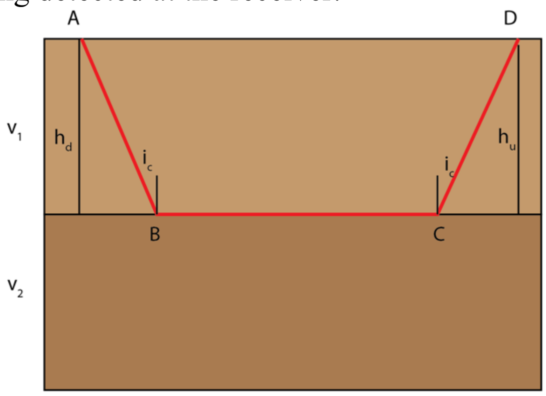
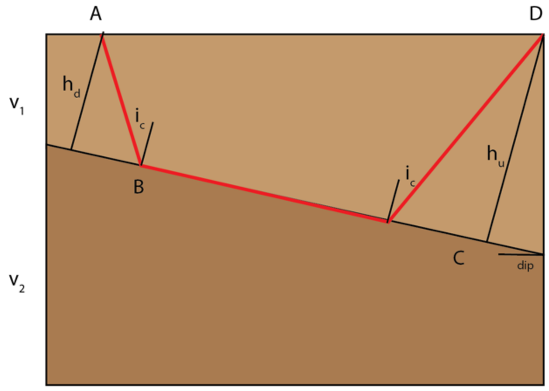
Seismic refraction exercise – Ying Ting Lau

Brief summary of the seismic refraction method

Seismic waves are first generated by a source such as dynamite. The seismic refraction method makes use of the arrival time of refracted head waves at different distances. Refracted head waves travel from the source, reflected from an interface and travel within a deeper layer before being detected at the receiver.

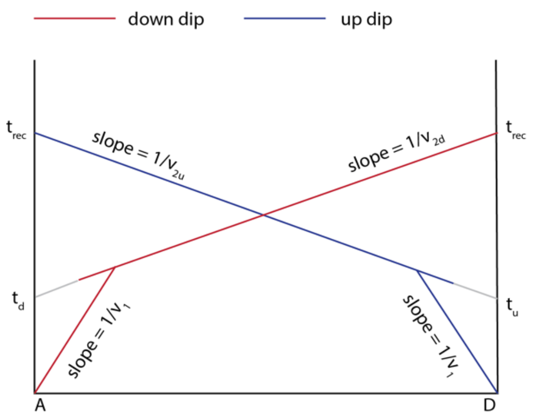


Horizontal layer

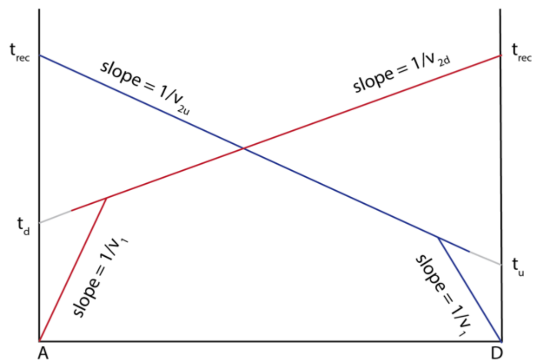


Dipping layer

By collecting data in forward/down dip (start from A) and reverse/up dip (start from D) direction with receivers placed between A and D, we can plot a distance-time graph. For dipping interface, $h_d \neq h_u$ (u and d mean up dip and down dip respectively), as a result $t_d \neq t_u$. Note that t_{rec} remains the same, which refer to the total travel time from A to D. Dipping interface results in an asymmetric graph.



Horizontal layer - symmetrical



Dipping layer - asymmetrical

Using the distance-time plot, we can determine t_d, t_u, v_{2u}, v_{2d} and t_{rec}. Then, by the following equation, we can calculate the dip δ, critical angle i_c, v_2, h_d and h_u.

$$i_c = \frac{1}{2}\left(sin^{-1}\left(\frac{v_1}{v_{2d}}\right) + sin^{-1}\left(\frac{v_1}{v_{2u}}\right)\right) \qquad \delta = \frac{1}{2}\left(sin^{-1}\left(\frac{v_1}{v_{2d}}\right) - sin^{-1}\left(\frac{v_1}{v_{2u}}\right)\right)$$

$$v_2 = \frac{v_1}{\sin i_c}$$

$$h_u = \frac{t_u\, v_1}{2\ \cos i_c} \qquad h_d = \frac{t_d\, v_1}{2\ \cos i_c}$$

Summary

Model	t_d (ms)	t_u (ms)	H_d (m)	H_u (m)	Dip (degrees)	Critical angle (degrees)	V_1 (m/s)	V_2 (m/s)
A	1.97	1.41	1525	1089	-1.10	17.19	1477	4996
B	4.96	4.96	2205	2205	0.00	21.73	826	2230
C	12.03	22.08	22442	41192	0.62	37.72	2952	4825
D	2.97	1.74	3314	1946	-1.92	21.17	2082	5764
E	7637	7592	12.2e+6	12.1e+6	0.04	24.25	2913	7093

Model	Brief interpretation of Layer A
A	Low velocity. Formed by rippable material, could be clay or sand.
B	Very low velocity. Formed by rippable material, could be soil or sand.
C	Moderate velocity. Formed by non-rippable material, could be shale or sandstone.
D	Moderate velocity. Formed by rippable or marginal material, could be clay, coal, shale or limestone.
E	Moderate velocity. Formed by non-rippable material, could be shale or sandstone.

