UNIVERSITY OF EXETER

College of Engineering, Mathematics & Physical Sciences

Camborne School of Mines

Tremough Campus Survey

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Abstract

A precise control network has been set up using a variety of surveying techniques, including a benchmark transfer and levelling around the closed traverse, turning angles and coordinate calculations of the station set ups. 9 Stations were recorded, with the baseline spanning A1 – A2, the exact bearing of these being obtained using GNSS (55° 58’ 00”). Detailing has picked up hard and soft detail based around the control network. Data has been post processed using LSS and AutoCAD and attached in the A0 Map showing the survey.

This report shows a survey undertaken from first principles, working whole-to-part.

Word Count: 3000 (Excluding Data Tables)

Contents

Aim

"Complete a topographic survey of Penryn Campus around Tremough House and gardens. Establish primary control on the site by means of a closed traverse, linking in to the OS Grid. Complete a detail survey of the site and present the data in the form of a topographic plan."

1.1.1. Site Overview

As stated in the **Aim**, a traverse, levelling run and subsequent coordinate calculations were undertaken on an area of Penryn Campus, Penryn, Cornwall (*50° 10' 7.32" N, 5° 7' 1.56" W).* The levelling run involved a benchmark transfer from the OSBM trig pillar 'Daniel' (*121.946 m AOD*). Elevations were gained for all stations C1 – C9. A base line was set up using Leica GS18 equipment between station C1 and C2, both with good lines of sight and clear overhead for the best satellite signal. This was used for coordinate calculations on the closed traverse undertaken around the site using Leica TS 1200 equipment. The survey has been undertaken by James Heslington, Tom Wilkie and Daniel Anderson.

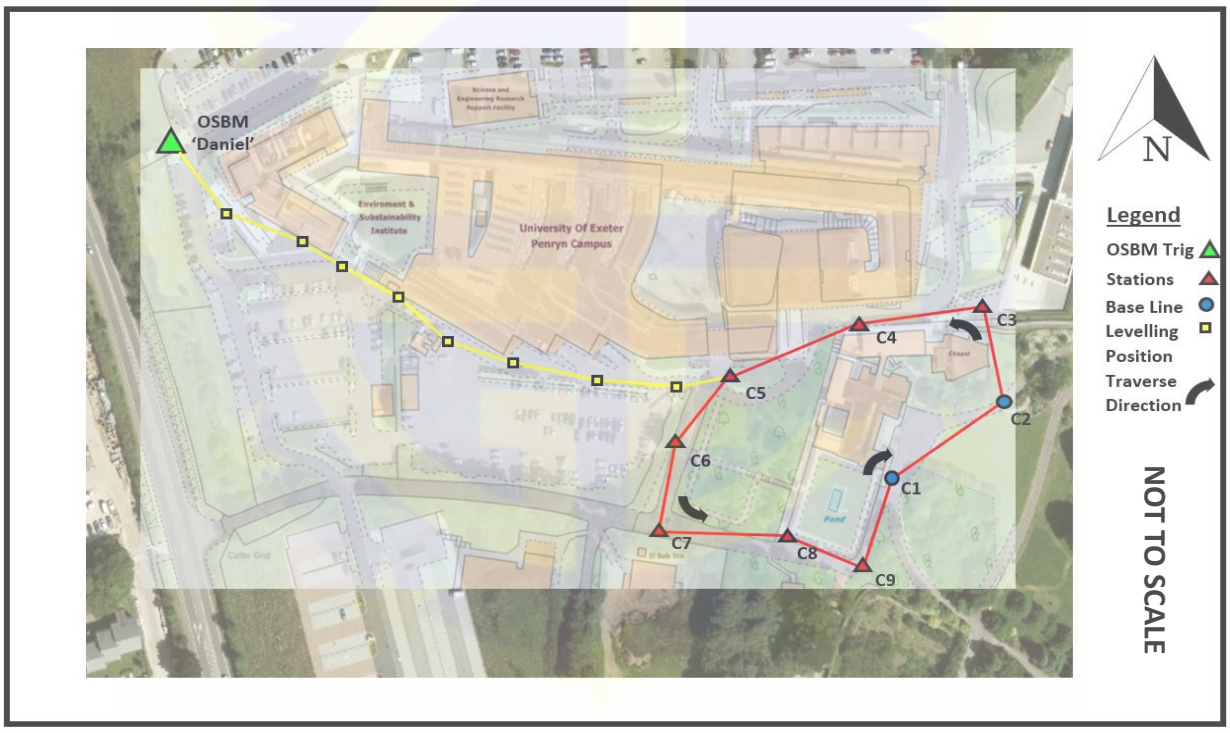


Figure 1: Plan overview of levelling route and control station positions, including traverse direction.

1.1.2. Equipment

- Leica TS1200
- 2x Leica Circular Prisms
- Leica GS18
- Booking Sheets; levelling and turning angles
- 3x Tripod Legs (wooden)
- 2x Tribrach
- Change Plates
- 1x Dumpy Level
- 1x 5m Levelling Staff
- 1x Tripod Legs (metal; levelling)

1.1.3. Benchmark Transfer

For this exercise, the heights of stations C1-C9, around Tremough House had to be measured. This was done by bringing in a known height from OSBM "Daniel"; a trig point with an elevation of 121.946 m. Using a Leica NA720 Automatic Level the reference benchmark height "Daniel", was transferred down to the control network around Tremough House using the rise and fall method of levelling whilst double set levelling. This method was chosen to ensure that any errors were not carried forward from the level run onto the control point elevations.

The above figure shows an approximation of levelling positions and the control network used in this exercise, the levelling was carried out using position markers to assure that the levelling staff was placed in the correct position. The rise and fall method requires a back sight reading and foresight reading to be taken for one station position. The often the calculation is BS - FS, if the result is positive it is a rise, if negative a fall. The reduced level can then be calculated by adding rises and subtracting falls. Levelling calculations are as follows (***BS – FS, BS – IS, IS – IS or IS – FS***).
The double set levelling method uses two station set up with the same staff positions. Working in this method allows the readings of the two set up to be compared, and if any errors ±2 mm occurred between the two reduced levels the process would be repeated.

