Fitting higher order polynomials to DST arrival time data sets for high resolution imaging

Introduction

BCE has developed a new DST analysis technique which "best fits" a high order polynomial to arrival time data sets. In this current mathematical design a Kalman filter formulation is utilized to estimate the coefficients of polynomials which "best fit" DST arrival time data sets. The best fit polynomial arrivals are then feed into BCE's FMDSM technique. This technique has the following highly desirable features:

1. Ability to utilize all arrival time estimates irrespective of measurement errors.
2. Ability to process small depth interval (≤ 0.5m) arrival time data sets.
3. Polynomial "best fit" function allows for user specification of desired depth intervals for data interpolation.
4. Facilitates sophisticated data fusion for significantly more accurate DST interval velocity estimation.
5. *RMS*, *MAPE*, R^2, and R^{2C} accuracy parameters facilitate selecting the appropriate polynomial order and quantify the accuracy of the "best fit" polynomial.

Implementation of this technique on both DST onshore and offshore arrival times has resulted in very impressive results. It is the intention of BCE to expand this analytical technique to tomographic modelling and absorption estimation.

On Shore DST Example:

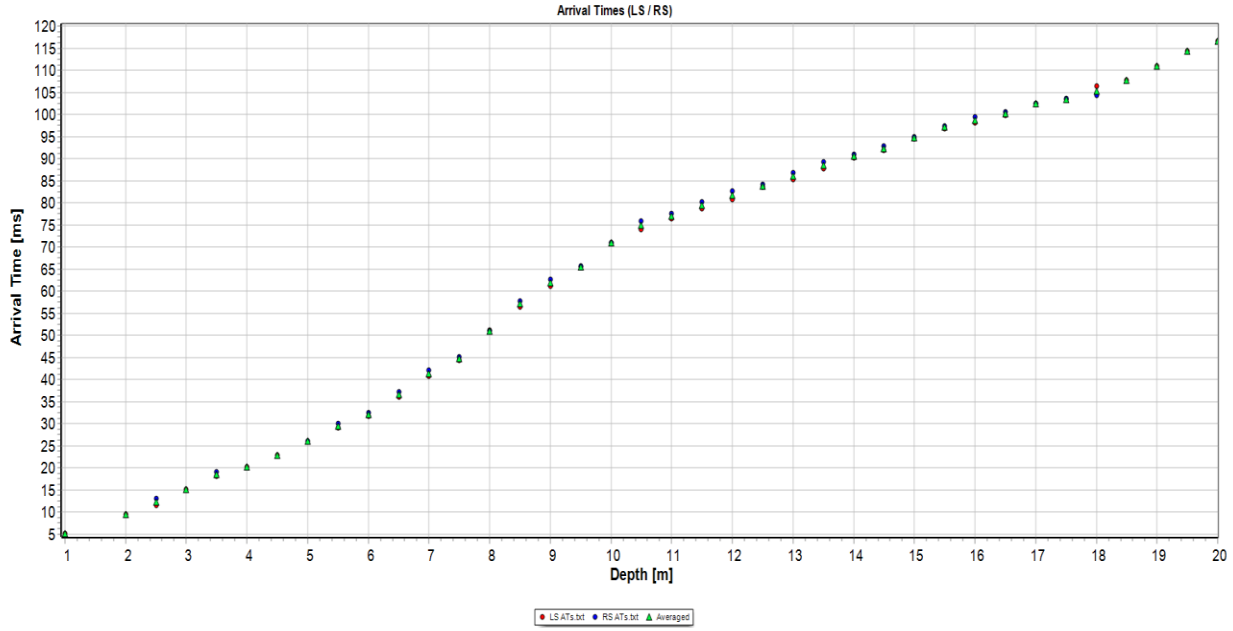


Figure 1. Left Side (LS), Right Side (RS), and averaged arrival times.

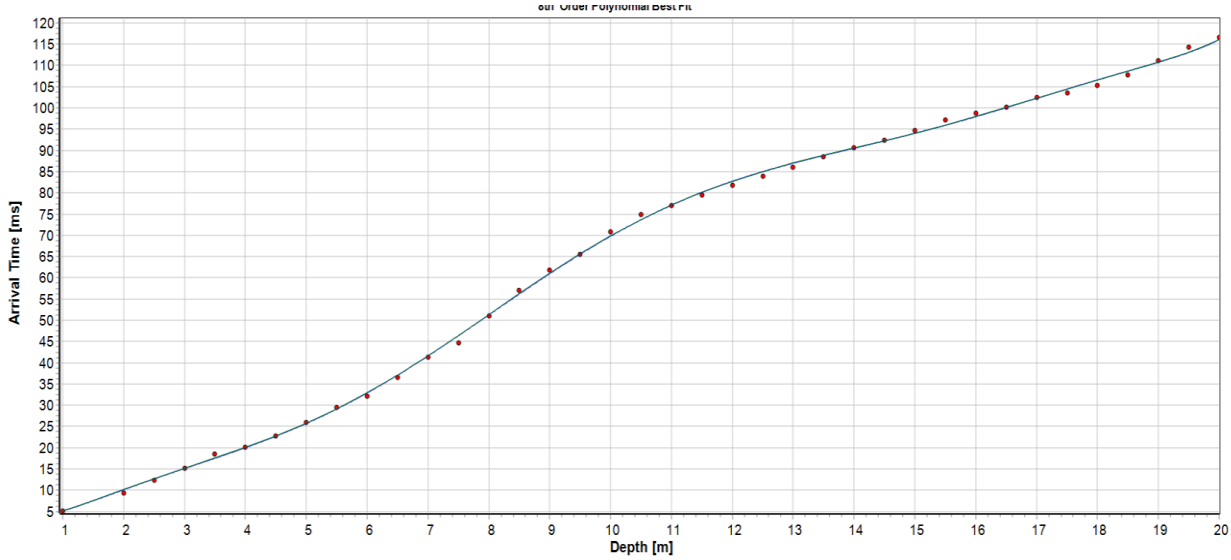


Figure 2. 8th order polynomial best fit estimate to averaged results of Fig. 1.

BEST FIT 8th ORDER S WAVE – 0.5m DEPTH INCREMENT		
Depth [m]	**Arrival Time [ms]**	**Interval FMDSM Velocity [m/s]**
1	5.1198	336
1.5	7.589288	181
2	10.18546	177.5
2.5	12.72785	183.1
3	15.17359	191.7
3.5	17.58675	196
4	20.08186	191.7
4.5	22.78291	179.1
5	25.79552	162
5.5	29.19001	144.7
6	32.9933	129.7
6.5	37.18784	118
7	41.71574	109.6
7.5	46.48668	104.2
8	51.38802	101.5
8.5	56.29613	101.5
9	61.08768	104
9.5	65.65014	109.3
10	69.89065	117.5
10.5	73.74286	129.3
11	77.17118	145.2
11.5	80.1724	165.6
12	82.77439	190.6
12.5	85.03231	219.2
13	87.02226	248.2
13.5	88.83311	272.5
14	90.55693	286.2
14.5	92.27886	286.8
15	94.06745	276.5
15.5	95.96638	260.9
16	97.98908	245.3
16.5	100.1174	233.4
17	102.3065	227.2
17.5	104.4965	227.3
18	106.635	232.9
18.5	108.7099	240
19	110.797	238.5
19.5	113.1239	213.7
20	116.1525	164

