ACCURACY OF ROMDAS ULTRASONIC MEASUREMENT SYSTEM

TPL Technical Memo - ST2

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by

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1. INTRODUCTION

This is the second Technical Memo describing static testing of the ROMDAS Transverse Profile Logger (TPL) Ultrasonic Measurement System (UMS). The objective of this series of tests was to establish the accuracy of the UMS measurements under static testing.

The tests were conducted using the PC based software provided with the UMS and not the ROMDAS system.

2. TESTING PROCEDURE

The UMS was installed vertically pointing down at a flat surface. All sensors except the centre sensor were blocked.

A 3 mm circular shim (22.3 mm diameter) was taped to the surface directly below the centre of the sensor. This was done to eliminate any effects of the surface not being perfectly flat.

A stack of 8 shims of the same diameter with a total height of 25.0 mm were placed on top of the fixed shim. The UMS output was then established as the shims were individually removed from the stack. The tests were done twice to ensure that the results were consistent. No major differences in readings were found.

Upon testing a stack, the height of the UMS was changed. The process was then repeated. This resulted in measurements being taken at heights of 205 - 597 mm. Heights below 200 mm were not tested due to the inability of the UMS to record data at these heights.

Annex A presents the test data. It was found that when the UMS was above 479 mm the spread of the beam gave unreliable readings with only one shim. The four data points were therefore eliminated from the analysis.

3. UMS HEIGHT MEASUREMENTS

The data collected consisted of a series of 86 elevation measurements of known heights. In the first UMS tests (ST1) a relationship between height and the UMS output was investigated by moving an object away from the UMS and noting its distance from a tape measure. Since the shims offered a more accurate

quantification of the distances, an analysis was made of the relationship between the UMS readings and the height. The data are plotted in Figure 3.1.

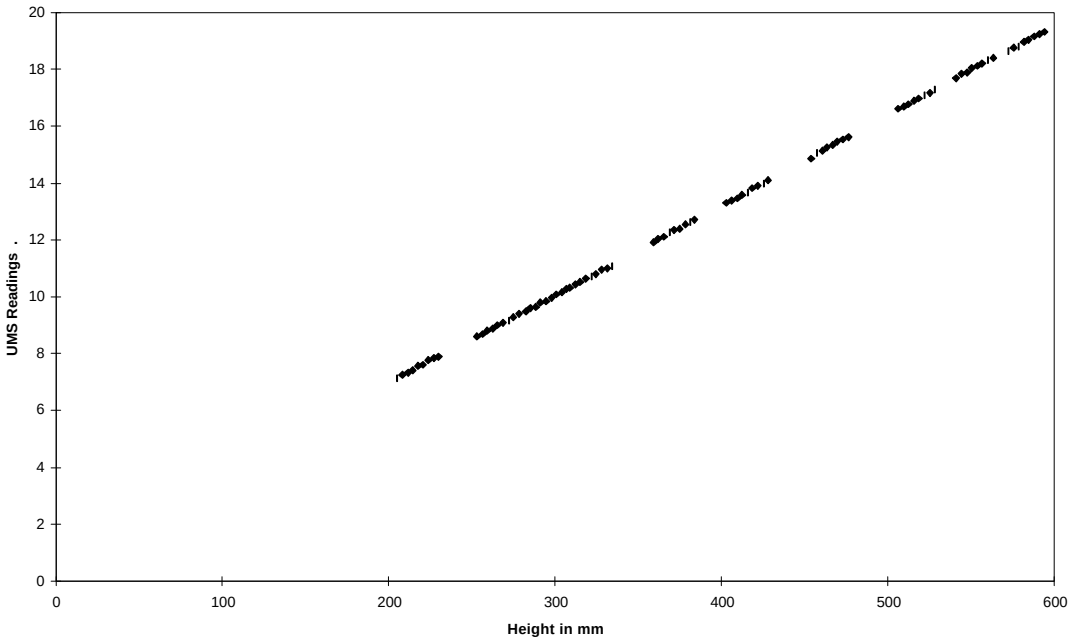

Figure 3.1: Effect of Distance on Measurements

It can be observed that, as in the ST1 test, the data follow a strongly linear trend. This was also found in the previous static testing. A regression line was fitted to the data which resulted in the following equations:

