Use of microtremors for site hazard studies in the 2D Tamar rift valley, Launceston, Tasmania

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Abstract

Analysis of microtremor for risk zonation is conventionally interpreted in terms of sub-horizontal layered geology. This assumption not being valid in some cases, there is a need to take into account the impact of 2D/3D geology for analysis of more complicated models. Bard and Bouchon (1980a, 1980b, 1985) intensively studied SH, SV and P waves motions in sediment-filled valleys. Identification of 2D and 3D effects has been analyzed by Field (1996), Steimen et al (2003), and Roten et al (2006) using spectral amplification and phase behavior. Modeling and interpretation of 2D microtremor data is the next challenge, and several methods have been developed to do so. A finite-difference code was developed by Moczo and Kristek (2002) within the European SESAME project. Tessmer et al (1992) and Faccioli et al (1997) present the basis of a pseudo-spectral approach combined to domain decomposition techniques for modeling of propagating waves. The research group led by Komatitsch and Tromp developed a spectral element code for 2D and 3D seismic wave propagation (Tromp3D), using a combination of finite-elements method with spectral analysis. Assessment of the different methods available for detecting, modeling and interpreting 2D and 3D effects is the main objective of this project, using both H/V and SPAC data. Modeling methods will be compared with microtremor data acquired over a 2D rift valley (the Tamar Valley in Launceston, Tasmania) where there is a history of earthquake damage associated with site effects.

Introduction

Figure 1 shows the location of Launceston in Tasmania, south of the Australian mainland. Even if Launceston is not located in a very seismically active zone, damage has occurred in the past from earthquakes. Epicenters of earthquakes are located in two seismic zones:

- West Tasman Sea Zone,
- Western Tasmanian Zone.

Earthquake damage in Launceston is thought to be caused by site amplification response due to 2D geology effects. Figure 2 presents the results of the microzonation project at Launceston (Michael-Leiba, 1995). Profiles are obtained from a gravity survey (Leaman, 1994). Bedrock is Jurassic dolerite, which presents low seismic risk when outcropping. The survey outlines the presence of at least 2 deep NNW-SSE trending valleys filled with Tertiary and Quaternary sediments:

- along Tamar Valley axis, maximum sediment thickness of 250m,
- along North Esk Valley (floodplain), maximum sediment thickness of 130m.

Microtremor survey has previously been done in Launceston, using the H/V spectrum ratio (Nakamura, 1989) to estimate the natural site period of site amplification at 56 sites, and to create zoning maps of Launceston. Periods calculated present a large range of values from 0.1 to 1.5 sec. These variations in the calculated periods over the 56 sites do not appear to fit known geological depth; hence they may be explained by 2D effects generated by the presence of deep and narrow valleys. More data will be obtained with SPAC processing of array data as well as H/V data, with the aim being to identify and model 2D effects in the Tamar rift valley.

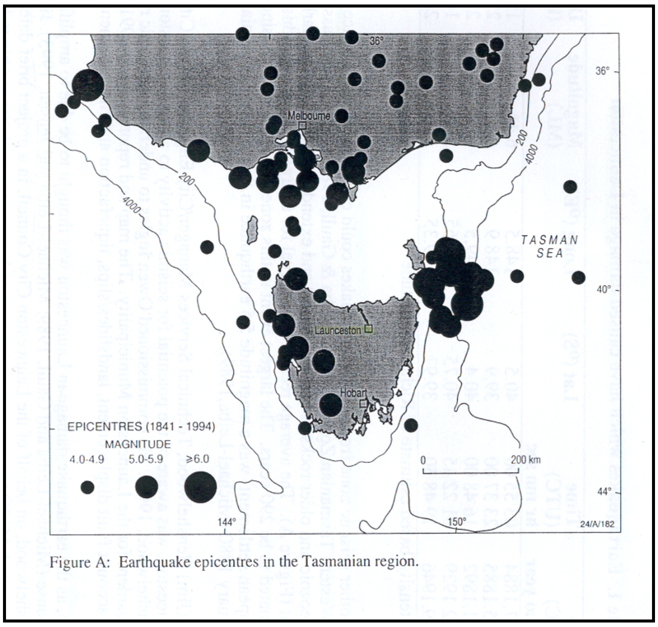

Figure 1. Location of Launceston, Tasmania. Epicenters of earthquakes with Richter magnitudes of 4.0 or more around Tasmania from 1884-1994 (from Michael-Leiba, 1995)

