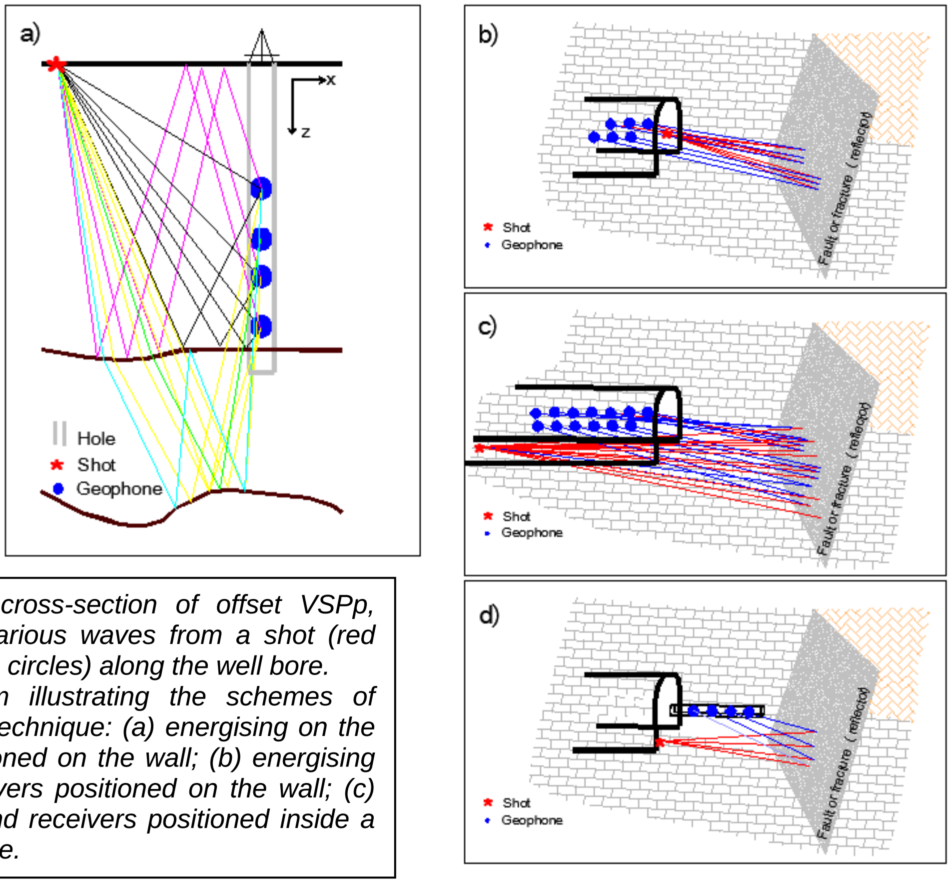


Figure 6a. A sketched cross-section of offset VSPp, where ray paths show various waves from a shot (red star) to the receivers (blue circles) along the well bore.
Figure 6 b-c-d. Diagram illustrating the schemes of acquisition in the T.S.P. technique: (a) energising on the face and receivers positioned on the wall; (b) energising far of the face and receivers positioned on the wall; (c) energising on the face and receivers positioned inside a sub-horizontally drilled hole.

T.S.P techniques are based on the recording of seismic traces near the hole. Frequency characteristics and processes are similar to those of near-surface seismic reflections, without disturbances associated with surface waves. The acquisition method consists in energising on the face of the excavation in progress (Figure 6c – 6d) or at a certain distance from it (Figure 6d), and in the reception of signals transmitted by geophones which can be positioned on the walls of the excavated tunnel (Figure 6b-6c) or positioned inside a sub-horizontally drilled hole at the tunnel face. The first event to reach the geophone is the direct wave associated with the linear path between the shot point and the geophone. Subsequent signals are reflection events, with their beats and reverberations (the so called multiples). Figure 6 shows a TSP executed in a hydraulic tunnel GIBE II (Ethiopia). Effusive volcanic complexes are generally characterised by a chaotic deposition, and their resistance properties sometimes differ even within an extremely limited space. Extending the use of the TSP methodology to excavated tunnels in this type of soil poses a series of problems as compared with previously discussed sedimentary rocks, insofar as reflective horizons are predominantly associated with various conditions of rock rigidity, in terms of lineaments and/or faults. Application with geophones placed at the far end of the tunnel, with energising carried out at the far end (classic configuration): during the excavation of a hydraulic tunnel in Ethiopia (Figure 5), 57 TSP tests were carried out systematically along the entire tunnel (26 km), revealing over 350 discontinuities (Baldi et al. 2011). The analysis (figure 7) revealed critical zones and/or discontinuities to which a tolerance band was always attributed, varying not only in relation to the distance from the excavation face, but also in relation to the intensity of the recorded seismic signal; this tolerance band was generally between ± 8 – 15 ml. Subsequent excavation using a TBM confirmed the reliability of predictions, with the results reported in table 3:

