TEST METHOD T 193

ESTABLISHING AND MAINTAINING CONTROL CHARTS FOR CONCRETE BASE COURSE THICKNESS

REVISION SUMMARY

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TEST METHOD T 193

ESTABLISHING AND MAINTAINING CONTROL CHARTS FOR CONCRETE BASE COURSE THICKNESS

1.0 SCOPE

This Test Method describes the procedures for:

- establishing an ***acceptance*** control chart for the percentage of a concrete base course less than the design thickness;
- determining the process control limits for the ***process*** control chart;
- re-calibrating the ***process*** control chart,
- the actions arising from control chart analysis,

when sampling pavement courses thicknesses in accordance with Test Method T 195 and with RTA model specification for construction of concrete pavements. This Test Method applies to thickness measurements determined by conformance verification surveys of the subbase and base surfaces.

2.0 PURPOSE

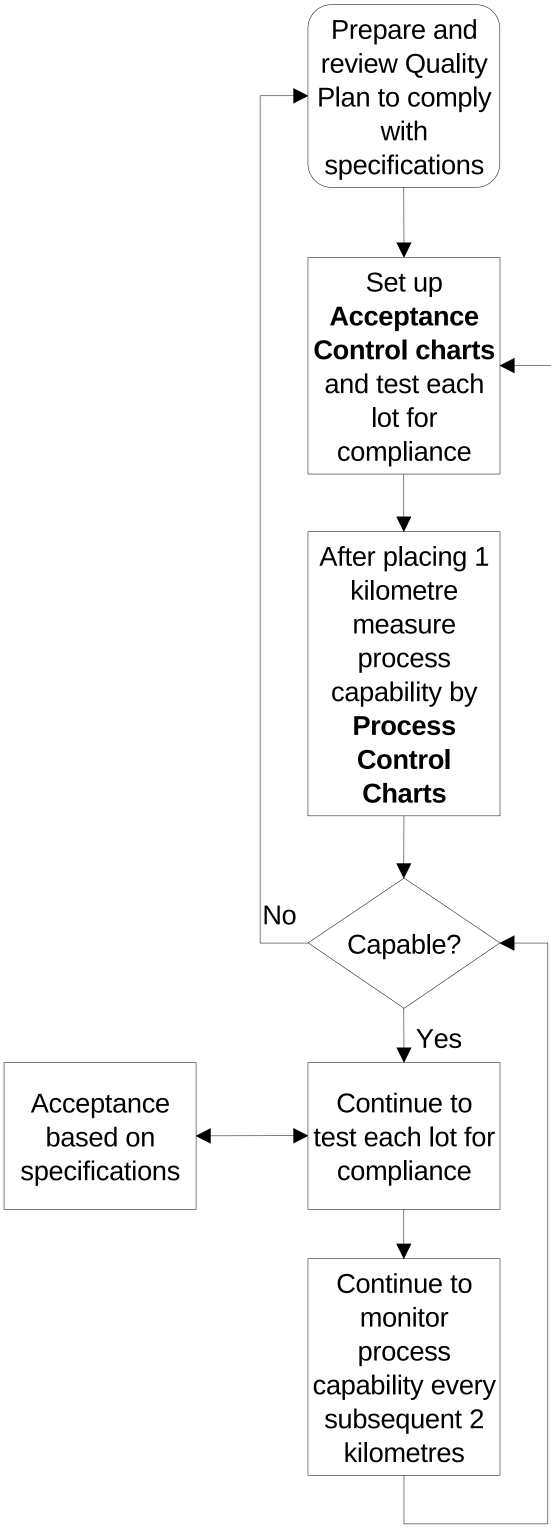
The purpose of the control charts is to measure and control the variance of the constructed concrete base course thickness to ensure that no more than a specified percentage is less than the design thickness. The process control charts also enable estimation of the capability of the construction process to achieve this outcome.

3.0 OVERVIEW

The acceptance limits on the acceptance control chart are based on the percentage of the base course less than the design thickness. The statistical theory that defines the Q statistic in RTA Specification Q of the model RTA specifications, also defines the acceptance limits for base course thickness. However, this Test Method uses K (capital) for determining acceptance, while Part Q uses k (lower case). The K value of this Test Method differs from the k value of Part Q due to a different producer's risk and the acceptable percentage defective. Data correlation of the thickness measurements also affects the acceptance limits defined by this Test Method.

Diagram 1

Flow Chart showing the timing and role of acceptance control charts and process control charts to controlling pavement surface heights.



4.0 DEFINITIONS

The definitions contained in RTA specification clauses for construction of concrete pavements also apply to this Test Method.

Test Method T 195, Clause 5.1, contains the definitions for full and residue lots.

5.0 APPARATUS

To assist electronic data transfer, control charts should be plotted electronically by computer software such as spreadsheet or dedicated statistical packages.

6.0 PROCEDURE

The acceptance limits and process control limits, defined by this Test Method, require compliance with the sampling plan given in Test Method T 195.

This Test Method samples the pavement on a lot by lot basis, with each lot defined as 100 lineal metres of pavement of a day's homogeneous work. However, due to various factors it is not possible to assume that an even multiple of 100 metres of pavement will be placed each day. Test Method TM 195 describes the method of sampling the residue portion of the pavement from the end of the last even 100 lineal metres of pavement to the end of the day's pour. Tables 1, for Acceptance Limits, and Table 2, for Process Control Charts, provide parameters for residue lots.

