Appendix C
Geophysical Survey Report

Report
prepared for

Pells Sullivan Meynink

On behalf of

Eurobodalla Shire Council

SEISMIC REFRACTION SURVEY
Batemans Bay, NSW

June 2021 ETS Report No ET524.01

Report prepared by:
Earth Technology Solutions Pty Ltd
ABN 12 078 325 658
35 O'Keefe Crescent
Eastwood NSW 2122

Ph: 02 9804 1752

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1.0 INTRODUCTION

At the request of Pells Sullivan Meynink (PSM) on behalf of Eurobodalla Shire Council, seismic refraction testing was completed at sites at Surfside, Long Beach and Tomakin, NSW.

The seismic survey was undertaken as part of an investigation for sediment erosion at these sites. The objective of the seismic study was to provide the subsurface seismic velocity distribution to assist the assessment of the bedrock profile and general subsurface conditions at each site.

A single seismic refraction line was completed at each site as close as possible to the indicated preferred positions, given any minor site and access constraints. A site plan is provided in Figure 1 which shows the location of each seismic line on aerial photographs of the sites.

The coordinates of the start and end points of each of the seismic lines, are listed in section 4.0, and are also shown on the interpreted seismic sections.

The fieldwork was carried out from the 22nd to 24th June 2021. The seismic data acquisition was carried out in accordance with the standard engineering seismic practice as described below.

2.0 EQUIPMENT

2.1 Seismograph

Geometrics STRATAVISOR 48 channel engineering seismographs were used. This unit has internal calibration, paper printer and hard and floppy disc drive capability. A sampling interval of 0.064 milliseconds was used and typically a record length of 120 millisecond.

2.2 Geophones

The geophones used for the survey were Geospace GS11D, with a natural resonant frequency of 8Hz. A rigid coupling with the ground was obtained with 75mm tapered spikes on the geophone base. The seismic refraction testing was completed using a linear array of up to 48 geophones, connected via two 24 channel multi-core cables to the seismograph.

2.3 Seismic Source

A triggered 14lb sledge hammer impacting an aluminium strike plate was used as the seismic source. A number of impacts were stacked until sufficient quality seismic data was achieved. Typically between 5 and 15 impacts were required, depending on the position within the spread and the level of background noise.

In general the background noise was relatively low with minimal traffic, and relatively low wave energy. The data acquisition at the Surfside site was impacted by some heavy vehicles on the adjacent Wharf Road, however sufficient breaks in traffic at this site enabled very good quality data to be acquired.

3.0 FIELD PROCEDURES

3.1 Geophone and Source Point Configurations

A 3m geophone spacing was used with a source spacing of 9m for the Surfside profile, whilst at the remaining sites a 2m geophone spacing and 12m shot spacing was considered more appropriate. The end source points were generally external - undertaken 1.5m beyond the end geophone. Typically 3 to 4 offset source points were used for each spread at approximately 13m, 25m, and 45m from the end shots were access permitted.

Generally access for the offset source points was very good. Typically 15 to 20 seismic source positions were used for each full spread resulting in reversed coverage seismic data with source-receiver offsets of over 150m.

3.2 Positioning

The seismic lines were positioned based on the lines indicated on aerial photo plans provided by PSM. Some minor repositioning of some of the seismic lines were required to avoid surface features.

Generally the ground surfaces were relatively flat. Surface elevations along each seismic line were surveyed by the seismic crew and tied in to adjacent State Survey Marks to allow reduction to AHD. Positioning along the lines during the seismic survey was maintained using 100m tapes along the ground surface.

3.3 Records and Documentation

All seismic data were recorded on hard drive and copied to field computer. A complete set of seismic data and field records has been archived.

4.0 SUMMARY OF SEISMIC LINES COMPLETED

A summary of the seismic refraction work completed is provided below.

Line	Start & End	Distance	Position: MGA56 & AHD(m)		
			Easting	Northing	Elevation
Surside (South)	Start	0m	245837	6045210	1.2
	End	123m	245928	6045132	0.8
Surfside (North)	Start	0m	246579	6045591	2.4
	End	24m	246556	6045588	2.3
Long Beach	Start	0m	249700	6045510	2.3
	End	184m	249516	6045530	2.6
Tomakin	Start	0m	246193	6031078	4.2
	End	26m	246181	6031101	4.1

5.0 INTERPRETATION PROCEDURES

The digital seismic records were examined and the first arrival times were determined using REFRACT2006 software. Generally the data was considered of good to very good quality signal to noise.

The seismic data were interpreted using the interpretation program REFRACT 2006, which is based on the Intercept Time Method and the Reciprocal Method in accordance with accepted engineering seismic practice.

Following manual identification and editing of the travel-times of the first arrival seismic energy. As the seismic source was surface impacts no shot depth corrections were required. Reciprocal time checks were determined automatically and edited manually to reduce any reciprocal time errors. The interpretation continued with segmentation of the T-X graph to identify individual layers. Velocity analysis followed using the computed Minus-Time Graph, derived from the reverse overlapped phantomed data for each layer. Least squares fitted lines were manually selected from each refractor, allowing identification of lateral velocity changes along the profile, and the velocities were computed.

The time depths and layer thicknesses, which were computed automatically, were checked, edited to remove any obvious errors, and any highly irregular layer surfaces manually smoothed.

