Surveying and Geospatial Engineering, School of Civil and Environmental Engineering, UNSW

Project Surveying Questions

A compilation of selected exam questions and assignments for the course
Surveying Applications and Design (UNSW GMAT3100)

Images top clockwise: my laser scan Feb 2001, word cloud GMAT3100 week 1, me, my laser scan June 2023, monitoring ANZAC bridge, centre deformation monitoring Toongabbie bridge.

Bookmarks are provided in this pdf file (instead of a contents page) and **searching** is enabled.
Answers to exam questions are intentionally separated from the questions so that they are not read with the questions. Some topics feature in several different sections of this book.

Images in this book are often smaller than original but can be viewed more easily with the zoom feature in pdf readers.

PREAMBLE

Background

There are very few textbooks for senior surveying courses (subjects). One reason is that technology in this field changes rapidly, so books become out of date. Another reason is that people doing surveying projects may be too busy or reluctant to write about their surveys. In this course at UNSW, we aim for problem solving and design of solutions to new and challenging projects. In 1948 R.B. Horner wrote a book called Survey Computations – A compilation of Examination Questions and Methods of Solution. That was written in the pre-computer era and many of the questions in that book are still useful and challenge students to think and to problem solve! At UNSW there was a textbook called "Project Surveying" by P. Richardus in the 1960s, with two editions. In the mid-1990s Jean Rüeger taught the Project Surveying course and produced an excellent and comprehensive set of class notes and tutorial questions. Since then I have been teaching the course with lectures, field exercises and class notes for my students. Some parts of the materials will become outdated. However the exam questions and assignments that we use might last a little longer than class notes, even though the solutions will probably change with time and new technologies.

This compilation of exam questions is based on 2-hour final exams and mid-term tests. There are small enrolments, so students sit in a computer lab and are usually given a computer with any required data sets and software. They are not completely open book exams but do have access to software and the ability to type answers. A list of equations is usually given. Of course, we cannot assess everything we want students to learn from the course in a short exam. The questions are not of equal marks.

My solutions supplied here are not meant to be comprehensive or perfect. Nor are they meant to be memorised. Often key words or ideas are given. For many of the questions there are multiple good correct answers. You might disagree with my answers or have better solutions – that is fine and is a worthy topic for in-class discussion.

If I ask a question after teaching a particular topic (e.g. laser scanning) then students may try to solve the problem/project by discussing an approach using that topic. However, I try to get them to consider alternative approaches to a project and justify their choice.

In my courses I provide students with previous year's exam papers to help them study. It is difficult to create good new real or realistic questions each year. Now that I have compiled the past papers into this book, I see that my questions are becoming somewhat predictable. Time for a new teacher to offer new challenges that require students to innovate and create solutions to new problems.

I have not written this book in third person impersonal style favoured by technical publications. That may annoy some readers. Instead I have tried to write in the style that I use to talk to students. I have tried to make the language easy to read so that you can concentrate on the technical and intellectual issues.

Project Surveying Definition

Project surveying is site specific and often associated with an engineering activity. An example of a project is tunnel surveys at a particular site, not tunnel surveying in general. Project surveying usually involves producing survey information for planning of technical projects, setting out of the project, control of the correct construction, and monitoring of deformations.

In this course we use Problem Based Learning or Project Based Learning (PBL) and the Socratic method. PBL is learning the fundamentals by solving real world problems. The process of finding a solution to a problem is the means of learning the facts and principles. It is not the usual, learn facts and principles and then apply them to solving a problem.

PBL exercises may be a new concept for students and to begin they may be hesitant. But as the course progresses, they learn that there may be no "wrong" answer only an "alternative solution". They grow more confident in their abilities and began to like the challenge of trying to work out solutions to problems that they have had no experience in. "At a time when the routine tasks traditionally carried out by engineers is being undertaken by technicians with access to powerful computers, there is an urgent need to reframe the education of engineering students to move beyond rote learning and think creatively about real-world problems by providing innovative context focused, usable and appropriate solutions." World Engineers Convention, Nov 2019.

Summary of the UNSW GMAT3100 Course

This course introduces the student to a wide variety of surveying applications undertaken as part of engineering projects. Selected topics of specialist survey applications are dealt with using lectures, guest speakers and technology use. Topics are selected from the following: project surveying methodology, laser scanning, mining and tunnel surveying (including azimuth and coordinate transfer, north-seeking gyros, plumbing of shafts), industrial and construction surveying (including high structures), alignments, monitoring of deformations and settlement of terrain, structures and machines, design of precise engineering networks, advanced least squares analysis, and briefly hydrographic surveying and surveying for sports events.

The course aims to broaden and deepen the knowledge of surveying instrumentation, to discuss equipment used in related areas of measurement, and to introduce students to specialised surveying techniques relevant to engineering and certain surveying sub-disciplines. A broad range of surveying instrumentation is covered in this course. Our aim is to cover topics and methods that are specialist skills of a consultant surveyor - not commonplace skills. But it does **not** aim to give the student a vast knowledge of all of them. It is not expected that every graduate will need to know all of the particular topics covered, or necessarily work in these sub-discipline areas on graduation. However, some graduates will need to know some of the topic areas in great detail and may spend a considerable part of their career in one of the fields introduced in this course. Even if students do not work in the specific topic areas dealt with in the course, the educational process and underlying knowledge may valuably be applied to other surveys. One of the learning objectives of this course is for graduates to be able to work professionally on novel surveying projects.

There are nine weeks of classes, with each week having two 2-hour lectures that incorporate discussions and a 2-hour computer lab or field class. The field classes are "mini pracs" that give students an opportunity to experience a variety of equipment and techniques. The course does not include much GNSS, Remote Sensing, GIS, photogrammetry or cadastral material because those matters are covered in other courses at UNSW.

From chores to Wow

Several years ago I read about The Wow Project by Tom Peters. I extract some of those ideas here. 'Wow Projects': projects that add value, projects that matter, projects that make a difference, projects that leave a legacy … ". Maybe some of your surveying projects will be WOW projects, maybe your work will be routine. Wow can mean exciting or impressive or sensational or surprising or … You might choose to volunteer for lousy, boring, not important projects that come along. Somewhere, someone is working away in obscurity on the project that 10 years from now everyone will acknowledge as the company's proudest moment. Why isn't that someone you? He says the point of the exercise is not to do a "good job" of managing the project that your boss dumped into your lap. It's to use every project opportunity that you can get your hands on to create surprising new ways of looking at old problems. Some steps or questions he suggests to make the project successful are: Does it matter; No project is too mundane, if you have the passion for it and see it as an opportunity; treat it as a learning opportunity; make a little (eg prototype), try it, improve it, repeat; avoid getting too much money or resources too soon; and when the project is complete judge it yourself and "sell" it. For surveyors selling it includes publication and conference presentations – can you describe it in a few minutes? You can read more about WOW projects yourself if you are interested.

You might hear teachers complaining about how tiring it is to mark exams and assignments. Some would say that it is a boring and exhausting task. Perhaps that leads to setting questions that are easier to mark. I have generally avoided doing that. I find that creating good new questions every year to be very challenging, and I have been doing it for many years. Have I turned exam setting and marking 'chores' into a Wow project by writing this book? If not, then perhaps the book has some uses for someone.

Overconfidence - The Dunning-Kruger effect

It happens from time to time that students get very confident that their calculations are correct or that their measurements are correct. Then they get their exam mark or assignment mark and get a sad shock. Even those with lots of work experience cannot believe that they could have made a mistake in a simple radiation for example. Please read this as part of your professional development. It might sound harsh, but it could help your education. My advice is to check your calculations by independent methods and to make sure your survey measurements include enough redundancy (check measurements). For example, I do not like unchecked radiations.

We do not want our graduates to make mistakes like errors in their cadastral plans, or setting out of buildings, bridges etc. Our clients and the community in general want the results to be reliable, not whether you should get paid just because your method was partly correct. I make mistakes sometimes and so do the surveyors I know, but we work on it. It's the overconfident ones that are a worry. Which category are you and what type of professional will you become?

David Dunning and Justin Kruger in their 1999 research paper 'Unskilled and Unaware of it: How difficulties in recognising one's own incompetence lead to inflated self-assessment', concluded that 'the dumb get confident, while the intelligent get doubtful', when studying people's perceptions of their own talents. It's the idea that the worse you are at something the more likely you'll hold an inflated view of your own performance. In their tests, the students at the bottom end of the class held inflated opinions of their own talents, hugely inflated. Even when poor students were shown good answers to their exams, they still did not become aware of their own mistakes. This explains the utter confidence of those who, with no expertise, remain stubborn in their views regardless of overwhelming evidence. The incompetent does not become aware of their problem until they become more competent. The key is education. For an entertaining consideration of this concept take the link to Ma and Pa Kettle doing maths: www.youtube.com/watch?v=X0aPKvNI9ek (if YouTube and the link still exist when you read this).

So, ignorant overconfidence is a problem. However, confidence in your abilities and some lack of experience can be a good thing. That can sometimes lead to innovative ways to do surveying projects. An experienced person might not take a risk if similar approaches have failed before. But trying things and failing is part of learning. What matters, what is important, is what you do if you have a failure. How do you cope with it, what do you learn from it, can you fix it? Some new managers you might meet who have no experience try things with confidence, but how well they cope with failures is interesting to observe. We want our graduates to be confident and capable. If you accept a surveying project as a challenge that might not succeed, and you warn your client about that and they are still willing for you to try, then go ahead and benefit from it. I have done that on several surveying projects and talk about my experiences in class.

Downloading

The amount of class and reference material that students can read is now enormous. Many people download files because if they have the file, they can read it at any time … so they don't have to read it now. Some people rarely read and only collect files and store them away. Is getting copies of all the material the only way you can keep up? Have you tried an alternative? It's an old-fashioned process where you place the pages in front of your eyes, and you let it go through there into the brain and it is much better than storing a download. Similarly, doing questions is a much better way to learn, than reading worked solutions.

Non-UNSW Sydney readers

The material in this book is intentionally focussed on UNSW and Sydney. Other teachers and students might find the questions generate ideas for application in their own environment. FIXIT is my least squares (LS) network software written for educational purposes. There are many other software packages that will do similar work. Monograph 13 is my least squares textbook (see below). SCIMS is the government database that provides coordinates of established control marks in NSW. MGA is the Map Grid of Australia; it is a transverse Mercator projection of 6° width with a central scale factor not equal to 1. Moodle is the learning management system currently used at UNSW to provide materials to students.

References

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A TYPICAL EQUATION PAGE IN AN EXAM:

We do not use all these equations in exams, it is up to students to recognise which equation is relevant if needed.

$RL_B = RL_A + HI + SD\cos(ZA) - HT$	$\Delta H = SD\cos(ZA) = HD / \tan(ZA) = D\cot(ZA)$
1 ppm = 1mm/km	$-L(1-COSQ)$ $L\,A\,(T_F - T_S)$ $-W^2L^3COS^2Q/(24N^2T_F^2)$ $L\,(T_F-T_S)/AE$
$\text{ellip dis} \approx \text{horiz dis}\left(1-\frac{h_m}{R}\right)$	$K' = D*10^{-6}*(272.51 - \{(79.15 * p)/(273.15+t)\}$
GRID DIS = ELLIP DIS * K	$K = 0.9996\left\{1.0+\left(\frac{y^2}{2r^2}\right)+\left(\frac{y^4}{24r^4}\right)\right\}$
GRID DIS = HORIZ DIS * CSF	$CSF = K\left(1-\frac{h_m}{R}\right)$
$E_B = E_A + D_{AB}\sin\beta_{AB}$ $N_B = N_A + D_{AB}\cos\beta_{AB}$	$d = \sqrt{(E_Q - E_P)^2 + (N_Q - N_P)^2}$
$\beta = \tan^{-1}\left(\frac{E_Q - E_P}{N_Q - N_P}\right)$	SLOPE DIS = $\sqrt{(\Delta E^2 + \Delta N^2 + \Delta H^2)}$ HORIZ DIS = HD = $\sqrt{(\Delta E^2 + \Delta N^2)}$ SLOPE DIS = $\sqrt{(HD^2 + \Delta H^2)}$
ZA = $\cos^{-1}$ (ΔH/SLOPE DIS)	$L = R\,\theta^r = R*(\theta''*\pi/(3600*180))$
$\frac{\text{distance moved}}{s_{dis}} < 2$	$VF = \frac{v^T P v}{n-u} \approx \frac{\sum \left(v/s\right)^2}{n-u}$
$\bar{x} = \sum_{i=1}^{n} E_i x_i \Big/ \sum_{i=1}^{n} E_i$	$H_B - H_A = HI - HT + \left(d_e \cot ZA + \left\{\left(\frac{1-k/\sin ZA}{\sin^2 ZA}\right)\frac{d_e^2}{2R}\right\}\right) \times \left(1+\frac{h_A+h_B}{2R}+\frac{N_A+N_B}{2R}+\frac{d_e^2}{12R^2}\right)$
$k = \frac{R_E}{r_L}$ $\delta = k\frac{\gamma}{2}$ $k = 1+\frac{\pi-(ZA_{12}+ZA_{21})}{\gamma}$	$H_B = H_A + h_i - h_t + \Delta h$ $\Delta h = HD\cot ZA + \frac{HD^2}{2R}(1-k)$ R≈6400km
$\delta = \frac{\beta}{2} = \frac{SD}{2r} = \frac{SDk}{2R} \approx \frac{k}{2}\gamma$	$H_2 - H_1 = SD\cos ZA_1 + \frac{(1-k/\sin ZA_1)}{2R}(SD\sin ZA_1)^2$
$F = \frac{SD_{coords}}{SD_{msd}}$	$H_2 - H_1 = \frac{SD}{2}(\cos ZA_{12} - \cos ZA_{21})$
$\Omega = Bearing_{coords} - Direction_{obs}$	$C = (ZA_{coords} - ZA_{msd}) / SD_{coords}$

A SELECTION OF MID-TERM AND FINAL EXAM QUESTIONS

Marking is usually based on the quality of the answer not merely a memory recall. Simply reading the suggested answers supplied here and recalling them in an exam, is not highly rewarded. Some of the answers supplied here are direct copies of students' exam answers.

We start with many questions about **surveying methodology**. They are an easy way to start a test. Some years I did not ask a methodology question. The topic aims to get students to think about how to do a surveying project that is different to anything that they have done before or learnt about in class or textbook.

Q1. Methodology
When a professional surveyor is involved in a challenging survey project that has aspects or problems not previously experienced by the surveyor, what important aspects of methodology should be considered?

Q2. Methodology
One of the reference papers in this course is "Project Surveying Methodology" by Brunner and Harvey. The paper lists several elements of surveying methodology. The last element in the list is "Quality Control and Presentation of Results". Describe and discuss what is recommended to be done at the end of a survey project.

Q3. Methodology
A surveyor has modern automatic instruments (such as robotic total stations with automatic pointing and Laser Scanners) and knows how to "Push the Buttons". Similarly, the surveyor has software that automates the calculations and plan drawing. Describe the important aspects of the "art of measurement" for professional surveyors involved in challenging survey projects that have aspects or problems not previously experienced by the surveyor.

[The term "Push the Buttons" was described by Staiger, and the "art of measurement" was described by Schwarz at FIG, as discussed in our week 1 class materials. If you don't remember the detail that is fine, write your own views on these matters.]

Q4. Methodology
For about the last ten years high precision surveying equipment has been getting easier to use. Describe and discuss what graduate surveyors should be able to contribute to a large new survey project apart from taking observations.

Q5. Methodology
One of the reference papers in this course is "Project Surveying Methodology" by Brunner and Harvey. The paper lists several elements of methodology. The first element in the list is "Understand the problem and then design the solution". The last element in the list is "Quality and presentation of results, and archiving". Describe and discuss at least 3 other essential elements of the methodology of doing a surveying project.

Q6. Methodology
One of the example case studies of Project Surveying Methodology in this course is van Cranenbroeck's project "Design for Hydro Power Plant Structural Geodetic Monitoring Network". Lists several elements of methodology mentioned in the case study.

Q7. Methodology
One of the reference papers in this course is "Project Surveying Methodology" by Brunner and Harvey. The paper lists several elements of methodology. The last element in the list is "Quality control and Presentation of Results". Describe and discuss this element in the context of a survey project.

Q8. Expert Witness
You have been invited to be an Expert Witness in a Federal Court case. The case involves determining the distance between two points. Both points are well inside multi storey buildings. It is not possible to measure the distance directly between the points. The Barrister says this project is urgent. Describe the methodology you would use for this project. Consider the way evidence must be collected and reports written for use in court.

Q9. Ethics
Give examples of ethical issues that can arise in Project Surveys.

The next section includes **Laser Scanning** questions. I started using, teaching and researching Laser Scanning in 2001 with a Cyrax 2400 and did my last survey in 2023 with a Leica BLK360. There have been many improvements in the technology since 2001, many make it easier to use. Most of these questions are based on real survey projects. Our lecture classes show many other example projects. The answers will change as the technology and software continues to involve. Notably the need for targets has decreased, though they are still important in some projects. Many people can now use laser scanners to create point clouds. They can look very nice. A professional surveyor considers how accurate they are as well as their uses. There were more questions on laser scanning, but I think there are enough here for your study.

Q10. Laser Scanning, Morpeth Tower
It is proposed to measure the volume and surface irregularities of a conical water tower by terrestrial laser scanning survey. You are to design the survey to measure the tower. Assume the walls are of negligible thickness. You do not need to survey the top surface (roof / lid) of the tower. The tower is about 20m tall. A Google Earth image and a site photo are shown below. The scale bar in bottom left is 0-69 metres. The surrounding area is flat grass but there is a row of trees near the tower.

a) What criteria or specifications would you set to decide which laser scanner to use?
b) Where would you set up your instrument and targets? Draw sketches.
c) List the field and office tasks that you would do when using a laser scanner on this site.
d) What problems might be encountered with this survey and how could they be overcome?
e) After the scanning and processing is complete, how do you assess the accuracy of points in the cloud?

Q11. Laser Scanning, CDB façade
It is proposed to survey the façade (front) of a heritage building in the Sydney CBD by a terrestrial laser scanning survey. Site photos supplied by the client and Google images are shown below. You are to design the survey and discuss the feasibility of the project, without prior visiting the site. The survey is to measure the façade and the small features on it but is not required to survey other parts of the existing building or surrounds. The façade is high above ground level, above the awning shown in the figure below.

Describe the methodology you would use to do this survey. Include details of matters specific to this project, including, but not limited to:

- What questions would you ask the client and what preparations you would make prior to the survey.
- Where would you set up your instrument and targets? Give reasons. Draw sketches.
- Explain how you would laser scan the small features so that 3D models could be made of them.
- What problems might be met with this survey and how could they be overcome?

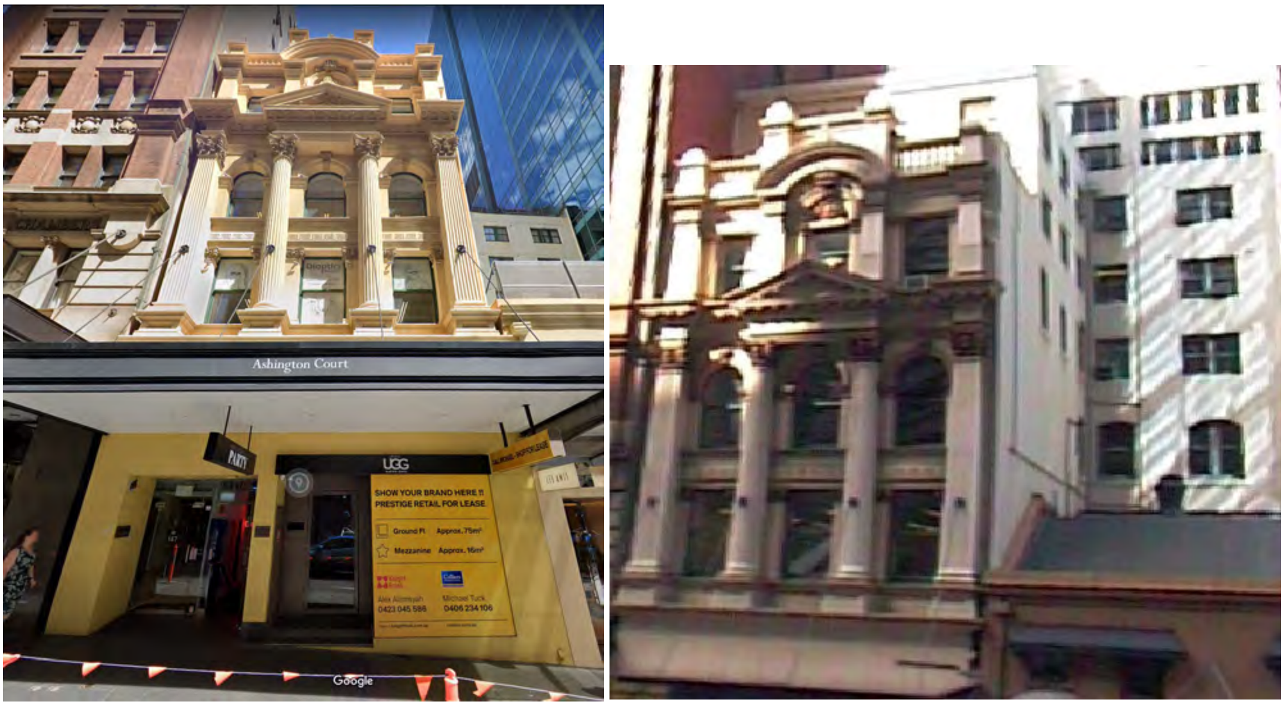


Fig. Façade of the building (two views)

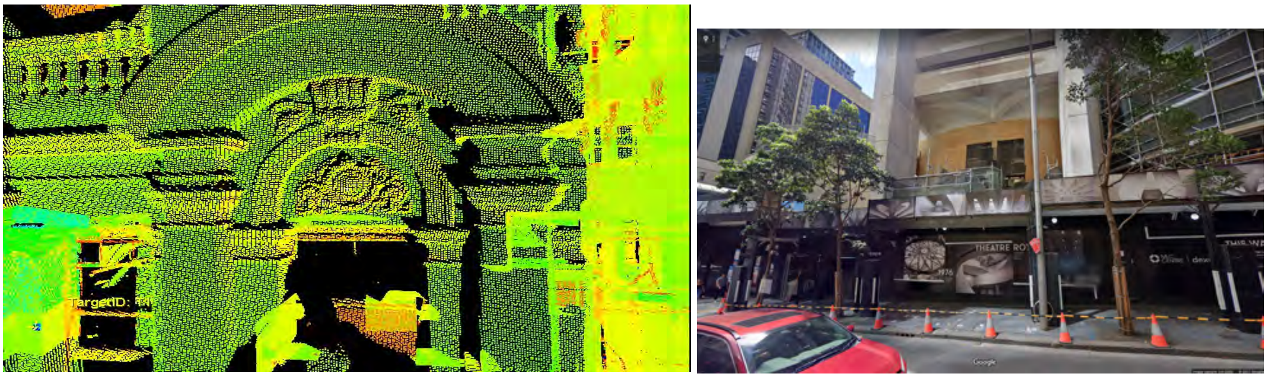


Fig. (LH) Close up image of part of the façade   (RH) Street view of the opposite side of the road to the façade

Q12. Laser Scanning, rock slope

A steep rock slope beside a busy road is to be monitored once a month for stability using a terrestrial, fixed mount, Laser Scanner. It is not safe to walk on the surface of the rock face. Photo of site shown below.

a) Where would you set up your instrument and targets (if any)? Draw sketches.
b) What problems might be encountered with this survey and how could they be overcome?
c) How would you determine whether the surface of the slope has moved from one survey to the next?

Q13. Laser Scanning, coal stockpile

A large stockpile (about 100m across the base) of loose coal is to be surveyed by a Leica C10 Laser Scanner to determine the volume of coal once every three weeks.

a) What are the relevant specifications of the chosen laser scanner?
b) Where would you set up your instrument and targets? Draw sketches on the photo above or separately below. Indicate the field of view to be scanned from each setup.
c) List the field and office tasks that you would do when using a laser scanner on this site.
d) What problems might be encountered with this survey and how could they be overcome?

Q14. Laser Scanning, Heritage Building

Your client passionately wishes to preserve the sculptures on the façade (front wall) of a heritage building in Annandale, Sydney. The client gives you a lot of background information. The sculptures were carved in sandstone by stone mason Thomas Wran in 1873. The sculptures are now starting to decay due to weathering. The sculptures are regarded as a very important heritage for Australia. Firstly, the excellent sculptures are of Australian native animals. The close detail and naturalism of them are outstanding. Secondly, it might be the first building to use Australian elements. Before that, architectural style had been borrowing European and American style.

It is proposed to survey the façade (front) of the heritage building by terrestrial laser scanning survey. Site photos supplied by the client and aerial Nearmap and Google images are shown below. You are to design the survey and discuss the feasibility of the project, without prior visiting the site. The survey is to measure the façade and the small sculptures on it, but is not required to survey the roof, other walls, surrounding trees, or fences. Some of the sculptures are high above ground level.

a) Where would you set up your instrument and targets? Draw sketches (overlayed on the photos shown below or separate sketches)
b) Explain how you would laser scan the small sculptures so that 3D models could be made of them.
c) Describe the Registration processing that would be needed for laser scanning of this site.
d) What problems might be encountered with this survey and how could they be overcome? Do you think the project is feasible? Give reasons.

Fig. Façade of the Annandale Creative Arts Centre and a close-up photo of some of the sculptures

Fig. Google Earth and Nearmap aerial images of the building, footpath, and road.

Q15. Laser Scanning, Berry Cottage

It is proposed to survey an old heritage cottage by terrestrial laser scanning survey. A Nearmap image and a site photo are shown below.

You are to design the survey to measure the cottage but not required to survey the surrounding trees, garage or fences. You do not need to survey the top surface (roof) of the cottage.

a) Where would you set up your instrument and targets? Draw sketches.
b) Explain how laser scanning of a target is able to find the centre of the target.
c) Describe the Registration processing that would be needed for laser scanning of this site.
d) What problems might be encountered with this survey and how could they be overcome?
e) After the scanning and processing is complete, how do you assess the accuracy of points in the cloud?

Q16. Laser Scanning, Opera House

It is proposed to measure the roof surface of the Sydney Opera House by terrestrial laser scanning to produce a high definition detail (i.e. many millions of points) survey. You are to design the survey to measure the outside of the roofs and the surrounding area. The insides of the buildings are not required. Discuss your considerations and plans.

<u>Instruments Section</u> There are also Moodle quiz questions about instruments later in this book.

Q17. Short Answer Questions

a) If you cannot see a mark from your total station because it is obscured, then how can you measure its coordinates?
b) How can you get more range (measure further) from a laser scanner or reflectorless EDM?
c) Rank the following survey techniques from more accurate to least accurate (in most cases):
    A) measuring coordinates of an existing mark, or
    B) setting out a mark at desired coordinates, or
    C) measuring the change in position of a point?
d) What are the safety precautions for using a class 3R laser?
e) Total station or theodolite horizontal direction measurement through a window (the glass is not perpendicular to the line of sight):
    A) causes the line of sight to deflect through a small angle so it has more effect on distant targets,
    B) offsets the line of sight by up to the thickness of the glass regardless of the distance to the target,
    C) has no effect on direction observation.

Q18. Testing TLS and reflectorless EDM

a) Describe how to test the accuracy of a Laser Scanner (TLS). You may include sketches.
b) Describe how to test the accuracy of total station automatic target recognition (ATR pointing).
c) Describe some of the error sources common to reflectorless EDM and laser scanners, and methods to avoid the error sources.

Another version:
How, and why, do you determine the additive constant (AC) and scale factor (SF) of the reflectorless EDM component in a total station or Laser Scanner (TLS)? Are there any special considerations that apply compared to the well-known measurement and calculation process used for prism mode EDM?

Q19. Tilting prism pole

Leica has recently released a prism pole for use with total stations that has tilt compensation, auto pole height and presumably azimuth corrections.

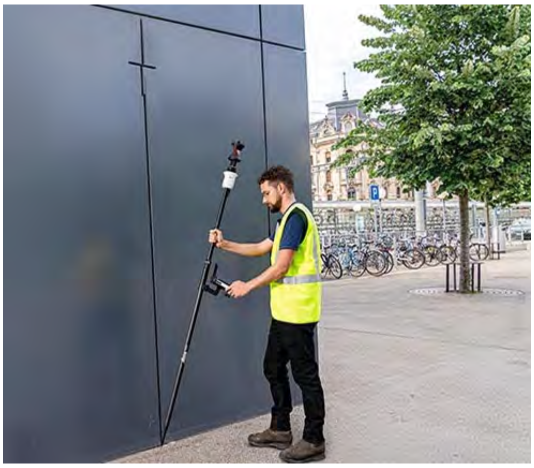


Photo from Leica website (https://leica-geosystems.com/products/total-stations/ap20-autopole)

a) Describe how you would test its accuracy,
b) What alternative methods are there to measure to points that are difficult to observe.

Mining surveying and tunnel surveying

Q20. Mining surveying

a) Briefly describe the role of a Registered Mining Surveyor in underground and surface mining operations. Who regulates and examines Registered Mining Surveyors in NSW?

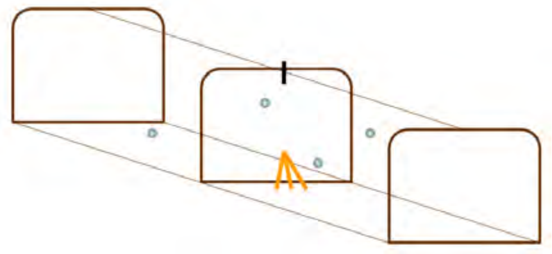
b) Describe by sketch and discussion how you would transfer survey control (bearings, EN coordinates and Heights) down into a mine via a curved spiral entry drive.

c) Describe by sketch and discussion how you would transfer survey control (bearings, EN coordinates and Heights) down a mine shaft that is about 5m wide and 150m deep.

d) Describe by sketch and discussion how you would transfer survey control along a tunnel 5m wide around a 50m centreline radius curve that spirals down several levels. Approx how long is the longest observable straight line? The tunnel descends at a 6% grade. Mention heights as well as 2D control.

Q21. Mining or tunnel surveying

In a mine or tunnel should we use roof marks, or should we use wall marks and free stationing / resections? What equipment would you prefer to use for these surveys? Give reasons.

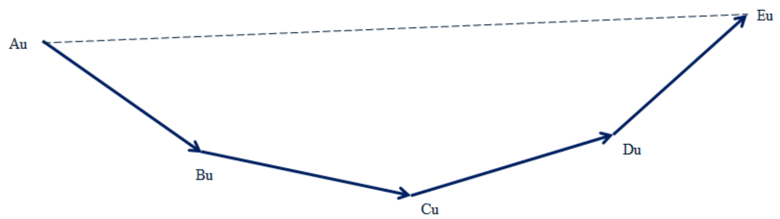


Q22. Underground surveys

a) Give two reasons why gyro azimuths are not used on every line in an underground survey.

b) How are gyro theodolites calibrated in the field, i.e. 'on site'?

c) An underground traverse for a new rail tunnel was surveyed from Au to Eu via Bu, Cu and Du as shown in the plan below (not to scale).



The bearing of line Au to Bu was initially assumed to be 30°00'00" and the distance was 151.123m. The distances in the underground traverse were local horizontal distances, not grid distances. The join between Au and Eu was calculated to be 355° 20' 30" and 562.276 m. The CSF (combined scale factor) for MGA distances on the site is 0.999860. The grid convergence at the site is -1° 18' 37".

