USING ACSW FOR SEISMIC & LIQUEFACTION ASSESSMENT

Guidance Note SSGN021

Background

Advanced Continuous Surface Wave (ACSW) testing allows ground stiffness profiles to be rapidly determined non-intrusively by measurement of the speed of surface Rayleigh waves (Vr) over range of frequencies (f) - see SSGN010 for full description of ACSW theory. Inversion of the V_r versus f data (the 'dispersion curve') allows determination of a shear-wave velocity (V_s) and a

Small Strain Shear Modulus (G_0) against depth. In this inversion process conservative assumptions of Poisson's Ratio to derive V_s , since within its normal range this influences the values derived by less than 10% and hence representative shear wave velocity profile can be derived using CSW testing. Vs profiles are used as the basis of seismic and liquefaction assessment for the design of structures. Difficulty in reliably obtaining these profiles lead to the development of relationships between V_s and other measured properties such as shear strength and cone end resistance. However, ACSW testing's non-intrusive and cost-effective nature means it is an attractive means of rapidly obtaining in-situ V_s profiles for seismic design, as well as providing accurate stiffness parameters for routine engineering design.

This Guidance Note outlines the approaches for using ACSW data for seismic and liquefaction assessment. As for all test data, however, appropriate professional engineering judgement in the context of a suitable range of ground investigation information on must be applied in using ACSW data.

Seismic Assessment

Most seismic codes use V_s profiles for site classification using a $V_{s,30}$ value, i.e. a Vs value for the upper 30m of strata. Table 2 presents site classification from US standards ASCE 7-10; Table 2 presents a similar classification from Eurocode 8.

Table 1: Site classification using Vs30 from ASCE 7-10

V_s (m/s) for upper 30m of geologic profile	ASCE 7-10 seismic site class	ASCE 7-10 description
>1524	A	Hard Rock
762 -1524	B	Rock
366 - 760	C	Very Dense Soil and Soft Rock
365 - 183	D	Stiff Soil
<183	E	Soft Clay Soil

Table 2: Site classification using Vs30 from Eurocode 8.

Ground type	Description of stratigraphic profile	Parameters		
		$V_{s,30}$ (m/s)	N_{SPT} (blows/30cms)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5m of weaker material at the surface.	>800	_	_
B	Deposits of very dense sand, gravel. or very stiff clay, at least several ten metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 - 800	> 50	>250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 - 360	15 - 50	70 - 250
D	Deposits of loose to medium-dense cohesionless soil (with or without some soft cohesive layers), or of predominantly soft to firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvial laver with V_s values of Type C or D and thickness varying between about 5m and 20m, underlain by stiffer material with V_s >800m/s			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soil clays/silts with a high plasticity index (PI >40) and high-water content.	<100 (indicative)	_	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in Types A - E or S^2			

Whilst ACSW testing can provide profiles to 10 to 15m depth using standard portable sources in typical soils, this range is stiffness dependent and profiles to 20m depth are often obtained in rock. Furthermore, providing there is a general understating of the stratigraphy, it would in most cases be reasonable to assume that stiffness increases with depth allowing and assumed profile below the depth of the survey to be derived.

PEER2012/08 Guidelines for Estimation of Shear Wave Velocity Profiles provides guidance on the extrapolation of Vs profiles beyond the depth of survey for design $V_{s,30}$ values.

Liquefaction Assessment

V_s profiles are increasingly by being used for the assessment of liquefaction potential. A detailed methodology for assessment liquefaction potential from Vs profiles is provided within Andrus & Stokoe 2000 (see Figure 1) and further reviewed in Andrus, Stokoe & Juang, 2004 (see Table 3) confirms the suitability of surface wave methodologies for obtaining Vs profiles for liquefaction assessment.

