ANALYSIS OF TRANSVERSE PROFILE MEASUREMENTS FROM THE ROMDAS ULTRASONIC MEASUREMENT SYSTEM

TPL Technical Memo - FT1

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by

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1. INTRODUCTION

The ROMDAS Transverse Profile Logger (TPL) uses 30 ultrasonic sensors to collect data on the transverse profile of a pavement.

To evaluate the accuracy of the system a series of field tests were conducted. This memo describes the testing and presents the results.

2. DATA COLLECTION

The tests were conducted on Sunday 26 April 1996 on a test site near Priors Marson, Midlands, U.K. The test site was a public road crossing several farm paddocks. Built to a low standard, it suffered severe rutting and deformation.

A TRL Beam was used to collect data on the transverse profiles. This instrument consists of a 3.6 m long beam which is fixed at either end. The beam is levelled to give a horizontal datum. A linear vertical displacement transducer is connected to a wheel below the beam. As the wheel is moved along the ground the transducer is moved relative to the beam and the vertical displacement of the wheel is recorded. The data are displayed to an accuracy of 0.1 mm. The instrument was run in ‘Test’ mode which meant that the data were displayed continuously instead of at the 100 mm intervals which are usual with the TRL Beam.

Before the beam was operated a calibration test was conducted as per the manufacturer’s recommendations. This entailed setting up the instrument on a level floor and placing a calibration stand under the wheel. The heights from the TRL Beam were the same as those corresponding to the calibration stand. The instrument was further checked using the same shims as used in the earlier TPL calibration. It was found to give readings to within ± 0.1 mm of the known shim thickness.

A series of 20 transverse profile measurement sites were selected at nominal 12.5 m intervals along the test section. The TPL was mounted on a vehicle and parked over the measurement site. A total of 25 UMS sensors were used (i.e. the main bar and one wing) since the road was only 2.6 m wide. The TPL measurements were recorded for a period of 60 s. The start and end points of the TPL beam were painted on the road surface.

The TRL Beam was then used to record the transverse profile at 25 mm intervals. A tape measure was placed on the pavement surface zeroed at the left edge of the pavement. The TRL Beam wheel was then moved across to the right hand edge with the values displayed every 25 mm being recorded on data collection forms. At 5 sites two sets of TRL Beam readings were taken, however, it was found that the values were effectively identical so only one set was taken at the remaining sites.

Site 1 was not included in these tests as it was measured for a dynamic test of the TPL. These dynamic tests will be reported in a later memo.

3. DATA REDUCTION

Due to a problem with the ROMDAS interface, a number of inconsistent readings – essentially consisting of 0 elevations -- were obtained from the TPL. The data were edited to remove these readings. Annex A summarises the edited data for each site by UMS Sensor. It also gives the corrected TPL and corresponding TRL Beam data at the same locations.

The TRL Beam gave the change in elevation relative to a horizontal datum. The TPL gave the distance to the surface from the TPL bar which will seldomly be horizontal. It was therefore necessary to make a number of adjustments to the data to make them comparable.

Figure 3.1 shows the TRL Beam profile data and the raw TPL data. The TRL Beam data were recorded at 25 mm intervals; the TPL data at 100 mm intervals. It can be observed that the TPL data profile is a ‘mirror’ of the TRL Beam profile. This is because of the different datums used by the two instruments. The first adjustment was thus to invert the TPL data so that it had a similar datum to the TRL Beam data.

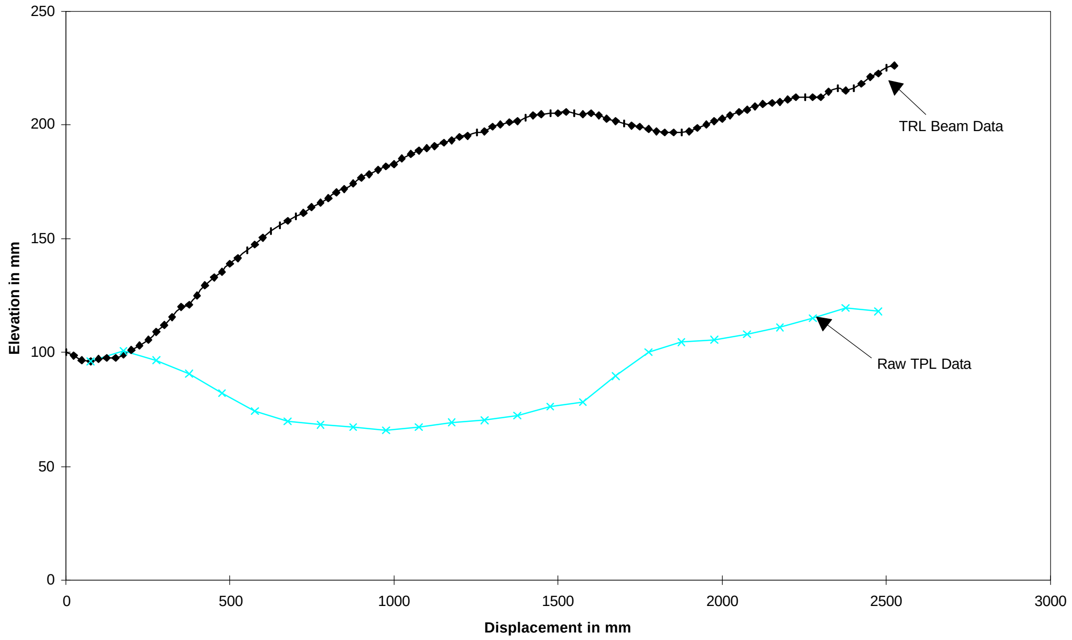

Figure 3.1: TRL Beam and Raw TPL Data

The data were inverted as follows:

1. The UMS data were converted to mm using the following equation derived in earlier tests: DIST = 31.7277 UMS - 27.36
2. The data were normalised to an elevation of 100 mm by subtracting the difference between the start UMS elevation and 100 mm from each reading.
3. The elevation of each point relative to the minimum elevation was calculated as RELEVi = min(ELEVi to ELEVn) - ELEVi
4. The data were then inverted using the equation:
   INVi = ELEV1 - RELEV1 + RELEVi

Figure 3.2 shows the results of this for Site 2.

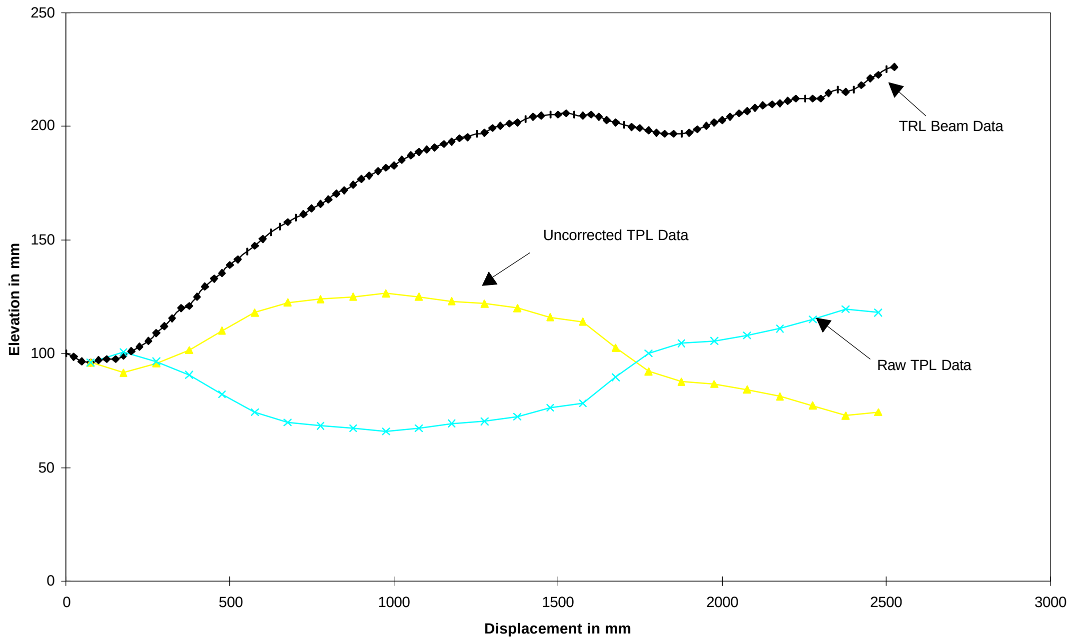

Figure 3.2: Inverted Raw Data

It will be noted from Figure 3.2 that although the inverted TPL data has a similar profile to the TRL Beam data, the measurements have different slopes. This is due to the TRL Beam being horizontal and the TPL following the cross-fall of the pavement. To make the two sets of data coincident the following was done:

1. The point where the TRL Beam and TPL data coincided at the left of the pavement was established.
2. The point where the TRL Beam and the TPL data should coincide at the right of the pavement was established.
3. The data were 'rotated' around the left point by adding a value proportional to the difference in TPL and TRL Beam right point elevations to each reading. This value was calculated as:
   ADJi = CHAINi (TRLe - TPLe) /CHAINDIFF

where	ADJi	is the adjustment for chainage I in mm
	CHAINDIFF	is the distance between the left and right readings in mm
	CHAINi	is the displacement in mm
	TRLe	is the TRL Beam elevation at the end point in mm
	TPLe	is the TPL elevation at the end point in mm

In practice it was often necessary to test several start and end points to obtain a good correlation between the two profiles.

Figure 3.3 shows the final corrected data for Site 2.

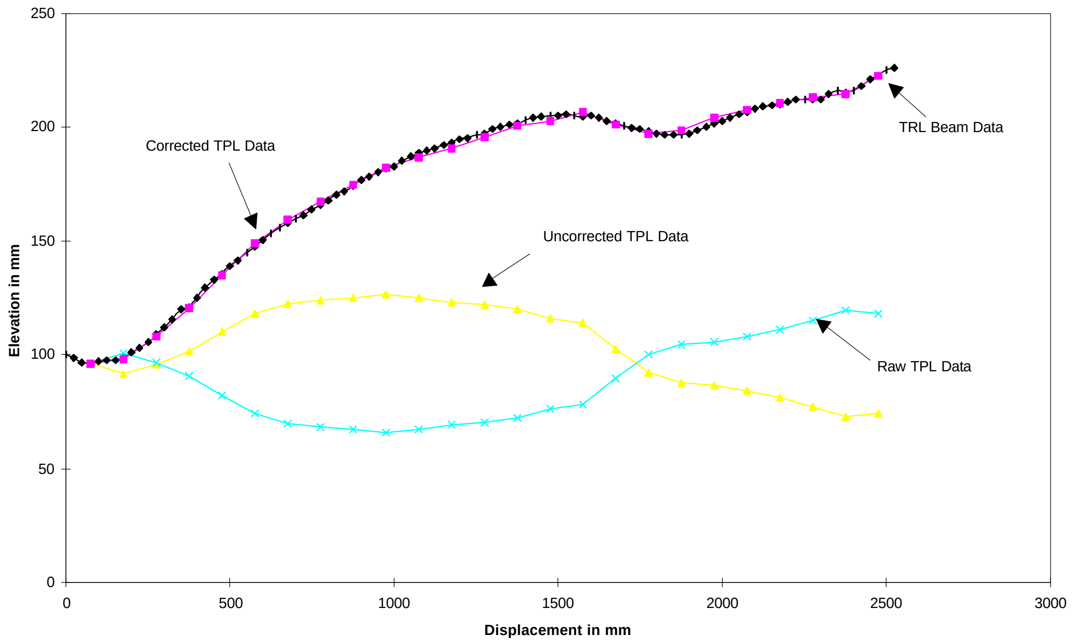

Figure 3.3: Final Corrected Data

4. EVALUATION OF TRANSVERSE PROFILES

Using the data reduction process described in Section 3, the data were reduced for each of the 19 test sites. Annex B shows the profiles for each of the test sites. In these figures the labels are as follows:

- **raw data**: data collected by the TPL;
- **uncorrected data**: raw data inverted to the same datum as the TRL Beam;
- **corrected data**: raw data adjusted so that the measurements were coincident with the TRL Beam profile;
- **TRL Beam data**: data measured at 25 mm spacings with TRL Beam.