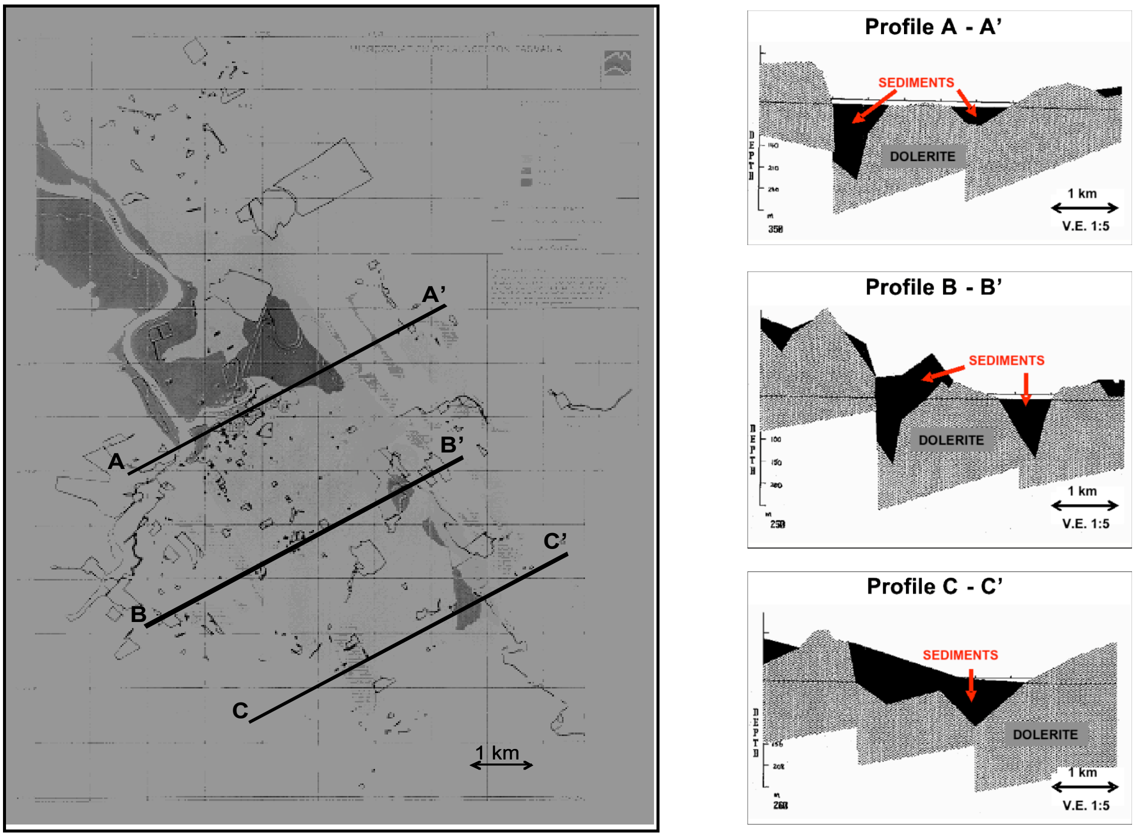

Figure 2. Microzonation of Launceston (Michael-Leiba, 1995). Sites where microtremor data have been obtained with H/V spectrum ratio. Geological profiles obtained from a gravity survey (Leaman, 1994)

Review of the problem

Interpretation of single-station H/V microtremor data has traditionally used the hypothesis of a layered geology, where waves of fundamental modes are assumed to dominate the signal. From Nakamura's technique, natural period of a layered site is calculated as:

$$T = 4H/V,$$

where H is the layer thickness and V is the shear wave velocity in the layer. Developments have been made analyzing variations of H/V spectral ratios and reference site method (RSM) along a profile over a valley to detect and analyze 2D effects.