Best Fit Polynomial FMDSM results 0.5m Depth Increments

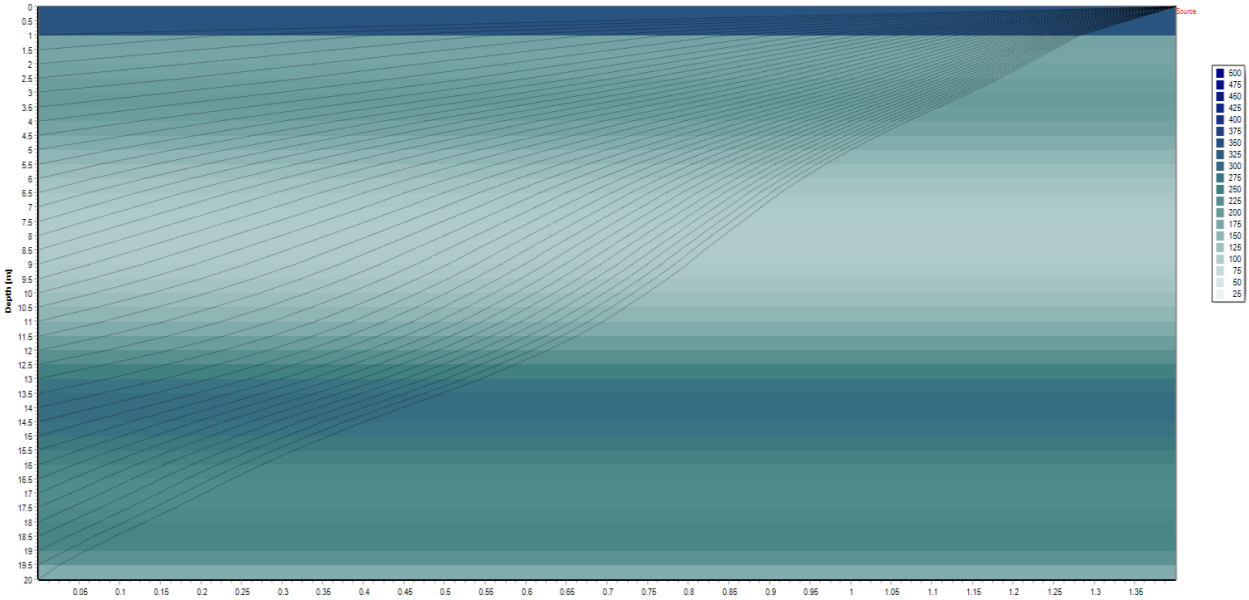


Figure 3. "Best fit" polynomial FMDSM profile.

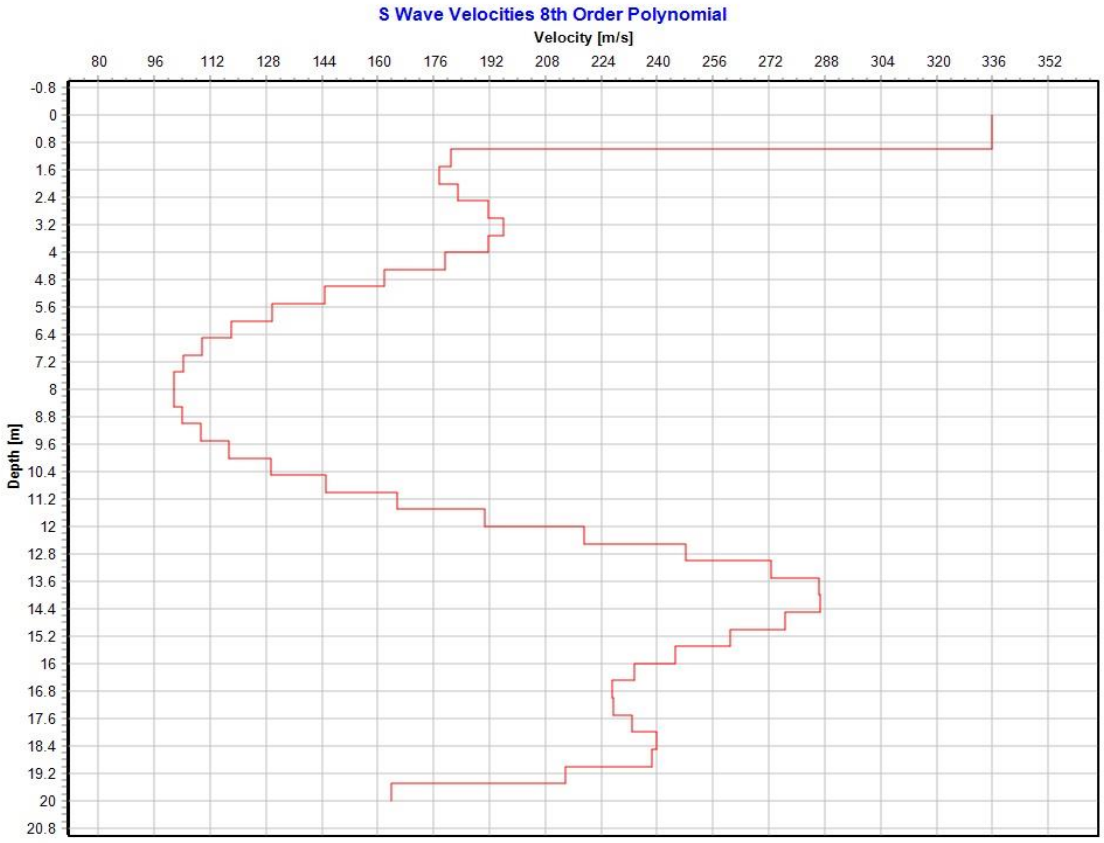


Figure 4. "Best fit" polynomial interval velocity plot.

Off Shore DST Example 1:

Four sets of SH source waves acquired (left side top and bottom sensors (LS TS and LS BS, respectively) and right side top and bottom sensors (RS TS and RS BS, respectively).

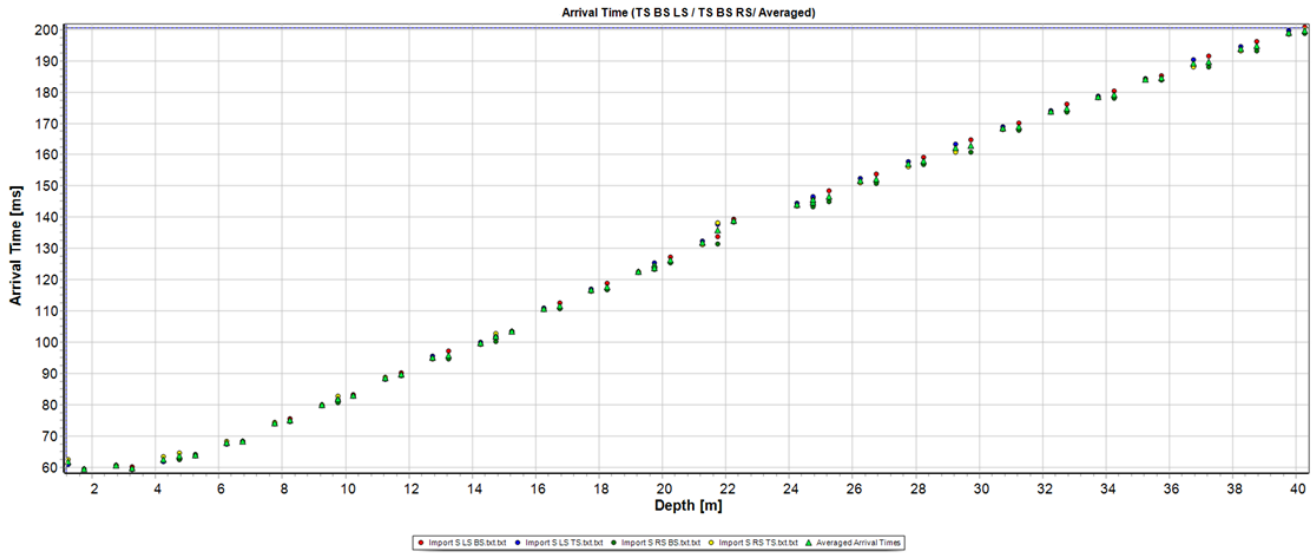


Figure 5. Left Side (LS TS and LS BS), Right Side (RS TS and BS), and averaged arrival times.