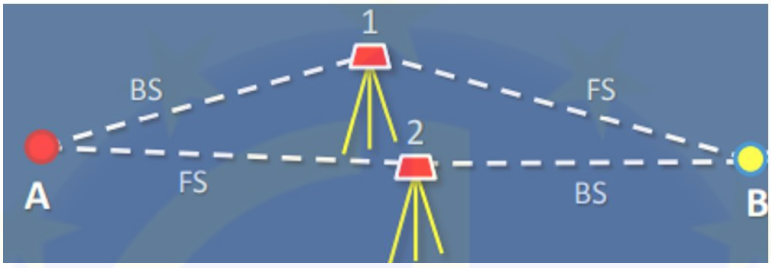


Figure 2: Shows a typical double set levelling position (Image courtesy of ELE)

1.1.4. Closed Circuit Traverse

In addition to establishing the heights of the control station positions, a traverse was carried out around Tremough House. The traverse was carried out using the pre-established station positions C1 - C9, each marked with a survey nail and identifying spray paint. A clear line of sight between the stations was maintained and the survey carried out in as reasonable light conditions as possible.
At each position the total station would be set centred and level over each nail, in this case a 3" Leica 1200 total station; the targets were Leica circular prisms with a 0.0 mm prism constant mounted on centred and levelled tripods over target stations. For each set up a back sight and foresight angle would be taken in both left and right face, as well as a distance measured for both target stations. This process would then be repeated for several rounds, resetting the azimuth of the total station in a random direction between each round to ensure different angles. The process of taking a left and right face reading onto the same target station highlights any errors picked up during the survey. This was then repeated at each control station position around Tremough House, working in a clockwise direction from C5 measuring the internal angle of the polygon seen in the traverse plan overview. With GNSS data collected using a GS18 at C1 and C2; when inputted into the equation below, gives the initial bearing 55° 58' 00".

$$\tan^{-1}\frac{\Delta Eastings}{\Delta Northings}$$

1.1.5. Risk Assessment

Seen in ***Table 1*** and ***Table 2***, are two examples of risk assessments undertaken for the activities during the survey. These identified the key hazards and risks and allowed us to put controls in place to minimise the risk. The risks varied daily due to other factors; such as weather and footfall, however, the main points are covered below. To minimise the variable risks, Go-no-go assessments were undertaken before any activity to ensure minimal risk.

Table 1: Risk assessment for the survey undertaken.

Potential Hazard	**Control measures**	**Risk rating**	**Responsibilities**
Vehicle collision (Equipment)	Equipment to be placed so traffic flow is unobstructed and risk collision lowered as much as reasonably practicable. Equipment to be moved if road blocked.	1 2 ③ 4 5	Survey team to ensure equipment is set up suitably and maintain good awareness of traffic conditions. Standing near equipment when necessary.

Vehicle collision (Persons)	Persons to stand out of the road and wear high visibility clothing whilst surveying.	1 2 3 ④ 5	Ensure that set up positions allow survey team to remain out of traffic routes. High visibility clothing to be worn throughout and awareness of traffic maintained.
Third party moving equipment	Equipment to be set up away from pedestrian thoroughfares where possible. If necessary, have a person stand by the equipment and explain to passers-by to avoid moving the equipment	1 ② 3 4 5	Ensure that doorways are not blocked and that set ups of blind corners have persons stand nearby.
Wind moving equipment	Tripods to be set up as wide as reasonably practicable, legs to be pushed firmly into the ground.	1 ②3 4 5	Ensure equipment set up with a reasonable base, whilst also avoiding interfering with traffic and pedestrians. In strong winds have persons stand near to the equipment.
Rain	Weather forecast to be checked before surveying. Appropriate measures to be taken to ensure equipment doesn't get too wet.	1 ② 3 4 5	Ensure that equipment is either covered over or packed away.
Manual handling	Equipment to be removed from tripod legs and placed with in boxes for transport.	① 2 3 4 5	Ensure that equipment is stripped down and transported suitably between positions.
Ground conditions	Suitable footwear to be worn. Equipment to be placed sensibly when considering ground conditions; dug into mud, not laid in a puddle.	1 ② 3 4 5	Be aware of footing whilst on uneven / slippery ground. Equipment to be set into soft ground and put down on reasonable ground.

Table 2: JSA Risk assessment for the survey undertaken.

Job / Task Step	Unwanted Events arising from or associated with the job / task step or equipment usage	Requirements (controls) to protect people from the identified Unwanted Events
1. Equipment set up	1.1 Equipment struck by passing vehicle.	1.1.1 Equipment to be placed so traffic flow is unobstructed, and risk of collision lowered 1.1.2 Personnel to stand near to equipment and direct traffic around equipment if necessary. 1.1.3 As a last resort equipment to be moved in the case of unavoidable obstruction.
	1.2 Personnel struck by passing vehicle.	1.2.1 Equipment to be placed so traffic flow is unobstructed, and risk of collision lowered 1.2.2 Personnel to stand out of road ways when able. 1.2.3 High visibility clothing to be worn during survey. 1.2.4 Personnel to apply SLAM technique whilst operating in high traffic areas.
	1.3 Equipment moved by third party.	1.3.1 Equipment to be placed so pedestrian access is unobstructed, and risk equipment tampering lowered 1.3.2 Personnel to stand close to equipment in busy areas, directing people around equipment as required.
	1.4 Equipment effected by weather.	1.4.1 Weather forecast to be observed for surveying days. 1.4.2 Equipment to be covered over or packed away in the event of rain. 1.4.3 Equipment to be dug into ground as much as reasonably practicable.
	1.5 Unstable ground conditions.	1.5.1 Equipment to be dug into ground as much as reasonably practicable 1.5.2 Suitable footwear to be worn.
2. Moving equipment	2.1 Equipment struck by passing vehicle.	2.1.1 Equipment to be placed so traffic flow is unobstructed, and risk of collision lowered. 2.1.2 Personnel packing down equipment to remain watchful of traffic. 2.1.3 Equipment to be carried along pedestrian routes where available.
	2.2 Personnel struck by passing vehicle.	2.2.1 Equipment to be carried along pedestrian routes where available. 2.2.2 High visibility clothing to be worn during survey.
	2.3 Equipment damaged during transport.	2.3.1 Equipment to be removed from tripods. 2.3.2 Equipment to be placed in boxes where available. 2.3.3 Personnel to carry a tripod and one other piece of equipment.
	2.4 Equipment moved by third party.	2.4.1 Personnel to keep equipment with them at all times. 2.4.2 to be placed so pedestrian access is unobstructed.
	2.5 Equipment placed in unsuitable location	2.5.1 Personnel to locate equipment in accordance to Job task 1.1 2.5.2 Equipment to be placed out of road way and with minimal obstruction to pedestrians when not in use. 2.5.3 Ground conditions to be checked before equipment set down.
3. Taking readings	See 1. Equipment set up.	See 1. Equipment set up controls.

2.1. Levelling Results

Table 3: Raw data of levelling run undertaken.