The SPAC method measures the covariance at different frequencies between the signals observed at different stations. Phase velocities are determined by averaging signal coherency between the different points of observation in an array of receivers. Depending on the components of the signal analyzed, Rayleigh and Love waves can be analyzed to determine a 1D shear velocity depth profile.

Bard and Bouchon (1980a, 1980b and 1985) studied the variation in spectral amplitude of SH, SV and P waves along a profile over 2D geology. Trying to extend the H/V spectrum ratio technique to more complex geology, Field (1996) found that the method did not fit the sediment to bedrock ratio over a 2D geology. He recognized that H/V spectral ratio could be used to detect 2D effects. He observed shifting in the peak frequency along a profile over a valley. Data obtained with SPAC method in Launceston will be of interest to see if the use of H/V ratio and SPAC data simultaneously is of interest to better detect and analyze 2D effects in microtremor data.

Working hypotheses

Measurement of Vs depth profile using array methods will provide quantitative shear velocities to use in models.

H/V spectral ratios are an efficient tool to detect and analyze 2D effect in microtremor data.

Array methods (SPAC) applied over a basin edge will give perturbed microtremor phase velocities; these types of perturbations can be studied using 2D or 3D models.

Information deduced from SPAC data will help improve the detection and interpretation of 2D effects in microtremor data.

Methodology

The first step is to obtain H/V spectral ratio and SPAC microtremor measurements on a profile crossing the Tamar Valley in Launceston. H/V spectral ratio data should then be analyzed using 2D effect developed by Bard and Bouchon (1985) and Roten et al (2006). Modeling should then be used to represent Launceston area, using both 1D and 2D geology models. Comparison between SPAC data modeled from 1D and 2D geology would better assess the type of data recorded at Launceston. Recognition of 2D effects from SPAC data is the final step in the project, using both modeled and field data.

Few programs can be used to model complex geology. Two approaches will be assessed in this study; the spectral element method, and the joint mode-summation and finite-difference method.

Spectral Element Method (SEM)

- Work with Tromp3D program using SEM method (Komatitsch and Tromp, 1999)
- Weak formulation: integral formulation of seismic equations of motion. The weak formulation naturally satisfies the stress-free surface boundary condition.
- Hexahedra elements (quadrangles in 2D)
- Lagrange high-order polynomial representation of elements
- Gauss-Lobatto-Legendre approximation used for integration of equations of motion
- Mass matrix diagonal by construction in SEM: reduces cost of calculations.

Mode-summation and finite-difference modeling

- 3D fourth-order staggered grid finite-difference for modeling seismic motion and seismic wave propagation (Moczo et al, 2002)

- Mode-summation method is used to model wave propagation from source position to local 2D/3D irregularity. Path from source to irregularity is assumed to be flat, homogeneous layers.
- Finite-difference method is used in the laterally heterogeneous part of the model (Tamar rift valley). Spurious effects might be created due to the need to impose artificial boundaries to the model to save on CPU time and memory.

Conclusion

Analysis of microtremor data conventionally assumes a 1D homogeneous geology. This hypothesis does not hold in Launceston, Tasmania, due to the presence of the Tamar rift valley. Amplification of seismic waves is thought to occur at Launceston due to patterns of earthquake damage in historic quakes. 2D site effects are suspected.

The expected pattern in H/V spectrum ratio can be used to identify these 2D effects in the Launceston area. SPAC measurements will be used to complete the study. Microtremor data acquired over Launceston will be used to assess modelling over 2D and 3D effects, using the SEM method and the joint mode-summation and finite-difference method.

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