Survey Control During Construction of RTA Roads

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ABSTRACT

This paper reports research by the RTA to develop specification clauses based on the latest technology for ensuring delivery of the design base course thickness of RTA roads. Compliance with specification requirements is verified by survey measurements. The concept of process measurement is introduced and the important role surveyors have in tracking process improvement by contractors. Contract surveyors need to be able to demonstrate the accuracy of their surveying procedures as the RTA moves towards rewarding contractors for improved process control. Background information is provided into the expected influence of the RTA research on the road network infrastructure.

The paper also reports the findings of RTA research into the accuracy of a surveying procedure used for measuring pavement surfaces for compliance with current RTA contract specifications. The procedure uses EDM trigonometrical heighting for height determination. The paper lists factors that affect the accuracy of the procedure and suggests procedures to minimise their effect. The paper concludes that EDM trigonometrical heighting give more accurate height determinations than traditional differential levelling with an optical level. A questionnaire determined the level of industry compliance with the recommended procedures to estimate the capability of the industry to support the adoption of the new specification clauses.

The research gained the award in the Engineering Section of the 1998 Institution of Surveyors Excellence in Surveying Awards.

INTRODUCTION

This paper describes recent RTA research that not merely asserted the role of surveyors in the construction of RTA roads but raised their status even higher. Prior to this research, surveyors were under threat of removal from the process. Due to this research they are now in a position of being able to provide measurements of road quality for asset management and for incentive payments for contract administration.

The judging panel for the ISA 1998 Excellence in Surveying Awards selected this project for the award in the Engineering Section.

The Road Network Infrastructure

To appreciate the importance of the research, an appreciation of the magnitude of its influence upon the cost of maintaining and enhancing the road network infrastructure is needed. Austroads (1995), the peak body of State Road Authorities in Australia, which includes the RTA, estimates that the value of the Australian road network infrastructure exceeds $100b. Road transport alone, as an industry in its own right, accounts for 2.4% of Australia's GDP and employs 2.5% of the Australian workforce. This industry relies on the road network and is seen an important facilitator of the national economy. Additional benefits flow from commuter traffic and tourism.

Annual expenditure on the national road network infrastructure is about $6b, with about 50% of that spent on maintenance and rehabilitation. Closer to home, the RTA spends annually about $300m on maintenance and rehabilitation of the pavement and at any time may have road construction contracts to the total value of $700m operating. This makes the annual expenditure on the road network infrastructure in NSW approximately $1b.

That gives an appreciation of the size, in dollar terms, of the road network infrastructure. How will this research influence those dollars?

Pavements are the most dominate influence on the on the long term costs of the road asset (Austroads, 1995). Premature pavement failure adds unnecessary costs to maintaining the infrastructure and delays to road users.

Pavement courses constructed less than design thicknesses are a major cause of pavement failure. RTA research (RTA, 1993) estimates that a 10% reduction in base course thickness will reduce the design life of the pavement by about 90%. Current construction procedures depend upon surveyors' input to control pavement course thicknesses. The research looked at surveying and construction procedures to give greater assurance of construction of the designed pavement thickness. Specification clauses developed by the research are expected to reduce to almost zero the probability of the RTA inadvertently accepting base courses less that the design thickness. Acceptance criteria for the specifications are survey measurements. Surveyors therefore, have a seminal role to ensure delivery of the road network infrastructure in the most cost effective manner.

The Objects Of The Research

The objectives of the research were to:

- analyse current construction procedures to determine the capability of the road construction industry to construct specified pavement surface heights and course thicknesses,
- develop surveying procedures for measuring pavement surfaces for compliance with specification clauses and
- define contract specification clauses, based on statistical techniques, to ensure delivery of designed pavement course thicknesses.

The research was carried out under the supervision of the University of Wollongong as a Master thesis in Total Quality Management, specialising in statistical quality control. The findings of the research have been verified by the University of Wollongong and the examiners of the thesis from the CSIRO and the University of NSW. The thesis (Ollis, 1997) combined my surveying and construction experience with the university's statistical and quality control expertise.

SURVEYORS ROLE IN CONTROLLING PAVEMENT COURSE THICKNESS

Pavement Design

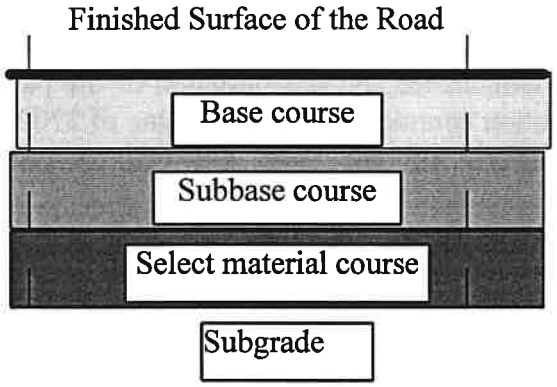

Diagram 1: Cross Section of a Typical Pavement Design

The arrows show that for each pavement course only the upper surface is controlled for height to control course thickness

A pavement course is any one of the strata of the cross section shown in Diagram 1 (for example, select material, subbase or base). The bottom of the cross section referred to, as "subgrade" is the natural earth foundation of the road. This may be the bottom of an excavation or the top of a constructed earthworks embankment.

Several factors influence pavement design, including the intended use of the road, the availability of materials and the natural terrain. For these reasons, one or more of the courses in Diagram 1 may not be present in a particular pavement design. However,

the base course is present in all pavement designs. The strength of the pavement lies in the strength of the base course, the purpose of the other courses is to support and/or protect the base course. The design thickness of pavement courses will vary with pavement designs.

The Construction Process

Pavement course thickness is controlled by pavement surface heights. If the top of the pavement course is at the correct height and the bottom of the pavement course is at the correct height, then the distance between the top and bottom of the pavement course, that is the thickness, is also correct. The bottom of a pavement course is the top surface of the previously constructed and controlled (lower), pavement course. Therefore, only the top surface of each subsequent course needs to be controlled.

Diagram 2 is a cross sectional view (looking along the centre line of the pavement) of the process of laying concrete pavements. The paving machine lays the full width of the pavement course as it slowly progresses in the direction of the road centre line.