BackSight (m)	IntermediateSight (m)	ForeSight (m)	Rise/ Fall (m)	Reduced Level (m)	Remark	Error
0.153				121.946	TBM DAN	
1.535		1.540	-1.387	120.559	CP1	
		0.148	1.387	121.946	TBMDAN	0
0.741				120.559	CP1	
1.804		1.942	-1.201	119.358	CP2	
		0.603	1.201	120.559	CP1	0
0.143				119.358	CP2	
1.966		1.877	-1.734	117.624	CP3	
		0.232	1.734	119.358	CP2	0
0.416				117.624	CP3	
1.966		2.003	-1.587	116.037	CP4	
		0.379	1.587	117.624	CP3	0
0.571				116.037	CP4	
1.865		1.798	-1.227	114.81	CP5	
		0.638	1.227	116.037	CP4	0
0.396				114.81	CP5	
2.024		2.000	-1.604	113.206	CP6	
		0.420	1.604	114.81	CP5	0
0.179				113.206	CP6	
1.957		2.013	-1.834	111.372	CP7	
		0.123	1.834	113.206	CP6	0
0.388				111.372	CP7	
1.993		1.986	-1.598	109.774	CP8	
		0.395	1.598	111.372	CP7	0
0.868				109.774	CP8	
0.955		0.924	-0.056	109.718	C5	
		0.899	0.056	109.774	CP8	0
0.220				109.718	C5	
1.932		2.033	-1.813	107.905	CP9	
		0.119	1.813	109.718	C5	0

0.134				107.905	CP9	
1.976		2.030	-1.896	106.009	CP10	
		0.080	1.896	107.905	CP9	0
1.025				106.009	CP10	
1.651		1.719	-0.694	105.315	C4	
		0.957	0.694	106.009	CP10	0
0.85				105.315	C4	
2.033		2.027	-1.177	104.138	CP11	
		0.856	1.177	105.315	C4	0
0.534				104.138	CP11	
1.437		1.436	-0.902	103.236	C3	
		0.535	0.902	104.138	CP11	0
0.173				103.236	C3	
1.973		1.958	-1.785	101.451	CP12	
		0.188	1.785	103.236	C3	0
0.069				101.451	CP12	
1.966		1.953	-1.884	99.567	CP13	
		0.082	1.884	101.451	CP12	0
0.075				99.567	CP13	
1.978		1.950	-1.875	97.692	CP14	
		0.103	1.875	99.567	CP13	0
1.067				97.692	CP14	
1.042		1.125	-0.058	97.634	C2	
		0.984	0.058	97.692	CP14	0
1.482				97.634	C2	
0.401		0.553	0.929	98.563	CP15	
		1.33	-0.929	97.634	C2	0
1.568				98.563	CP15	
1.369		1.451	0.117	98.680	C1	
		1.486	-0.117	98.563	CP15	0
1.455				98.680	C1	
1.531		1.488	-0.033	98.647	C9	
		1.498	0.033	98.68	C1	0

1.773				98.647	C9	
0.131		0.099	1.674	100.321	CP16	
		1.805	-1.674	98.647	C9	0
1.854				100.321	CP16	
0.793		0.774	1.080	101.401	C8	
		1.873	-1.08	100.321	CP16	0
1.878				101.401	C8	
0.316		0.147	1.731	103.132	CP17	
		2.047	-1.731	101.401	C8	0
1.955				103.132	CP17	
0.161		0.118	1.837	104.969	CP18	
		1.998	-1.837	103.132	CP17	0
2.049				104.969	CP18	
0.079		0.118	1.931	106.900	CP19	
		2.010	-1.931	104.969	CP18	0
2.001				106.900	CP19	
0.215		0.263	1.738	108.638	C7	
		1.953	-1.738	106.900	CP19	0
0.215				108.638	C7	
0.161		0.153	0.062	108.700	CP19	
		0.223	-0.062	108.638	C7	0
1.879				108.700	CP19	
0.632		0.659	1.220	109.920	C6	
		1.852	-1.220	108.700	CP19	0
1.321				109.920	C6	
		1.523	-0.202	109.718	C5	0

Double set levelling was used in order to minimise error in the data. If error was identified, the set was repeated again in order to eliminate the error. The green colouring shows that the error is acceptable and the run can carry on to the next station. The yellow colouring shows the station levels. This ensures the highest accuracy of results. The circuit around the stations was closed with 000 mm error, which was allowable when compared to our allowable misclosure (*see below*).

$m = \sqrt{n}$ m = accuracy constant n = number of set ups

$3 = \sqrt{28}$ = 15.875 allowable misclosure [*the value of **0.000** is acceptable and within limits*]

STN	Height (m)
C1	98.680
C2	97.634
C3	103.236
C4	105.315
C5	109.718
C6	109.920
C7	108.638
C8	101.401
C9	98.647

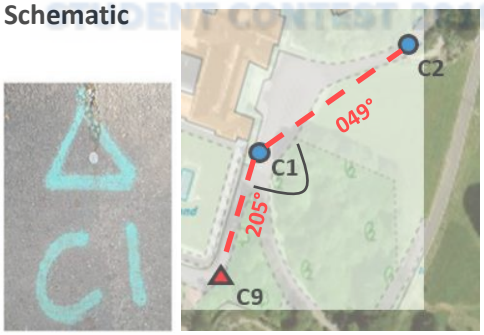
Table 4: Summary station heights

STN C1

Survey Nail

Date	15/11/18
Time	12:30
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Thick Mizzle, 12°C

Schematic



Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C1	C9	235° 30’ 53”	055° 30’ 53”	235° 30’ 53”	235° 30’ 53”	214° 08’ 59”
	C1	C2	089° 39’ 49”	269° 39’ 54”	089° 39’ 54”	089° 39’ 52”	
2	C1	C9	320° 39’ 10”	140° 39’ 11”	320° 39’ 11”	320° 39’ 11”	214° 08’ 52”
	C1	C2	174° 48’ 05”	354° 48’ 01”	174° 48’ 01”	174° 48’ 03”	
3	C1	C9	063° 43’ 21”	243° 43’ 23”	063° 43’ 23”	063° 43’ 22”	214° 08’ 54”
	C1	C2	277° 52’ 18”	097° 52’ 14”	277° 52’ 14”	277° 52’ 16”	
4	C1	C9	168° 01’ 26”	348° 01’ 20”	168° 01’ 20”	168° 01’ 23”	214° 08’ 54”
	C1	C2	022° 10’ 16”	202° 10’ 18”	022° 10’ 18”	022° 10’ 17”	
5	C1	C9	030° 53’ 01”	210° 52’ 58”	030° 52’ 58”	030° 53’ 00”	214° 08’ 53”
	C1	C2	245° 01’ 52”	065° 01’ 53”	245° 01’ 53”	245° 01’ 53”	
6	C1	C9	052° 47’ 07”	232° 47’ 09”	052° 47’ 09”	052° 47’ 08”	214° 08’ 53”
	C1	C2	266° 56’ 01”	086° 56’ 01”	266° 56’ 01”	266° 56’ 01”	
						Mean Angle	214° 08’ 54”
						Range	000° 00’ 07”

From	To	Distance (m)
C1	**C9**	36.469
C1	**C2**	65.175

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
176997.255	34673.914	99.680

Notes

Mizzle creating issues with sighting; possible error. Multiple rounds run due to issues with other teams moving tripods. What seems to be precise and accurate results; no need for exclusion of data. Slightly larger range, but within acceptable misclosure limits (*18”*).

