

Rhys Whiteman – HNC Quantity Surveying

ACBA4002 – Digital Surveying

Extended Essay (resit option)

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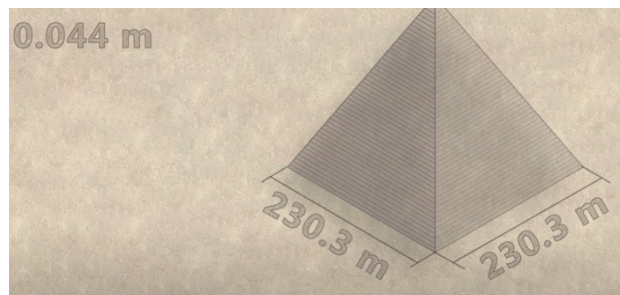


Part 1 – History of Surveying

Surveying has been the backbone of all construction projects throughout history. Although, it may seem that surveying in today's age seems a million miles away from how it would have been done in the past – but that is not necessarily the case. Many traditional methods and techniques have been adapted overtime.

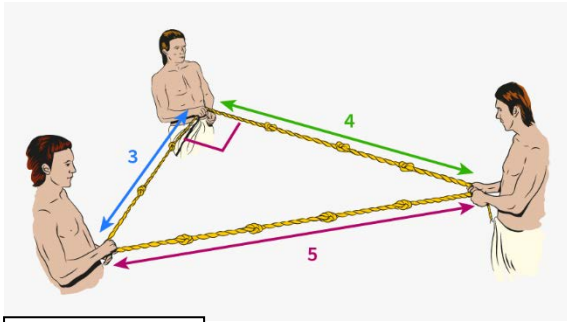
Ancient Egypt

The first recorded documents of surveying were a “recorded land register in Egypt” (ICSM, 2014) that dated to approximately 3000BC. It is understood that the land register was used to establish boundary lines between farmlands, as annual flooding destroyed the existing boundary markers. No more than 500 years later, arguably the world most famous construction project commenced in Egypt – The Great Pyramids of Giza. The linear length of the square base is recorded to be 230.3m. The largest discrepancies are between the northern and southern edge with is only “44mm” (Real Engineering, 2017). So, the question is, how did they make this possible?



(Real Engineering, 2017).

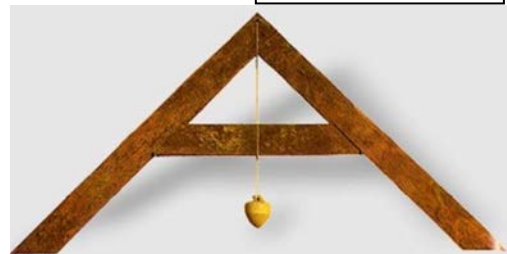
The answer all comes down to their measurements. The Egyptians perfected a system of measurement based on the human arm. From the bend in the elbow to the fingertips was measured as a cubit. Additionally, the palm as well and the fingers were also used as measuring tools. A cubit (forearm) can be broken down, “so four fingers equal one palm & seven palms equal one cubit” (Paulson, 2005). All the listed measurements would then have been marked into a cubit rod – which is essentially the ancient version of a rules. For larger scale measurements the ancient Egyptians would have used calibrated rope, with knots at equal intervals, that had a total length equal to 100 cubits. Because of this, Egyptian surveyors were given the phrase “Harpedonaptae, which translates to Rope Stretcher” (D&T, 2017).



(PNG, 2008).

construction schemes today - were great levels of accuracy are not required. This formula allowed the surveyors to check the diagonals ensuring all right angle were square. Recordings would have been taken by a "Scribe of the field" (Ancient Egypt, 2017). Scribes were multiskilled in surveying, calculation & engineering. Interestingly, only children of upper class would have been presented with this opportunity. A scribe would have had to learn over 700 hieroglyphic signs, strict discipline would have been enforced by the time the child was just aged 12.

Additionally, to the cubit rod and calibrated rope the ancient Egyptians also mastered the use of other hand tools. Prime examples are the plum bob and square level. In practical use the plum bob can show a true vertical line, much like a spirit level. It was these tools which allowed the ancient Egyptians to construct such immense structures. The Great Pyramids are still to this day a massive inspiration to people who push the boundaries of construction.



(Pinterest, 2015).

Ancient Greece

Uncountably there were some outstanding builds that comes from the ancient Greeks, but it's interesting to know these would have been impossible if not for the ancient Egyptian. As recorded by Herodotus, the first known historian, "the Greeks adapted many of the Egyptian calculation and surveying techniques" (Brook, 2004). Amazing isn't it? Although nearly 2000 years apart, the best learning tool for the ancient Greeks

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was to study the works of the ancient Egyptians before them. Pythagoras & Thales, two of the most renowned mathematicians of their era took on the quest for knowledge. The two mathematicians transposed their learning back to pupils in Greece – with a more refined system of measurement.

MacTutor, 2001).