The final output of the seismic refraction method is an interpreted seismic section, which is a 2 dimensional representation of the earth beneath the survey line. Discrete layers of differing seismic velocity were interpreted with measured lateral velocity variations indicated within each layer.

The surface elevations along each seismic line as measured by the project surveyor were input into REFRACT 2006 to allow reduction of the interpreted seismic sections to AHD.

6.0 RESULTS

The interpreted seismic sections for each of the seismic refraction lines completed are provided in Figures 2 to 5. The seismic lines for Surfside (south) and Long Beach are presented at a natural scale of 1:500 (A3) and at 1:250 (A3) for the shorter lines at Surfside (North) and Tomakin. The distance shown on the x-axis is the distance along the line from the start of each seismic line.

The interpreted seismic sections were also provided to PSM in .DXF format as output by REFDRAW, to enable inclusion of these seismic sections with other geotechnical data if required.

Typically three to four layers of differing seismic velocity were interpreted with interpreted seismic velocities range from 300m/s in the surface layer to 3500m/s at depth.

As with all seismic methods, seismic refraction has some inherent limitations in effectively representing subsurface conditions in all geological environments. Some of these issues are presented in Appendix A – Guide to the Use of Interpreted Seismic Sections. This offers some general information on the seismic refraction method including the precision and accuracy of results and the possible effects of violations of the assumptions on which the method and interpretation procedure is based.

A brief summary of the interpreted seismic velocity ranges for each seismic layer identified, and the key points and limitations of the seismic interpretations are provided for each seismic line. A general geological interpretation for each seismic layer is provided based solely on the seismic velocity range and general site observations. The interpretations should be correlated with any available geological mapping and borehole information where possible.

Surfside South (Figure 2)

The seismic line at Surfside was positioned along the beach at approximately the high tide mark. The work was undertaken at or near low tide.

There is some evidence in the seismic travel-time data of velocity increase with depth within Seismic Layers 2 and 3.

The following geological interpretations have been based on the interpreted seismic velocities obtained in comparison with previous seismic surveys. The results obtained are summarised below in terms of a generally layered earth.

Layer	Seismic Velocity (m/s)	General Geological Interpretation (Based on seismic velocity ranges)
1	1500–1550	Saturated SAND Medium Dense to Dense
2	2200–2800	HW to MW ROCK, Moderate to High strength.
3	2800–3500	SW to Fresh ROCK, High to Very High strength.

The bedrock profile (Seismic Layer 2) is interpreted at a level varying from approximately RL-1.5m (approx 2.3m depth) in the South East of the seismic line and deepens to generally RL -6m (approx 8m depth) towards the North West.

Surfside North (Figure 3) adjacent to Cullendulla Reserve

Seismic Layers 2 and 3 are relatively thin, and the velocities of these layers are based on limited data (hatched areas on the interpreted seismic sections)

The following geological interpretations have been based on the interpreted seismic velocities obtained in comparison with previous seismic surveys with borehole correlations and the results obtained are summarised below in terms of a generally layered earth.

Layer	Seismic Velocity (m/s)	General Geological Interpretation (Based on seismic velocity ranges)
1	300–350	Dry SAND, Medium Dense to Dense
2	1100-1350	Partially saturated to saturated SAND, M Dense to Dense
3	1950–2200	EW to HW ROCK, Low to Moderate strength.
4	2250–2400	HW to SW ROCK, Moderate to High strength.

The bedrock profile (Seismic Layer 3) is interpreted at a level varying from approximately RL-1.5m to RL-3m (approx 3.5m to 6m depth).

Long Beach (Figure 4)

There is some evidence in the seismic travel-time data of velocity increase with depth within Seismic Layer 4.

The following geological interpretations have been based on the interpreted seismic velocities obtained and the results obtained are summarised below in terms of a generally layered earth.

Layer	Seismic Velocity (m/s)	General Geological Interpretation (Based on seismic velocity ranges)
1	300-450	Dry SAND, Medium Dense to Dense
2	600–1450	Partially saturated to saturated SAND M Dense to Dense
3	1700–1950	Highly Fractured EW to MW ROCK, Moderate to High strength, or potentially very Dense SAND /GRAVEL with ROCK boulders.
4	1900–2300	MW to SW ROCK, Moderate to High strength.

The seismic velocities of Layer 3 are not unambiguously indicative of a ROCK profile and could potentially represent very dense saturated SAND/GRAVEL. However given the nature of the highly fractured and weathered rock reefs visible on the adjacent headland and just offshore from that section of the beach, it is considered that this layer represents highly fractured and/or weathered rock.

Seismic Layer 3 is interpreted at a level varying from approximately RL-0.5m to RL-2.5m (approx 3.5m to 5m depth).

Tomakin (Figure 5)

The following geological interpretations have been based on the interpreted seismic velocities obtained in comparison with previous seismic surveys.

Layer	Seismic Velocity (m/s)	General Geological Interpretation (Based on seismic velocity ranges)
1	350	Dry SAND, Medium Dense to Dense
2	600–950	Partially saturated SAND M Dense to Dense
3	1550–1650	Highly Fractured EW to MW ROCK, Moderate to High strength, or potentially Dense to very DENSE SAND /GRAVEL.
4	2000–2100	EW to MW ROCK, Low to Moderate strength.