The sensors of the paving machine follow the string lines to control the height of the pavement surface and its edge alignment. Surveyor's pegs, set flush with the ground, control the height and position of the string line. The surveyor sets the pegs at about 10 metre chainage intervals along the road and clear of the path of the paving machine. He then determines their heights and calculates the distance up from each peg to set the string line.

When a grader trims the pavement surface, a string line pulled across the pavement controls the heights of the pavement, as shown in Diagram 3. The field assistant tapes down from the string line to the pavement surface and tells the grader operator the amount of material still to be trimmed. Pavement material is compacted higher than the design finished surface height of the pavement and trimmed to the finished height. Trimming by the grader is an iterative process usually requiring several passes before achieving an acceptable finish.

Variability of the Construction Process

The reality is that pavement surfaces can not be constructed everywhere at precisely the correct height but will have small height variations about the design height. Surveyors measure the amount of variability in the constructed surface height about its design height and report the results in Survey Conformance Reports.

The research analysed the effect of small height variations of the pavement surface on the design thickness. This analysis enabled setting of specified limits for the survey conformance results to give an assurance that the pavement course had not been constructed less than the design thickness.

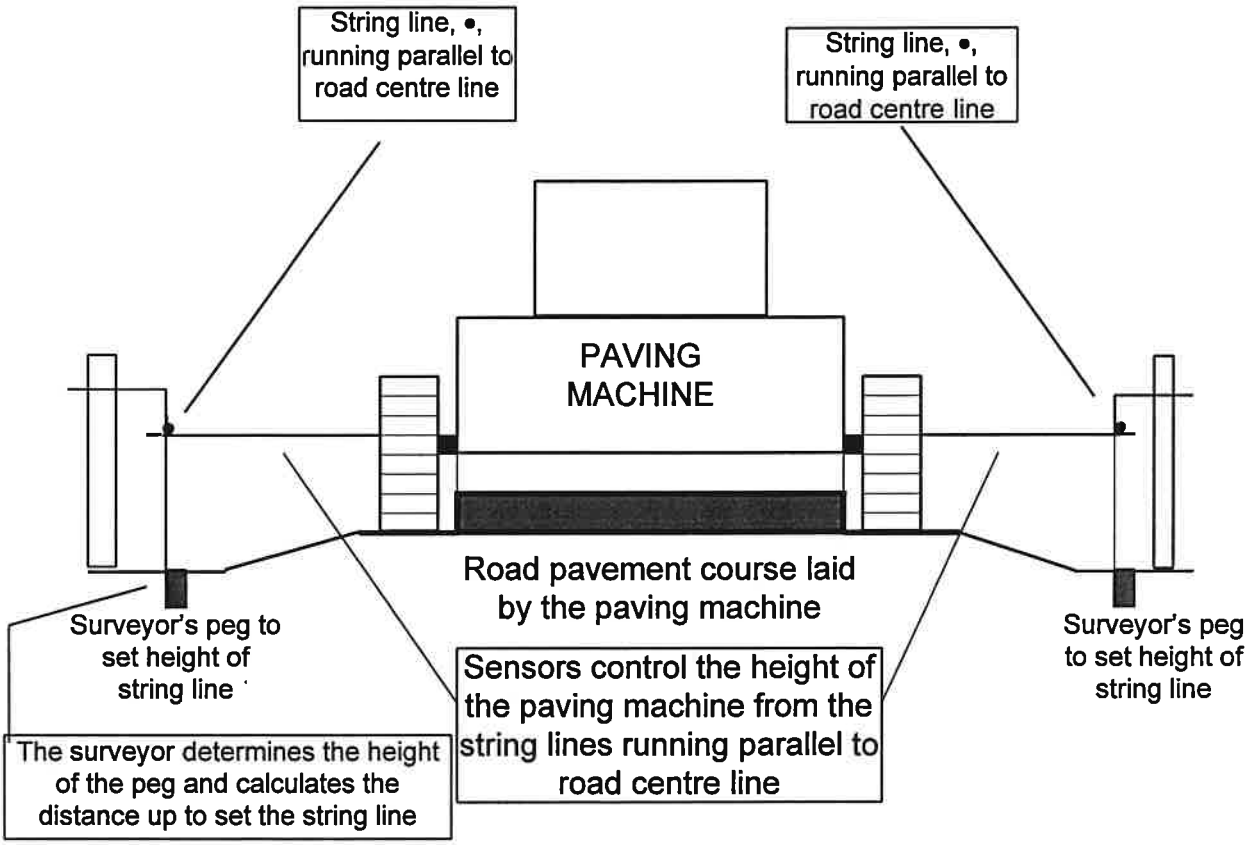

Diagram 2 Control of Paving Machine Heights by String Lines Running Parallel to Road Centre Line

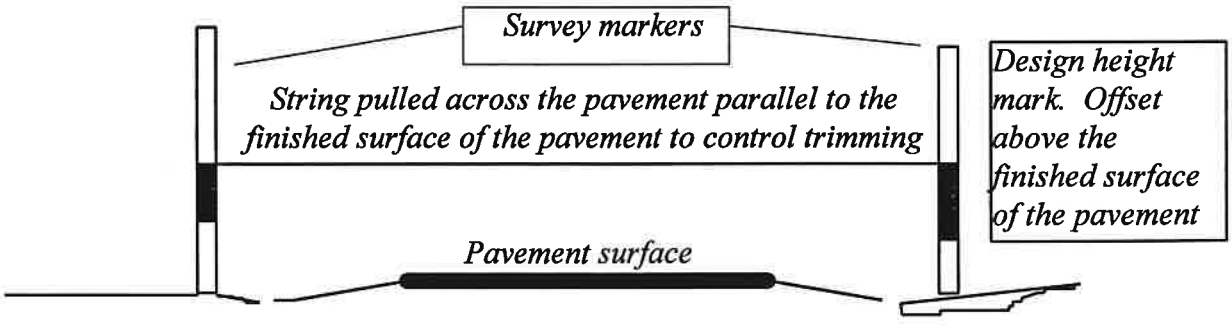

Diagram 3 How the Design Height Marks on the Trim Pegs Control Heights During Trimming by a Grader

PROBLEMS IDENTIFIED WITH EXISTING PROCEDURES

The general feeling within the RTA for sometime has been that current construction and acceptance procedures, could not assure pavement thickness. The concern was that the RTA may be accepting pavements constructed less than the design thickness. This fear was confirmed when developments in Ground Penetration Radar technology allowed the RTA to measure constructed pavement thicknesses of some national highways within NSW during 1993. The measurements showed significant portions of pavement constructed with less than the design thickness.