It will be noted from the figures in Annex B that it was possible to obtain excellent correlations between the TPL profile data and the TRL Beam data at almost every site. This is illustrated in Table 4.1 which gives the correlations between the TPL data and TRL Beam data at the same displacements.

Table 4.1
Correlations Between Transverse Profiles

Site	Correlation Between TPL and ROMDAS Profiles	Site	Correlation Between TPL and ROMDAS Profiles
2	0.9994	12	0.9939
3	0.9955	13	0.9955
4	0.9982	14	0.9986
5	0.9856	15	0.9992
6	0.9569	16	0.9985
7	0.9850	17	0.9992
8	0.9906	18	0.9980
9	0.9620	19	0.9990
10	0.9962	20	0.9989
11	0.9943		

This analysis has shown that the TPL can give a reliable representation of the transverse profile when the vehicle is stationary.

5. RUT DEPTHS

It is proposed to express the TPL rut depths in terms of the rutting under a user defined straight-edge length. An analysis was made of the data to investigate the rut depths predicted using the data from the TPL and the TRL Beam.

Two sets of analyses were conducted:

- **TPL versus TRL Beam at 100 mm Intervals.** The objective of this analysis was to compare the rut depths that arose with the TPL readings with those for the TRL Beam at the same locations. Since the measurements were from the same location on the road, any differences would be due to the different instrument measurements.
- **TPL and TRL Beam at 100 mm Intervals versus TRL Beam Profile.** The objective of this analysis was to compare the rutting from discrete measurements – 100 mm – with that from a more continuous measurement interval (25 mm). Any differences here are due to the use of a larger measurement interval.

The profiles for each site were plotted and the points where a straight edge would have rested on the pavement for the left and right wheelpaths were established using a ruler. The low point under this straight edge was also established. The rutting is defined as the difference in elevation between this low point and the straight edge. As illustrated in Figure 5.1, there are two situations which arise when calculating the rut depth: the straight edge rises or falls from the start point.

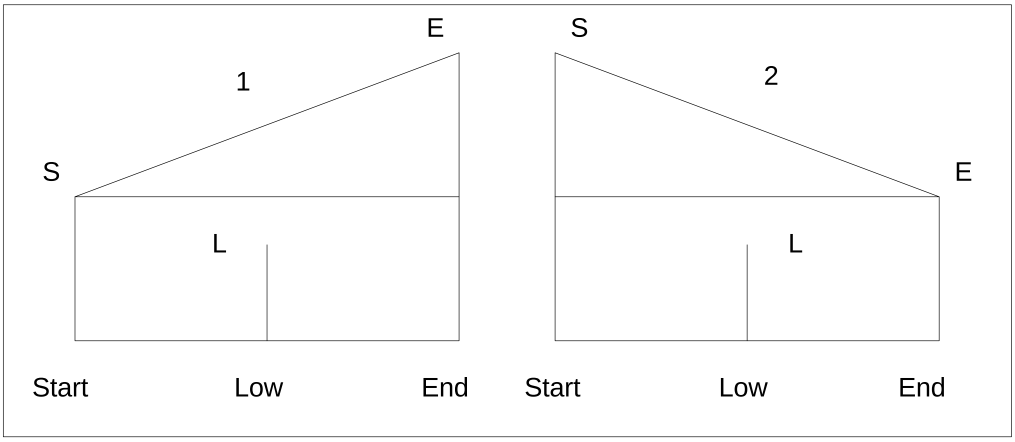

Figure 5.1: Rut Depth Calculation Scenarios

The rut depth is calculated by establishing the height of the hypotenuse above the low point and then adjusting this for the elevation of the low point. This is done using the following equations:

<u>Case 1: Start Elevation < End Elevation</u>

$$RD = (ES - EL) + (EE - ES)(CL - CS)/(CE - CS)$$

<u>Case 2: Start Elevation > End Elevation</u>

$$RD = (EE - EL) + (ES - EE)(CE - CL)/(CE - CS)$$

where RD is the rut depth in mm
ES is the elevation of the start point in mm
EL is the elevation of the low point in mm
EE is the elevation of the end point in mm
CS is the chainage of the start point in mm
CL is the chainage of the low point in mm
CE is the chainage of the end point in mm

It was found that for some sections there was no discernible rutting in some wheelpaths, whereas in others there was significant rutting. This is illustrated in Table 5.1 which shows the values calculated.

Figure 5.2 compares the rut depths calculated from the TPL data and the TRL Beam at the 100 mm spacing sample intervals. It can be observed that there is good agreement between the two sets of values. The correlation coefficient is 0.93 for these data.

Table 5.1
Calculated Rut Depths

Site	Rut Depth in mm Under 2.0 m Straight Edge					
	Left Wheelpath			Right Wheelpath		
	Complete TRL Beam Profile	TPL	TRL Beam Using Same TPL Sample Points	Complete TRL Beam Profile	TPL	TRL Beam Using Same TPL Sample Points
2	15.7	9.3	7.7	16.4	13.1	14.1
3	12.9	9.3	9.0	29.0	21.2	26.4
4	24.7	14.2	10.1	15.7	12.5	15.6
5	8.4	6.9	6.1	0.0	2.8	2.9
6	15.1	12.5	15.1	10.5	0.0	0.0
7	15.5	19.9	15.8	0.0	4.7	5.3
8	11.6	8.7	10.1	11.4	9.5	11.4
9	16.3	10.5	10.5	13.4	5.6	8.3
10	19.5	15.1	17.1	23.1	16.9	22.2
11	15.8	6.4	5.2	11.4	5.7	7.7
12	19.3	10.2	7.1	11.3	8.6	10.4
13	8.4	0.0	0.0	7.5	0.0	0.0
14	6.0	0.0	0.0	8.0	0.0	0.0
15	10.4	8.6	10.1	4.9	0.0	0.0
16	13.1	6.5	4.8	9.8	9.3	8.4
17	15.9	9.0	7.9	9.2	7.6	7.0
18	16.6	9.2	7.9	4.6	0.0	0.0
19	0.0	0.0	0.0	14.7	10.3	10.5
20	5.3	5.0	4.7	4.5	4.0	4.5

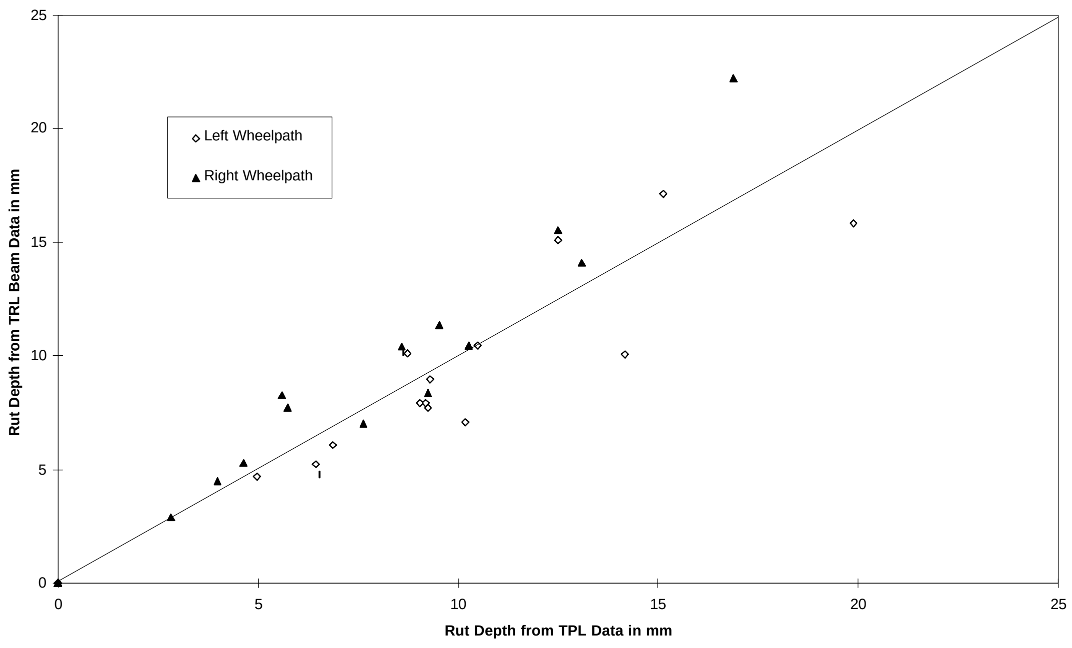

Figure 5.2: Comparison of 100 mm Interval TPL and TRL Beam Rutting

The results from Figure 5.2 show that the rut depths calculated from the TPL agree with those which would have been established from taking measurements at the same locations using a static device. However, another issue which needs to be addressed is how these values compare with the true rut depth of the pavement.

Rutting is defined as the difference in elevations between a straight edge resting on two high points to the lowest point under the straight edge. It is thus based on a continuous profile. The TPL, as with any vehicle mounted rut measurement device, does not measure the continuous profile. It instead takes samples of this profile at discrete intervals – in the TPL case 100 mm. Since is it unlikely that the TPL measurements will exactly coincide with the high and low points of the pavement, there will always be a difference between rutting when measured with samples versus that arising under a straight edge.

To investigate the magnitude of the errors, the rut depths were established using the 25 mm samples from the TRL Beam profile. These were given in Table 5.1. Figure 5.3 compares these profile rut depths with the rut depths calculated from the same TRL Beam data but at 100 mm spacings corresponding to the TPL samples. Figure 5.4 shows the same profile data with the TPL rut depths.

It will be observed from these figures that in both instances the sample data underestimated the true rut depth. In some instances the sample data reported that there was no rutting when the profile indicated significant rutting. This was due to in part to the pavement having curvature at the very edge and the sampling measurements not extending this far.