Table 3:

discontinuities considered	% inexistent	% outside band	% centred
certain	25	26	49
uncertain	27	19	54

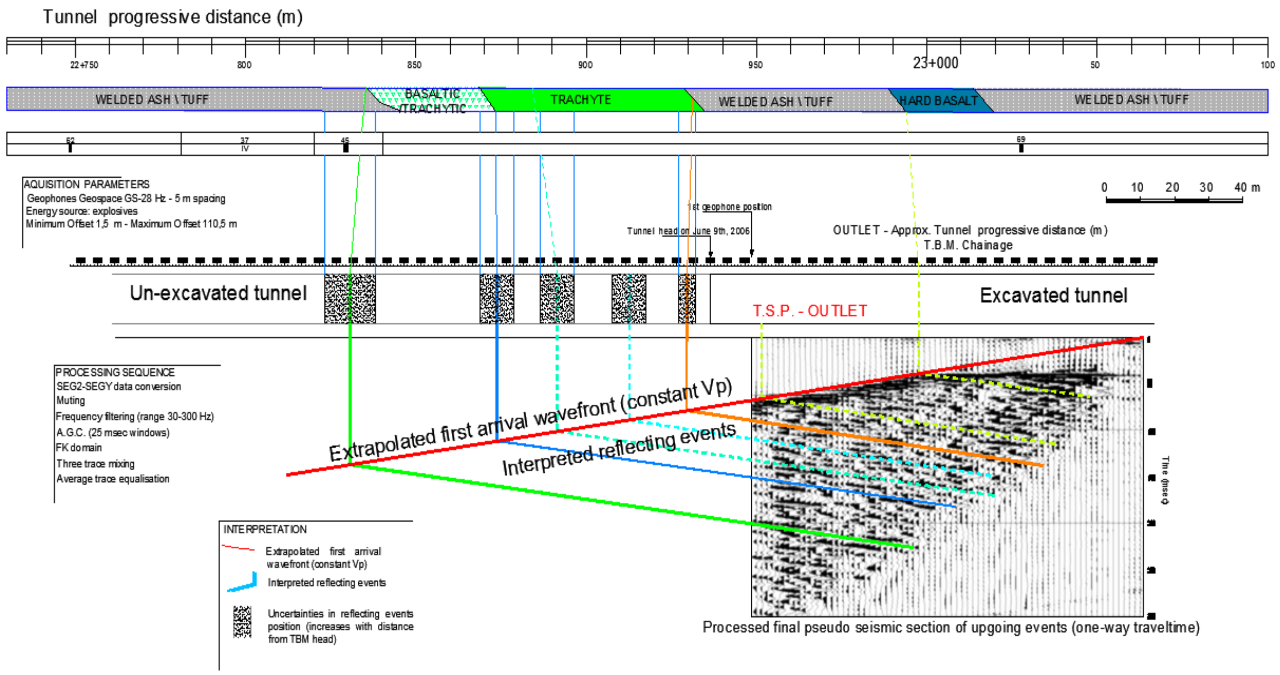


Figure 7. T.S.P. in effusive volcanic rocks for an hydraulic tunnel in Ethiopia with TBM. Results of the elaboration with the identification of the discontinuities.

Through the examination of the discontinuities confirmed by the results of the excavation, it has therefore been attempted to analyse whether the same discontinuities can be correlated with lithologic and/or tectonic factors, or rather with the changed mechanical properties of the rock (RMR index). The results of such analyses showed that resolving power proved higher for correlations associated with rock type (RMR index), as compared to correlations associated with lithologic differences or tectonic lineaments.

