Assessing The Underworld
An Integrated Performance Model of City Infrastructures

Surface wave surveys for imaging ground property changes due to a leaking water pipe – Work Stream 4

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Objectives

- To test the feasibility of using the multi-channel analysis of surface wave (MASW) to detect and image the temporal and spatial disturbances caused by:
  - The excavation of shallow pits for the installation of underground pipes for water and gas utilities, and
  - The potential zone of compromise to the support given to the pipe due to invasion of water leaking from a pipe into the surrounding ground

Why use geophysical methods to image the ground about utilities

Non-invasive geophysical imaging over surface-based arrays, buried just beneath the pavement or towed along the surface for example, offer the potential not only to provide early warning of leaks occurring, but also to provide accurate location AND condition monitoring of leak-affected ground. Surface wave surveys provide a reliable means of non-invasively imaging the shear wave velocity and associated stiffness distributions within earthworks[1, 2, 3]. The Multi-channel Analysis of Surface Waves (MASW) technique produces shear wave velocity images of the ground about the water pipe, from which the ground stiffness could also be estimated. These MASW survey observations formed a component part of a larger study of the temporal and spatial ground property changes caused by the invasion into the formation of the water leaking from the pipe. This included observations on a Subsurface Sensor Network described by the poster “Quantitative soil condition monitoring of geotechnical assets using Time Domain Reflectometry” [4] and using Elasticity Tomography described by the poster “4D ERT monitoring of water pipe leakage during a controlled field experiment” [5].

Seismic geophysical methods

MASW surveys use seismic field records gathered using the same receiver array configuration adopted in shallow seismic refraction profiling using surface waves, Fig. 1a. This survey employed a light hammer-plate source capable of providing a broad range of frequencies, and groups of 12 geophones at 0.3m centres, Fig. 1b. Two-thirds of the total seismic wave energy generated by a vertical impact propagates as Rayleigh waves [3], the ground roll that radiates from the vertical impact, Fig. 1c. Rayleigh waves are dispersive meaning their (phase) velocity, varies with frequency, and therefore each different wavelength for each frequency propagates within different depth intervals in the ground, Fig. 1a. The shear wave velocity (Vs) is approximately 1.1 times the Rayleigh wave velocity and this is controlled by the small strain stiffness and density of the soil [3]. Producing multi-frequency Rayleigh waves therefore forms the basis of a shear wave velocity and stiffness ground imaging technique.

The excavation, the water pipe installation and the leak

Excavation: The experimental installation required excavating a pit 8 m by 1.2 m by 1.2 m deep into weathered / disturbed, red-brown, soft to stiff clayey SILT with gravel and cobble-sized, dolomitic SILTSTONE and limestone of what was probably the original, unweathered MUDSTONE, Fig. 2a. The canopy and water uptake from the trees resulted in ground appearing relatively dry in the near surface, especially within the topsoil, Fig. 2a.

Water Pipe: Standard Ø32 mm MDPE pipe was run between two stop cocks at a depth of 0.7 m. Figs. 2a. One end of the pipe was connected via the stopock and a flow meter to the water mains network, which had an operating pressure between 4 and 5 bar (400 – 600 kPa), while the other could be open ended or closed, controlled by its stop cock. Fig. 2a.

Leak: The leak was simulated by a small (Ø33 mm), upward facing hole, drilled into the pipe at the mid-point between the two stop cocks. The trench was back-filled with the soil originally excavated and re-compacted using a plate compactor (Fig. 2b), with the final ground surface of the backfilled trench being level with the surrounding ground.

Detection of the excavation and the leak in the geophysical images

Excavation: Similar Vs distributions in the pre- / post-Trench images due to similar densities of formation and backfill, Fig. 3a. Increase in penetration resistance (Fig. 3b) and Vs at base of trench due to localised increase in the speed of sound within the water / compacted trench floor, increasing stiffness, Fig. 3a. vs in the upper 1.2m (Trench backfill), range from 90 – 120 m/s, consistent with soft to firm, fine-grained soils.

Minor Leak: 2.095 m³ of water discharged at 1.5 l/min. A narrow funnel constrains the drainage of water from the leak, into fully saturated formation (> 2.2 m), where water drains laterally, Fig. 3c (left). Reduced penetration resistance from 0.8 m (leak) to top of formation consistent with soil softening due to increased moisture, Fig. 3b. Vs in the trench and deeper formation increases largely unaffected by minor leak with a reduction of 15% (15 – 20 m/s) mapped below leak between 2 – 3 m depths, Fig. 3a.

Major Leak: 20.68 m³ of water discharged at a rate > 5 l/min. An ∼92 m bundle develops beneath the leak. Fig. 3c, with ingress of water through downwards drainage, lateral and upwards infiltration into the backfill. Bund growth during the test, reaching a max. Ø3 – 4 m and breaks the surface, with a reduction in Vs of 15 – 20 m/s (10 – 15%), extending to a depth of 3-4 m (Fig. 3a). Localised reduction in the penetration resistance in trench-fill area and leak below 0.5 – 1m depths correlates with significant reduction of Vs, in excess of 25 m/s (30%), Fig. 3a.

Conclusions: Shear wave velocity or stiffness changes provide a proxy for monitoring the effect of ground disturbances associated with trenching. Water ingress on the strength and supporting capacity of the ground. Ground disturbances causing low velocity (or stiffness) anomalies can be localised on MASW images with high spatial resolution. Anatomical imaging is possible, including the location of the leak, the width and location form and location of progressive ground disturbances following water leaks also possible.

References: