Surface Wave Method - A Tool for Lifeline Earthquake Engineering

by

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Appendix G - Surface Wave Method - A Tool for Lifeline Earthquake Engineering, Submitted by Dr. Ronald Andrus

Examples of Correlating V_S and Liquefaction Potential

Stokoe et al. (1988b) applied the strain approach by Dobry and his colleagues (1982) in an analytical study of the liquefaction potential of sandy soils in the Imperial Valley, California, to generate liquefaction assessment charts based on measured V_S and maximum horizontal ground surface acceleration, a_{max}, for stiff soil (nonliquefiable clay) site at the candidate-site location. The chart for 15 cycles of shaking, the approximate number of cycles of the Borah Peak earthquake ($M_S = 7.3$), at a level ground site with the liquefiable sand in the upper 12 m is shown in Figure 2. Liquefaction is predicted to occur right of the shaded region. Within the shaded region, liquefaction would likely occur depending on thickness and depth of the liquefiable layer. Liquefaction is predicted not to occur left of the shaded region because the sand is too dense to liquefy. During the Borah Peak earthquake, the estimated values of a_{max} at Goddard Ranch and Larter Ranch are 0.34 g and 0.6 g, respectively. As illustrated in Figure 2, liquefaction is predicted at Goddard Ranch in sediments with $V_S \leq 110$ m/s and liquefaction likely in sediments with 110 m/s $< V_S \leq$ 170 m/s. Similarly, liquefaction is predicted at Larter Ranch in sediments with $V_S \leq 165$ m/s and liquefaction likely in sediments with 165 m/s $< V_S \leq$ 280 m/s.

At Goddard Ranch, liquefaction occurred as evidenced by numerous sand boils in the low-lying areas (Youd et al. 1985). Shown in Figure 3 are sediment layers beneath the gravelly side bar investigated. Also shown are several penetration profiles determined by the Cone Penetration Test (CPT) and the Standard Penetration Test (SPT). Liquefaction most likely occurred in

Introduction

Liquefaction of granular soils is one of the major causes of lifeline damage in past earthquakes. Screening techniques based on geology, hydrology, and soil conditions can identify areas along the lifeline corridor requiring more rigorous analyses. These areas can extend for several kilometers, however. The Spectral-Analysis-of-Surface-Waves (SASW) method has great potential for rapid determination of the layer thickness and small-strain shear wave velocity, V_S, of soil deposits. The SASW method is nonintrusive and nondestructive. It is based on the principal that surface seismic waves of high frequency propagate only in near-surface layers, and surface waves of low frequency propagate at different velocities if stiffness varies with depth. Thus, different portions of the soil profile can be tested by using surface waves over a wide range of frequencies. The general SASW test configuration of source, receivers, and recording equipment is shown in Figure 1. Liquefaction potential and V_S of granular soils are influenced by many of the same factors (e.g., density, confinement, and geologic age). This paper evaluates the ability of the SASW method to delineate liquefiable soil using data from two sites (Goddard Ranch and Larter Ranch) where liquefaction occurred during the 1983 Borah Peak, Idaho, earthquake and the liquefaction assessment procedure by Stokoe et al. (1988b). Application of the SASW method to lifelines is discussed.

Unit C1, a loose (low penetration resistance) sandy gravel with less than a few percent fines (Andrus 1994). Unit C2, a loose to medium dense sandy gravel, using penetration resistance is predicted to be liquefiable to marginally liquefiable material. Unit B is a sandy silt with clay, and is nonliquefiable. Three V_S profiles determined by the SASW method are shown in Figure 4. Profile SA-85 was determined in an earlier study (Stokoe et al. 1988a) before penetration and borehole data were available. Profiles SA-2 and SA-3 were determined assuming the layering observed in penetration profiles. Regions of liquefaction and liquefaction likely have been shaded in Figure 4 using values of V_S, and are in good agreement with the assessment based on penetration resistance. Soil type is needed to correctly assess no liquefaction for Unit B.

At Larter Ranch, liquefaction caused the steeply sloping (about 34 percent) distal end of an alluvial fan to move laterally downslope about 1 m. Numerous sand boils erupted along the toe of the fan. Shown in Figure 5 are sediment layers beneath the slide. Also shown are penetration profiles determined by the CPT, SPT, and Becker Penetration Test (BPT). Liquefaction most likely occurred in Unit C, a loose to medium dense sandy gravel with about 7 percent fines (Andrus 1994). Beneath the zone of fissures, Unit C is predicted marginally liquefiable since it exhibits higher penetration resistances. Three V_S profiles determined by the SASW method are shown in Figure 6. These profiles were determined in an earlier study (Stokoe et al. 1988a) before penetration and borehole data were available. Regions of liquefaction and liquefaction likely have been shaded in Figure 6 using V_S, and are in good agreement with the assessment based on penetration resistance.

These findings illustrate the ability of the SASW method to delineate liquefiable materials in granular deposits. Soil type is needed to correctly predict behavior in deposits with layers of soft clay.

Application of the SASW Method to Lifelines

The SASW method consists of making field measurements of surface wave velocity at various frequencies and determining V_S profile through a process called inversion. Several different source and receiver spacings are required to measure over a wide range of frequencies due to attenuation and near-field effects. Although it is preferable to conduct the test with receivers spaced about a common midpoint (see Figure 1) and source locations reversed, the common source test configuration shown in Figure 7a is more appropriate for automation. Hiltunen and Woods (1990) demonstrated that the sacrifice in quality is small with the common source configuration. Recent work by Nazarian et al. (1994) has shown that inversion can be automated, reducing the time for testing and determining V_S profile at a site like the one shown in Figure 7a to about 30 min. For alignments of moderate length, test arrays could be effectively overlapped, as shown in Figure 7b, to produce profiles at discrete intervals of 4x. Since most liquefiable soil layers lie within the upper 10 m of soil deposits, a typical value of x would be 2 m for profiling depths of 0.5 m to 10 m. Moving source-receiver systems are under development at the University of Texas at Austin (Stokoe 1995) for generating continuous V_S profiles rather than profiles at discrete locations. Based on these developments, the SASW method appears well suited for rapid profiling along lifelines.

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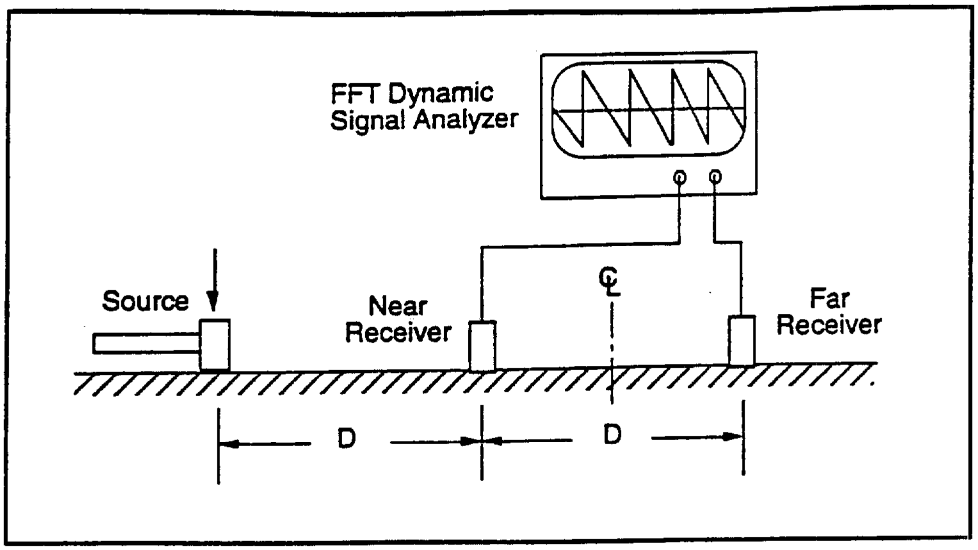

Figure 1. General SASW field testing configuration

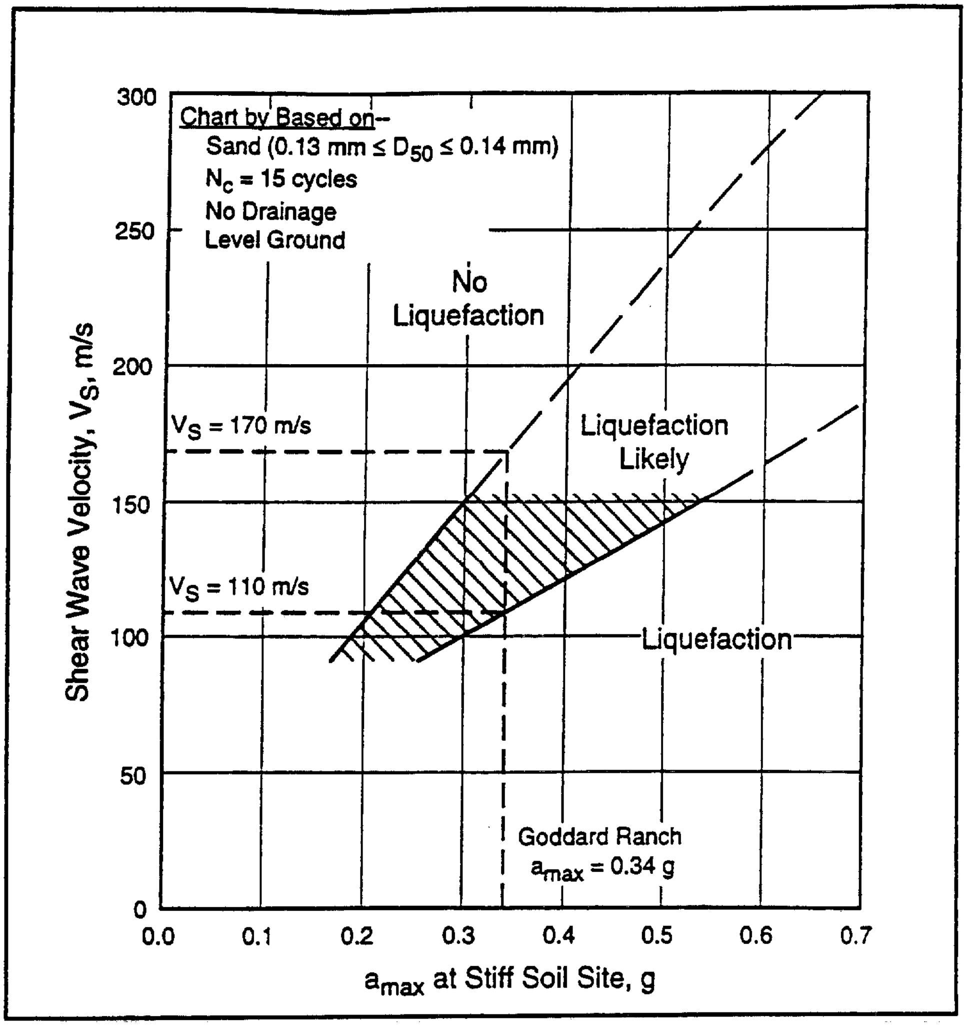

Figure 2. Liquefaction assessment chart by Stokoe et al. (1998b) based on V_S and peak horizontal ground surface acceleration, a_{max}, at stiff soil site for 15 cycles of shaking, N_c

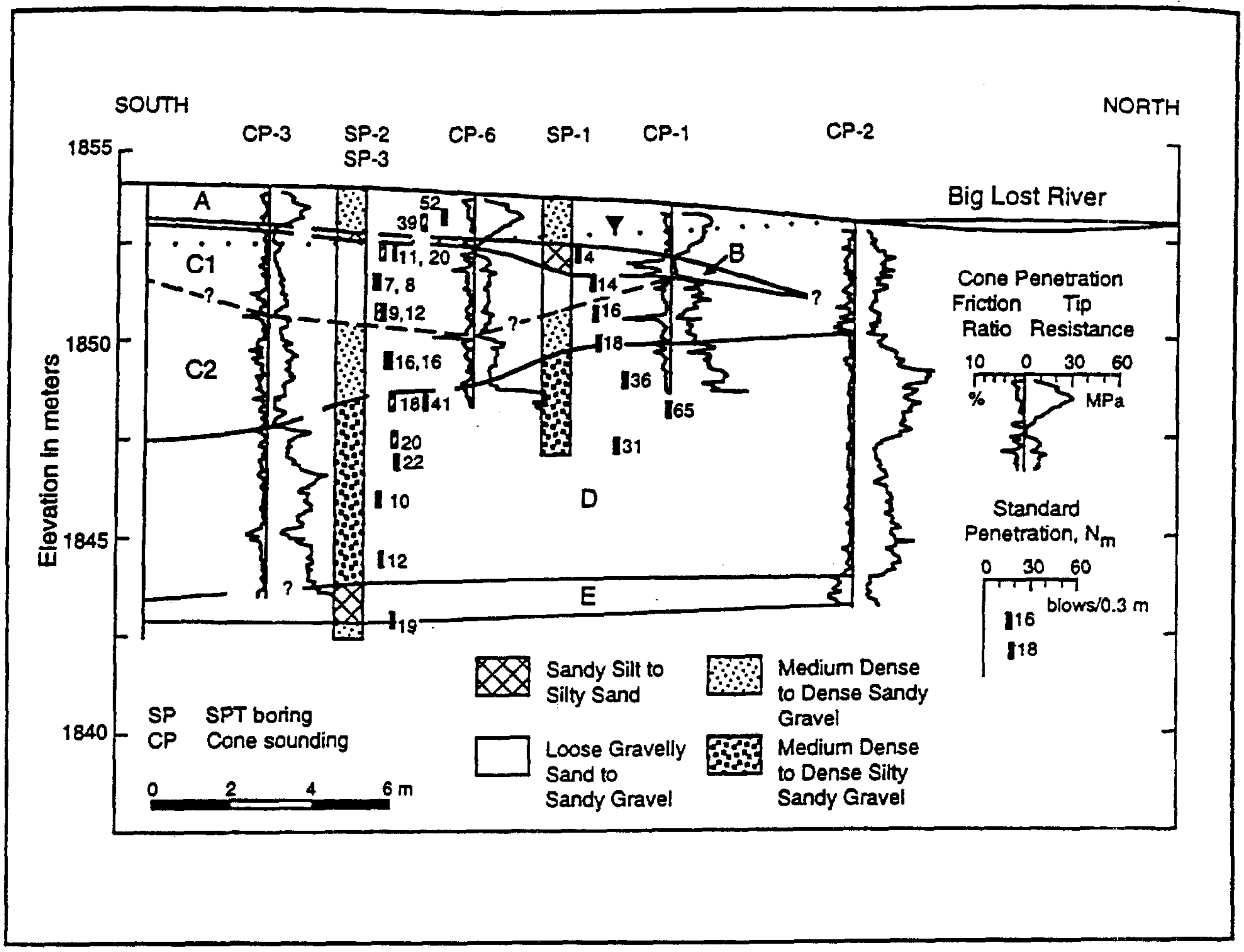

Figure 3. Cross section of the gravelly side bar at Goddard Ranch (Andrus 1994)

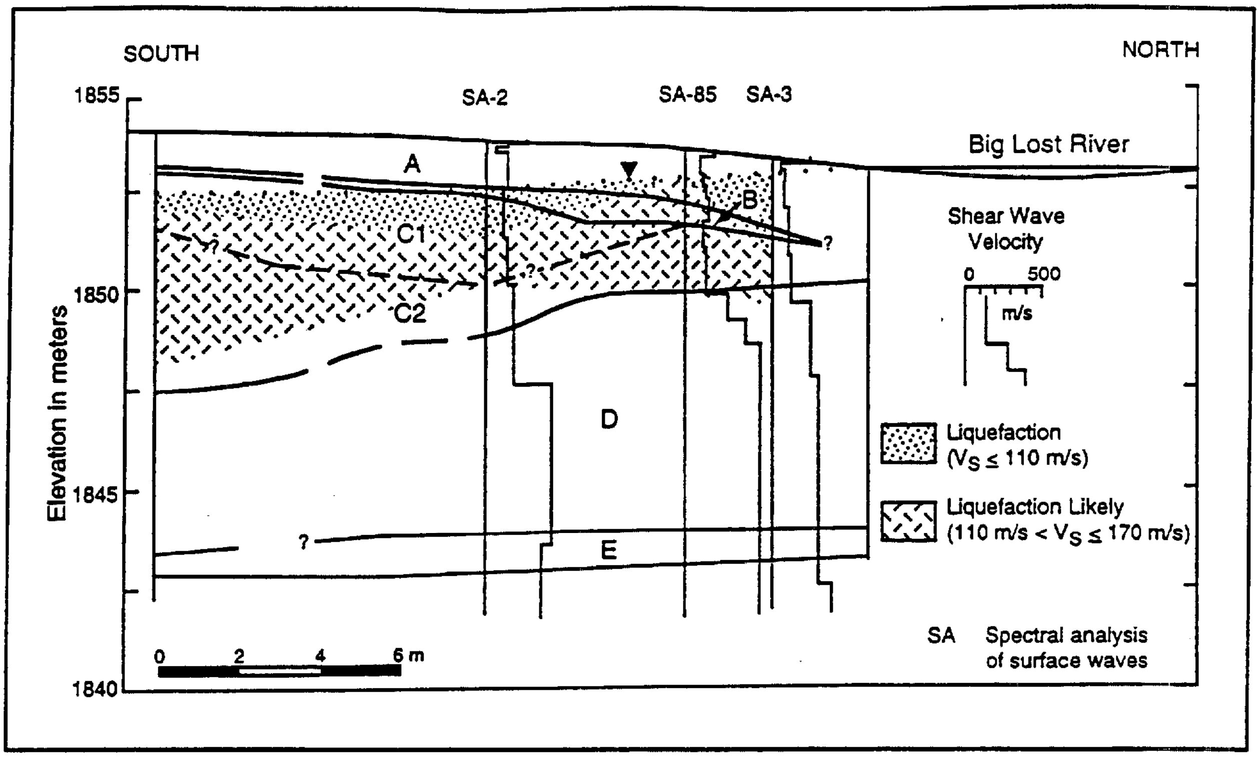

Figure 4. Liquefaction assessment based on V_s of sediments beneath the gravelly side bar at Goddard Ranch