In addition, trial pavements, equipment breakdown and inclement weather, may lead to less than 80 lineal metres of pavement being placed during a day's work. Where one day's work consists of less than 80 metres of pavement, then sample the pavement as one lot in accordance with Test Method T195. Lts less than 80 metres in length are assessed for thickness in accordance with Table A.

Table A - Assessment criteria for thickness for lots less than 80 metres in length

Text Reference	Thickness deficiency (mm) Mean (mm)		Individual (mm) Result	Individual (mm) Frequency	Status/ Action
Conformance with Cl 5.4.3	Nil	⇦ and ⇨	5	≤ 2	Conforming
			and ⇧⇩		
			≥ 10	Nil	
Nonconformance	Nil	⇦ and ⇨	5	> 2	Nonconforming 12% deduction
			and ⇧⇩		
			≥ 10	Nil	
Nonconformance	≥ 15				Nonconforming, remove and replace
Nonconformance	≤ 10	⇦ and ⇨	≥ 20	≥ 1	
Nonconformance	5	⇦ and ⇨	≥ 20	Nil	Nonconforming, 24% deduction
	10	⇦ and ⇨	≥ 20	Nil	Nonconforming, 60% deduction
Nonconformance	Nil	⇦ and ⇨	5	> 2	Nonconforming, 45% deduction
			and/or ⇧⇩		
			10 to 15	≥ 1	
			and ⇧⇩		
			≥ 20	Nil	

6.1 ESTABLISHING THE ACCEPTANCE CONTROL CHART

6.1.1 Calculating The Acceptance Limits

The acceptance limit for the sample mean of each lot of constructed base course is defined as;

$$AL = DT + Ks_t \qquad (1)$$

Where: AL *is the acceptance limit for the lot;*
DT *is the design thickness in accordance with the specifications;*
s_t *is the standard deviation of the thickness measurements of the lot as given by equation (4) in Clause 6.2*
K *is given in Table 1 for full lots and residue lots between 80 and 175 metres in length.*

A lot conforms for thickness requirements when its sample mean is equal to or greater than its acceptance limit.

Table 1
K values for Full Lots and Residue Lots

Lot Type	Length of Lot	K	Lot Type	Length of Lot	K
Residue Lot	80 m	1.94	Residue Lot	130 m	1.82
Residue Lot	85 m	1.93	Residue Lot	135 m	1.81
Residue Lot	90 m	1.91	Residue Lot	140 m	1.80
Residue Lot	95 m	1.90	Residue Lot	145 m	1.80
Full Lot	**100 m**	**1.89**	Residue Lot	150 m	1.79
Residue Lot	105 m	1.87	Residue Lot	155 m	1.78
Residue Lot	110 m	1.86	Residue Lot	160 m	1.77
Residue Lot	115 m	1.85	Residue Lot	165 m	1.77
Residue Lot	120 m	1.84	Residue Lot	170 m	1.76
Residue Lot	125 m	1.83	Residue Lot	175 m	1.75

6.1.2 Preparing The Acceptance Control Chart

Prior to placing base concrete, establish an acceptance control chart for base course thickness that shows the following:

- a vertical scales to show the mean thickness $\bar{t}$, for each lot in millimetres,
- a horizontal scale showing the lot numbers in order of construction,
- a horizontal line showing the design thickness DT, of the base course in accordance with the specifications,
- a series of short horizontal lines for the acceptance limit of each lot AL, calculated in accordance with equation (1).

Plot the sample mean thickness $\bar{t}$, of each lot on the acceptance control chart in the order of construction and draw a straight line to the previously plotted sample mean. Calculate and plot the acceptance limit (AL) for each lot by equation (1) to show its relationship to the acceptance criterion for thickness.

6.1.3 The Lot Schedule

Prepare a Lot Schedule of that, initially, includes,

- a unique identifier of each lot,
- date of construction,
- full or residue lot,
- sample standard deviation of thickness,
- sample mean thickness,
- sample size,
- the acceptance limit for each lot.

After calculation of the process control lines by Clause 6.2, add the following,

- the process mean,
- the upper process control line,
- the lower process control line,
- the expected average acceptance limit.

Adopt the same unique identifier for the thickness lots as adopted for the base surface lots as described in TM194.

6.1.4 Plotting Results

Plot the mean thickness of each lot no later than 48 hours of placement of base concrete.

Plot surveys results, first in date order and then in time order of placement of concrete for each day's pour to track the construction process.

6.2 ESTABLISHING THE PROCESS CONTROL CHART

6.2.1 Plot Process Control Lines on the Acceptance Control Chart

Calculate and plot process control lines on the acceptance control chart after surveying one kilometre of the base course. Addition of the following process control lines converts the acceptance control chart into the process control chart:

a) a horizontal line, $\bar{\bar{t}}$, showing the overall mean thickness, also known as **the process mean**;

b) two horizontal lines for the **upper and lower process control limits**;

c) **the expected average acceptance limit** showing the expected acceptance limit, based on recorded process data, if lots continue to have the same average sample standard deviation.

6.2.2 Calculation of the Process Control Lines

Include all lots surveyed in the first kilometre for calculations. After calculations, add values of the process control lines to the Lot Schedule described in Clause 6.1.3.