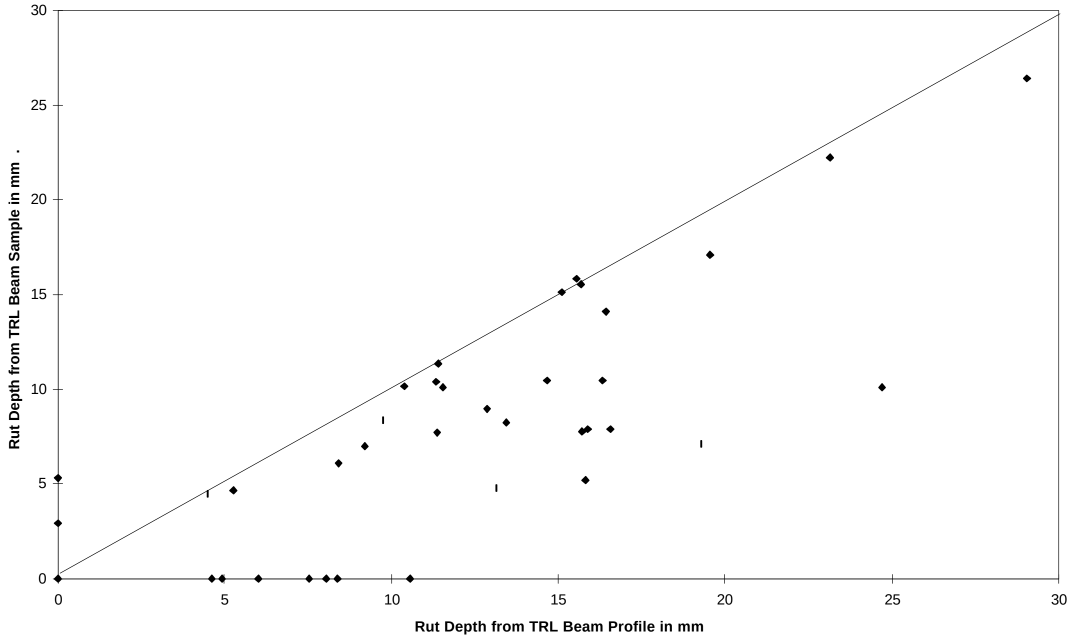

Figure 5.3: Rut Depths from TRL Beam Profile and TRL Beam Samples

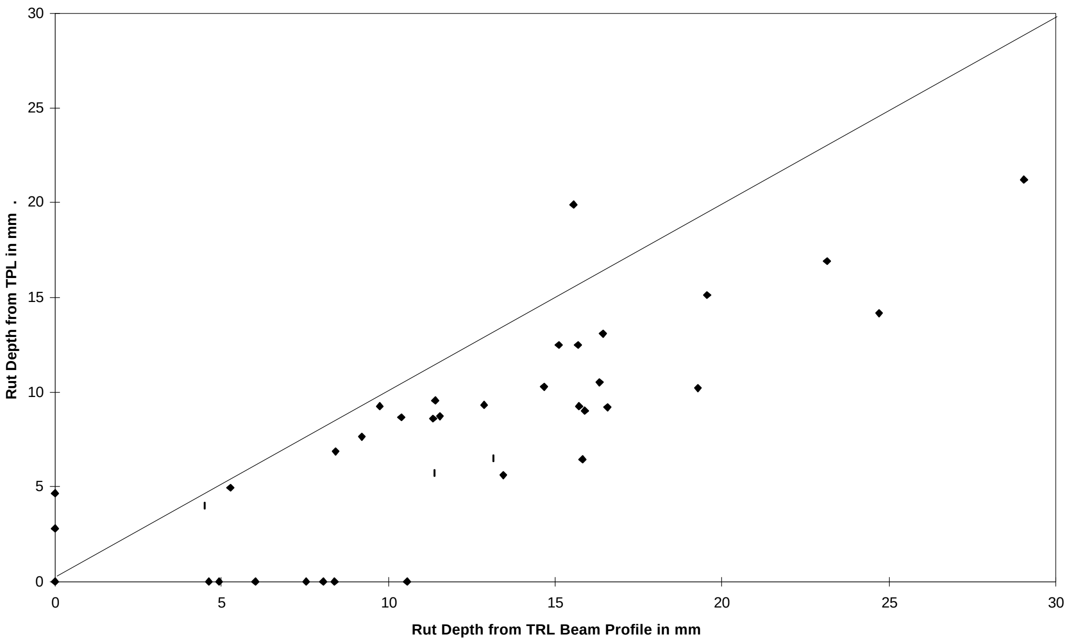

Figure 5.4: Rut Depths from TRL Beam Profile and TPL Samples

Others have found poor agreement between profilometer measurements and straight edge rut depth[1] and this sampling interval effect is undoubtedly a contributing factor.

This highlights the fundamental tradeoff with any high-speed data acquisition. One obtains a representative sample of data at frequent intervals but it is only a sample. If more accurate data are required it is necessary to use a different type of data collection. It should be noted that the differences will be proportional to the spacing of the measurement sensors so these distances should be minimised. Furthermore, the total coverage of the device, in terms of the lane width measured, should also be as wide as practical.

Table 5.2 presents the summary statistics for the rut depth data. It will be noted that there is good agreement between the TPL and TRL Beam sample data. As suggested by the earlier analysis, the agreement with the profile based rutting is not as good.

An evaluation was made of the impact of using the raw TPL data for calculating rutting instead of the data which had been corrected to have the same slope as the TRL Beam data. It was found that there were no differences in the calculated rut depths. This may initially appear to be counter intuitive, however, it is a reflection of the fact that the corrections made were linear and that there were no changes to

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[1] Cenek, P.D. *et al.* (1994). New Zealand Experience in Comparing Manual and Automatic Pavement Condition Rating Systems. Proc. Third International Conference on Managing Pavements, Vol. 2, pp. 265-278. Transportation Research Board, Washington, D.C.

Jameson, G.W., *et al.* (1989). Australian Experience with the Swedish Laser Road Surface Tester. Proc. 14th ARRB Conference, Part 8, Vermong South, Victoria, Australia, pp. 244-259.

the relative elevations. Thus, it is not necessary to take into account the road slope for calculating rut depths.

Table 5.2
Statistics for Rut Depth Data

Statistic	Rut Depth Under 2.0 m Straight Edge in mm								
	Both Wheelpaths			Left Wheelpath			Right Wheelpath		
	TRL Beam Profile	TPL	TRL Beam Sample	TRL Beam Profile	TPL	TRL Beam Sample	TRL Beam Profile	TPL	TRL Beam Sample
Mean	12.0	7.7	8.0	13.2	8.5	7.8	10.8	6.9	8.1
S. Dev	6.6	5.6	6.3	5.8	5.1	4.9	7.2	6.1	7.5
Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	29.0	21.2	26.4	24.7	19.9	17.1	29.0	21.2	26.4

6. CONCLUSIONS

This memo has presented the results of an analysis of the transverse profiles and rutting from static operation of the ROMDAS TPL. The main conclusions of this analysis are as follows:

- the TPL gives and accurate reflection of a road profile measured at 25 mm intervals;
- the rut depths calculated from the TPL data agree with those from the transverse profile measured at the same 100 mm intervals;
- there is a poor correlation between the 100 mm rut depths and those based on the 25 mm sample intervals. This will be a problem with any instrument similar to the TPL.

Table A.1
Edited TPL Data

Statistic	Station	ELEV_6	ELEV_7	ELEV_8	ELEV_9	ELEV_10	ELEV_11	ELEV_12	ELEV_13	ELEV_14	ELEV_15	ELEV_16	ELEV_17
Mean	S2	13.31	13.45	13.33	13.13	12.87	12.62	12.49	12.44	12.40	12.35	12.40	12.47
Mean	S3	12.98	12.99	12.96	12.77	12.47	12.20	12.12	12.05	11.97	12.10	12.20	12.27
Mean	S4	12.99	13.13	13.12	12.78	12.46	12.20	12.13	12.11	12.00	12.11	12.19	12.33
Mean	S5	13.08	13.21	13.13	12.95	12.75	12.69	12.63	12.63	12.69	12.78	12.91	12.98
Mean	S6	12.85	13.21	13.23	13.31	13.17	13.11	13.10	13.11	13.09	13.06	13.17	13.23
Mean	S7	13.53	13.88	13.99	14.11	14.03	14.09	14.11	14.05	13.94	13.78	13.72	13.66
Mean	S8	13.25	13.39	13.43	13.40	13.28	13.14	13.05	12.99	12.90	12.87	12.90	12.88
Mean	S9	12.88	13.31	13.55	13.55	13.47	13.46	13.46	13.44	13.28	13.05	13.02	12.89
Mean	S10	13.11	13.23	13.15	12.98	12.98	12.99	12.87	12.61	12.21	12.04	12.12	12.19
Mean	S11	13.81	13.82	13.54	13.32	13.12	12.90	12.65	12.54	12.33	12.20	12.12	12.13
Mean	S12	13.12	13.26	13.04	12.72	12.42	12.31	12.02	11.81	11.71	11.72	11.81	11.91
Mean	S13	13.72	13.53	13.28	13.21	13.08	12.81	12.68	12.57	12.48	12.54	12.56	12.62
Mean	S14	12.24	13.44	13.38	13.09	12.87	12.67	12.57	12.55	12.49	12.51	12.60	12.61
Mean	S15	12.78	12.93	12.81	12.54	12.38	12.17	12.12	12.07	12.06	12.22	12.27	12.40
Mean	S16	13.66	13.52	12.96	12.62	12.30	12.02	11.99	11.99	12.10	12.14	12.25	12.33
Mean	S17	13.46	13.54	13.26	12.97	12.63	12.39	12.34	12.28	12.20	12.33	12.53	12.61
Mean	S18	14.24	14.14	13.47	13.11	12.78	12.35	12.24	12.22	12.29	12.51	12.54	12.66
Mean	S19	12.73	13.31	13.23	13.01	12.82	12.65	12.40	12.34	12.20	12.20	12.34	12.48
Mean	S20	13.48	13.46	13.23	12.93	12.74	12.53	12.31	12.33	12.36	12.31	12.37	12.31

NOTES: 1/ Data are converted to mm using equation DISPL = 31.7277 UMS - 27.36
2/ UMS Sensors 1 to 5 were not used in the tests

Table A.1 - Continued

Statistic	Station	ELEV_18	ELEV_19	ELEV_20	ELEV_21	ELEV_22	ELEV_23	ELEV_24	ELEV_25	ELEV_26	ELEV_27	ELEV_28	ELEV_29	ELEV_30
Mean	S2	12.50	12.55	12.68	12.75	13.11	13.43	13.58	13.61	13.69	13.79	13.92	14.05	14.01
Mean	S3	12.18	12.07	12.24	12.45	12.90	13.18	13.29	13.32	13.33	13.41	13.54	13.41	13.27
Mean	S4	12.39	12.45	12.60	12.83	13.35	13.57	13.73	13.90	13.95	14.16	14.29	14.48	14.52
Mean	S5	13.00	13.11	13.23	13.27	13.40	13.59	13.70	13.67	13.62	13.68	13.79	14.03	14.21
Mean	S6	13.29	13.34	13.35	13.28	13.39	13.43	13.48	13.55	13.63	13.74	13.95	14.31	14.48
Mean	S7	13.62	13.60	13.63	13.54	13.65	13.76	13.81	13.95	14.23	14.49	14.61	14.79	14.93
Mean	S8	12.81	12.82	12.88	12.86	12.97	13.12	13.18	13.49	13.81	13.95	14.07	14.22	14.18
Mean	S9	12.80	12.74	12.75	12.79	12.98	13.17	13.13	13.37	13.61	13.92	14.18	14.25	14.36
Mean	S10	12.23	12.34	12.47	12.55	12.84	13.14	13.38	13.80	14.08	14.22	14.38	14.45	14.34
Mean	S11	12.22	12.43	12.82	12.92	13.25	13.44	13.71	14.01	14.30	14.47	14.64	14.83	14.56
Mean	S12	12.05	12.19	12.35	12.70	13.18	13.53	13.82	14.14	14.36	14.64	15.00	15.22	15.39
Mean	S13	12.69	12.78	12.95	13.23	13.63	13.84	13.97	14.16	14.31	14.58	14.86	15.01	14.92
Mean	S14	12.69	12.79	12.89	12.93	13.24	13.53	13.83	14.15	14.37	14.71	15.08	15.40	15.71
Mean	S15	12.50	12.61	12.73	12.84	13.22	13.53	13.94	14.32	14.65	14.99	15.37	15.81	16.18
Mean	S16	12.37	12.46	12.60	12.71	13.03	13.37	13.61	13.94	14.15	14.39	14.64	14.79	14.82
Mean	S17	12.69	12.75	12.88	12.95	13.28	13.57	13.94	14.23	14.51	14.84	15.20	15.39	15.52
Mean	S18	12.76	12.89	13.04	13.22	13.61	13.91	14.22	14.50	14.72	15.01	15.28	15.44	15.54
Mean	S19	12.54	12.61	12.81	12.90	13.26	13.68	14.05	14.43	14.74	14.95	15.02	15.32	15.57
Mean	S20	12.37	12.51	12.71	12.93	13.27	13.58	13.86	14.19	14.44	14.72	14.98	15.20	15.54

