of analytical solutions, which describe the expected value of temperature at different depths in sediments affected by processes of heat transport by advection, it is possible to obtain quantitative information on the groundwater velocity.

The velocity values found by thermal methods for P8 and P10 wells are comparable with the velocities introduced in the flow model for the Cantarana well filed, deducted by means of hydraulic properties (hydraulic conductivity $K = 5 \cdot 10^{-5}$ m·s^{-1} and hydraulic gradient $i = 0.1$), validating the numerical model.

On the contrary, the low groundwater flow velocities found for the well placed out of the Cantarana well filed suggest the piezometric map elaborated for the area and its hinterland is correct.

All this information may improve the numerical flow model of Maggiore Valley well field, introducing in the hydrogeological models a warm horizontal flux, located in the Asti Sand at depths greater than 60 meters, with flow velocity of about 10^{-6} m·s^{-1}, as highlighted by thermal logs.

References

Carraro F. (Ed.); 1996: Revisione del Villafranchiano nell'area-tipo di Villafranca d'Asti. Il Quaternario (It. Journ. Quatern. Sc.), 9 (1): 5–119.

Castellaro S., Mulargia F., 2009: Vs30 estimates using constrained H/V measurements. Bulletin of the Seismological Society of America, Vol. 99, (2A): 761–773.

Forno M.G., Gattiglio M., Comina C., Barbero D., Bertini A., Doglione A., Irace A., Gianotti F., Martinetto E., Mottura A., Sala B.; 2015: Stratigraphic and tectonic notes on the Villafranca d'Asti succession in type-area and Castelnuovo Don Bosco sector (Asti reliefs, Piedmont). Alpine and Mediterranean Quaternary, 28(1), 5-27

Gattiglio M., Forno, M.G., Comina, C., Doglione A., Violanti, D. and Barbero, D.; 2015: The involving of the Pliocene-Pleistocene succession in the T. Traversola Deformation Zone (NW Italy). Alpine and Mediterranean Quaternary, 28(1), 59-70.

Ibs-von Seht M., Wohlenberg J.; 1999: Microtremor measurements used to map thickness of soft sediments. Bull. Seismol. Soc. America, 89, 250-259.

Lasagna M., Caviglia C., De Luca D.A.; 2014: Simulation modeling for groundwater safety in an overexploitation situation: the Maggiore Valley context (Piedmont, Italy). Bull. Eng. Geol. Environ., 73,341–355.

Pasquale V., Chiozzi P., Gola G., ,Verdoya M.; 2008: Depth-time correction of petroleum bottom-hole temperatures in the Po Plain, Italy. Geophysics, 73, 187–196

Pasquale V., Verdoya M., Chiozzi P.; 2010: Evaluation of heat and water flow in porosity permeable horizons. Boll. Geofis. Teor. Appl., 51, 361-371.

Pasquale V., G. Gola, P. Chiozzi., Verdoya M.; 2011: Thermophysical properties of the Po Basin rocks. Geophy. J. Inter.. 186, 69-81.

Pasquale V., Verdoya M., Chiozzi P.; 2014: Geothermics, heat flow in the lithosphere. Springer, Heidelberg, 119 pp.

Verdoya M., Pasquale V., Chiozzi P.; 2008: Inferring hydro-geothermal parameters from advectively perturbed thermal logs. Inter. J. Earth Sc., 97, 333-344.

SEISMIC TOMOGRAPHY TESTS APPLIED TO A GRAVITY DAM

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The control of the safety assessment of a dam is largely dependent on knowledge of the mechanical parameters of the actual construction, as well as its geological substratum (Karastathis *et al.*, 2002). The application of geophysical methods can be used in existing dams to evaluate the materials (strength properties) and to verify if they match design expectations, as well as to contribute to the safety control (Bond *et al.*, 2000; Kepler *et al.*, 2000; Loperte *et al.*,