STN C2

Survey Nail

Date	16/11/18
Time	10:20
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Cloudy, 14°C

Schematic

Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C2	C1	101° 54’ 52”	201° 54’ 53”	101° 54’ 53”	101° 54’ 53”	097° 42’ 58”
		C3	199° 37’ 57”	019° 37’ 44”	119° 37’ 44”	199° 37’ 51”	
2	C2	C1	199° 47’ 33”	019° 47’ 39”	119° 47’ 39”	199° 47’ 36”	097° 42’ 50”
		C3	297° 30’ 24”	177° 30’ 28”	297° 30’ 28”	297° 30’ 26”	
3	C2	C1	206° 53’ 20”	026° 53’ 20”	206° 53’ 20”	206° 53’ 20”	097° 43’ 07”
		C3	304° 36’ 26”	124° 36’ 28”	304° 36’ 28”	304° 36’ 27”	
4	C2	C1	218°26’ 53”	38° 26’ 58”	218° 26’ 58”	218° 26’ 56”	097° 42’ 55”
		C3	316° 09’ 50”	136° 09’ 52”	316° 09’ 52”	316° 09’ 51”	
5	C2	C1	121° 22’ 27”	301° 22’ 20”	121°22’ 20”	121° 22’ 24”	097° 42’ 55”
		C3	219° 05’ 21”	039° 05’ 16”	219° 05’ 16”	219° 05’ 19”	
6	C2	C1	201° 03’ 50”	021° 03’ 52”	201° 03’ 52”	201° 03’ 51”	097° 42’ 55”
		C3	298° 46’ 45”	118° 46’ 48”	298° 46’ 46”	298° 46’ 46”	
						Mean	097° 42’ 55”
						Range	000° 00’ 08”

From	To	Distance (m)
C2	**C1**	65.174
C2	**C3**	28.965

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
177051.263	34710.388	97.634

Notes

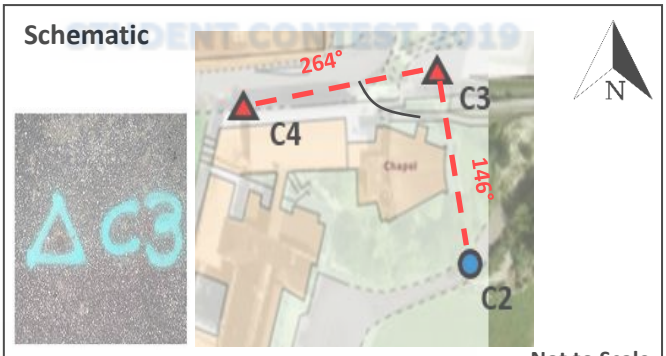
Round 3 excluded as anomalous (*shown in red*); lower range and mean makes a smaller linear misclosure. Mizzle creating issues with sighting; possible error. Branch in sight line to C3. Large height change resulting in potential for error in Hz.

STN C3

Survey Nail

Date	16/11/18
Time	12:00
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Cloudy, 14°C

Schematic



Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C3	C2	338° 41’ 08”	158° 41’ 09”	338° 41’ 09”	338° 41‘ 09”	112° 36’ 07”
	C3	C4	091° 17’ 15”	271° 17’ 16”	091° 17’ 16”	091° 17’ 16”	
2	C3	C2	045° 22’ 35”	225° 32’ 33”	045° 32’ 33”	045° 32’ 34”	112° 36’ 06”
	C3	C4	158° 08’ 40”	338° 08’ 40”	158° 08’ 40”	158° 08’ 40”	
3	C3	C2	300° 20’ 42”	120° 20’ 41”	300° 20’ 41”	300° 20’ 42”	112° 36’ 08”
	C3	C4	052° 56’ 44”	232° 56’ 50”	052° 56’ 50”	052° 56’ 50”	
4	C3	C2	050° 27’ 35”	230° 27’ 35”	050° 27’ 35”	050° 27’ 35”	112° 36’ 07”
	C3	C4	163° 03’ 42”	343° 03’ 42”	163° 03’ 42”	163° 03’ 42”	
5	C3	C2	050° 04’ 03”	230° 04’ 04”	050° 04’ 04”	050° 04’ 04”	112° 36’ 03”
	C3	C4	162° 40’ 08”	342° 40’ 05”	162° 40’ 05”	162° 40’ 07”	
6	C3	C2	063° 07’ 33”	243° 07’ 37”	063° 07’ 37”	063° 07’ 35”	112° 36’ 06”
	C3	C4	175° 43’ 39”	355° 43’ 42”	175° 43’ 42”	175° 43’ 41”	
						Mean Angle	112° 36’ 06”
						Range	000° 00’ 05”

From	To	Distance (m)
C3	**C2**	28.957
C3	**C4**	52.663

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
177038.422	34736.346	103.236

Notes

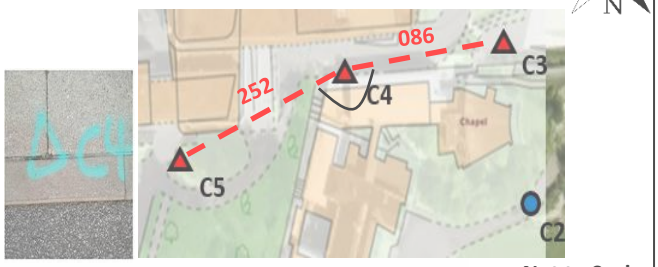
Branch in sight line to C3. Large height change resulting in potential for error in Hz. What seems to be precise and accurate results; no need for exclusion of data.