The MGA coordinates of a point directly above Au at the ground surface (As) were measured by GNSS. Similarly, MGA coordinates of a point directly above Eu at the ground surface (Es) were also measured by GNSS. The grid bearing and grid distance between As and Es was calculated from these MGA coordinates to be 358° 30' 52" and 562.197 m.

From the given data calculate: the MGA grid bearing of the line Au to Bu to the nearest second, and the MGA grid distance for the line Au to Bu to the nearest millimetre.

d) Describe by sketch and discussion how you would transfer survey control (bearings, EN coordinates and Heights) down into an underground tunnel in a suburban area without a drive-in access route.

Q23. Underground surveys

The distance between two underground points in the Snowy Mountains of NSW was measured by EDM. The applicable MGA zone is 55. The measured slope distance corrected for instrument calibration but not corrected for atmosphere effects = 506.234 m. The correction for atmosphere effect on distance has been calculated as -9 ppm.
Height difference between the two points = 80.00 m.
MGA central scale factor, ko = 0.9996. Local grid scale factor, K = 0.999875.
Local combined scale factor, CSF = 0.999732.
The azimuth (from true north) of the line as measured by gyro theodolite = 49°32'14".
Grid convergence at this site = -1° 18' 37".

From the given data calculate:

the MGA grid bearing of the line between the two points to the nearest second, and
the MGA grid distance for the line to the nearest millimetre.

Q24. Coordinate systems

Write a reply to this email. It is a modified version of a real email.

I am in the process of setting up a new tunnel and have been pondering on the best way to set up the coordinate system for underground. Any input, pro's and con's would be great. …

…we are right on the edge of Zone 55, and … a scale factor of 0.999576

Some surface work is done by GNSS and converted back to MGA2020. Other surface survey work is done with the total station using this scale factor, which in itself is not the best as I am using the scale factor to install new stations, however all construction work needs to have a scale factor of 1.00000 to work in a true scale! So I am having to have 2 coordinate systems on the surface in localised areas – one (0.999576) being for surface works such as building roads, dams, and general topo; and another coordinate system (1.00000) for building the offices and workshops and processing plant; all off the same stations, with different coordinates.

This is all fine, as I know what is going on and can document it easily.

… Where I am having to think a little harder, is in the situation of taking these coordinates underground. …our current location is 1400m in distance from the entry portal. Entry is via a ramp with a gentle curve. …. If I were to apply the scale factor of 0.999576 to the total traverse down to our current location to keep in line with MGA2020 coordinates, I have a total distance of 1399.4m….I would like to keep everything at 1.00000. However when drilling ventilation shaft holes from the surface in MGA2020 this has to break through into a 5m wide tunnel 100m down. …

Can you think of more pro's and con's and ideas on how the underground coordinate system is best established to suit an MGA2020 coordinate system? Should I get some lines measured with a gyro?

<u>Another year a modified version of this question was used:</u>

I am in the process of setting up control survey in a new tunnel in an underground mine near Appin NSW. I have been pondering on the best way to set up the coordinate system for underground. Any input, pro's and con's would be great. …

…we are in MGA Zone 56, and … the scale factor is 1.000036

Can you think of more pro's and con's and ideas on how the underground coordinate system is best established to suit an MGA2020 coordinate system? Should I get some lines measured with a gyro? Do you have any questions for me?
Regards,

Least Squares and Data Analysis

The students in this course have already completed an earlier course on Least Squares (LS) based on my textbook, Practical Least Squares and Statistics for Surveyors (reference given on page 4). This course extends that learning with some more advanced topics that are useful for some project surveys.

Q25. Least Squares, Berry

A small control survey was measured by students around a project site at Berry, NSW with a total station measuring grid distances, ΔH and directions. A plan of the network is shown in figure below. The data is supplied in a separate file in an exam and access to a LS network adjustment program, but for this book the data is included in the table below. Control marks 900, 914 and 996 (red squares in the figure below) have coordinates supplied from a previous higher quality survey. The default input standard deviations of the observations are ±(3mm+1ppm) for distances, ±5” for directions and ±1mm centring (plumbing) at instrument and at target, and ±3mm for height differences.

Coordinates (m)		
Point E	N	H
996 289982.218	6147475.258	9.686
914 290078.811	6147465.594	12.536
900 289856.680	6147404.573	12.011
800 290012.1202	6147384.9230	11.8710
801 290026.9092	6147442.7736	12.5909
802 289942.0053	6147414.6632	12.0630
803 290003.4682	6147519.6411	6.8591
804 290091.4121	6147475.8258	12.2558
From To Directions (° ’ ”)	From To Grid Distances (m)	From To Height Difference (m)
996 803 25 35 01	996 803 49.208	996 803 -2.832
996 802 213 34 15	996 802 72.723	996 802 2.378
803 996 205 35 07	803 996 49.207	803 996 2.822
803 804 116 28 55	803 804 98.257	803 804 5.398
804 803 296 28 55	804 803 98.257	804 803 -5.398
804 914 230 55 27	804 914 16.232	804 914 0.280
804 801 242 52 04	804 801 72.475	804 801 0.332
801 804 62 52 06	801 804 72.476	801 804 -0.341
801 800 194 20 26	801 800 59.711	801 800 -0.721
801 803 343 2 42	801 803 80.361	801 803 -5.729
800 801 163 02 46	800 801 59.713	800 801 0.719
800 802 81 41 23	800 802 76.161	800 802 0.192
802 800 261 41 15	802 800 76.161	802 800 -0.192
802 900 51 57 32	802 996 72.723	802 900 -0.036 ± 999.
802 996 182 16 20		802 996 -2.376

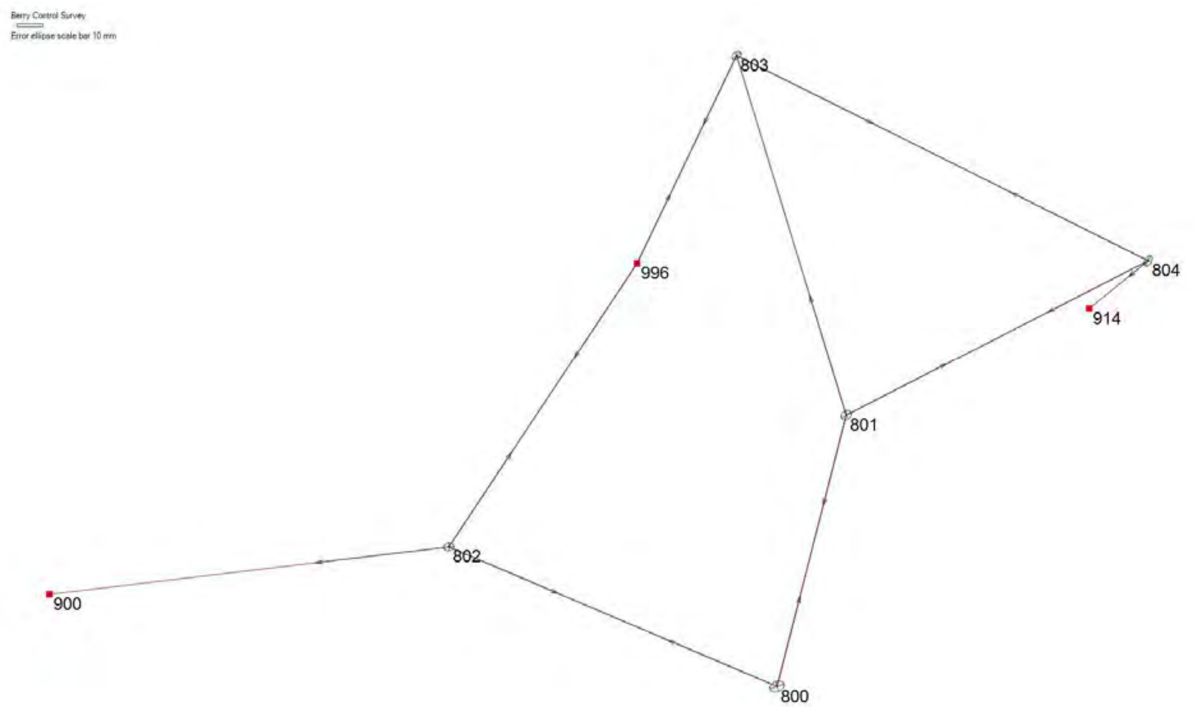


Figure. Plan of control network at Berry

You do not need to resolve errors in the data. Do not change the default standard deviations. Do not change observations. Do not down-weight observations.

The data can be processed using a few different approaches:

a) Conventional constrained Least Squares solution (as shown in figure).
b) L1 Norm solution
c) Free net solution
d) 'Bayesian' solution with coordinates of all control points having prior values to ± 10 mm.

For each of the approaches above discuss why a surveyor would consider applying the method.
Comment briefly on the differences between the output results that you would expect from each of the methods.

Q26. Least Squares, email
The following (edited) email was received a few weeks ago. Your task is to write a reply to the email.

Hi Bruce,
Long time no see. I hope you're staying healthy and the surveying faculty is surviving COVID-19…
Since leaving uni I've been working at … and have been doing a lot of LS adjustments. I have a question for you.
Since moving to GDA2020 and shifting to constrained adjustments, rather than fixed, like we typically see much lower VFs than we did in the past. The result is that the Chi-Squared test no longer seems to be a useful indicator of how appropriate the observational weightings are.
I've been investigating whether or not there is perhaps a different test or a better indicator that the weighting are right for the adjustment – do you have any recommendations?
Thanks Bruce – of course, happy for you to use my email for the exam. I'm glad to be able to help torture your students. I look forward to hearing the response from the class.

The email above mentions the Chi-Squared test. That is the same as the F test of the Variance Factor (VF) that you are familiar with. Constrained adjustment refers to holding some point coordinates fixed.
Your answer should focus on the topics of Bayesian, Freenet, and L1 robust adjustments and the considerations of minimum constraints or over constrained, whether onto SCIMs marks and MGA, or local coordinates.
Your answer should also comment on the effects of these decisions on adjusted coordinates, residuals, VF, and error ellipses.

Q27. Least Squares Datum, email
Imagine you are a graduate surveyor working in a private survey company in Sydney. In such a role, answer the following email from another surveyor in the same company as you, but she is based on the north coast of NSW.

Hello [insert your name],
I am just starting work on a new project to build a shipyard for the Navy to modify some new submarines in dry dock (the subs will be in the shipyard but out of the water). I have to set up a control network so that later we can take accurate measurements of the submarines. Should I use a minimally constrained local coordinate system, or connect to the MGA coordinate system based on several points whose coordinates are in SCIMS (published by the Department of Lands)?

….
PS. My photo at the site is attached.

Reply to the email with an answer and justifications.

Q28. Data analysis methods, Chifley Dam
A survey network at Chifley Dam, Bathurst is shown in the plan below. The azimuth of the line 7 to 3 was held fixed. The data was adjusted by Least Squares with software that gave the following output:

PT.	FINAL COORDINATES E (m)	N (m)	STANDARD DEVIATIONS & ERROR ELLIPSES (mm) E	N	S-Maj	S-Min	Brg
1	9279.756	5154.881	15.0	8.4	17.0	2.2	119°
2	9360.468	4622.875	19.9	8.2	21.2	3.8	110°
3	8831.421	3959.710	26.2	12.4	28.9	2.6	115°
4	8669.752	4674.148	19.4	14.0	23.8	2.5	126°
5	8794.484	4889.779	17.7	13.1	21.8	2.6	126°
6	8871.106	5227.392	14.3	12.2	18.6	2.7	130°
7	10064.072	6612.433	FIXED				

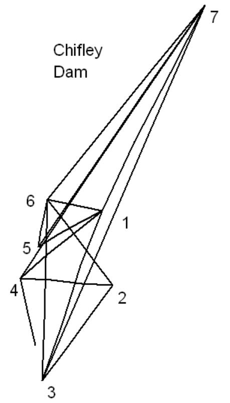


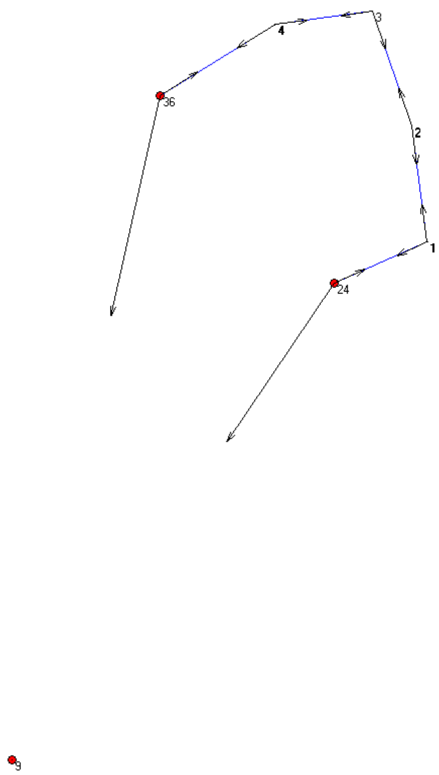
Fig. Chifley Dam survey network. Black lines show which measurements were observed.

For question parts a, b, and c below, all solutions use the same observation data and the same input standard deviations of the observations.

a) Describe the effects for this network that a free net adjustment or free net transformation would have on the error ellipse of point 3.
b) Under what circumstances might an L1 Norm solution be applied to this survey?
c) Describe the effects for this network that a 'Bayesian' solution with coordinates of point 7 had prior values from GPS to ±0.010m in E and in N.

Q29. Data analysis methods, simple traverse Morpeth

A small control survey was measured around a project site. A plan of the network is shown at right. The data was processed using three different approaches. The output files are shown below in Tables 1, 2 and 3.



Comment on the differences between these output files and discuss the special features of each of the methods. All solutions used the same observation data.

Default standard deviations: Distances ±5 mm Directions ±4.6 "
There were no (0) ppm or centring contributions to the standard deviations of observations.

The a priori variance factor is 1.0 and the output Variance Factor is the estimated variance factor (as usual for UNSW FIXIT use).

Input / starting coordinates for all solutions:

Pt	E	N
9	87313.331	41010.993
24	87515.406	41309.029
36	87406.208	41426.489
1	87574.0	41335.0
2	87564.0	41407.0
3	87539.0	41479.0
4	87478.0	41471.0

Table 1. Least Squares solution

```
There are 8 coordinate parameters, 6 orientation parameters and 17 obs
 Adjusted Coordinates
Point Fixed                      E m          N m
   9   EN                   87313.3310   41010.9930
  24   EN                   87515.4060   41309.0290
  36   EN                   87406.2080   41426.4890
   1                        87573.4909   41334.8696
   2                        87563.9159   41407.1151
   3                        87539.4398   41478.9036
   4                        87478.3961   41471.0008
 RESIDUALS AFTER ADJUSTMENT
OBS    TYPE      FROM  TO    MEASUREMENT   STD DEV        V        V/S   Redun
 1 Direction     24     9      0 00 01.7    4.6sec     4.8sec    1.0    0.1
 2 Direction     24     1    211 52 54.7    4.6sec    -4.8sec   -1.0    0.1
 3 Direction      1    24      0 00 01.4    4.6sec     2.2sec    0.5    0.1
 4 Direction      1     2    106 26 06.7    4.6sec    -2.2sec   -0.5    0.1
 5 Direction      2     1      0 00 00.3    4.6sec     0.1sec    0.0    0.1
```

```
 6 Direction     2    3   168 43 23.0    4.6sec    -0.1sec    0.0   0.1
 7 Direction     3    2   359 59 56.5    4.6sec    -1.6sec   -0.3   0.1
 8 Direction     3    4   101 26 53.7    4.6sec     1.6sec    0.3   0.1
 9 Direction     4    3     0 00 00.6    4.6sec     0.5sec    0.1   0.1
10 Direction     4   36   155 43 07.1    4.6sec    -0.5sec   -0.1   0.1
11 Direction    36    4   359 59 56.6    4.6sec     4.1sec    0.9   0.2
12 Direction    36    9   134 15 36.1    4.6sec    -4.1sec   -0.9   0.2
13 H Distance   24    1       63.5780    5.0mm     -4.5mm    -0.9   0.2
14 H Distance    1    2       72.8690    5.0mm      8.2mm     1.6   0.4
15 H Distance    2    3       75.8370    5.0mm      9.4mm     1.9   0.4
16 H Distance    3    4       61.5460    5.0mm      7.1mm     1.4   0.3
17 H Distance    4   36       84.8050    5.0mm      3.2mm     0.6   0.2

After iteration 5 the Variance Factor is 4.67
Standard Deviations and Error ellipses in mm
  [These are NOT multiplied by sqrt VF]
Point      SE      SN      Semi-   Semi- Bearing
                           major   minor   degs
    9       0.0     0.0       0.0     0.0     0
   24       0.0     0.0       0.0     0.0     0
   36       0.0     0.0       0.0     0.0     0
    1       3.9     2.6       4.4     1.7    61
    2       4.1     4.4       4.5     4.1    21
    3       5.1     3.5       5.1     3.5    93
    4       4.1     2.7       4.4     2.2    64
```

Table 2. L1 Norm solution

```
There are 8 coordinate parameters, 6 orientation parameters and 17 obs
Adjusted Coordinates
 Point Fixed                     E m          N m
     9 EN                    87313.3310    41010.9930
    24 EN                    87515.4060    41309.0290
    36 EN                    87406.2080    41426.4890
    1                        87573.4937    41334.8744
    2                        87563.9176    41407.1115
    3                        87539.4365    41478.9078
    4                        87478.3916    41471.0020
 RESIDUALS AFTER ADJUSTMENT
OBS   TYPE    FROM   TO   MEASUREMENT    STD DEV       V          V/S
 1 Direction    24    9     0 00 01.7      4.6sec     0.0sec     0.0
 2 Direction    24    1   211 52 54.7      4.6sec   -20.3sec    -4.4
 3 Direction     1   24     0 00 01.4      4.6sec     0.0sec     0.0
 4 Direction     1    2   106 26 06.7      4.6sec     0.0sec     0.0
 5 Direction     2    1     0 00 00.3      4.6sec     0.0sec     0.0
 6 Direction     2    3   168 43 23.0      4.6sec     0.0sec     0.0
 7 Direction     3    2   359 59 56.5      4.6sec     0.0sec     0.0
 8 Direction     3    4   101 26 53.7      4.6sec     0.0sec     0.0
 9 Direction     4    3     0 00 00.6      4.6sec     0.0sec     0.0
10 Direction     4   36   155 43 07.1      4.6sec     0.0sec     0.0
11 Direction    36    4   359 59 56.6      4.6sec     0.0sec     0.0
12 Direction    36    9   134 15 36.1      4.6sec     0.0sec     0.0
13 H Distance   24    1       63.578       5.0mm      0.0mm      0.0
14 H Distance    1    2       72.869       5.0mm      0.0mm      0.0
15 H Distance    2    3       75.837       5.0mm     18.3mm      3.7
16 H Distance    3    4       61.546       5.0mm      8.7mm      1.7
17 H Distance    4   36       84.805       5.0mm      0.0mm      0.0
The Variance Factor is 11.98
```

Table 3. ‘Bayesian’ solution

```
There are 14 coordinate parameters, 6 orientation parameters and 23 obs
Adjusted Coordinates
 Point Fixed                       E m          N m
     9                         87313.3313    41010.9923
    24                         87515.4006    41309.0332
    36                         87406.2131    41426.4855
     1                         87573.4875    41334.8747
     2                         87563.9138    41407.1158
     3                         87539.4397    41478.8997
     4                         87478.3997    41470.9970
 RESIDUALS AFTER ADJUSTMENT
OBS   TYPE    FROM  TO    MEASUREMENT   STD DEV       V        V/S  Redun
 1 Direction    24    9     0 00 01.7    4.6sec     2.6sec     0.6   0.1
 2 Direction    24    1   211 52 54.7    4.6sec    -2.6sec    -0.6   0.1
 3 Direction     1   24     0 00 01.4    4.6sec     1.4sec     0.3   0.1
 4 Direction     1    2   106 26 06.7    4.6sec    -1.4sec    -0.3   0.1
 5 Direction     2    1     0 00 00.3    4.6sec     0.4sec     0.1   0.1
 6 Direction     2    3   168 43 23.0    4.6sec    -0.4sec    -0.1   0.1
 7 Direction     3    2   359 59 56.5    4.6sec    -0.4sec    -0.1   0.1
 8 Direction     3    4   101 26 53.7    4.6sec     0.4sec     0.1   0.1
 9 Direction     4    3     0 00 00.6    4.6sec     0.5sec     0.1   0.1
```

```
10 Direction     4   36   155 43 07.1    4.6sec    -0.5sec    -0.1   0.1
11 Direction    36    4   359 59 56.6    4.6sec     2.2sec     0.5   0.1
12 Direction    36    9   134 15 36.1    4.6sec    -2.2sec    -0.5   0.1
13 H Distance   24    1        63.578    5.0mm     -2.3mm     -0.5   0.2
14 H Distance    1    2        72.869    5.0mm      3.7mm      0.7   0.2
15 H Distance    2    3        75.837    5.0mm      4.3mm      0.9   0.2
16 H Distance    3    4        61.546    5.0mm      3.5mm      0.7   0.2
17 H Distance    4   36        84.805    5.0mm      1.6mm      0.3   0.2
18 EPP           9          87313.331    5.0mm      0.3mm      0.1   0.0
19 NPP           9          41010.993    5.0mm     -0.7mm     -0.1   0.0
20 EPP          24          87515.406    5.0mm     -5.4mm     -1.1   0.2
21 NPP          24          41309.029    5.0mm      4.2mm      0.8   0.2
22 EPP          36          87406.208    5.0mm      5.1mm      1.0   0.2
23 NPP          36          41426.489    5.0mm     -3.5mm     -0.7   0.2

After iteration 5 the Variance Factor is       2.30
Standard Deviations and Error ellipses in mm
 [These are NOT multiplied by sqrt VF]
Point      SE      SN      Semi-   Semi- Bearing
                           major   minor   degs
   9       4.9     5.0       5.0     4.9    26
  24       4.3     4.5       4.6     4.2    32
  36       4.5     4.4       4.7     4.3    53
   1       5.4     5.5       5.8     5.0    41
   2       5.8     6.1       6.2     5.6   151
   3       6.9     5.6       7.0     5.4   109
   4       6.2     5.0       6.2     4.9    82
```

Deformation Monitoring

Q30. Control and Deformation Networks

a) Explain the **differences** between a control survey and a deformation survey if there are likely to be systematic errors in observations.

b) For a deformation survey it has been recommended to do a “zero epoch test”. What is that and why is it good practice?

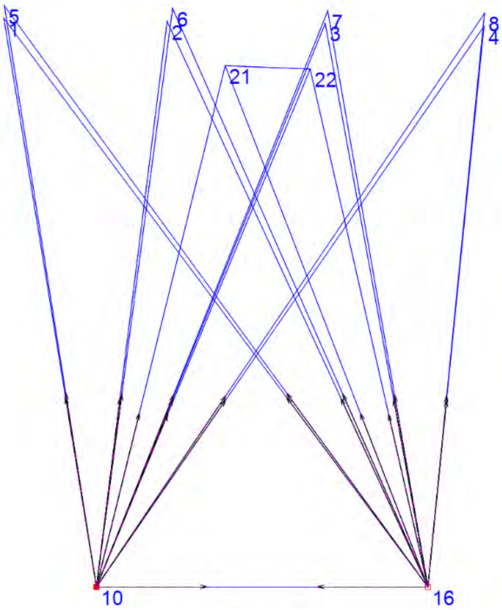
c) Explain the advantages and disadvantages for a control survey of over-constraining a network. Consider: Should I use a minimally constrained local coordinate system, or connect to the MGA coordinate system based on several points whose coordinates are in SCIMS (published by the NSW government)?

Q31. Car Park Deformation

A survey for deformation monitoring was measured at the UNSW Barker Street Carpark to monitor targets on the wall of a car park. A photo of the site is shown in figure below. Measurements were taken in 2 epochs. One was about 8am in the morning when the car park was nearly empty. Another epoch was about 1pm in the afternoon when the car park was full.

Sokkia Total stations observed directions, ZA and slope distances from points 10 and 16 about 10m from the target wall. A Scale bar (points 21 and 22) was placed about 1.5m in front of the target wall. Points 1 to 8 are the targets placed on the wall (see figure below). In epoch 1 they are numbered 1 to 8 in epoch 2 they are numbered 201 to 208.

Photo of site



Plan of control network

An extract from the output file of a least squares solution of both epoch’s data combined is given below.

Calculated Lines between adjusted coordinates (all in mm)

From	To	Horiz Dist	Slope Dist	Height Diff
1	201	0.59 ± 0.63	1.90 ± 0.31	-1.8 ± 0.20
2	202	0.16 ± 0.52	1.86 ± 0.20	-1.9 ± 0.19
3	203	0.03 ± 0.21	1.85 ± 0.18	-1.8 ± 0.18
4	204	0.91 ± 0.63	3.10 ± 0.22	3.0 ± 0.19
5	205	0.90 ± 0.68	0.90 ± 0.68	0.1 ± 0.19
6	206	0.24 ± 0.37	0.29 ± 0.31	0.2 ± 0.18
7	207	0.28 ± 0.50	0.41 ± 0.38	0.3 ± 0.18
8	208	0.04 ± 0.65	0.30 ± 0.21	0.3 ± 0.19

Statistically test the points for deformation and comment.

[In one exam this question supplied an input file and software to process the data. But 200 lines of data are too much for this book.]

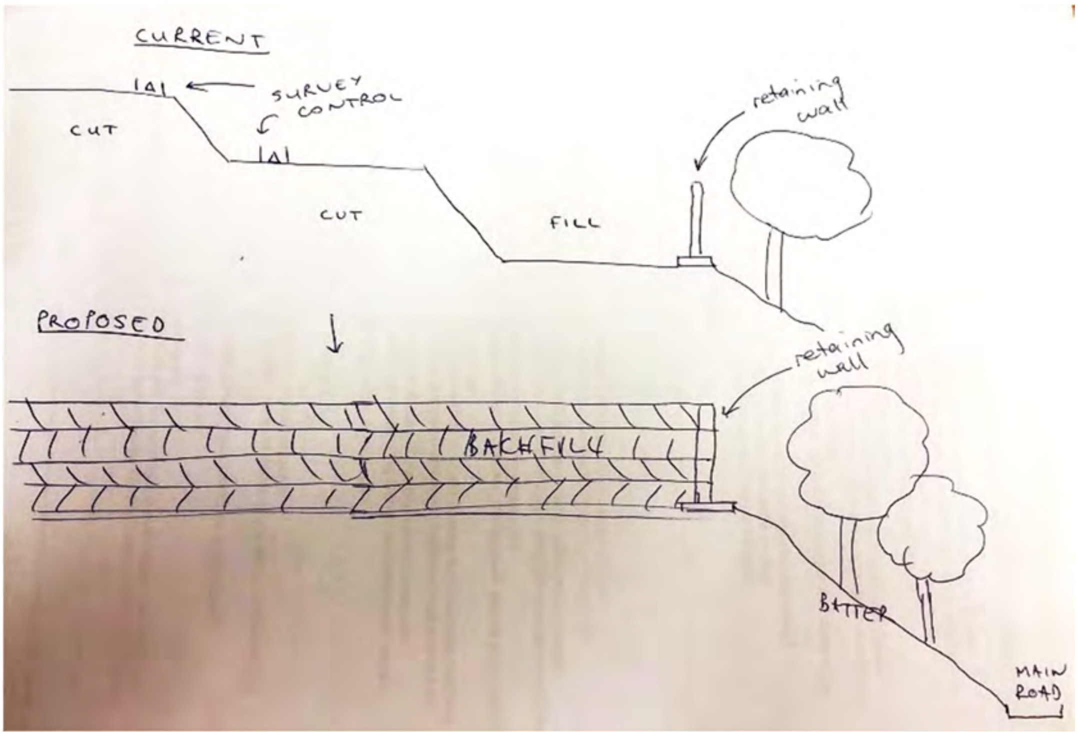
Q32. Deformation design, email

The following (edited) email was received.

Hi Bruce,

I am working at a construction site at the moment, and we are building a retaining wall that we need to monitor for deformation/movement over the next 12 months. The retaining wall is being built up in layers and successively backfilled to the current layer height so the option of placing retros or targets on the face of the retaining wall is not possible. Also, behind the back of the retaining wall is a steep batter that goes down to a main road and is heavily vegetated with thick bush and trees making it very difficult to place and sight to targets on the back face of the wall as well. Currently, we have survey control on two layers that are cut zones, so eventually these will be lost when this material is pushed over and used as fill (See attached drawing). If you had any thoughts on how you would go about setting up targets/monitoring the wall for deformation this would be very insightful.

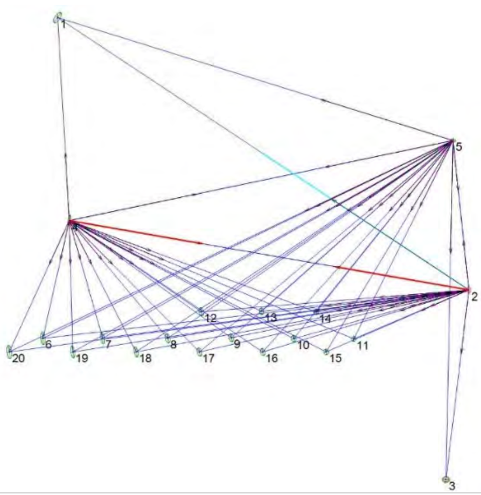
Kind regards,



The equipment you 'own' is the same as in the UNSW survey store. Draw a plan showing the location of equipment and targets. In your answer reply to the email and discuss:

- methodology of the survey,
- measurements including a description of techniques used and processing required,
- type of equipment and expected accuracies.

Q33. Deformation Data Analysis – Monitoring survey



The first epoch survey for deformation monitoring of a dam in the NSW Snowy Mountains region was measured with a high-quality total station by experienced surveyors in November 2002. The rock fill dam wall is 44 metres high and 518 metres long. A plan of the network is shown in the figure. This question uses real, not simulated data. Points 1 to 5 are stable survey pillars. Points 6 to 20 are targets on the dam.

You are given the FIXIT input file "JOUNAMA DAM for 3100 exam.inp". The file contains epoch 1 observations and an END line. Nothing is read by FIXIT after and END line. If the END line is removed, then the following lines in the supplied input file give the data for a Simulation adjustment of epochs 1 and 2.

[Students were given a copy of the input file on their computer and the FIXIT software. There are almost 400 lines in the data file – too many to put into this book. I have included this question here as an example of the type of questions we sometimes ask.]

A) Analyse the data and comment on the suitability of this survey data as epoch 1 of a deformation survey and whether you consider a similar second epoch should be measured, or changes made to this survey before a second epoch.

B) Use LS simulation to analyse the size of deformation detectable if a repeat second epoch with the same observation lines was to be conducted in November 2018.

Q34. Deformation Data Analysis – Rail Monitoring survey

A control survey for deformation monitoring was recently measured at a project site. A plan of the network is shown in figure 1. This question uses real, not simulated data.