Again the seismic velocities of Layer 3 are not unambiguously indicative of a ROCK profile and could potentially represent dense saturated SAND or GRAVEL. However given the highly fractured and weathered rock reef visible immediately offshore from this section of the beach, it is considered that this layer represents highly fractured and/or weathered rock or at least a significant concentration of ROCK boulders. This layer varies from approximately 2m to 4m thick.

Seismic Layer 4 is interpreted at a level varying from approximately RL-3m to RL-5.5m (approx 7m to 9.5m depth).

7.0 CONCLUSIONS

Seismic refraction testing was successfully completed along the designated profiles and the seismic data acquired is considered generally of good quality. This seismic study has generally delineated 4 layers of differing seismic velocity within the shallow subsurface with interpreted seismic velocities range from 300m/s in the surface layer to 3500m/s at depths of up to 15m.

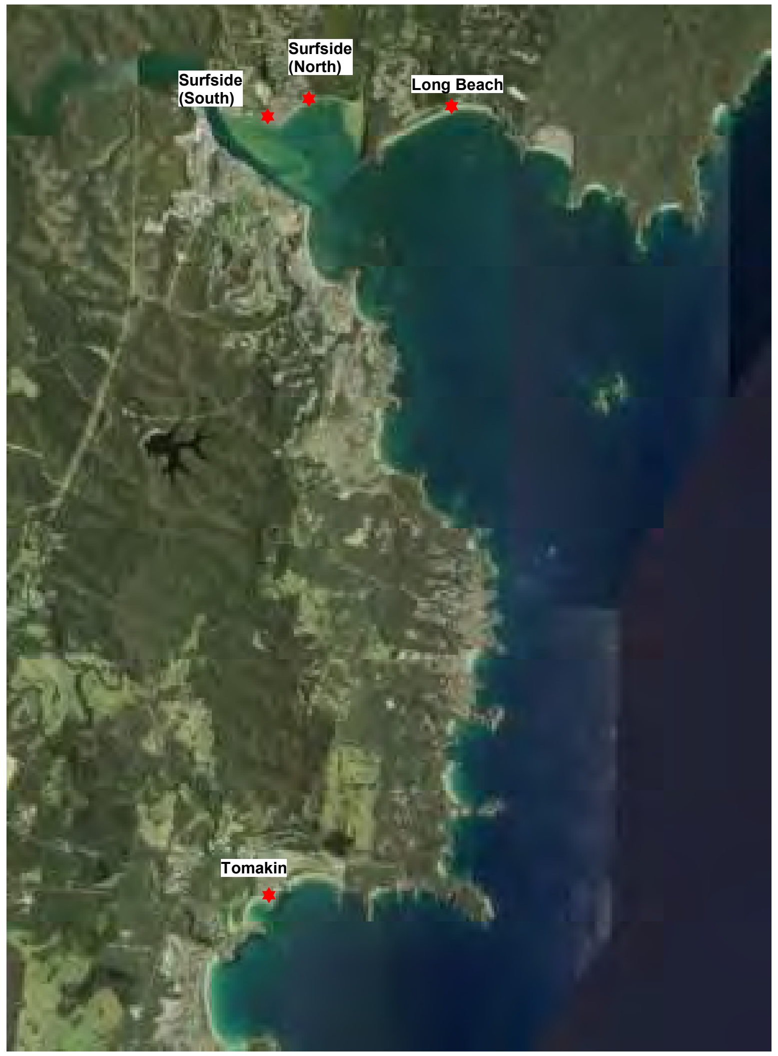
Whilst these seismic velocity ranges are indicative of and consistent with a range of material from dry SAND through to Fresh High strength ROCK and a general interpretation based on the interpreted seismic velocity ranges have are provided. There is some ambiguity of the geological interpretation of Seismic Layer 3 at Long Beach and Tomakin due to the intermediate seismic velocities obtained.

This seismic information should be correlated, where possible, with any boreholes or other geotechnical information, to increase the understanding of the subsurface conditions. Appendix A – Guide to the Use of Interpreted Seismic Sections is provided to offer some general information on the seismic refraction method including the precision and accuracy of results and should be read before using the seismic sections.

Surfside Beach (South)

Surfside Beach (North - adjacent Cullendulla Reserve)