Unlike the Egyptians, the Greek took into consideration humidity levels and the fact that it would affect the over-all length of measuring tools.

A cord cut to a standard length was still used as the tool for measuring, but now referred to as a Schoinion. As a means of ensuring all schoinions retained its desired length the cord would have either been smeared in wax to stiffen the cord. Or weights would have been applied to the cord to stretch the cord out. Finger width was still used to

records a single digit. In the Greek period several additional smaller items of measurement were used in order to allow for more refined works.

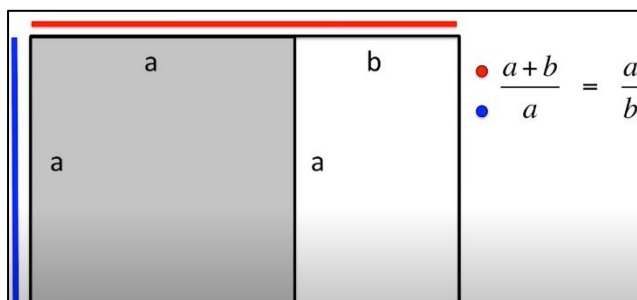
Units of Measurement during the Greek Period

1 digit or *daktylos* - plural : *daktyloi* (19.3 mm)
 2 digits = 1 *condylos*
 4 digits = 1 *palaiste*
 8 digits = 1 *dichas*
 12 digits = 1 *spithame*
 16 digits = 1 *pous* or foot - plural *podes* (309 mm)
 20 digits = 1 *pygon* (called "Remen" by the Egyptians)
 24 digits = 1 *pechya* or *pechys* (ῥεχυσ) (**small cubit**)
 40 digits = 1 *bema*
 72 digits = 4.5 feet = 1 *xylon*

1 foot *pous* – plural *podes* (309 mm)
 6 feet = 1 *orgyia* (1.854 m)
 10 feet = 1 *akaina*
 100 feet = 1 *plethron*
 600 feet or 6 *plethra* = 1 *stadion* (185.4 m)

1 *stadion* (185.4 m) (Different variants of the stadion exist with around + - 30 m differences)
 2 *stadia* = 1 *diaulos*
 6 *diauloi* = 1 *dolichos*

Possibly one of the most recognised mathematical discoveries of the ancient Greek period was the golden ratio 4:9, which can also be referred to as divine proportion. Discovered by "Pythagoras, 5th B.C.E" (Dove, 2015). In simple terms, the golden ratio



Tipping Point Maths, (2017).

is the ratio between sides of a special rectangle - when a section is removed from the rectangle the remaining section will be in the same proportions as the original rectangle. This is shown in the adjacent algebraic equation.

How to Architect, (2015).



In geometric terms, if a rectangle is drawn with the shortest length equal to 1. Following the ratio, the perpendicular will be 1.618. The Greeks thought the golden ratio as special because of the way it appeared in nature, for example, the same numerical sequences can

be seen on the spiralled skin of a pineapple!

Fo ndness for the golden ratio can be seen all over ancient Greece – such as The Parthenon, designed by Phidias who was a sculptor and mathematician. Constructed in “438 B.C.E” (Lotha, 2019) The Parthenon is renowned for it precise accuracy and proportional excellence. Just by looking at the perimeter of the building, with a “base of 30.8m and a length of 69.51m” (Meisner, 2013) this equals a ratio for 4:9. Examples



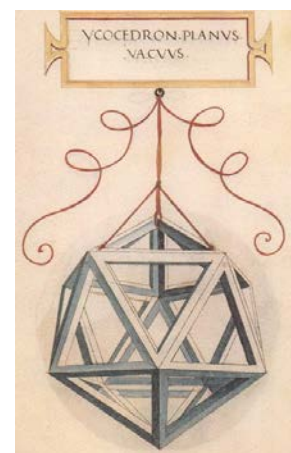
(Meisner, 2013).

of the golden ratio in use are present all over the structure. Column width being a great example. The width is a proportion form by the distance from the centre line of the column to the outside of the column.

Renaissance Europe

Fast wording 2000 years from the construction of The Parthenon and we find ourselves in renaissance Europe. This period has been classed as the golden period and the true birth of modern day thinking in terms of architecture. Great developments were also made in art during this period by the likes of Leonardo da Vinci. Da Vinci illustrated such drawings as the Vitruvian Man & Icosahedron that both detail proportions line with the golden ratio.

(Pinterest, 2017).



Part 2 – Current Technologies

Topographic Surveys

Commonly referred to in the trade as a Topo survey – the Topographic survey is used to determine the shape of the ground, as well as the location and elevation of both natural and man-made features. Topo surveys are a crucial to understand the geographic positioning of features within the worksite.