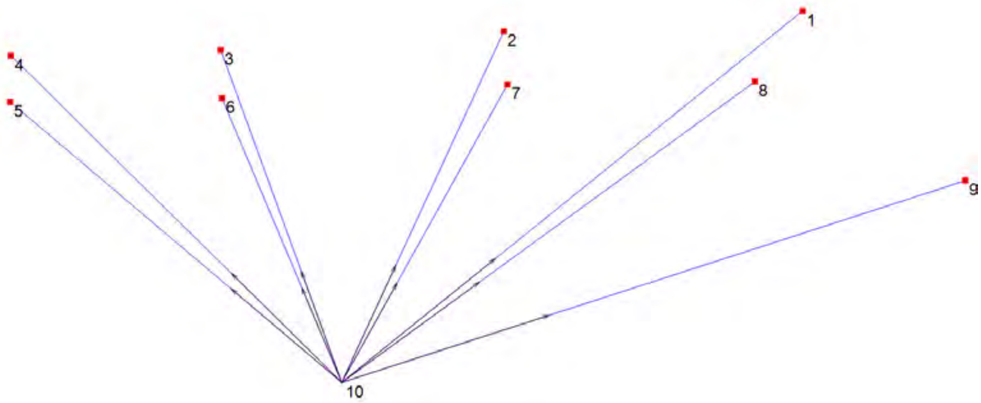


Figure. Plan of control network

Points 1 to 9 are targets on a railway line in regular use that is to be monitored for movement. The coordinates of points 1 to 9 are from previous surveys and are on a local datum with no projection scale factor. Point 10 is occupied by a high quality motorised total station. The recorded data was not corrected for atmospheric effects.

For the purposes of this exam question we are going to assume targets 1 to 9 have not moved and we investigate whether point 10 has moved.

Two conventional LS 3D adjustments were done with FIXIT4 software. Both adjustments used the same standard deviations for the observations and the same input coordinates with points 1 to 9 held fixed. Given below are the results for two epochs of data. One epoch was observed at about 1pm local time. Another epoch of data was observed about 12 hours later at 1am. They were analysed separately with the same control coordinates and standard deviations. An edited extract of the output follows.

Default standard deviations:
Distances 1.1 mm + 0.0 ppm ZA 1.0" and 0.0 mm Hi and Ht std dev
Directions 1.0" and 0.0 mm centring std dev at inst and at target

	Epoch 1 = 1pm		Epoch 2 = 1am	
Adjusted ENH Coordinates Point 10	485.5093 456.1968 30.3087		485.5099 456.1961 30.3099	
	Observations	v	Observations	v
Dir 10 1	51 07 19.0	-1.4sec	51 07 09.9	-1.4sec
Dir 10 2	24 46 13.1	0.8sec	24 46 05.0	-0.9sec
Dir 10 3	340 00 08.1	-1.8sec	339 59 58.1	-0.4sec
Dir 10 4	314 38 33.7	-1.1sec	314 38 25.7	-0.6sec
Dir 10 5	310 14 24.2	1.4sec	310 14 17.4	0.8sec
Dir 10 6	337 08 45.2	1.5sec	337 08 35.8	2.3sec
Dir 10 7	29 03 54.5	1.6sec	29 03 46.3	-0.3sec
Dir 10 8	53 55 43.2	0.3sec	53 55 33.4	0.8sec
Dir 10 9	72 03 56.9	-1.2sec	72 03 47.0	-0.2sec
SD 10 1	123.8391	-1.3mm	123.8397	-1.9mm
SD 10 2	81.5882	-1.2mm	81.5886	-1.0mm
SD 10 3	75.0078	-0.1mm	75.0095	-0.7mm
SD 10 4	97.8855	-1.0mm	97.8879	-2.3mm

SD 10 5	91.6613 1.2mm	91.6636 0.0mm
SD 10 6	65.9186 0.7mm	65.9202 0.2mm
SD 10 7	72.3825 0.2mm	72.3832 0.1mm
SD 10 8	107.2268 -1.1mm	107.2270 -1.2mm
SD 10 9	137.0004 -0.8mm	137.0008 -1.5mm
ZA 10 1	96 00 36.4 2.3sec	96 00 40.8 -0.1sec
ZA 10 2	99 28 02.5 -0.6sec	99 28 06.1 -1.3sec
ZA 10 3	100 59 11.4 2.4sec	100 59 15.7 1.0sec
ZA 10 4	98 40 24.8 2.6sec	98 40 28.4 1.3sec
ZA 10 5	99 36 40.9 -3.9sec	99 36 42.2 -2.8sec
ZA 10 6	103 12 57.2 -2.8sec	103 12 57.2 0.4sec
ZA 10 7	101 29 04.6 -0.2sec	101 29 05.4 2.2sec
ZA 10 8	97 18 21.3 2.1sec	97 18 26.0 -0.2sec
ZA 10 9	95 34 58.1 -0.4sec	95 35 00.9 -1.3sec
Variance Factor	2.95	1.76
95% Confidence Level of point 10 in mm	E 1.5 N 1.0 H 0.5 maj 1.6 min 0.9 106°	E 1.2 N 0.8 H 0.4 maj 1.2 min 0.7 106°

A) Comment on the differences between the above output files and discuss the likely causes.
B) What other analysis could be done on this data? Explain.

Q35. Deformation Analysis

The table below shows part of an output from program FIXIT. Discuss whether points 4 or 5 or both have moved.

```
Adjusted Coordinates after iteration 5
          Point Fixed Name                      E m           N m
COORDINATE    7 EN Windy Corner        10064.0720     6612.4330
COORDINATE   11 EN Evernden              451.0110     4884.8170
COORDINATE   12 EN Ovens               22099.2200    21416.7130
COORDINATE    1    Rod                  9279.7535     5154.8840
COORDINATE    2                         9360.4517     4622.8688
COORDINATE    3                         8831.3637     3959.7362
COORDINATE  104                         8669.7382     4674.1811
COORDINATE  204                         8669.7471     4674.1833
COORDINATE  105    B Bolt               8794.4722     4889.8005
COORDINATE  205    B Bolt               8794.4697     4889.8132

 RESIDUALS AFTER ADJUSTMENT
OBS   TYPE     FROM  TO   MEASUREMENT    STD DEV        V       V/S
 1 Direction     1    2  330 48 43.     2.1sec     0.3sec     0.1
 2 Direction     1  105   40 47 30.     2.1sec     0.0sec     0.0
 3 Direction     1    7  187 43 19.     2.0sec     0.8sec     0.4
 4 Direction     2    1   30 21 49.     2.1sec    -0.5sec    -0.2
 5 Direction     2    3  257 34 24.     2.0sec     0.9sec     0.5
 6 Direction     3    2   13 39 09.     2.0sec    -1.4sec    -0.7
 7 Direction     3  104  322 19 14.     2.0sec    -2.4sec    -1.2
 8 Direction   104    3  131 31 00.     2.0sec     1.2sec     0.6
 9 Direction   104  105  354 18 49.     2.3sec    -1.5sec    -0.7
10 Direction   105    7  179 59 52.     2.0sec    -4.2sec    -2.1
11 Direction   105    1  204 57 35.     2.1sec     2.9sec     1.4
12 Direction   105  104  353 39 16.     2.3sec     2.0sec     0.8
13 Direction     7   11    0 00 00.     2.0sec    -0.4sec    -0.2
14 Direction     7   12  139 17 49.     2.0sec     1.9sec     1.0
15 Direction     7    1  308 28 22.     2.0sec     1.2sec     0.6
16 Direction     7  105  316 34 43.     2.0sec     0.3sec     0.2
17 H Distance    1    2     538.103     3.5mm     -2.3mm     -0.7
18 H Distance    1  105     552.968     3.6mm     -5.7mm     -1.6
19 H Distance    1    7    1655.179     4.7mm     -3.9mm     -0.8
20 H Distance    2    1     538.099     3.5mm      1.7mm      0.5
21 H Distance    2    3     848.340     3.8mm     -1.0mm     -0.3
22 H Distance    3    2     848.336     3.8mm      3.0mm      0.8
23 H Distance    3  104     732.502     3.7mm     -3.3mm     -0.9
24 H Distance  104    3     732.498     3.7mm      0.7mm      0.2
25 H Distance  104  105     249.098     3.2mm      1.0mm      0.3
26 H Distance  105    1     552.958     3.6mm      4.3mm      1.2
27 H Distance  105  104     249.102     3.2mm     -3.0mm     -0.9
28 H Distance    7    1    1655.175     4.7mm      0.1mm      0.0
29 H Distance    7  105    2139.940     5.1mm      0.8mm      0.1
30 Direction     1    2  330 48 42.     2.1sec     1.3sec     0.6
31 Direction     1  205   40 47 39.     2.1sec    -4.4sec    -2.1
```

```
32 Direction     1    7  187 43 18.     2.0sec     1.8sec     0.9
33 Direction     2    1   30 21 49.     2.1sec    -0.5sec    -0.2
34 Direction     2    3  257 34 25.     2.0sec    -0.1sec     0.0
35 Direction     3    2   13 39 08.     2.0sec    -0.4sec    -0.2
36 Direction     3  204  322 19 10.     2.0sec     4.2sec     2.1
37 Direction   204    3  131 31 09.     2.0sec    -4.0sec    -2.0
38 Direction   204  205  354 18 31.     2.3sec     5.2sec     2.3
39 Direction   205    7  179 59 50.     2.0sec    -0.2sec    -0.1
40 Direction   205    1  204 57 39.     2.1sec     4.6sec     2.2
41 Direction   205  204  353 39 12.     2.3sec    -5.4sec    -2.3
42 Direction     7   11    0 00 00.     2.0sec    -0.4sec    -0.2
43 Direction     7   12  139 17 52.     2.0sec    -1.1sec    -0.5
44 Direction     7    1  308 28 23.     2.0sec     0.2sec     0.1
45 Direction     7  205  316 34 46.     2.0sec    -1.7sec    -0.9
46 H Distance    1    2      538.101    3.5mm    -0.3mm     -0.1
47 H Distance    1  205      552.960    3.6mm    -1.6mm     -0.5
48 H Distance    1    7     1655.178    4.7mm    -2.9mm     -0.6
49 H Distance    2    1      538.098    3.5mm     2.7mm      0.8
50 H Distance    2    3      848.342    3.8mm    -3.0mm     -0.8
51 H Distance    3    2      848.336    3.8mm     3.0mm      0.8
52 H Distance    3  204      732.506    3.7mm    -7.1mm     -1.9
53 H Distance  204    3      732.491    3.7mm     7.9mm      2.1
54 H Distance  204  205      249.099    3.2mm     3.3mm      1.0
55 H Distance  205    1      552.957    3.6mm     1.4mm      0.4
56 H Distance  205  204      249.105    3.2mm    -2.7mm     -0.8
57 H Distance    7    1     1655.171    4.7mm     4.1mm      0.9
58 H Distance    7  205     2139.930    5.1mm     2.0mm      0.4

Variance Factor is  1.75 [n-u = 36]

Standard Deviations and Error ellipses in mm  |     95% Confidence Level
[These are NOT multiplied by sqrt VF]         | [These are multiplied by √VF F]
                                              | [ie *√(VF*2*F0.05,2,n-u)]
Point    SE      SN      Semi-   Semi-    Brg |    E       N       Semi-   Semi-
                         major   minor     °  |                    major   minor
  7      0.0     0.0      0.0     0.0     0   |   0.0     0.0      0.0     0.0
 11      0.0     0.0      0.0     0.0     0   |   0.0     0.0      0.0     0.0
 12      0.0     0.0      0.0     0.0     0   |   0.0     0.0      0.0     0.0
  1     10.1     5.7     11.5     2.0   118   |  34.3    19.4     38.8     6.9
  2     14.1     5.6     14.8     3.3   108   |  47.8    18.8     50.1    11.3
  3     19.5     9.0     21.3     3.2   114   |  66.0    30.5     71.9    10.8
104     13.7    10.3     16.8     3.3   126   |  46.4    34.8     56.9    11.2
204     13.7    10.3     16.8     3.3   126   |  46.4    34.8     56.9    11.2
105     12.1     9.2     14.9     2.8   127   |  40.9    31.3     50.5     9.6
205     12.1     9.2     14.9     2.8   127   |  40.9    31.3     50.5     9.6

Calculated Lines between adjusted coordinates
From  To  Horiz Distance +/-    Bearing     Relative error ellipse in mm
                m        mm                  Semi-maj Semi-min  Brg°
104  204      0.0092    4.1     75 36 55      4.2      3.2       93
105  205      0.0129    3.6    348 53 04      3.9      2.9      130
```

Q36. Cost-effective Monitoring of Slope Failure

Background

On a very dark stormy night, a 20m long section of a national motorway simply disappeared because of slope failure as a result of days of heavy rainfall. But no one knew anything about this geological disaster. On the motorway a young couple was driving their Toyota, following a motor cyclist at a distance because of the heavy rain. At a sharp turn, the cyclist just vanished at the above mentioned section of the road. The young couple reacted quickly and managed to stop their car just in front of the collapsed segment of the road. They rang the traffic management centre to report the incident and set up road blocks to warn other drivers before the arrival of police.

Problem
How can such slope failures (and similar geological disasters) be monitored in real-time and cost-effectively, so that timely warnings can be sent to road users and traffic management authorities?

[Thanks to Linlin Ge for supplying this question.]

Q37. Survey Design, building movement
Imagine you are a graduate surveyor working in a private company in Sydney. Read the following email and write a reply. You may ask the sender for more information, and you should suggest a few alternative survey designs. For each of your survey designs you should mention some of the important considerations, constraints or issues. Include sketches in your answer.

Hello [insert your name],

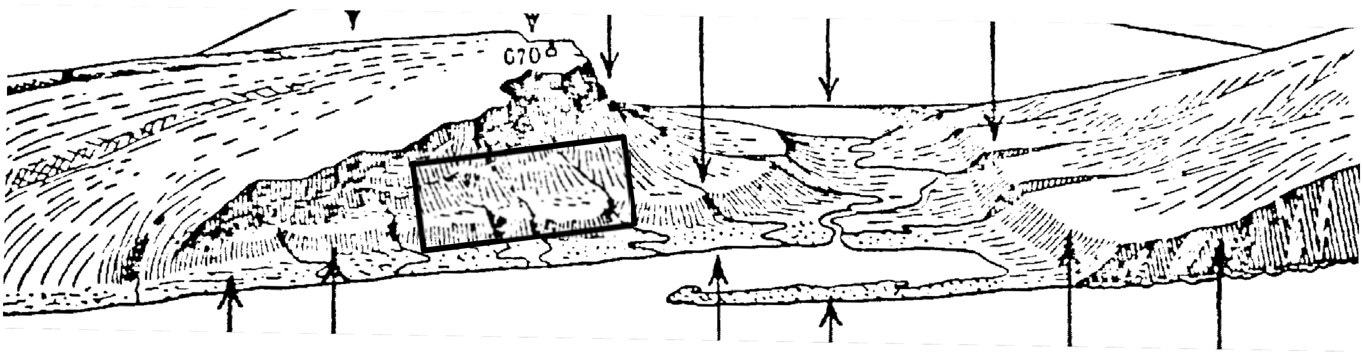
I am Project Director on the new building being built for xxx University. The new building is going to accommodate the School of Engineering.

As a tool to assist lecturers in the engineering discipline it has been suggested as a good initiative if the project could install a measuring device or two that could measure the movement in the building in some way. The design and construction team are looking for some advice on what to install and how. This could be on a stair, a column a slab or we are not sure!

Have you any ideas? Or can you point me in the right direction, it would be great.

Regards
Fred …

Q38. Land Stability Monitoring, design
An area of land, approximately 100 m by 300 m has been selected for future subdivision and urban development. The area of land is shown by the box in the figure below. The land is situated between Sydney and Wollongong near a coastal beach on the steep slope. Coal mining has been performed under this area. There may be possible land slips so it is necessary to monitor any surface movement that might occur. Ignore the arrows in the figure below.



Discuss the factors you would take into consideration in designing a survey to measure and monitor any possible movement in this site and outline how you might undertake the survey.

Q39. Bridge deformation survey design

Background information:
A group of researchers aim to monitor the structural integrity of a cable-stayed bridge due to a vehicle passing over the bridge, at the level of ± 1mm or better. You have been employed as a consultant surveyor to monitor the displacement of the bridge at discrete points.

The bridge crosses over the Great Western Highway in western Sydney. Site photos viewed from south of the bridge and an elevation drawing of the bridge, with dimensions, viewed from the north side of the bridge, are shown. (At right and below)

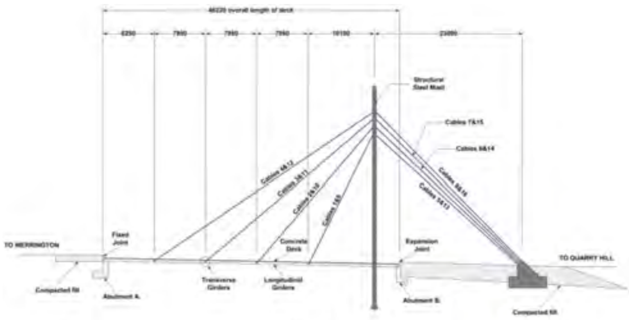
The bridge has two abutments with a major span length of 42m between abutment A and the bridge mast. This bridge carries one traffic lane and one sidewalk with maximum loading capacity of 30 T. The deck has a width of 6.3m.

Survey targets can be directly mounted on the top of the side guide rail. The equipment available includes, digital level, Robotic Total Station, a laser scanner and ancillaries. You are requested to survey four discrete points along the bridge span. These four points correspond to the intersection of the cables with the deck.

(a)

(b)

(c)



(a) Bridge elevation.

You are asked to give a written reply to this request. In your reply:

- Include any requests you might have for further information from the client.
- Comment, with reasons, on which equipment(s) you would use and marks you would place.
- Design, with the aid of simple plan view sketches, the survey you would recommend.
- Comment on how you would ensure the accuracy (not merely precision) of any deformations you find.
- Describe the analysis techniques and statistical testing you would use in this project.

Q40. Deformation, Height under building

The following (edited) email was received recently. Your task is to write a reply to the email.
Background information: This question is about accurately measuring changes in relative heights (settlements) with marks at the base of each column and on the roof beams in the photo below. Absolute height is not required (that is, no connection to AHD). The site is in Sydney under a building.

Hi Bruce,
A quick question if I may; we have a project where we are wanting to get differential movements over of an area that is maybe 50 metres by 50 metres underground (a clearance to the ceilings of about 3 metres). My question is, using conventional surveying means, and setting up a say 7 metre by 7 metre grid of points, what differential accuracy can I achieve over this length if I were to come back at various times of a period of say 6 months or 1 year? Is better that 0.5 mm accuracy doable? Also, could we put markers overhead on the slab above and also get any movement? …
Cheers
…..
In your reply to this email:

- Comment on the equipment you would use and marks you would place.
- Design, with the aid of simple plan view sketches, the survey you would recommend.
- Comment on how you would ensure the accuracy (not merely precision) of any deformations you find.
- Describe the analysis techniques and statistical testing you would use in this project.

Q41. Survey Design, Sydney Harbour Bridge
The following (edited) email was received on …. Write a suitable reply to it, considering how the survey might be done and what considerations need to be made.

Hi …,

… I have received a job and I would appreciate your thoughts on what is the best way to do it.

We are requested to survey 3 survey prisms located at ends and centre of the Sydney Harbour Bridge arch (western side) to find out horizontal and vertical movement in each point caused by passing trains. Observations should be simultaneous to each prism (at say 1 sec intervals), with notes of train positions at the time (bridge ends and particularly centre). Survey should be done during morning peak hours with heaviest load. …. We would need to synchronise time between instruments somehow and relate survey stations.

What observations should be taken so we don't miss anything and where from?

The bridge arch is moving, and we need to find out by how much. The results will be used for fatigue analysis.

Many thanks…

Atmospheric and earth curvature effects

Q42. Atmospheric effects

Referring to figures below, total station observations were made on stable ground surrounding an open cut mine slope from pillar 100 to four control sites (1, 2, 5, 6) with known coordinates. A few monitoring points (8, 13, 22) were observed on the mine slope. The horizontal distance 100 to 22 is 594 m and the Zenith Angle 100 to 22 is 91°.

a) **Describe** a method that could be used to calculate the height of point 22, using the zenith angle from 100 to 22 corrected for refraction and earth curvature.

b) **Describe** any assumptions about atmospheric conditions in this method.

c) **Calculate** the effect of earth curvature on the height difference 100 to 22 and estimate the range of possible effects of atmospheric bending on the height difference 100 to 22.

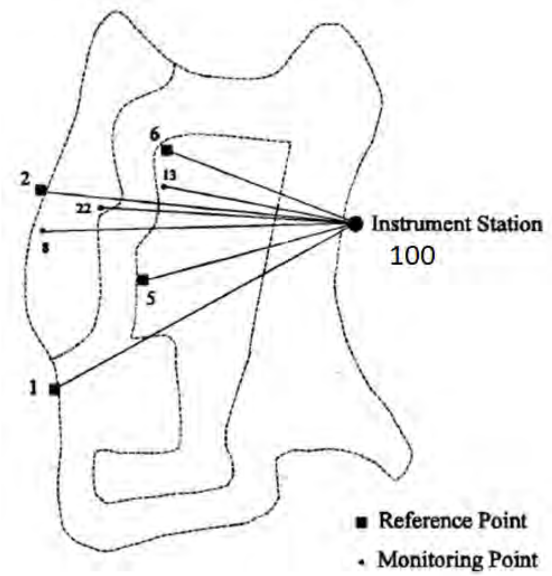


Photo of a Cobar Mine, western NSW, supplied by Joshua Maile.

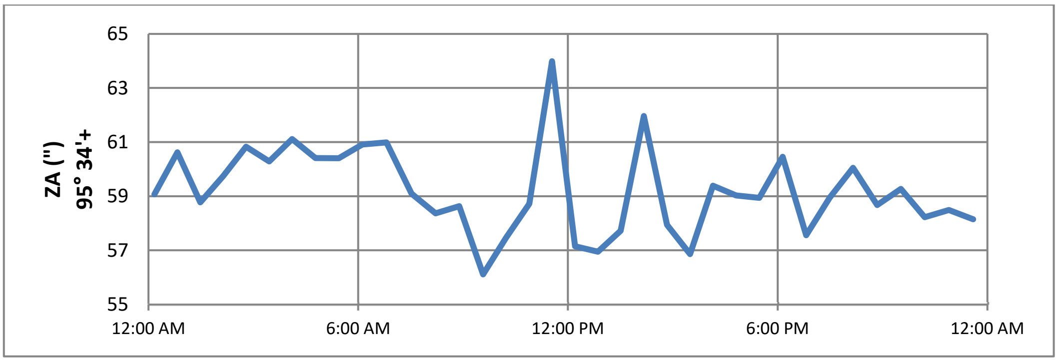
Q43. Atmospheric effects, email

The following (edited) email was received.

Hi …,

… I have collected some ZA data on a job in Burwood with a Robotic TS and I would appreciate your thoughts on what is the best way to do it.

The ZA data was recorded for a 24 hour period at about 50 minute intervals and is plotted in graph below. The recorded data was not corrected for atmospheric effects or earth curvature. The horizontal distance from instrument to prism is about 137 metres.



Any comments you have would be most appreciated. Maybe you could use this as an exam question?

Cheers ….

In your reply to this email:

a) Interpret the data in the graph and comment on your conclusions.
b) What would you suggest could be done in this project to improve the monitoring of the heights of this prism?
c) Estimate or calculate the magnitude of the effect of earth curvature on height difference for this non-reciprocal observed line.
d) Estimate or calculate the magnitude of the effect of atmospheric bending on height difference for this non-reciprocal observed line. Specify what value of k you use.

Q44. Atmospheric effects, Anzac Bridge

Total station observations were made from pillar 2 to three sites (3, 4, 5) with accurate known coordinates on stable ground or structures surrounding the ANZAC bridge, Sydney. Figure below is for illustrative purposes only and does not relate specifically to the measurements. A point (6) was observed on the edge of the bridge deck as part of a monitoring survey to determine how much the bridge deck moves up and down. Point 6 is not shown in the figure. [There were actually many other points on the bridge deck but this question only deals with point 6.]

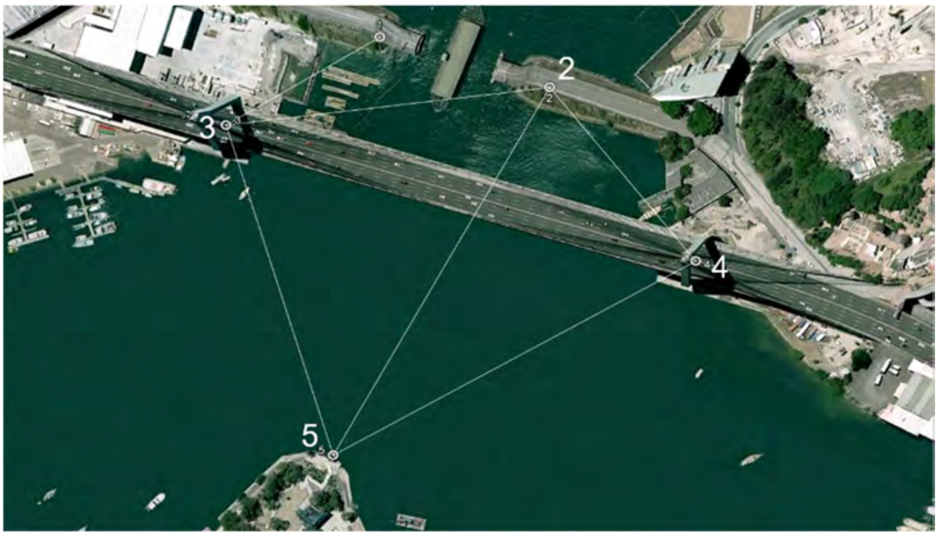


Figure ANZAC bridge survey

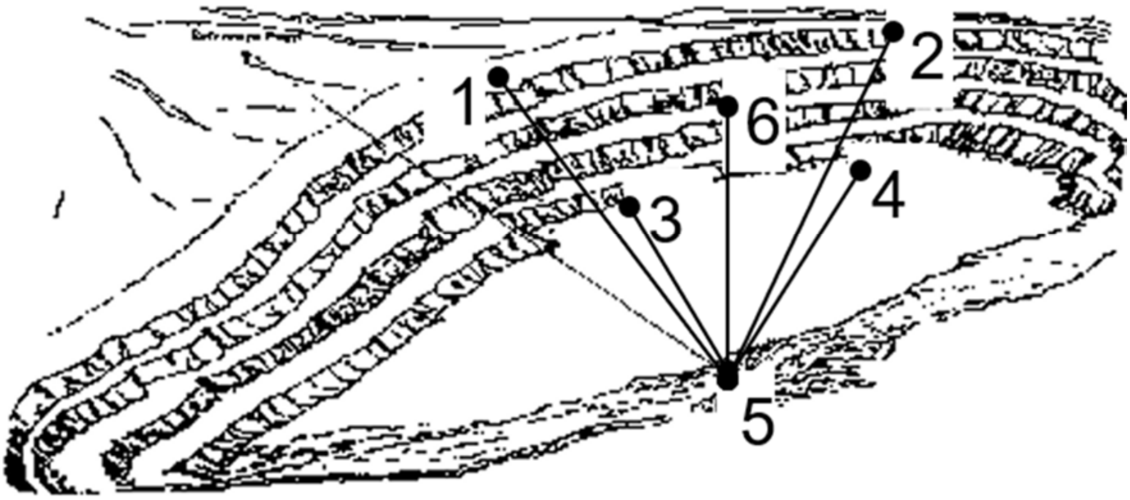
From the known ENH coordinates of points 2, 3, 4 and 5 the Zenith Angle (ZA) and slope distance were calculated and shown in the table below. Also shown in the table are the measured values (mean of FL and FR). Assume the differences between measured and calculated values are due purely to atmospheric effects.

From	To	Measured ZA	ZA from coordinates	Measured Slope Dist (m)	Slope Dist from coordinates (m)
2	3	85°24’06”	85°24’15”	227.663	227.669
2	4	83°34’22”	83°34’29”	162.907	162.911
2	5	91°22’00”	91°22’12”	311.854	311.862
2	6	81°04’13”		142.886	

a) Calculate the zenith angle from 2 to 6, corrected for atmospheric effects, using the data in the table.
b) Briefly describe the method that you used to correct the zenith angle from 2 to 6 in part (a) above. Also describe any assumptions about atmospheric conditions in this method.
c) Calculate the slope distance from 2 to 6, corrected for atmospheric conditions using the data above.

Q45. Atmospheric effects, Open Pit mine

Referring to the figure below, total station observations were made from pillar 5 to four sites (1-4) with known coordinates on stable ground surrounding an open cut mine slope. One point (6) was observed on the mine slope.



a) **Describe** a method that could be used to correct the zenith angle from 5 to 6 for refraction.
b) **Describe** any assumptions about atmospheric conditions in this method.
c) **Calculate** the zenith angle from 5 to 6, corrected for refraction using the data below. The observations below are the mean of FL and FR observations.

Observation	From	To	Measurement	Values derived from control coordinates
DIRECTION	5	1	0°00′00″	134°13′03″
DIRECTION	5	2	53 34 54	187 48 00
DIRECTION	5	3	2 02 54	136 15
DIRECTION	5	4	55 58 30	190 11 34
DIRECTION	5	6	33 14 35	
SLOPE DIST	5	1	747.384 m	747.375 m
SLOPE DIST	5	2	709.290	709.281
SLOPE DIST	5	3	605.148	605.140
SLOPE DIST	5	4	541.612	541.606
SLOPE DIST	5	6	594.410	
ZENITH ANG	5	1	88°14′15″	88°13′20″
ZENITH ANG	5	2	87 29 59	87 29 09
ZENITH ANG	5	3	95 48 41	95 48 01
ZENITH ANG	5	4	96 40 28	96 39 50
ZENITH ANG	5	6	91 15 29	

Construction site surveys

Q46. Construction surveys

A) Your total station has a laser plummet, but it is not working (total stations with laser plummets do not have an optical plummet). How can you set up accurately over a mark to continue a traverse? You have no other theodolites or total stations with you in the field and you do not leave the field.

B) Describe a precise and accurate survey technique to measure the distance from a survey instrument to a mark (a cross drawn with a thin felt tip pen) on the face of a smooth wall. The wall is not perpendicular to the line of sight and the distance is about 20 – 30m.

C) Describe at least two independent methods of transferring Easting, Northing and Height coordinates from ground level up to each floor of a new high rise building during construction. The building is in the Central Business District of a city like Sydney and is to be about the same height as several of the tallest buildings currently in the city. Include sketches.

Q47. Construction surveys, glass

As a surveyor at a construction site you are considering whether to take observations through a glass window. Your observations will be directions, zenith angle and distance or a laser scan point cloud. Your instruments are a laser scanner and a total station. The total station has EDM that can measure to a prism or in reflectorless mode and it has ATR (automatic pointing). Discuss your considerations.

Q48. Construction surveys, bridge

A new bridge is going to be built over a floodplain on the NSW coast. The bridge project will span several years. The process from a survey involvement perspective will be a control survey, then Digital Terrain Modelling surveys for final design and to produce details survey plans and 3D models of the site, cadastral boundary surveys, construction set out surveys, as-built (WAEx) surveys, and ongoing deformation monitoring surveys after completion. There will be many different surveyors involved. The MGA combined scale factor for the site is 0.999603. Some details of the bridge: 3.5 kilometres long, maximum clearance is 15m above the flood plain; 93 piers; the prefabricated slabs for each span are very heavy and move the bridge pylons/piers during placement; and each span is 34m in length. The bridge is not a straight line in plan view.