The Executive Summary of an interim RTA report (RTA, 1997) expressed the RTA concerns as:

> *"At present, there is a general lack of confidence that the construction and construction control processes in use today can reliably deliver in-situ pavement course thicknesses which meet designers' intentions. There is a certain degree of "hit and miss" in meeting the design."*
> *(RTA, 1997: 3)*

Analysis of survey data for the research found further evidence of the problem during 1996. On one extreme case, over 50% of the base course on a three-kilometre section of a national highway was less than the design thickness. Edge measurements, not survey, determined compliance of the base course for thickness under the contract that controlled construction of that section of road.

Surveyors Placed in a Vunerable Position

As surveyors were an integral part of assuring pavement thickness and evidence showed that the system had problems, our role came under review.

As a matter of formality, the RTA investigated the use of methods other than survey for measurement such as Ground Penetrating Radar, Impact-echo Method and destructive coring. The alternate methods demonstrated the required capabilities but all had limitations. Survey was the only method that offered assistance in constructing the pavement as well as the capability for acceptance sampling.

At this stage survey was not seen as a failure. However, due to the magnitude of the problem all avenues were explored, including the role of survey. If survey could not demonstrate that it was capable then the RTA would have the opportunity to investigate and develop other methods. Surveyors could then lose their long held role of controlling and measuring pavement surface heights during road construction. This would affect the prestige of the surveying profession in general and result in considerable loss of income for many surveyors, both within the RTA and contact surveyors.

However, the accuracy of survey measurements had to be examined. The key to implementing changes to construction and sampling procedures is survey control with the capability to match the higher quality processes to be specified.

FIELD TEST TO DETERMINE ACCURACY OF SURVEYING PROCEDURE

The Survey Conformance Procedure

A field test was set up to estimate the accuracy of the procedure used by RTA surveyors in Wollongong for conformance surveys. Conformance surveys of pavement surfaces measure the difference between the constructed height of the surface and its design height. Construction set out surveys apply the same surveying techniques for height determination and position fixing as conformance surveys. These procedures determine heights by EDM trigonometrical heighting.

The layout for the procedure is shown in Diagram 4. The total station is placed remote of the control marks, ***CM1***, ***CM2*** and ***CM3***. The surveyor sights to the same ranging pole and reflector placed on each of the 3 control marks in turn. Sightings are on both faces of the total station. The total station transfers all observation; horizontal direction; vertical angle; slope distance and height of the ranging pole, electronically to the Sharp pocket computer for instantaneous processing. Its software uses a least squares adjustment to calculate the three dimensional coordinates of the total station from these observations. Observations to sampling points on the pavement surface use the coordinates of the axis of the total station to determine their coordinates.

Simultaneously with height determination, the software calculates the grid coordinates of the sampling points. The software uses the stored design parameters of the road to convert grid coordinates to design chainages and offsets to calculate the design heights of the pavement at the sampling points. A comparison between the constructed heights and the design heights give the surface level departures of the sampling points. All processing is carried out in "real-time" while the field assistant carries the ranging pole between sampling points.

The survey conformance report provides a schedule of all surface level departures along with their chainages and offsets. The usual practice is to pick up points on the pavement surface in a defined grid pattern to give a uniform coverage of the pavement surface.

Restriction of all sight distances, including those to control marks, to less than 100 metres and setting the height of sight lines to greater than 1.5 metres, minimise the effect of refraction. Observations to sampling points are on one face only with the vertical circle index error measured and the correction applied at each set up. By using the same ranging pole for sighting the sampling points as used for sighting the control marks, without changing its height, staff errors are negated.