5 SEISMIC BOREHOLE ON THE TUNNEL'S AXIS

The execution of the seismic core boring with methodology tomographic cross-hole, also set to notable distance, integrated with other geophysical methods, it allows the reconstruction through an exact geologic and geomechanic profile of the grounds along the axis of a tunnel. The examples of application explained in the note show a geophysical research during the phase of a tunnel's planning. In the first example (Figure 8) the plan of the geophysics research included the execution of arrays of seismic reflection and refraction together with the seismic core boring. Particularly they were performed 10 vertical surveys long the plan of the tunnel with depth between the 20 and the 140 meters. The seismic reflection survey had the task of verifying the structural disposition of the formations in the downtown, where is not possible a check of surface, and to identify zones to high indicator of invoicing connected to tectonic events. The seismic tomographic section (Fig.8) is the result of some cross-hole performed between couples of boreholes and between these and the surface. The measurements of seismic velocities have been performed in two phases: the first with a receiver cable located in all the boreholes and shooting from the surface in several points, in order to obtain a high coverage; in the second recording phase the receiver cable was located in a borehole and shooting at the same depths in the other borehole (cross-hole technique). Field data have been interpreted with tomographic methodology, thus defining by this way a model represented by a seismic section subdivided into to a mesh with squared cells having side of 4,8 meters. The mesh size selected was achieved after some preliminary interpretations which allowed verifying that all of the cells had a good seismic coverage. P-waves velocity calculations were performed with a tomographic algorithm that creates a model of seismic velocity distribution by the calculated transit times and compares them with the experimental values. Testing each possible model velocity of each single cell, it is possible to obtain an optimised model, where the least error on transit times is record. The transit times calculated follow the classic wave propagation laws within non-homogenous media.

This section was a good indicator of the mechanical characteristics of the rocks and can be taken in consideration to predict the performance of the main parameters of operation of the TBM (Tunnel Boring Machine).

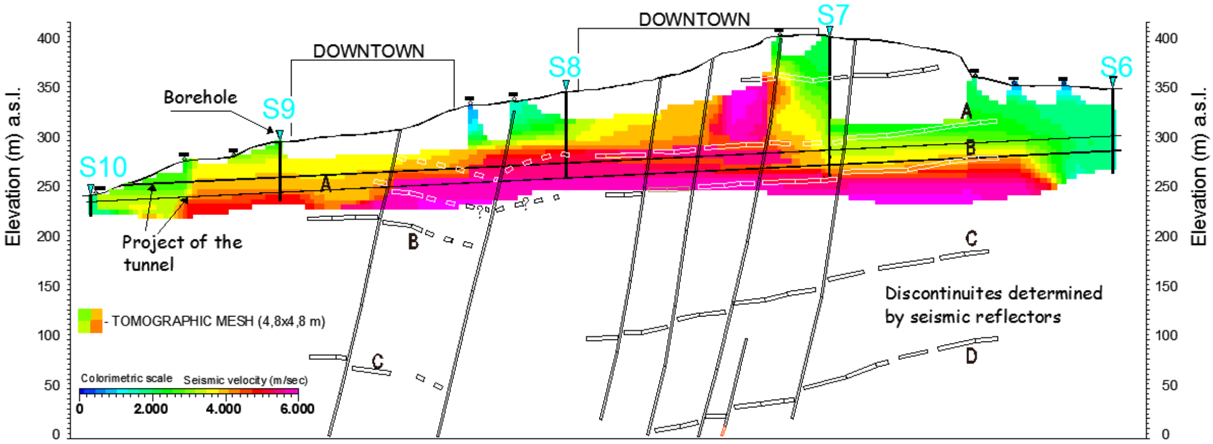


Figure 8: results of tomographic methodology and seismic reflection for the definitive project for the redoubling of the S: S: n°47 Valsugana (Trento, Italy).