Overall Site Plan



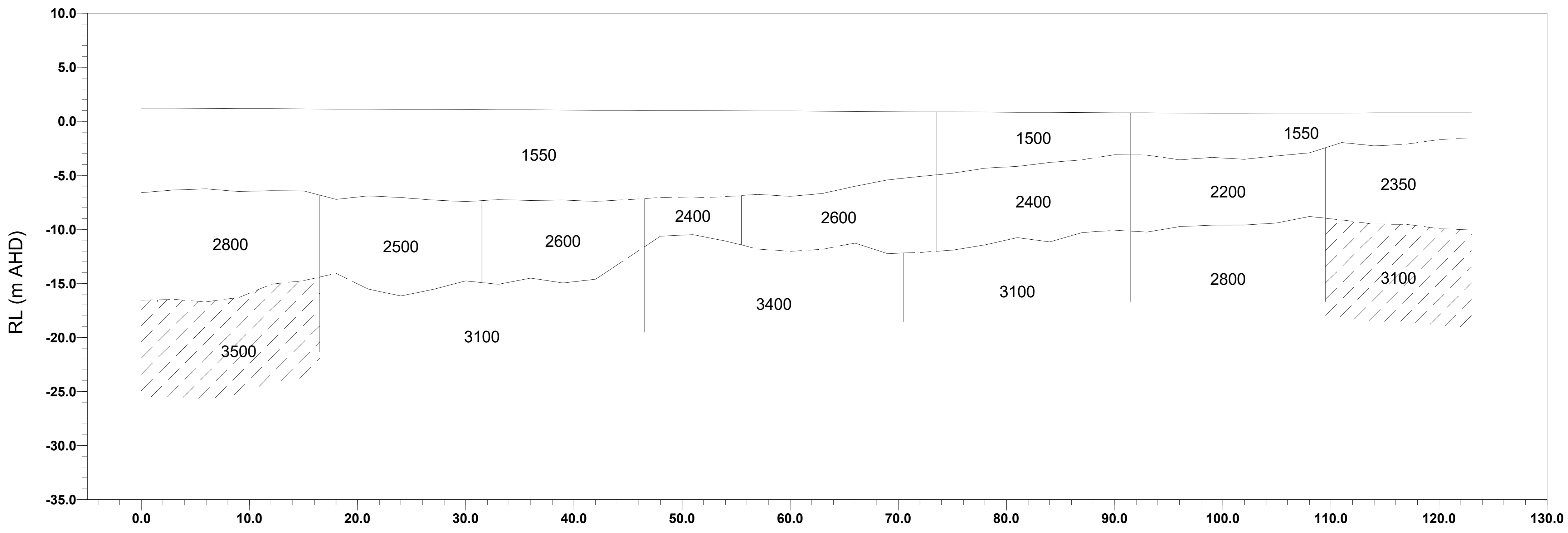
Long Beach

Tomakin

Location of Seismic Lines and coordinates of End Points

Pells Sullivan Meynink / Eurobodalla Shire Council Seismic Refraction Survey Selected Sites, Batemans Bay, NSW Site Plan - Showing Location of Seismic Lines	Earth Technology Solutions Pty Ltd ABN 12 078 325 628 Job No.: ET524.1 Date : 29/06/21 ETS
	Figure 1

INTERPRETED SEISMIC SECTION : SURFSIDE (SOUTH)



North West
0m (start)
E: 245837mE
N: 6045210mN RL: 1.2m AHD

South East
123m (end)
E: 245928mE
N: 6045132mN RL: 0.8m AHD

Scale H 1:500 (@ A3)
V 1:500

LEGEND

Seismic velocity (m/s) and interpreted refractor boundary based on reciprocal method minus time and time depths 1800

Seismic velocity (m/s) based on reciprocal method minus times, interpreted refractor boundary based on reciprocal method time depths (solid line) or limited data* [(2), (3)] (dashed line) 1800

Seismic velocity based on limited data* [(1), (3)] (hatched area) and the value of the hatched area is the same as the adjacement minus times velocity 1800

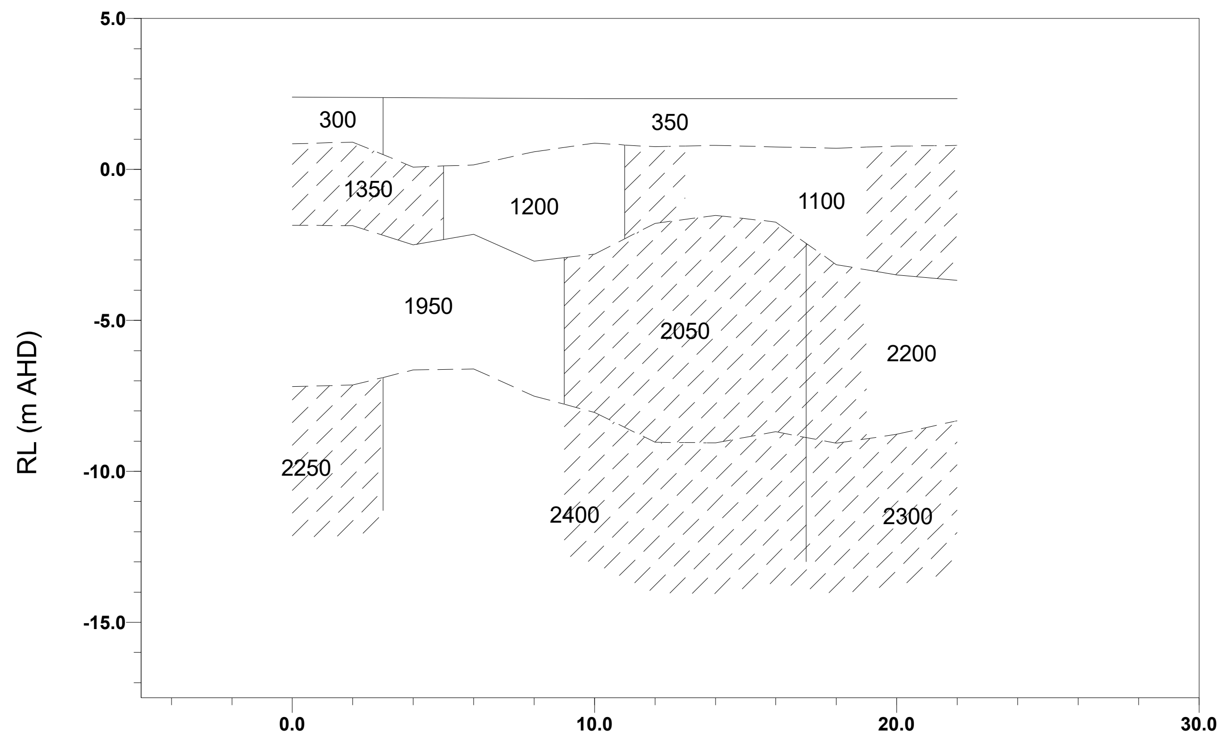
Seismic velocity (m/s) based on limited data* [(1), (3)] (hatched area) and interpreted refractor boundary based on limited data* [(1), (2) & (3)] (dashed line) 1800

Lateral seismic velocity boundary ....