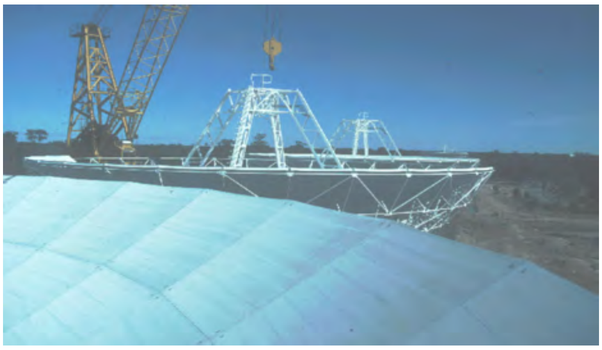
Describe the important survey considerations that have to be planned and specified by the project's survey manager dealing with the construction surveying parts of the project.

Q49. Recovery marks

Give two reasons for using **nearby** relocation (recovery) marks around reference point survey marks in deformation or construction site networks? To what accuracy would you expect to relocate a point, using common total station instruments?

Q50. Radio telescope surface

Several new radio telescopes are being built in NSW. You have been asked to survey the surface of one telescope's dish to find any imperfections at the 0.5 mm level. The dish is about 20m diameter and is required to be parabolic to focus the radio waves to the receiver at the centre of the telescope. A high precision surface enables high quality radio astronomy data. The dish is composed of about 160 panels. Each panel has a target at its four corners. The heights of the panels can be adjusted up and down with bolts under the four corners. Design and describe a survey method to meet these requirements.



Other questions

Here are a few other topics. There are some topics in our course that are important, but I have never asked exam questions about them. Some of the weekly quiz questions do cover other topics. Sometimes we ask questions that are not specific to any one type of instrumentation. Students choose their preferred method and justify their answer. Any choice is fine as long as it is appropriate and well justified.

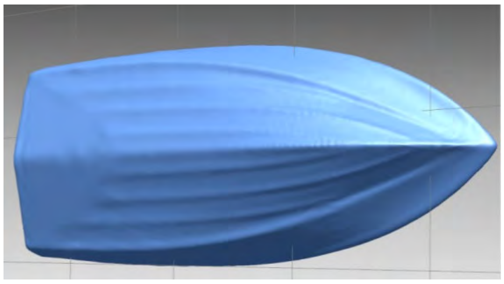
Q51. Guest lectures on Project Surveying

In 2023 there were two guest lectures (Steven and Alastair) that described some challenging survey projects. Briefly summarise five of the key points raised in those lectures. Place an emphasis on the messages and wisdom conveyed, rather than a list of topics presented.

In 2021 one of our guest lecturers (Michael) described a deformation survey across a valley that contained a creek and waterfall in a natural wilderness area. A longwall coal mine excavation approaches under the site. Describe the method and discuss the reasons for the method that Michael adopted.

Q52. Survey design

A mould has been constructed to produce fibreglass boats 3m long, 1.5m wide, and 1m deep. A survey is required to measure the coordinates of about 30 key points on the mould to ±1mm precision. The equipment you own is the same as in the UNSW survey store. Draw a plan showing the location of equipment and targets.



Discuss:

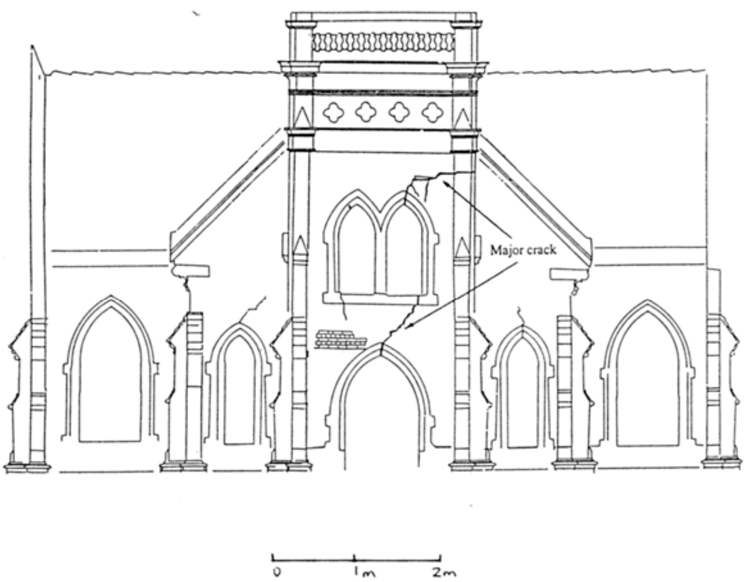
- measurements and processing required,
- type of equipment and expected accuracies,
- can this survey be done without a laser scanner?

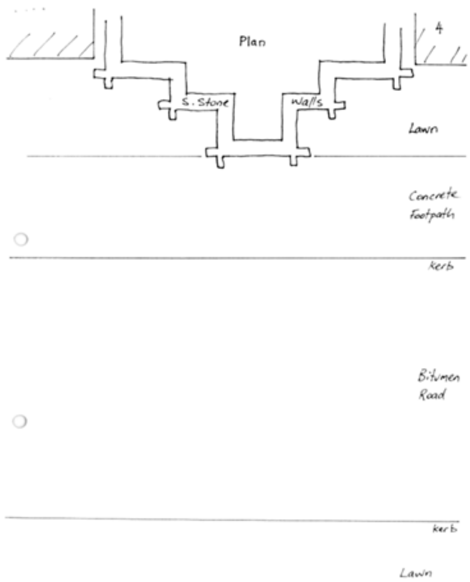
Q53. Survey Design, Church façade

[I asked this question 30 years ago, it might be useful now?]

The front elevation and plan views of an old sandstone building are given below. The interior and rear of the building are to be demolished and rebuilt. The intention is to preserve the front of the old building. List 3 survey methods / technology / instrumentation that could be used to do this survey? Choose one method that you think is best for this survey and justify your choice.

Describe the measurements you would take to monitor movements of the front walls during demolition and construction. Mark the positions of instrument sites and targets on the plan and elevation below. Describe the type of targets you would use. How would you process the data? Estimate the magnitude of movements you could reliably detect. Estimate how long would the fieldwork take and how long the office work.





Q54. Survey Design – axes determination
In an indoor industrial setting a large (3m long) turbine generator is being installed. The turbine's shell (housing) is open, and the inner workings can be rotated about a concealed axle. It is not possible to put targets on the ends of the centreline of the axle. It is important for the axle to be horizontal. Describe how you would determine the location and orientation of the centreline of the axle i.e. the coordinates of a point on the centreline and the bearing and slope of the centreline. Mention both measurement and analysis aspects in your answer. Include a sketch to illustrate your method.

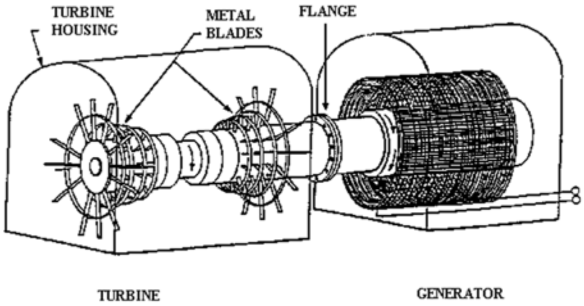
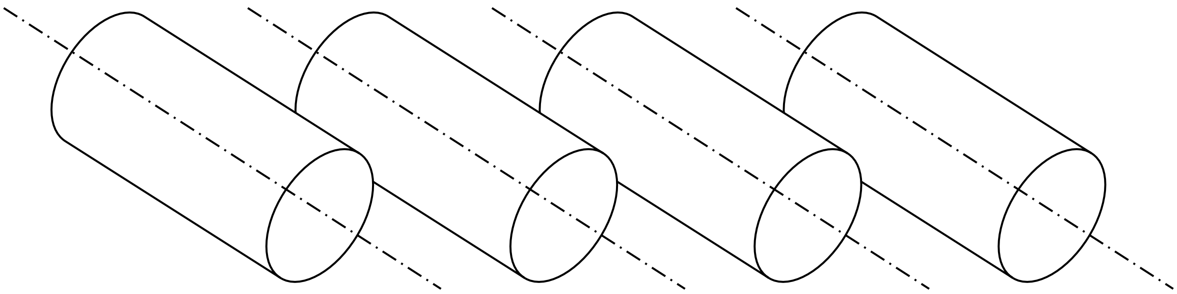


Figure. Turbine

Q55. Survey Design – axes determination
In an indoor steelworks twenty large (3m long) roller bearings form a conveyor to transport very hot metal slabs. If the rollers are not carefully aligned, then the metal slab will slide towards the side of the conveyor or be buffeted up and down as it moves. The tops of the rollers form an approximately horizontal plane. Each roller bearing rotates about a concealed axle. It is not possible to put targets on the ends of the centreline of the axle.

Describe how you would determine the location and orientation of the centreline of all the axles i.e. the coordinates of a point on the centreline and the bearing and slope of the centreline. Mention both measurement and analysis aspects in your answer. Include a sketch to illustrate your method.



Q56. High Precision Theodolite intersection survey
Estimate the accuracy of 3D coordinates that you could get from a survey of a small aircraft undercarriage given the following information. The maximum dimension of the aircraft part is 10 m long. You have two theodolites that can read directions and zenith angles to better than ±1", sturdy tripods, and an accurately calibrated scale bar. There are clear cross targets marked on the object. Draw a sketch to show your design of such a survey, including instrument and scale bar location.

Q57. Sports
Describe the survey measurement aspects of one Olympic or World Championship sporting event. Include diagrams in your answer. Events covered in this course include field throwing and jumping, swimming pool lane lengths, and marathon length.

<u>Another version of this question:</u>
Assume you are managing a survey company that has the equipment, software and experience for the following survey. You have been requested to survey and certify that the pool in your city is suitable for world swimming records to be set. Under Olympic rules every lane in an Olympic pool has to be no shorter than 50 metres. At each end of each lane of the pool there are touch pads under water. The shortest distance between the touch pads in each lane has to be measured. You cannot drain water out of the pool. Design a suitable survey method. Describe the method and include diagrams.

POSSIBLE ANSWERS OR SUGGESTIONS

Hopefully you have spent some time and thought to answer the questions before reading this section. Trying to solve them is an important part of your education. If you have tried to answer the question, then refer to the comments below to self-assess your answers.

There are many good solutions to some problems. You might find the Barometer question interesting. Read about it at en.wikipedia.org/wiki/Barometer_question, or elsewhere. By the way, one of my teachers (John Allman) did his PhD at UNSW on using barometers to determine heights.

Q1. Methodology

Some key words in your answer: Understand the problem and any non-surveying aspects of the project; literature search or similar for other surveyors solving similar problems; which equipment to use; which points and lines; accuracy required; LS simulation; archive the data, results, and report, and possibly conference presentation at the end. Also refer to aspects from Brunner's list in the class notes.

This question focusses on some differences between a professional surveyor and a field assistant. Many students answer this well, some thoughtful, some merely writing about what they read. We are trying to prepare you for a future career with challenging and rewarding projects, not doing the same work every day for 40 years.

Q2. Methodology

Fritz Brunner was one of my teachers. He wrote the paper: Brunner, F. K., (2007) On the methodology of Engineering Geodesy. Journal of Applied Geodesy 1 (2007), pp 57-62, de Gruyter. I extended the paper in 2021 and supply the extended version to my students, but it is not published elsewhere.

Some student answers:

- Quality control by built in **checks** (gross and systematic errors) , **QA procedures** etc.
- A professional conclusion to the project.
- The results might be presented in **a report**, a conference presentation or a publication that is a clear communication of the results.
- prove that the client's desired precision and accuracy has been achieved.
- Some projects have a clear ending, but others are ongoing. Ongoing projects may have progress reports.
- After all tasks have been finished quality control of the final results to prove that the desired precision has been achieved.
- Sometimes **the successful result** of the project is physically evident, e.g. tunnel boring from two directions with successful breakthrough, tall building completed, safety warnings from deformation monitoring that were effective in predicting collapse or not, alignment of conveyor roller bearings that "work" (the red-hot ingots move correctly along them and don't skew off onto the nearby floor).
- In some projects **statistical tests**.
- Report describes the original task and compare it with the results in terms of confidence and reliability measures (e.g. coordinates need error ellipses)
- Communication can be tested by **feedback from the client**.
- Reports can include graphical communication with graphs, plans, maps, profiles, 3D visualisations etc.
- liability protection and disclaimers about the breadth of responsibility.
- collecting fees; and
- **archival** of data and other records of the project.

Q3. Methodology

Reference: Rudolf Staiger, "Push the Button – or Does the Art of Measurement Still Exist?" This paper has been prepared and presented as a keynote presentation in Plenary Session 3 – GNSS, Geosciences and Surveying at the FIG Working Week 2009. International Federation of Surveyors, Article of the Month – June 2009. www.fig.net/resources/proceedings/fig_proceedings/fig2009/papers/ps03/ps03_staiger_3513.pdf

Reference: Johannes Schwarz, "Surveying in the Year 2020 - Potential impacts of emerging technologies on surveying applications and instrumentation - A manufacturer's perspective", FIG International Conference, Sydney, 2010. www.fig.net/resources/proceedings/fig_proceedings/fig2010/ppt/alt03/alt03_schwarz_ppt_4655.pdf

Reference: Peter Byrne and Gail Kenny, The ABC of x.y.z - 21 Principles for consideration by Surveyors and other Geospatial Professionals, Papers TS 7E, FIG Woking Week 2007, Hong Kong, 13-17 May 2007, 18 pages
www.fig.net/resources/proceedings/fig_proceedings/fig2007/papers/ts_7e/ts07e_02_byrne_kelly_1466.pdf

These are some of our students' answers. The surveyor:

1. Can design and execute a network or solution using the most effective and efficient form
2. Need to use the most appropriate instruments for the task
3. Must be able to optimize their measurements while aiming to reduce errors. And include checks
4. understands the reasons and the causes of errors in the field that may arise when executing survey. Thus, being familiar with methods to eliminate/prevent these errors
5. Understanding the problem, both what the client has requested, and what they might actually want (not always the same!)
6. Tailor a unique solution for the client.
7. Ability to change these plans on the go, should any new issues arise
8. capable of evaluating the situation, and using this analysis to choose the right tool for the job
9. understanding the rules and the regulations for different surveys is also important.
10. consult with others in the profession who may have had experience in solving similar challenges and ultimately come up with an 'outside the box' solution.
11. surveyors are now able to follow the on-screen prompts and in many cases set the total station to automatic mode, in which it will automatically measure and record results. This can be problematic in that the surveyor will often assume that all recorded measurements are true and accurate rather than checking each measurement individually and using intuition to determine whether the results make sense and are accurate and reliable.
12. Checks, capability and logistics of doing things are important as the instrument
13. Archiving is also an important final step in the process

Q4. Methodology

- Having a thorough and in depth knowledge of surveying. More than just remembering information about survey techniques and equipment.
- Understand the problem, know what the "client" needs even if he/she doesn't really know themself, then design the solution
- Discussion: eg, the client might ask for 0.1mm accuracies, when they are told by the surveyor that that will be much more difficult and expensive than a survey at say 1mm accuracy, then they may reconsider.
- Consider alternative approaches
- Think about the most appropriate technique. Should we use equipment or software we have or procedures we are most familiar with, or is something else better? Examples: Should we traverse and radiate with a total station, or use GPS? Should we use laser scanning or photogrammetry?
- "Organisation". Have the skills to manage a medium to large scale project.
- Checks! No surveyor should tackle any job without taking good quality checks to ensure no mistakes slip through costing, the company or the surveyor reputation, court cases or faulty jobs that lead to injury or death.
- Having developed problem solving skills throughout their studies graduate surveyors should be able to contribute to survey design and tackling problems that may arise in the survey design of a large scale survey project.
- They should also be able to contribute to the technological advancement of a company giving ideas on possible new techniques or instruments that may be used to carry out particular parts of a large scale survey project. They should also be able to test these new instruments to ensure they are right for the jobs, by testing for possible instrument errors.

Q5. Methodology

This is mostly a memory question for those students who have read the reference material. List:

- Organisation and logistics
- Point sampling of natural surfaces and objects
- Observations and coordinates
- Coordinate reference systems and datums
- Parameters and desired precisions
- Network design
- Quality control of equipment and measurements

- Choice of adjustment models and software

Descriptions, eg

- LS simulations to assist design.
- Quality control by built in checks (gross and systematic errors) , QA procedures etc.
- After all tasks have been finished quality control of the final results to prove that the desired precision has been achieved.
- Sometimes the successful result of the project is physically evident, e.g. tunnel boring from two directions with successful breakthrough, tall building completed, safety warnings from deformation monitoring that were effective in predicting collapse or not, alignment of conveyor roller bearings that "work" (the red-hot ingots move correctly along them and don't skew off onto the nearby floor). In other projects statistical tests.

Q6. Methodology

Reference: Joël van Cranenbroeck, "New Design for Hydro Power Plant Structural Geodetic Monitoring Network", FIG Working Week, Morocco, 2011.
www.fig.net/resources/proceedings/fig_proceedings/fig2011/ppt/ts01e/ts01e_vancranenbroeck_4763_ppt.pdf

- Understand the project.
- Site visit and meetings, site inspection and final design
- Design where to place survey marks and type of equipment.
- Simulation on the final design proposal (by Least Squares adjustment)
- 24/7 observations. Installation and network processing
- Fine tuning and acceptance, contractual maintenance, and support.
- A professional conclusion to the project. The results might be presented in a report, a conference presentation or a publication that is a clear communication of the results.

Q7. Methodology

This required you to have read the references and give some details, not just say reduce errors and have a good presentation – which was the title of that section. Mention things like:

- Quality control by built in checks (gross and systematic errors) , QA procedures etc.
- The results might be presented in a report, a conference presentation or a publication that is a clear communication of the results.
- Prove that the client's desired precision etc has been achieved.
- Some projects have a clear ending, but others are ongoing. Ongoing projects may have progress reports.
- Sometimes the successful result of the project is physically evident, e.g. tunnel boring from two directions with successful breakthrough, tall building completed, safety warnings from deformation monitoring that were effective in predicting collapse or not, alignment of conveyor roller bearings that "work" (the red hot ingots move correctly along them and don't skew off onto the nearby floor).
- In other projects statistical tests.
- Report describes the original task and compare it with the results in terms of confidence and reliability measures (e.g. coordinates need error ellipses)
- Communication can be tested by feedback from the client.
- Reports can include graphical communication with graphs, plans, maps, profiles, 3D visualisations etc.
- Liability protection and disclaimers about the breadth of responsibility.
- Collecting fees.
- Archive of data and other records of the project and backup.

Q8. Expert Witness

In NSW expert witnesses are independent. They do not represent either party in the case. In class I present a real project that I did that is similar to the circumstances in this question. That can guide students' answers. Be careful when told that results are required urgently. Rushing can lead to mistakes. If you are concerned about the time limit, either withdraw from the project or make it clear that the work will take some time.

Q9. Ethics

This question requires examples of ethical issues not a description of a code of ethics. The examples could be linked to some aspects of codes of ethics. Sometimes answers to this question come from student's work experience.

Sometimes examples of ethical issues in surveying projects come from seminar presentations in our classes (see assignments below). These seminars are based on conference or other publications studied by students.

Q10. Laser Scanning, Morpeth Tower

a) e.g.

- Does not need long range or 360 ° so can be more accurate instrument.
- Speed not so important
- laser class not critical
- Spot size small, eg 5mm dot OK
- Tower is stationary so may not need faster phase-based instrument. If you choose phase and justify it well (eg that is the type your firm has, and the tower is within the range of the instrument) that is OK.
- One that can be set up over a survey mark and levelled might be helpful for coordination.
- Find out what the client really wants/ needs e.g. scan interval / resolution. Otherwise moderate not high resolution for this smooth surface. Grid interval 5cm might be small enough.
- Camera / images not needed.

b) Some students did not design the survey in a way that joins the multiple scans together (registration) well. The conical surface is reasonably featureless so the object itself is not good enough to join point clouds. Targets need to be observable from at least two instrument stations. If targets are placed on instrument locations (like constrained centring traversing) that helps with the registration of the point clouds for this project.

- Decent sketch plan.
- Probably 3 or 4 instrument locations. Too many instrument setups and too many targets is time consuming and expensive. Not too close to tower (observations to the higher sections may not reflect well).
- Instrument and target locations designed to assist joining (registering) the multiple scans together.
- Targets on ground around tower and a few higher up stuck on sides (with ladder) but not more than a few metres above ground.
- Overlap of scans from multiple sites via common targets

c)

- H&S eye protection, especially class 3R: trained operators, warning signs. Don't look at beam with another survey telescope. Safety if climbing to place targets.
- Local control survey (MGA not necessary) to coordinate scanner setup locations or locations of targets. The control marks will be places so that there is a convenient network geometry and also that their coordinates can be determined from other methods such as traversing or GPS.
- Set up in a safe place, away from pedestrians and out of harm's way such as traffic movement areas.
- Scan targets from multiple locations
- Test and or calibrate the scanner.
- Register / combine the scans.
- Remove unwanted points / noise.
- Model conical surface and investigate deviations from best fit. Are there any bulges or indents? Is the centre line of the tower vertical?

d) Problems

- It is important that the **angle of the surface is close to perpendicular** in relation to the beam so that diffuse reflections are avoided.
- Non reflection from upper end of tower, especially if it is wet.
- Occultation's due to pipes etc at base of tower.
- Choose to setup in a location that is stable.
- Scanning the northern side of the tower could be difficult due trees.
- Instrument not too close to tower so lines not too steep (with poor reflection due to incidence angle)
- Temperature effects on metal structure, significant or not?

Q11. Laser scanning, CDB façade

Examples of student answers. I did this project when laser scanning was new (early 2000).

a) Which parts require high resolution? Is deformation monitoring required or is this a once only survey? Can we access the site to place targets eg via upstairs windows? Test the instrument and software – calibration if not done recently. Can we access across the road and higher up for the instrument.

b) Instrument in two or more locations to get more hidden features. Targets near windows so multi scans can be registered, can also use the awning cables to assist with registration. Sketch.
c) Scan high resolution for the small parts. Scan from more than one location. Might also consider using a handheld scanner held near the sculptures in addition to the ground-based TLS of the façade.
d) Access for instrument on other side of road. Can we set up high enough to see features. Road and pedestrian traffic if cannot set up above them. Not able to put targets on building then can use features to register scans. Is feasible or not? – no right or wrong answer, if they make a claim and justify well then that is worth a mark. I think it is feasible as long as the client is made aware that some parts of some of the sculptures might not be captured. Wet surface = poor reflection if raining.

Q12. Laser Scanning, rock slope

This project was completed by one of our former students (Hi George) in Hong Kong.

a) 1 or 2 Instrument locations, set up across the road, not on the road, not too close to wall because the wall will block some of the site, targets not on rock slope (it is dangerous), if more than one setup then put a target on the other instrument location eg constrained centring. To aid registration of multiple point clouds and point clouds observed on different days place targets with constrained centring at instrument locations if multiple set ups. Targets on road barrier, and possibly above the unstable rock eg buildings behind. Perhaps set up instrument over marks (or pillars) if repeat visits are likely.

b) Traffic online so perhaps observe at night or take multiple repeat scans, OHS working near roads, scanner located safe position, vibration of instrument, rain, …

c) Compare point clouds and change of location of any targets. Set up instrument in same location (over a mark) each time and backsights also same location each time.

Q13. Laser Scanning, coal stockpile

a) Answers should be specific to this job, e.g.

- Find out what accuracy the client really wants or needs e.g. scan interval - resolution. Probably don't need mm.
- Does not need long range or 360° scanning so can be more accurate model.
- Laser class not critical.
- Stockpile is stationary so don't need faster instrument.
- Battery life – that used to be a problem especially for laptops. Can be overcome.
- Scan speed not so important – but don't want to delay operations too long.
- Camera images not needed.
- Spot size small, eg 5mm dot not critical. Grid interval 5cm might be small enough.

b) Decent sketch plus:

- Probably 3 or 4 instrument locations
- Targets on ground around pile and perhaps one on end of conveyor
- Overlap of scans from multiple sites via common targets
- Targets at other instrument locations (eg traversing / constrained centring)
- Probably traverse mode scanning – inst /target constrained cent
- Survey might be repeated weekly/monthly so perhaps place permanent marks to set up on with known coordinates and backsights.

c) Field and office tasks

- Local (MGA not necessary) control survey to coordinate scanner setup locations or locations of targets.
- Register / combine the scans.
- Remove unwanted points / noise.
- 3D Model surface with a Triangulated Irregular Network (TIN) and calculate volume.
- H&S eye protection, especially class 3R: trained operators, warning signs. Don't look at beam with another survey telescope. Safety if climbing up conveyor.
- The control marks will be places so that there is a convenient network geometry and also that their coordinates can be determined from other methods such as traversing or GPS.
- Set up in a safe place, away from pedestrians and out of harm's way such as traffic movement areas.
- Scan targets from multiple locations.
- Test and or calibrate the scanner.

d) Problems

- Ground vibrations and dust

- Poor reflection from black coal
- raining affects volume and reflections of laser difficult.
- It is important that the **angle of the surface is close to perpendicular** in relation to the beam so that diffuse reflections are avoided.
- Non reflection from upper end of pile, especially if it is wet.
- choose to setup in a location that is stable, such as on a concrete or paved surface but is also away from high traffic areas of pedestrians or cars to avoid the instrument from being disturbed and also for safety reasons.
- Inst not too close to pile so lines not too steep
- Vehicle traffic
- Need to scan when stockpile is not being added to. eg conveyor stopped at night.

Perhaps it would be better to use a handheld mobile laser scanner that can also observe from the end of the conveyor belt, or fly above the site with a drone lidar? Before laser scanners were available photogrammetry was sometimes used – that could still be used now. Doing a topo survey by walking a prism on the stockpile is a little dangerous.

Q14. 2020 Laser Scanning, Heritage Building in Annandale

a) Marks for good design with overlap of a few scan locations with targets on front wall. Possibly mention a scanner mounted up high to get different angle of scans, eg on roof etc of building nearby. The tips of spires and a few other clear parts of the building can be used as targets for registration purposes. A setup across the road on the residential house's front balcony can help to provide a better height resolution as it was mentioned that some points on the façade were quite high up.
b) Try to get close to them and do high resolution scan from multiple angles, might also consider using a handheld scanner held near the sculptures in addition to the ground based TLS of the façade.
c) Download to software like Cyclone, label targets with common number/names in the multiple scans, select a home scan and add another scan to it, then all the other scan clouds from any other setup locations, look at residuals of the target fittings.
d) Hard to set up instrument at height of the high sculptures, hard to get close to some of the sculptures, fine detail of the sculptures means some detail will be occluded (in shadow of) by other parts of the sculpture, H&S issues of road traffic and pedestrians, possible occlusion by passing cars if set up on other side of road, rain or very wet surface. Is feasible or not – no right or wrong answer, if you make a claim and justify well then that is worth marks. I think it is feasible if the client is made aware that some parts of some of the sculptures might not be captured. This survey was successfully completed by a supervised student, separate to the examination.

Q15. Laser Scanning, Berry Cottage

a) Answers should be specific to this job, e.g.

- Decent sketch plan. For a survey of a rectangular building set the instrument near the corners of the building, not in the centre of each face of the building. That allows better scan cloud overlap and registration.
- Probably 3 or 4 instrument locations – intervisible and cover whole building.
- Instrument and target locations designed to assist joining (registering) the multiple scans together.
- Targets on ground around building and a few higher up stuck on sides of structure. This building has many veranda supports and other clear and distinctive features that make scan cloud registration possible without using targets. When we did this survey, we did use targets so that students gained experience at the survey and use of targets in laser scanning.
- Overlap of scans from multiple sites via common targets

b) Many points at high resolution. Calculates average XYZ or ENH of the points that hit the target.

c)

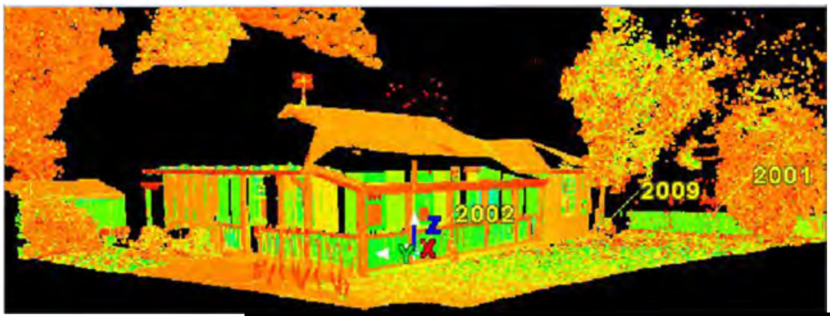
- Scan targets from multiple locations
- Use eg Cyclone software.
- Register / combine the scans – like a least squares transformation adjustment.
- Look at residuals of fit of targets – outliers?
- Remove unwanted points / noise.
- Model surfaces (eg planes, lines) and investigate deviations from best fit.

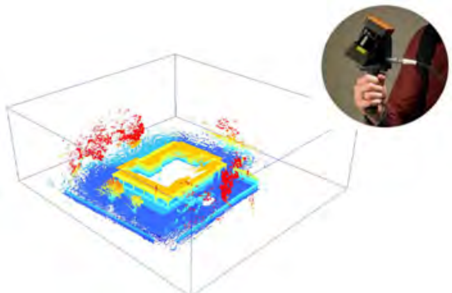
d) Problems:

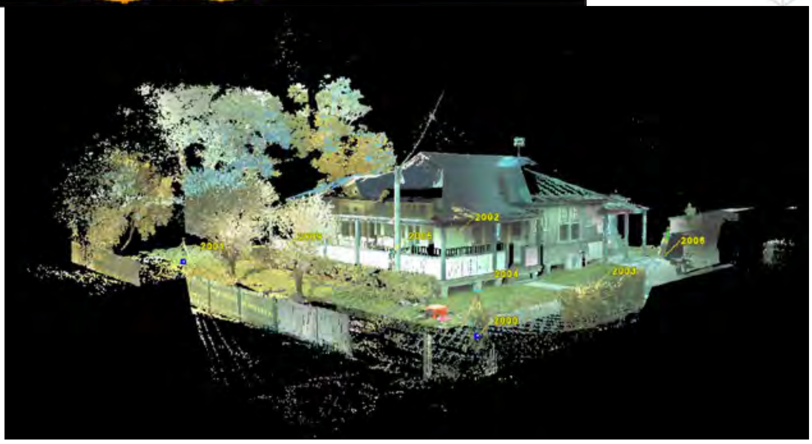
- WHS eye protection, especially class 3R: trained operators, warning signs. Don't look at beam with another survey telescope. Safety if climbing.

- Local control survey (MGA not necessary) to coordinate scanner setup locations or locations of targets. The control marks will be places so that there is a convenient network geometry and also that their coordinates can be determined from other methods such as traversing or GPS.
- Set up in a safe place, away from pedestrians and out of harm's way such as traffic movement areas.
- Occultation's due to posts etc on veranda, (shadowing) due to trees
- choose to setup in a location that is stable, such as on a concrete or paved surface but is also away from high traffic areas of pedestrians or cars to avoid the instrument from being disturbed and also for safety reasons.
- Ghosting/multipath reflections from windows

This site was surveyed by students with a Leica C10 and separately by a mobile ZEB REVO scanner, as part of another UNSW course.







Q16. Laser Scanning, Opera House

Answers should be specific to this job, e.g.