STN C4

Survey Nail

Date	15/11/2018
Time	13:30
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Rain, 12°C

Schematic



Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C4	C3	121° 37’ 52”	301° 37’ 53”	121° 37’ 53”	121° 37’ 53”	162° 46’ 50”
		C5	284° 24’ 46”	104° 24’ 40”	284° 24’ 40”	284° 24’ 43”	
2	C4	C3	134° 32’ 17”	314° 32’ 14”	134° 32’ 14”	134° 32’ 16”	162° 46’ 43”
		C5	297° 18’ 58”	117° 18’ 59”	297° 18’ 59”	297° 18’ 59”	
3	C4	C3	045° 16’ 42”	225° 16’ 49”	045° 16’ 49”	045° 16’ 46”	162° 46’ 38”
		C5	208° 03’ 27”	028° 03’ 20”	208° 03’ 20”	208° 03’ 24”	
4	C4	C3	324° 36’ 12”	144° 36’ 11”	324° 36’ 11”	324° 36’ 12”	162° 46’ 42”
		C5	127° 22’ 53”	307° 22’ 55”	127° 22’ 55”	127° 22’ 54”	
5	C4	C3	297° 33’ 46”	117° 33’ 53”	297° 33’ 53”	297° 33’ 50”	162° 46’ 36”
		C5	100° 20’ 28”	280° 20’ 24”	100° 20’ 24”	100° 20’ 26”	
6	C4	C3	009° 31’ 05”	189° 30’ 54”	009° 30’ 54”	009° 31’ 00”	162° 46’ 44”
		C5	172° 17’ 45”	352° 17’ 42”	172° 17’ 42”	172° 17’ 44”	
						Mean	162° 46’ 41”
						Range	00° 00’ 08”

From	To	Distance (m)
C4	**C3**	52.659
C4	**C5**	57.940

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
176985.869	34732.929	105.315

Notes

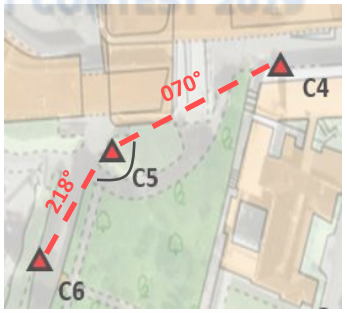
Round 1 excluded as an anomalous result (*shown in red*); increases range to 14”. Slightly larger range, with exclusion, but within acceptable misclosure limits (*18”*). Excluded as lower mean creates a lower linear misclosure. Rain creating potential for error.

STN C5

Survey Nail

Date	09/11/2018
Time	09:45
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Cloudy, 13°C

Schematic



Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C5	C4	032° 34’ 28”	212° 34’ 28”	032° 34’ 28”	032° 34‘ 28”	149° 23’ 23”
	C5	C6	181° 57’ 48”	001° 57’ 54”	181° 57’ 54”	181° 57’ 51”	
2	C5	C4	040° 19’ 30”	220° 19’ 40”	040° 19’ 40”	040° 19’ 35”	149° 23’ 22”
	C5	C6	189° 42’ 56”	009° 42’ 57”	189° 42’ 57”	189° 42’ 57”	
3	C5	C4	151° 04’ 29”	331° 04’ 22”	151° 04’ 22”	151° 04’ 26”	149° 23’ 13”
	C5	C6	300° 27’ 37”	120° 27’ 40”	300° 27’ 40”	300° 27’ 39”	
4	C5	C4	280° 29’ 06”	100° 29’ 04”	280° 29’ 04”	280° 29’ 05”	149° 23’ 12”
	C5	C6	069° 52’ 17”	249° 52’ 17”	069° 52’ 17”	069° 52’ 17”	
5	C5	C4	129° 24’ 10”	309° 24’ 07”	129° 24’ 07”	129° 24’ 09”	149° 23’ 12”
	C5	C6	278° 47’ 20”	098° 47’ 22”	278° 47’ 22”	278° 47’ 21”	
6	C5	C4	265° 15’ 21”	085° 15’ 32”	265° 15’ 32”	265° 15’ 27”	149° 23’ 05”
	C5	C6	054° 38’ 32”	234° 38’ 31”	054° 38’ 31”	054° 38’ 32”	
						Mean Angle	149° 23’ 16”
						Range	000° 00’ 11”

From	To	Distance (m)
C5	**C4**	57.942
C5	**C6**	24.052

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
176931.751	34712.220	109.718

Notes

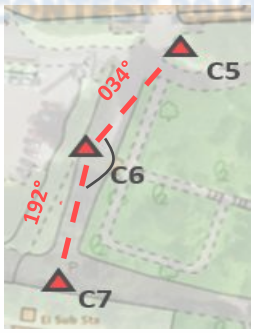
Round 6 excluded as an anomalous result (*shown in red*); increases range to 18”. Slightly larger range, with exclusion, but, within acceptable misclosure limits (*18”*).Soft and muddy ground; ensuring legs are fully dug in to avoid potential for error. Issues with large rate of footfall; levelling runs on STN; potential for legs being knocked and error.

STN C6

Survey Nail

Date	16/11/2018
Time	11:20
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Cloudy, 14°C

Schematic



Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C6	C5	000° 02’ 03”	180° 02’ 01”	000° 02’ 01”	000° 02’ 02”	159° 49’ 15”
		C7	159° 51’ 17”	339° 51’ 17”	159° 51’ 17”	159° 51’ 17”	
2	C6	C5	000° 16’ 52”	180° 16’ 49”	000° 16’ 49”	000° 16’ 51”	159° 49’ 12”
		C7	160° 06’ 03”	340° 06’ 03”	160° 06’ 03”	160° 06’ 03”	
3	C6	C5	071° 36’ 17”	251° 36’ 20”	071° 36’ 20”	071° 36’ 19”	159° 49’ 12”
		C7	231° 25’ 31”	051° 25’ 30”	231° 25’ 30”	231° 25’ 31”	
4	C6	C5	300° 07’ 25”	120° 07’ 22”	300° 07’ 22”	300° 07’ 24”	159° 49’ 18”
		C7	099° 56’ 45”	279° 56’ 38”	099° 56’ 38”	099° 56’ 42”	
5	C6	C5	313° 02’ 00”	133° 01’ 53”	313° 01’ 53”	313° 01’ 57”	159° 49’ 18”
		C7	112° 51’ 15”	292° 51’ 15”	112° 51’ 15”	112° 51’ 15”	
6	C6	C5	000° 10’ 23”	180° 10’ 20”	000° 10’ 22”	000° 10’ 22”	159° 49’ 15”
		C7	159° 59’ 36”	339° 59’ 38”	159° 59’ 38”	159° 59’ 37”	
						Mean	159° 49’ 15”
						Range	000° 00’ 06”

From	To	Distance (m)
C6	**C5**	24.057
C6	**C7**	39.734

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
176916.792	34693.380	109.920

Notes

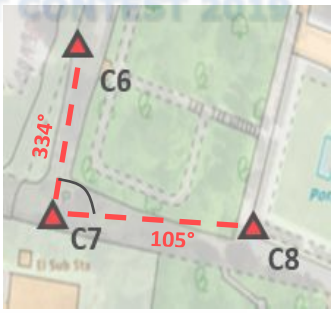
What seems to be precise and accurate results; no need for exclusion of data. Low range of 06”. Potential error in tree cover; darker light conditions. Error potential in large vehicular presence along path; tight pathway and must be tucked into the side. Rock positioned close to set up position, ensure leg is fully dug in.