Figure 9 shows a section performed long the board in project of a new railroad tunnel with the purpose of to rebuild the thickness of the blankets slackened superficial and to determine the depth of the bedrock. The measures of seismic velocities to the inside of the core boring were performed through the execution of a seismic core borehole with methodology cross-hole. Because of the considerable distance between the boreholes, a seismic refraction profile was realized joining themselves. The acquisition of the geophysical data was realized simultaneously in surface on the geophones of the array and in two hole of survey across two chains of three-dimensional geophones. This new technical of application allowed in this way to carry out an elaboration joined of all seismic data refer to the profile on axis of the tunnel and to guarantee so a greater detail of the tomographic interpretation. To completeness of the researches (Fig. 9) were performed specific seismic acquisitions of type Re.Mi. (Refraction Microtremor), with which was possible then to determine the geophysical model of the ground, regarding the S-waves' propagation. The results emphasized a not negligible thickness, of the order of 10–15 meters, of grounds slackened superficial (a). Besides, the interpretation carried out agreed to define the course of the solid substrate, emphasizing so inside them likely zones of alteration (b1, c1, c2, d1, d2).

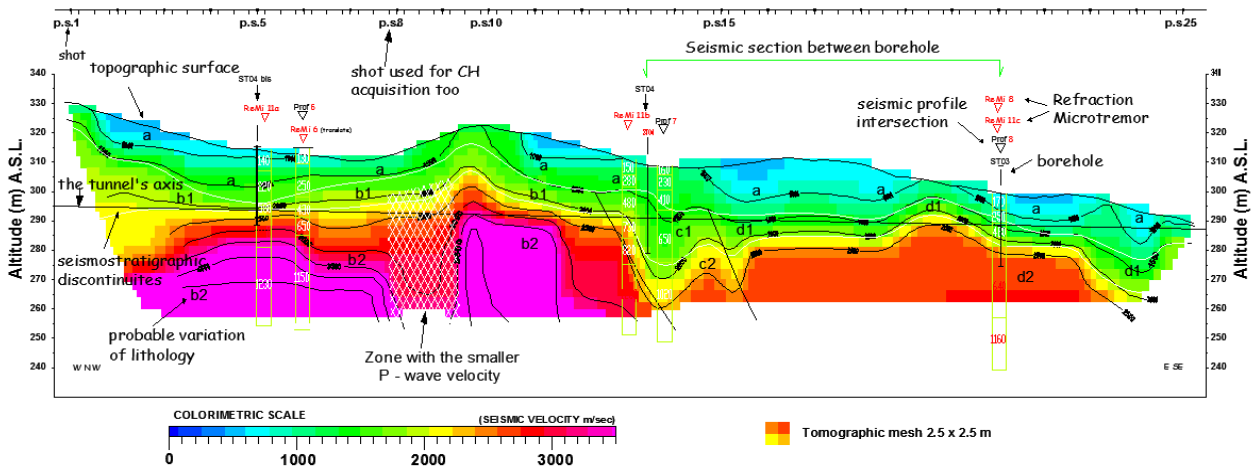


Figure 9: results of cross-hole methodology and Refraction Microtremors technique for infrastructural development of redoubling the Orte-Falconara railway (Italy). Field data have been interpreted with tomographic methodology, thus defining by this way a model represented by a seismic section subdivided into to a mesh with squared cells having side of 2.5 meters.

