SHEAR WAVE SEISMIC REFLECTION SURVEY IN THE 2012 EMILIA EPICENTRAL AREA

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Introduction. We present the results obtained from a reflection seismic survey performed in the Cavezzo area. This acquisition was performed to evaluate if SH-wave reflection seismic method can be applied for delineating the subsurface in the study area and, possibly, to obtain new information in term of geometry and seismic velocity of the sedimentary sequences.

The study area is located at Cavezzo (Emilia-Romagna, Northern Italy) in the Po plain, very close to the epicenter of the earthquake (M_L 5.8) that occurred at 29 May 2012.

Geology. The subsurface geology of the Cavezzo area is marked by the presence of compressional structures of the Apennines covered by marine and continental clastic deposits of the Po plain.

The subsoil of the Cavezzo area is mainly composed of Plio-Quaternary sedimentary sequences with alternating sand, silts and clays. These alluvial deposits are referable to two major depositional cycles: the Emiliano-Romagnolo Inferiore (AEI) synthem (0.7 – 0.4 Ma) and the Emiliano-Romagnolo Superiore (AES) synthem (0.4 Ma – present). This continental succession overlays the marine and transitional deposits of the lower and middle Pleistocene (Quaternario Marino - QM), referable to the Yellow Sands or Imola sands of the Appennino-Po Valley margin (RER & ENI-Agip, 1998). The depth of the base of the alluvial succession varies according to the presence of the geometry of Ferrarese folds. In the study area, located close to the Mirandola anticline, the AEI synthem has a reduced thickness and the QM top expected depth is at about 220 m below sea level. Several Quaternary thrusts are pointed out by a dense network of seismic lines acquired for hydrocarbon exploration (e.g., Pieri and Groppi, 1981; Cassano *et al*., 1986; Fantoni and Franciosi, 2009). Stratigraphic, morphologic, geodetic and seismic evidences indicate a still active convergence of northeast-verging Apennines and south-verging Southern Alps structures (e.g. Serva, 1990; Castiglioni *et al*., 1997; Boccaletti *et al*., 2004; Toscani *et al*., 2009; Boccaletti *et al*., 2011; Comerci *et al*., 2012; Michetti *et al*., 2012). Earthquake focal mechanisms (Frepoli and Amato, 1997) and other stress indicators (Montone *et al*., 2004) confirmed this evidence.

Methodology. At the beginning, a seismic transect along NE-SW direction to cross the buried Mirandola high structure in dip direction was proposed. The lack of the landowner authorization forced to change the orientation from dip to strike direction. During five days, including crew mob/demobilization, field layout and parameter testing, one SH-wave reflection seismic profile and one P-wave reflection seismic profile were acquired. The L1 seismic line was 478 m length and it was located along the Malaspina road. Cavezzo municipality allowed to close the road during the acquisition time so the absence of vehicular traffic was beneficial for the S/N ratio improvement. This line was first acquired by SH-wave seismic source and horizontal geophones and afterwards was re-acquired by P-wave seismic source and vertical geophones. The topographic surveys for source and receiver locations were performed using real-time differential GNSS positioning techniques called VRS-Virtual Reference Station.

A MiniVib in SH-wave mode was used to acquire SH-wave data. At the end of the seismic line deployment a test was performed to evaluate the best seismic sweep to be adopted. The SH-wave acquisition parameters are reported in Table 1.

Tab. 1 - SH-wave acquisition parameters.

Source: IVI MiniVib T-2500 (SH-wave mode), upsweep 10 – 120 Hz, 12 s, 1800 - 2000 Lb
Sensors: horizontal geophone (40 Hz)
Line: 475 m
Channel interval: 2 m
Active channels: 240 (fixed spread)
Pilot signals: Ground Force, Filtered Ground Force, Baseplate, Reaction mass, Synthetic
Seismic source interval: 4 m
N. energizations/point: 2 – 4
Sampling rate: 2 ms
Data length: 15360 ms
Correlated data length: 3000 ms (Ground Force)

Horizontal geophones (oscillation axis perpendicular to the line) were deployed to detect SH-wave. Data acquisition was performed by DMT- Summit II seismograph with a shot by shot QC.

The acquired reflection seismic data underwent a standard processing sequence developed for shear-wave data (Table 2). Static corrections were not applied due to a flat topography and the absence of surface lateral variations. A reliable interactive velocity analysis was performed owing to the inter-receiver spacing of 2 m and the presence of near horizontal seismic interfaces (i.e., seismic line oriented along the strike direction).

Tab. 2 - Data processing sequence.

SEG2 > SEGY data conversion
Data editing
Vertical stack
Geometry
Top muting (direct, refracted wave, spurious P-wave))
Spherical divergence compensation
CDP sorting
Velocity analysis
NMO correction
Stack
Time to depth conversion (smoothed version of NMO correction)

Discussion. Seismic data penetration and resolution depend on the seismic source and receiver, acquisition geometry and on the geological conditions of the study area. The SH-wave reflection surveys are not frequently executed and, before this pilot study, no data were available in this area. Data acquired are of good quality and several clear reflections can be recognized