UMS = 0.6135 + 0.0315 DIST R^2 = 1.00 S.E. = 0.0339
(48.6) (1030.0)

DIST =-19.42 + 31.70 UMS R^2 = 1.00 S.E. = 1.08
(-46.4) (1030.0)

where DIST is the distance from the UMS in mm
UMS is the UMS reading

These equations are almost identical to those established in ST1 using the different measurement technique, which were as follows:

UMS = 0.8634 + 0.0315 DIST R^2 = 1.00 S.E. = 0.0194
(112.2) (1705.8)

DIST = -27.38 + 31.73 UMS R^2 = 1.00 S.E. = 0.62
(-105.4) (1705.8)

The only significant differences are with the constants. These may be due to difficulties in accurately establishing the vertical height of the sensor relative to the flat surface or else the measurement target in ST1 not being perfectly vertical.

4. ACCURACY OF MEASUREMENTS

The objective of the tests was to verify the accuracy of the UMS measurements. For each test height, the data were reduced to obtain two values: the height of each individual shim and the height of the stack with different number of shims. Annex A contains the reduced data. Table 4.1 and Table 4.2 give the summary statistics for these data calculated from the measurements made at the different UMS heights.

Table 4.1
Shim Height Statistics

Shim Number	Shim Height in mm							t	Number of Obs.
	Actual	Measured	S.Dev	Min.	Max.	S.E.	C.I.		
1	3.2	3.23	0.77	2.22	4.44	0.28	0.63	0.12	10
2	3.1	2.60	0.74	1.90	4.12	0.27	0.62	-1.83	10
3	3.1	3.65	0.82	2.22	4.44	0.29	0.65	1.90	10
4	3.1	2.95	0.70	2.22	4.12	0.26	0.60	-0.57	10
5	3.2	3.08	0.87	2.22	4.44	0.30	0.67	-0.42	10
6	3.3	3.42	0.70	2.22	4.12	0.26	0.60	0.47	10
7	3.0	2.66	0.58	1.90	3.80	0.24	0.55	-1.40	10
8	3.0	2.91	0.79	1.90	3.80	0.36	0.93	-0.26	6
All	3.13	3.07	0.79	1.90	4.44	0.10	0.20	-0.54	76

NOTES: 1/ S.E. = Standard Error; C.I. = Confidence Interval; t = t statistic for means (Z test used with 'All' data due to larger sample)
2/ The highlighted cell had a significantly different mean at 95% confidence.

Table 4.2
Stack Height Statistics

Number of Shims	Stack Height in mm							t	Number of Obs.
	Actual	Measured	S.Dev	Min.	Max.	S.E.	C.I.		
1	3.2	3.23	0.77	2.22	4.44	0.28	0.63	0.12	10
2	6.3	5.83	0.81	4.76	6.66	0.28	0.64	-1.64	10
3	9.4	9.48	0.84	8.24	10.78	0.29	0.65	0.27	10
4	12.5	12.43	0.97	11.10	13.63	0.31	0.70	-0.24	10
5	15.7	15.50	0.43	14.58	15.85	0.21	0.47	-0.95	10
6	19.0	18.93	0.79	18.07	19.97	0.28	0.64	-0.26	10
7	22.0	21.59	0.82	20.61	22.51	0.29	0.65	-1.43	10
8	25.0	24.73	0.28	24.41	25.04	0.22	0.56	-1.26	6

NOTES: 1/ S.E. = Standard Error; C.I. = Confidence Interval; t = t statistic for means

The results in Table 4.1 show the following:

- for 7 of the 8 shims the mean predicted shim thicknesses from the different heights were not significantly different to the actual thickness at a confidence of 95% using a t test. The one shim where there was a difference was approximately 3% outside of the acceptable limits.
- using a Z test, the mean thicknesses of all shims was not significantly different to the mean predicted thickness.