6 SEISMIC BOREHOLE INTO TWO TUNNELS

Figure 10 shows the geophysics investigation consisting in acquiring measures of seismic velocities inside two canes of a road tunnel. The measures of velocities have been executed inside 6 couples of mechanical borehole and on the ground portion placed between the two canes of the road tunnel for a stroke of 50 meters. In particular the jobs have developed with the execution of seismic core boring (cross-hole) for the characterization of the ground place outside the covering of the tunnel in building, through the velocity parameter of the p-waves. The mechanical boreholes placed on the wall of covering of the tunnel to about 3 meters of height by the field plane, had been horizontally pierced and had depth between the 10 and the 17 meters. The measurements of seismic velocities with tomographic methodology have been performed in two phases: the first with a receiver cables located contemporaneously in couples of boreholes and shooting from the surface in several points, in order to obtain a high coverage; in the second recording phase receiver cable was located into a borehole and shooting at the same depths in the other borehole (cross-hole technical). The execution of the seismic measures of velocity between the walls of two pipes of the gallery was carried out with the classic methodology of the seismic refraction. In practice 24 geophones were positioned with wheelbase of 2 meters on the wall of covering of a pipe of the tunnel and 24 geophones, always with wheelbase of 2 meters, were positioned on the wall of covering of the opposite pipe. For the acquisition it was used a seismograph with 48 channels. Field data have been interpreted with tomographic methodology, thus defining by this way a model represented by a seismic section subdivided into to a mesh with squared cells having side of 0,4 meters. The results (Fig. 10) have allowed a detailed definition of the mechanical features of the grounds. The tomographic interpretations of the all couples of seismic boreholes puts in obviousness the presence of a superficial part with low seismic velocities that can referred with the part of the rocks relaxed after the excavation of the tunnel. There is the presence of grounds marked by seismic velocities inferior to 2.000 m/sec that can be associated to the polygenic breccia into the couples of boreholes S3-S4-S5-S6. The seismic section between the walls of the tunnel performed to investigate the grounds places between the two pipes of the tunnel in construction puts in obviousness a seismic difference of velocities between the pipe made with reinforced cement and the pipe made with spritz-beton. In fact, while in the first one the seismic velocities reach always values superior to 3.000 m/sec on the second one the seismic velocities reach always values inferior to 2.000 m/sec.

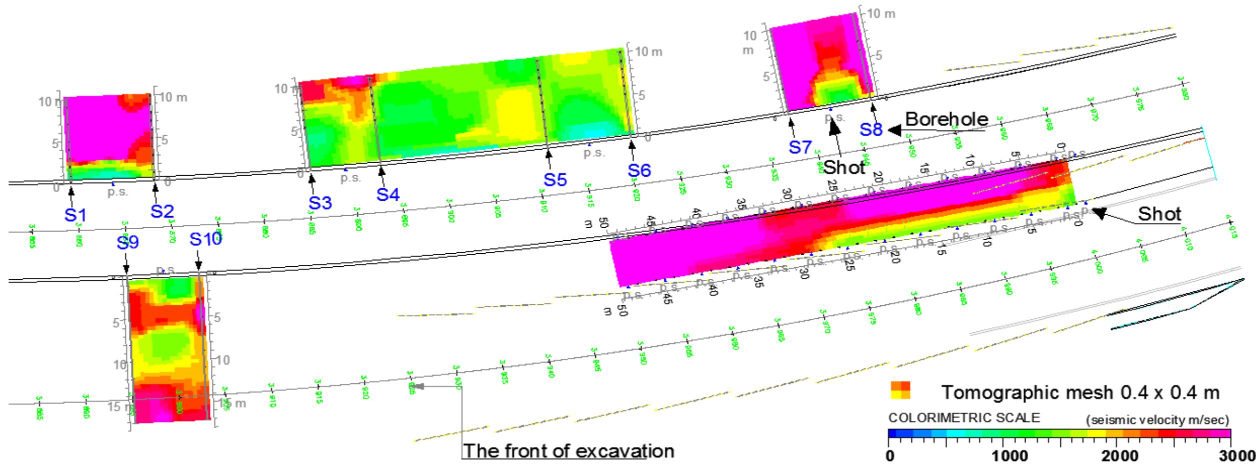


Figure 10: results of seismic boreholes into a tunnel (executive project for the redoubling of the S: S: n°47 Valsugana - Trento, Italy).

Figure 12 shows the results of a geophysical campaign performed inside a highway tunnel called Melide-Grange in Swiss territory. The campaign geophysics has interested both the tunnel tubes and was performed in support of the executive project for the construction of a mini tunnel technician, to be carried below the existing two barrels. Prospecting work were conducted using the methodology of the shooting seismic velocity between the two tunnel tubes (Fig. 11), and also running a registration with seismic refraction line on the same alignments; these arrays were placed inside the gallery. 3D receivers was put on the wall coating of the both tubes.