- need range to see far enough considering size of opera house, (how far you can measure). Need one that can measure at least 200m with a full 360° scan.
- Find out what the client really wants/ needs e.g. scan interval / resolution.
- Decent sketch showing setup and target locations.
- Set up on top of the two main sails and on ground around building, away from pedestrians and out of harm's way such as traffic movement areas.
- Set up on 'opposite' side of Harbour, especially to get the eastern sides.
- Overlap of scans from multiple sites.
- OHS eye protection. Safety if climbing to top of sails
- Control survey to coordinate scanner setup locations or locations of targets. The control marks will be places so that there is a convenient network geometry and also that their coordinates can be determined from other methods such as traversing or GPS.
- Scan targets from multiple locations
- Test and or calibrate the scanner
- It is important that the angle of the surface is close to perpendicular in relation to the beam so that diffuse reflections are avoided. Non reflection from some tiles that are shiny and not normal to the laser beam. May pick up their edges?
- Multiple set ups or repeat observations helps avoid **occlusions** (ie missing some detail or people walking across the scan) and less reliance on observations to surfaces oblique to the beam (less accuracy and perhaps not returned to scanner if shiny wet surface).
- Remove unwanted points / noise
- Need to register/ merge multiple scans together.

- Scanning between the two structures could be difficult due to limited space.
- Consider using drone based LIDAR (not available when this question was used).

Q17 Short Answer Questions

a) Use a hidden point rod with observations to 2+ targets, rod does not need to be vertical but should be still during obs. Alternative answers: Set up on top of that mark and do a resection. Use a prism pole at different height until the view isn't obscured. Shoot to another mark, which doesn't have an obscured view to the original mark you wanted to point at, then point at that mark. Perhaps use GPS instead, depending on sky view and accuracy requirements. If the survey is a detail/topo survey we might be able to take offsets.

b) Try observing at night with better SNR, or hire a long range model.

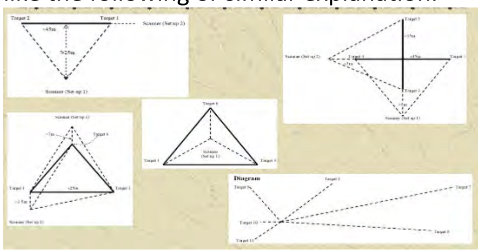
c) C A B

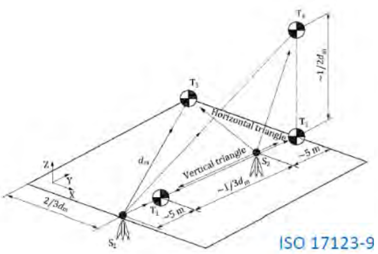
d) Protect eyes, do not look into laser with a magnifier or telescope.

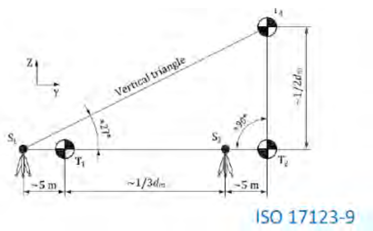
e) B

Q18. Testing TLS and reflectorless EDM

a) Could test the distance component on an EDM calibration baseline, and angles and height differences with a figure like the following or similar explanation.







b) Possible error sources in ATR pointing :

- Cross hairs not aligned with laser beams,
- False targets (e.g. safety vests or reflective tape or background behind prism)
- Two or more prisms in field of view
- Close range pointing error at ± 1 mm is a large angle.
- Wrong prism type set e.g. 360 versus circular prism.
- Usual theodolite error sources too, e.g. not levelled instrument, centring error, collimation error, …
- When pointing close to sun, can be hard to find target. Sometimes difficult in heavy rain too.

Tests:

- Compare with manual pointing, check direction and ZA readings in **both faces**. Consider the possibility of collimation errors etc.
- Set up instrument and 3+ targets in a control network with accurate coordinates predetermined – compare ATR directions and ZA with bearings and ΔH from control network
- Comparing the residuals across a number of different targets would give an indication of its accuracy.
- Make observations with the ATR feature on, then perform the same measurements with a completely different instrument (total station). Constraint centering will limit the errors caused by switching machines and will provide a good redundant check.
- Over long sight distances use RTK GNSS or government database (eg NSW SCIMS) coordinates to check the ATR observations.
- Use an instrument's internal calibration tests (if applicable).
- Generally the closer the target the less accurate the ATR pointing.
- Obstacles could be placed randomly to see the effect on ATR pointing of things such as multiple prisms in a similar direction, cars, people and fences.

c)

- The beams of the laser may diverge so the longer the distance of measurement the greater the spot size, and therefore partial reflection from more than one target.
- Not receiving a return due to weather eg rain or dust or fog
- Misalignment of reflectorless EDM beam and cross hairs
- Return of the signal depends on the reflectivity of the surface, the texture, roughness and wetness/dryness of the surface.
- Wrong distance may be obtained due to obstacles in the way (online), change focus through a range to find any

online obstacles.
- Incorrect calibration (EDM calibrated for prism measurements, but not in reflectorless mode) – calibrate.
- When measuring to the edge or corner of an object.
- Transparent objects can provide a return signal when not desired (such as windows, water or flyscreens).
- Angle of incidence may be too inclined.
- Wet targets or objects might be a mirror like surface that reflects the beam away from the instrument.
- Measuring to a prism in reflectorless EDM or laser scanning mode gives wrong distance, don't do it.

Another version of the question:
- reflectorless EDM on an EDM baseline
- TLS on an EDM baseline and on a network
- Flat targets with centre mark, not prisms
- Apply atmospheric corrections appropriate for the wavelength
- Beam width may reflect off more than the target
- Why – so that you can rely on the results of a survey

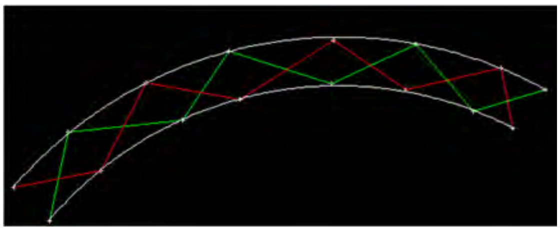
I could write more notes on testing reflectorless EDM and TLS. Detailed notes on how, why, special targets, beam wavelength and width, range and other comments. But that would then become a textbook rather than a series of questions specific to projects. So I resisted the temptation to write too much.

Q19. Tilting prism pole
This question was used about 1 month after the first local advertisements for these poles. Students had not used them and had not read their "instrument manuals" for ideas about testing or calibration.

a) set up the pole over a mark where the pole can be held vertically measure coordinates of mark, lean pole over at various tilts and reobserve and compare, lean pole at different azimuths reobserve and compare answers – especially if working on a local coordinate system with azimuth not aligned with grid or true north. Or add another prism to the pole and use it as a hidden point pole – tricky to mount the extra prism online, would have to be on top of the pole

b) hidden point pole with two prisms mounted on the same pole, along the centre line of the pole.

Q20. Mining surveying
a) Takes responsibility for accuracy, timeliness and safety, signs plans, can do many surveying and GIS tasks … BOSSI NSW.
b) Answer should include description of carry bearings around a curve in a tunnel, such as Zig Zag method from both sides, wall brackets with resections, 3D Traverse or levelling (with roof marks). Accurate / realistic sketch. Not gyro (lines too short and too many of them). Consider lateral refraction. Good starting control. Come back up to close the traverse. Include some checks.
c) Bearings: Weisbach method with wires of plummet lines, or gyro. If use a gyroscope then do the true/grid correction. Or if there is other shaft on the way I would connect it to the network to be able to tie it up.
EN: vertical optical or laser plummet. To avoid any mistake I would do it around the circle and take the average.
H: measure upwards with EDM, or use a steel band from the surface or perhaps even a Disto if accuracy sufficient. Marks for sketches that are useful.
d) Give a description of carry bearings around a curve in a tunnel such as Zig-zag method from both sides, wall brackets and resections, 3D Traverse or levelling with roof marks.



- Accurate / realistic sketch
- Zig zagging to wall brackets would have traverse lines not longer than 45 m. The lines would subtend about 130 ° at the centre of the circle spiral so about 3 lines are needed to do a full 360° revolution. Calcs are based on RA triangle: inner radius = 47.5m outer radius = 52.5m. So a grazing ray would be a tangent to inner circle, triangle from tangent to circle centre to instrument on outer wall can be solved to find half length of traverse line. $a^2 + 47.5^2 = 52.5^2$, a = 22.4m, half angle: sin half ang = 47.5/52.5 = 64 ° angle = 130 °
- Not gyro (lines too short <45m and too many of them)
- Consider lateral refraction

- Good starting control
- Include some checks not just a traverse, eg measure back to start with new lines and stations to close the traverse, or another zig zag from opposite point.

Q21. Mining or tunnel surveying

Some student answers:

- Robotic TS with ATR makes observations to prisms easier in dark conditions.
- Wall marks are easier to observe to than roof marks but require more calculations. So Free stationing and resections may be preferred. The reason is that setting up over mark can have *centring error* specially centring on the roof is even harder. Set up the instrument by resection can avoid this error.
- Wall marks are better in curved tunnels or spiral mine tunnels, zig zag to avoid refraction and has more *redundant* measurements.
- Roof marks are simpler in long straight tunnels eg longwall mines and have fewer potential calculation errors.
- Roof marks are less likely to be damaged.
- Both methods are good when ground marks are likely to be damaged or under mud/water.
- There may be large temperature gradients when using wall marks, and this means *refraction errors* come into play.
- Using a total station is most practical for these types of jobs, however a laser scanner may be used if the client needs a 3D model of the tunnel profile.

Q22. Underground surveys

a)

- Not as precise as a total station's angle reading ability. More marks if you give a good, detailed description.
- Gyros measure to true north so when being used to adjust traverse data the gyro measurement must be corrected for whatever grid system is used by the mine.
- Need to apply grid convergence because gyros refer to true north and MGA to grid north.
- They are slower to use than reading an angle by total station.
- Can't be used in hazardous (spark) zones.
- Cost

b) Measure azimuth of a line of known azimuth (or bearing and Grid convergence known) between two marks on site above ground, before and after underground survey. This technique is also useful if you have an instrument that measures magnetic bearings.

c) Distance = 151.102 ie 151.123 *CSF since GNSS join is assumed to be a perfect distance. Bearing, need to add 3° 10' 22" to original value so = 33° 10' 22". Grid convergence is not involved in this calculation.

d) Briefly (students would have longer answers and sketches): If shaft is shallow and wide, use TS observations from one edge at top to prisms at base on opposite side, do same from other side of top of shaft. If shaft is deep and narrow, set up at base with 2 or more points spread apart and site to targets above, perhaps vertically. Check with UG traverse to another shaft.

Q23. Underground surveys

slope distance = 506.234
atmospheric ppm = -9ppm = -4.6 mm for a line 506m long
slope distance corrected for atmosphere = 506.2294
ΔH = 80
horizontal distance = 499.868 using Pythagoras
local CSF = 0.999732
Grid distance = **499.734**
Azimuth = 49 32 14
Grid Conv = -1 18 37
bearing = Az + GC = **48° 13' 37"**

Q24. Coordinate systems

Briefly: carry coordinates as you traverse UG. Use two jobs, one with MGA Scale Factor (SF) and coordinates, the other with SF=1 and local coordinates. This is not much slower than doing 2 arcs and if you have ATR instruments can be done quickly. So have both sets of coordinates on hand in the field without extra transformation calcs. Make sure to use different point numbering in each job. Eg in job 1 (or rename it job local) survey mark may be called point 1284, in the other job (MGA job) that same mark is called eg 4284. Different but coded in a way that you know they are the same physical mark.

Gyros are useful if the tunnel is one way only with no earlier shafts during the 1400m, and if there is possible lateral refraction due to grazing rays with a significant temperature gradient across the tunnel. After you reach the shaft you can transfer coordinates down to the UG traverse and readjust it.

Parts answers from students:

1. My suggestion is to keep using the two separate coordinate systems as proposed.
2. Giving the MGA scale factor is close to the site specific SF of 1, and the area to hit is reasonably large (5 metres over a depth of only 100m), you should be able to use one set of coordinates on the surface to drill down to the tunnel, based on underground coordinates in the other system. This is because the difference in distance between the two coordinates is likely to be much less than the 5m hole you are trying to hit… Given that the effect of the scale factor is only 0.6m, and specifically along the direction of line, it will not make a difference in whether the ventilation shaft successfully joins with a tunnel, as long as it is on line. Thus feel free to keep the scale factor as 1.
3. Obviously, this difference could be estimated and incorporated into any known drilling uncertainty, to check that it's still within tolerance.
4. As for using a gyro, I'd recommend using in a number of spots to check azimuth, but not all. Overall accurate of angles is less for gyros than a good total station but allows for error checking over longer distances. 5-10 check measurements should be sufficient.
5. A con is obviously that it is possible to get these two systems confused. Ensure that your staff and field hands are up to date with the process and there is no confusion in applying this in the field.
6. I would strongly recommend using a gyro underground as there is no check and errors tend to "drift". A gyro measurement every 10 lines should be more than enough to suit. Please run this in a LS Simulation first though to ensure that would meet the specs of your survey.
7. I would recommend using both coordinate systems underground like what you are doing above ground. This can be done whereby you are working off the same stations, but they have different coordinates. This, however, might get confusing and hard to check since you cannot observe to any PMs in the tunnel.
8. Also consider the severity and precision requirements for the ventilation shaft. If it is not that imperative to get to sub mm accuracy, then it won't have a very large effect on what coordinate system you drill the hole. The shaft is only 100m deep and is 5m wide. When traversing 1400m it only changes the distance by 0.6m. Therefore, depending on the accuracy needed of the ventilation shaft, drilling down to a 5m wide shaft would still work, again depending on the accuracy needed.
9. Consider doing multiple traverses forwards and backwards to check any coordinates of points that have been placed or will be placed.
10. For a start it is good that you are aware of this situation and on top of this. It is important that you keep everything documented and organised.
11. Underground tunnels should maintain coordinates in MGA2020 for a variety of reasons. For starters, it ensures that boundaries aren't breached. The whole mine site will eventually have to be in MGA2020 because of regulation so could be easier to work in MGA from the get-go.
12. You have to apply scale factor to be able to keep the correlation to the surface.
13. (This question is hard, I remember this email in the lecture ☹)

For the second version of the question -

You might ask: How deep is the mine (mine depth affects the combined scale factor)? How far do you survey UG? Is there ramp access or shaft only? Do you carry coordinates as you traverse UG?

You might consider use two "jobs", one with MGA Scale Factor and coordinates, the other with Scale Factor = 1 and local coordinates. This is not much slower than doing 2 arcs and if you have ATR instruments can be done quickly. So you have both sets of coordinates on hand in the field without extra transformation calculations. Make sure to use different point numbering in each job. For example, in job local a survey mark may be called point 1284, in the MGA job that same mark is called eg 4284. Different ID but coded in a way that you know they are the same physical mark.

Gyros are useful if the tunnel is one way only with no shafts to check coordinates for say 1km, and if there is possible lateral refraction due to grazing rays with a significant temperature gradient across the tunnel. If you reach a shaft along your traverse or control survey you can transfer coordinates down to the UG traverse and readjust the network.

"I am in the process of setting up control survey in a new tunnel in an underground mine" so they are a surveyor familiar with mine surveying, we don't need to tell them how to do mine surveying.

" the best way to set up the coordinate system for underground. " – you could discuss the pros and cons and methods to using local coordinates only (no scale factor so we have true 3D distances, use MGA bearings and AHD heights but local EN), or MGA2020 coordinates only (eg regulations, lease boundaries, rescues from above), or a dual system where both coordinate systems are used. If you use both how to avoid confusion or errors…

"Should I get some lines measured with a gyro?" – many people answer that well, depends on cost/budget, and not do every line due to precision limits, but good for accuracy checks.

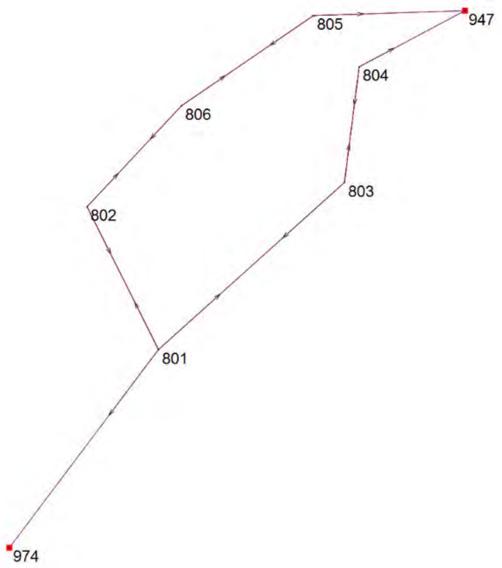
" Do you have any questions for me?" Mine depth because that affects CSF. Length of survey especially in EW direction, that can mean significant variations in the CSF. A fairly small scale correction (eg SF <40ppm) in mining excavations is not too onerous if the tunnel is short eg 1km.

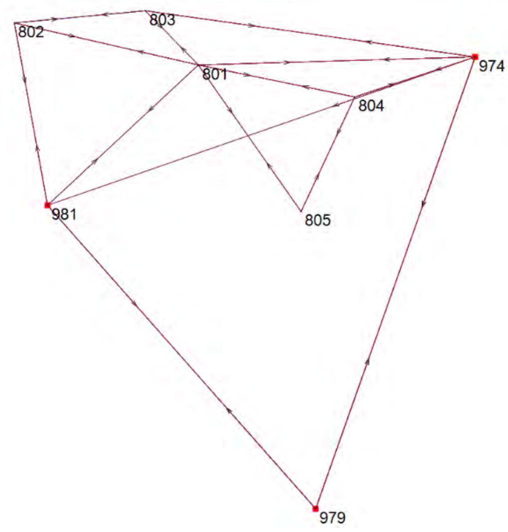
Another part answer from students:
- Consider the workload in calculating two sets of coordinates, and possible safety / confusion issues. A concern is that it is possible to get these two systems confused. Ensure that your staff and field hands are up to date with the process and there is no confusion in applying this in the field.

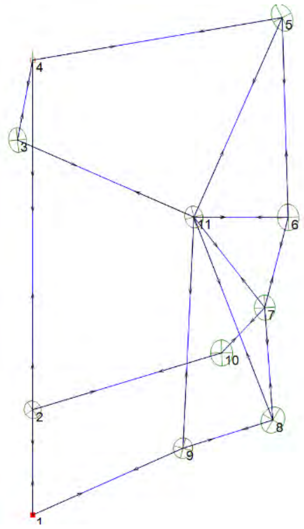
Q25. Least Squares, Berry

Reasons for applying			
Constrained: uses existing marks to detect internal errors in survey, onto MGA/AHD for use with GNSS, able to connect to other surveys, etc	L1: Good for detecting outliers or other errors in input file, L1 would have some large residuals (v) and many v = 0. An L1 solution can help identify problems and will converge when a LS might crash.	Freenet: Does not get distorted by any errors in control points, error ellipses are not affected by datum, error ellipses are usually smaller.	Bayesian: More realistic (larger) error ellipses, allows small changes to fixed point coordinates and can detect errors in some of the control points, inclusion of GNSS data - using independent data gives a more robust solution and detection of errors.
Comparison with conventional solution	**L1 norm**	**Freenet**	**Bayesian**
Semi major axis of Error ellipse of point 801 = 2.1	No error ellipses produced.	2.8 not much different because point is near centre of net.	7.8, Larger
Largest v/s = 2.0	4.5	2.0	2.0
VF = 0.95	1.82	1.13	0.93
Ave Redundancy = 0.52	0.52	0.43	0.43

Other years there were similar questions with different data from Cataract, NSW student surveys.







Another year we had a similar question using the Oatley data set that is described in my Least Squares book (Monograph 13).

Q26. Least Squares, email

I have replied to our former student with my own comments, and two student's exam answers.

Many students chose to answer the question by describing the features of the topics of Bayesian, Freenet, and L1 robust adjustments and the considerations of minimum constraints or over constrained, whether onto SCIMs marks and MGA, or local coordinates. That is the effects of these decisions on adjusted coordinates, residuals, VF, and error ellipses. That was enough to pass, but not to get full marks. Some students misunderstood some aspects of the different adjustment types.
I don't think anyone talked about changing the input standard deviation of the observations, and that is an important consideration. Not many talked about whether to use local coordinates or not.
As one student says, presumably the GDA2020 coordinates of points that you have fixed or constrained are better quality than earlier adjustments, especially the relative precision of points separated by longer distances. So new data should fit in better (ie smaller residuals, smaller VF).

Next, lets clarify '*constrained* adjustments, AND *fixed'.* I think we agree what fixed means. The coordinate parameter is not allowed to move. I also use the term constrained to mean that. So I talk about minimally constrained solutions where just enough parameters are fixed to avoid crash during matrix inversion or solution of equations. An over-constrained solution is where we hold more parameters or more points fixed, eg existing high quality SCIMS marks don't change their coordinates.
Bayesian adjustment. Here those points that we already know the coordinates of (from some previous or superior adjustment) and have an idea about their quality are used in the adjustment not as fixed but like they are observations of coordinates with ± standard deviations (and maybe in even a full VCV). Then the points are moved in

the adjustment based on the weighting of their input standard deviation. This is not a tolerance or limit or like the point can only move within its error ellipses – though that is the common effect. If for example, we give points with coordinates in this type of adjustment a ± of 20mm in E then the E could move (ie have a residual) perhaps less than 20mm but sometimes 2 or 3 times larger than that. How much the coordinate moves depends on how well it fits with the new data.
This method of allowing the coordinates of 'control' points to move a bit instead of being held fixed does mean the observations (eg distances, directions) do not have to change quite so much to fit. Thus smaller observation residuals and VF. In this environment it would be reasonable in my opinion to lower the input standard deviations of the observations. So v and VF are smaller – but have a look at the point error ellipses and the relative error ellipses to see what happens to them. The point ellipses may now be larger than when you held points fixed.
So I suggest you continue using the Chi Sq (VF) test. Perhaps modify input standard deviations of observations and of the control point coordinates. Also look at histograms of v or v/s. And of course, investigate and fix outliers – as s changes the v/s will change too.
If you are doing freenet adjustments, be careful that you use good starting coordinates for all points.

Hope this feedback helps. I look forward to hearing about your future survey projects. Maybe I should send you all student replies so you could mark them?

[One student said: *As you should have remembered form GMAT3100… there are a variety of alternative methods available for observation adjustment aside from good old LS. Some to consider are: … Learn a bit about each and use what is best of the job at hand, it should be all in your notes anyway. … Anyway, good to talk, but with questions like these, I think you might have to come back and do GMAT3100 again :P*]

Q27. Least Squares Datum, email

- Local with Minimum constraints does not inherit errors or **distortions** from control mark coordinates, which is significant when survey is more precise than the control.
- Use Local coordinates if there are no nearby 'SCIMS' control points
- Local coordinates can be aligned/oriented to the submarine's main axes Centreline etc
- With local coordinates we can decide which points to hold fixed eg near centre, this affects error ellipses
- Grid projection in SCIMS MGA coordinates affects distance **scale** – beware construction is in ground distances not MGA distances.
- Using SCIMS control is important when survey covers large area or is the accumulation of many short traverse lines (or similar) or **accumulation of** systematic **errors** eg refraction.
- SCIMS MGA enables project to be **linked** with other projects, gives global location…
- Consider the quality (class, order etc) of the SCIMS MGA point's coordinates.
- If the submarines' guidance systems need to be compared against true north, then use SCIMS control.

Part of a student answer:
A famous Surveying principle is to work from the whole to the part. In respect to this it might appear that using the MGA coordinates is a good option. However, if the coordinates supplied by the DOL are actually less accurate than the proposed project then special care needs to be taken when doing adjustments such as Least Squares.

As the coordinates are known, the first instinct would be to hold the coordinates for all the points fixed. However, this creates an over constrained network. If the DOL coordinates are less accurate this will skew the accurate results of the survey. They are forced to conform to the MGA marks. Alternatively, other Least Squares techniques, such as Freenet solution or Bayesian, could be used. In Freenet no points are held fixed. In Bayesian, the parameters as well as their quality and correlation are input. Therefore, all points can more approximately within their error ellipse.

However, an advantage of using MGA is that other information that may be relevant to the project may be on MGA and therefore, no transformations are required. The other option is to use a minimally constrained local datum. The advantage of this is that the survey will not be affected by any discrepancies in the MGA coordinates. Another problem that is not so common is to check that all the marks from LPI are in the same adjustment, sometimes marks close to each other are on different adjustments and do not agree with each other as close as what their class and order would have you believe.

Q28. Data analysis methods, Chifley Dam

This question does not supply the data, so it requires students to use their knowledge and experience with this type of data analysis to predict the likely outcomes.

a) Changes size of error ellipses and standard deviations, about half original size. Point 7 gets an error ellipse that is about same size as point 3 (ie about 15mm).
b) If the solution crashed or very large and many outliers that we could not debug. For example, L1 norm solution may be applied if the data is not fitting together well in normal LS, indicating that there could be a gross error somewhere in the data. L1 norm helps to show which observation has the gross error by putting a larger residual on it. This observation is generally easier to identify than in a normal LS or free net adjustment. Once the bad observations are rectified, go back to normal LS.
c) Pt 7 gets std dev of 10 mm in E and N and all other points get bigger by about 10mm in E and N.

Other useful comments E.g.

Compared to LS: L1 would have some large v and many v=0. No error ellipses. Similar coordinates (within about the size of the error ellipses). When a conventional least square solution does not converge, an L1 solution can help identify the problem and will converge.

Compared to LS: Free net would have smaller pt error ellipses pts 1 and 4 would have error ellipses, ie no points held fixed same residuals and VF as in conventional minimally constrained LS slightly different coordinates depending on what values you start with.

Compared to LS: Bayesian would have larger point error ellipses. Points 1 and 4 would have error ellipses, ie no points held fixed. Similar residuals, but different VF compared to convent minimally constrained LS. Slightly different coordinates depending on what values you start with.

Q29. Data analysis methods, simple traverse Morpeth

Table 1 is standard LS with 3 fixed points. LS has no outliers.
Table 2 is L1 norm, 3 fixed points too. L1 has many residuals (v) = 0, all the errors/corrections "pushed into" 1 direction and 2 distances. Looks like gross error in that direction and one of the distances. L1 Coordinates differ to standard LS by few mm.
Table 3 is Bayesian, with no points fixed. Bayesian residuals similar (a bit smaller) to LS. Bayesian error ellipses slightly larger than LS and probably more realistic. Bayesian coordinates differ to LS by few mm.
Comments on VF etc …
Many lengthy and detailed student answers.

Q30. Control and Deformation Networks

A) Briefly, if a systematic error is similar in each epoch, then it cancels out in deformation analysis and we get smaller ± for the changes in coordinates than we can get for a control survey that has the aim of providing accurate coordinates. Deform surveys are interested in Δcoordinates or Δobservations. Control surveys are interested in coordinates.
Deform surveys require multi epochs. For control surveys one epoch is often enough.
Good answers elaborated more about this.
B) Zero epoch tests are two or more surveys during which time there is not expected to be significant movements. So if your analysis shows significant movements then they are due to problems with your survey not real movements. They also indicate the confidence level of your deformation results.
C)

Advantages of over constraining to MGA/SCIMS	Disadvantages of over constraining
It is a useful check to see that observations agree with an established network such as MGA. It is useful for gross error detection in your survey. Connecting onto MGA may help with inclusion of GNSS observations, and to overlay with GIS and utilities data and imagery such as Google Earth and similar products. Advantages of over constraining a network with SCIMS marks is that if the SCIMS marks are good then a LS solution will pick up measurement errors in the survey as indicated by large v/s observations.	Can deform the network as there is less 'flexibility' and observations are made to agree with fixed positions. The quality of the marks that will be held fixed may not be as good as your observations and thus influence the quality of the network. It may not be possible when there is a lack of marks to hold fixed in a network. A disadvantage is that if the SCIMS marks are bad (wrong or poor quality) and the survey you have done is good, then there will be large v/s from LS adjustment due to the SCIMS marks errors and will distort the network coordinates.

Your decision to use MGA marks or not depends on :

- Quality of SCIMS marks available, 95% confidence interval and positional uncertainty needs to be considered.
- Purpose of survey, e.g. high precision or detail survey or construction setout survey.
- For 3D surveys, will the scale factor affect vertical height difference calculated by the instrument. Check instrument to see how calculations are done to see potential issues.

Both adjustments should be done as it gives a check to see quality of survey observations compared to control network points used and detect errors.

Q31. Car Park Deformation

The data shows that four of the points moved significantly in height but not in 2D. Points 1 2 3 moved down ≈ 2mm, point 4 moved up ≈ 3mm. Use the '2-sigma' statistical test. Your answer should say how much they moved, and the confidence level. A comment about whether that amount of movement is likely to be within the structural design specifications (even if you don't know what the specifications are you can say that they should be considered). Some students give useful comments, such as, a horizontal scale bar is used as a scale control, and the horizontal distances show no deformation. There is no staff used to control network height scale, and there is a deformation in the heights. Maybe this is an irrelevant co-incidence, maybe not. Is it possible to repeat the survey with an invar staff on a stable mark for network height scale?

Q32. Deformation design, email

This is another real email. I often use questions from former students or other surveyors in my exams. I remove names and other identifying information. Generally marks are awarded for each good point that a student makes. Usually there is no single correct answer. I reward the logic and quality of the answer.

In your reply you might ask the 'client' some questions, for example, how much movement is expected, can trees be cut, can we visit the site, are their site photos, can they supply a plan view of the site …

Some ideas:
Bolts on RH face of wall protruding slightly.
Hidden point rod placed on the bolts with 2 + prisms on the rod visible above the wall. Hold the rod still eg bipod while observing.
Place control marks around the site in stable positions.
Resect in 3D the instrument location at each epoch.
Total station with accurate specifications, possibly ATR.
Accuracies in 3D of around ± 2mm.
Zero epoch test.
Levelling on top of wall for sinking.
Plumbline for bulging wall or tiltmeters.

One student wrote:
First and foremost some items to be clarified with the client:

1. The wall has been installed with a backwards lean for stability but not so much that option two below is made useless.
2. The main issue for the wall is that of the face bulging outwards, which would lead to potential failure. More so than the ground sinking.
3. The part of the wall on which the deformation survey is being done is less than 30 metres long, and therefore it is reasonable to have a field party manually check over the entire thing within a half day visit, such that we are dealing with differing environmental factors.
4. What is either side of the construction site? this is visited further in the vertical measurement section.
5. What amount of deflection of the wall represents an issue?
6. The bush on the main road side is so thick that there is an impossibility to setup a total station or laser scanner on that side of the wall. However access to the face of the wall can be made, maybe standing in shrubbery or between trees.
7. Similar to the above, photogrammetry would be rendered useless as the distance from the wall to get appropriate overlap cannot be obtained.

It is my belief that the movement of the wall needs to be measured in vertical and horizontal axis in essentially separate methods. Despite in the above the horizontal movement of the wall being regarded as more important. This

is because the measurement to the top of the wall will not give much information able the bulging of the wall (as it will be least effected here) and the measurement proposed below to the face of the wall will not give vertical change.
Vertical Measurement: Install monitoring prisms on the top of the wall, this would indicate whether the wall was sinking.
Horizontal measurement (plumb bob) …
Horizontal measurement (inclinometers)…
Things that will not work: …

Q33. Deformation Data Analysis – Monitoring survey
A) The data set has nonreciprocal ZA observations over long distances. Say they should have been pre-processed to remove earth curvature and refraction (unless the LS program does that) or else use precalculated Δh as observations. Comment that for deformation, on each line earth curvature is constant and therefore cancels out.