- the standard errors are in the range of 0.24 - 0.36 mm for each of the shims, and 0.10 mm for the measurements of all the shims. This corresponds to confidence intervals of 0.55 - 0.93 mm for the individual shims; 0.20 mm for all shims.

The data in Table 4.2 for the stack height indicate:

- at 95% confidence there was no statistically significant differences in the actual versus predicted mean heights.
- the confidence intervals for the means were in the range 0.47 - 0.70 mm.
- the stack height data appear to have a downward bias in that the predicted mean in 6 out of the 8 cases was lower than the actual height. However, as the scatter plot in Figure 4.1 shows, there is no evidence of a systematic bias or error in the data.

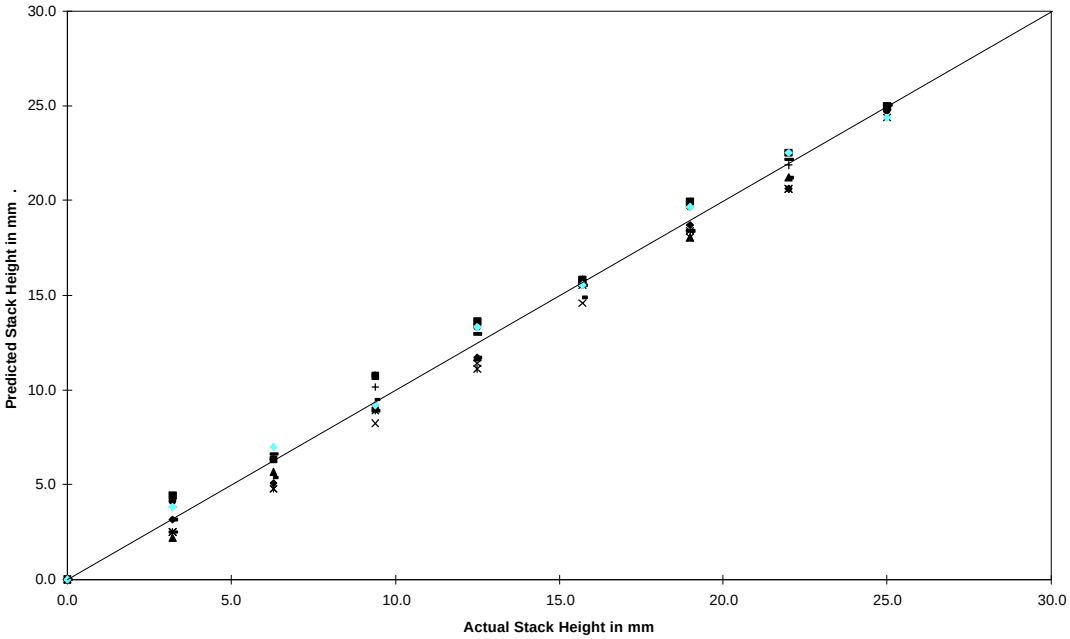

Figure 4.1: Scatter Plot for Stack Height

5. CONCLUSIONS

On the basis of these tests it is concluded that:

- the UMS was able to accurately establish the height of 3 mm shims as well as a stack of shims with heights of 3 - 25 mm.
- the UMS height measurements are made with an accuracy better than 1.0 mm. This is based on the 95% confidence intervals for the measurement of the individual shims and the stack all of which were below 1.0 mm.
- eliminating the test with only 6 measurements, the data suggest an accuracy of better than 0.70 mm.
- there is no systematic bias evident in the height measurements with the measurements falling on either side of the actual height.
- the linear relationship between the UMS measurements and distance was confirmed. The slope was identical to that derived using a different method.