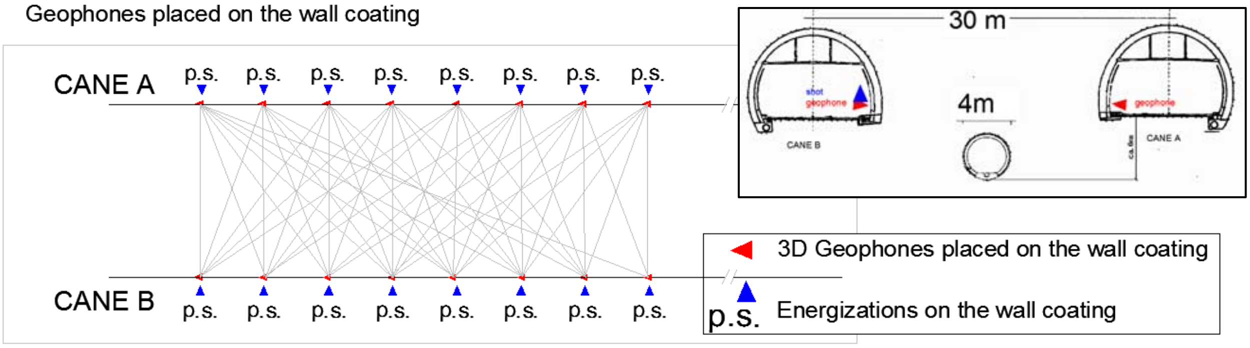


Figure 11: diagram showing the shot point and receivers positioned on the barrel and the seismic ray path (tunnel Melide-Grange. Switzerland).

The P and S_H tomographic interpretations carry out in obviousness at the begin (receivers 1 to 6) and at the end of the section (after receiver n°17) low seismic velocities that can referred respectively with the presence of tectonic discontinuity and with rocks relaxed after the excavation of the tunnel.

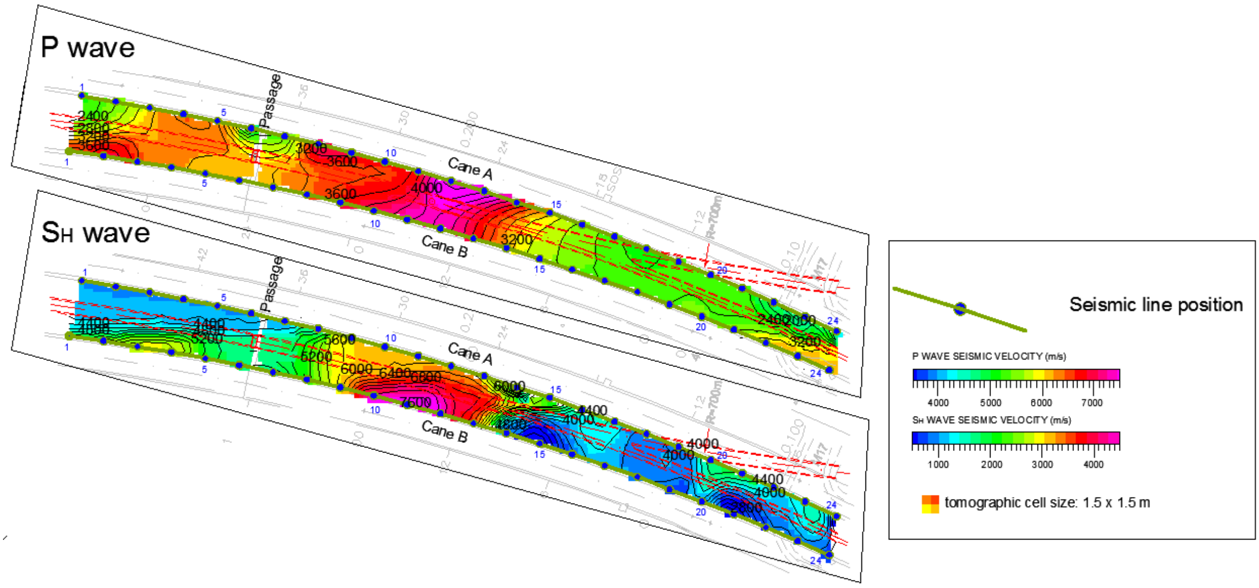


Figure 12: results of shooting seismic velocity between the two tunnel tubes and the seismic refraction line on the same alignments (tunnel Melide-Grange. Switzerland).

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