* NB - Limited data includes harmonic mean velocity (1), interpolated time depth (2) or edited data (3)

EARTH TECHNOLOGY SOLUTIONS PTY LTD ABN 12 078 325 658			ETS
AUTHORISED : PF DATE : 29 June 2021	Pells Sullivan Meynink / Eurobodalla Shire Council SEISMIC REFRACTION SURVEY Interpreted Seismic Section SURFSIDE BEACH (South)		
DRAWN BY PF FOR ETS	REPORT ET524/ 1	SCALE H 1:500 @ A3	Figure No. 2

INTERPRETED SEISMIC SECTION : SURFSIDE (NORTH)



SEISMIC LINE DISTANCE (m)

East
0m (start)
E: 246579mE
N: 6045591mN RL: 2.4m AHD

West
22m (end)
E: 246556mE
N: 6045588mN RL: 2.3m AHD

Scale H 1:250 (@ A3)
V 1:250

LEGEND

Seismic velocity (m/s) and interpreted refractor boundary based on reciprocal method minus time and time depths 1800

Seismic velocity (m/s) based on reciprocal method minus times, interpreted refractor boundary based on reciprocal method time depths (solid line) or limited data* [(2), (3)] (dashed line) 1800

Seismic velocity based on limited data* [(1), (3)] (hatched area) and the value of the hatched area is the same as the adjacement minus times velocity 1800

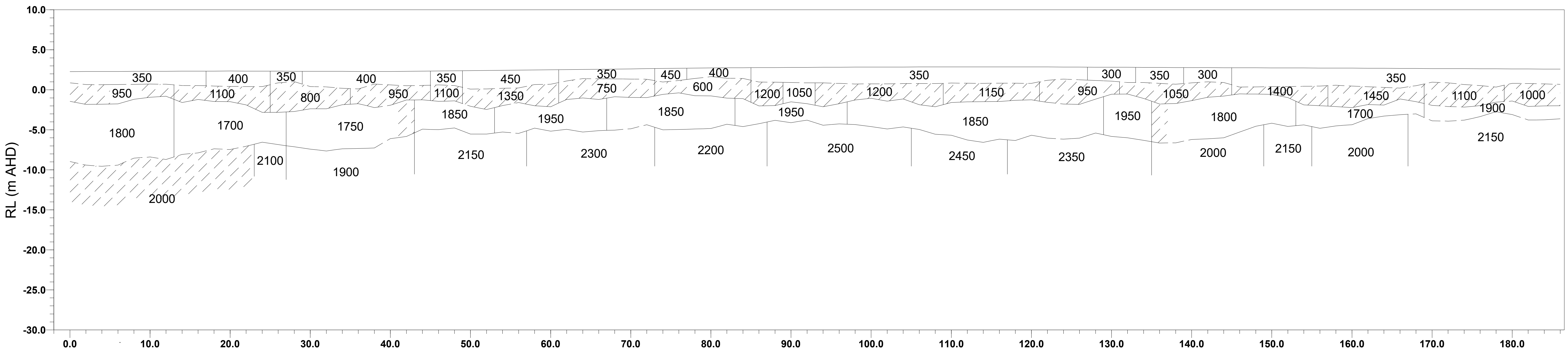
Seismic velocity (m/s) based on limited data* [(1), (3)] (hatched area) and interpreted refractor boundary based on limited data* [(1), (2) & (3)] (dashed line) 1800

Lateral seismic velocity boundary ....

* NB - Limited data includes harmonic mean velocity (1), interpolated time depth (2) or edited data (3)

EARTH TECHNOLOGY SOLUTIONS PTY LTD ABN 12 078 325 658				ETS
AUTHORISED : PF DATE : 29 June 2021	Pells Sullivan Meynink / Eurobodalla Shire Council SEISMIC REFRACTION SURVEY Interpreted Seismic Section Surfside Beach (North) near Cullendulla Reserve			
DRAWN BY PF FOR ETS	REPORT ET524/ 1	SCALE H 1:500 @ A3	Figure No. 3	

INTERPRETED SEISMIC SECTION : LONG BEACH



SEISMIC LINE DISTANCE (m)

East
0m (start)
E: 249700mE
N: 6045510mN RL: 2.3m AHD

West
184m (end)
E: 249516mE
N: 6045530mN RL: 2.6m AHD

Scale H 1:500 (@ A3)
V 1:500

LEGEND

Seismic velocity (m/s) and interpreted refractor boundary based on reciprocal method minus time and time depths 1800

Seismic velocity (m/s) based on reciprocal method minus times, interpreted refractor boundary based on reciprocal method time depths (solid line) or limited data* [(2), (3)] (dashed line) 1800

Seismic velocity based on limited data* [(1), (3)] (hatched area) and the value of the hatched area is the same as the adjacement minus times velocity 1800

Seismic velocity (m/s) based on limited data* [(1), (3)] (hatched area) and interpreted refractor boundary based on limited data* [(1), (2) & (3)] (dashed line) 1800

Lateral seismic velocity boundary ....