The process mean, $\bar{\bar{t}}$, is the overall mean of the base course thickness measurements in the first kilometre and is calculated by:

$$\bar{\bar{t}} = \frac{\sum_{i=1}^{m} n_i \bar{t_i}}{\sum_{i=1}^{m} n_i} \tag{2}$$

where, $\bar{t}_i = \frac{\sum_{i=1}^{n} t_i}{n}$ *is the sample mean thickness of the i th lot, which has* n_i *thickness measurements and there have been m lots surveyed.*

The pooled estimate of the process standard deviation, $s_{t\ pooled}$, estimates the average variability within each lot and is given as:

$$s_{t\ pooled} = \sqrt{\frac{\sum_{i=1}^{m} (n_i - 1) s_t^2}{\sum_{i=1}^{m} n_i - m}} \tag{3}$$

where m and n_i *are given in equation (2) and* s_t *is the sample standard deviation of the ith lot which is defined as:*

$$s_t = \sqrt{\frac{\sum_{i=1}^{n_i} \left(t_i - \bar{t_i}\right)^2}{n_i - 1}} \tag{4}$$

where t_i *is the ith sample of the ith lot, which has a sample mean of* $\bar{t}_i$ *.*

Equations (2) and (3) give the same estimates of the process mean and standard deviation as AS 3942, when all lots have the same number of sample measurements. However, variable pour widths and residue lots make it unlikely that all lots will have equal sample sizes.

Process variability, $s_{t\ process}$ **,** measures the variability of the process about the process mean $\bar{\bar{t}}$ and is given as;

$$s_{t\ process} = \sqrt{\frac{\sum_{j=1}^{N} \left(t_j - \bar{\bar{t}}\right)^2}{N - 1}} \tag{5}$$

where, N is the total number of thickness measurements from all lots in the first kilometre of paving, t_j *is the jth thickness measurement and* $\bar{\bar{t}}$ *is given by equation (2).*

The **process variability** is the standard deviation of all thickness measurements, from all lots, since the previous calibration. It will usually differ from the pooled estimate of the process standard deviation, given by equation (2), due to effect of data correlation.

The upper and lower process control limits for the control chart for sample mean thicknesses, $\bar{t}$, are set equi spaced about $\bar{\bar{t}}$ as:

$$\bar{\bar{t}} \pm 3 s_{t\ process} \mathrm{F}_t \tag{6}$$

where F_t *is 0.475 for lots of 100 metres in length.* Table 2 *contains* F_t *values for lots between 80 and 175 metres in length.*

Table 2

F_t, for Lots Between 80 and 175 metres in Length

Lot Type	Lot Length (m)	F_t		Lot Length (m)	F_t
Residue	80	0.525	Residue	130	0.425
Residue	85	0.505	Residue	135	0.415
Residue	90	0.495	Residue	140	0.410
Residue	95	0.485	Residue	145	0.405
Full	**100**	**0.475**	Residue	150	0.395
Residue	105	0.465	Residue	155	0.390
Residue	110	0.455	Residue	160	0.385
Residue	115	0.445	Residue	165	0.380
Residue	120	0.440	Residue	170	0.375
Residue	125	0.435	Residue	175	0.370

Due to the effect of data correlation on the sample mean, factor F_t in equation (6) differs from Clause 4.3 of AS 3942, which uses $1/\sqrt{n}$ for determining the positions of the process control limits.

The expected average acceptance limit for the sample mean is calculated as:

$$EAAL = DT + Ks_{t\ pooled} \qquad (7)$$

Where, *EAAL is the Expected Average Acceptance Limit,*
K is the value for full lots from Table 1 and
$s_{t\ pooled}$ *is given by equation (3)*

6.2.3 The Producer's Risk

The producer's risk for the process control chart is set at 0.0027. This infers that when the process is in control, one lot in 370 lots may signal a false alarm by wrongly indicating that the process is out of control.

6.3 RECALIBRATION OF THE PROCESS CONTROL LIMITS

Re-calibrate the process control charts at the subsequent prescribed interval of two kilometres of pavement after initial calibration. Only use measurements from the subsequence two kilometres of pavement to determine the positions of the process control lines during re-calibration

Re-calculate and re-plot the process lines by equations (2) to (7). The re-plotted process control lines commence from the first lot constructed after the two kilometres of pavement used for re-calibration. Do not remove or change process control lines from previous calibrations. The purpose of re-calibrating process control charts is to track any changes in the process. It may show an improvement, deterioration or consistency in quality control since the previous calibration.

Where any recalibration of the process control charts identifies that the process does not conform and corrective action is required to the process, then the next recalibration interval must be 1 kilometre in accordance with Diagram 1.

6.4 HAND PLACED CONCRETE

Establish separate acceptance and process control charts for hand placed concrete, using the same formulae as concrete placed by a paving machine, as described in Clauses 6.1 to 6.3.

7.0 REPORTING

7.1 ACCEPTANCE CONTROL CHARTS

Acceptance of the base course for thickness is on a lot by lot basis. Accept lots as meeting the requirements for base course thickness if the sample mean thickness $\bar{t}$, is equal to or greater than AL by equation (1).

7.2 PROCESS CONTROL CHARTS

7.2.1 Relationship between Acceptance Control Charts and Process Control Charts

The acceptance limits on the acceptance control chart reflect RTA (customer) requirements, as set out in the specifications. The process control limits on process control charts reflect the level of quality possible by the construction process, controlled by the Contractor. The limit lines of the acceptance control chart and the limit lines of the process control chart are therefore independent. However, the Contractor needs to establish process controls that reflect the product quality as defined by the acceptance limits in the specifications to meet RTA requirements.