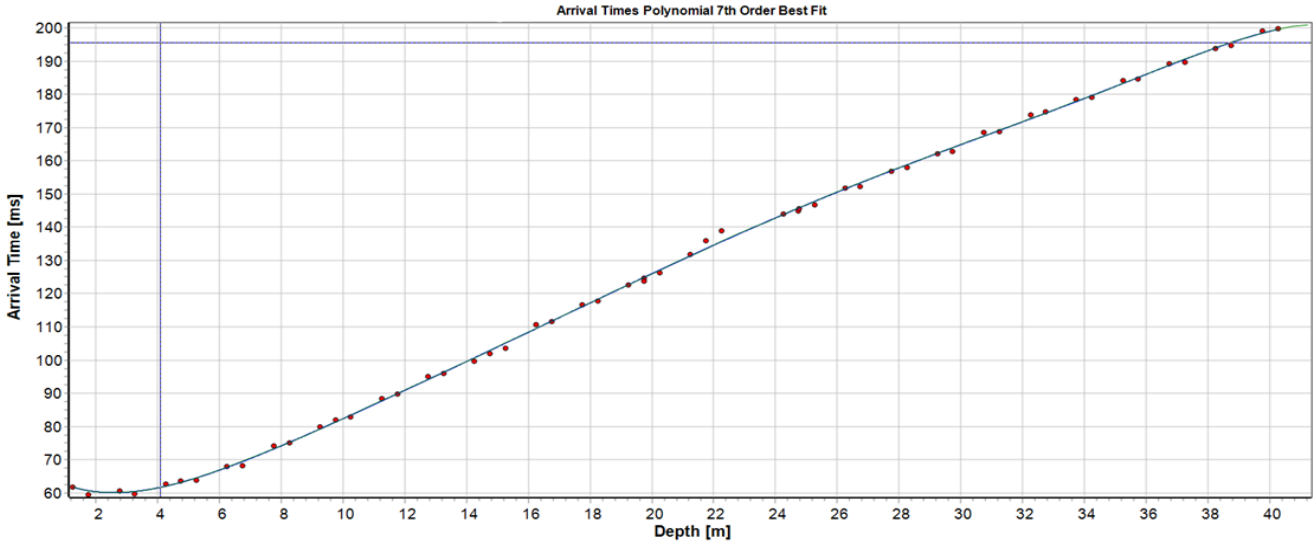


Figure 6. 7th order polynomial best fit estimate to averaged results of Fig. 5.

BEST FIT 7th ORDER S WAVE – 0.5m DEPTH INCREMENT		
Depth [m]	**Arrival Time [ms]**	**Interval FMDSM Velocity [m/s]**
1.24	61.7406	89.7
1.74	60.65947	99.6
2.24	60.13957	108
2.74	60.07694	116.5
3.24	60.40377	125
3.74	61.06047	133.1
4.24	61.99495	140.6
4.74	63.16193	147.3
5.24	64.52227	153.3
5.74	66.04235	158.7
6.24	67.69348	163.4
6.74	69.45141	167.8
7.24	71.29577	171.7
7.74	73.20963	175.4
8.24	75.17906	178.8
8.74	77.19274	181.9
9.24	79.24159	184.8
9.74	81.31842	187.6
10.24	83.41764	190.1
10.74	85.53499	192.4
11.24	87.66726	194.6
11.74	89.81209	196.6
12.24	91.96777	198.4
12.74	94.13304	200
13.24	96.30699	201.4
13.74	98.48888	202.7
14.24	100.6781	203.8
14.74	102.8738	204.9
15.24	105.0754	205.8
15.74	107.282	206.7
16.24	109.4924	207.6
16.74	111.7054	208.4
17.24	113.9195	209.3
17.74	116.1329	210.3
18.24	118.3437	211.4
18.74	120.5497	212.6
19.24	122.7488	214
19.74	124.9384	215.5
20.24	127.1161	217.2
20.74	129.2793	219.2
21.24	131.4256	221.4
21.74	133.5525	223.8
22.24	135.6577	226.5
22.74	137.739	229.4
23.24	139.7947	232.6
23.74	141.823	236
24.24	143.8227	239.7
24.74	145.7931	243.5
25.24	147.7336	247.4
25.74	149.6442	251.5
26.24	151.5255	255.7
26.74	153.3785	259.8
27.24	155.2047	263.8
27.74	157.0061	267.7

BEST FIT 7th ORDER S WAVE – 0.5m DEPTH INCREMENT		
Depth [m]	**Arrival Time [ms]**	**Interval FMDSM Velocity [m/s]**
28.24	158.7853	271.2
28.74	160.5451	274.5
29.24	162.289	277.2
29.74	164.0207	279.5
30.24	165.744	281.1
30.74	167.4632	282.1
31.24	169.1824	282.4
31.74	170.9057	282.1
32.24	172.6368	281.1
32.74	174.3791	279.7
33.24	176.1353	277.8
33.74	177.9073	275.6
34.24	179.6956	273.4
34.74	181.4996	271.3
35.24	183.3165	269.6
35.74	185.1418	268.6
36.24	186.9684	268.6
36.74	188.786	270.1
37.24	190.5813	273.6
37.74	192.337	279.8
38.24	194.0314	289.9
38.74	195.638	305.5
39.24	197.1248	329.7
39.74	198.4534	368
40.24	199.5789	432.3
40.74	200.4486	553.5
41.24	201.0016	843.4

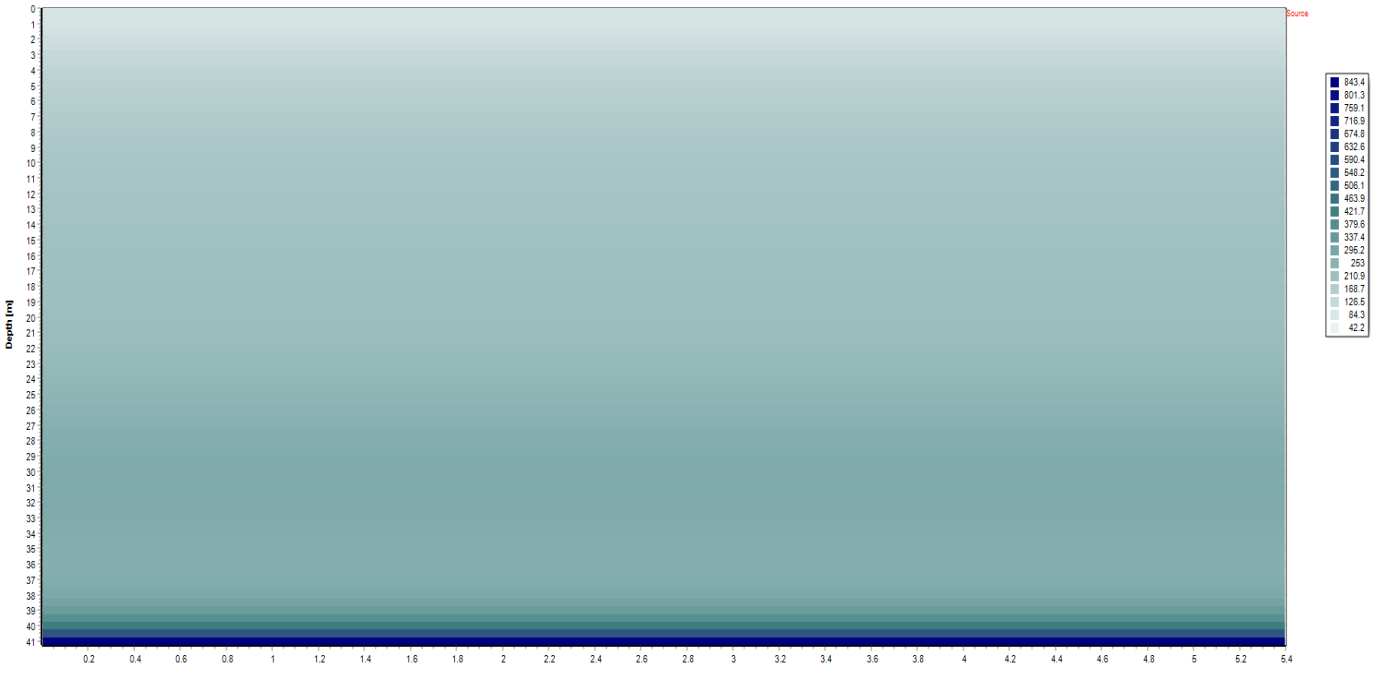


Figure 7. "Best fit" polynomial FMDSM profile.