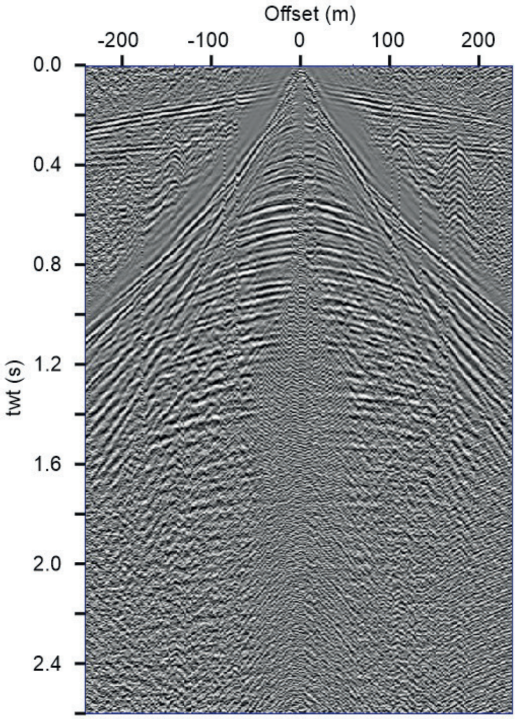

Fig. 1 - SH-wave common-shot-gather: clear reflections are observed until 1.8 s twt (about 400 m).

between 0.15 – 1.8 sec twt corresponding to a maximum penetration of about 400 m below the ground surface (Fig. 1).

Subsurface seismic velocities can be obtained by seismic borehole measurements: vertical seismic profile (VSP) and/or by cross-hole survey (CH). However if boreholes are not available to perform direct measurements, shear and compression wave velocities can be obtained through non-invasive seismic surveys. The picking of first arrivals (direct and refracted waves) performed on the shot gathers gives information about velocity but, typically, only about the shallower layers. Also reflection seismic data contain information about the seismic velocities. In this case data processing requires to perform the normal-move-out (NMO) correction to obtain the best stack of the reflected events over the available offset range. The choice of the stack velocity (Vstack) can be rather subjective, however in presence of horizontal layers with no lateral variations, small offsets and good S/N ratio, Vstack approximates Vrms and Dix formula can be reasonably applied. The acquired data meet these conditions so the interval velocities computed by Dix equation are reasonably reliable. Figure 2 shows the stack section converted in depth with the superposition of SH-wave velocity model and the stratigraphic units.

Conclusions. The SH-wave reflection seismic method was successfully applied in the study area. Data present clear reflections and the absence of surface wave noise that, at some sites, can inhibit the signals detection. Recent acquisition performed by OGS nearby Pieve di Cento also confirms the results obtained in the Cavezzo area.

The velocity model obtained by SH-wave reflection data shows SH-wave velocity lower than 500 m/s until the depth of 240 m below ground level. In correspondence of the marine sediments (QM – Quaternario Marino) a velocity increasing can be observed with values greater than 700 m/s.

Table 3 shows the shear wave velocity associated to the different stratigraphic units.

Tab. 3 - SH-wave interval velocities (m/s) within main stratigraphic units.

AES6	*321*
AESind	*400*
AEI	*482*
QM - Quaternario Marino	*712*

These values are in good agreement with velocities obtained by downhole measurements performed at Medolla and Mirandola (Martelli and Romani, 2013). Also Mirabello downhole data (Minarelli *et al.*, 2016) show SH-wave velocity lower than 800 m/s, which formally defines the “seismic bedrock” by the European Building Code (EN 1998-5 2004) and the Italian Building Code (NTC 2018).

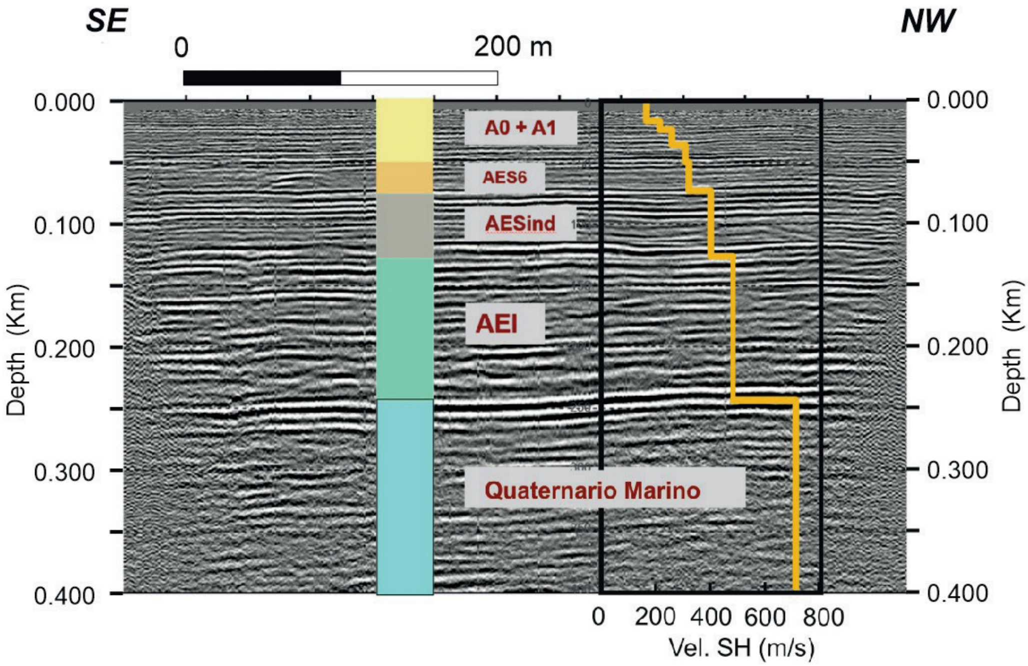

Fig. 2 - SH-wave reflection data converted in depth (0.000 m corresponds to the ground level, about 20 m a.s.l.) with the superposition of SH-wave velocity model and stratigraphic units.

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