The acceptance limits are set to prevent inadvertent acceptance of lots that have greater than $2^1/_2$ % (of the lot) less than the design thickness. The relationship between the expected average acceptance limit and lower process control limit graphically demonstrates the capability of the process to construct the base course to a thickness greater than the design thickness. A lower process control limit that plots above the expected average acceptance limit indicates that the process is capable of constructing the base course with at least $97^1/_2$ % of it greater than the design thickness, practically all of the time.

A lower process control limit that plots below the expected average acceptance limit indicates a significant probability that the process will produce non-conforming product, which will lead to lot rejection. This is true even though no non-conforming lots may have yet been detected. In these instances a review of process controls is advisable to reduce the risk of lot rejection and to ensure product quality.

7.3 CONTROL CHART ANALYSIS

Carry out actions to the base surface levels, as required under Test Method T 194, before carrying out control chart analysis described by this Test Method. Actions required under TM194 may also address actions arising from this Test Method.

Follow the sequence for carrying out control chart analysis for Test Method T 194 and this Test Method as shown in Diagram 2.

7.3.1 Actions Where the Process Does Not Conform.

The process for constructing the base course to the specified thickness does not conform when the lower process control limit plots lower than the expected average acceptance limit.

Where the process does not conform, after adjusting the base surface controls by TM194, then adjust the base course thickness by adjusting the base surface process controls. Adjustment to the process control lines must be by the same amount that the lower process control limit is lower than the expected average acceptance limit.

After adjusting the process control lines of the thickness control charts, then adjust the process control lines of the base surface control charts by the same amount.

Clause 7.3 of TM194 provides the description of a method for adjusting the base surface process controls.

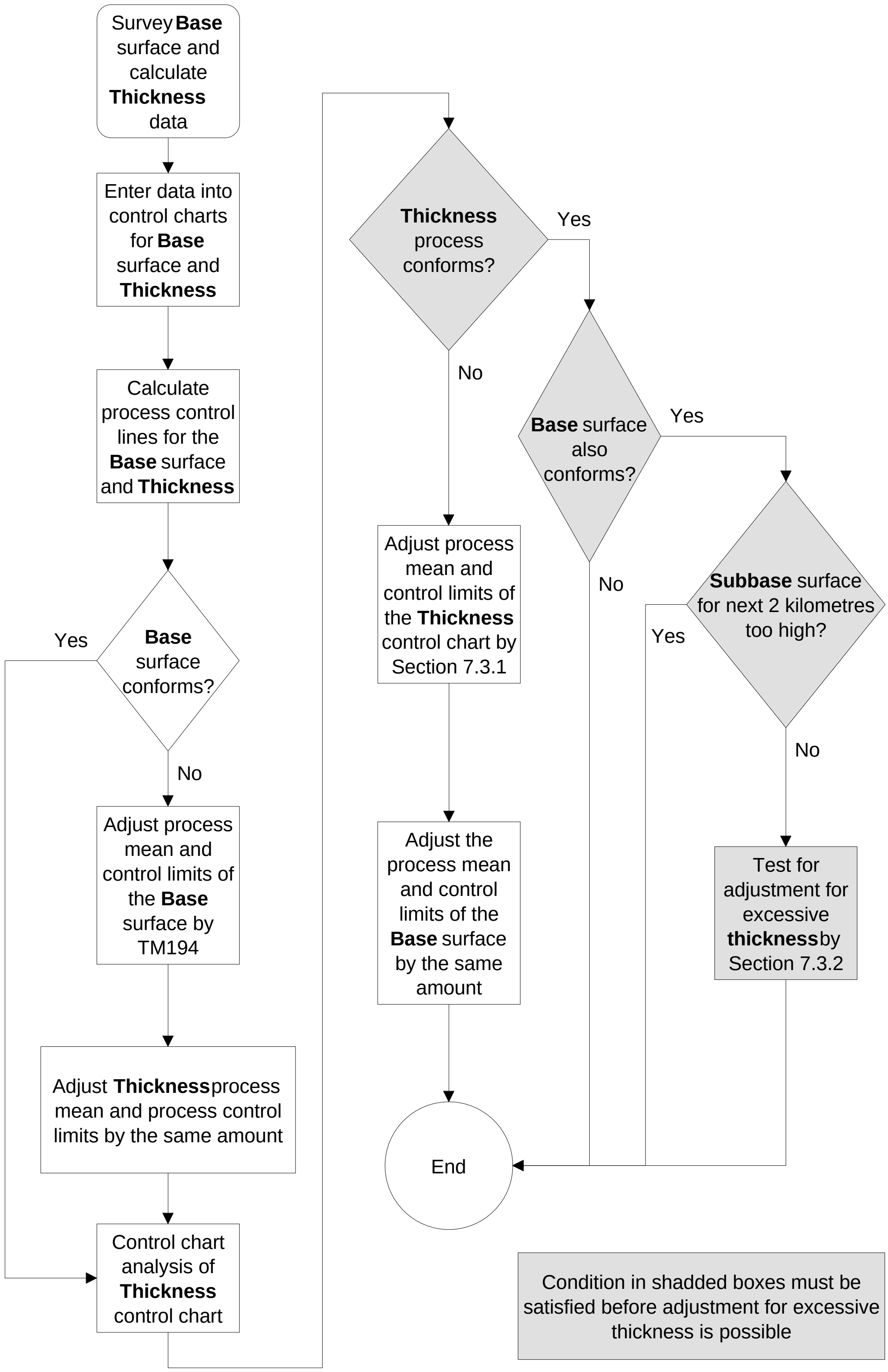


Diagram 2

Flow Chart Showing Sequence for Testing Conformity of Process for Constructing Thickness

7.3.2 Adjustment for Excessive Thickness

Adjustment for excessive thickness is only possible where:

- the process for constructing the base surface to the correct level conforms,
- the process for constructing the base course to the correct thickness conforms and
- control chart analysis of the subbase surface, for at least the next two kilometres over which base concrete will be placed, did not find that the subbase surface was too high.