STN C7

Survey Nail

Date	16/11/2018
Time	07:45
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Cloudy, 10°C

Schematic



Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C7	C6	073° 55’ 27”	253° 55’ 28”	073° 55’ 28”	073° 55’ 27”	076° 59’ 10”
	C7	C8	150° 54’ 35”	330° 54’ 38”	150° 54’ 37”	150° 54’ 37”	
2	C7	C6	102° 59’ 48”	282° 59’ 50”	102° 59’ 50”	102° 59’ 49”	076° 59’ 11”
	C7	C8	179° 58’ 58”	359° 59’ 01”	179° 59’ 01”	179° 59’ 00”	
3	C7	C6	059° 14’ 42”	239° 14’ 42”	059° 14’ 42”	059° 14’ 42”	076° 59’ 09”
	C7	C8	136° 13’ 51”	316° 13’ 51”	136° 13’ 51”	136° 13’ 51”	
4	C7	C6	319° 01’ 29”	139° 01’ 28”	319° 01’ 28”	319° 01’ 29”	076° 59’ 13”
	C7	C8	036° 00’ 44”	216° 00’ 40”	036° 00’ 40”	036° 00’ 42”	
5	C7	C6	102° 10’ 50”	282° 10’ 49”	102° 10’ 49”	102° 10’ 50”	076° 59’ 08”
	C7	C8	179° 09’ 59”	359° 09’ 56”	179° 09’ 56”	179° 09’ 58”	
6	C7	C6	061° 57’ 30”	241° 57’ 31”	061° 57’ 31”	061° 57’ 31”	076° 59’ 10”
	C7	C8	138° 56’ 40”	318° 56’ 41”	138° 56’ 41”	138° 56’ 41”	
						Mean Angle	076° 59’ 11”
						Range	000° 00’ 04”

From	To	Distance (m)
C7	**C6**	39.736
C7	**C8**	50.262

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
176904.333	34655.646	108.638

Notes

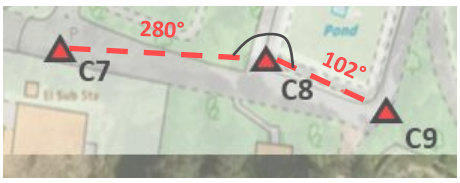
What seems to be precise and accurate results; no need for exclusion of data. Low range of 04”. Potential error in tree cover; darker light conditions. Error potential in large vehicular presence along path. Steep slope to C8; potential for error in Hz and sighting. Bush close to C8 set up; ensure high tripod set up.

STN C8

Survey Nail

Date	16/11/2018
Time	08:45
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Cloudy, 10°C

Schematic



Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C8	C7	193° 35’ 32”	013° 35’ 36”	193° 35’ 36”	193° 35’ 34”	195° 16’ 07”
		C9	028° 51’ 40”	208° 51’ 41”	028° 51’ 41”	028° 51’ 41”	
2	C8	C7	295° 52’ 32”	115° 52’ 28”	295° 52’ 28”	295° 52’ 30”	195° 16’ 16”
		C9	131° 08’ 47”	311° 08’ 45”	131° 08’ 45”	131° 08’ 46”	
3	C8	C7	086° 52’ 49”	266° 52’ 46”	086° 52’ 46”	086° 52’ 48”	195° 16’ 23”
		C9	282° 09’ 13”	102° 09’ 09”	282° 09’ 09”	282° 09’ 11”	
4	C8	C7	065° 58’ 31”	245° 58’ 35”	065° 58’ 35”	065° 58’ 33”	195° 16’ 08”
		C9	261° 14’ 41”	081° 14’ 41”	261° 14’ 41”	261° 14’ 41”	
5	C8	C7	262° 30’ 13”	082° 30’ 14”	262° 30’ 14”	262° 30’ 14”	195° 16’ 15”
		C9	097° 46’ 29”	277° 46’ 29”	097° 46’ 29”	097° 46’ 29”	
6	C8	C7	212° 22’ 28”	032° 22’ 28”	212° 22’ 28”	212° 22’ 28”	195° 16’ 13”
		C9	047° 38’ 39”	227° 38’ 42”	047° 38’ 42”	047° 38’ 41”	
						Mean	195° 16’ 12”
						Range	00° 00’ 09”

From	To	Distance (m)
C8	**C7**	50.263
C8	**C9**	31.313

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
176954.382	34651.040	101.401

Notes

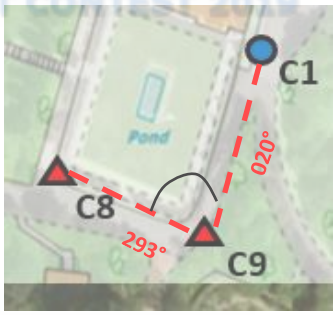
Round 3 excluded as an anomaly (*shown in red*); range decreased from 16” to 09”. Lower mean angle results in a smaller linear misclosure. Potential error in tree cover; darker light conditions. Steep slope to C8 and C9; potential for error in Hz and sighting.