Recordings are gathered using “GPS and electronic distance metering” (Oklahoma, 2019). A 2D image is then produced using contour lines to represent the Earth’s surface and shown different levels of elevation. This image will lay out all the existing features within the worksite and identify relationships between features. Information can also be gathered from below ground level and can be used to determine if there are any utility services running through the worksite. Topo surveys can also be used to calculate the required cut & fill when site clearance is taking place. For example, as shown in the adjacent picture, the ground level at the top of the site is lower than the bottom section of the site. If a level ground was required, then some of the fill materials from the bottom of the site can be place at the top of the site to create a more level section throughout. This is assuming the ground had been tested prior.



(Green Planning, 2016).

I will now explain where I personally had to use a topographic survey within my job role as a quantity surveyor.

Network Rail approached us with a single source tender to undertake some scour protection works. Scour was occurring underneath of a rail over river bridge, this is referred to as an overbridge or O/B. Network Rail own the structures and therefore must ensure the surrounding land is maintained. Natural Resources Wales were also



involved as a third party, although there was no contractual link between our self and them.

Our first task was to determine the full extent of the scour in order to come up with a reasonable solution – this would be confirmed with a topo survey. Enquiries were sent out to a total of three capable sub-contractors, who in turn submitted their quotations. After reviewing the quotations, I selected a sub-contractor with the price being the main deterring factor.

Upon completion of the survey it was clear to see there was a small area of scour which would lead to undermining of the foundation to the overbridge. The scour occurred due to much greater volume of water travelling down the river than usual, which was a result of the flooding's in March earlier this year.

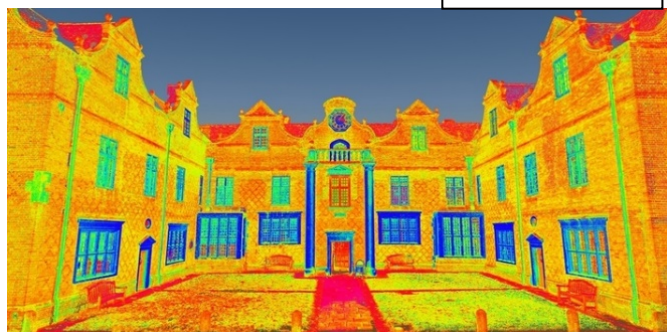
The survey was issued to our Client and discussions commences on how to prevent further scour in the area. It was decided that concrete bag-work that is fixed with stitching bars would be the safest and most cost-efficient way to prevent any further scour in the area. To allow this our first protocol was to carry out an ecological survey to gather information on any species that may be present in the river itself or the surrounding area. With positive results from the ecological survey our next task was create a dry area within the river. The river was diverted with the use of submersible pumps and an aqua dam. Once the desired section of the river was dry the concrete bag-work was fixed in place to act as the barrier, thus prevent further scour.

Laser Profiling

The use of laser scanners within construction has immensely improved our ability to resort history structures by accurately profiling the structure to show how it would have looked in its original state. With the use of basic point cloud and

Terrain, 2014).

rendered photographic imagery a detailed survey can provide an extremely accurate representation an historic structure. Laser scanning is now the preferred method when working with historic structures as it



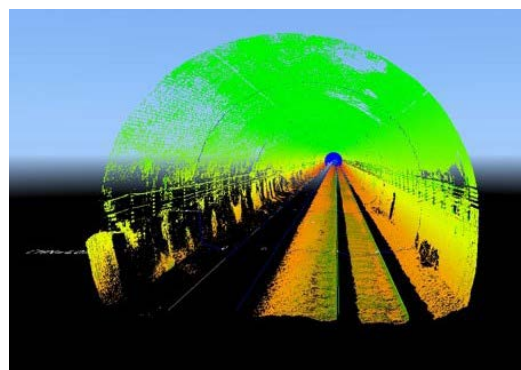
“helps avoid assumptions” (Severn Partnership, 2016). It’s near on impossible to completely avoid all assumptions, but the use of a laser scanner differently lowers the risks. Inaccessible areas with no direct access can easily be surveyed, whereas in the past a lot of estimation would have gone into these areas. Another way that assumptions can be avoided comes from the use of reverse engineering. Also referred to as called back engineering, reverse engineering is a process that in effect “deconstructs to reveal the design & architecture” (Khalili, 2018)

The process of obtaining data starts by shining a reflector-less laser over the entire surface of the desired area. A camera sensor that is fitted to the laser scanner that captures this data which is recorded in “accurate dense 3D points in space” (Severn Partnership, 2016). Unlike topographic surveys, the result will be presented as a 3D image. The 3D image can be link to software’s such as AutoCAD, allowing the information to easy be used alongside existing information, such as the topographic survey of the site.

I have used laser surveying in the form of a laser sweep survey within my job role. The laser sweep survey is widely used on the railway and is used a means of determining clearances specs between structures and live trains. We needed to survey done prior to any works starting, all being masonry repairs to the underside of the bridge. We were going to be re-casing bricks; therefore, temporary works are required to secure the brickwork until it has set. The laser sweep was needed to determine the levels of clearance between the temporary works and the live trains.



Balfour Beatty, (2020).



(Severn Partnership, 2016).