* NB - Limited data includes harmonic mean velocity (1), interpolated time depth (2) or edited data (3)

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ETS

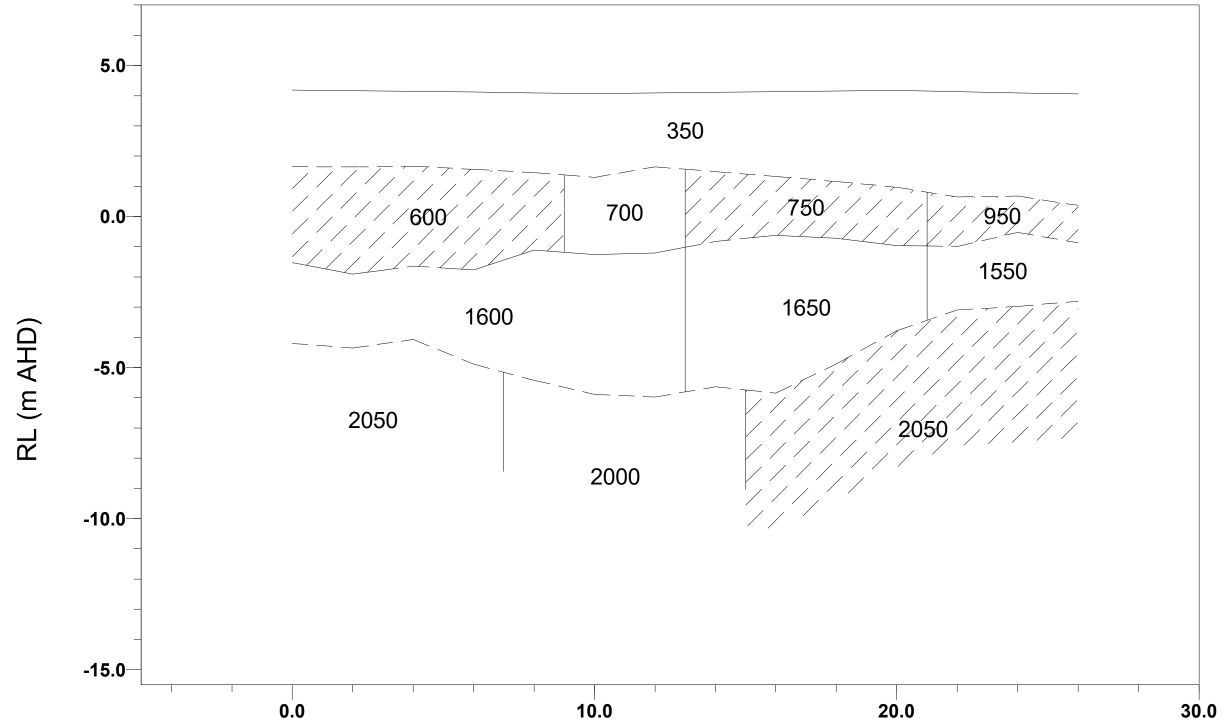
AUTHORISED : PF

DATE : 29 June 2021

Pells Sullivan Meynink / Eurobodalla Shire Council
SEISMIC REFRACTION SURVEY
Interpreted Seismic Section
LONG BEACH

DRAWN BY PF FOR ETS	REPORT ET524/ 1	SCALE H 1:500 @ A3	Figure No. 4

INTERPRETED SEISMIC SECTION : TOMAKIN



South
0m (start)
E: 246193mE
N: 6031078mN RL: 4.2m AHD

North
26m (end)
E: 246181mE
N: 6031101N RL: 4.1m AHD

Scale H 1:250 (@ A3)
V 1:250

LEGEND

Seismic velocity (m/s) and interpreted refractor boundary based on reciprocal method minus time and time depths 1800

Seismic velocity (m/s) based on reciprocal method minus times, interpreted refractor boundary based on reciprocal method time depths (solid line) or limited data* [(2), (3)] (dashed line) 1800

Seismic velocity based on limited data* [(1), (3)] (hatched area) and the value of the hatched area is the same as the adjacement minus times velocity 1800

Seismic velocity (m/s) based on limited data* [(1), (3)] (hatched area) and interpreted refractor boundary based on limited data* [(1), (2) & (3)] (dashed line) 1800

Lateral seismic velocity boundary ....

* NB - Limited data includes harmonic mean velocity (1), interpolated time depth (2) or edited data (3)

EARTH TECHNOLOGY SOLUTIONS PTY LTD ABN 12 078 325 658			ETS
AUTHORISED : PF DATE : 29 June 2021	Pells Sullivan Meynink / Eurobodalla Shire Council SEISMIC REFRACTION SURVEY Interpreted Seismic Section Tomakin		
DRAWN BY PF FOR ETS	REPORT ET524/ 1	SCALE H 1:500 @ A3	Figure No. 5

APPENDIX A

A1 GUIDE TO THE USE OF INTERPRETED SEISMIC SECTIONS

The results of seismic refraction surveys are presented as vertical sections beneath the line of traverse. These sections show a two-dimensional distribution of seismic velocities, which have been interpreted from first arrival travel time data obtained in the field.