Table A.2
TPL and TRL Beam Elevations in mm At Same Displacements

Site 2			Site 3			Site 4			Site 5			Site 6			Site 7		
Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL
75	96.1	96.1	75	100.2	100.2	125	86.3	86.3	25	97.9	97.9	25	102.4	105.8	0	104.6	100.0
175	97.9	99.2	175	104.1	104.3	225	88.5	89.5	125	97.5	99.2	125	93.6	93.6	100	93.5	93.5
275	108.1	108.9	275	109.3	108.9	325	95.1	99.0	225	103.9	104.6	225	95.6	93.8	200	90.1	89.9
375	120.4	121.2	375	119.8	119.4	425	112.4	115.6	325	113.2	114.4	325	95.9	98.7	300	86.1	88.0
475	134.7	135.5	475	133.3	132.4	525	129.1	130.8	425	123.6	123.4	425	103.0	103.7	400	88.8	88.6
575	149.1	147.5	575	146.2	142.8	625	143.9	143.3	525	129.1	128.1	525	107.7	107.1	500	86.6	86.6
675	159.4	157.7	675	153.1	153.0	725	152.7	153.2	625	134.9	134.1	625	110.7	110.4	600	86.2	87.7
775	167.1	165.9	775	159.6	159.2	825	159.7	161.8	725	138.5	137.6	725	113.3	115.2	700	87.7	90.8
875	174.6	174.5	875	166.4	165.7	925	169.9	169.0	825	140.7	140.4	825	116.4	117.9	800	91.3	94.9
975	182.3	182.0	975	166.4	168.3	1025	172.9	174.6	925	141.5	142.1	925	120.4	120.0	900	96.3	100.2
1075	186.9	188.7	1075	167.6	169.9	1125	176.7	179.2	1025	141.2	143.4	1025	119.4	121.9	1000	98.2	102.2
1175	190.8	193.0	1175	169.7	172.8	1225	178.7	182.8	1125	142.7	146.1	1125	120.4	122.9	1100	99.9	104.7
1275	195.9	197.5	1275	176.7	178.6	1325	183.5	186.5	1225	145.7	148.9	1225	121.2	123.8	1200	101.4	105.8
1375	200.5	201.9	1375	184.3	184.5	1425	187.9	190.4	1325	146.2	150.7	1325	122.4	125.7	1300	101.9	106.3
1475	202.6	205.0	1475	183.3	192.8	1525	189.7	191.5	1425	146.0	150.8	1425	124.5	127.9	1400	100.9	106.1
1575	206.6	204.9	1575	180.8	184.1	1625	189.1	187.8	1525	148.7	151.7	1525	129.6	129.5	1500	103.7	105.0
1675	201.4	201.9	1675	171.0	174.9	1725	178.9	179.5	1625	148.2	148.1	1625	128.9	129.4	1600	100.0	103.1
1775	197.4	198.5	1775	166.4	169.2	1825	178.5	177.7	1725	146.1	147.2	1725	130.2	129.9	1700	96.5	99.8
1875	198.7	196.7	1875	167.1	166.6	1925	179.8	177.0	1825	146.4	148.3	1825	131.5	130.3	1800	95.0	94.8
1975	203.9	201.9	1975	170.3	168.9	2025	181.0	181.6	1925	151.0	151.3	1925	131.9	129.6	1900	90.3	88.6
2075	207.6	206.9	2075	174.2	171.2	2125	185.9	183.9	2025	156.4	157.0	2025	132.2	127.1	2000	81.5	81.5
2175	210.8	210.2	2175	175.9	175.1	2225	185.9	183.7	2125	158.2	157.3	2125	131.4	123.9	2100	73.1	72.5
2275	212.9	212.3	2275	176.0	177.1	2325	188.1	184.5	2225	158.5	157.2	2225	127.3	120.3	2200	69.3	68.6
2375	214.8	215.3	2375	184.5	182.2	2425	188.8	186.4	2325	154.9	154.9	2325	118.8	118.8	2300	63.4	63.4
2475	222.4	222.4	2475	193.2	193.2	2525	194.0	194.0	2425	142.7	156.6	2425	114.5	124.3	2400	58.9	60.7

Table A.2 - Continued

Site 8			Site 9			Site 10			Site 11			Site 12			Site 13		
Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL
50	97.4	97.4	0	109.6	100.0	50	97.4	101.1	100	95.6	95.6	50	96.0	96.0	75	98.0	98.0
150	93.1	94.0	100	97.0	92.5	150	97.9	97.9	200	99.0	100.1	150	97.9	101.6	175	108.6	108.9
250	91.9	91.6	200	91.1	91.1	250	105.0	102.5	300	111.7	111.8	250	111.1	119.0	275	121.2	121.0
350	93.2	91.5	300	92.3	92.7	350	114.7	113.5	400	122.3	122.2	350	127.2	135.0	375	127.8	130.1
450	97.1	93.0	400	96.3	95.4	450	119.0	117.3	500	132.5	130.8	450	143.0	145.6	475	136.6	137.8
550	101.4	97.9	500	97.9	97.2	550	123.0	121.6	600	143.4	141.0	550	152.5	160.3	575	149.4	147.5
650	104.5	102.0	600	99.3	100.1	650	131.4	131.2	700	154.8	153.9	650	168.0	173.9	675	158.2	157.3
750	106.5	105.2	700	101.1	105.2	750	143.9	145.6	800	162.1	163.8	750	180.6	184.8	775	166.1	166.5
850	109.4	107.8	800	107.5	113.0	850	160.9	162.6	900	172.5	171.2	850	189.9	192.1	875	173.6	174.5
950	110.6	109.2	900	116.2	117.5	950	170.8	168.8	1000	180.4	181.2	950	195.8	198.0	975	176.0	179.8
1050	109.6	110.2	1000	118.5	123.3	1050	172.7	173.6	1100	186.7	188.2	1050	199.1	202.9	1075	179.9	182.8
1150	110.3	113.1	1100	123.9	128.6	1150	174.9	176.4	1200	190.0	192.2	1150	202.0	205.1	1175	182.6	186.8
1250	112.7	114.4	1200	128.3	132.2	1250	178.0	179.2	1300	190.9	193.6	1250	203.9	206.6	1275	184.7	189.2
1350	112.3	114.0	1300	131.4	134.1	1350	178.9	179.7	1400	188.0	190.9	1350	205.5	208.2	1375	186.5	190.5
1450	110.6	113.8	1400	132.6	133.3	1450	179.1	179.9	1500	179.4	184.9	1450	206.4	206.4	1475	185.5	191.0
1550	111.3	111.3	1500	132.6	129.5	1550	181.0	178.5	1600	179.8	178.4	1550	201.6	197.4	1575	181.2	187.9
1650	108.1	108.1	1600	127.8	125.0	1650	176.0	175.5	1700	173.3	175.0	1650	192.3	189.7	1675	172.9	179.9
1750	103.5	102.6	1700	123.4	122.8	1750	170.9	170.8	1800	171.0	170.7	1750	187.3	184.1	1775	170.8	173.9
1850	101.6	98.0	1800	125.8	118.8	1850	167.6	164.7	1900	166.0	165.9	1850	184.2	180.8	1875	171.2	170.5
1950	91.6	91.0	1900	119.7	113.9	1950	158.7	157.7	2000	160.1	160.4	1950	180.3	178.5	1975	169.6	167.8
2050	81.7	81.2	2000	113.4	106.5	2050	154.4	150.1	2100	154.9	154.0	2050	179.5	176.1	2075	169.5	167.0
2150	77.5	73.7	2100	104.7	98.6	2150	154.2	148.6	2200	153.3	150.3	2150	176.8	172.5	2175	165.4	164.6
2250	73.7	70.7	2200	97.9	95.2	2250	153.6	149.2	2300	151.6	148.2	2250	171.3	170.1	2275	161.1	161.1
2350	68.9	68.9	2300	97.1	93.6	2350	155.6	155.6	2400	149.2	149.2	2350	170.5	170.5	2375	160.7	160.7
2450	70.4	72.1	2400	94.9	94.9	2450	163.5	167.4	2500	161.4	150.1	2450	171.3	171.4	2475		