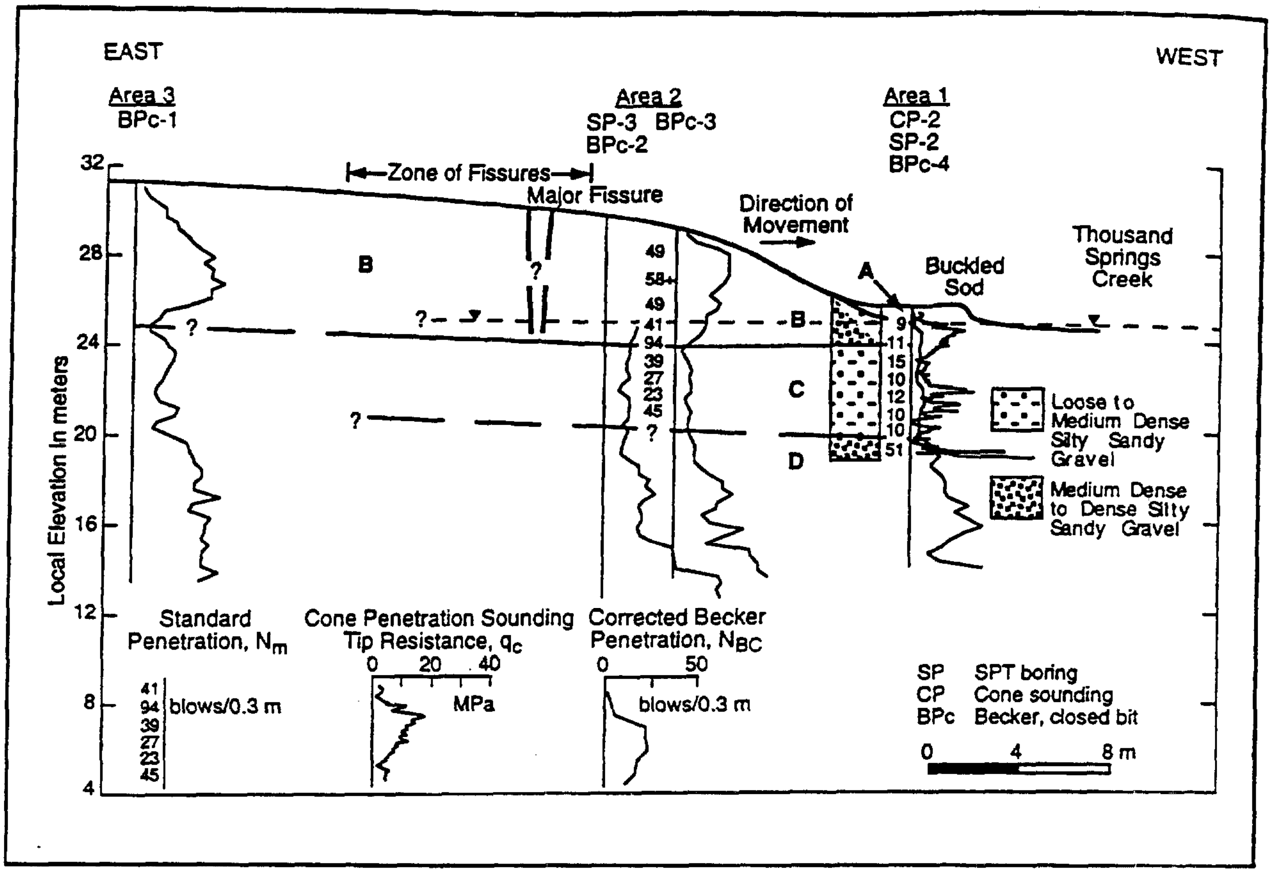

Figure 5. Cross section of the lateral spread at Larter Ranch (Andrus 1994)

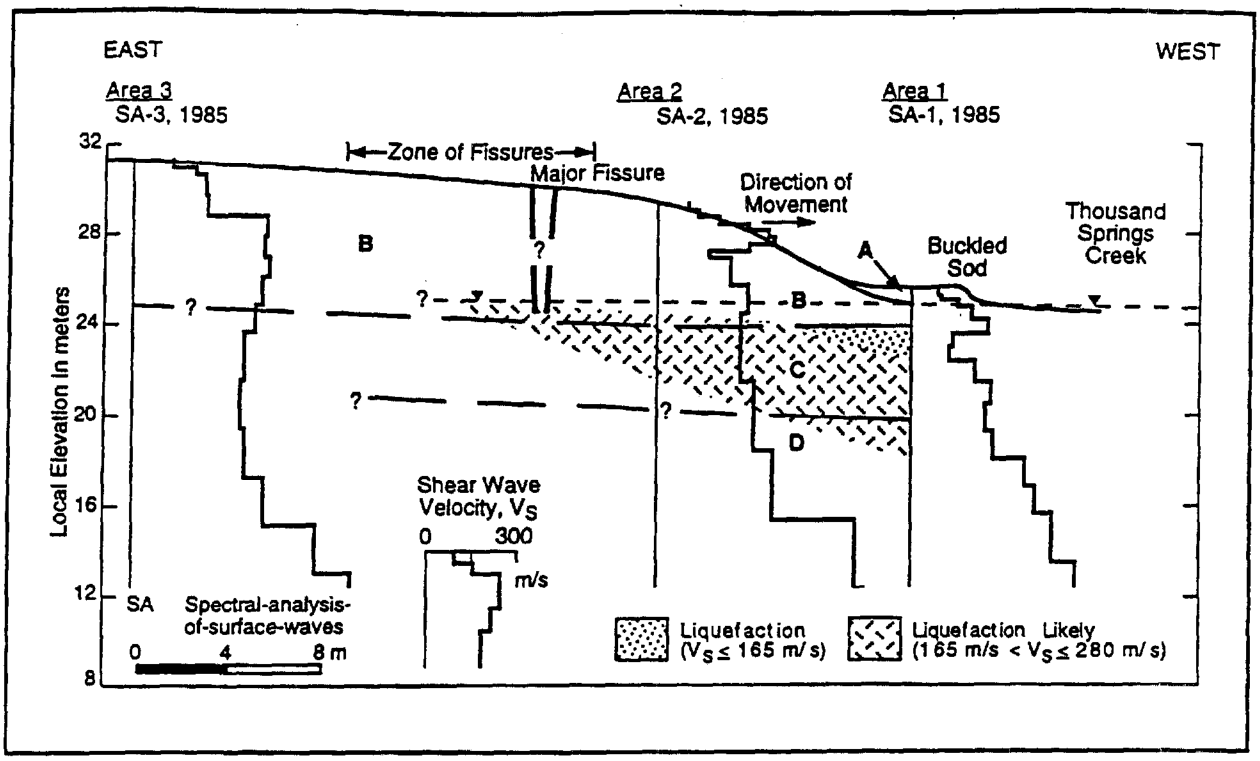

Figure 6. Liquefaction assessment based on V_S of sediments beneath the lateral spread at Larter Ranch