The following general summary is intended to assist in the understanding of the interpreted seismic sections provided.

A1.1 Methods Of Interpretation

First arrival travel times obtained for individual source locations representing the arrival at individual detectors of seismic waves which have travelled through the earth via least-time paths are determined interactively from the digital seismic field records. These times are plotted against distance from the source, as travel-time curves. These times are examined, reviewed and edited as necessary.

Further quantitative seismic interpretation, aimed at providing subsurface depth and velocity information, is carried out using the intercept time or reciprocal methods as appropriate. The interpretation method applied is determined by the field procedure used, the nature of the subsurface at the site, and by the objectives of the seismic study.

The interpretation provides a simplified seismic picture of the subsurface and depends on a number of assumptions about its nature. The major assumptions are:

i) The subsurface essentially consists of a series of discrete uniform layers which may vary laterally in velocity,
ii) The boundaries between these layers are distinct. For the simpler methods of interpretation, these boundaries are also assumed to be planar, but can be highly irregular,
iii) The seismic velocities of successive layers increase with depth,
iv) Each layer is of sufficient thickness to critically refract energy, and to produce a refracted wave arrival at the surface of sufficient energy to be detected as a first arrival.

These assumptions demonstrate requirements of the interpretation procedure for ideal conditions of which all of the requirements are unlikely to be fulfilled in reality. The extent to which each assumption is valid may vary from site to site and within a site. Consequently, at all sites, interpreted seismic sections are a simplification of the actual subsurface velocity distribution. The degree of simplification depends on the interpretative method used, the amount of data available for analysis and the extent to which the basic assumptions are violated at a site.

Some violations of the basic assumptions, such as diffractions from large irregularities, and non-critical refractions, may be observed in the seismic data or may be undetectable. Consequently the interpretation process is partly subjective; other interpretations of the data are possible and may differ considerably from the interpretation presented.

The effects of common violations of the assumptions are discussed in Section A1.3, below. Other effects, which may be relevant to the understanding of the seismic sections, are discussed in Section A1.4.

It should be noted that, at a given site, these effects can occur in virtually any combination and that, as a result, even highly complex subsurface conditions may give rise to relatively simple-looking seismic sections.

A1.2 Precision And Accuracy Of Results

A given seismic velocity does not necessarily uniquely determine the engineering properties of an earth material, even for the one rock type. For example a medium strength rock may have the same seismic velocity as a mixture of extremely low strength rock, and boulders or corestones of very high strength rock.

Moreover a relatively small proportion of extremely low strength material can dramatically lower the composite seismic velocity. For example a material composed of 50% boulders with seismic velocity 4000 m/s, and 50% of material with seismic velocity 800 m/s, then the composite velocity is lowered to 1333 m/s.

Interpreted velocities are usually shown on the seismic sections to the nearest 50 or 100 m/s. Interpreted velocities, as a measure of the actual field velocities, are not regarded as being accurate to better than ± 10%, but can be independently calibrated using drilling or excavation.

Calculated layer thickness' are subject to a similar level of experimental error. This has a cumulative effect on interpreted depths to deeper interfaces. For example, the interpreted depth to the base of the first layer defined is often considered accurate to better than ± 10%, however depths to deeper layers may not be accurate to better than ± 30% (Dampney and Whiteley, 1978).

These experimental errors are inherent in the procedure and must be taken into account in any use which is made of the seismic sections e.g., in estimating the volume of material represented by each layer in a proposed excavation.

A1.3 Effects Of Violation Of Assumptions

A1.3.1 Assumption of Discrete, Uniform Layers.

The most common problems are:
i) continuous increase in velocity with depth.
ii) inhomogeneity below the scale of resolution of the survey.

The first of these occurs in many geological settings, particularly in sediments, or highly weathered sedimentary rocks. It can be allowed for in a number of ways but contributes to the uncertainty in depth calculations based on constant layer velocity. Often the seismic sections show the "average" velocity of the layer.

For the second type of problem, under ideal conditions a refraction study can resolve features as small as 1.5-2 times the geophone spacing. In general, however, the practical limit of resolution is 2-3 times this spacing although the presence of inhomogeneity may be observable from the travel time curves, without more detailed interpretation being possible.

Calculated seismic velocities are averages which represent the bulk properties of the interpreted layers. It is possible for this averaging to conceal major, local variations in velocity on a scale up to at least twice the geophone spacing. The likely nature of these variations depends on the geological setting of the site but clearly boulder conditions and rapid lateral changes in weathering or lithology would be among the difficult sites.

A1.3.2 Assumptions of Distinct Boundaries

Real geological boundaries, especially those related to weathering, are often gradational and/or irregular. The seismic method inevitably disguises gradation and smoothes irregularity. The importance of this varies from site to site, but it is common for interpreted seismic boundaries to appear at an intermediate level somewhere between the limits of gradation. For example, if there is an irregular boundary between fresh and highly weathered rock, the interpreted boundary frequently appears at a level some metres below the highest points at which fresh rock is found.