Where these conditions apply, then calculate the process capability ratio, PCR_k by equation (8), to determine whether the thickness is excessive and if adjustment is possible.

$$PCR_k = \frac{\bar{\bar{t}} - DT}{3s_{t\,process}} \qquad (8)$$

where: $\bar{\bar{t}}$*, the process mean thickness by equation (2)*

$s_{t\,process}$ *is the process variability by equation (5)*

DT *is the specified design thickness.*

Where the PCR_k is greater than 1.33 then the process mean thickness may be reduced by lowering the process mean of the base surface. The base surface process mean may lowered by,

$$\bar{\bar{t}} - \bar{\bar{t}}_{t\arg et} \text{ mm} \qquad (9)$$

where: $$\bar{\bar{t}}_{t\arg et} = 3s_{t\,process} + DT \qquad (10)$$

The process control lines for the base surface and the thickness control charts must be recalibrated after placing one kilometre of base concrete following adjustment of the base surface process mean.

Where this calibration finds the PCR_k is equal to or greater than 1.00, then continue recalibration at two kilometre intervals in accordance with Diagram 1.

Where this calibration finds the PCR_k is less than 1.00, then adjust the base surface process mean by equations (9) (10).

Provided the processes for the base surface and thickness still conform then continue to monitor the processes at the prescribed two kilometre intervals in accordance with Diagram 1.

7.4 CONTROL CHARTS AS A MANAGEMENT TOOL

Control charts are a management tool that provides feedback to construction personnel on the quality of the processes to which they contribute. This feedback gives recognition to process improvement and looks for input from construction personnel when the process goes out of control or becomes incapable of meeting specified requirements. For this to be effective, project management may consider placing the control charts in a prominent position on site, with all personnel involved in the process having access to view them.

ATTACHMENT

FIELD EXAMPLE OF THICKNESS CONTROL CHARTS

The following example is from a pilot study conducted by the RTA. The contract controlling the project specified construction of the subbase surface within the range of –0 to –20 millimetres of its design height and the base surface within the range of +0 to +20 millimetres of its design height. The following example contains the acceptance control chart and process control chart for base course thickness.

No judgement can be made on the product quality shown in this example, as requirements described by this Test Method do not reflect the conditions that controlled pavement construction for this project.

Lot No.	Lot Location				Statistical Summaries			Full/ Res.	Accept. Limits	Process Limits for Sample Mean (mm)		
	Start Ch.	Offset	Stgs	Const. Date	Stdev	Mean	n			Centre	Lower	Upper
1	48k 330	4L to 4R	3	30/10/1999	3.0	256.0	58	F	255.7			
2	48k 230	4L to 4R	3	30/10/1999	3.7	256.9	57	F	257.0			
3	48k 135	4L to 4R	3	1/11/1999	4.3	255.1	60	F	258.1			
4	48k 035	4L to 4R	3	1/11/1999	4.9	261.4	60	F	259.2			
5	47k 935	4L to 4R	3	1/11/1999	3.4	253.9	60	F	256.4			
6	47k 835	4L to 4R	3	1/11/1999	3.5	257.1	81	F	256.2			
7	47k 700	4L to 4R	3	4/11/1999	3.0	256.0	60	F	255.6			
8	47k 600	4L to 4R	3	4/11/1999	3.8	256.3	60	F	257.2			
9	47k 500	4L to 4R	3	4/11/1999	2.7	256.4	48	R	255.2			
10	47k 420	4L to 4R	3	5/11/1999	3.7	255.8	60	F	257.0			

Table A1 - *A lot Schedule in Accordance with Clause 6.2.3 for the Base Course Thickness*
Lot Locations are in Metres, Control Limits are in Millimetres

Table A1 shows the survey conformance results for the first kilometre of the pavement, which is prior to calculation of the process control lines.
Column 1 contains the lot numbers in sequential order of construction.
Columns 2 and 3 contain the start chainage of each lot and offsets to both sides of the lot. This uniquely defines each lot of the base course. These are the same lots as the base surface level departures. Subtraction of the start chainages of consecutive lots gives the length of each lot. This project constructed the pavement in the direction of decreasing chainages.
Column 4 contains the number of strings across the lot for sampling the pavement.

Column 5 contains the construction date.
Columns 6, 7 and 8 contain the statistical summaries of each lot; the standard deviation, mean and sample size (*n*).
Column 9 identifies if it is a full or a residue lot.
Column 10 contains the acceptance limit for the sample mean in accordance with Clause 6.1.
Columns 11, 12, and 13 are blank for the first kilometre of pavement construction. Data from the first kilometre of construction allow calculation of the process control lines for process control chart for the sample mean.