Part 3 – Explaining The Terms

Triangulation

Triangulation cannot be defined without an understanding of similar triangles. Similar triangles focus directly on the internal angles oppose to the external lengths of the triangle. 3-4-5 is the perfect example of this, please refer to Appendix 01. As demonstrated in the example the external lengths will all increase/ decrease with length in relative proportion to each other given that the internal angles stay the same.

As a practical example I would like you to imagine a newly proposed green-field site which is going to be used for a new housing estate. Situated in the centre of the proposed site is a large tree which needs to be removed before ground clearance can commence. The height of the tree can be calculated using triangulation. It is assumed that the tree is at a true right angle (90°) from the ground, also that the ground is level. The base of the tree will act as the first survey point, to establish the second survey point measure a set distance, I will use 20m, away from the tree. This has now given the baseline length. Now the second survey point has been established an "inclinometer" (Hilaroad, 2011) can be used to calculate the angle from the survey point to the top of the tree – for the purpose of the example I will say 25°. The sum of all internal angles of the triangle equal 180°. Therefore, the angle from the top of the tree to the second survey point can be checked with the below equation.

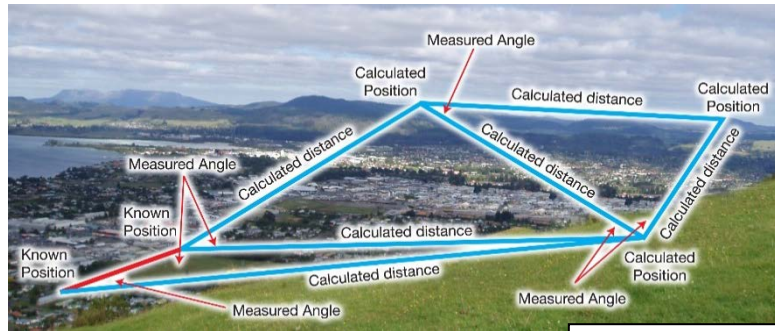
$$180^{\circ} - (90^{\circ} + 25^{\circ}) = 65^{\circ}$$

With this information the total length of the tree can easily be calculated, shown in Appendix 02.

Triangulation can be used on a much larger scale for more complex projects, such as sourcing a suitable area for a wind farm. A similar process is used as above but with the addition of more survey points – this is known as a "Triangulation Network" (ICSM, 2014). There must be two known points in order to start, the distance is measured between these two points and recorded as the "baseline" (Hahne, 2017). The baseline



will be the only distance that is measured. Prior to the use of GPS in construction the baseline distance would have been very carefully measured using lengths of accurately cut rod. This meant the length of the baseline was usually



(ICSM, 2014).

no more than a Kilometre in length. Distances between all other points will be calculated using the internal angles of the triangle. Point are commonly positioned on higher areas of ground to avoid any obstructions. A theodolite, an instrument with a telescope, is used to record the internal angles. Angles are calculated by two rotating circle – one measuring the horizontal angle and the other measuring the vertical angle.

Triateration

Although triangulation and trilateration have the same purpose, both terms are often confused, the main difference being trilateration measures distances oppose the angles. Therefore, trilateration is used when angular measurements are difficult or impossible. These distances are not physically measured – they are calculated using GPS. GPS stands for the Global Positing System. There is a total of five systems, but Navstar is the most comply used in construction schemes. Navstar was a system that was original made for use by the US military in 1973 but was then released for public use in 1983. Since then, equipment has been developed which allows us take extremely accurate reading of a precise location.

(GPS, 2020).



Firstly, to gather a better understanding of GPS, I will take about how it's transmitted and received. A total of “24 satellites” (GPS, 2020) are orbiting the Earth. From almost any position on the Earth there will be a direct line of sight to at least four satellites. Whilst in orbit these satellites constantly broadcast two pieces of data, which are “their own location and their current clock time” (Karon, 2014).

However, this data is useless without a receiver. Receivers come in many forms: from

Signature

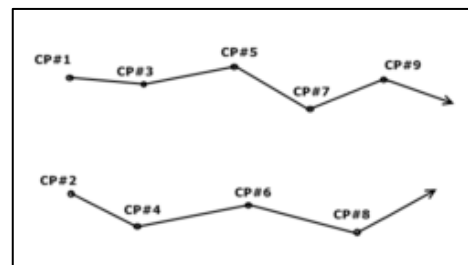
our mobile phones to the navigation systems in our cars, but mostly importantly for us electromagnetic distance measuring equipment, or EDM for short. Receivers can calculate their exact position by comparing the current clock time transmitted by each of the satellites to the time the frequency was received. By multiplying these time differences with the speed of light, a distance can be calculated between the receiver and each of the satellites that lay within the direct line of sight.

Traversing

Traversing is done by calculating linear measurement of straight line, whereas the methods above both works using networks of triangles. A traverse will consist of a series of straight line, the end of each line is then referred to a traverse station. The first and last point are not always connected. If the point last point joins back to the first traverse station this will create a “closed traverse” (EngineersDaily, 2020). When the points don’t meet, true to its name, we have an “open traverse” (EngineersDaily, 2020).