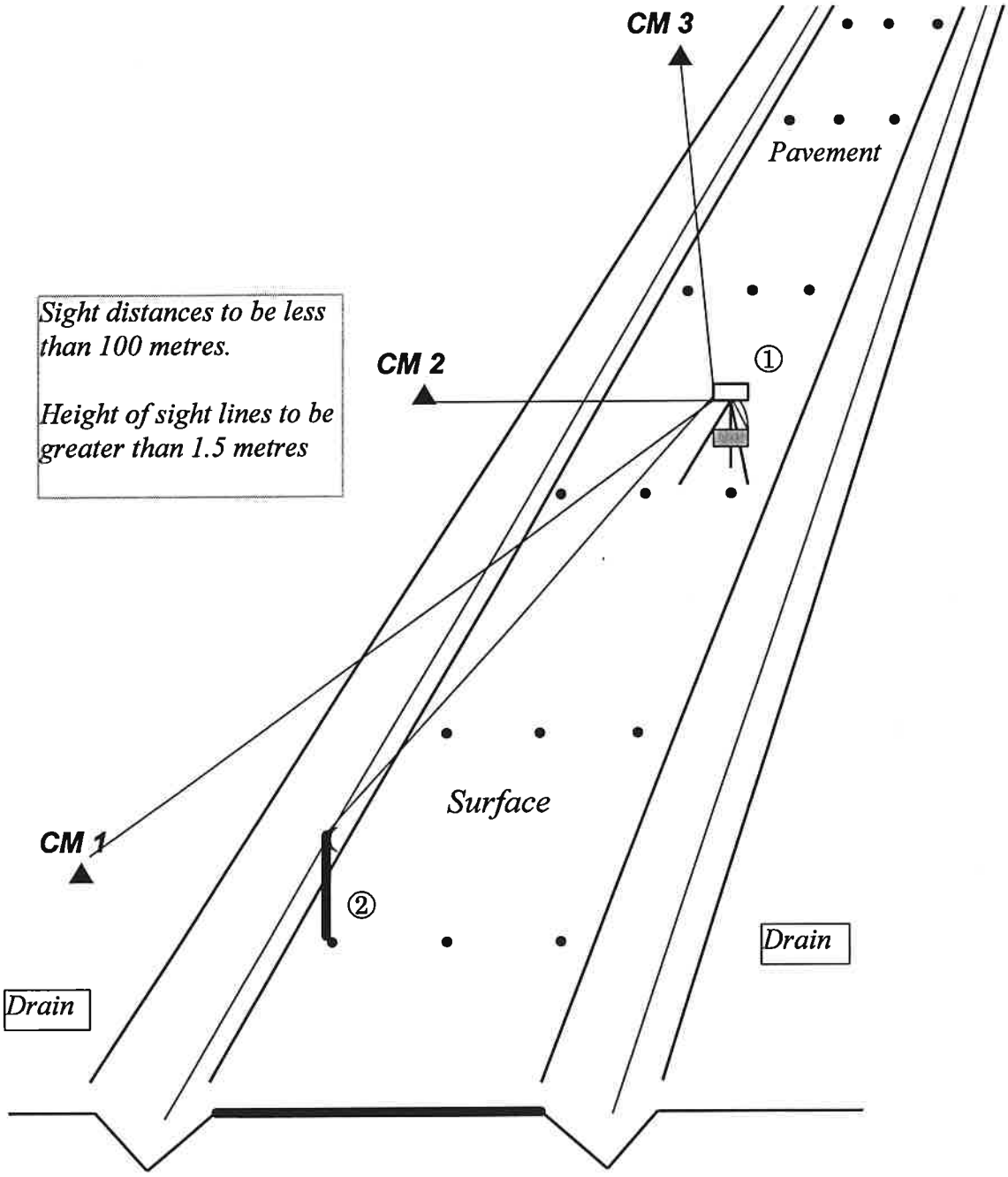

Diagram 4 General Layout of Survey Conformance Procedure

Legend:

1. ***CM1***, ***CM2*** and ***CM3*** are Control Marks 1, 2 and 3, each with known Easting, Northing and Height coordinates.
2. Total station, with pocket computer attached, is situated at point ①
3. A reflector mounted on a ranging pole is situated at point ②.
4. Positions where height determinations on the pavement are taken are shown thus •

Survey Accuracy Test

The Layout

The layout of the accuracy test is shown in Diagram 5. Hiltis in dumpy pegs, placed in a straight line at 10 metre intervals, formed the datum marks for testing the accuracy of the procedure. As the procedure restricts sight distances to 100 metres, the length of the datum line was restricted to approximately 100 metres.

A closed traverse, including the three control marks and the line containing the datum marks, determined the coordinates of the two end datum marks in relation to the control. The bearing of the line of datum marks and the individual distances between the dumpys determined the coordinates of each datum mark. The Sharp, loaded with the design parameters, converted the grid coordinates of each datum mark to chainage and offset in relation to the road centreline.

A double level run with a Leica NA 3000 digital level determined the heights of each of the datum marks, which were quoted to 0.1 mm.

The Field Procedures

The datum marks at 10-metre interval for 100 metre gives 11 marks, including the start and end marks. Observations of the datum marks were by two Topcon GTS3b's placed at three locations and observed by three operators. Sight distances varied between 2.6 metres and 106 metres. Three operators by three locations by two totals stations gives 18 determinations by the procedure of the three dimensional coordinates of each datum mark. Eighteen determinations of 11 marks give 198 determination of each coordinate (chainage, offset and height) for analysis to estimate the accuracy of the procedure.

The Sharp output of heights is usually to the nearest millimetre however, with minor manipulation, it gave the output to the nearest 0.1 mm. This allowed a more precise estimate of height accuracy. It is reasonable to quote the heights to 0.1 mm by this procedure as the vertical circle reading and the slope distance determines the heights. As one second was the smallest count of both total stations, the rounding error at 100 metres is 0.25 mm. for 0.5 second rounding of vertical circle observations.

The Results

The results of the accuracy field test of height determination by EDM trigonometrical heighting surprised and delighted me. It also raises some questions for those surveyors who still consider that if you want the right answer you had better get the level out of the truck. For road and indeed bridge, construction I say leave it in the truck if you want the better result. These comments apply to optical automatic levels as used by most surveyors involved in road construction. They do not necessarily apply to digital levels such as the Leica NA 3000.