Figure A1 is the acceptance control chart for the sample mean of thickness measurements. The mean thickness for each lot shown in Table A1 is plotted against the corresponding lot number. The acceptance limit for each lot is calculated by equation (1) and plotted as a short horizontal line above the corresponding lot number. Where the acceptance limit is below the corresponding sample mean, the lot conforms and where the acceptance limit is plotted above the sample mean, the lot does not conform.

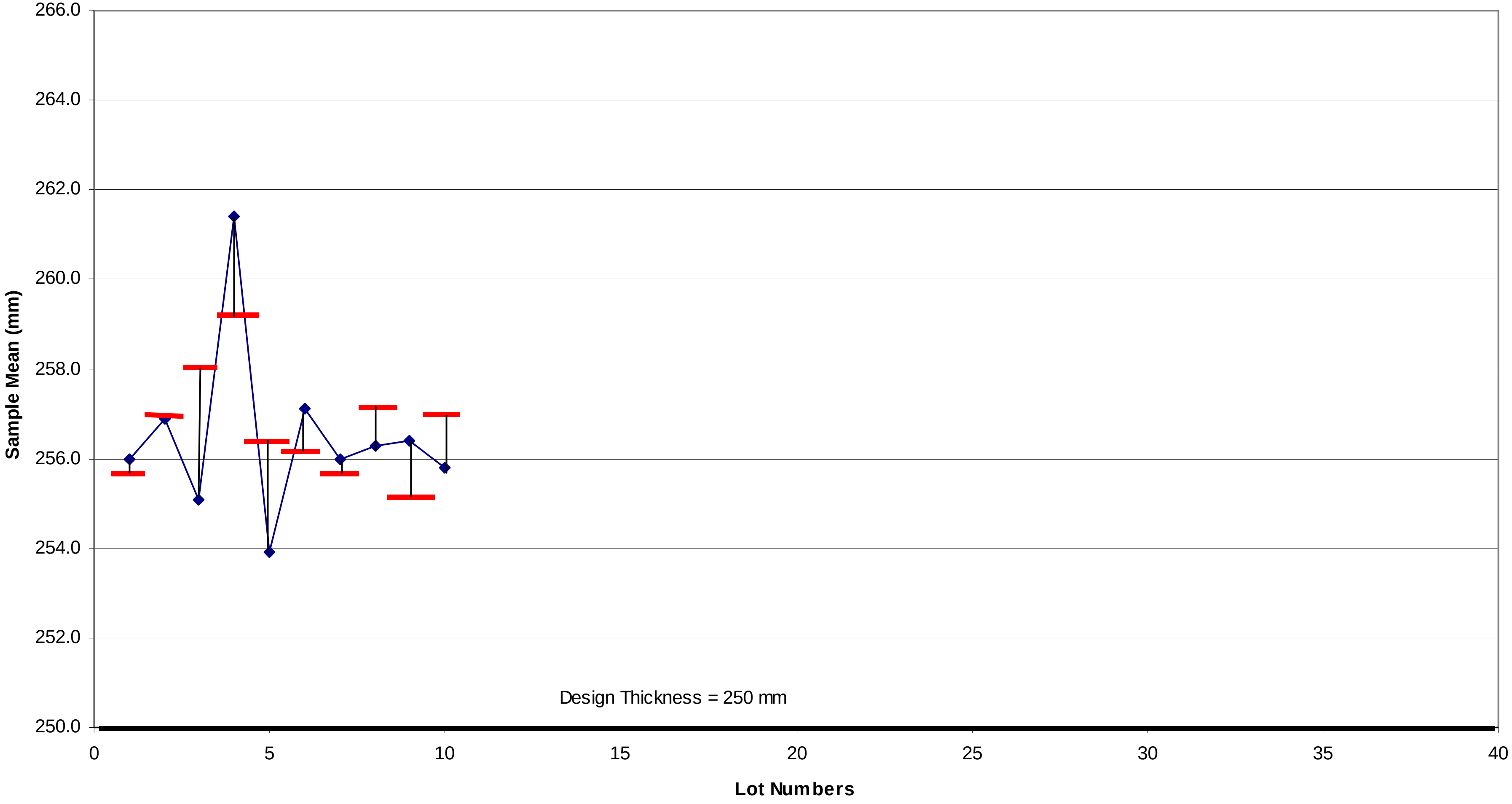


Figure A1 – Acceptance Control Chart for Base Course Thickness

A1 Calculation of Process Control Lines for Sample Mean

Figure A1 is the acceptance control chart for the sample mean, this compares the sample mean with tolerances given in the specifications. The control chart shows that 5 of the 10 lots were less than their respective acceptance limit and would have been rejected.

The next stage is to convert this into a process control chart, which estimates the state of process control and the capability of the process to meet specified requirements for base course thickness.

A1.1 The Process Control Chart for the Sample Mean

The Process Mean

Equation (2) calculates the process mean for the first kilometre of the pavement.

$$\bar{\bar{t}} = \frac{\sum_{i=1}^{m} n_i \bar{t}_i}{\sum_{i=1}^{m} n_i} \qquad (2)$$

The Table A1 provides the data for solving equation (2). The $\bar{t}_i$ values are contained in column 7 and the n_i values are contained in column 8. The sum of the multiplications of the sample size times the sample mean for each lot is the numerator of equation (2). The denominator is the sum of column 8, which is the combined sample size of all the lots contained in the first kilometre of pavement.

The process mean by equation (2) for this example is 256.62 millimetres.

The Process Control Limits

Equation (2) determines the centre line position for the sample mean process control chart. The upper and lower process control limits are set equispaced about the centre line as given by equation (6).