Opening traversing is a useful control for projects such as the construction of road as well as the installation of underground utilities. A key aspect of these surveys is the length between each traverse station, which can be many miles. Distances

(EngineersDaily, 2020)



between the traverse stations is mainly recorded using electronic distances meters - smaller schemes may still use measure tapes. A new traverse station is added when a change of direction occurs, sticking with a theme, a turn in the road for example. These angles needed to be recorded and are done so with the use of a theodolite. Angles are often measured twice as a form of checking. This is done because open traversing can extend for long distances without any real way of checking the accuracy of the ongoing works.

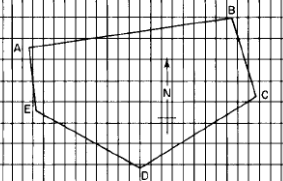
Before any angle can be measured a control point must be established, this will be the basis for measurement and must not be moved through the duration of the survey. Preferably the control point would be secure to allow for checking or future surveys but that's is not always the case. The control point is marked out with a "surveyor's nail or a stake" (Jonson, 2015). After the control point has been marked angles can now be measured. To start the tripod legs are to be extended so the theodolite will be at eye-level with the surveyor, this avoids the need for bending down improving his ability to take more accurate recordings. The legs will all then need to be firmly secured in the ground to avoid wobbling. When the surveyor is happy, he can mount the theodolite to the tripod, remembering to keep the "bulls-eye level" (Jonson, 2015). If necessary, the length of the legs can be slightly altered as well as use of the levelling knob to ensure the bullseye is level. The distance between the ground and the equipment must be recorded and will be referred to as the height of collimation. Now the theodolite is ready for use. Angles are measured from the prolongation of the line to the next transverse station. The direction of the angle can either go left or right depending on the position of the station, this will then be recorded with a R or L on the field notes.



CivilToday, 2017)

(EngineersDaily, 2020)

DISTANCES			
COURSE	FORWARD	REVERSE	MEAN
AB	100.00	100.00	
	64.94	64.96	
	164.94	164.96	164.95
BC	88.41	88.41	88.41
CD	100.00	100.00	
	21.70	21.68	
	121.70	121.68	121.69
DE	100.00	100.00	
	15.88	15.90	
	115.88	115.90	115.89
EA	68.42	68.67	
		68.42	68.42
ANGLES			
STATION	DIRECT	DOUBLE	MEAN
A	101° 28'	202° 56'	101° 28'
B	102° 11'	204° 23'	102° 11' 30"
C	104° 42'	209° 24'	104° 42'
D	113° 05'	226° 11'	113° 05' 30"
E	118° 34'	237° 08'	118° 34'
		538° 120'	60"
			= 540° 01'



As mentioned above when using a closed traverse, a reading will be taken between the first and last stations. When using this method distances are simple measured between each point using an EDM instrument. Simply to an open traverse when measuring angles all

measurement is to be taken twice to avoid mistakes. The main difference being a closed traverse will only measure the internal angles.

Part 4 – Defining Eastings, Northing & Whole Circle Bearing

Distance Between A & B

To calculate the distance between points A & B a right-angled triangle must be drawn on the grid, as demonstrated in appendix 03. The lengths from each point to the right angle is used as the basis to measure the distance. Please see below workings

$$25^2 + 50^2 = AB^2$$

$$\sqrt{(25^2 + 50^2)} = AB$$

$$AB = 55.902m$$

The Whole Circle Bearing from B – A

The measured distances are used to calculate the angle from the vertical position of North to point A. Trigonometry calculation shown below

$$\tan a = 50 / 25$$

$$a = \tan^{-1}(50 / 25)$$

$$a = 63.434949^\circ$$

$$WCB\ B - A = 63^\circ\ 26'\ 06''$$

Referenced on appendix 03 as 'a'

The Whole Circle Bearing from A – C

Firstly, the angle must be calculated for 'b'. As all angles in a triangle are equal to 180° the below formula can be applied.

$$b = 180^\circ - 90^\circ - a$$

$$b = 180^\circ - 90^\circ - 63.434949^\circ$$

$$b = 26^\circ\ 33'\ 54''$$



The exterior angle BAC of 170deg had already been measured, therefore it was simply a case of subtracting the other known angles.

$$\text{WBC A} - \text{C} = 170^\circ - 90^\circ - b$$

$$\text{WBC A} - \text{C} = 170^\circ - 90^\circ - 26^\circ 33' 54''$$

$$\text{WBC A} - \text{C} = 53^\circ 26' 06''$$

Referenced on appendix 03 as 'c'

The Northings and Eastings of point C

With the measured distance of 75m given between points A – C and the angle 'c' calculate above the trigonometry can be applied to determine the eastings and northings for point C.