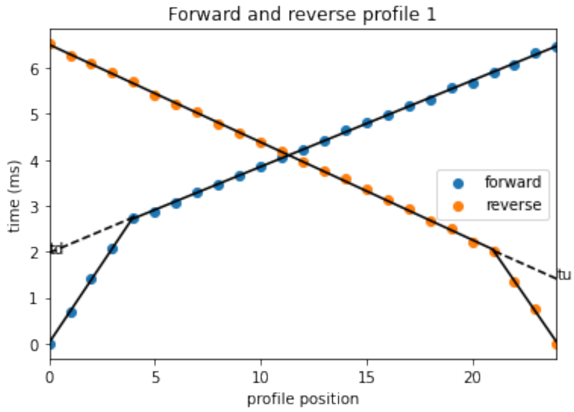
Model	Brief interpretation of Layer B
A	High velocity. Formed by non-rippable material, could be sedimentary or igneous.
B	Moderate velocity. Formed by rippable or marginal material, could be clay, coal, shale or limestone.
C	High velocity. Formed by non-rippable material, could be sedimentary or igneous.
D	Very high velocity. Formed by non-rippable material, could be metamorphic or igneous.
E	Very high velocity. Formed by non-rippable material, could be metamorphic or igneous.

Model	Layer interface
A	The layer is dipping towards the left.
B	The layer is horizontal without dipping.
C	The layer is dipping towards the right.
D	The layer is dipping towards the left.
E	The layer is dipping towards the right.

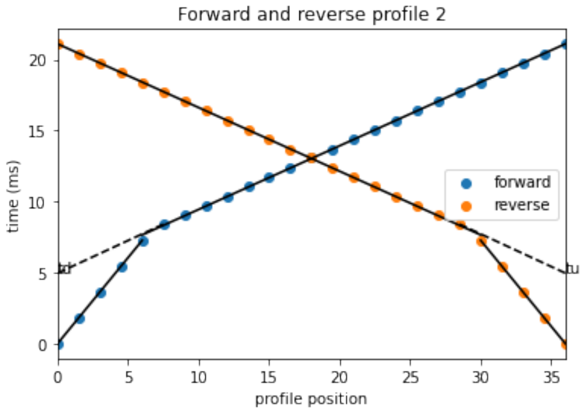
Model	Uncertainties
A	/
B	/
C	The arrival time difference is insignificant for slope interpretation.
D	The travel time is scatter, resulting potential misinterpretation of layer interface arrival time.
E	The unit of time and position should vary from other profile, causing high t and H value.

Distance-time graph

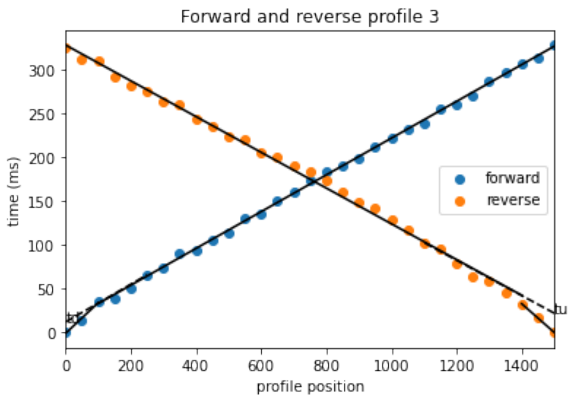
Model A



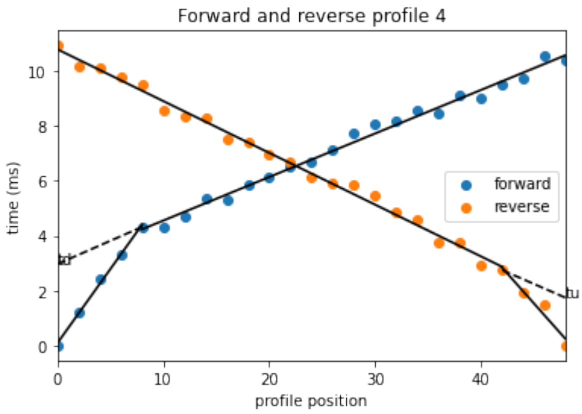
Model B



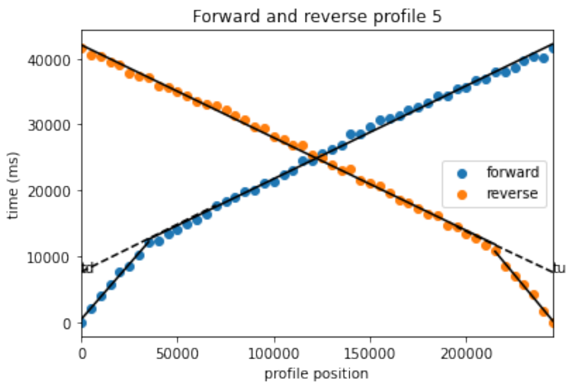
Model C



Model D



Model E



Appendix A
In the supplementary material zip file, there is one step-by-step annotated python script which produce all 5 models' distance-time graph. The annotated script read data from the PROFILE txt files. Graphs and calculations will be generated automatically by running the script using Jupiter notebook.

---Python script---
Seismic refraction exercise.ipynb

---PROFILE txt files---
PROFILE1_forward.txt
PROFILE1_reverse.txt
PROFILE2_forward.txt
PROFILE2_reverse.txt
PROFILE3_forward.txt
PROFILE3_reverse.txt
PROFILE4_forward.txt
PROFILE4_reverse.txt
PROFILE5_forward.txt
PROFILE5_reverse.txt