STN C9

Survey Nail

Date	16/11/2018
Time	09:30
Surveyors	J.H, D.A, T.W
Instrument	Leica TS 1200
Weather	Cloudy, 10°C

Schematic



Not to Scale

Round	At	To	Left Face	Right Face	Reduced Right Face	Mean	Angle
1	C9	C8	281° 51' 09"	101° 51' 06"	101° 51' 06"	281° 51' 08"	091° 17' 34"
	C9	C1	013° 08' 41"	193° 08' 42"	013° 08' 42"	013° 08' 42"	
2	C9	C8	088° 40' 44"	268° 40' 40"	088° 40' 40"	088° 40' 42"	091° 17' 33"
	C9	C1	179° 58' 15"	359° 58' 14"	179° 58' 14"	179° 58' 15"	
3	C9	C8	317° 23' 22"	137° 23' 18"	317° 23' 18"	317° 23' 20"	091° 17' 36"
	C9	C1	048° 40' 54"	228° 40' 58"	048° 40' 58"	048° 40' 56"	
4	C9	C8	051° 22' 54"	231° 22' 56"	051° 22' 56"	051° 22' 55"	091° 17' 31"
	C9	C1	142° 40' 26"	322° 40' 26"	142° 40' 26"	142° 40' 26"	
5	C9	C8	307° 33' 45"	127° 33' 44"	307° 33' 44"	307° 33' 45"	091° 17' 31"
	C9	C1	038° 51' 17"	218° 51' 14"	038° 51' 14"	038° 51' 16"	
6	C9	C8	270° 30' 30"	090° 30' 32"	270° 30' 32"	270° 30' 31"	091° 17' 32"
	C9	C1	001° 48' 01"	181° 48' 05"	001° 48' 05"	001° 48' 03"	
						Mean Angle	091° 17' 33"
						Range	000° 00' 05"

From	To	Distance (m)
C9	**C8**	31.308
C9	**C1**	36.468

Total Coordinates		
Eastings (m)	**Northings (m)**	**Elevation (m)**
176983.703	34640.059	98.647

Notes

What seems to be precise and accurate results; no need for exclusion of data. Low range of 05". Set up involves soft muddy ground; ensure legs are fully dug in to avoid potential error. Error potential in large vehicular presence along path; tight pathway and must be tucked into the side. Steep slope to C8; potential for error in Hz and sighting.

4.1. Coordinate Calculations

As the adjustment cannot produce a decimal of an angle, the mean angles for C1, C3 and C4 were adjusted by one second as these had the longest traverse lengths and therefore the greatest margin for error in readings.

Table 5: Summary table of mean angles and adjustment; showing adjusted angles.

	Internal Mean Angle (Excluding Anomaly)	Adjustment	Adjusted Angle
C1	214° 08' 54"	- 000° 00' 01"	214° 08' 53"
C2	097° 42' 55"	-	097° 42' 55"
C3	112° 36' 06"	- 000° 00' 01"	112° 36' 05"
C4	162° 46' 41"	- 000° 00' 01"	162° 46' 40"
C5	149° 23' 16"	-	149° 23' 16"
C6	159° 49' 15"	-	159° 49' 15"
C7	076° 59' 11"	-	076° 59' 11"
C8	195° 16' 12"	-	195° 16' 12"
C9	091° 17' 33"	-	091° 17' 33"
Sum	1260° 00' 03"	-	1260° 00' 00"

Angular Misclosure = Σ of Internal Angles = (2n + 4) x 90°

n = number of angles measured

((2 x 4) + 4) x 90° = 1260° 00' 00"

Angular Misclosure = (1260° 00' 03") = 000° 00' 03"

There is an angular misclosure in the measurements of 000° 00' 03". The allowable misclosure is therefore calculated to assess whether the angular misclosure is acceptable.

Allowable Misclosure (") = KS √n 2 x 3 √9 = 18"

S = Total Station specification K = multiplication factor 1 to 3

n = number of angles measured [2 as variable weather]

Table 6: Summary table of distances recorded and mean distance used for calculations.

Traverse Line	1st measurement (m)	2nd Measurement (m)	Mean distance (m)
C1 – C2	65.175	65.174	65.175
C2 – C3	28.965	28.957	28.961
C3 – C4	52.663	52.659	52.661
C4 – C5	57.940	57.942	57.941
C5 – C6	24.052	24.057	24.055
C6 – C7	39.734	39.736	39.735
C7 – C8	50.262	50.263	50.263
C8 – C9	31.308	31.313	31.311
C9 – C1	36.468	36.469	36.469

Whole Circle Bearing Calculations

The bearing for the baseline C1 – C2 was calculated using coordinates collected by a Leica GS18 GNSS for Station C1 and C2. The bearing was calculated using the formula:

$$\text{Bearing} = \tan^{-1} \times \frac{\Delta \text{ Eastings}}{\Delta \text{ Northings}}$$

Therefore the calculation was tan-1 x 54.001/36.470 = 55.967. This was converted to degrees to become 55° 58' 00".

Station	Adjusted Angle	Line	Angle + previous bearing	Adjustment	Whole Circle Bearing
C1	214° 08′ 53″	C1 – C2	235° 58′ 00″	- 180°	055° 58′ 00″
C2	097° 42′ 55″	C2 – C3	153° 40′ 55″	+ 180°	333° 40′ 55″
C3	112° 36′ 05″	C3 – C4	446° 17′ 00″	- 180°	266° 17′ 00″
C4	162° 46′ 40″	C4 – C5	429° 03′ 40″	- 180°	249° 03′ 40″
C5	149° 23′ 16″	C5 – C6	398° 26′ 56″	- 180°	218° 26′ 56″
C6	159° 49′ 15″	C6 – C7	378° 16′ 11″	- 180°	198° 16′ 11″
C7	076° 59′ 11″	C7 – C8	275° 15′ 22″	- 180°	095° 15′ 22″
C8	195° 16′ 12″	C8 – C9	290° 31′ 34″	- 180°	110° 31′ 34″
C9	091° 17′ 33″	C9 – C1	201° 49′ 07″	- 180°	021° 49′ 07″

Table 7: Summary table of stations, adjusted angles and subsequent WCB calculated.

Partial Coordinates = Partial Easting = Hz x sin (WCB)
Partial Northing = Hz x cos (WCB)
Bowditch Adjustment = Closing Error (dE or dN) x (Length of traverse line total/ Horizontal distance)

Corrected Partial Coordinates = Partial Coordinates ± Bowditch Adjustment
Total Coordinates = Previous coordinates ± Bowditch Adjustment [Add if positive, Subtract if negative]