Table A.2 - Continued

Site 14			Site 15			Site 16			Site 17			Site 18			Site 19			Site 20		
Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL	Displ.	TPL	TRL
0	105.0	105.0	0	100.0	100.0	75	99.5	99.5	50	96.7	96.7	75	96.3	96.3	0			25	102.0	102.0
50	101.9	100.6	100	104.4	102.5	175	109.7	110.4	150	101.5	102.8	175	106.9	107.2	100	100.0	100.0	125	109.3	109.2
150	109.9	111.1	200	117.2	117.4	275	133.0	130.9	250	117.6	117.9	275	135.9	127.0	200	110.1	110.2	225	123.0	122.9
250	125.5	125.7	300	135.1	136.1	375	149.6	147.8	350	134.1	135.3	375	155.0	152.7	300	124.9	122.9	325	138.8	137.6
350	138.4	137.4	400	149.5	149.5	475	165.4	163.2	450	151.9	152.7	475	173.4	170.5	400	138.5	136.2	425	151.4	150.6
450	151.1	150.8	500	165.2	163.2	575	180.1	176.9	550	167.0	165.8	575	194.5	186.5	500	151.7	147.8	525	164.4	162.0
550	160.6	160.7	600	176.1	175.0	675	186.6	186.8	650	175.7	174.5	675	206.0	204.2	600	167.2	164.6	625	177.8	175.1
650	167.5	167.3	700	186.7	189.2	775	192.4	192.2	750	184.8	186.0	775	214.1	216.9	700	176.9	177.0	725	183.6	182.9
750	175.7	174.6	800	196.5	195.1	875	194.7	197.8	850	194.6	194.2	875	219.7	221.6	800	188.9	187.0	825	189.2	187.8
850	181.3	180.4	900	200.4	202.7	975	199.0	200.4	950	197.6	197.5	975	220.3	222.9	900	196.8	194.3	925	197.3	194.7
950	184.6	186.3	1000	208.1	209.6	1075	201.2	203.5	1050	198.3	199.6	1075	227.2	229.2	1000	199.9	200.5	1025	202.0	201.9
1050	190.4	191.9	1100	213.1	216.2	1175	204.5	208.1	1150	203.2	206.2	1175	231.1	235.2	1100	203.3	205.4	1125	210.4	212.5
1150	194.2	195.8	1200	219.2	221.0	1275	209.0	212.2	1250	208.0	210.4	1275	235.7	239.1	1200	209.1	210.7	1225	214.8	218.0
1250	197.3	198.7	1300	225.0	227.6	1375	211.6	215.2	1350	213.2	216.8	1375	239.2	242.8	1300	214.6	215.4	1325	216.8	219.7
1350	200.4	202.3	1400	230.3	231.4	1475	213.0	216.9	1450	216.4	218.4	1475	242.0	245.4	1400	215.9	218.0	1425	216.8	220.8
1450	205.2	203.9	1500	236.1	233.9	1575	215.1	216.6	1550	221.3	219.9	1575	244.1	246.3	1500	220.7	219.2	1525	216.6	219.4
1550	201.8	201.5	1600	233.2	234.0	1675	210.6	213.7	1650	217.9	218.5	1675	239.4	245.0	1600	217.0	216.9	1625	212.2	215.6
1650	198.7	197.0	1700	232.6	231.8	1775	205.8	209.6	1750	216.1	215.1	1775	237.8	240.4	1700	211.4	212.1	1725	208.6	211.4
1750	195.3	193.4	1800	228.8	228.7	1875	203.6	204.5	1850	211.4	210.4	1875	235.5	237.9	1800	207.3	207.9	1825	206.2	207.0
1850	191.6	190.3	1900	225.9	225.2	1975	199.0	201.1	1950	209.6	208.0	1975	234.4	236.6	1900	202.8	204.1	1925	202.3	203.2
1950	190.8	188.5	2000	224.6	222.9	2075	198.1	198.0	2050	207.9	206.1	2075	235.1	235.5	2000	200.7	199.8	2025	200.8	200.6
2050	186.1	183.6	2100	223.2	220.9	2175	196.2	195.9	2150	204.6	203.7	2175	233.6	234.2	2100	201.8	199.8	2125	198.3	198.2
2150	180.8	181.0	2200	220.2	217.8	2275	193.8	194.0	2250	200.4	202.2	2275	232.7	233.7	2200	207.1	204.0	2225	196.7	196.7
2250	176.8	176.8	2300	215.5	215.5	2375	194.7	194.7	2350	201.4	201.4	2375	235.5	235.5	2300	205.3	205.3	2325	196.0	196.0
2350	173.3	178.5	2400	213.0	214.0	2475	199.6	198.3	2450	204.8	205.5	2475			2400	205.3	205.4	2425	191.8	192.9