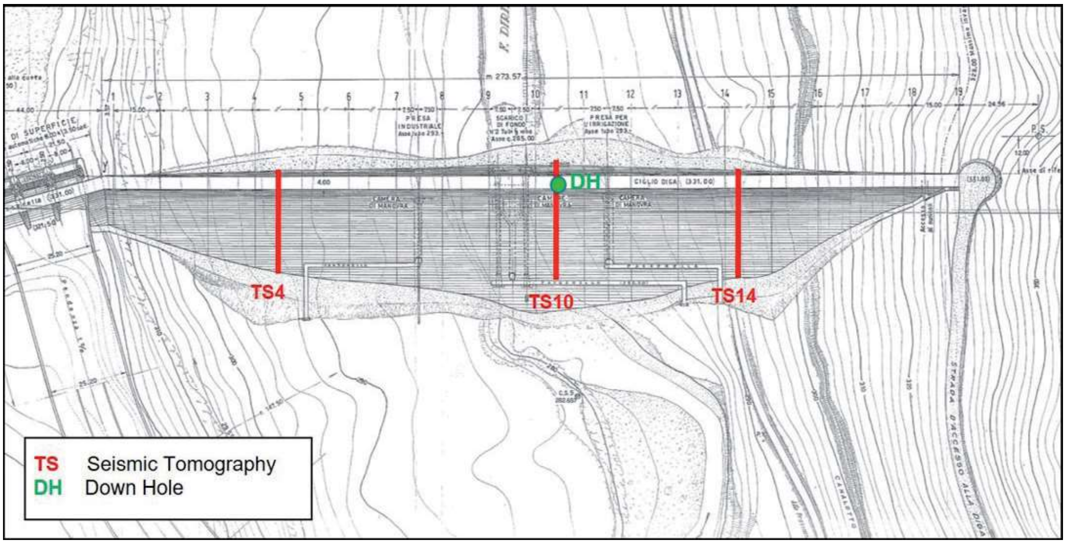

Fig. 1 – Positioning of geophysical surveys.

2011; McCann and Forde, 2001). In particular seismics methods can considerably contribute to the examination indicating the less consolidated material and the degradation of mechanical parameters (Karastathis *et al*., 2002).

For the characterization of the concrete conservation three seismic tomographies (TS4, TS10 and TS14) and a vertical seismic profile (DH) on the dam body were performed (Fig. 1).

All seismic surveys were performed using the digital seismograph X610-S (M.A.E.). Three 2D seismic topographies were carried out in the body of the dam, energizing on the upstream and receiving signals on the downstream face. The receiving points were spaced of 2.5 m, while the source points were positioned with spacing of 1 m. A total of 704, 888 and 744 raypaths were used for TS4, TS10 and TS14 respectively. The energizations were made using a sparker source. In particular it was used the IPG800 pulse generator that provides an energy up to 1000J to 800V to the BIS-SH-DS probe, by means of an electrical impulse. The different depths of immersion of the source is linked to the different level of filling of the sediment in the lake. Traveltime data were inverted using the commercial software package GeoTomCG, based on the tomography program 3DTOM (Jackson and Tweeton, 1996). It performs inversions with the simultaneous iterative reconstruction technique (SIRT, Peterson et al., 1985). SIRT calculations modify an initial velocity model by repeated cycles in three steps: forward computation of model travel times, calculation of residuals and application of velocity corrections to the set of voxels contained in the model. The cycle recurs through a specified number of iterations. For a more accurate estimation of the P-wave velocity, a curved ray inversion was performed with a revised form of ray bending, derived from the method given by Um and Thurber (1987).

The three tomographic models (Fig. 2) show similar velocity distributions, with P-wave velocity ranging between 3000 m/s and 4500 m/s. Variations of the velocity values can be justified by different degree of water saturation. Really P-wave velocity values increases in the presence of water filling the porous of the concrete (Karastathis *et al*., 2002). High velocity values can then be associated to infiltration areas, which seem to be present in the lower part of the dam body. In addiction, all velocity models show slightly lower values in the highest part of the dam body still remaining within the typical range of a good quality concrete.

Finally, at the TS10 section of the dam body a vertical seismic profile (DH) was acquired. The vertical seismic profile showed P-wave velocity ranging between 3800 m/s 4750 m/s and