			Partial Coordinates		Bowditch Adjustment		Corrected Partial Coordinates		Total Coordinates		
Line	Horizontal Length (m)	WCB	ΔE (m)	ΔN (m)	ΔE (m)	ΔN (m)	ΔE (m)	ΔN (m)	Eastings	Northings	Station
C1 – C2	65.175	055° 58′ 00″	54.011	36.477	-0.003	-0.003	54.008	36.474	177051.263	34710.388	C2
C2 – C3	28.961	333° 40′ 55″	-12.840	25.959	-0.001	-0.001	-12.841	25.958	177038.422	34736.346	C3
C3 – C4	52.661	266° 17′ 00″	-52.550	-3.414	-0.003	-0.003	-52.553	-3.417	176985.869	34732.929	C4
C4 – C5	57.941	249° 03′ 40″	-54.115	-20.706	-0.003	-0.003	-54.118	-20.709	176931.751	34712.220	C5
C5 – C6	24.055	218° 26′ 56″	-14.958	-18.839	-0.001	-0.001	-14.959	-18.840	176916.792	34693.380	C6
C6 – C7	39.735	198° 16′ 11″	-12.457	-37.732	-0.002	-0.002	-12.459	-37.734	176904.333	34655.646	C7
C7 – C8	50.263	095° 15′ 22″	50.052	-4.604	-0.003	-0.002	-50.049	-4.606	176954.382	34651.040	C8
C8 – C9	31.311	110° 31′ 34″	29.323	-10.979	-0.002	-0.002	29.321	-10.981	176983.703	34640.059	C9
C9 – C1	36.469	021° 49′ 07″	13.554	33.857	-0.002	-0.002	13.552	33.855	176997.255	34673.914	C1
			dE	dN							
Sum	**386.571**		**0.020**	**0.019**	**-0.020**	**-0.019**	**0.000**	**0.000**			

Table 8: Summary table of coordinate calculations undertaken to produce total coordinates.

Linear misclosure (d) is calculated using the formula:
$(d) = \sqrt{(dE^2 + dN^2)}$ Therefore linear misclosure = $\sqrt{(0.020^2 + 0.019^2)}$
Linear misclosure = 0.028

Fractional Linear Misclosure is calculated by Total horizontal length of the traverse / linear misclosure.
Fractional LM is 386.571/0.028 = 1 in 13,806.107. This means the results can be considered accurate enough for the campus survey.

5.1. Summary

Table 9: Summary table of collected station data.

Station	Height (m)	External Mean Angle	Traverse line	Mean Length (m)	Eastings	Northings
C1	98.680	214° 08’ 54”	C1 – C2	65.175	176997.255	34673.914
C2	97.634	097° 42’ 55”	C2 – C3	28.961	177051.263	34710.388
C3	103.236	112° 36’ 06”	C3 – C4	52.661	177038.422	34736.346
C4	105.315	162° 46’ 41”	C4 – C5	57.941	176985.869	34732.929
C5	109.718	149° 23’ 16”	C5 – C6	24.055	176931.751	34712.220
C6	109.920	159° 49’ 15”	C6 – C7	39.735	176916.792	34693.380
C7	108.638	076° 59’ 11”	C7 – C8	50.263	176904.333	34655.646
C8	101.401	195° 16’ 12”	C8 – C9	31.311	176954.382	34651.040
C9	98.647	091° 17’ 33”	C9 – C1	36.469	176983.703	34640.059

The levelling run was completed to an error of 000 mm. This was well within the allowable misclosure of 15.875 mm. This was due to double set levelling. Before continuing to the next set up, the accuracy was checked and minimal error ensured. If the error was noticeable, then the double set was repeated. To ensure maximum accuracy, the staff was not extended further than 2 m. This minimised the potential error from horizontal variation due to staff wobble. The weather had minimal effect during the run, which also helped minimise error. By cross checking readings on the level, potential for human error was also reduced. A two-peg test was undertaken prior to the survey to identify any collimation error was present in the machine.

The Leica TS1200 machines have an accuracy of 03”. The traverse had an accuracy of 03”, this was within the allowable misclosure of 18”. The weather was variable during the traverse, thus causing potential for error. Multiple rounds were taken on each station to ensure maximum precision and accuracy. The accuracy was determined by the final value and the amount of error; the exclusion of some potential outliers in the results brought down the error, therefore increasing our accuracy. Coordinates could be cross checked using the Leica GS12, however, due to poor weather and cloud cover, the accuracy was 6 mm (**3D**) out. This limited the ability to cross check the total coordinates as it would be hard to define the error. Inaccurate centre and levelling is the main cause of error in a traverse. To keep this to a minimum each set up was cross checked and torches were used over the nails to ensure the centre could be clearly defined. The steep slopes around C2 – C3 and C7 – C8 – C9 caused a potential for error in the distances. Multiple distance readings were taken, in both left and right face, which ensured consistent and precise results. The machines carried some collimation error; observed when turning from left to right face and the subsequent angle not being exactly 180° 00’ 00” out. This was generally no more than 10”; if it was over 06” then the angle measurement was repeated. The ATR lock was sometimes off centre, thus manual adjustments were made in order to compensate for potential error.

Figure 3: Locations of total coordinates in relation to traverse. [gridreferencefinder.com]

The data observed in this report is deemed to be highly precise by the use of multiple rounds and double set levelling, along with being precise due to the low levels of errors identified.

6. Detailing Methodology

Equipment

- Leica TS1200
- 1x Tripod Legs (wooden)
- 1x Leica GRZ4 360° Prism
- 1x Tape
- 1x extendable carbon detail pole

Completing a topographic survey and picking up detail is the undertaking of precise measurements, via the use of a total station, in relation to the coordinate system required. This survey is based on all data collection as stated in this report, through the creation of the control put in.

The secondary survey stations were used to pick up further detail from the primary control, this method is defined as working whole-to-part.

The total station was set up over one of the stations and centre and levelled. The tolerances were required to be below 5 mm in the X and Y plane to minimise potential error. The machine height was measured and inputted. Once set up, a known backsight setup was used in the machine calibration and the coordinates of the station set up and backsight were inputted (coordinates known from the primary control traverse undertaken). It is important to also input the correct height of the target. This related the machine to the known coordinates and fed back a known error. The backsight was shot using the detail pole. To prevent carry through of error, the set up was not accepted unless under ± 5 mm error. Combined with the potential error of ± 5 mm error in the centre and level of the machine, this limited the potential error of the survey to no more than ± 10 mm.

One member controlled the total station, and another member was in control of the detail pole. Detail was picked up in a logical order and recorded with the LSS coding. For detail that could not be measured via the pole (e.g rooflines), reflectorless shooting was used. The data was uploaded daily into LSS and converted to a .DWG for post processing in AutoCAD.

*For relevant risk assessments please see **1.1.5. Risk Assessment.***

Please see attached PDF (James Heslington CLGE Contest Topography Submission Survey) for final survey.

Limitations

Using a detail pole to shoot the backsight limited the precision of the shot, using a tripod set up would achieve greater accuracy. The tolerance and sensitivity of the survey allowed for the method used. The total station robotic mode was limited, therefore the pairing was needed, which slowed data collection. The use of reflectorless shooting for inaccessible detail further limited the precision of the data collection.