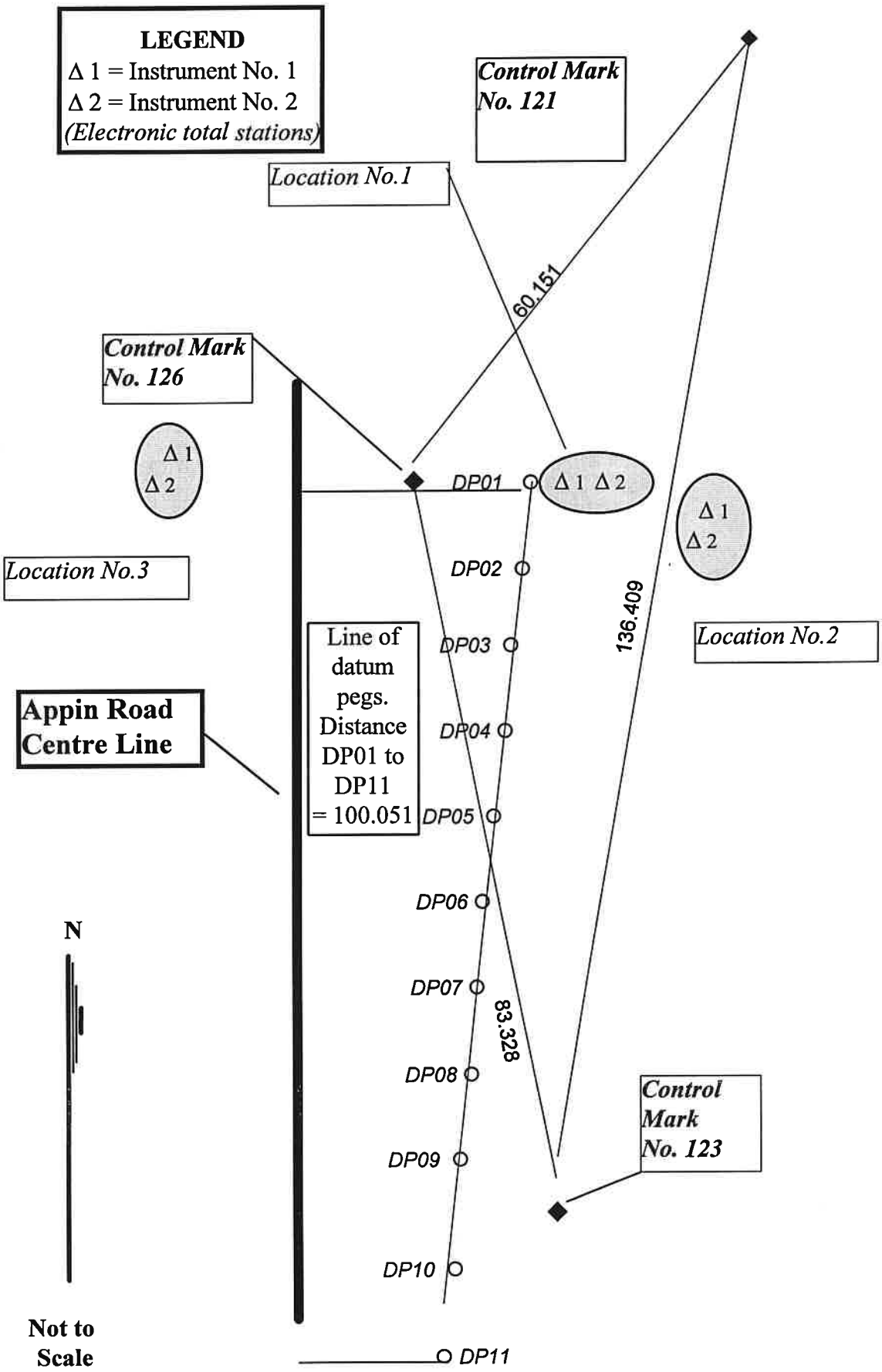

Diagram 5 The Layout of Survey Accuracy Field Test on Appin Road

Height Determination Precision

The results of the height precision are shown in Diagram 6. The height precision of the procedure is proportional to the sight distance. For sight distances up to 100 metres the standard deviation of the height error at sight distance d_i metres, is estimated as:

$$\hat{\sigma}_i = 0.23 + 0.0096 d_i \text{ millimetres} \quad (1)$$

The constant term, 0.23 mm, is the error in determining the height of the axis of the total station from the control marks. This implies that at zero (or negligible) sight distance there is still a height error.

The constant term shown will vary with the average sight distance to the control marks. During the accuracy test the average sight distance to the control marks was about 57 metres. For the maximum average sight distance of 100 metres the value of the constant term is about 0.4 mm.

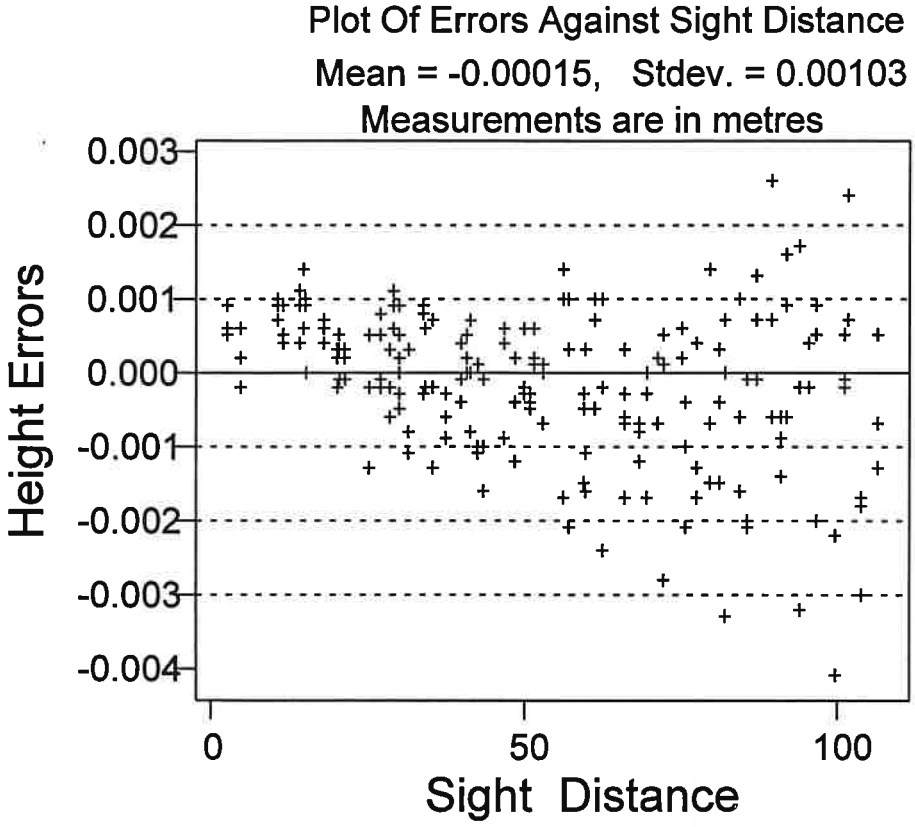

Diagram 6 Height Errors Against Sight Distance

Positional Precision of Procedure

The positional precision of the procedure was better than expected. At no stage during the accuracy test was a tripod used for a backsight, all sightings were to a hand held ranging pole without braced support. Sightings on a single face from the total station fixed the positions of the datum pegs after a resection fixed the position of the total station. Therefore, any error in the position of the total station would be magnified when determining the position of a sampling point. However, given these factors the

positional error had a smaller than expected standard deviation of less than 5 mm. This implies that the positional errors by this procedure are expected to be less than 10 mm about 95% of the time. The analysis also concluded that the positional error was not proportional to the sight distance.