$$\sin c = \text{opposite} / \text{hypotenuse}$$

$$\sin (53^\circ 26' 06'') = \text{opposite} / 75$$

$$\sin (53^\circ 26' 06'') \times 75 = \text{opposite}$$

$$60.24\text{m} = \text{opposite}$$

$$\text{Eastings of point C} = 100 + 60.42$$

$$\text{Eastings of point C} = 160.42\text{E}$$

The same principal is applied to calculate the northings with the use another formula as it is now the adjacent line that need to be measured

$$\cos c = \text{adjacent} / \text{hypotenuse}$$

$$\cos (53^\circ 26' 06'') = \text{adjacent} / 75$$

$$\cos (53^\circ 26' 06'') \times 75 = \text{adjacent}$$

$$44.68\text{m} = \text{adjacent}$$

$$\text{Northings of point C} = 125 + 44.68$$

$$\text{Northings of point C} = 169.68\text{N}$$



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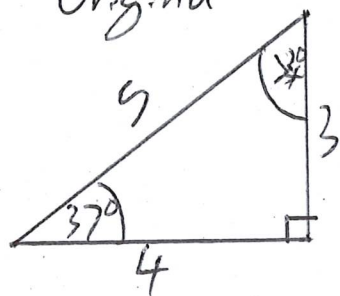


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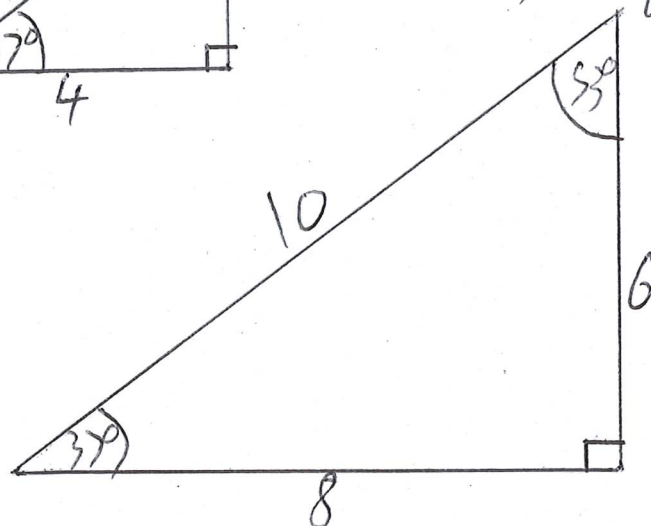