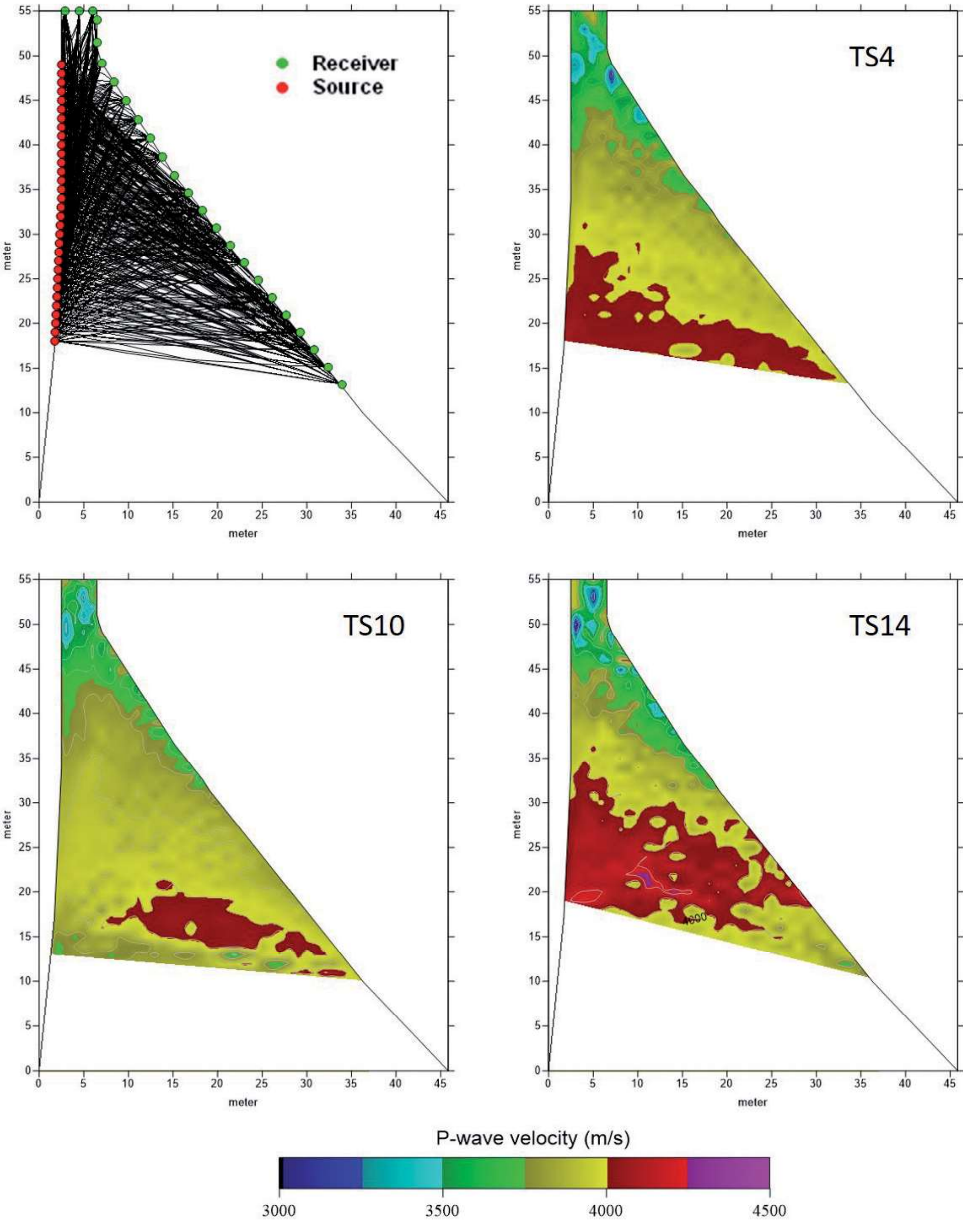

Fig. 2 – An example of curved raytracing obtained for TS4 section and P-wave tomographic model obtained for TS4, TS10 and TS14 sections.

S-wave velocity ranging between 1100 m/s and 2520 m/s (Fig. 3). Also in this case lower values are present in the upper part of the dam body, as well as show the three seismic tomographies. Even Poisson ratios show typical values of the concrete in good condition, varying between 0.29 and 0.41 (at the upper part of the dam body), which are representative values for concrete.