Annex B
Transverse Profiles

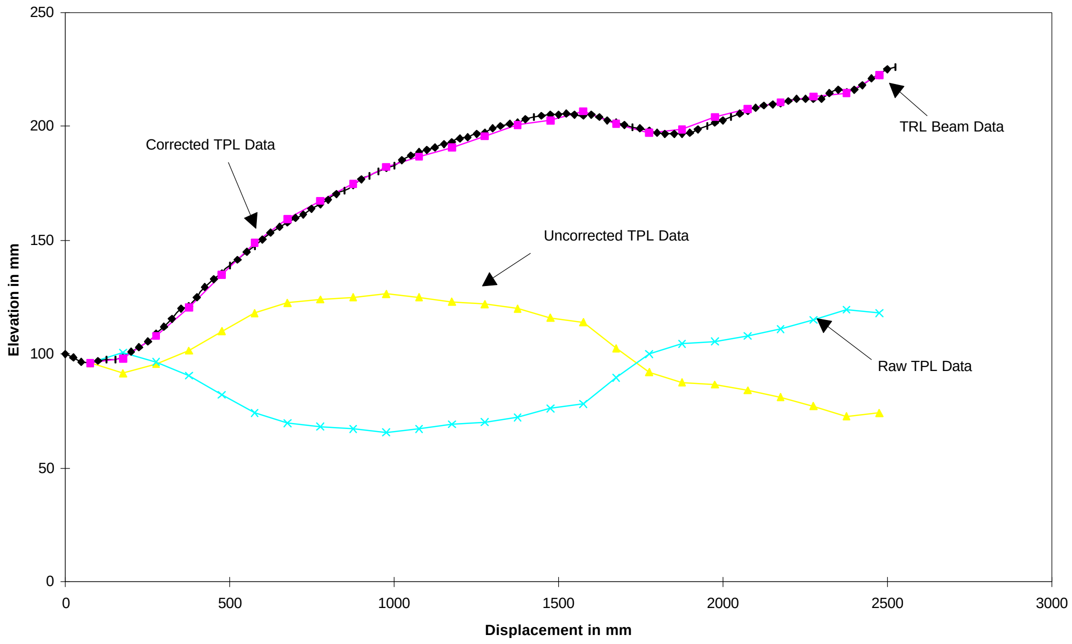

Figure B.1: Transverse Profiles - Site 2

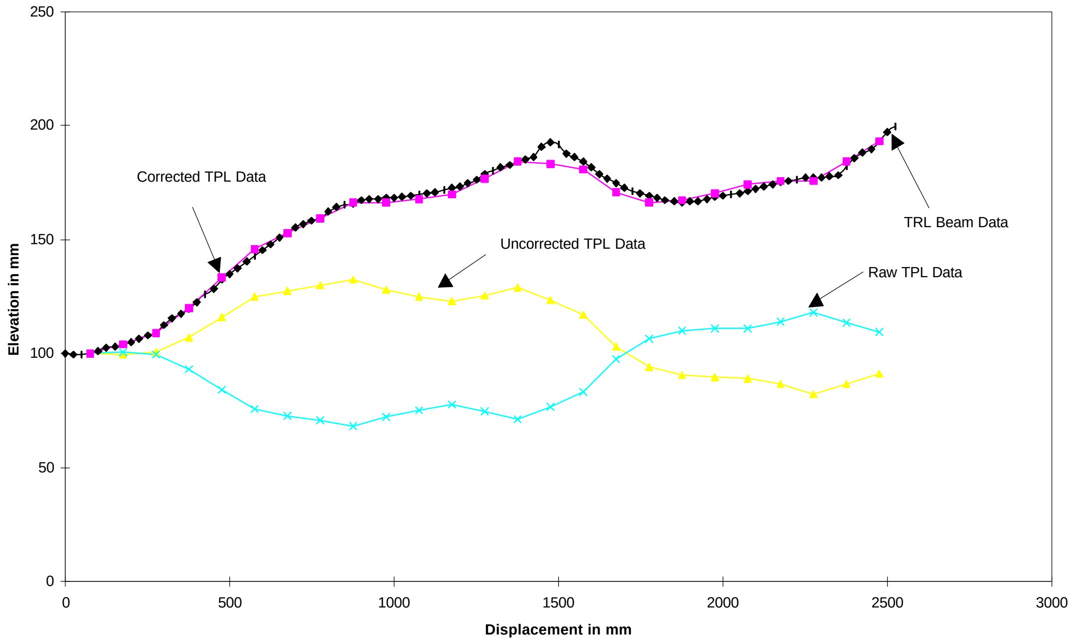

Figure B.2: Transverse Profiles - Site 3

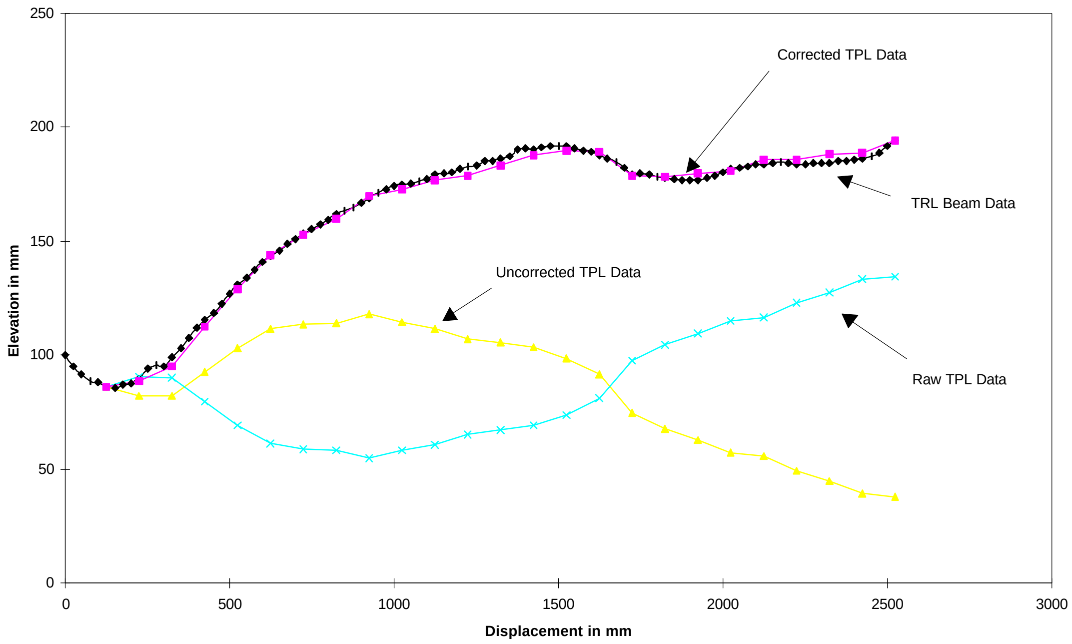

Figure B.3: Transverse Profiles - Site 4

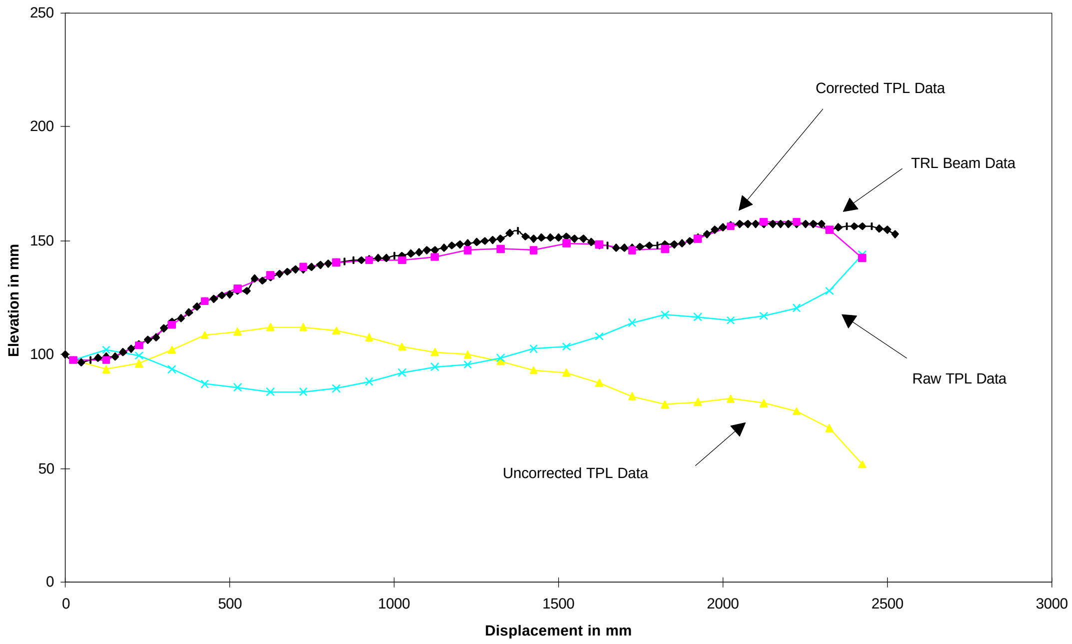

Figure B.4: Transverse Profiles - Site 5

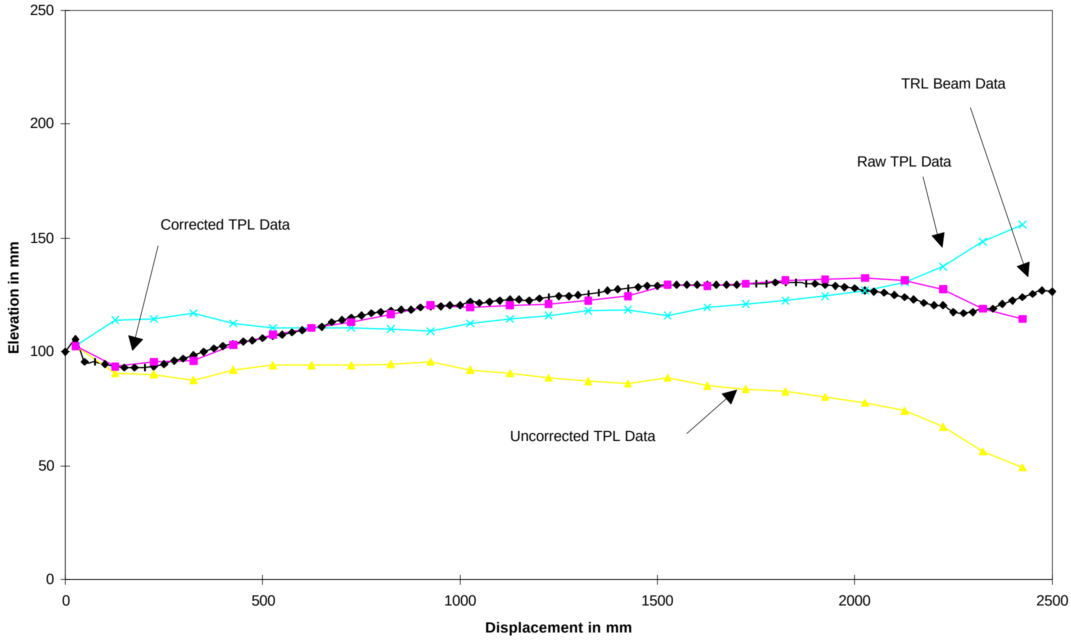

Figure B.5: Transverse Profiles - Site 6

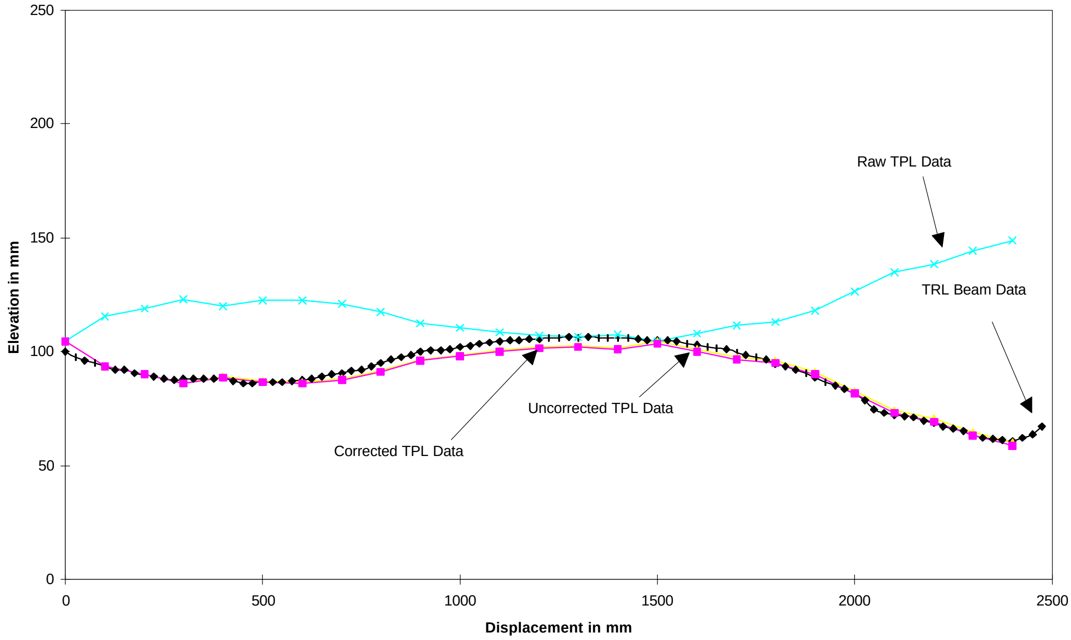

Figure B.6: Transverse Profiles - Site 7