Factors that Affect Accuracy

The research analysed nine factors identified by survey experience as affecting the accuracy of the procedure, as listed below:

1. The instrument
2. Location of the instrument in relation to the control network
3. Instrument operator
4. Sight distance
5. Curvature of the earth's surface
6. Errors in estimating the chainage and offset of the sampling point
7. Errors in the heights of the control marks
8. Vertical refraction
9. Vertical circle index error

The effect of **"the Instrument"** is due to the reading accuracy of the vertical circle and the accuracy of the EDM. As two Topcon GTS3b measured the datum pegs there was, ultimately as shown in Section 4.2.7, no significant difference between measurements by the two instruments.

The affect of factor "**Location of the instrument in relation to the control network**", was investigated at the request of my university supervisors. It made no significant difference.

Analysis of the affect of factor, "**Instrument operator**", demonstrated that surveying expertise and developed skills are not necessary to maximise the accuracy of the procedure. Unlike differential levelling where there needs to be a developed skill in reading the staff.

The accuracy of the procedure is proportional to "**sight distance**" as shown by equation (1).

Most software for EDM trigonometrical heighting, including the Sharp, automatically corrects height determinations for the effect of the **"earth's curvature"**. The correction is about 0.8 mm for sight distance of 100 metres.

Conformance surveys measure the difference between the constructed height of the pavement and its design height. The design height is calculated from the stored design parameters and the measured position (chainage and offset) of the sampling point. **"Errors in estimating the chainage and offset of the sampling points"** will cause errors in design heights, due to the pavement's cross fall and longitudinal gradient and as a consequence, errors in the surface level departures. The smaller than expected positional error of the procedure means that the effect of this factor is negligible.

Errors in the heights of the control marks

The purpose of using three control marks in the tested RTA procedure is to detect and correct for disturbances of the control marks. Data from projects where I have been the RTA project surveyor shows the magnitude of movement possible by construction activity on road construction projects as shown in Diagram 7. Movement recorded is greater than 3 mm, with some are as large as 30-40 mm.

NORTHERN DISTRIBUTOR MR626 - Contract No. 0626.497.RC.0014					
Control Mark Number	Type Of Mark	Date Adjusted	Movement - Metres		
			From	To	Difference
2A	Hilti in conc.	27/03/93	15.244	15.240	-0.004
3	Bolt	3/02/93	9.438	9.434	-0.004
15	Indicator	1/03/93	25.403	25.398	-0.005
33	Hilti in conc.	5/08/92	13.126	13.120	-0.006
35	Peg + hilti	2/11/92	11.048	11.055	+0.007
36	Dumpy	27/7/92	20.865	20.855	-0.010
** 50	Hilti in Kb.	2/10/92	21.560	21.552	-0.008 **
51	Peg + hilti	16/10/92	15.469	15.477	+0.008
51	Peg + hilti	2/11/92	15.477	15.444	-0.033
59	Peg + hilti	3/02/93	16.302	16.295	-0.007
59	Peg + hilti	6/04/93	15.295	15.260	-0.035
71	Peg + hilti	15/02/93	14.949	14.956	+0.007
86	Peg + hilti	28/07/92	21.534	21.544	+0.010
87	Peg + hilti	28/07/92	19.675	19.681	+0.006
88	Peg + hilti	16/07/92	16.919	16.909	-0.010
89	Indicator	1/12/92	14.380	14.371	-0.009
90	Star picket	1/12/92	14.651	14.642	-0.009
Eighteen control marks disturbed by more than 3 mm. from 100 control marks used on the project					

APPIN ROAD WIDENING - Project No. 1722/3/CL3S					
Control Mark Number	Type Of Mark	Date Adjusted	Movement - Metres		
			From	To	Difference
11	Peg + hilti	1/02/95	374.959	374.934	-0.025
One control mark disturbed by more than 3 mm. from 35 control marks used on the project.					

PICTON ROAD WIDENING - Contract No. 0095.497.RC.2730					
Control Mark Number	Type Of Mark	Date Adjusted	Movement - Metres		
			From	To	Difference
SSM 27802	Conc. Blk	24/06/94	316.240	316.280	+0.040
SSM 27803	Conc. Blk	24/06/94	297.790	297.825	+0.035
** SSM 27861	Conc. Blk	24/06/94	365.150	365.129	-0.021 **
16	Dumpy	31/08/94	302.547	302.551	+0.004
33	Peg + hilti	22/08/94	307.067	307.056	-0.011
SSM 27865	Conc. Blk.	24/06/94	409.630	409.607	-0.023
68	Peg + hilti	22/08/94	299.256	299.250	-0.006
Seven control marks disturbed by more than 3 mm. from 56 control marks used on the project.					

Diagram 7 Disturbance of Control Marks

Continuous movement of station number 50 on MR626, which was placed in a concrete kerb, was tracked over a couple weeks from two adjacent marks that showed no movement. SSM 27861 on Picton Road showed no visible signs of either disturbance of the mark or the ground around the mark. However, major earthworks on the opposite side of the road had obviously affected the height of the whole road.

The message from these tables is that no control mark can be accepted without some checking if the survey is to achieve the required accuracy. The results shown in these tables reflect feedback from site surveillance of roads constructed by contractors that reports similar movement of control marks.

The research also looked at current surveying procedures used by road construction contractors to assure pavement course thicknesses. The results of a questionnaire (Ollis, 1997) showed that procedures using EDM trigonometrical heighting were better equipped to detect movement in control marks than procedures using differential levelling.

An additional improvement offered by observing to three control marks is the reduction in the inherent variability of the adopted heights of the control marks. The process used to determine the original heights of the control marks is subject to variability, no matter how small it may be.

Refraction

The RTA procedure adopts controls to minimise the affect of vertical refraction on height determinations. These are to restrict the sight distances to less than 100 metres and to set a minimum height of sight lines of 1.5 metres. The accuracy test did not test the effectiveness of these controls, so a separate field test was carried out. The results are shown in Diagram 8.

