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Some considerations on electrical resistivity imaging for characterization of waterbed sediments ☆

Luciana Orlando *

Department Ingegneria Civile Edile e Ambientale, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy

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ABSTRACT

The paper focuses on defining the performance and limits of ERI in the detection and sedimentary characterization of near-bottom thin layers. The analysis of the resolution of floating and submerged cables, and the effect of the accuracy of a priori information (resistivity and thickness) in the data inversion, is based on theory, models and actual data. Theoretical models show that the actual reconstruction of the near water-bottom sediments, in terms of geometry and resistivity, can be obtained only with the submerged cable, however, the data, unlike that acquired with the floating cable, require a priori information on water resistivity and thickness for the data inversion. Theoretical forward models based on wrong a priori water thickness and resistivity information influence the inverted model in different ways, depending on the under- and over-estimation of water resistivity and thickness, and the resistivity contrast of the water–solid layer; however a water–solid resistivity contrast of less than 2 and within 10% of error in water resistivity has no effect. Overestimating water resistivity depicts a ground similar to the actual ground in terms of resistivity, more so than the underestimation of water resistivity. Moreover, the data inversion is less influenced by water parameter error in the case of low resistivity contrast in the water–solid layer, than it is for high resistivity contrast. Wenner and Schlumberger arrays give comparable results, while a dipole–dipole array seems to be more sensitive to the accuracy of apparent resistivity measurements and a priori information on water.

The theoretical considerations were validated by actual data acquired with a submerged cable on the Tiber River. The study has shown that if highly accurate measurements are made of water thickness and resistivity, then electrical resistivity imaging from the submerged cable can be used in addition to, or even to substitute, seismic data for the reconstruction of the features and sedimentary characterization of near-bed sediments where seismic data fail to give a suitable resolution.

1. Introduction

In recent years geophysical methods have been commonly used to study alluvial plains, deltas and basins crossed by rivers, the depositional and erosive mechanisms of river sediments and erosion associated with bridge piers, pollutant infiltration, etc. Usually, single and multi-beam and side-scan sonars are respectively used for bathy-morphology studies and sedimentary characterization of river bed sediments, and single and multi-channel seismic methods are employed to investigate sedimentary deposits on the river bottom. Excellent results in terms of investigation depth (some hundred metres) and resolution have been obtained in big rivers like the Mississippi, the Hudson, and the Danube (Childs et al., 2003), where the sediments consist mainly of clay deposits.

Since 2002, I have been using seismic studies to investigate the hydrodynamics, sedimentology, stratigraphy, pollution, archaeology and navigability of the Tiber River (Bernabini et al., 2006; Bosman, 2004; Orlando, 2007; Orlando et al., 2003), but, unfortunately my studies, unlike those mentioned above, have not resulted in such excellent seismic data results for the lower course of this river (central Italy): Indeed, the near-water bed sediments are, for the most part, characterised by opaque seismic facies and high river-bed reflectivity, making it virtually impossible to define the sediment type (dense clay, cemented sand and/or gravel) (Bernabini et al., 2006).

The multi-fold data (Fig. 1a) show a low signal-noise ratio with low resolution and, in most cases, an investigation depth of a few metres; only in a few zones was the investigation depth 50–75 m (Orlando et al., 2003). Indeed, the single-fold data (Bernabini et al., 2006) provided higher resolution of the near surface sediments than did the multi-fold data (Fig. 1b and c).

To characterise the lithology and thickness of near water-bed sediments, I also used electrical resistivity imaging (ERI). This method has the potential to detect the near-bed layer with a resolution comparable to that of a seismic survey, and also gives information on sediment type.

* Tel.: +39 06 44585078; fax: +39 06 44585080.
E-mail address: luciana.orlando@uniroma1.it.