ANNEX A
TESTING DATA

Table A.1
Raw Data

Stack Height in mm	UMS Reading by Measurement Height									
	597 mm	566 mm	531 mm	479 mm	428 mm	384 mm	334 mm	307 mm	278 mm	230 mm
25.0	18.66	17.69	16.61	14.98	13.32	11.92	10.31	9.49	8.60	7.13
21.8	18.76	17.83	16.68	15.06	13.40	12.05	10.43	9.59	8.68	7.25
18.7	18.82	17.89	16.79	15.13	13.47	12.12	10.51	9.66	8.81	7.35
15.6	18.95	18.03	16.90	15.24	13.60	12.26	10.63	9.79	8.88	7.42
12.5	19.03	18.12	16.98	15.34	13.67	12.34	10.73	9.86	9.01	7.55
9.3	19.16	18.19	17.11	15.44	13.81	12.41	10.81	9.96	9.09	7.62
6.0	19.25	18.32	17.18	15.55	13.90	12.54	10.94	10.07	9.18	7.75
3.0	19.31	18.40	17.28	15.63	13.97	12.63	11.00	10.16	9.30	7.84
0.0	19.32	18.42	17.32	15.66	14.09	12.70	11.09	10.28	9.39	7.90

Table A.2
Distances to Top of Stack from UMS

Stack Height in mm	Distance to Top of Stack in mm by Measurement Height									
	597 mm	566 mm	531 mm	479 mm	428 mm	384 mm	334 mm	307 mm	278 mm	230 mm
25.0	572	541	507	455	403	358	307	281	253	207
21.8	575	546	509	458	405	363	311	285	256	210
18.7	577	548	513	460	408	365	314	287	260	214
15.6	581	552	516	464	412	369	318	291	262	216
12.5	584	555	519	467	414	372	321	293	266	220
9.3	588	557	523	470	418	374	323	296	269	222
6.0	591	561	525	474	421	378	327	300	272	226
3.0	593	564	528	476	423	381	329	303	275	229
0.0	593	565	530	477	427	383	332	306	278	231

NOTES: Distances calculated using relationship DIST = -19.42 + 31.7014 UMS

Table A.3
Height of Individual Shims

Shim Number	Shim Thickness in mm	Thickness of Shim in mm by Measurement Height									
		597 mm	566 mm	531 mm	479 mm	428 mm	384 mm	334 mm	307 mm	278 mm	230 mm
1	3.2	3.2	4.4	2.2	2.5	2.5	4.1	3.8	3.2	2.5	3.8
2	3.1	1.9	1.9	3.5	2.2	2.2	2.2	2.5	2.2	4.1	3.2
3	3.1	4.1	4.4	3.5	3.5	4.1	4.4	3.8	4.1	2.2	2.2
4	3.1	2.5	2.9	2.5	3.2	2.2	2.5	3.2	2.2	4.1	4.1
5	3.2	4.1	2.2	4.1	3.2	4.4	2.2	2.5	3.2	2.5	2.2
6	3.3	2.9	4.1	2.2	3.5	2.9	4.1	4.1	3.5	2.9	4.1
7	3.0	1.9	2.5	3.2	2.5	2.2	2.9	1.9	2.9	3.8	2.9
8	3.0	0.3	0.6	1.3	1.0	3.8	2.2	2.9	3.8	2.9	1.9

Table A.4
Height of Stack

Height of Stack in mm	Height of Stack in mm by Measurement Height									
	597 mm	566 mm	531 mm	479 mm	428 mm	384 mm	334 mm	307 mm	278 mm	230 mm
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.2	3.2	4.4	2.2	2.5	2.5	4.1	3.8	3.2	2.5	3.8
6.3	5.1	6.3	5.7	4.8	4.8	6.3	6.3	5.4	6.7	7.0
9.4	9.2	10.8	9.2	8.2	8.9	10.8	10.1	9.5	8.9	9.2
12.5	11.7	13.6	11.7	11.4	11.1	13.3	13.3	11.7	13.0	13.3
15.7	15.9	15.9	15.9	14.6	15.5	15.5	15.9	14.9	15.5	15.5
19.0	18.7	20.0	18.1	18.1	18.4	19.7	20.0	18.4	18.4	19.7
22.0	20.6	22.5	21.2	20.6	20.6	22.5	21.9	21.2	22.2	22.5
25.0	25.0	25.0	25.0	25.0	24.4	24.7	24.7	25.0	25.0	24.4