VF is 1.15 which is good, a couple of outliers in ZA reciprocal observations on line 2-4 – no worries mean height will be OK. Average redundancy is good 0.64, and there are no r = 0, except the azimuth line. Average error ellipse major axis is about 3mm. Group VF for zenith angle (2.88) is poor VF could be because reciprocal zenith angle is not possible as targets are placed on dam walls.

B) Remove END line and run simulation. Average redundancy still good. No zeros except the azimuth. Error ellipses still about the same. Need to add JOIN lines, eg 6 to 206 then standard deviation of slope distance and horizontal distance is about ± 1-2 mm. Movement in height can be determined to about ± 2mm.

From doing the joins of epoch 1 to epoch 2, it seems the maximum standard deviation of distance is ± 2.2 mm for measuring changes in slope distance. Therefore detectable deformation is 2.2 mm x 2 = ±4.4 mm. Or say detectable deformation is 5 mm for simplicity.

Q34. Deformation Data Analysis – Rail Monitoring survey
A) Examples:

- Coordinates of point 10 have changed by 0.6, 0.7 and 1.2 mm in E N H.
- Could be due to changes in atmosphere or movement of point 10.
- The changes in E & N are not statistically significant compared to the 95% CI.
- The change in H is significant, about 3 times 95% CI.
- The VF are not 1, most likely the input standard deviations are too small, not likely to be outlier errors in the obs.
- The v/s and VF and 95%Ci ellipses are smaller in the second epoch.
- Distances are generally shorter for epoch 1, and zenith angles are higher on epoch 1

B)

- Could solve for atmospheric bending of ZAs if we had more data, e.g. 24 hours of observations or use local scale parameter,
- Could solve for atmospheric scaling effect on slope distances, if we had more data, e.g. 24 hours of observations or use local scale parameter. Or correct the distances if we had met data.
- Could do a free net adjustment so none of the control points are fixed, in case they have moved or their coordinates are in error.
- Could do a minimum constrained solution, in case the control points have moved or their coordinates are in error.
- Could do Bayesian solution, so the control points are allowed to move a bit and not be treated as perfect.
- As the coordinates of points 1-9 are supplied from a previous survey, there accuracy may not be good enough to hold fixed (or they may have moved). This over constrained network could be skewing the results. So we should check the control marks for movement.

Q35. Deformation Analysis
The FIXIT output shown in this question does not include all the usual output information. The v/sv and redundancy number columns are not included. The group variance factors are also not included in this question.

Pt 4 9.2 ± 4.1 mm at 95% level ≈ ± 8 mm so it is marginally moving.
Pt 5 12.9 ± 3.6 mm at 95% level ≈ ± 7 mm it is moving.

A student also wrote: It is worth noting that this survey has been done over a very large area.

Q36. Cost-effective Monitoring of Slope Failure

This question was asked some years before students were aware of drone LIDAR.

Briefly: Robotic total station and targets or GPS with communication of data back to base. Is there phone access/coverage at the site. 'Ned Kelly' hood or shelter for the instrument. Backup power supplies. Target types to be considered re theft or vandalism protection. Discussions with geotech and groundwater engineers about likely deformation location and timing etc.

Parts of some student answers:

1) Monitoring in real time and cost effectively requires setting up a network of instruments which regularly check for such large slope failures and which report results back to a central base location. It minimizes the amount of human time and effort and works 24/7. Depending on the system needed, the detection devices do not strictly need to be exclusive to surveying equipment. A rudimentary system just to monitor for catastrophic failure, like the example given, might contain a tiltmeter or some other motion sensor located at regular intervals along the side of the road, each connected to a communication device which sends the recorded data over wireless network to be analysed (On the other hand, surveying equipment such as GPS or laser scanning could provide more information about gradual movement, and help to predict these failures, but costs would rise subsequently). Any large outliers, caused by sudden catastrophic failure, can instantly show up in analysis, and warning system can send this info to road users.

2) Need to have some belief that the slope is going to eventually fail. A surveyor would need to work with geologist/ local council to know which areas are most likely to fail. Surveyor would need to find a place which is below the cliff, down near the trees which would be able to see the rock face adequately. A place to build a concrete pillar would also need to be located to put the total station. Total station would need to have ATR as prisms will be bolted to the side of the rock face. And the total station would look to these prisms and monitor deformation. The ATR would also need to sight to prisms outside the area of influence to make sure that those points or the pillar are not moving, and that the only movement recorded is due to the slope failure. Having a system that constantly takes observations to prisms, maybe every half hour or so, in FL and FR, would indicate if there is any deformation. This can then notify the surveyor (who is not on site) via computer and local authorities. Presumably, there is some deformation before the actual failure or the slope, so the accuracy required would need to be on the less than 5 mm scale. But it must be designed so that atmospheric changes through day and night are accounted for, and that there are no false readings. Also need to determine if there are any trends in the data.

3) Having an automated system than can operate continuously and precisely.
   - Does not necessarily have to be accurate.
   - TS + ATR + prisms and a computer system to store data is one method. Checks and calibration would be performed routinely, can do sets of angles very fast. However, would only able to measure at small junctions of the road with prisms within LoS and limited range.
   - Series of GNSS receivers with good sky view and connection to base station, double-difference solution + CPH measurements, send out lots of data but only precise to ~ a few mm. Expensive.
   - Series of Tilt meters + connected to computer system + control. May be the most cost effective since less expensive hardware and could be installed for a long leg of the road, however susceptible to weather and elements and has systematic errors due to temperature.

4) As total stations and laser scanners are very expensive, hard to protect against weather conditions and also difficult to use over a long distance, using tilt sensors is my solution to this problem. However some civil engineering knowledge is required if this method is to be used while being cost-effective. The reason is that civil engineering knowledge helps surveyors and other engineers understand where the road is most vulnerable to movement and where it moves first and the most before collapsing. By placing tilt sensors at these vulnerable positions and monitoring them constantly, these natural disasters could be identified in real time therefore warning messages could be sent out when there is a significant tilt in the road, indicating a sign of collapse. However these tilt sensors must be calibrated consistently and be protected from weather and cars driving by to give the highest quality results.

5) A cost benefit analysis must be completed when implementing real-time monitoring procedures on structures such as buildings, roads etc. There are no-doubt a number of methods that can be implemented giving beyond-adequate information on such an issue, but often at a significant expense. … After determining areas of risk, a suitable monitoring system should be designed. Such systems may include:

- continuously operating GPS receiver/s: these receivers may be placed in such a location such that a sudden shift in local terrain would correlate with a shift in their position. A system could be designed such that a shift in the receiver's position of a certain magnitude (outside of a specified threshold) would raise an alert via some sort of communication medium (such as nearby office where receivers are monitored remotely)
- tilt meters: similar to above, tilt meter/s could be mounted on bridges or other structures that continuously monitor any longitudinal rotation of the structure (about the centreline of the road). Once again and tilt measured to exceed a given threshold would trigger an alert via remote data communication enabling sufficient warnings to be transmitted.
- a combination of the above

Obviously, the above methods would be very expensive to implement on a large scale. For this reason, the initial decision as to where areas of risk exist is essential. This would require involvement of a number of parties to best determine where geological disasters are likely to occur.

Q37. Survey Design, building movement

A student wrote:

First of all more information would be nice, such as the minimum amount of movement they would like to detect, and in which direction (e.g. horizontal movement or vertical movement) they would like. Also I'm not sure if they only want it for the construction phase or for continual monitoring after construction. It also doesn't say how big the building would be as the height of the building would influence the methods used to calculate the movement of the building …

Some ideas

- To calculate the movement of a building one of the simplest techniques would be to install a plum bob system in a large vertical gallery such as a stairwell and also a wire alignment in a large horizontal gallery such as a hallway. These two methods can give very precise measurements of movements and are very simple to measure. However these may be better for monitoring when the building is complete (they still would be helpful during construction, they just may be removed…)
- GNSS antennas on the roof of the building are helpful both during construction and afterwards. Although these are often not a very precise way of measuring movement, they can give warning of significant movement and can be set up to be continuously operated. They can be set up in a network across the top of the building, however if required accuracy is not that great then maybe only one or two could be set up. Wherever they are installed they require a good sky view and so when building on top of each level, they would require moving up to the new level…
- A total station set up network can be good for monitoring movement during construction, so long as the building is not going to be too tall (e.g. 50-100m+). It would require a good control network set out far away enough from the building that it would not be influenced by any deformation or construction the building may involve. From the set up points (a few would be required in order to see the whole building) resection or distance by reflectorless EDM can be a very helpful way of collecting data to many points on the outside of the building to detect movement. Depending on the size of the building, roughly 6 reference marks should be seen from each station set up and numerous points that can be consistently seen should be used on the face of each side of the building.

These are just 3 ideas. There are many others that can be done. Diagrams are provided on exam paper.

Q38. Land Stability Monitoring, design

a) How much deformation is expected? How long to monitor? Have some points on stable ground, distant ROs and or recovery marks. Some points on object ie in slip area is assumed so no marks for that. Calibrate instruments. What budget? How much tree cover re GPS and visibility or targets? Correlation with UG mining… find out how extensive the coal mining is in case it affects the control reference marks too. Put base station or automatic total station on opposite side of river and about same height is about 450m away.

b) Analysis: renumber object points but not reference points in each epoch, statistical test displacement against Confidence ellipse of the join, LSP for atmosphere effects, etc.

Q39. Bridge deformation survey design

This is a design question with no exact answer. It is based on a real survey with published results in 2019. Students would not be familiar with the publication when they did the exam. Here are some thoughts.

- A good diagram/plan.
- We mainly want changes in heights, not heights, not EN.
- What does the client mean by ±1mm? Std dev, or 95% or …
- OHS issues
- Digital levelling is good. Can use bolts or nails, can use inverted staff. But instrument cannot be on bridge.
- If TS then talk about limits of pointing accuracy and needing ZA and distance to calculate height. So maybe deformation at 1mm (at say 95% confidence) is not doable, but what we get still might be good enough for the project. Not reciprocal obs. Atmos effect over short distance is…
- Laser tracker, you would need to ask about leaving many prism socket mounts on site. Expensive
- Laser scanner probably accurate enough for 4 targets not for point cloud
- When you measure to a mark (eg an intermediate level shot, or a TS radiation) make sure you measure that mark again from another instrument set up or another technique. Important to measure to each mark from more than one location. That checks accuracy – gross errors, and it helps indicate the precision of your survey. Loop miscloses too.
- Have some stable marks nearby, eg benchmarks outside the area of influence. You don't need them to be AHD connected, but you do need to connect to them as monitor points. If they seem to move, then you can't trust your measured deflections of targets.
- For deformation surveys you need to be able to connect epoch 1 heights with epoch 2 heights. Each 'control survey' epoch needs to be accurately connected to the other epochs – else you don't know how much targets have moved.
- Important to have a control network and adjust it, or at least have loops that you can check miscloses.
- Do a LS network adjust that looks at miscloses, residuals, outliers, error bars in H, and combines multi epoch data.
- Number the target points in a way that each epoch of a single mark has a different number.
- Calculate joins between epochs and statistical test against 2 * std dev of join dist.
- Zero epoch tests to confirm the quality of your deformation survey technique.
- Request a site visit.

And other things

- Ask the client: How many, and what type of vehicles are regularly passing over the bridge? What would the maximum weight of these be? It seems from the photos that some small to medium size trucks pass over the bridge. If this survey was to test the structural integrity of the traffic that is to go over it, it should be tested with the heaviest vehicles so that we know it is able to cope with this. Should the test just assume the maximum load limit of the bridge (30T) and test to that?
- Is any deformation/flex in the bridge expected? What is a safe amount of deformation/flex that the bridge could take?
- Can the bridge be closed so that the survey can take place without interference from others?
- Is there a control network already established from the construction of the bridge that could be used to minimize the time taken for the survey?
- Budget?

Q40. Deformation, Height under building

This is a design question with no exact answer. Here are some thoughts.

Ask the client about the nature of the load above the roof, is it uniform or likely to be larger somewhere, what is likely size of displacement or critical size for damage. Is there power and lighting?

We want changes in heights sub mm, not heights, not EN.

Digital levelling is good. Can use bolts or nails, can use inverted staff. Need good lighting.

If TS then talk about limits of pointing accuracy and needing ZA and distance to calculate height. So maybe deformation at 0.5mm (at say 95% confidence) is not doable, but still might be good enough for the project.

Did you consider a laser tracker, if you did you would need to ask about leaving many prism socket mounts on site.

When you measure to a mark (eg and intermediated level shot, or a TS radiation) make sure you measure that mark again from another instrument set up. Important to measure to each mark from more than one location. That checks accuracy – gross errors, and it helps indicate the precision of your survey. Loop miscloses too.

Have some stable marks nearby, eg benchmarks outside the area of influence. You don't need them to be AHD connected, but you do need to connect to them as monitor points. If they seem to move, then you can't trust your

measured deflections of targets. Also, for deformation surveys you need to be able to connect epoch 1 heights with epoch 2 heights. Each 'control survey' epoch needs to be accurately connected to the other epochs – else you don't know how much targets have moved.
Important to have a control network and adjust it, or at least have loops that you can check miscloses.
Do LS network adjust that looks at miscloses, residuals, outliers, error bars in H.
Number the target points in a way that each epoch of a single mark has a different number.
Calculate joins between epochs and statistical test against 2 * standard deviation of join distance.
Zero epoch tests to confirm the quality of your deformation survey technique.

Q41. Survey Design, Sydney Harbour Bridge
The year after the exam this project was done (not by these students) and received an industry excellence award. I have seen their method and results, well after the exam was completed.
Some considerations:

- where to place instruments: on pylons, and or on headlands
- include sketches/plans
- refraction on ZA
- time sync of observations from multiple instruments
- control survey to link instrument locations
- How to know where trains are at certain times – video monitoring
- etc

Part of a student's answer:

Another student:
I would ask for what types of precisions are required for the survey, too.
Locations to place the instruments must be selected so they will not be disturbed, even during peak hour measurements as the survey requires. If the job is a long-term job, I would recommend the placement of permanent pillars at these locations. Reconnaissance is needed.
The high frequency of the measurements requires synchronization of all the instruments. I would recommend the use of three total stations with ATR all connected to a laptop. All three of the total stations can be programmed to measure to the prisms at whatever interval is required simultaneously.
If it is not possible to have all three instruments in a similar physical location, they could instead be programmed to take a measurement every interval required, synced to internet time. This would require each total station to be connected to a laptop with a reliable internet connection.
To obtain data about the location of the train, a video camera could be set up on a tripod looking at the bridge and plugged into a laptop. The laptop's time (which is the same time as the total stations) can be used to timestamp the video.
Because of the complexity of the system, I suggest performing a test run of everything including post-processing in a time that's not peak hour to see if it works.
[This student didn't mention atmosphere]

Another student:
Hi…
There are various ways to approach this problem, each with their pros and cons. Here are a few to consider:
While precision is stated for this job, GPS is not very accurate in terms of height (which is part of what the client is interested in) and there would be a lot of multipath from the metal structure of the bridge, so GPS would not be used

for this job. However, GPS time can be measured very precisely so this could be useful if it could be integrated into the design to know that measurements are being taken simultaneously.
For vertical movement another more appropriate consideration would be levelling, however to make its simultaneous you would need many surveyors/assistants and a number of digital levels and bar code staves to transfer the level almost simultaneously across the bridge (see back page of exam). This could be performed when the trains area going across at peak times and then later when there is minimal traffic, using the same points (marks) and comparing their heights to analyse whether the bridge is being caused to move vertical by passing trains. While logistically difficult, this would be precise and give you the result you seem to be looking for. [If the level instrument is on the moving bridge…?!]
In terms of horizontal movement this could be done using aerial laser scanning, or aerial photogrammetry. Both of these methods have been mentioned as they are non-contact with the bridge so their location is not affected by the movement of the bridge itself if it is moving due to the trains.

Q42. Atmospheric effects

a) I hope to see a discussion of the method of solving for the refraction parameter when there is no ability to do reciprocal ZA observations or a level run. We compare ZA observation with calculated ZA from coordinates for each of the control points, use a Local Scale Parameter (LSP) method and apply mean corrections proportional to the length of each lines. Earth curvature effect is a simple calculation and can be removed by instrument or post processing or as part of the LSP method.

b) We assume the control marks did not move and that the atmospheric conditions are constant during the time period of our survey and that is reasonable to average / interpolation in space and time. Refraction corrections correction for our monitor points are proportional to distance (i.e. "/dist). The effect on ZA is larger over longer distances.

c) The actual calculations involved inserting numbers into the equations given at the start of the paper.

$$H_B = H_A + h_i - h_t + \Delta h$$

$$\Delta h = HD \cot ZA + \frac{HD^2}{2R}(1-k)$$

For earth curvature only k = 0, $\Delta h = 594^2/(2*6400000) = 28$ mm (we use the second term in the equation above with k = 0)

For atmospheric effect you need to select a typical value of k. Let's say 0.2 (you can pick any value you want with a small range) At k =0.2 then the effect is 0.8 of the above value = 22mm. At k = 1 → 0mm, k = 0.13 → 24mm, k = -1 → 55 mm.

One student's answer:

d) The following method could be used to measure the height of point 22 (using the local scale parameter [LSP])

1. Measure the distance and zenith angles from 100 to the four control sites (1, 2, 5, 6) and point 22. Complete in face left and face right.
2. Reduce the FL and FR measurements to the control sites (and to 22). This results in slope distance measured (SD_{msd}) and zenith angle measured (ZA_{msd}).
3. Complete joins between 100 and the 4 control sites using their previously known coordinates. Compute the slope distance (SD_{coords}) and the zenith angle (ZA_{coords}), incorporating height of instrument and target if required.
4. Compute the scale factor for each of the slope distances via the following equation:

$$F = \frac{SD_{coords}}{SD_{msd}}$$

5. Compute the average scale factor (SF_{LSP}) for the site conditions at the time of observation.
6. Compute the zenith angle correction to each of the control points, via the following equation:

$$C = \frac{ZA_{coords} - ZA_{msd}}{SD_{coords}}$$

7. Compute the average zenith angle correction (C_{LSP}) for the site conditions at the time of observation.
8. Calculate the "corrected" distance from 100 to 22 via the following equation:

$$SD_{corrected} = SF_{LSP} * SD_{msd}$$

9. Calculate the "corrected" zenith angle from 100 to 22 via the following equation:

$$ZA_{corrected} = C_{LSP} * SD_{corrected} + ZA_{msd}$$

10. The height of point 22 can now be calculated via trigonometry using the corrected slope distance and zenith angle:

$$H_{22} = H_{100} + h_i - h_t + SD_{corrected} * \cos(ZA_{corrected})$$

The assumptions on atmospheric conditions used in this method are that the atmosphere was consistent of the course of measurements. K did not have to be zero, it was instead accounted for using the local scale parameter.

The horizontal distance was given as approximately 594m from 100 to 22. Therefore, the approximate impact of earth curvature is:

$$\Delta h_{curve} = \frac{HD^2}{2R} \qquad \Delta h_{curve} = \frac{594^2}{2 * 6400\,000}$$

$$\Delta h_{curve} = 0.02756m \qquad \Delta h_{curve} = 28mm$$

The range of possible effect of atmospheric bending is usually between $k = -1.0\ and\ k = 1.0$.

For k = -1.0:

$$\Delta h = HDcot(ZA) + \left(\frac{HD^2}{2*R}\right) * \left(1 - \frac{k}{\sin(ZA)}\right)$$

$$\Delta h = 594 * \cot(91°) + \frac{594^2}{2 * 6400\,000} * \left(1 - \frac{-1}{\sin(91°)}\right) \qquad \Delta h = -10.3132m$$

For k = 0.0: $\Delta h = 594 * \cot(91°) + \frac{594^2}{2*6400\,000} * \left(1 - \frac{0}{\sin(91°)}\right)$ $\quad \Delta h = -10.3407m$

For k = 1.0: $\Delta h = 594 * \cot(91°) + \frac{594^2}{2*6400\,000} * \left(1 - \frac{1}{\sin(91°)}\right)$ $\quad \Delta h = -10.3682m$

Therefore, the effect of refraction ranges from -27.5mm (for k = -1) to 0mm (for k = 0) to +27.5mm (for k = 1.0).

This is only an estimate however, and values of k can range even further, which can affect measurements. The current "done" thing in survey is to pick k = 0.13, but this really a guess, and is just as good as saying k = 0.

Q43. Atmospheric effects, email

a)

- We cannot say what the true ZA is, or the true height.
- We cannot say if the point is moving or if it is changing.
- Cannot say ZA is best at night.
- Max to min ZA is 8"
- But we also need to consider the quality of the instrument (±1"?) and it must be noted that the observations are taken using ATR which may be accurate to ±1mm pointing. Perhaps some of the variation in ZA is purely due to measurement noise.
- If the range for ZA values from the mean is **± 3"** (=1.45×10^{-5} radians). The change in height at target is calculated as, Δh = target distance * tan(ZA) = 137 * tan(1.45E-05) = 2 mm so this variation would result in Δh= 2 mm (change in height) for the target. For a **4"** ZA variation, change the height will be Δh=2.7 mm for this line.

b) To improve the monitoring:

- Best to observe to a nearby point that can be levelled or have reciprocal ZA observations – so we can monitor the atmospheric effect on the ZAs and remove it (e.g. local scale parameter model).
- Take observations on more days to see if there is a repeat diurnal effect.
- Any other good comment …

c) magnitude of earth curvature

Using : and k = 0

$$H_B = H_A + h_i - h_t + \Delta h$$

$$\Delta h = HD \cot ZA + \frac{HD^2}{2R}(1-k)$$

$=137^2/(2*6400000) = 1.5$mm

d) magnitude of atmospheric bending

Select a typical value of k. Let's say 0.2 (you can pick any reasonable value you want), no mark for unreasonable value. At k =0.2 then the effect is 0.2 of the above value = 0.3mm

Q44. Atmospheric effects, Anzac Bridge

a) Supplied formula: $C = (ZA_{coords} - ZA_{msd}) / SD_{coords}$

Compare ZA observation with calc ZA from coordinates, LSP method,

	diff "/km
2-3	39.53
2-4	42.97
2-5	38.48

Mean 40.3"/km

Corrected ZA 2 – 6 = **81° 04' 19"**

If you don't allow for distance dependence, we get 81° 04' 21" which is incorrect.

Local scale parameter model with mean corrections, assumes: reference marks did not move, and atmospheric conditions constant in time and average / interpolation in space, refraction corrections are proportional to distance ie formula or "/dist, ZA effect is larger over longer distances.

b) Local scale parameter model with mean corrections. Assumes: reference marks did not move, and atmospheric conditions constant in time and average / interpolation in space, refraction corrections are proportional to distance ie formula or "/dist, ZA effect is larger over longer distances.

c) $F = \frac{SD_{coords}}{SD_{msd}}$ gives **142.890** m.

Q45. Atmospheric effects, Open Pit mine

This method could also apply to monitoring prisms on the face of a dam wall.

More details for this method are given in a Moodle quiz question and in the reference: Rüeger, J.M., 1993 "Monitoring of Slope Movements Using Electronic Distance Measurement and Precision Theodolites", *Australian Mine Surveyor,* **9**(2): 24-34

One student noted that the diagram does not correspond with the ZAs so if 5 is at base of pit then ZA to all should be <90°, if it's at top of pit on opposite side then all ZAs should be >90° with 1 & 2 at about 90°. This is an example of me setting a question without a real survey basis.

a) Compare ZA observation with calculated ZA from coordinates, LSP method, mean corrections, reference marks did not move.
b) Atmos conditions constant in time and average / interpolation in space, refraction corrections are proportional to distance ie formula or "/dist, ZA effect is larger over longer distances.
c) 91° 14' 41.6" adj is -0.08"/m (=-79.8"/km or -47" for this line). Not 91 14 43 with a 46" correction which doesn't allow for distance.

Q46. Construction surveys

A) Laser plummet. If you have a prism with tribrach, then you can set the prism over the mark and then use constrained centring to replace the prism in the tribrach with the instrument. Other options include getting close to being over the mark (perhaps with a plumb bob) and then doing resections (if you are in a coordinated system with targets of know coordinates) and moving on the tripod until coordinates are correct. Another way is to not set up on the mark but to establish an eccentric or satellite station and take observations from there to the targets and to the nearby mark, then correct them so that they are over the mark or otherwise put them into a network adjustment.

One student wrote : First you know Murphy's law will kick in so a few more things will be going wrong that day. Then depending on how far into the traverse you are, you could move off the mark and …. This would take longer, and it may be a consideration to call the office and for a new total station to come during this process.

B) Mount prism on a mini pole put point against wall prism twisted to face instrument. Brace or support it. Instrument points at mark on wall first then lines up prism. Separately determine addition for length of pole. In many cases mini prisms have a tip on their reverse side which can be held against the intended target. This will have a known prism constant, so applying the appropriate prism constant into the instrument allows for accurate measuring of the point on the wall.

Or use steel band and apply corrections sag temp standard etc but must have a clear and small zero point (or make an adaptor).

Or Reflectorless to a mounted cardboard target with offset separately measured, but test reflectorless EDM to make sure it is accurate enough.

Or do a 2-instrument setup theodolite intersection with scale bar

Or use hidden point pole with observations to two prisms on it, and calculate position of tip of pole on mark

Do an independent check measurement e.g. radiate from another point or use intersection.

C) Transferring coordinates in a tall building. This is usually well done by almost everyone. Simply repeating standard lecture material. A nice easy way to finish an exam? A good description and sketches of any two of the following methods: Vertical optical or laser plummet through holes in the floor, or total station with diagonal eyepiece; Resection (free stationing) to targets on nearby buildings; GNSS on top floor as building grows, usually with a prism under each antenna; tilt sensors on several floors – but mainly for very tall buildings. Recent total stations with ATR and cameras built-in online of sight can be used for measuring up through the holes or from street level outside the building. Traversing or levelling up stairs is usually too slow and multiple set ups with short lines are error prone.

Q47. Construction surveys, glass

- Avoid observing through glass if you can, if not then consider what accuracy you want
- Angle of line of sight (LoS) to glass is critical, if 'square on' angles are OK, but distance is affected by about thickness of glass.
- The assumption is that that the glass acts as a parallel plate with truly parallel and truly flat surfaces. This might not entirely true for window glass.
- Line of sight is shifted by about glass thickness, not bent. There is minimal effect if line of sight perpendicular to glass.
- EDM Distance longer by about glass thickness or slightly more. n(glass) is about 1.5.
- reflectorless EDM and TLS might reflect off glass and give wrong distance or ghost image in point cloud.
- If angle of LoS is not 90 ° then LoS will shift parallel by about the thickness of the glass depending on the angle of incidence, it is an offset not a divergence.
- If 90 ° in direction but not 90 ° in ZA, then will only affect heights.
- If glass is dusty etc reflectorless or scanner might measure to front of glass, or a combination of distance to glass and to target.
- Laser scanner observations are affected similar to TS observations, plus scanner might give you ghost images from reflection off the glass onto another object and back again.
- ATR might work (best to be square on to glass) or it might not find your prism …

Q48. Construction surveys, bridge

This question is based on my 'bridge story' document supplied on the class website.
Example answer key points:

- Combined map grid scale factor (CSF) effect over length of bridge is…
- CSF effect over 34m span is …
- Scale factor affects 2D component of distances not the Δh or slope distance of prefab slabs.
- Need a local coordinate system at each pylon and must allow for tilts from vertical during varying load.
- Take care if joining GPS observations into a local coordinate system or series of local coordinate systems.
- Setting out marks accurately is more challenging than measuring the coordinates of existing marks.
- H&S of working on such a site e.g. on top of pylons.
- Sinkage of pylons when loaded.
- Design coordinates may not fit with MGA coordinates.
- Check for latest versions of engineering plans.

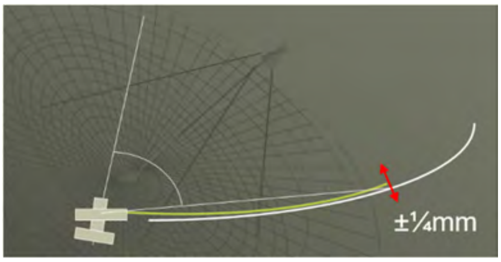
A student answer: The major consideration would be the design of the bridge and what coordinate system it was on. If it was designed in MGA, it needs to be converted from grid to ground. If not over 3.5km that would be a mis-match of 1.390m ((1-0.999603)*3500)), could cause massive problems at the end. Also over 3.5km maybe that distance is too long to have one Combined Scale Factor (CSF) …. Maybe an arbitrary site coordinate system should be adopted but then affects for the earth curvature could affect it. If they start at one end with a coordinate system, it will miss match at the other end. If they start with the coordinate in the middle, the alignment will be wrong. So, a possible solution is to have a different coordinate system at each pillar, as they will be different height and easting. However, using multiple coordinate systems care needs to be taken so that everyone involved knows what one they are on for each pillar to minimise a gross error. As there are many types of industries involved not just different surveyor companies, clear concise communication is a must. With clear instructions on methods and accuracy required and datums that the bridge is designed on, this will minimise errors. As there will be constant loading of weight on the bridge as well as atmospheric affects, especially heat, when the bridge is being built and when finished continuous monitoring should be implemented.

Q49. Recovery marks

- Loss of mark or movement of mark (due eg to construction trucks etc), centring error reduction, observations with a staff to get height of inst.
- To make sure you are on the correct mark.
- About ± 0.2mm (but certainly < 1mm) if marks are within a few metres of the instrument location.

Q50. Radio telescope surface

This question is based on one of my surveys and is discussed in class as a case study. The method we used placed a high quality total station at the centre of the dish and measured ZA to each target. The distance to the targets was measured with a specially calibrated steel tape that was laid on the parabolic surface. Calculations used the ZA and curved distance. Observations were taken at night. The vertical axis was held fixed so that it would move if the dish moved during the survey. The vertical circle compensator was not used.



Q51. Guest lectures on Project Surveying

You had to be there to answer this question, but I include it here as an example.
In 2023 our guests talked about several projects that they had done. Some of the things that our students learned (and gave examples of) were: the need to innovate and create solutions to unheard challenges; errors can be costly; being a Registered land surveyor can lead to getting projects that have no connection to cadastral work; responsibility; opportunities to travel for work projects; site considerations; wide range of applications and projects; new technologies are always emerging and surveyors should be trying to use them; think about how survey methods and software can be constantly updated to aid projects; etc.

In 2021 prisms were mounted directly to rock on either side of valley, in a line that lines up with the max strain expected, 'middle up' online in 3D, measure the distance directly, have another site with similar length line but not affected by mining – as a control / test case of the method, observe regularly over a few years with changing seasonal effects. A student wrote: Michael took several long-distance EDM measurements between the ridgelines on each side of the creek, correcting only for atmospheric conditions on each day. This is the rawest data form available, without any need for coordinate results or curvature/grid corrections. By using such a raw data form, it was possible to see extremely small variations in distance and therefore it was possible to notice deformation before significant damage occurred.

Q52. Survey design

- Laser scanner with targets at the key points – need to allow for target thickness, Terrestrial Laser Scan (TLS) targets may be too large but can get 1mm level. One setup
- Small reflective sheet targets and Robotic Total Station – need to allow for target thickness, can get 1mm level with multiple obs. one set up, or more for redundancy, if more connect the instrument stations by survey.
- Theodolite intersection survey, small crosses at key points, manual pointing, need scale eg scale bar or independent measurement of some distances, better then 1mm, at least 2 setups. The data collected would then be placed in a least squares software to compute the co-ordinates of the targets on the mould.
- Close range photogrammetry but mention how you would place targets.
- Don't use a laser tracker unless you say you hire one. They have a totally different operating procedure and precision.
- Since the survey is very small but higher accuracies are needed a local coordinate system would be fine to work on.