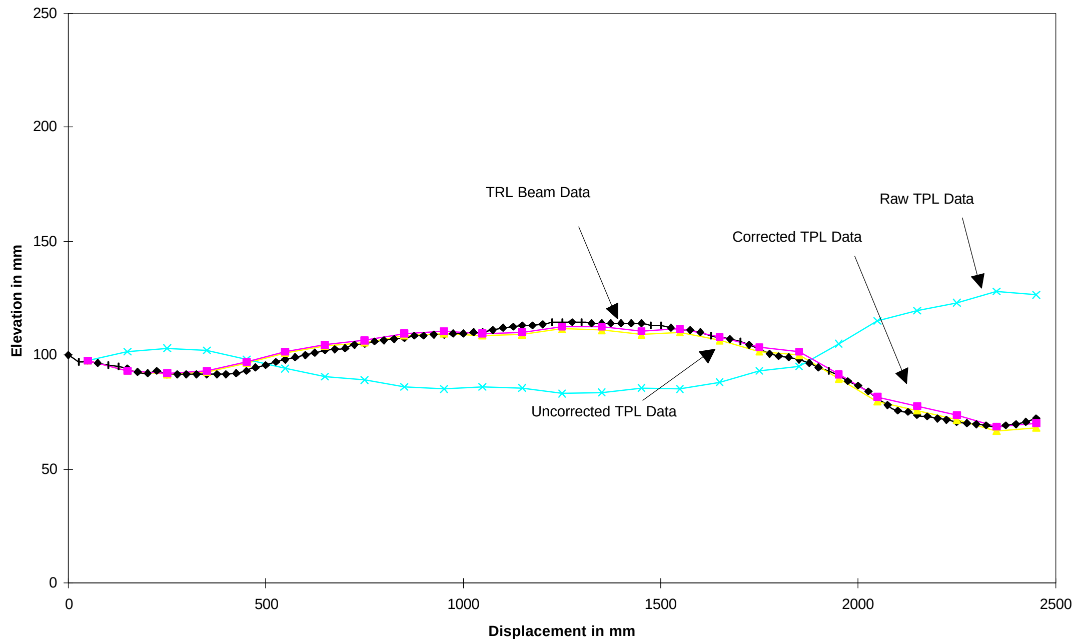

Figure B.7: Transverse Profiles - Site 8

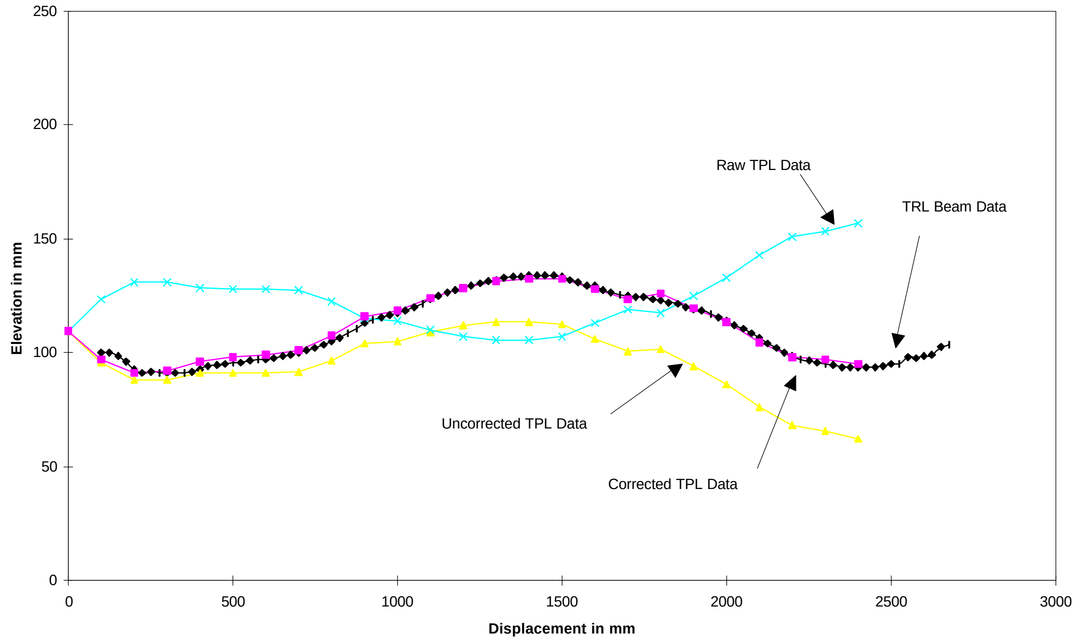

Figure B.8: Transverse Profiles - Site 9

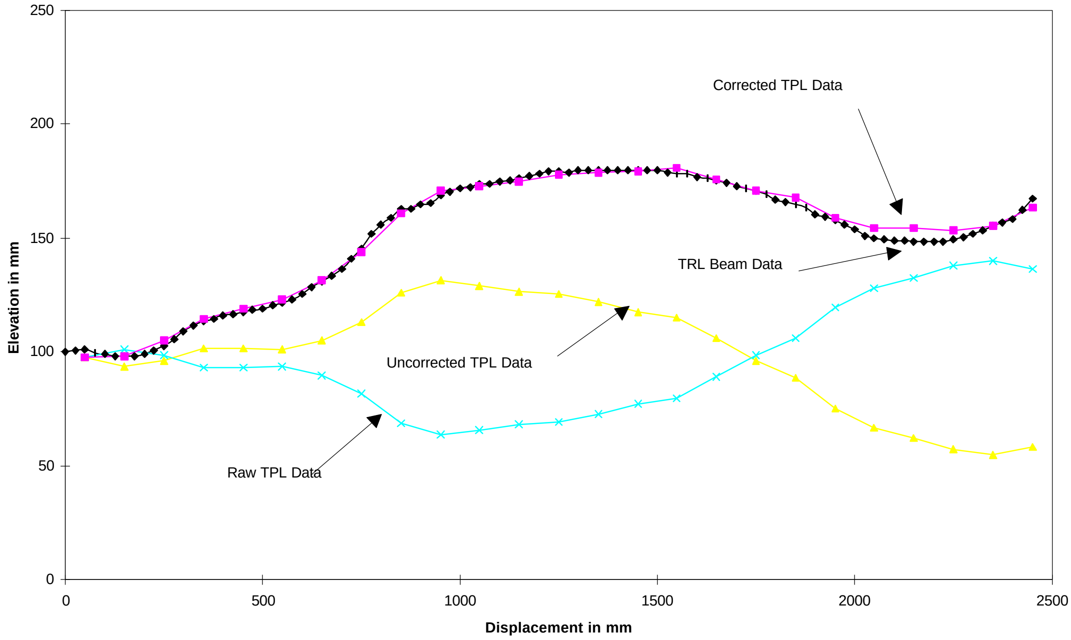

Figure B.9: Transverse Profiles - Site 10

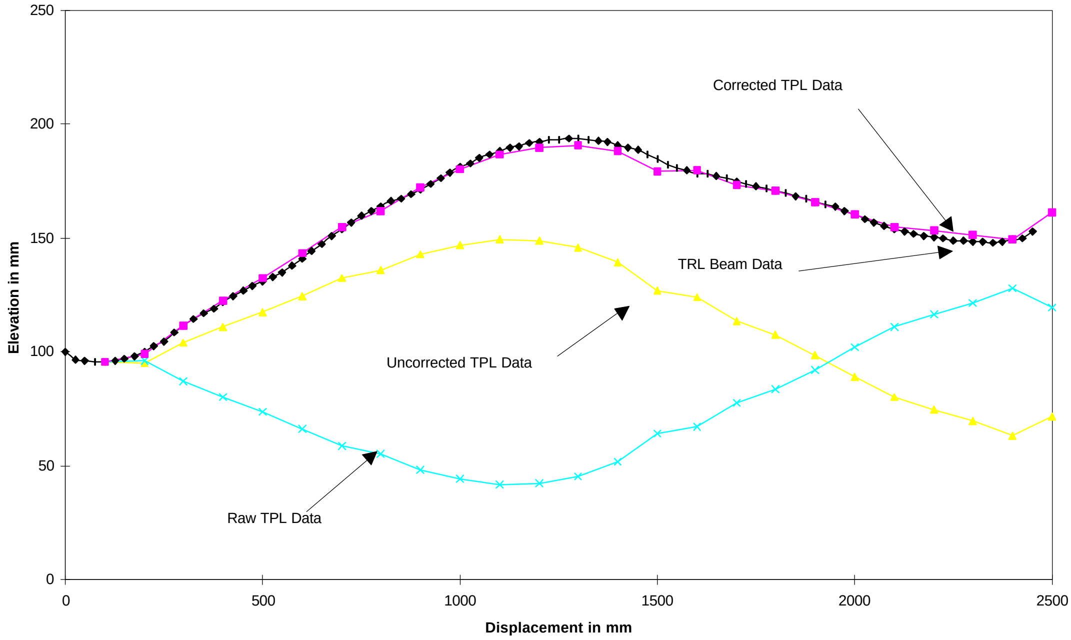

Figure B.10: Transverse Profiles - Site 11

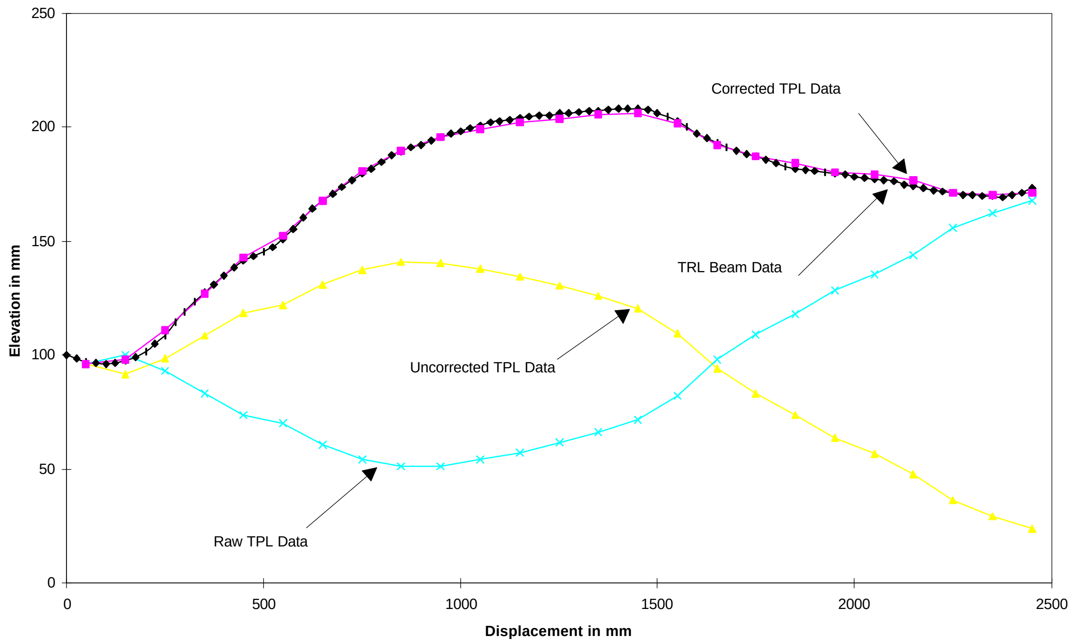

Figure B.11: Transverse Profiles - Site 12

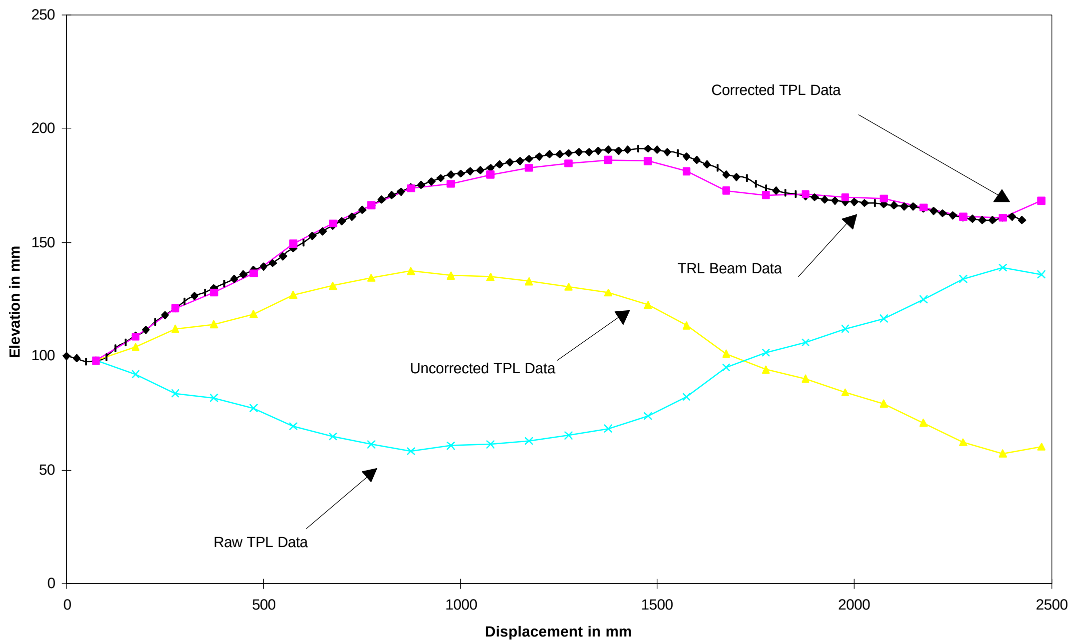

Figure B.12: Transverse Profiles - Site 13

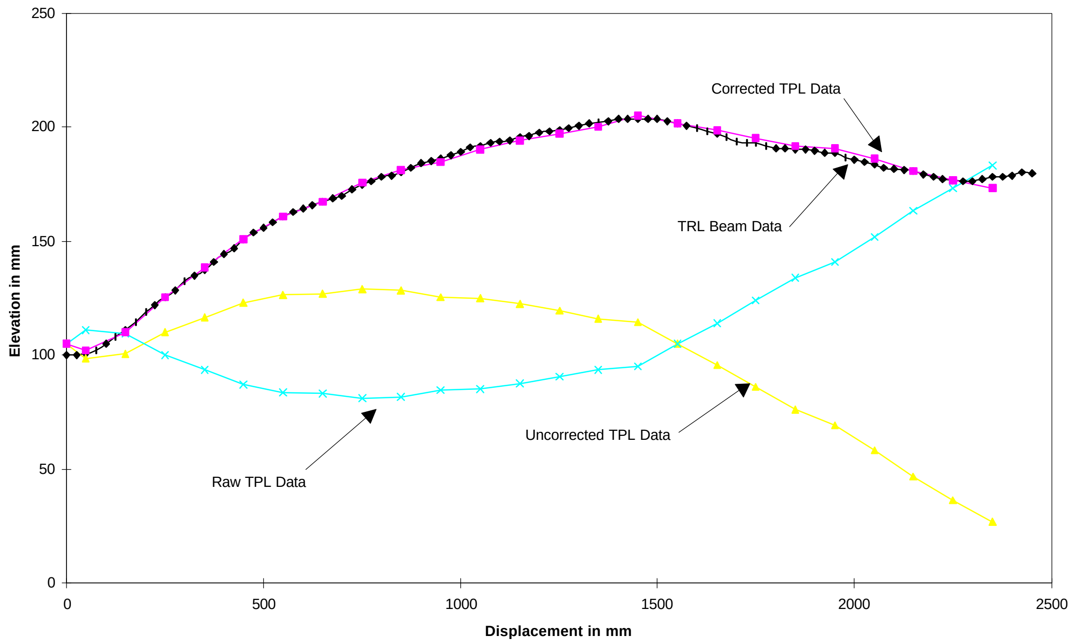