Appendix 01 - Relative Proportions

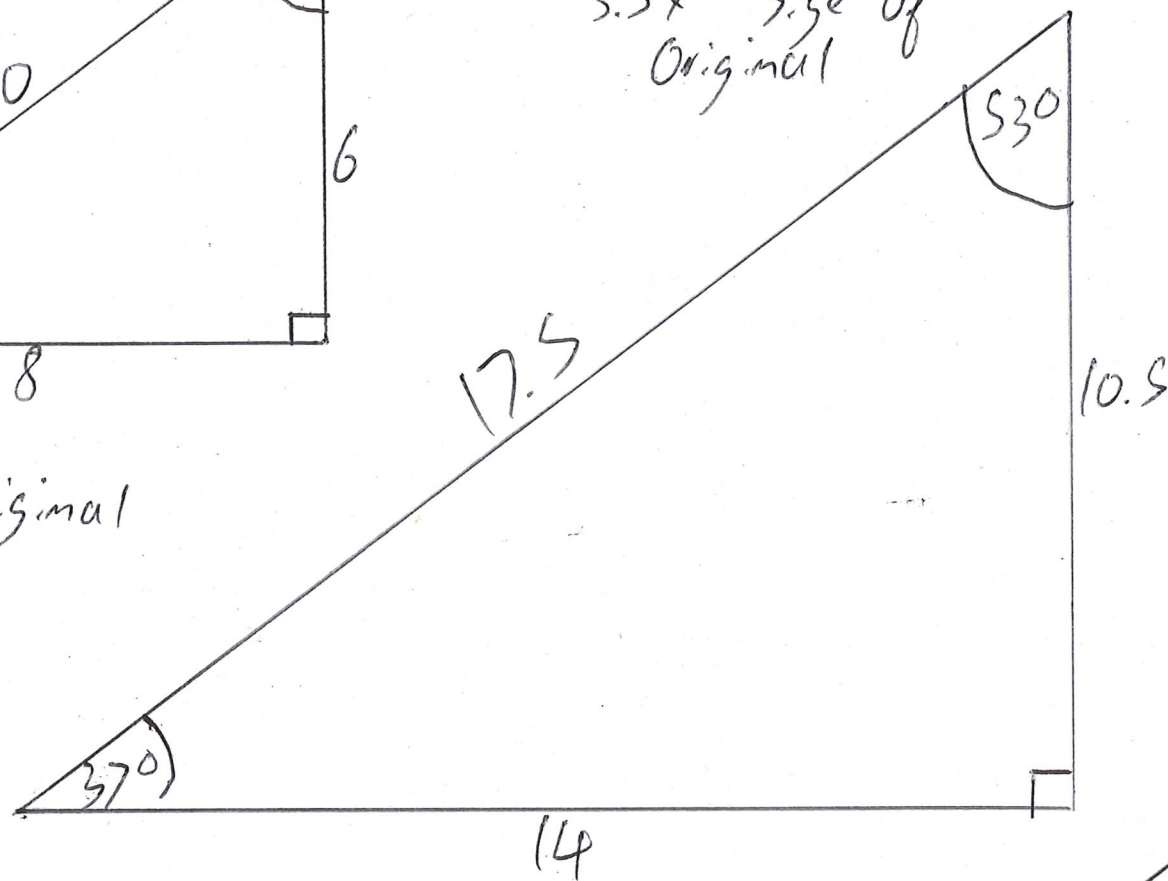
Original



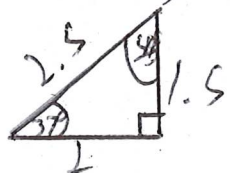
2x size of original



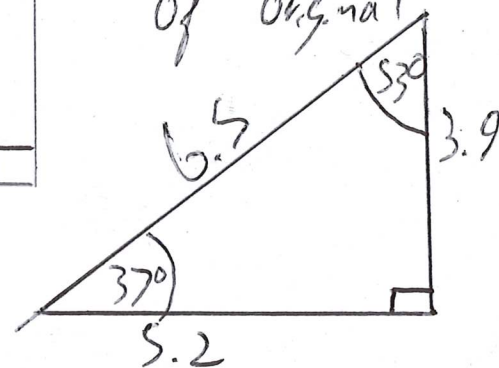
3.5x size of original



0.5x size of original