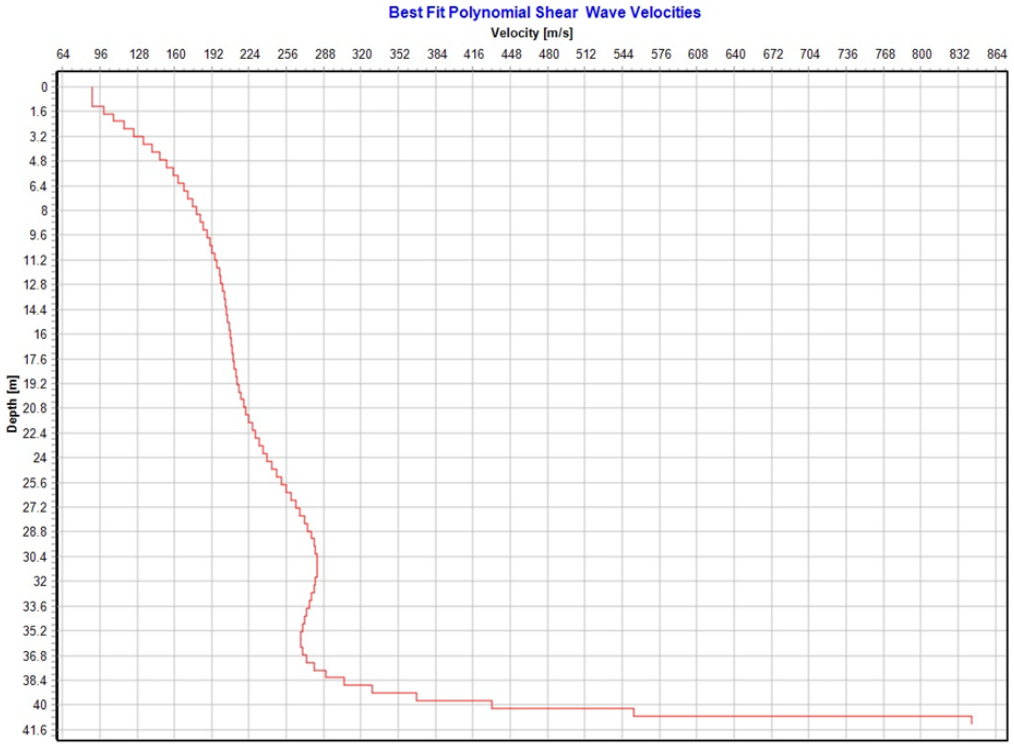


Figure 8. "Best fit" polynomial interval velocity plot.

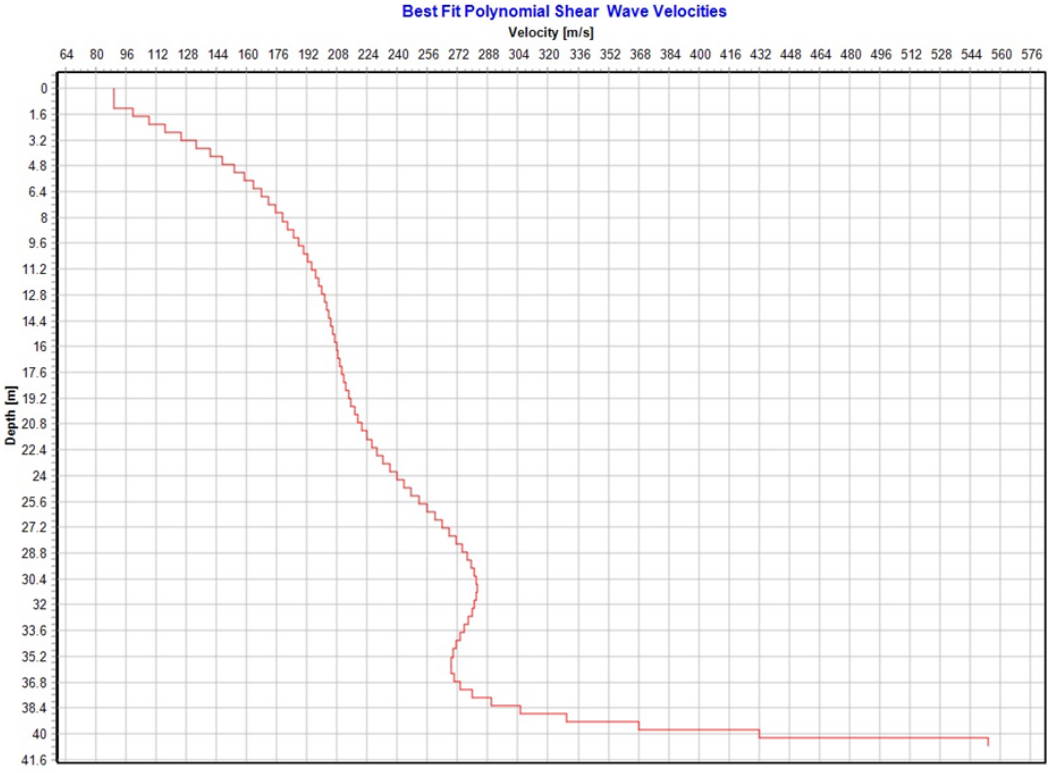


Figure 9. "Best fit" polynomial interval velocity plot (41.24m dropped) .

Off Shore DST Example 2:

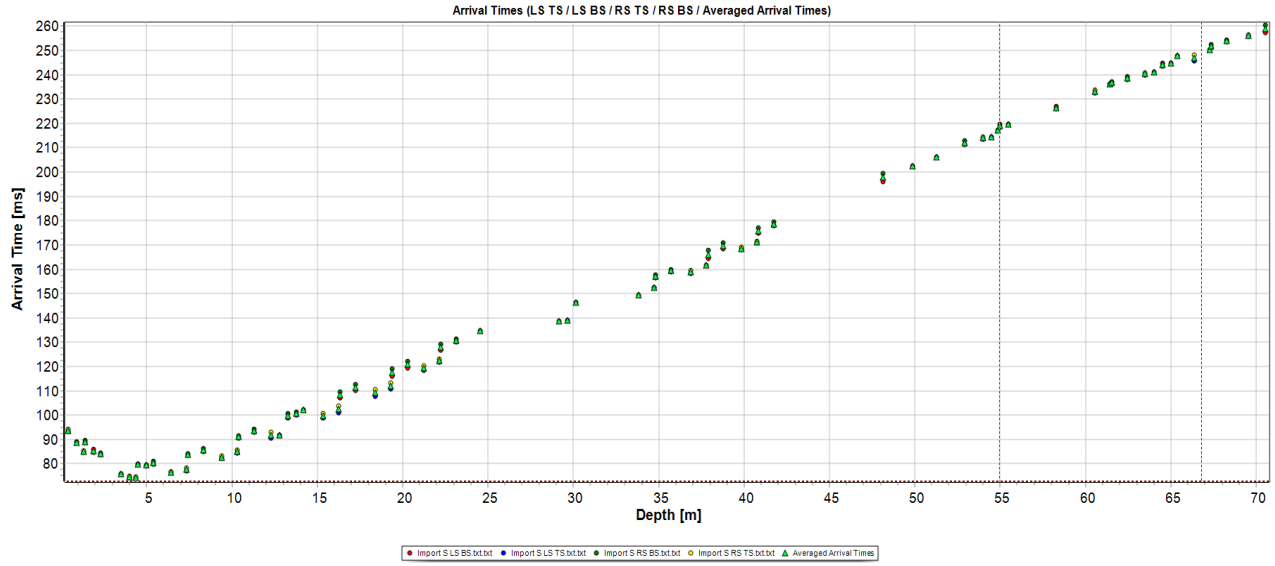


Figure 10. Left Side (LS TS and LS BS), Right Side (RS TS and BS), and averaged arrival times.