The graphs show the coefficient of refraction for heights of sight lines of 0.5, 1.0, 1.5 and 1.9 metres. The graphs for sight lines of 1.5 and 1.9 metre heights suggest that there is no significant improvement by increasing the height from 1.5 to 1.9 metres. Conversely, there is a significant increase in the absolute size of the coefficient of refraction when the height of sight lines is less than one metre.

EDM trigonometrical heighting procedures must contain controls to minimise the affects of refraction. Procedures that don't and ignore the affect of refraction will give significant errors, even for sight lines of less than 100 metres. On the day of the field test the maximum affect of refraction for sight line of 0.5 metres height was about 5 mm at 100 metres. At 200 metres the affect of refraction on height determination for sight line of 05. metres height would have been about 20 mm.

The graphs also show how the coefficient of refraction varies throughout the day. It is important to note the graphs are only a demonstration of the variability and the possible magnitude of the coefficient of refraction. Repeating this test at the same location under different environmental conditions will yield different results.

The effects of refraction are generally not well controlled by the road construction industry. Responses to a questionnaire (Ollis, 1997) by 20 road construction surveyors using EDM trigonometrical heighting found that only three set a minimum height of sight lines of at least 1.5 metres. Only two of these restricted the sight distance to 100 metres.

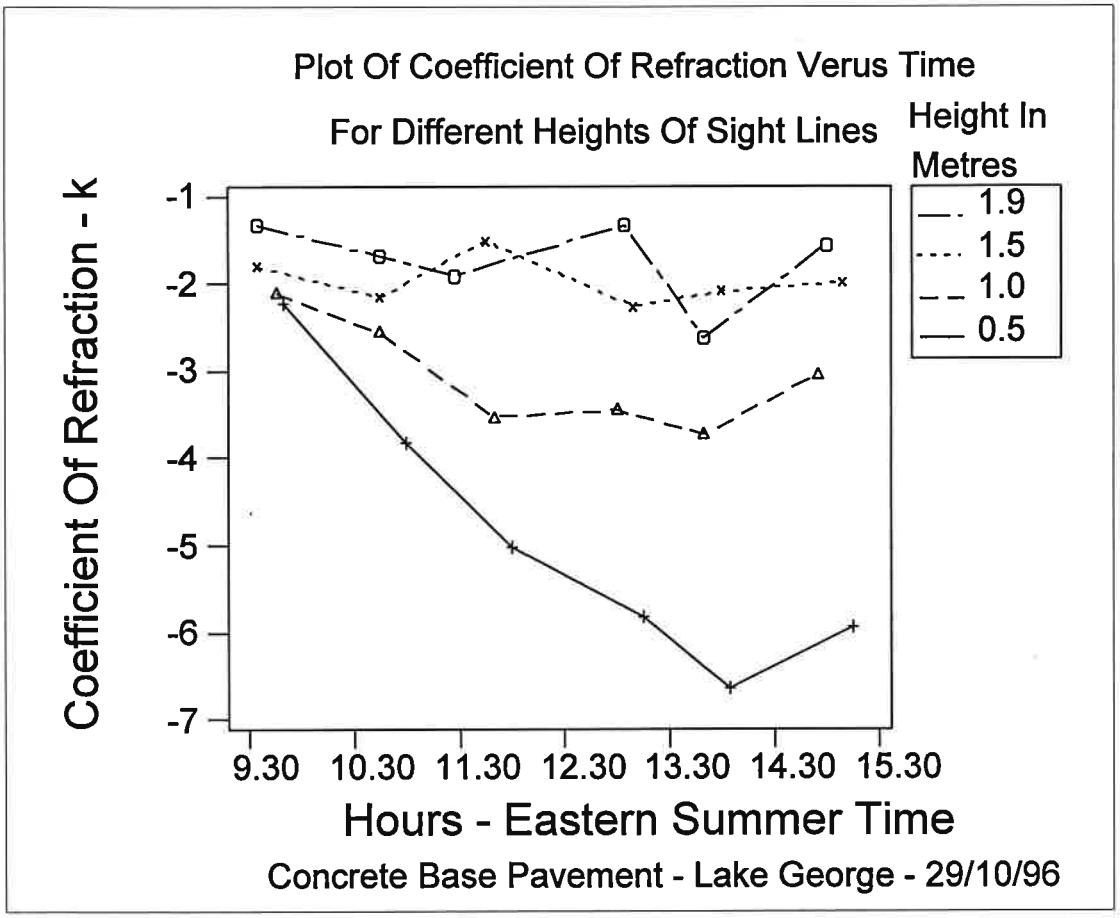

Diagram 8 Results of Refraction Field Test

Sunny all day, no cloud cover, temperature: 15 to 19 ^{oC}, strong wind blowing across sight lines

The Vertical Circle Index Error

Assuming procedures adequately control refraction, the accuracy test concluded that the greatest sources of errors for height determination by EDM trigonometrical heighting are poor procedures for measuring the vertical circle index error. Significant time was spent during the analysis to ascertain why the two instruments that carried out the field test gave different heights to the same datum points.

The error came about because I assumed that I knew the vertical circle index correction for my jigger. I assumed that it was 5 seconds of arc per face and had been so for some time. On the morning of the field test I measured the vertical circle index error as 6 seconds by one sighting on each face. Prior knowledge of the vertical circle index error

of my jigger affected my judgement and as a consequence I set the assumed vertical circle index correction of 5 seconds for the field test.

However, as the procedure requires sighting on both faces to each control mark, enough data were collected during the field test to give a better estimate of the vertical circle index error. This estimate was 8 seconds of arc per face. Applying this correction concluded that there was no significant difference between the two Topcon GTS 3b's, as expected. (It is worth noting that 6 seconds is within the 95% range of single determinations of the vertical circle index error of an instrument with a vertical circle index error of 8 seconds and a standard deviation of reading accuracy of 2 seconds.)

The analysis therefore concluded that a single sightings on each face of the instrument was not sufficient to measure the vertical circle index error to the accuracy required for conformance surveys. As a result of this test I have recommended that RTA procedures be changed to measure the vertical circle index error by three sightings on each face for conformance surveys.