A1.3.3 Assumption of Increasing Velocity with Depth

This assumption may be violated for a number of different reasons and such violations (termed velocity reversals, or velocity inversions) often cannot be detected from the travel time data alone. It may be possible (in some, but not all cases) to infer them from the geological setting, from borehole information, or from surface-to-borehole seismic. If the inversion layers do not persist laterally their effect may also be observable on the travel-time data.

In general, it is not possible to allow for a velocity inversion in the interpretation unless there is an independent means of estimating both the thickness and the velocity of the layer. If an undetected velocity reversal is present, all calculated depths below the reversal will be in error. In particular, depths to underlying high velocity layers may be significantly over-estimated. Areas where strong layers overlay weaker layers, for example, a basalt flow overlying sediments or weathered rock, or sandstone overlying coal, are sites where these problems sometimes occur.

A1.3.4 Assumption of Detectability

Two main types of violation occur:

i) When a layer is too thin to transmit the seismic wave.
ii) When a layer transmits the wave but is not detected because waves from a deeper, higher velocity layer reach the detector first.

The first type of problem may occur in many geological settings and means that relatively thin, higher velocity layers may occur undetected within lower velocity materials. “Thin” in this context is defined in terms of seismic detectability and can imply thickness of the order of 1-1.5m. The effect cannot be detected from the surface seismic refraction data alone, but may be inferred from borehole information, surface mapping or surface-to-borehole seismic. If such a layer were thick enough to be detected, it would form a velocity reversal (see Section A1.3.3).

The second type of problem (termed a hidden layer or blind zone) may be inferred from the geological setting, borehole data or sometimes from the seismic refraction data. If it is not detected, it also results in erroneous depth calculations in the interpreted section; normally the calculated depth to deeper interfaces is underestimated. In theory, between every pair of layers there could be a hidden layer (or blind zone), whose maximum thickness may be calculated for a range of intermediate velocities.

A1.4 Other Factors

Other common factors may lead to differences between the surface seismic refraction model and reality. While not strictly due to assumptions made in interpretation, they should still be taken into account, if the site conditions dictate, in any further use of the interpreted sections. These factors are:

i) Three-dimensional effects
ii) Effect of water
iii) Anisotropy

A1.4.1 Three-dimensional effects

The interpreted sections are two-dimensional representations and only apply to a narrow zone below the line of traverse typically 5 -10m either side of the seismic line. However, the real subsurface is three-dimensional and as a result significant lateral variations in conditions can occur without being detected, even within a short distance to the side of a traverse. If seismic signals originating from such features are obtained, they may result in the interpreted sections containing features, which are non-existent, displaced from their true position or shown with incorrect velocities. This problem is most common in sites with irregular topography, boulders and highly irregular rock masses.

In some cases three-dimensional effects may be observed by using cross seismic spreads at right angles to the main profile, or additional parallel seismic lines, or from other information.

A1.4.2 Effect of Water

The presence of water can greatly increase the field velocity of materials which have low velocities in the dry condition. The effect is most pronounced in soils or unconsolidated materials and is due to the difference in seismic velocity between air and water (340 m/s and 1470 m/s, respectively). It may however occur to a significant degree in materials with dry velocities as high as 2000-2500m/s. The change is not related to the normal trends of change in material properties with velocity.

Less frequently, it is possible for water saturation to cause a decrease in field velocity, most commonly in low velocity materials where highly expansive clay minerals are present and the material is unconfined. In the marine environment the presence of gas in otherwise water-saturated sediments can lower velocities below that in water.

Velocity changes due to the presence of a water table cannot normally be distinguished from the seismic data alone. The effect may be inferable from the geological setting and the interpreted velocities, but can only be confirmed by drilling.

A1.4.3 Anisotropy

Field velocities may vary with the direction of the seismic line. Usually if the velocity measured in different directions agree to within ± 10% the condition is treated as isotropic. Anisotropy is most common in steeply dipping sediments or metasediments but can occur in other settings. When measured across strike, the velocity is an average for the different materials present. Along strike the higher velocity of the fresher or more competent materials is measured. This effect may be detectable from cross spreads which show a markedly higher or lower velocity than longitudinal traverses. However it may not be detected, depending on the relative orientations of the traverses and the strike of the subsurface materials.

A more subtle form of anisotropy occurs in many sedimentary rocks where the vertical velocity differs from the horizontal velocity. Normally seismic refraction studies provide information on the horizontal velocities which are commonly higher than the vertical velocities. The possible effects of anisotropy are similar to those discussed above in section A1.3

A1.5 References

Dampney, CNG and Whiteley, RJ (1978). Velocity determination and error analysis for the seismic refraction method. Geophysical Prospecting, 28, pp. 1-17.

Dobrin, MG (1976). Introduction to geophysical prospecting. 3rd edition. McGraw-Hill,New York.

Hawkins, LV (1961). The reciprocal method of routine shallow seismic refraction investigations. Geophysics, 26(6), pp. 806-19.

Leung, T.M., Win, M.A., Walker, C.S., & Whiteley, R.J., 1997. A Flexible Algorithm for Seismic Refraction Interpretation Using Program REFRACT, from McCann, D.D., Eddleston, M., Fenning, P.J. & Reeves, G.M (eds), 1997, *Modern Geophysics in Engineering Geology*. Geological Society Engineering Special Publication No. 12, pp 399-407