The $s_{t\ process}$ value is determined by equation (5):

$$s_{t\ process} = \sqrt{\frac{\sum_{j=1}^{N} \left(t_j - \bar{\bar{t}}\right)^2}{N-1}} \qquad (5)$$

This calculation is <u>not</u> possible with the data provided in Table A1. It requires all the raw survey measurements taken on the first kilometre of pavement and for accuracy and efficiency, the use of a computer. The *N* value in equation (5) is same as the denominator of equation (2), which for this example is 604 measurements. The $s_{t\ process}$ value for this example is 4.07 millimetres by equation (5).

From Table 2 the F_t value for full lots is 0.475. Therefore, the upper and lower process control limits are given as:

256.62 mm ± 3 *x* 4.07 mm *x* 0.475
256.62 mm ± 5.80 mm
Therefore,
the upper process control limit = 262.42 mm and
lower process control limit = 250.82 mm

RTA specification clauses require calculation of all sample means and standard deviations to the nearest 0.1 millimetres. Therefore, all process control lines must be calculated to the nearest 0.1 millimetres. This requires calculations with variables quoted to 0.01 millimetres and rounding of results to 0.1 millimetres, as shown in this example. The control lines commence from the next lot surveyed after the first kilometre.

The process mean, along with the upper and lower process control limits, are now be drawn on the acceptance control chart to convert it into a process control chart, as shown in Figure A2.

Residue Lots

Residue lots have different F_t values from full lots, as shown in Table 2, which implies that the process control limits for residue lots are different from the process control limits for full lots. Therefore, when plotting sample means of residue lots that fall outside the process control limits for full lots, use the appropriate F_t value in Table 2 with equation (6), before concluding whether the process shows an out of control state or not.

A2 Expected Average Acceptance Limit

A2.1 Pooled Estimate of the Process Standard Deviation

Equations (3) and (4) give the pooled estimate of the process standard deviation, $s_{t\ pooled}$. This calculation is possible from the data contained in Table A1. Equation (4) is the sample standard deviation for each lot as given in column 6 of Table A1. The n_i value is the sample size as given in Column 8 and *m* is the number of lots, which for this example is ten. The use of a computer and a spreadsheet simplifies calculation of pooled estimate of the process standard deviation. For this example, $s_{t\ pooled}$ equals 3.64 millimetres.

The standard deviation used to calculate the process control limits for the sample mean (process control chart) differs from the pooled estimate of the process. For this example it is about 0.4 millimetres. If all of the thickness measurements were completely independent of each other it would be expected that these standard deviations would be the same. However, as there is high positive correlation between thickness measurements taken on concrete pavement surfaces, they are different.

The Expected Average Acceptance limit for full lots is:

$$\begin{aligned} EAAL &= LSL + K\, s_{t\ process} \\ &= 250 + 1.89 \times 4.07 \text{ mm} \\ &= 257.7 \text{ mm} \end{aligned}$$

Plotting this value on the process control chart provides an indication of the capability of the process to construct the pavement with the specified minimum thickness.

Figure A2 shows the process control limits plotted over the acceptance control chart.

Lot No.	Lot Location		Stgs	Const. Date	Statistical Summaries			Full/ Res.	Accept. Limits	Process Limits for Sample Mean (mm)		
	Start Ch.	Offset			Stdev.	Mean	*n*			Centre	Lower	Upper
1	48k 330	4L to 4R	3	30/10/1999	3.0	256.0	58	F	255.7			
2	48k 230	4L to 4R	3	30/10/1999	3.7	256.9	57	F	257.0			
3	48k 135	4L to 4R	3	1/11/1999	4.3	255.1	60	F	258.1			
4	48k 035	4L to 4R	3	1/11/1999	4.9	261.4	60	F	259.2			
5	47k 935	4L to 4R	3	1/11/1999	3.4	253.9	60	F	256.4			
6	47k 835	4L to 4R	3	1/11/1999	3.5	257.1	81	R	256.0			
7	47k 700	4L to 4R	3	4/11/1999	3.0	256.0	60	F	255.6			
8	47k 600	4L to 4R	3	4/11/1999	3.8	256.3	60	F	257.2			
9	47k 500	4L to 4R	3	4/11/1999	2.7	256.4	48	R	255.2			
10	47k 420	4L to 4R	3	5/11/1999	3.7	255.8	60	F	257.0			
11	47k 320	4L to 4R	3	5/11/1999	2.7	254.2	60	F	255.1	256.6	250.8	262.4
12	47k 220	4L to 4R	3	5/11/1999	2.7	254.2	60	F	255.1	256.6	250.8	262.4
13	47k 120	4L to 4R	3	5/11/1999	3.2	254.9	58	F	256.1	256.6	250.6	262.4
14	47k 020	4L to 4R	3	5/11/1999	4.8	255.1	60	F	259.0	256.6	250.8	262.4
15	46k 920	4L to 4R	3	5/11/1999	3.3	253.4	84	R	256.1	256.6	251.6	261.6
16	46k 780	4L to 4R	3	8/11/1999	4.4	255.1	60	F	258.3	256.6	250.8	262.4
17	46k 680	4L to 4R	3	8/11/1999	2.2	253.1	60	F	254.1	256.6	250.8	262.4
18	46k 580	4L to 4R	3	8/11/1999	3.3	256.1	60	F	256.2	256.6	250.8	262.4
19	46k 480	4L to 4R	3	8/11/1999	3.0	259.2	60	F	255.6	256.6	250.8	262.4
20	46k 380	4L to 4R	3	8/11/1999	2.8	255.9	63	F	255.3	256.6	250.8	262.4
21	46k 275	4L to 4R	3	10/11/1999	2.9	258.5	60	F	255.5	256.6	250.8	262.4
22	46k 175	4L to 4R	3	11/11/1999	2.7	258.8	60	F	255.1	256.6	250.8	262.4
23	46k 075	4L to 4R	3	11/11/1999	3.2	253.8	60	F	256.0	256.6	250.8	262.4
24	45k 975	4L to 4R	3	11/11/1999	3.0	258.9	60	F	255.6	256.6	250.8	262.4
25	45k 875	4L to 4R	3	11/11/1999	2.9	256.1	60	F	255.5	256.6	250.8	262.4
26	45k 775	4L to 4R	3	11/11/1999	3.1	255.3	60	F	255.8	256.6	250.8	262.4
27	45k 675	4L to 4R	3	11/11/1999	3.0	260.8	60	F	255.6	256.6	250.8	262.4
28	45k 575	4L to 4R	3	11/11/1999	2.0	258.9	60	F	253.8	256.6	250.8	262.4
29	45k 475	4L to 4R	3	12/11/1999	3.2	257.3	60	F	256.0	256.6	250.8	262.4
30	45k 375	4L to 4R	3	12/11/1999	3.0	254.5	75	R	254.6	256.6	251.3	261.9