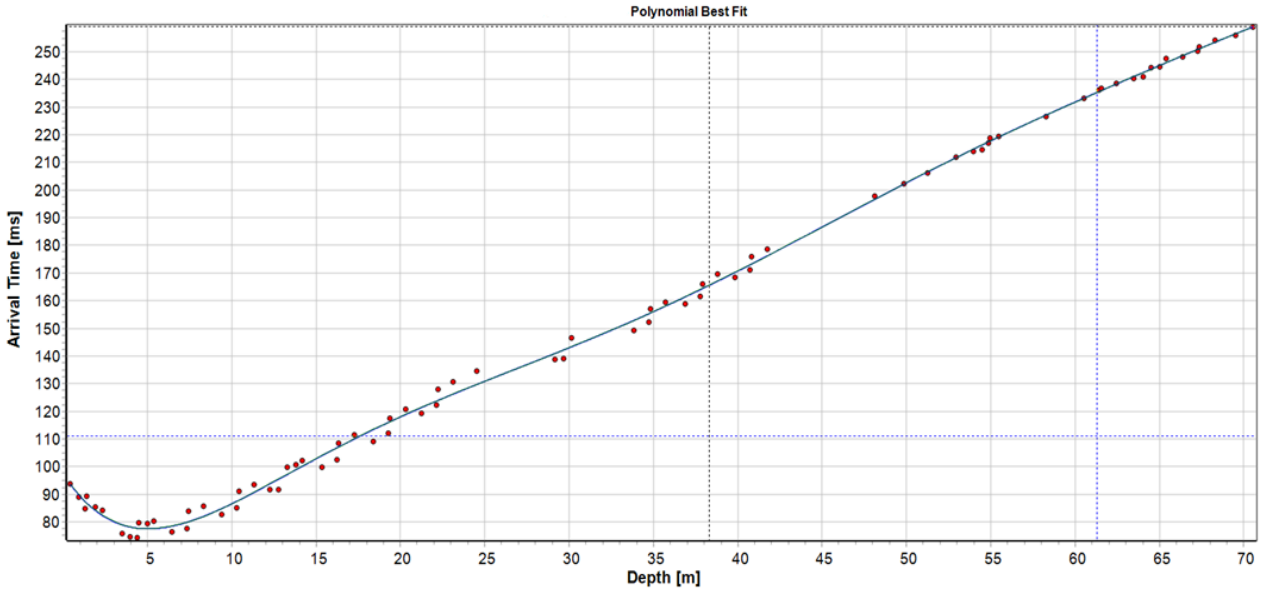


Figure 11. 7th order polynomial best fit estimate to averaged results of Fig. 5.

BEST FIT 7th ORDER S WAVE – 1m DEPTH INCREMENT		
Depth [m]	**Arrival Time [ms]**	**Interval FMDSM Velocity [m/s]**
0.41	93.77395	50.6
1.41	85.90899	58.8
2.41	81.12878	74.6
3.41	78.58437	99.3
4.41	77.68655	133.3
5.41	77.98234	174.5
6.41	79.13037	215.5
7.41	80.87925	245.9
8.41	83.04863	260.3
9.41	85.51293	263.7
10.41	88.18739	263
11.41	91.01646	262.3
12.41	93.96423	263.3
13.41	97.00677	266.5
14.41	100.1263	272
15.41	103.3067	279.5
16.41	106.5308	288.9
17.41	109.7786	299.9
18.41	113.0267	312
19.41	116.2487	325.1
20.41	119.4159	338.6
21.41	122.4994	352
22.41	125.4718	364.8
23.41	128.3095	376.4
24.41	130.9951	386.3
25.41	133.5193	394
26.41	135.8833	399.2
27.41	138.0999	401.8
28.41	140.1946	401.8
29.41	142.2055	399.4
30.41	144.1824	395
31.41	146.1853	388.8
32.41	148.2804	381.6
33.41	150.5362	373.5
34.41	153.0165	365
35.41	155.7724	356.5
36.41	158.8327	348.3
37.41	162.191	340.5
38.41	165.7918	333.3
39.41	169.5129	327
40.41	173.1466	321.4
41.41	176.3765	316.8
42.41	178.3231	313
43.41	181.5233	310.2
44.41	184.7442	308.4
45.41	187.9763	307.4
46.41	191.2096	307.4
47.41	194.4348	308.3
48.41	197.6429	310
49.41	200.8257	312.5
50.41	203.9757	315.8
51.41	207.0869	319.8
52.41	210.1542	324.4
53.41	213.1741	329.5
54.41	216.1443	335.1

BEST FIT 7th ORDER S WAVE – 1m DEPTH INCREMENT		
Depth [m]	**Arrival Time [ms]**	**Interval FMDSM Velocity [m/s]**
55.41	219.0641	340.9
56.41	221.9343	346.8
57.41	224.7567	352.7
58.41	227.5347	358.3
59.41	230.2725	363.6
60.41	232.9751	368.3
61.41	235.6476	372.5
62.41	238.2954	376
63.41	240.9231	378.9
64.41	243.5342	381.4
65.41	246.1301	383.7
66.41	248.7099	386.1
67.41	251.2687	389.3
68.41	253.7971	394
69.41	256.2802	401.3
70.41	258.6958	412.5