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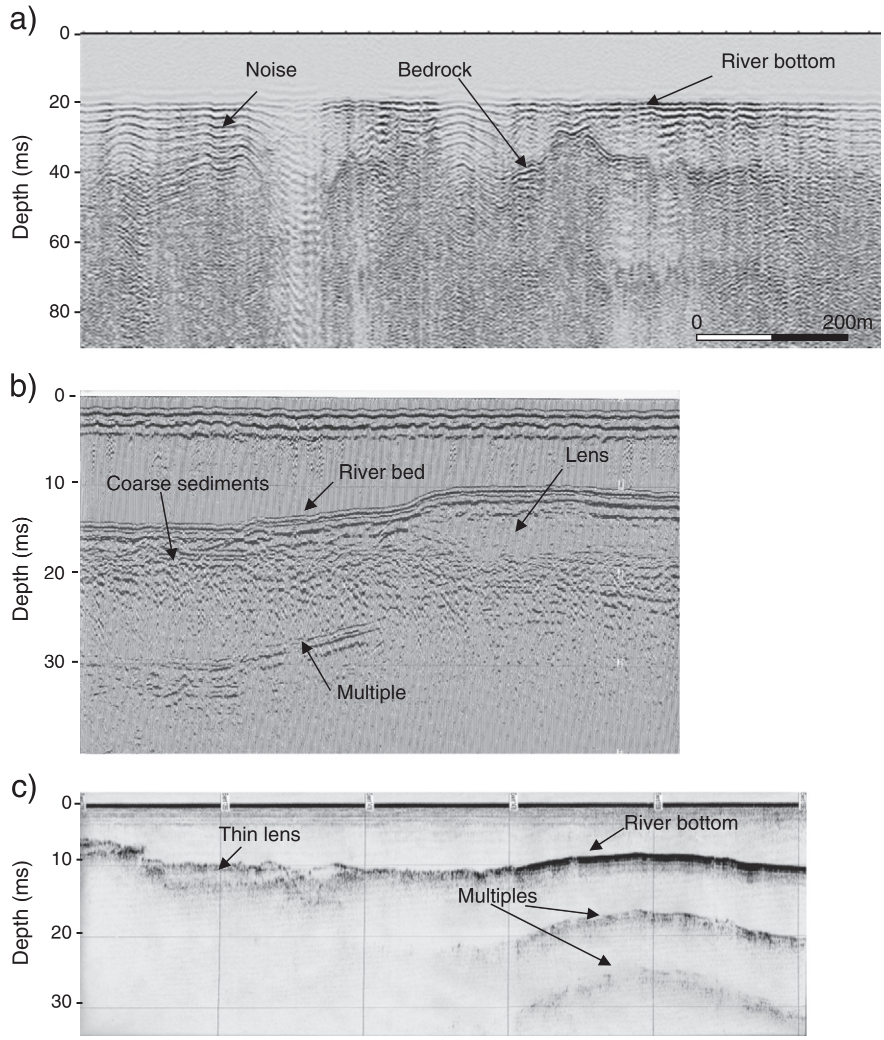

Fig. 1. a) Multi-fold seismic reflection section showing ringing and multiples; b) single-fold seismic section acquired with Sparker source showing lateral variation of type sediments; and c) single-fold seismic profile acquired with Pinger source showing clay lens.

Electric resistivity imaging with a floating cable was used by: Kwon et al. (2005) to study a fault zone underlying a river; by Snyder and Wightman (2002) to identify potential recharge areas; by Manheim et al. (2004) to detect fresh water lens; by Allen and Merrick (2006) to assess the connectivity between surface water and underground waters beneath rivers and channels; by Day-Lewis et al. (2006) for environmental purposes; and by Apostolopoulos et al. (2006) to study the geological setting of submerged marine sediments. Prior to the above studies Roy and Apparao (1971) stressed the dependence of resolution and investigation depth on water thickness, while Alfano (1962) and Snyder and Wightman (2002) demonstrated that the use of a submerged current electrode can, in part, by-pass the equivalence problem and increase the resolution. To increase the investigation depth Baumgartner (1996), and Baumgartner and Christensen (1998), developed a particular 1D method: electrodes placed in the water were aligned perpendicularly to the water level. This particular geometry allows the detection of the near-surface layer with good resolution, and increases the investigation depth. Some time ago Bernabini (1973) discussed vertical electrical soundings applied to a lake bed, and Scott and Maxwell (1989) multi-channel resistivity for mineral exploration in freshwater lakes.

The present paper discusses the possibility of using electrical resistivity imaging to complement, or replace, seismic data in investigating and characterising shallow sedimentary sequences, in cases where seismic investigation provides poor results. To define the performance and the limits of ERI in detecting near-bottom thin layers, I considered theoretical models with floating and submerged cables, and actual data acquired with submerged cable on the Tiber River. Moreover, I analysed the effect of the resistivity and the water thickness in the data inversion. I based the analyses of the resolution for the floating and submerged cables on one-dimensional master curves as they are easier to analyse than two-dimensional data and the conclusions are valid for 2 and 3 dimensional data. The effects on the data inversion of the accuracy of water-bottom topography and water resistivity were analysed on two-dimensional theoretical models. The theoretical considerations were validated by actual data acquired with a submerged cable on the Tiber River.

2. Theory and modelling

2.1. Modelling and analysis

From bibliography and theory, the latter discussed in Appendix A, I found that electrical resistivity imaging (ERI) acquired with floating and submerged cables can resolve, in different ways, the resistivity and thickness of near-bed layers, and for the submerged cable the