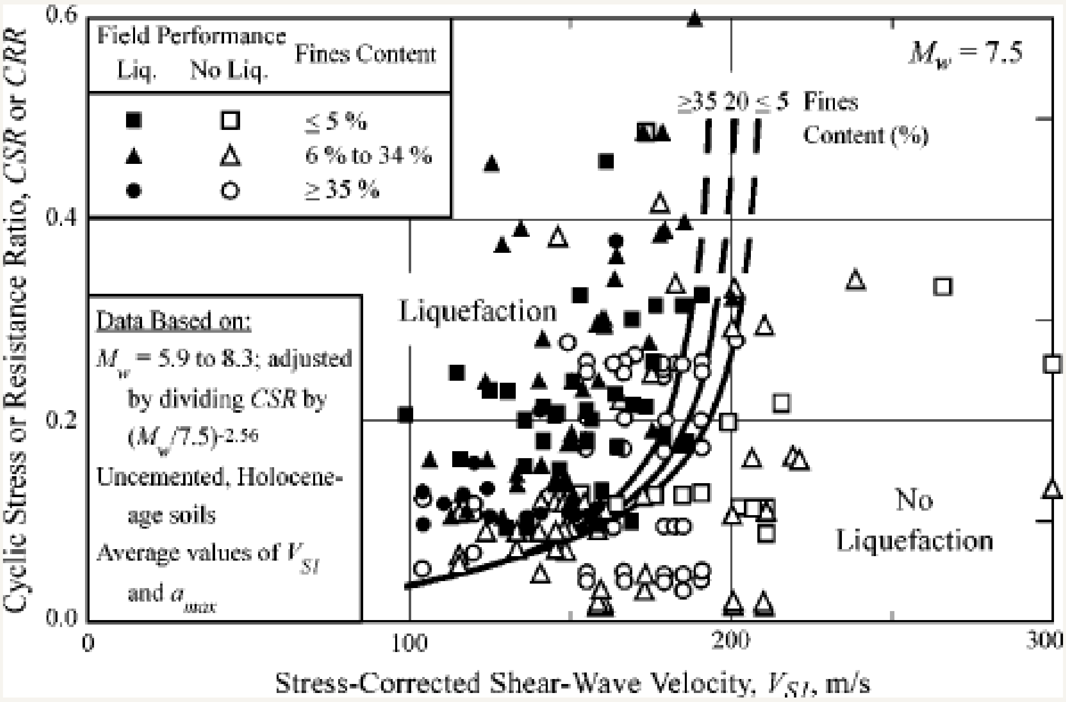

Figure 1: Example of liquefaction assessment approach using Vs from Andrus & Stokoe, 2000

Table 3: Review of methodologies for obtaining Vs profile for liquefaction assessment from Andrus, Stokoe & Juang, 2004

Feature	Measurement Method: Crosshole	Downhole & Seismic Cone Penetrometer	Suspension Logger	Spectral Analysis of Surface Waves	Surface Reflection/ Refraction
Number of holes required	2 or more	1	1	None	None
Quality control and repeatability[1]	Good	Good	Good	Good to fair; complex interpretation technique at sites with large velocity contrasts	Fair; often difficult to distinguish shear wave arrival
Resolution of variability in stiffness of soil deposits[2]	Good; constant with depth	Good to fair; decreases with depth	Good at depth; poor very close (3 to 6 m) to the ground surface	Good to fair; decreases with depth; provides good global average	Fair to poor; provides coarse global average
Major component of particle motion or wave propagation in vertical direction?	Yes, with vertically polarized shear waves	Yes, with test depth greater than distance between hole and shear-beam source	Yes, with refracted shear waves traveling parallel to vertical borehole	Yes, with vertical source	Yes, with horizontal source for reflection and vertical source for refraction
Limitations	Possible refraction problems; senses stiffer material at test depth; most expensive test method	Possible refraction problems with shallow layers; wave travel path increases with depth	Fluid-filled hole required; may not work well near the surface in cased holes and soft soils	Horizontal layering assumed; poor resolution of thin layers and soft material adjacent to stiff layers; no samples recovered	In refraction test, only works for velocity increasing with depth; no samples recovered
Other	Highly reliable test; measurements at each depth independent of other depths; well suited for tomographic imaging; independent checking of saturation with com-pression waves is possible	Penetration data also obtained from seismic cone; detailed layered profile with cone	Well suited for deep borehole testing; method assumes shear waves travel in undisturbed soil	Well suited for tomographic imaging large areas and testing difficult to penetrate soils	Well suited for screening large areas; independent checking of saturation with compression waves is possible

[1] Good quality depends on good equipment and procedural details, and good interpretation techniques for all methods.
[2] Resolution depends on test spacing for all methods.

Summary

Published guidance and design codes exists on the application of V_s profile data for seismic and liquefaction assessment. V_s profile data obtained by ACSW testing can provide a rapid and cost- effective means of obtaining representative in-situ V_s profiles, which have been traditionally difficult or expensive to obtain directly, improving the speed and accuracy of seismic and liquefaction assessment for many schemes.

Limitations

This document is intended to indicate potential approaches for the use of ACSW data by suitably qualified geotechnical engineers and part of a general design review. It may be subject to periodic review and change. No guarantees of accuracy are made and where necessary original references and relevant design guidance should be reviewed. All ACSW test data should reviewed against all available information on ground conditions as part of an appropriately scoped ground investigation.

References

- Guidance Note SSGN002 – Application of ACSW data
- Guidance Note SSGN010 - Description and limitations of ACSW technique
- ASCE 7-10 Minimum Design Loads for Buildings and Other Structures
- Andrus R D & Stokoe K H, 1999 Liquefaction resistance based on shear wave velocity Proceedings of the TRB Workshop on New Approaches to Liquefaction Analysis, Washington, DC, January 10, 1999
- Andrus R D & Stokoe K H, 2000 Liquefaction resistance of soils from shear-wave velocity
- Journal of Geotechnical and Geoenvironmental Engineering
- Andrus R D, Stokoe K H & Juang C H, 2004 Guide for shear-wave-based liquefaction potential evaluation Earthquake Spectra, Volume 20, No. 2, pages 285–308, May 2004 Earthquake Engineering Research Institute
- Eurocode 8 - EN1998-1:2004 Design rules for structures for earthquake resistance - general rules, seismic actions and rules for buildings
- PEER2012/08 Guidelines for Estimation of Shear Wave Velocity Profiles