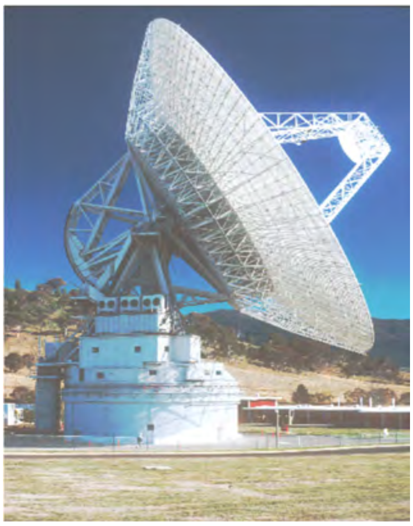
Yes, the boat hull could be surveyed without a laser scanner using the theodolite intersection or photogrammetry methods described above.

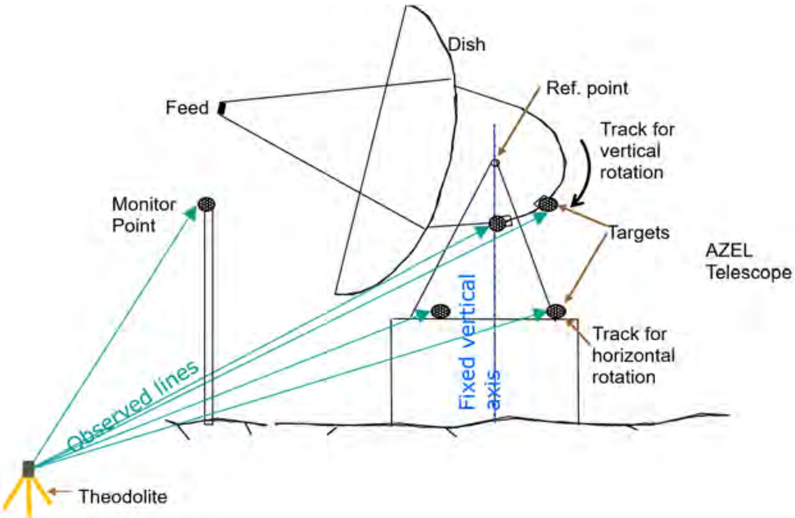
Q53. Survey Design, Church façade

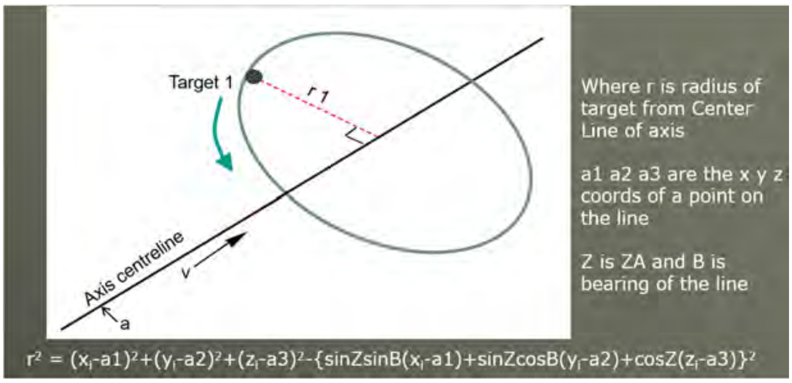
This feedback is intentionally brief. Purpose of survey is deformation, so it is not necessary to pick up all parts of building. Concentrate on areas with cracking. Put targets on neighbouring buildings as control. If Laser Scanning: Can do a laser scan from one central location, only small areas are occluded, but could use two setups. Use targets if two scans need to be registered. No targets put on wall. About 1 hour fieldwork. Can scan at night = less pedestrian and vehicle traffic. If 3D intersection: direction and ZA to marked targets, two setups plus scale bar in front. Targets are tape stuck on with a X on them. Least Squares adjustment better than 1mm. Whole day if many points. If reflectorless EDM: direction, ZA, dist. Measure to corners or stuck on target crosses. One setup gets most, but second setup could be used. On board coordinate calculation of coordinates few mm. Takes a few hours. If Photogrammetry …

Q54. Survey Design – axes determination

This question is similar to the radio telescope axes and reference point surveys discussed in class. It is important to have targets that rotate about the axis, not just try to observe to the centre of an axis because that is often obscured. Also, if there is a large diameter axle do not merely place targets around the perimeter and fit a circle with CAD – that obscures wobbles and orientation of the axle and may not be accurate enough for some applications.







For this turbine project:

- Targets place on moving parts.
- Targets measured in multiple places as turbine is rotated.
- LS best fit for circle and axis.
- Digital level to determine if parts are horizontal.
- Discuss manufacturer's tolerances and dimensions of the turbine.
- Total station radiations to targets not on centreline but **rotate**d about axis.
- Possibly observe to 4+ target locations for each cylinder.
- Possibly include some levelling observations to top of each end of each cylinder, but still need to rotate the cylinders.
- Coordinate targets, best fit circles by LS, then axis in 3D calculated.
- Include a good sketch of the survey, showing instrument and target locations.
- Other alternative solutions are OK too.

One student wrote a method that uses theodolite intersections without EDM (one of our course topics):
To find the bearing and slope of the centreline two points are required. If the housing is open, then it is possible to take measurements to the blades. To find the centre line a minimum of 3 measurements, to the each of the two blades, at different rotations is required as well as a few control measurements to determine scale and coordinates. Assuming the required accuracy for the survey is sub mm I would use a theodolite or two, a scale bar and a possibly a

few red and whites for this task. Again depending on the accuracy I would first setup a few control points, perhaps on the floor surrounding the turbine and the walls of the building. I would then set up and measure to a scale bar, this may not be necessary depending on the control points. I would then decide what point on the metal blades I would sight to. Unless there's a distinguishing feature on the blades I would sight to the intersection of a blade and the outer ring. Taking a measurement to both blades then rotating the blades around 45 degrees; then once the blades are out of view, I would select two new blades and do the same. Using these points to form two centres for each set of blades, after adjusting I would then join the 2 centres to form a centreline.

Another student (they did include some sketches, not reproduced here):
I would setup control points in the room and use a reflectorless total station. I would coordinate each of the points in a local coordinate system. I would find two sections of the shaft/flange that are exposed (ideally one close to the front, and one closest to the back). I would then set up the total station in a position where it is able to use EDM to measure the shaft at a perpendicular angle to the shaft. I would turn the laser on, and mark with a texta the position of where the laser beam is and mark it with a point number. I would then measure the position of that texta mark. Keeping the instrument in the exact position, (don't change the zenith angle or the horizontal angle), I would rotate the shaft 1/6 of a turn. Put a texta mark where the laser beam is, give it a point number and measure it with the instrument. I would repeat this process until have measure 6 points on the shaft. Once these 6 measurements are done, I would do the same process at the exposed shaft at the other end (but I would move the total station to the other end of the shaft and do a resection). Once the 6 measurements have been done at the other end too, I would get a micrometre and measure the diameter of the shaft at both of the exposed sections. From the measurement recorded by the instrument, I would take the average ENH of the 6 points at both ends. Then I would offset each of the points by half the radius of the shaft at each of the sections which will give me the centre of the shaft. I would then measure between the two points, which will tell me the alignment of the shaft.

Q55. Survey Design – axes determination
Total station radiations to targets not on centreline but **rotated** about axis, to 4+ target locations for each cylinder, possibly include some levelling observations to top of each end of each cylinder, but still need to rotate the cylinders. Coordinate targets, best fit circles by LS, then calculate axis in 3D. Supply a good sketch. Other alternative solutions or comments are OK too.

Student (they did include some sketches, not reproduced here):
Firstly, the circumference uniformity of the rollers would need to be checked, since any bumps could cause the metal slab to veer to one side. This could be done in a relatively simple fashion, by running a calibrated tape along each roller. The rollers should have a uniform circumference both along their length, and the same as each other. Next, the measurement of the location of the roller centrelines could be done by a variety of methods (laser scanner, reflectorless EDM, etc), however the method I would use is to set a total station up on either side of the conveyor and measure to reflective stickers on the end of the rollers, which scribe out a circle as the roller is rotated. Measurements would be taken to these with the roller at several different degrees of rotation. Two reflective stickers at different diameters would provide a check for calculation of the end of the centreline. As the site is an indoor steelworks, it is assumed that there is fairly limited space surrounding the conveyor. Accordingly, four rollers will be measured to from each station. A scale bar "leapfrogging" the instrument setup position (like a levelling run) would link the traverse and would highlight any distorting errors during analysis of the data.

A check could be done by setting the instrument up at the end of the conveyor with the tops of the rollers on the 90° telescope axis and using this line of sight to check for any irregularities in the rollers. The location and orientation of the centrelines would be calculated in post-processing. Firstly the location of the end points of the centrelines would be calculated as the centre of a circle, then the appropriate end points could be joined to create a line with a bearing and slope. Since the survey is done in a fairly small space, angular measurements introduce the largest source of error. ±Xmm in angular measurements will be translated into a ± for the final location and orientations of the rollers.

Another student:
For this job I would use a laser scanner. Multiple set ups would be needed to cover both sides of all twenty rollers and to account for any shadow effect. Fixed specialised laser scanning targets would be used on a local coordinate system as well as multiple marks would be placed on the ends of each roller. A scan would be taken with each roller in different position multiple times as if the roller was rolling through a full 360 degrees. The point clouds would then have to be joined for analysis. This would allow for each roller to have planes fitted to its surfaces and to determine at which point each roller is rotating around. The points where the roller is rotating around would be where the centreline of the axels and the planes fitted would be able to show orientation as well as the connection between the two axis points at each end of the roller.

Q56. High Precision Theodolite intersection survey
Between about ±0.1 mm and 0.5 mm, have a good plan with close to 90° intersections, inter-theodolite observations and or wall marks, and scale bar in good location. A least squares simulation would be useful.

Q57. Sports

- At least one diagram showing instrument or target locations.
- List or mention of equipment required.
- Checks described.
- Calculations described.
- Calibrate EDM or tape or other distance measuring device.
- For pool mention a shortest distance method not just one point on each touch pad and a comment on accuracy requirements.
- Several methods are valid – eg prism on pole, pole in water, local coordinate system aligned with pool lanes; Disto and pole in water; total station with radiations and calculations; laser scanner with target on pole; …
- Risk assessment eg no slip on wet surfaces; pool not in use; …
- etc

There are usually in class discussions about these topics in my courses, so those who attend should find this easy.

Assignments

In GMAT3100 at UNSW there are usually two assignments worth a total of 20% of the course mark. The first assignment is a seminar presentation, with each individual speaking to the class as described below. The second assignment is small (2-3 students) group work usually involving high precision survey measurements and least squares analysis. The second assignment changes every year. All students are expected to contribute ideas to their group's survey design, to learn from the ideas raised by their group partners, and to reach a consensus with one report per group. Submit a proposed survey design to the supervisor at least one week before the final report.

If a student is unable to attend campus because they have COVID etc or are overseas, as an alternative, students may do an alternative assignment as an individual.

About the seminar assignment

The aims of the assignment are to get students to read a surveying conference paper or presentation and to give them some experience at presenting at a conference or seminar. The assignment requires study of an international or local survey conference presentation (e.g. FIG or IAG or APAS) or survey project reports in a technical publication. The presentation topics directly relate to one of the topics in GMAT3100. So, we do not choose cadastral or GNSS or Remote Sensing or GIS papers.

As we do at surveying conferences, the presentation files should be submitted well before the day of the presentation class. The files and media must work on the lecture room's computer. The presentation should be a clear and concise summary of the base material and reveal an understanding of the topic.

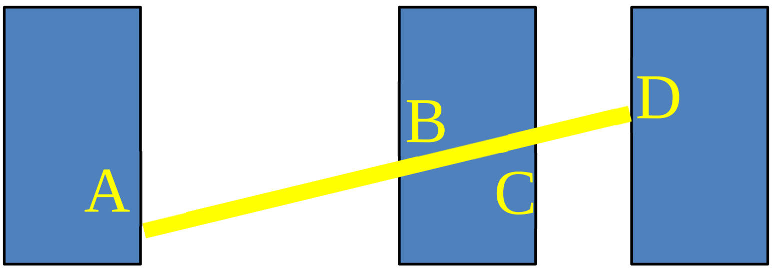
Links to some source materials are provided. Scanning through the papers to find one that interests you is part of the educational process. This selection process enables students to see what sort of topics, and their depth, are presented at surveying conferences. Each student has a different topic.

Each student makes a 5-minute live presentation to the class. It is challenging to summarise the key points of a whole paper into 5 minutes. Students are encouraged to not read notes or have all their text on a PowerPoint or pdf slide. Alternatively, some students are allowed to produce a movie (digital media) for their presentation, but it must be more sophisticated than a recorded narration of PowerPoint slides.

Assignment Q1. Boreholes

This assignment involves the design, field work and calculations for a survey of a 3D borehole line between two marks on UNSW building walls.

You are asked to do a survey to find the intersection points of a straight (sloping not horizontal) line joining two designated points on buildings on UNSW campus. Points A and D are two points on the outside walls of the Civil Engineering Building and the lower part of the Library Building, respectively. Your survey is required to find the 3-dimensional points of the intersections of the line joining A to D with the walls of the UNSW Student Development buildings at B and C and then locate (i.e. set out, mark, and check your B and C) these marks on the buildings themselves. You are required to establish the points to the highest possible precision given the equipment available within the School Survey Store. Several years earlier a similar assignment was on other UNSW buildings.



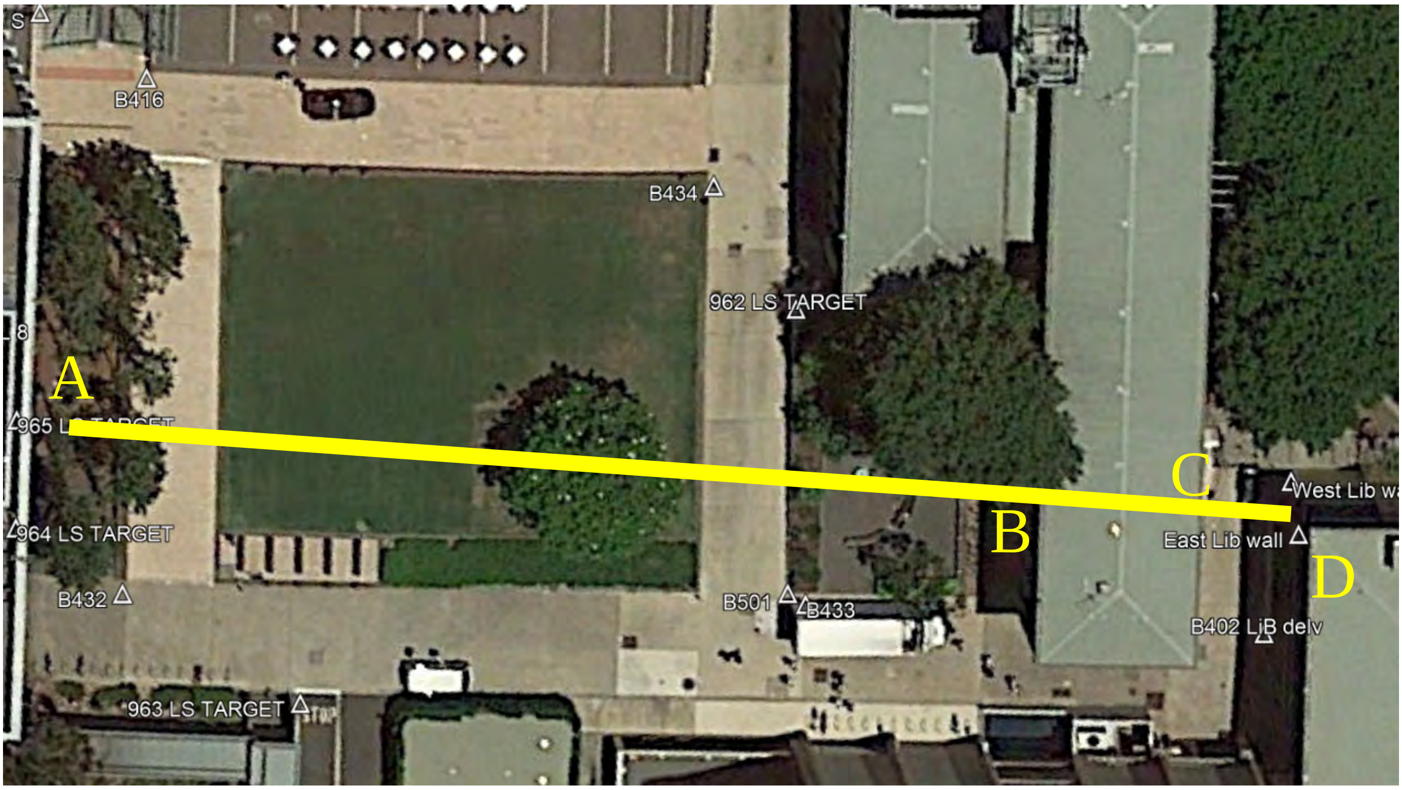
The survey can be tied into the University survey control network if you wish, but it does not have to be connected. Your report should discuss your reasons for the choice you have made.

You should analyse the problem and work out the best way of obtaining the required information. Decide which equipment to use, estimate its precision, decide where to set up instruments, which lines to measure, and which UNSW campus marks to connect to. Your lecturer will be available as a consultant in this matter. Whatever techniques you choose to establish the points, you should use independent measurements to check your results. When designing your survey be aware of obstacles at the site and that vehicles may drive or park on the roads adjacent to your marks. Be careful to not overdo the survey with too many measurements.

Your group decides when it does the fieldwork and prearranges the borrowing of equipment from the survey store.

Comment on how you guard against systematic and gross errors affecting your survey.

You will be shown the site and where the marks A B C D are located. The walls at B and C are not necessarily parallel to each other or perpendicular to the borehole. The borehole is not horizontal and there are some trees online. Your group can choose either Library wall mark as your point D, for the main part of the assignment. Treat the borehole as though it was about 2cm in diameter, not a tunnel.



Campus MGA and AHD Coordinates in m and their 95% Confidence Levels in mm

Point	E	CI	N	CI	H	CI
B402	336667.207	22	6245595.915	14	52.579	2
B416	336620.263	3	6245523.978	4	50.142	2
B432	336655.241	3	6245518.118	10	53.013	2
B433	336661.833	12	6245564.300	12	52.623	2
B434	336631.865	12	6245562.174	6	49.997	2

The campus CSF is 0.999924. You may use additional UNSW control marks if you wish, see lecturer for details.

Place temporary marks at B and C and give tape measurements to nearby features on the wall. Show the supervisor your B and C marks or include an annotated photo in your report. If B is not safely accessible do not mark it but do show a labelled photo indicating its approximate position.

"Honours" section
This section is for those students wanting more of a challenge and higher marks.
Working in local 3D coordinates survey the location of both laser scanning targets on the Civil Engineering wall ie 965 and 964, and the coordinates of both targets on the Library wall (East and West). This creates two straight inclined lines. One is from 965 to Lib East (437), the other is 964 to Lib West (436). Calculate the shortest distance between the two lines. You do not need to mark the location of the pedal points of this short line (they might be mid-air or inside a building). Then, if possible, determine the MGA/AHD coordinates of the pedal points, ie where the lines are closest to each other. Equations for the calculations of 2 lines in 3D are given in lecture material.

Checklist, requirements for report submission:

• In your report describe the accuracies of your results to determine the 3D coordinates of A, B , C and D.
• Discussion of survey design including details about the type of measurements and field techniques, procedures and methods
• List of equipment used for survey
• Plan of survey
• Annotated photos of B and C
• Show the calculation steps and a spreadsheet, or similar, to calculate the 3D coordinates of B and C.
• FIXIT (or similar least squares program) output file, and discussion of analysis
• What is the slope and bearing of the borehole AD?
• Calculate the shortest distance (not horizontal distance) from the point B433 to the line AD.
• Discussion of connection to control marks. Comment on whether you think the survey should be connected to the UNSW survey network (MGA and AHD) or not.

Give reasons to justify for and against the connections. (Hint: consider the accuracy of the UNSW control survey network and of your high precision survey, also consider the benefits of a minimum constraint datum or of connection of the network to global coordinate location).

• Discussion of Systematic and Gross errors
• Honours section: results and calculations, 3D calculations – formulas and results from above data

Acknowledgement: We thank Dr Tony Sprent (ex UTAS) for the idea for this assignment.

Additional notes

Using MGA/AHD coordinates from existing control marks has many advantages that you can discuss in your report but does not work so well in 3D surveys and calculations if the CSF is significantly different to 1. Using existing control marks in a local coordinate system with CSF = 1 also has some advantages (you can discuss this too). Sometimes we hold all the existing control mark's coordinates fixed, sometimes minimally constrained, sometimes with Bayesian estimates of their accuracy – another aspect for you to discuss.

If the size of your site and the survey accuracy requirements permit, then you may treat the CSF as constant for the site (if it is not, then we can still manage that but do not discuss how to do it here). We can convert MGA/AHD to Local coordinates and maintain the MGA bearings and internal geometry by at least two methods.

1) Pick one point in the control (usually near the centre) and calculate 2D joins to all the other points. Convert the grid distances to local horizontal distances using HDist = GridDist/CSF. Use these distances and already calculated bearings to generate new 2D coordinates of all the points. I would change the coordinates of the picked point to new values eg 100, 500; so that no confusion errors arise from misunderstanding whether the coordinates are MGA or local. There are no changes to the AHD heights of each point. Now you have local coordinates ready for 3D surveys and have still used the internal geometry of the control points – for strength and checking purposes.
2) Another way is to convert the 2D coordinates by scaling them directly. Think what happens when you inflate a balloon or stretch a rubber band. (More details in the Transformations section of CH8 in Mono 13.) Then calculate new local coordinates of existing control marks using:

   Local E = MGA E / CSF   Local N = MGA N / CSF   Local H = AHD

   I suggest you truncate these new local coordinates eg – 336000 from eastings, and – 6245000 from northings to avoid confusion-based errors. You can check the bearings between new local coordinates match the MGA bearings and that the HDists are the original GDist/CSF. You can now calculate true 3D slope distances and slope or ZA.

Feedback and results for Assignment Q1.

The purposes of the assignment were to get you to work and think in 3D, not 2D plus heights; to take measurements and do calculations and setouts, how to manage scale factors in our 3D world (it is not always insignificant). I had in mind that the boreholes were narrow with diameters of about 2cm to allow for things like gas pipes of fibre optic cables, not the centreline of a tunnel.

Some students used the built-in functions of Leica and Topcon instruments for setting on a line, some did not. Either way is fine. One group marked out the wrong borehole – not communicated well with client's requirements.

Coordinates from Campus network						
	MGA E	MGA N	AHD	Local E	Local N	H
965 LS W	336642.3108	6245512.334	52.2433	42.314	12.335	52.2433
437 Lib E	336660.8576	6245598.839	54.1679	60.862	98.846	54.1679
964 LS E	336650.1053	6245511.167	54.5988	50.109	11.168	54.5988
436 Lib W	336657.4991	6245599.311	54.571	57.503	99.318	54.571
ENDS of pedal points line converted from local back to MGA						
P1	336655.551	6245574.086	53.617	55.555	74.092	53.617
P2	336655.384	6245574.101	54.579	55.389	74.106	54.579
Shortest distance between lines		0.976				

Several groups did the calculations for the honours section. Most got the shortest distance correct, some of the coordinates of the pedal points were not so good, but everyone saw that the closest points are not in the same location as a plan view of the intersection of the lines.

A similar assignment was given in earlier years using different buildings on UNSW campus.

Assignment Q2. Design a deformation monitoring survey for Cataract Dam wall.

This assignment is for individual students who cannot attend campus.
The assignment involves the design and analysis of a dam deformation monitoring survey. Cataract Dam is located south of the Cataract Scout Park (near Appin). Your task is to design and simulate deformation analysis for two epochs. Note that the dam is in a mine subsidence area. Your survey can use total stations, digital levels, and GNSS. No other equipment is available. NSW SCIMS marks may be used if you wish. The approximate MGA zone 56 coordinates of the centre top of the dam wall are: 297773, 6206218.

Images of Cataract Dam from Google Earth and Nearmap

Checklist, requirements for submission:
- List of equipment required for survey
- Plan of survey
- Discussion of survey design including details about the network and type of measurements used
- Discussion of possible systematic and gross errors and strategy for dealing with them

• Discussion of subsidence of entire area
• FIXIT output file and discussion of analysis of deformation by simulation
• Comment on whether you think the survey should be connected to SCIMS control marks (MGA and AHD) or not
• Comment on whether you think the data analysis would benefit from using: L1 norm solution, Bayesian constraints, freenet analysis, minimum constraints or over-constraints.
• Conclusions

Feedback
Students had a variety of answers to this project. Some concentrated more on some aspects of the project than others.

Assignment Q3. Testing instrument software.

Design and implement testing of the on-board resection module of a supplied total station. In your future career you may need to test new instruments or new software. How do you know you can rely on them? When testing instruments or software we can seek situations or conditions that highlight or magnify possible errors or problems.

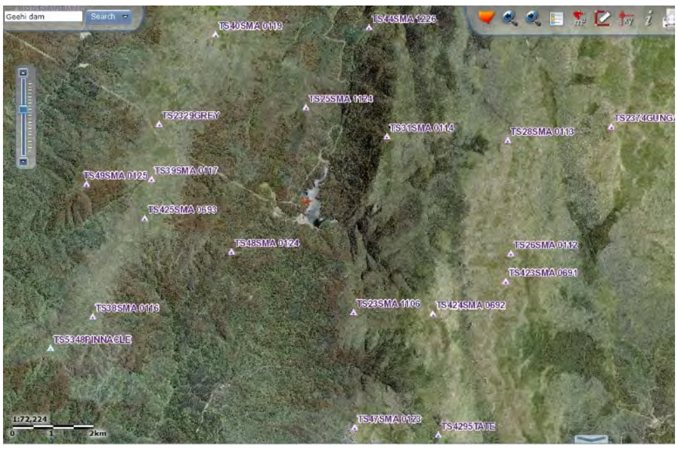
Possible activity includes:

1) Place several targets and or prisms around a site. Perhaps some near and some far.
2) Use a total station to observe these targets with 2D directions and distances. Do not measure distances to some targets. Record the observations and process by Least Squares. Do a resection calculation with the on-board module. Perhaps multiple observers.
3) Compare the outputs of Least Squares program and on-board. Comment on differences in output final coordinates, weighting of observations, treatment of outliers, error ellipses, redundancy numbers, etc.

Submit a detailed plan (logistics, drawing, methodology, instrument instructions) prior to fieldwork for feedback.

Assignment Q4. Geehi Dam monitoring survey.

The assignment involves the design and analysis of a dam deformation monitoring survey. It does not require on-campus field work. Geehi Dam in the Snowy Mountains area of NSW was surveyed as part of a deformation survey in 2005 by surveyor John Browne. He has kindly supplied his FIXIT input file "GEEHI DAM.inp" for student educational purposes. Your task is to design and simulate deformation analysis for a 2nd epoch in 2020 to see if the points on the dam have moved in the last 15 years. [The data file has 425 lines and is not printed in this book.] The approximate GDA 2020 MGA zone 55 coordinates of the centre top of the dam wall are: 618129, 5981439.

Aerial view of the dam and nearby SCIMS marks

A SCIMS search in Jan 2020 yielded the following data. Horizontal Datum: GDA2020, MGA zone 55, Vertical Datum: AHD71. The Hz class for all points is 2A and the Vt class for all points is U. It is not known if any of the pillars used in the 2005 survey are in this list:

Mark	Name	Height	MGA Easting	MGA Northing	Hz PU	Hz LU	CSF
TS 23	SMA 1106	1683	619356.770	5979074.073	0.06	0.06	0.999509
TS 25	SMA 1124	1589	618246.047	5984164.566	0.05	0.05	0.99952

TS 26	SMA 0112	1989	623291.803	5980471.525	0.05	0.06	0.999472
TS 28	SMA 0113	2003	623257.238	5983281.660	0.05	0.05	0.99947
TS 31	SMA 0114	1797	620248.168	5983415.516	0.05	0.05	0.999493
TS 39	SMA 0117	1667	614373.416	5982437.168	0.05	0.05	0.999497
TS 40	SMA 0119	1832	616022.136	5985999.643	0.05	0.05	0.999476
TS 44	SMA 1226	1549	619838.895	5986125.579	0.05	0.05	0.999531
TS 48	SMA 0124	1440	616345.068	5980612.256	0.06	0.06	0.999538
TS 423	SMA 0691	1996	623155.742	5979788.084	0.06	0.06	0.999471
TS 424	SMA 0692	1950	621338.089	5979005.303	0.05	0.06	0.999473
TS 425	SMA 0693	1653	614194.795	5981474.340	0.07	0.08	0.999499
TS 2329	GREY	1669	614587.897	5983797.467	0.04	0.05	0.999497

Checklist, requirements for submission:
- Discussion of survey design including details about the network and type of measurements used in the 2005 survey
- Analysis of 2005 survey data
- Discussion of systematic and gross errors
- List of equipment required for 2020 survey
- Plan of 2020 survey, including any extra points or lines compared to the 2005 survey, or any omitted points of lines
- FIXIT output file and discussion of analysis of deformation by simulation
- Comment on whether you think the survey should be connected to SCIMS control marks (MGA and AHD) or not
- Comment on whether you think the data analysis would benefit from using: L1 norm solution, Bayesian constraints, freenet analysis, minimum constraints or over-constraints.

Acknowledgement: We thank John Browne for the data for this assignment.

Assignment Q5. Car Park Sinking?

The assignment involves the design and calculations for a deformation monitoring survey of the northern face of the UNSW Botany St multi-level car park. The client wants to know how far the top floor sinks compared to the ground floor level due to the weight of many parked cars. This would require comparison between a time when the car park is nearly empty of cars e.g. early morning or late evening, and when it is nearly full of cars e.g. midday during teaching session.