Figure B.13: Transverse Profiles - Site 14

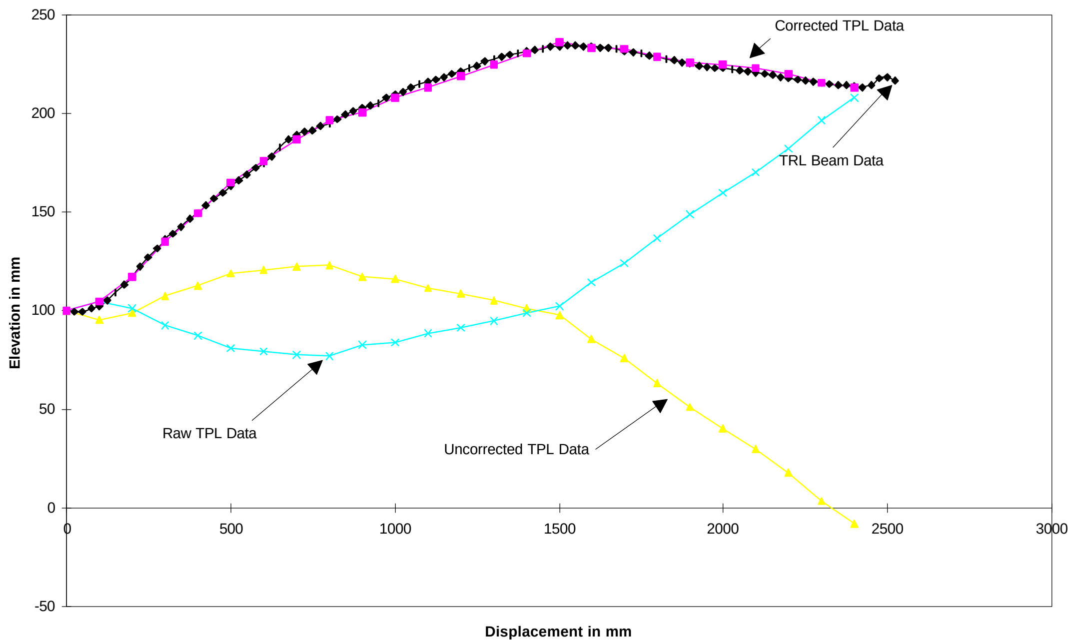

Figure B.14: Transverse Profiles - Site 15

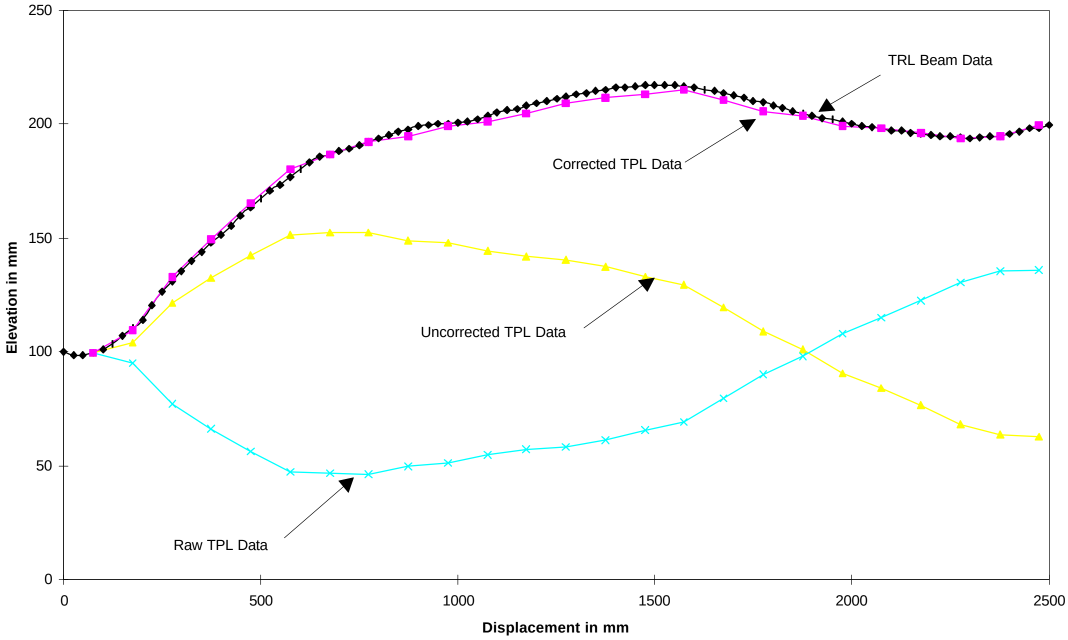

Figure B.15: Transverse Profiles - Site 16

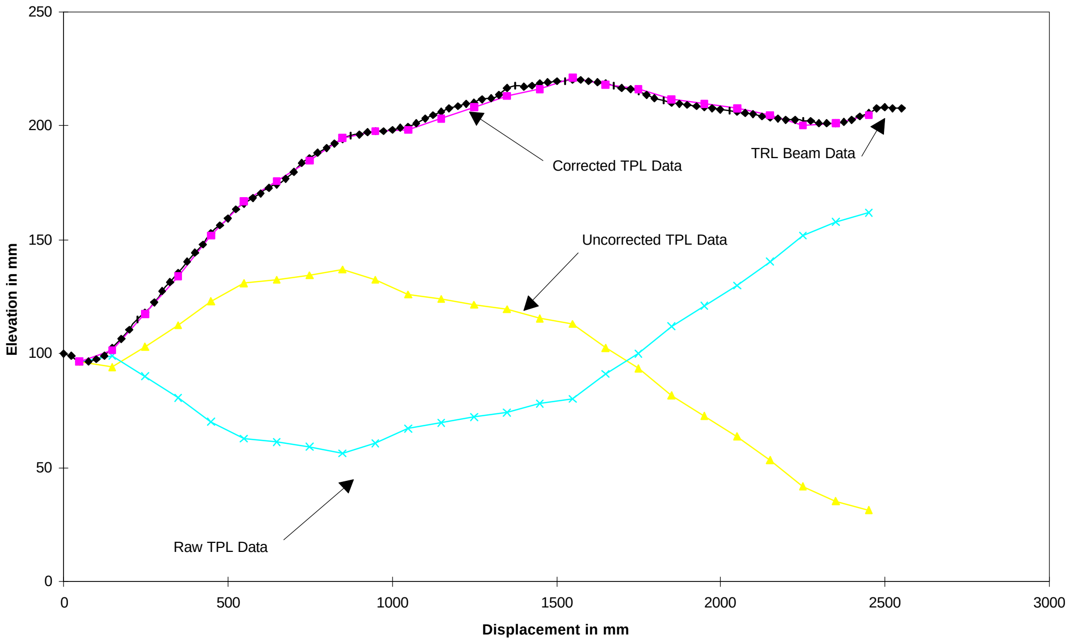

Figure B.16: Transverse Profiles - Site 17

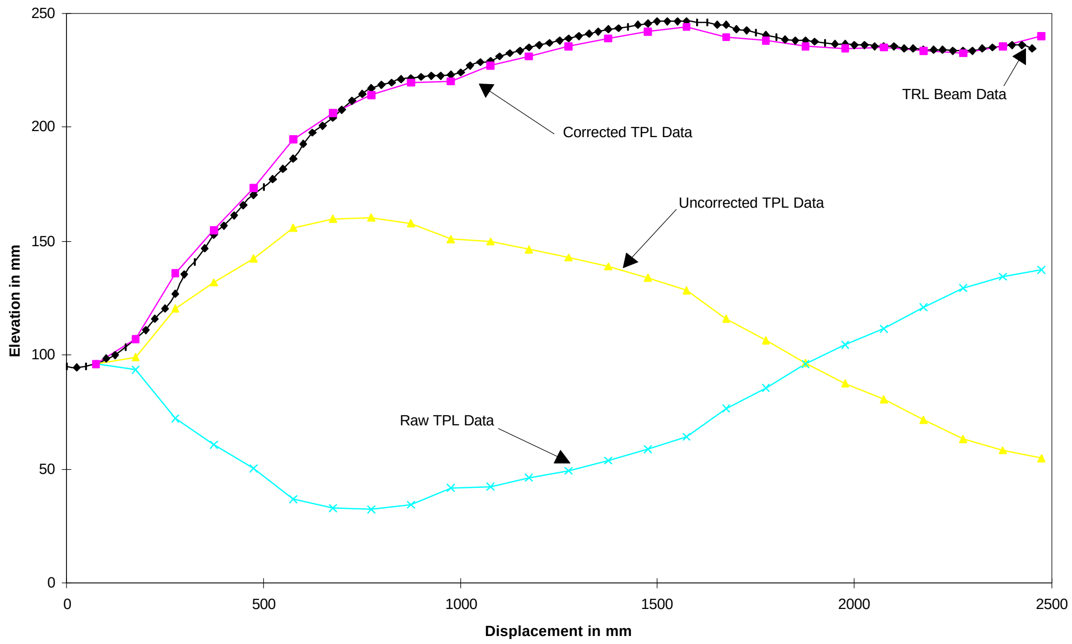

Figure B.17: Transverse Profiles - Site 18

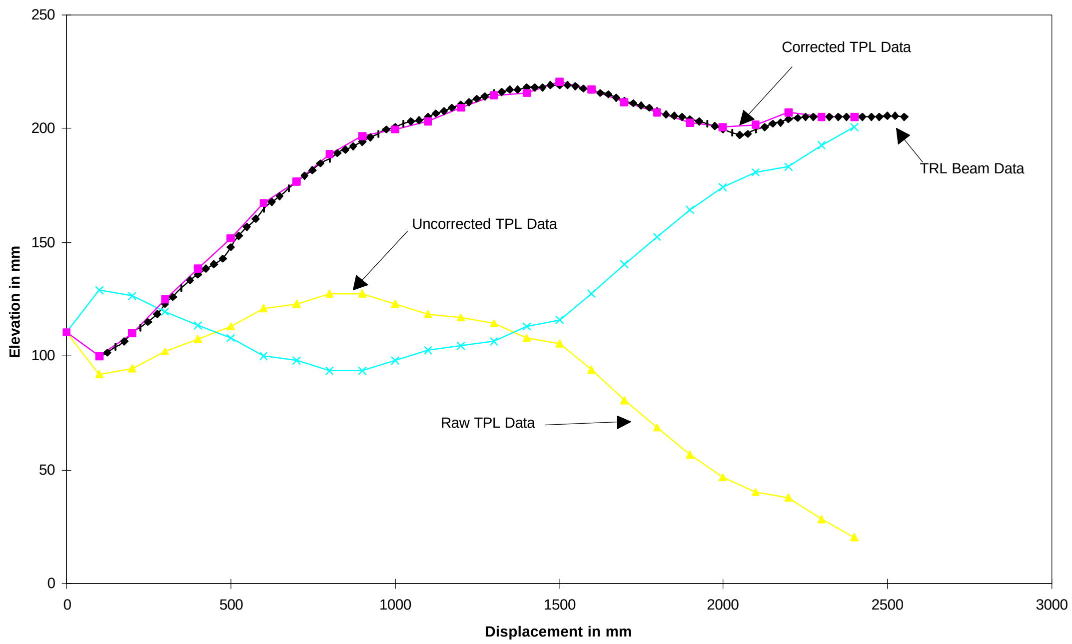

Figure B.18: Transverse Profiles - Site 19

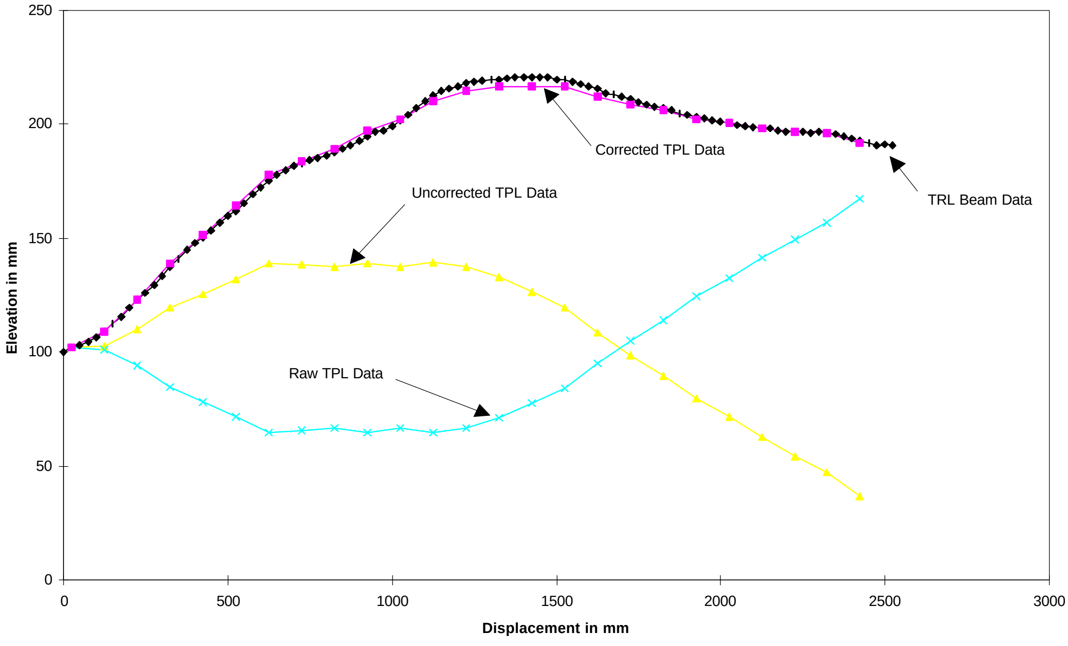

Figure B.19: Transverse Profiles - Site 20