FMDSM results 1m Depth Increments

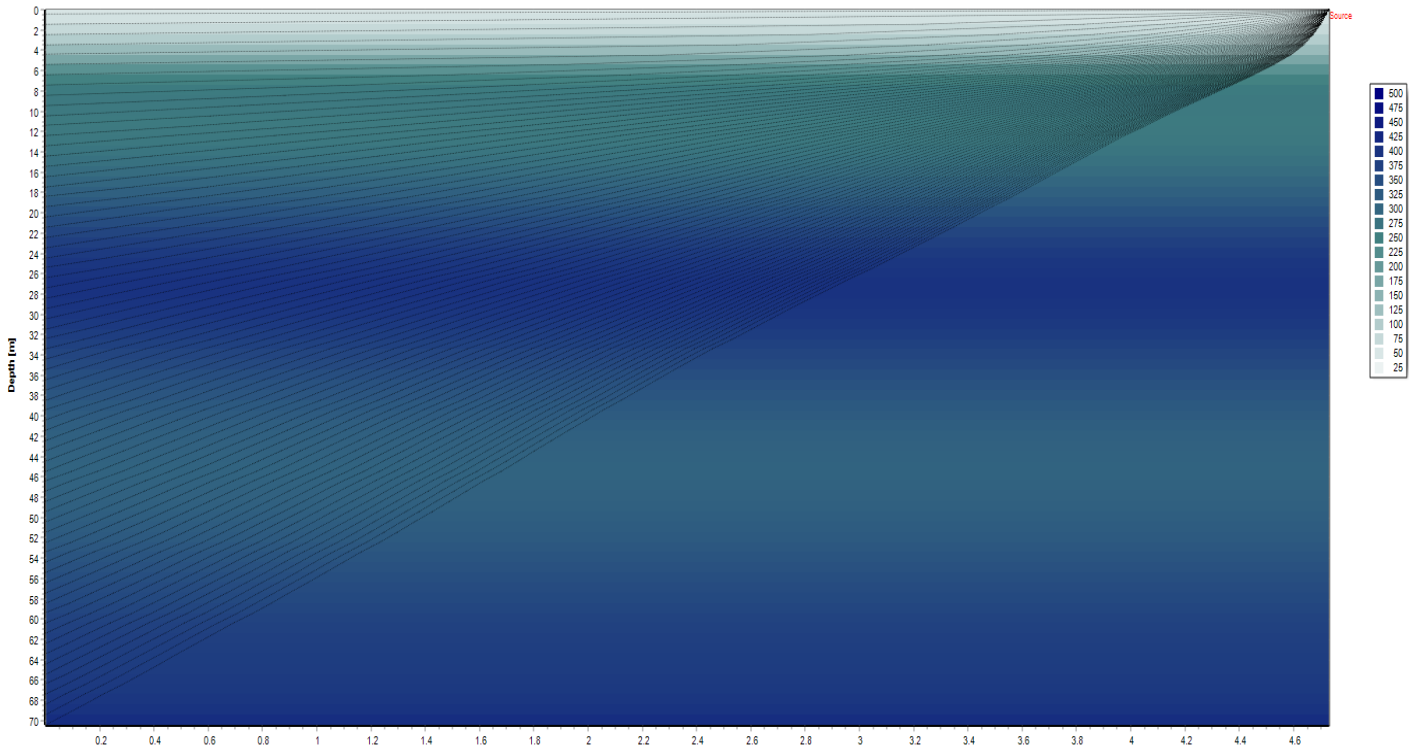


Figure 12. "Best fit" polynomial FMDSM profile.

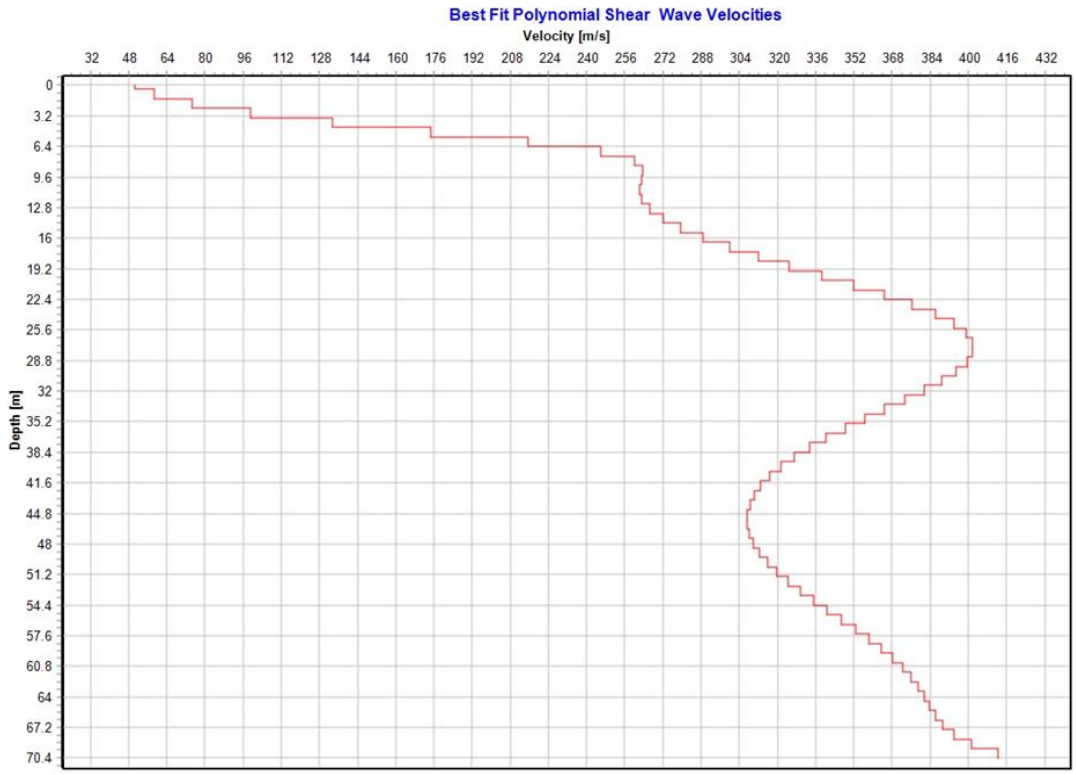


Figure 13. "Best fit" polynomial interval velocity plot.

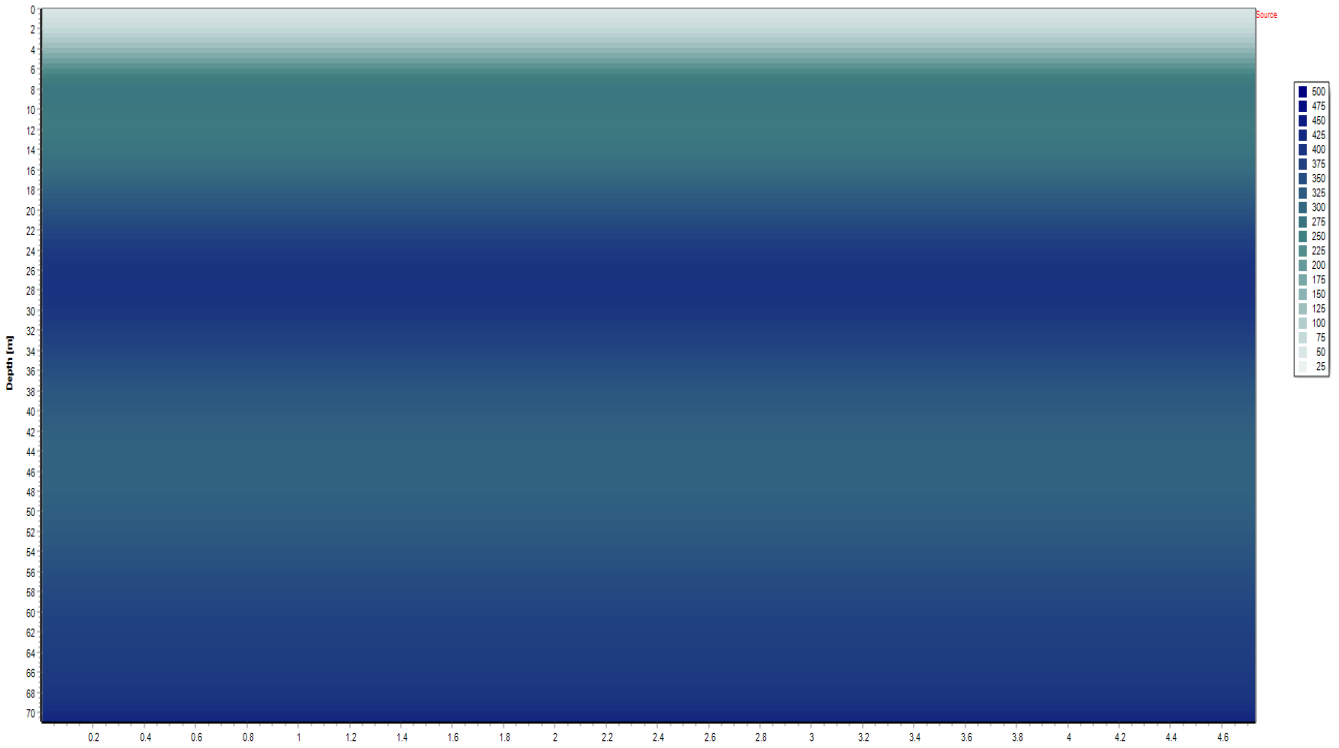


Figure 14. "Best fit" polynomial FMDSM profile (0.5m depth increment).