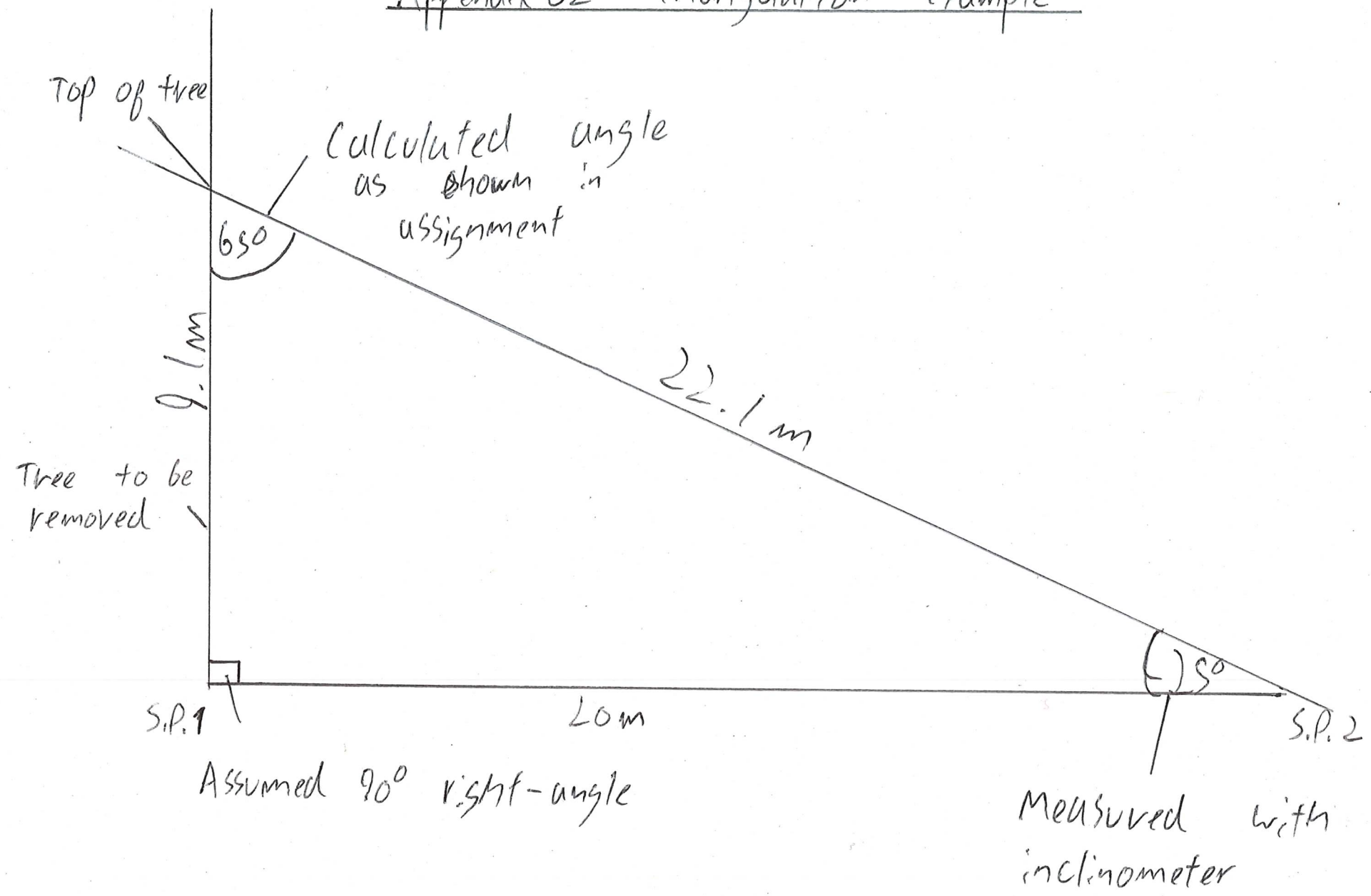
1.3x size of original



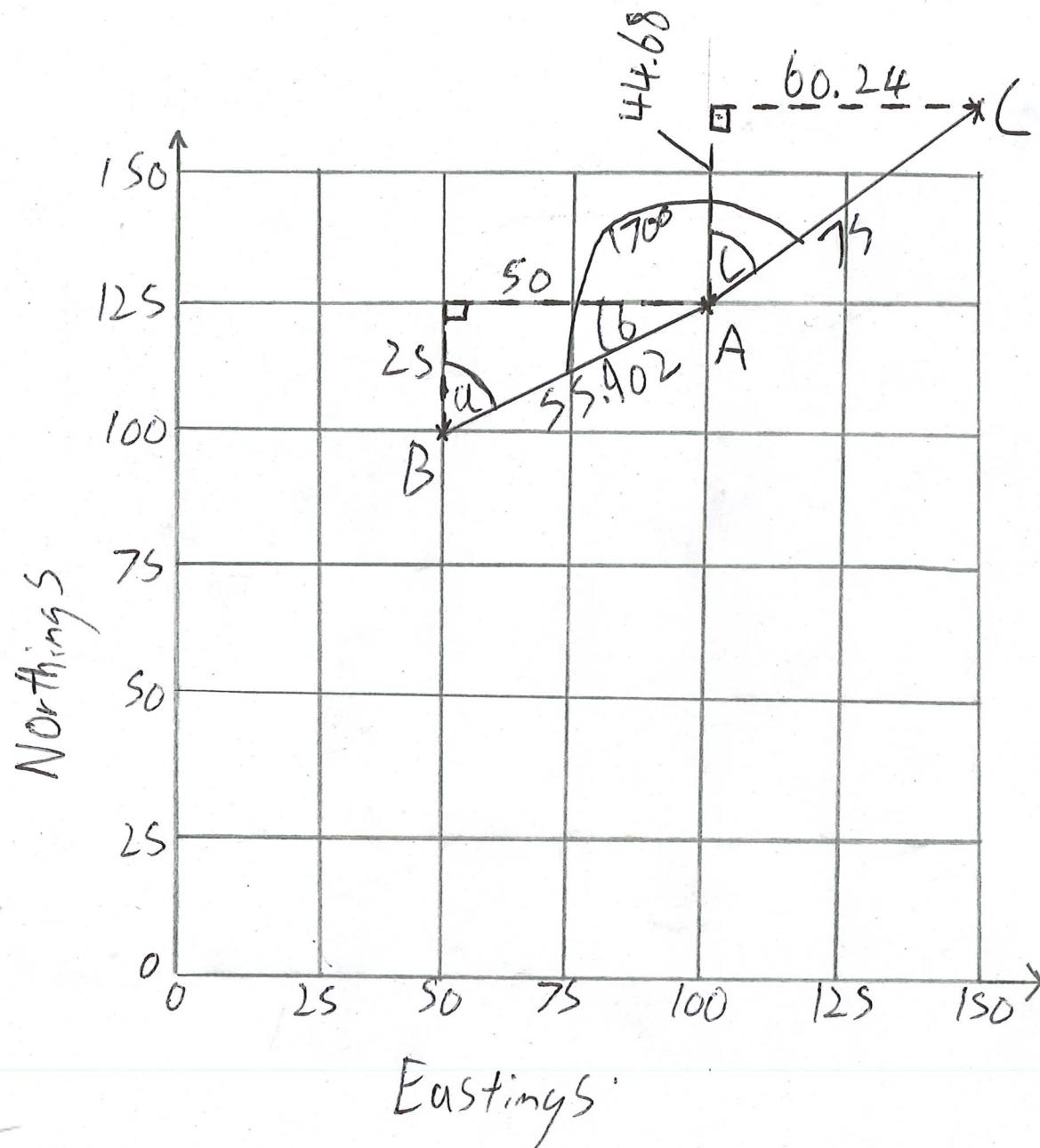
BR

Appendix 02 - Triangulation example

15/08/2020



[Signature]



$$a = 63^{\circ} 26' 06''$$

$$b = 26^{\circ} 33' 54''$$

$$c = 53^{\circ} 26' 06''$$

500