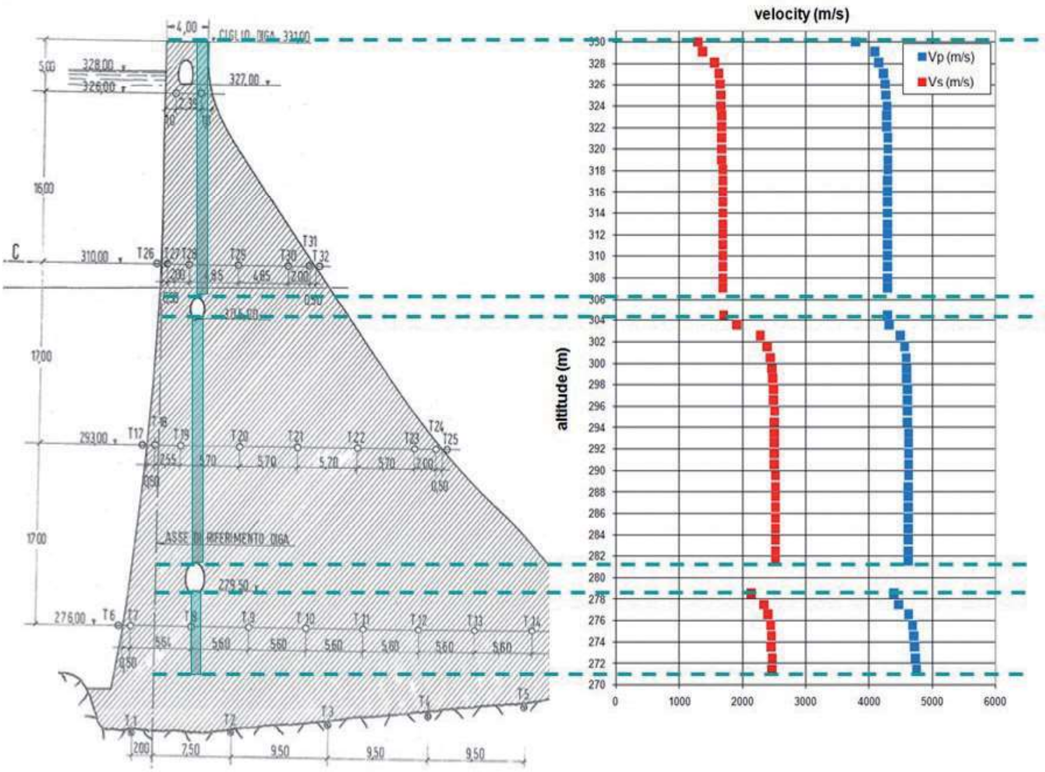

Fig. 3 – Vertical seismic profile of P-wave velocity at TS10 section.

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References

Bond, L.J., Kepler, W.F., Frangopol, D.M. [2000] Improved assessment of mass concrete dams using acoustic travel time tomography. Part I – theory. Construction and Building Materials, 14 (3), 133-146. doi: 10.1016/S0950-0618(00)00014-3.

Jackson, M.J. and Tweeton, D.R. [1996] 3DTOM: Three-Dimensional Geophysical Tomography. USBM RI 9617.

Karastathis, V.K., Karmis, P.N., Drakatos, G. & Stavrakakis, G. [2002] Geophysical methods contributing to the testing of concrete dams. Application at the Marathon Dam. Journal of Applied Geophysics, vol. 50, no. 3, 247-260.

Kepler, W.F., Bond, L.J., Frangopol, D.M. [2000] Improved assessment of mass concrete dams using acoustic travel time tomography. Part II – application. Construction and Building Materials, 14 (3), 147-156. doi: 10.1016/S0950-0618(00)00013-1.

Loperte, A., Bavusi, M., Cerverizzo, G., Lapenna, V. & Soldovieri, F. [2011] Ground penetrating radar in dam monitoring: The test case of Acerenza (Southern Italy). International Journal of Geophysics, vol. 2011, 1-9.

McCann, D.M., Forde, M.C. [2001] Review of NDT methods in the assessment of concrete and masonry structures. NDT and E International, 34 (2), 71-84. doi: 10.1016/S0963-8695(00)00032-3.

Park, R. D. Miller, and J. Xia, [1999] Multichannel analysis of surface waves", Geophysics 64, 3, 800–808.

Peterson, J.E., Paulson, B.N.P., McEvilly, T.V. [1985] Applications of Algebraic Reconstruction Techniques to Crosshole Seismic Data. Geophysics, 50: 1566-1580.

Um, J. and Thurber, C. [1987] A Fast Algorithm for Two-Point Seismic Ray Tracing. Bull. Seismol. Soc. Am., 77: 972-986.