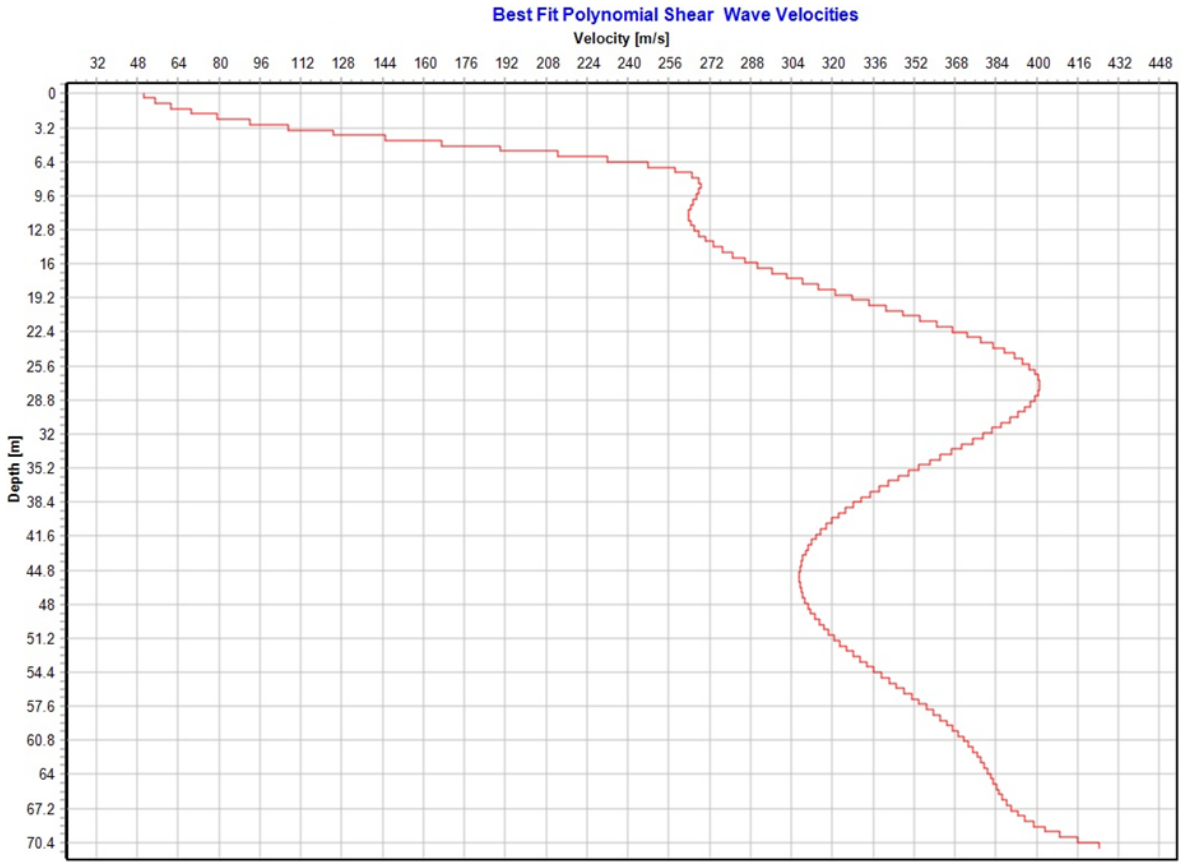
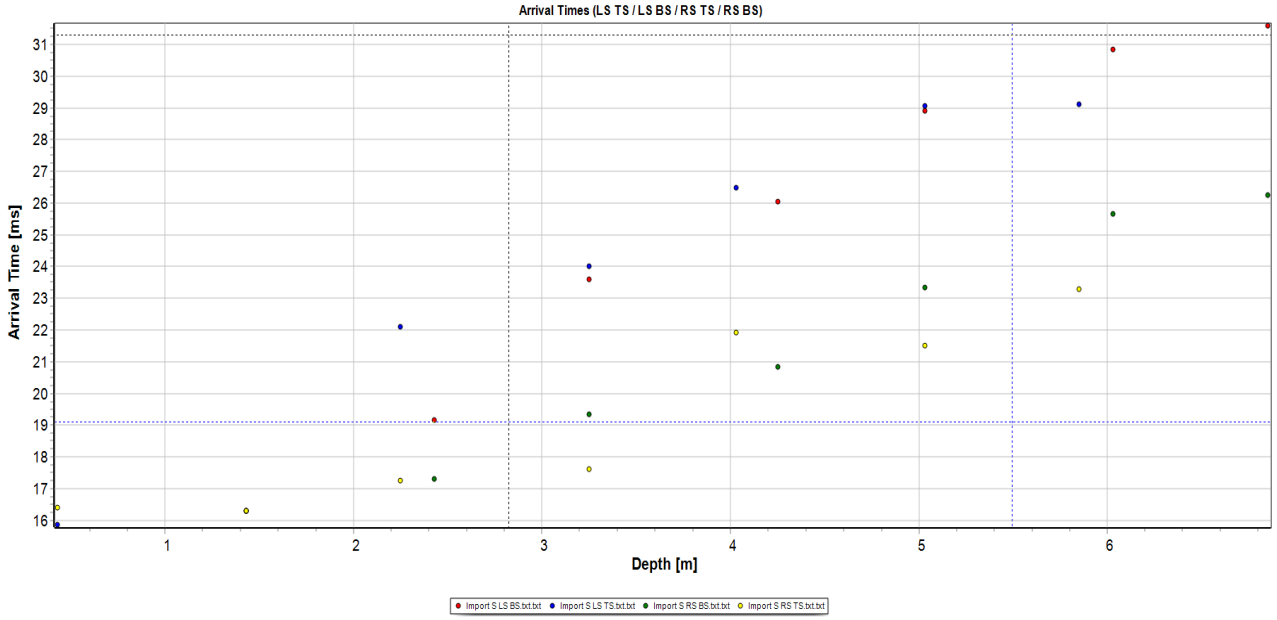
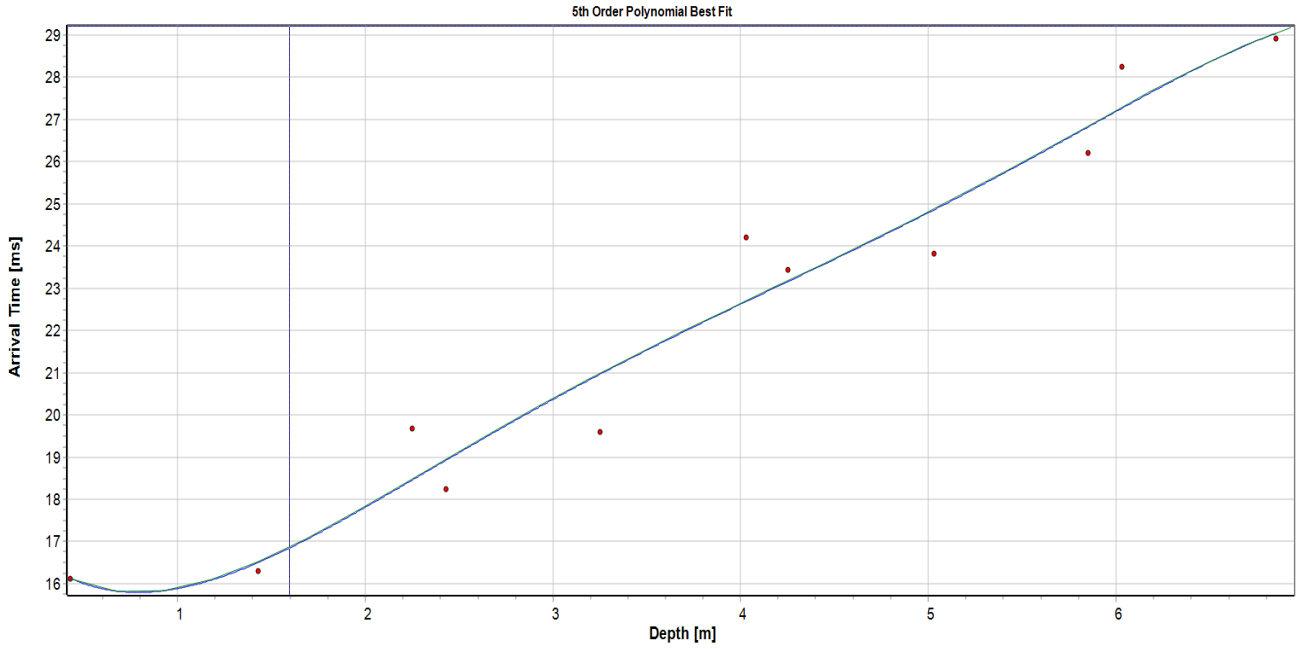