Sophisticated statistical analysis also identified an unusual behaviour of the data collected during the accuracy test. Solution of this problem called for surveying knowledge and the statistical expertise provided by the university. The analysis concluded that the unusual behaviour was due to variations of the vertical circle index error with temperature changes. Professor Rüeger, of the UNSW, supported this finding and verified the results with independent research, (Rüeger, 1997; Teskey, 1992). Due to the effect of temperature variation on liquid level sensors, as used by modern total stations, I have recommended measurement of the vertical circle index error at each set up for conformance surveys.

Responses by 20 construction surveyors using EDM trigonometrical heighting (Ollis, 1997) suggested that there is poor control of the vertical circle index error by the industry. Only five stated that they measured the vertical circle index error at each set up and 12 stated that they measured it only once every week or at longer intervals.

REQUIRED ACCURACY OF CONFORMANCE SURVEYS

This paper lists some controls for factors that affect the accuracy of EDM trigonometrical heighting. For some surveyors their survey experience tells them that these controls are a little "over the top". To test if they are "over the top", the question to ask is what is the purpose of conformance surveys of pavement surfaces.

The precision of what is being measured determines the required precision or accuracy, of the surveying procedure. At this stage the research has only analysed concrete pavement surfaces. The rest of this paper, therefore, will refer to concrete pavement surfaces only. Other pavement surfaces, such as gravel pavements and earthworks, will be analysed in the near future. However, it is clear from data already available that construction processes construct concrete pavement surfaces more precisely than other pavement surfaces.

Process Measurement

RTA quality assurance contracts require contractors to establish process controls to ensure delivery of specified characteristics that affect road life cycle costs. The critical characteristic that surveyors play an important role in is pavement surface heights, which ensures pavement thickness. By measuring the surface level departures surveyors are measuring the effectiveness of contractors' process controls. Process controls are factors that affect the accuracy of the process. To construct pavement surfaces to the correct height the process controls include but are not be limited to:

- The survey set out
- The string line that controls the paving machine
- Stability of the set out markers
- The paving machine operator
- The calibration of the paving machine
- Concrete mixes

Survey conformance reports provide objective evidence of the capability of contractors' process controls. Under the umbrella of the science of statistical quality control statistical, (Montgomery, 1996) conformance surveys provide "process measurements". This is an important concept to grasp. It means that surveyors can measure the performance of contractors. These measurements will show when process controls have improved or when the contractor has allowed process quality to slip.

Surveyors have been measuring processes for years without realising the potential of their measurements. Not just in pavement surface heights but wherever "work as executed" or conformance surveys are carried out. The value of this research was the application of statistical techniques to survey measurements to demonstrate process control and process capability. This allows the RTA to reward contractors for good process control and warns contractors when there are problems with process controls. The overall effect is expected to see improvement in product quality and reduced construction costs.

Precision of the Process

Surveyors will play an integral role in the expected reform of the road construction industry. However, if their procedures are not accurate enough then major reform will eventually fail. As contractors will be rewarded for improved process control, survey measurements must be accurate enough to track process improvement. Therefore, measurements need to be an order of accuracy higher than the precision of the process.

The precision of the process is determined by its capability, which is determined by accurate and objective measurements of the output of the process. The research estimated the industry standard from survey conformance reports of completed projects as 6.0 millimetres. Therefore, the standard deviation of the surveying procedure, by the propagation of error theory, should be no greater than 0.6 mm.

Average Standard Deviation of Surveying Procedure

To track process improvement the pavement surface is measured in lots or sections. Equation (1) gives the standard deviation of height determinations by the procedure as a function of sight distance. Applying an average sight distance during a conformance survey of a lot estimates the standard deviation of the procedure during measurement of a lot. The average sight distance adopted was 58 metres, which gave a standard deviation of height determination of 0.79mm for the surveying procedure. Add to this the effect of positional error to give a standard deviation of 0.86 mm for measuring surface level departures.

This value, 0.86, is greater than the desired limit of 0.6 mm. Therefore the controls placed in the procedure are not "over the top" as some may feel. Analysis shows that the effect of errors of the surveying procedure, although theoretically too large, add negligible distortion to process measurements. Surveying procedures with standard deviations of greater than 1.25 mm add too much distortion to surface level departure measurements to track process improvement. Failure to adequately control refraction, the vertical circle index error, disturbance of the control marks or other factors, has the potential to push the standard deviation of the procedure above 1.25 mm. Auff (1983) estimates the accuracy of differential levelling for measuring surface level departures as about 2.5 mm.

CONCLUSION

This paper lists controls for factors that affect the accuracy of EDM trigonometrical heighting for conformance surveys of pavement surface heights. The RTA recommends the use EDM trigonometrical heighting in preference of differential levelling for conformance surveys. Surveyors have for sometime realised the benefits of EDM trigonometrical heighting for ease of data collection and improved proficiency of field procedures. However, the research demonstrates that EDM trigonometrical heighting also gives more accurate height determinations than traditional differential levelling with an optical automatic level; provided procedures listed in this paper are followed.

Few surveyors here today will be required to carry out conformance surveys for the RTA. However, I ask all surveyors to consider the controls suggested in this paper to improve the accuracy of EDM trigonometrical heighting, wherever they may use it.

This paper also reveals a potential of survey measurements that surveyors would have not known (I hope that I will be corrected on this assumption). That is the potential of survey measurements to become process measurements, which in turn reflects product quality.

Most professionals today know of the three cross-functional measures that determine the performance and viability of an organisation they are; time, cost and quality. Modern managers are adept in the providing figures on time and cost performance but few can provide data to objectively demonstrate product quality. It is interesting to

note the number of Government projects that are completed "ahead of schedule and under budget", while not mentioning the quality of the completed works.

Survey measurements will provide the RTA with an object performance measure in the important area of pavement course thickness. The statistical techniques applied to pavement surface measurements can be applied to other road components requiring survey measurements for acceptance, such as batter planes. If surveyors wish to step up to this important role of providing performance measures of product quality, they need to demonstrate their capability to measure to the required accuracy. The required accuracy is the capability to track process improvement. The opportunity now exists for surveyors to play an important role to change the culture of an industry to focus on quality as well as time and cost. This is expected to facilitate major reform in a $6b Australian industry.

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