Table A2 – *Lot Schedule of Base Course Thickness with Process Limits*

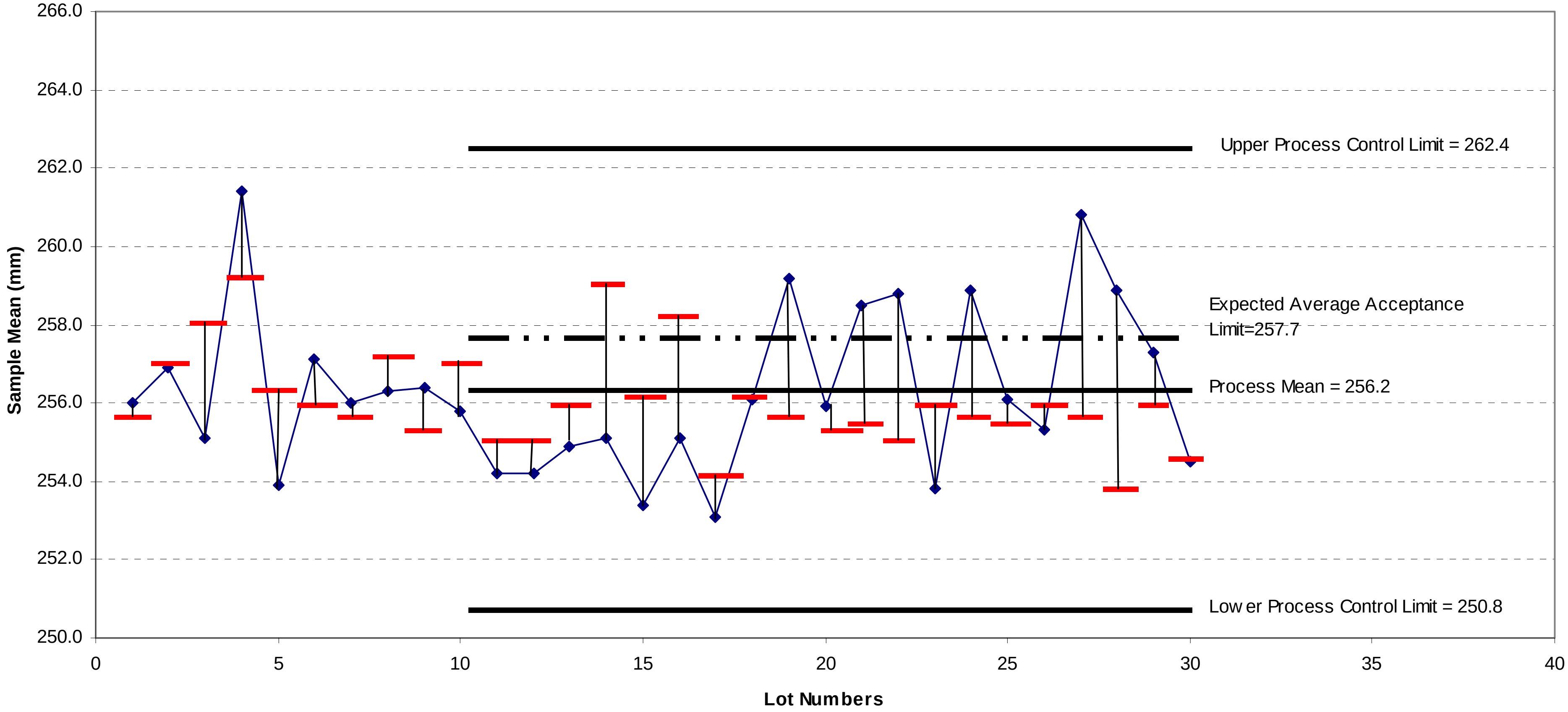


Figure A2 - $\bar{x}$ Acceptance Control Chart Converted to $\bar{x}$ Process Control Chart by Addition of Process Control Lines