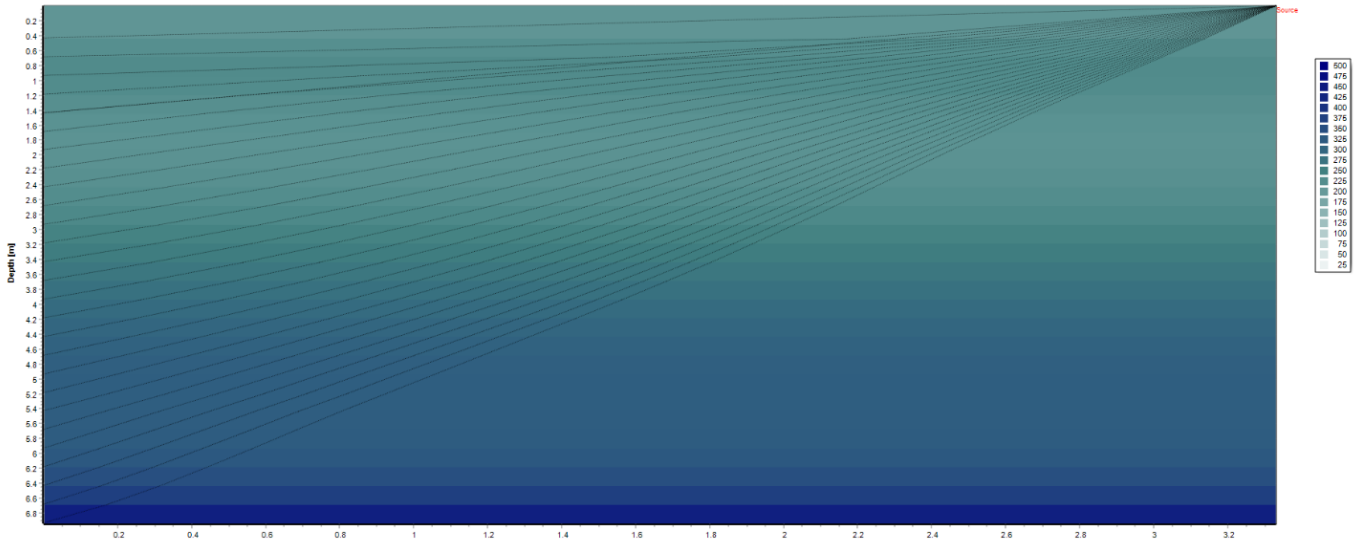
Figure 15. "Best fit" polynomial interval velocity plot (0.5m depth increment).

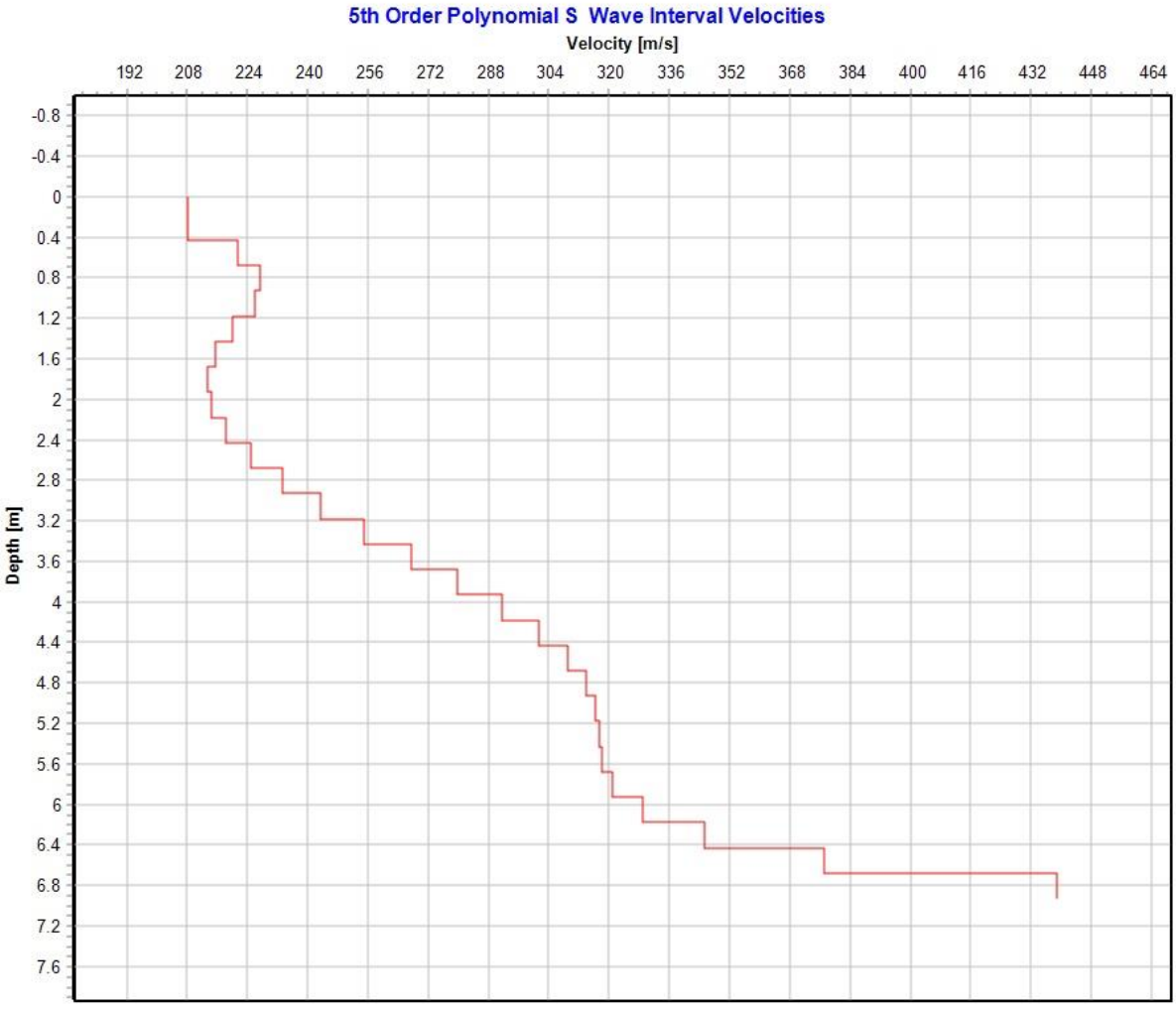
Off Shore DST Example 3:





BEST FIT 5th ORDER S WAVE – 0.25m DEPTH INCREMENT		
Depth [m]	**Arrival Time [ms]**	**Interval FMDSM Velocity [m/s]**
0.43	16.12815	208.2
0.68	15.81966	221.4
0.93	15.84154	227.4
1.18	16.0963	226.1
1.43	16.51827	220.2
1.68	17.05338	215.5
1.93	17.65814	213.5
2.18	18.29866	214.5
2.43	18.94968	218.4
2.68	19.59355	224.8
2.93	20.21926	233.2
3.18	20.82146	243.5
3.43	21.39945	255.1
3.68	21.95619	267.5
3.93	22.49736	279.9
4.18	23.0303	291.6
4.43	23.56308	301.5
4.68	24.10347	309.1
4.93	24.65798	314
5.18	25.23087	316.4
5.43	25.82314	317.3
5.68	26.43157	318.1
5.93	27.04769	321.1
6.18	27.65685	328.8
6.43	28.23719	345.2
6.68	28.75865	377
6.93	29.18201	438.9





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Gerald Verbeek

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