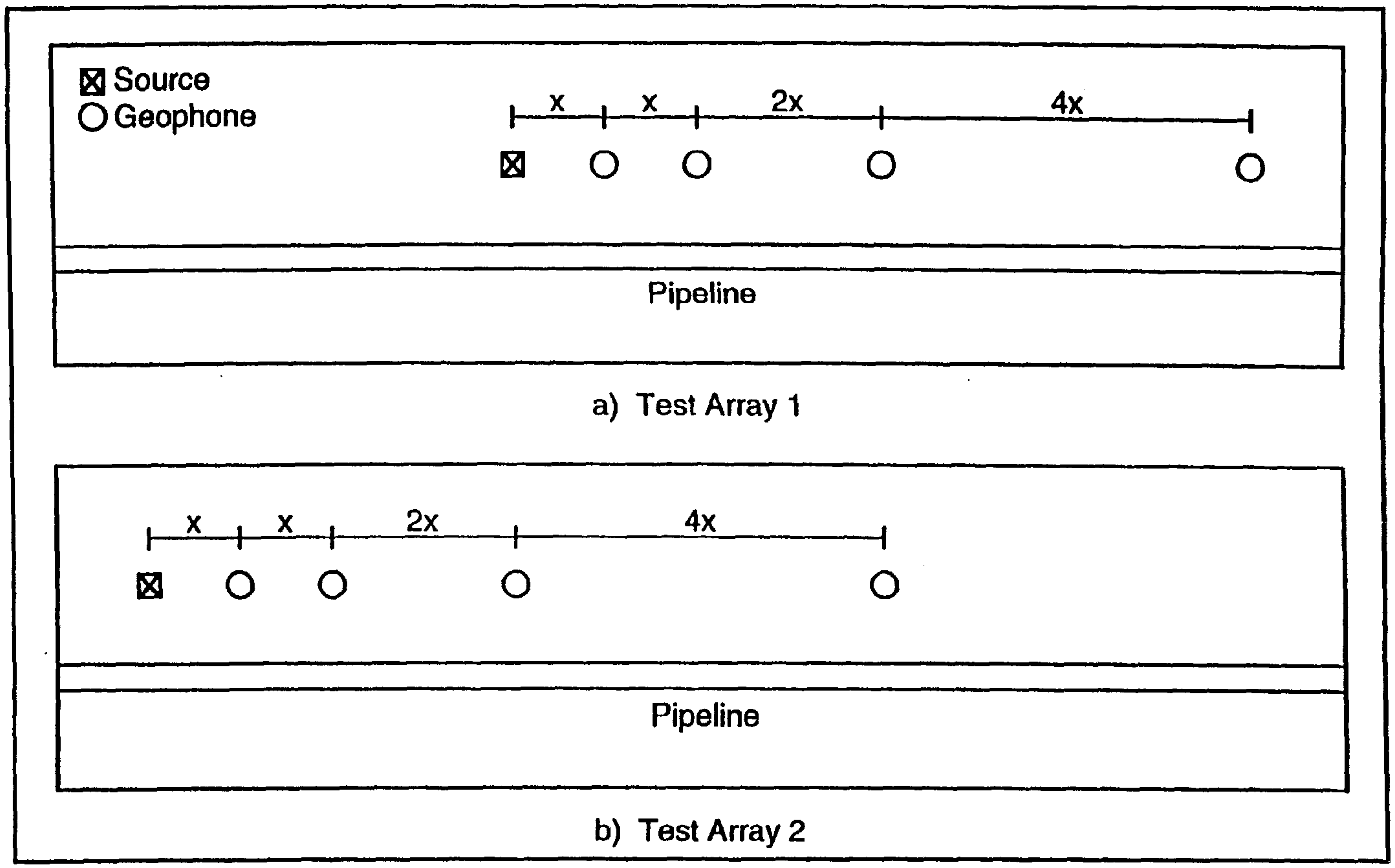

Figure 7. SASW testing with common source configuration along pipeline