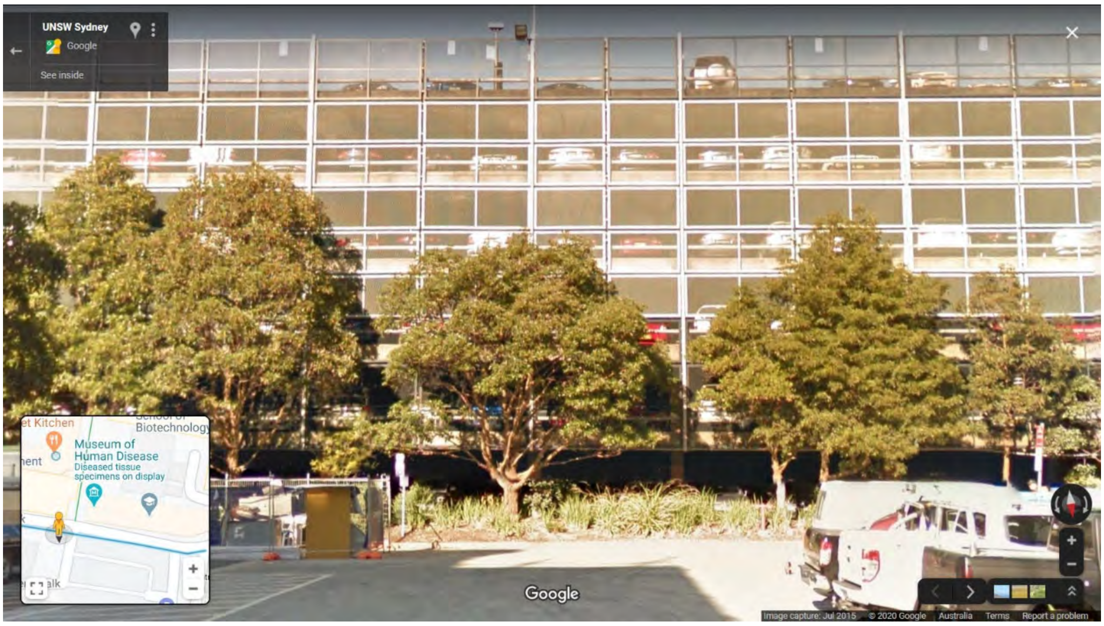


Image from Google Street View

Normally you would be required to survey to the highest possible precision and accuracy given only the equipment that is currently available within the School. However, for this assignment students are **not** to do any **precise** measurements – just design the survey and use least squares simulation. You are **not** required to visit the site on campus. You may take approximate measurements, e.g. by scale off a campus map or Google Earth or similar, to determine approximate coordinates (ENH) of your instrument locations and any other survey points you wish to use. Also check line of sight is possible (eg avoiding trees and other buildings).

You should describe any pre-processing calculations and pre survey calibrations or testing that might be required. Health and safety aspects during the design process and during a potential survey need to be considered and documented as part of this assignment.

That is, you are required to do the work a consultant surveyor would do before doing the survey measurements. You should analyse the problem and work out the best way of obtaining the required information.

The lecturer will be available as a consultant in this matter. Decide which equipment to use, estimate its precision, decide where to set up instruments, which lines to measure, and which UNSW campus marks to connect to. When designing your survey be aware of current obstacles at the site. You should also be careful to not 'over do' the survey with too many measurements.

The site constraints are that you are not able to occupy any of the building roofs on UNSW campus. Students work in groups of 2 or 3. Each student in the group is expected to contribute ideas to their group's survey design, to learn from the ideas raised by the others, and to reach a consensus with one report per group.

Describe the survey method and likely accuracies of your results. List of equipment required for survey. Plan(s) of survey. Least squares simulation output file. You may use any of UNSW control marks if you wish. Comment on whether you think the survey should be connected to the UNSW survey network (MGA and AHD) or not. Give reasons to justify for and against the connections. (Hint: consider the accuracy of the UNSW control survey network and of your high precision survey, also consider the benefits of a minimum constraint datum or of connection of the network to global coordinate location).

Comment on how you guard against systematic and gross errors affecting your survey. Discuss the precision of deformations that could be reliably detected (not just precision of coordinates). Comment on whether you think the data analysis would benefit from using: L1 norm solution, Bayesian constraints, freenet analysis, minimum constraints or over-constraints.

Feedback:
One group's network plan:

Assignment Q6: Lightning Pole deformation

This assignment involves the design and calculations for a deformation monitoring survey of a roof top lighting conductor (LC154) on the UNSW Mechanical Engineering building. The client wants to know how far the top of the conductor moves due to solar heating and cooling or due to winds that are possible on UNSW site in winter or summer. [If you are studying this book and are not on UNSW campus assume that the building is 18m high, the mild steel pole length is 3m and its diameter is 0.05m.]

Photo. Mech Eng building with roof top Lightning Conductor pole

You would be required to survey to the highest possible precision and accuracy given only the equipment that is currently available within the School. However, for this assignment students are **not** to do any precise measurements – just design the survey and use least squares simulation. You should describe any pre-processing calculations and pre survey calibrations or testing that might be required.

That is, you are required to do the work a consultant surveyor would do before doing the survey measurements. You should analyse the problem and work out the best way of obtaining the required information.

The lecturer will be available as a consultant in this matter. Decide which equipment to use, estimate its precision, decide where to set up instruments, which lines to measure, and which UNSW campus marks to connect to. When designing your survey be aware of current obstacles at the site. You should also be careful to not 'over do' the survey with too many measurements.

The site constraints are that you are not able to occupy any of the roofs on UNSW campus, except you may design the survey assuming observations from the pillars on K17 are possible, if you wish. Observations from ground level are allowed. Importantly, you may not go to the conductor (LC154).

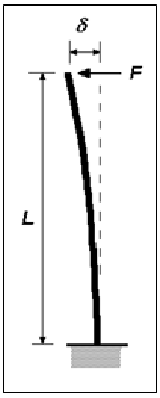
Students work in groups of 3. Each student in the group is expected to contribute ideas to their group's survey design, to learn from the ideas raised by the others, and to reach a consensus with one report per group.

You may take approximate measurements, e.g. with a GNSS phone app or scale off a campus map or Google Earth or Nearmap or similar, to determine approximate coordinates of your instrument locations and any other survey points you wish to use.

Describe the survey method and likely accuracies of your results to determine the movements of LC154. Also, how would you determine if the pole is leaning significantly compared to the diameter near its base? Comment on how you guard against systematic and gross errors affecting your survey.

You may use any of UNSW control marks if you wish. Comment on whether you think the survey should be connected to the UNSW survey network (MGA and AHD) or not. Give reasons to justify for and against the connections. (Hint: consider the accuracy of the UNSW control survey network and of your high precision survey, also consider the benefits of a minimum constraint datum or of connection of the network to global coordinate location).

Some background information supplied with this assignment included notes on deformation of poles. They are meant as an example of the sort of background knowledge you might need to investigate when designing a survey for a project in a field new to you. Students were advised to not try to learn this particular set of notes, simply read them and get an overview. The notes covered structural engineering concepts as well as the external forces on acting on poles such as solar radiation, wind loads and building movement. The possible deformations may be identified by using beam deflection calculations using Young's modulus of elasticity, thermal expansion and other engineering theory. Students could also access Bureau of Meteorology data about wind and temperature ranges at UNSW. Assume the pole has a strong and stable mount but no guy wires.



Checklist, requirements for submission:
• Discussion of survey design including details about the type of measurements and field techniques, procedures and methods
• List of equipment required for survey
• Plan of survey
• Least Squares simulation output file
• Discussion of connection to control marks
• Discussion of Systematic and Gross errors
• Discussion of precision of deformations, not just of coordinates, of LC154

Feedback:
There was much good discussion about many aspects of this project. One group's network design follows, other groups were quite different but also effective. Where would most of the observations to monitor movements be taken from? How frequently would observations be made? What type of monitoring measurements would be made?

Figure: Final Design Network (3 stations) vs Test Design (2 stations) – image not accurately aligned with coordinates of the network.

Some years after this assignment was run lectures included in class discussions of how to monitor movements of a lighting tower at the nearby Sydney Cricket Ground.

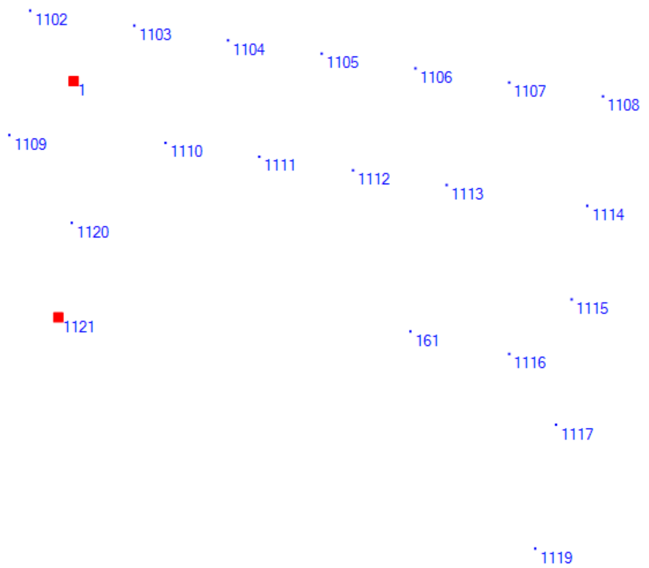
Assignment Q7. Roof Pillars High Precision Survey

This task will require you to execute a high precision survey as a single epoch of a deformation monitoring survey. It will be similar to an industrial survey, for deformation purposes, of a bridge that has had 20 prisms placed on it. The difference here is that the prisms will be < 20 m away. Each group of students will measure one epoch only.
The basic task is to determine precise 3D local datum coordinates of the 20 survey pillars on the roof of UNSW H20 building and if time permits, to determine the height difference to at least one ground mark on the UNSW campus

network.

The fieldwork should follow Work Health and Safety (WHS) practices and should not inconvenience other people on UNSW campus.
Prepare for the survey *before* the day of the fieldwork. Read instructions and user manuals, have booking sheets if required, and practice using the instruments (including downloading data). You decide whether to book manually or to download data, or to do both.

This task is an opportunity to use ATR for control surveying and to analyse its accuracy. Use a digital level to determine relative heights of the pillars. You are to carry out measurements with the highest possible precision given the equipment available within the School. Use a minimum constrained network solution. All points' coordinates should have their precision determined. Do use a combined scale factor for horizontal distances = 0.999924
Your final submission is to include a FIXIT input file of the observations. The data to be entered are the grand mean directions, mean grid distances, and mean height differences. Each observation in the input file should also be given a standard deviation. Adjust the data in FIXIT or other similar least squares program.



Consider that some prisms will be on almost the same line of sight from the total station. How close can they be to each other or to online? What can you do about that? Consider the effect of atmosphere and earth curvature and set up the instrument or your post processing appropriately. Discuss this matter in your report.

Transfer of heights from roof pillars to ground mark can be done by reciprocal ZA observations or by a level run in the stair wells or by EDM in the stair wells, or a combination of them, or by some other precise and accurate method.

Feedback
Some students did not practice using the instrument before the day of the assignment fieldwork – they had major problems with their data. Lack of preparation also causes groups to work slower and inconvenience those students after them. The combination of data from all groups helped improve our campus network, for the benefit of future students. The distance between 1108 and 1121 is about 11m.

Assignment Q8. Targets, EE Level 4, GPS towers, Conveyor Belt Survey
There were four different projects to choose from in the year this assignment was offered.

This assignment requires you to propose a solution for a non-routine survey problem that a new client might bring to a consultant surveyor. Sometimes clients are very brief in their initial instructions about what they want. You need to deal with that in this assignment. The highest marks will go to those who can propose a good method, justify it well, and communicate their proposed solution to a client clearly and reliably. Pass marks will go to those who can present a reasonable problem solution and a reasonable justification for their proposal. Note that in this assessment task there is more than one correct answer and different surveyors might propose a variety of valid solutions. So, your answers should include justifications for your methods, you do not need to try to find or guess what the examiner's personal opinion or solution might be.

Students work as part of a small group (2 or 3 students) to design, implement and write a report on a field exercise.

Each of the projects will help you learn about how to solve an unusual survey problem with the latest technology and methods. Reference material will also be provided. The fieldwork should be organised for a time outside of class time, it should follow OHS practices and should not inconvenience other people on UNSW campus. It is expected that students will spend about 30 hours on this assignment. Students are expected to contribute ideas to their group's work, to learn from the ideas raised by others in the group, and to reach a consensus with one report per group. Select ONE of the following questions, some require prior knowledge of least squares.

Q8A. Target testing

This assignment question involves testing, by measurement and analysis, of a new type of survey reflective targets for use with EDM. They are now available in Australia but with mixed results. Some surveyors claim they do not work reliably. We have some of the targets for you to test. You are to design a survey to test the targets, take the measurements, analyse them, and write a comprehensive report. The survey should use a variety of our school's EDM and at various angles of incidence, various distances, in prism and reflectorless modes. The report should determine additive constants for the targets and the standard deviations of distance measurement compared to EDM measurement to standard prisms and reflectorless measurement to white cardboard. It should also report which instruments and under what conditions these targets are reliable.

Q8B. EE Level 4 Survey

This assignment question involves the measurements and analysis of a survey to obtain 3D coordinates of two marks on the floor level 4 of the UNSW EE building. The marks will be indicated by the lecturer. They are about 36m apart and oriented close to East – West. You are asked to do a survey to find the 3D coordinates of these points and the azimuth of the line joining them, by connecting them to other coordinated points on UNSW campus. The bearing of the line is required in MGA and azimuth from true north and determine the precision of the bearing. The coordinates are required in MGA E, N (with their error ellipses) and GDA latitude and longitude. Height is required on the AHD, plus its standard deviation relative to other marks on campus.

Some years ago, students in this course designed surveys and measured and analysed them. In those cases, the surveys were allowed to take observations through windows from level 4 directly to outside ground marks. This version of the question does not allow those observations, it requires survey access via one and only one of the stair wells, working as though you are inside a sealed mine or tunnel.

You are to design your survey and carry out simulation analysis and to show the supervisor. Once this has successfully been completed then you carry out measurements with the highest possible precision given the equipment available within the School (e.g. no error greater than 2mm). All surveys are to be carried out using Standard for the Australian Survey Control Network Special Publication 1 (*SP1*) recommended procedures. All points should be tied into the University network and their precision determined. See the Campus Mark software on our lab computers for locations and approximate coordinates of campus marks. See the supervisor for accurate coordinates of fixed points.

Q8C. GPS Tower Monitoring Survey Design

The aim of this assignment question is to determine:

- How would we monitor the stability of GPS CORS towers – independently i.e. without GPS obs?
- How could we determine the coordinates of the towers independently without GPS observation?

Your task is to design a survey solution to the problem and write guidelines. We want a "standard" that is fast and not too costly. No fieldwork is required for this question.

There are three types of towers to consider:

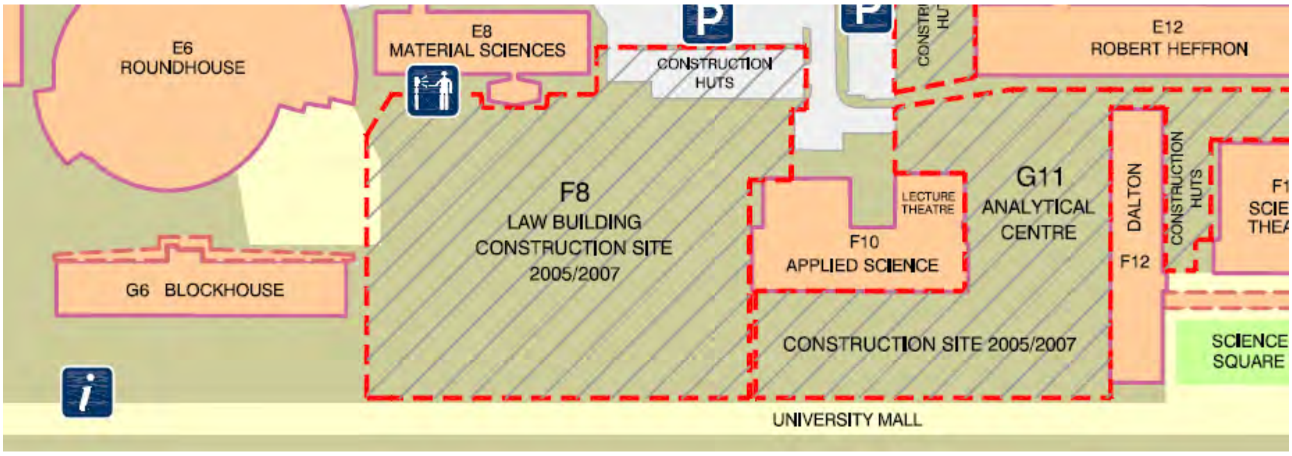
a) Ground-mount 8'
b) Ground-mount 16'
c) Building-mount 80"

A photograph of each of these is shown below. Assume that the concrete has dried completely before starting the operations.

Q8D. Conveyor Belt Survey Design

For this assignment students are **not** to do any precise measurements – just design the survey using least squares simulation and do some simple field measurements to determine approximate coordinates. That is, you are required to do the work a consultant surveyor would do before doing the survey measurements. You should analyse the problem and work out the best way of obtaining the required information. I will be available as a consultant in this matter.

Assume that the University has decided to replace the Dalton Building with a high volume stone crushing unit. You have been engaged to complete the survey and design work for an ultra modern conveyor belt, bought cheap in a Japanese Christmas sale, to feed the unit with quarried blue metal. The location of the start point of the conveyor belt is on the ground at a point 7m due south of the SE corner of the Blockhouse (see figure below). The end point of the conveyor belt is at the SW corner of Dalton Building on top of the building. The conveyor belt will be a circular curve of radius 4000 m in plan view (curving to the southern side of the straight join) and have a vertical parabolic curve of maximum length between the end points and zero (horizontal gradient at the ground end). The maximum span between vertical supports is to be 50 m.



Reconnaissance of Control Survey

The first field task is used to design your control survey (e.g. 3D traverse) in the field. Several control marks are available on campus. Check that the marks you wish to use do still exist on campus. You should select enough traverse stations so that the vertical support points (stanchions) on the conveyor can be easily set out and so that the end points can be measured with sufficient accuracy. The lines of sight between the stations must be unobstructed and should not be along and over footpaths, for obvious reasons. The selected traverse stations should be temporarily marked, and approximate 3D coordinates determined. You are not allowed to climb onto the Dalton Building; so to determine its height you need to do remote measurements. Do not enter the construction site. On the basis of your approximate coordinates of end points, compute the 3D coordinates of the top of the stanchions.

Control Survey Design

Do a LS simulation of your control survey. Analyse the design. Revisit the field and modify the design if necessary. Take photographs of your proposed survey site and overlay survey points and lines on the photographs.
Your network should connect to the UNSW control survey and produce MGA and AHD coordinates. Decide which equipment to use, estimate its precision, decide where to set up instruments, which lines to measure, and which UNSW campus marks to connect to. Whatever techniques you choose to establish the points, you should use an independent method to check your results. When designing your survey be aware of obstacles at the site.

Computation of Setting Out Data

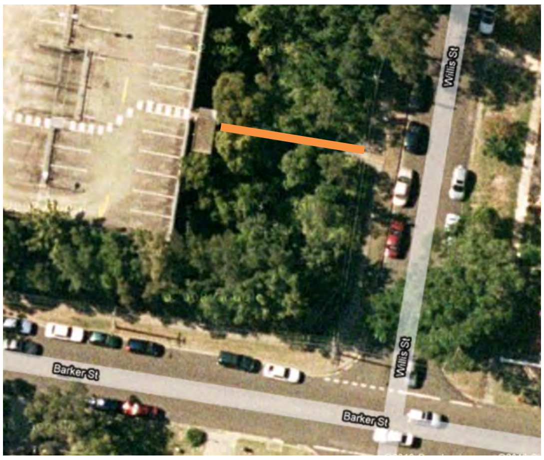
In a real survey, after the control survey has been done it would be necessary to compute the bearings and the distances and height differences to all stanchions from all traverse stations that are likely to see the stanchions. Note that you must convert the MGA distances that you compute from the coordinates to equivalent ground distances, using the reverse process of that used when reducing observed distances to the MGA. Calculate the appropriate scale factor and the corresponding mm correction term for your longest radiation.

Acknowledgment: This assignment question 8D is based on a field practical exercise prepared by: S. Ganeshan and J. Rüeger.

Assignment Q9. Bridge deformation

There is a pedestrian bridge between Willis St and the UNSW Barker Street car park. It is 17m long. You can feel it flex as you walk along it. How much does the centre of the bridge deform (sink) when people stand on the bridge?

[This exercise was originally an assignment, later a “mini prac” where students design the survey, observe, and analyse the data. Now it is often done with high school visitors. For a high school visit activity a staff member leads the exercise and tells High School students what to do. But asks them questions of a problem-solving nature too.]




Discussion of the site before the survey:
One of a surveyor’s role is to design a survey method and equipment specific to each job. Design – measure – analyse – report. Large bridges would be done differently to our small bridge. For this survey we want to find out how much the bridge sinks with people on it, and whether it returns to original undamaged position when people move off it. Can you think of ways to measure the deformation? The trees around the bridge limit our options. On large bridges we might have other problems. We cannot stand in the water under a bridge or under this bridge. GPS or drones do not have enough sky coverage on this site. Total station pointing to a prism does not get sub mm accuracy. Can we put a box on the bridge that measures up and down – they don’t exist (yet). Tilt meters do exist but are not useful for this job. Consider alternative methods such as photogrammetry, laser scanning, etc. Could we hold a tape vertically from the bridge to a mark on the ground below?

Analysis
How much did the bridge deform? Did it return to original position? Analyse and plot the results deformation in mm against number of students.
Observations to the stable reference point – how much variation?

Feedback about our survey design:
We set up a digital level on the footpath on Willis St in line with the bridge. Place a digital level staff half way along the bridge on a suitable mark (heavy base plate). Either have one person holding the staff or tie the staff to the bridge. Place a firm level spike or heavy base plate along Willis St at a similar distance to the instrument to the bridge staff. Observe a second level staff on this stable mark before during and after observations to the bridge staff, to ensure the instrument is stable and to confirm the accuracy of measurements. Instrument set to simple measure mode and display readings to 0.0001 m. Need to consider lighting / shadows on staff.

- We have a staff on the footpath about the same distance away from the instrument to check whether the instrument is moving up or down.
- Setting up a digital level at the other end of the bridge on the car park and a second staff on the bridge is not suitable. The car park moves and is not a stable setup.
- Using a total station and prism to observe ΔH (with manual or robotic ATR pointing of the cross hairs), might have $\pm$ 1 mm pointing errors and the effort it takes is not as good as digital level over these short distances. If the bridge was longer then a single set up of a digital level would not be successful.
- What if the batteries on the digital level go flat – what can you do?

Observe to the bridge staff with no students on the bridge (if possible), then add one student half way along the bridge and measure the staff again. Add another student to the bridge and measure again. Repeat until about 15-20 students are on the bridge. Then reverse the process taking one student off the bridge observing, repeat until only staff holders on bridge. Did bridge return to its original height? This assumes that the students are all of similar weight. We could use 20kg bags of sand instead of people.

Example results
This example does not show what happens as we reduce the number of people on the bridge, but other data sets show that the centre of the bridge sinks up to several millimetres and does return to its original position within

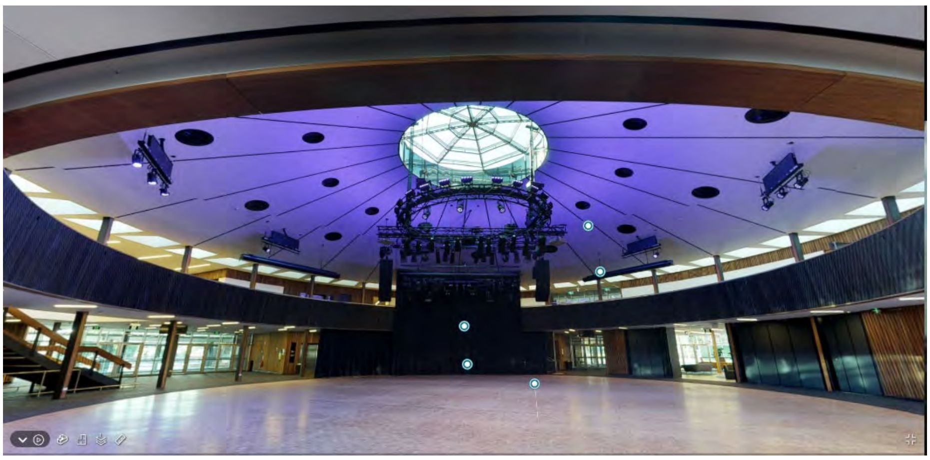
0.1mm. So no damage is done? One of my structural engineering colleagues asked: what is the design load of this bridge? A good question. I do not know the answer.

Bridge survey by digital level			
Reading to reference mark	Reading to midpoint of bridge	number of people on bridge	Displacement of midpoint of bridge from arbitrary datum in mm
1.26971			
	1.06217	1	-0.00217
	1.06281	2	-0.00281
	1.06317	3	-0.00317
	1.06376	4	-0.00376
1.26964			
	1.06399	4	-0.00399
	1.06428	5	-0.00428
1.26952			
	1.06489	6	-0.00489
	1.06518	7	-0.00518
	1.06549	8	-0.00549
1.26956			
	1.06566	9	-0.00566
	1.06614	11	-0.00614
	1.06647	12	-0.00647
1.26959			
	1.06714	15	-0.00714
	1.06792	17	-0.00792
1.26951			
Std dev to ref			
0.08 mm			

Assignment Q10. Is the Roundhouse Round?

(Currently this activity is part of another of my courses at UNSW, but it fits well with this book).

Aims and learning objectives:
To apply a combined least squares solution to a problem without a pre-existing software solution. To use reflectorless EDM in total station to take measurements. The survey is on not on AHD or MGA. Group fieldwork, individual calculations, and reports.



This project replaced projects at previous survey camps, namely: the Berry flying fox/zipline 300m cable survey that fitted a parabola or catenary curve by least squares; and the Morpeth water tower survey that determined the volume of a 20m high cone by least squares fitting of circles. The Least Squares calculations for those projects are taught in other courses at UNSW. This project requires students to apply the method of circle fitting by combined least squares solution to their own data.

Client's Requirements:
The client requires: the radius of a best fit circle of the balcony, the horizontal distance between the centre of the circle and the centre of the building as defined by the centre point of the roof, the imperfections of the balcony from the best fit circle. Also, the variations in height around the balcony – is it level? This shows how well the building was constructed.

Brief description of measurements:
Set up a total station on the floor inside the main hall of the UNSW Roundhouse somewhere near the centre of the building. Measure 3D coordinates of points on the wooden surface of the level one balcony, using Reflectorless EDM and scale factor = 1. Coordinates are in your own local datum. Book ENH manually or record and download later (or do both).

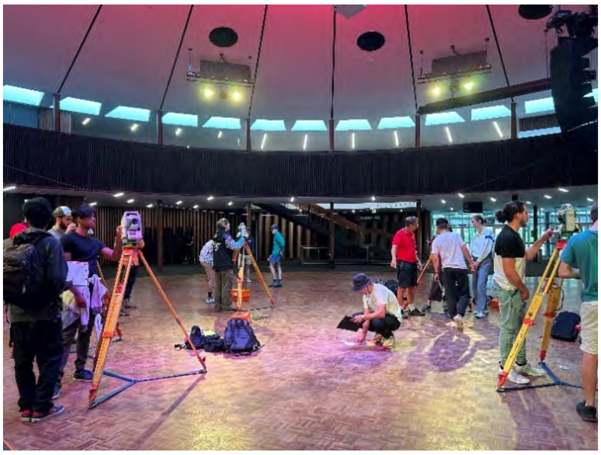
The diameter of the balcony is about 23m. Supervisor will specify which part of the rim of the balcony – usually about 4m above the floor. The height difference between the ceiling and the floor is about 12m. Measure about 20 points evenly spread around the balcony (e.g. 18-20° intervals). The points should start at a clearly marked target as indicated by the supervisor. Measure to a point on the floor directly below the centre of the roof or to the centre of the roof. Measurements do not take a long time and can be done in wet weather. We can have multiple groups observing at the same time.

Analysis and Submission:

- Calculate a combined method LS best fit circle to the balcony points, using their EN coordinates and ignoring any variations in height. This is usually done on a spreadsheet – not with CAD.
- Calculate the best fit radius and the (local) coordinates of the centre of the circle. Determine the bearing and distance from the floor mark (below the roof centre) to the centre of your best fit circle.
- Calculate the radial distance from each measured point to the best fit circle. Comment on these and produce graphics.
- Calculate the mean height of the balcony points and the difference to the height of the floor mark. Comment on the variations in height and whether the balcony is level or sloping.
- Comment on your input standard deviations of observations, variance factor, outliers, and anything else relevant to the analysis.

This project takes considerable calculation work if you create your own spreadsheet. Think of it as an opportunity to learn something rather than just a task to get marks. How much of the calculations and analysis you do depends on how interested in it you are, and on how much you already know about Least Squares.

Feedback:
Students usually obtain the radius to about ±1mm and find a few points that have a 'bulge' of 2-3 cm. Most of the points fit a circle very well.



The reports should include comments on your chosen standard deviations of observations; comments on your Variance Factor (VF); the roof centre offset from circle centre; the best fit radius and its 95% CI; comments on outliers; graph(s) of the offsets from best fit circle; and heights. Some people used CAD circle fit as well as LS, but you probably do not know what algorithm was used to calculate the circle or arc in CAD and it doesn't allow variations in the weighting of some points. Doing the combined Least Squares solution via the spreadsheet allows you to know exactly what is done, and it is the best answer.

Is your input standard deviation of the observations consistent with the instrument specifications especially the distance component? For this project the distance measurements from a place near the centre of the circle are far more significant than pointing with directions and ZAs. If there are no bulges in your part of the balcony then the residuals will be very small and you may get an unusually small VF. That is OK. Can you explain why?

An xy graph of the offsets from the best fit circle is clearer for the client to see that than a plan view of the entire circle. Perhaps showing both is best.

This building was designed and built before Australia converted to the metric system. So, our radius of this part of the balcony is about 38 feet. In 2023 some people found an outlier at one point of a few cm and downweighed it. This might be an error in observation, or a 'bulge' in the balcony. A variation in the height for that measurement (or to any of the targets) would not make a significant change to your horizontal distance measurement (or the associated EN coordinates). More than one group independently found the same point on the balcony to be inconsistent with the best fit circle, so it is likely to be a small construction fault rather than an observation or calculation error.

Improvements to this survey. Some students suggest placing reflective targets with clear centre at constant height compared to the edge of the balcony.

Alternative sites:
We could use RTK GNSS at Kensington Park near UNSW or similar, to determine the best fit circle to the picket fence. Measure the coordinates of major posts so that we have points evenly spread around the oval. Calculations and report are similar to the roundhouse survey. This survey could be on MGA and AHD. The Kensington oval is not anywhere near circular, neither are the Sydney or Melbourne Cricket Grounds.

Assignment Q11. Pollard to Robinson Wall Mark Tunnel Traverse

(Currently this activity is part of another of my courses at UNSW, but it fits well with this book).

Aim and learning objectives: To experience some aspects of underground mine or tunnel surveying and to focus on accuracy and precision of survey in a constrained site. This will involve the wall survey technique around a curve. In previous years, it involved the propagation of a straight line. The objective of this survey is to transfer azimuth and to carry height difference. The survey is not on MGA or AHD. Field work is group work. Individual reports and analysis are to be submitted.

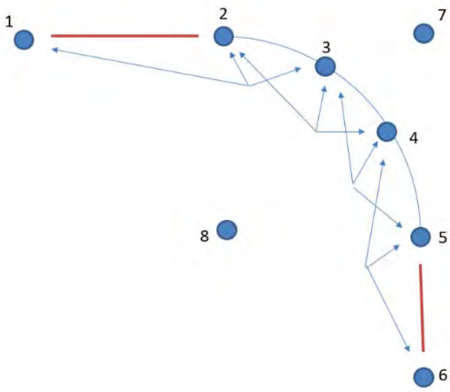


Figure. Plan of Wall Mark Tunnel survey on Physics lawn.

360° EDM prisms will be placed by staff at wall mark locations 1 to 5, and another 360° prism with a different constant will be placed at mark 6. In our case they will be mounted on tripods, in a real survey they would probably be mounted on brackets or similar on a wall. Students do not use marks 7 (the intersection point of the curve) and 8 (the centre of the circular curve) in the above figure.

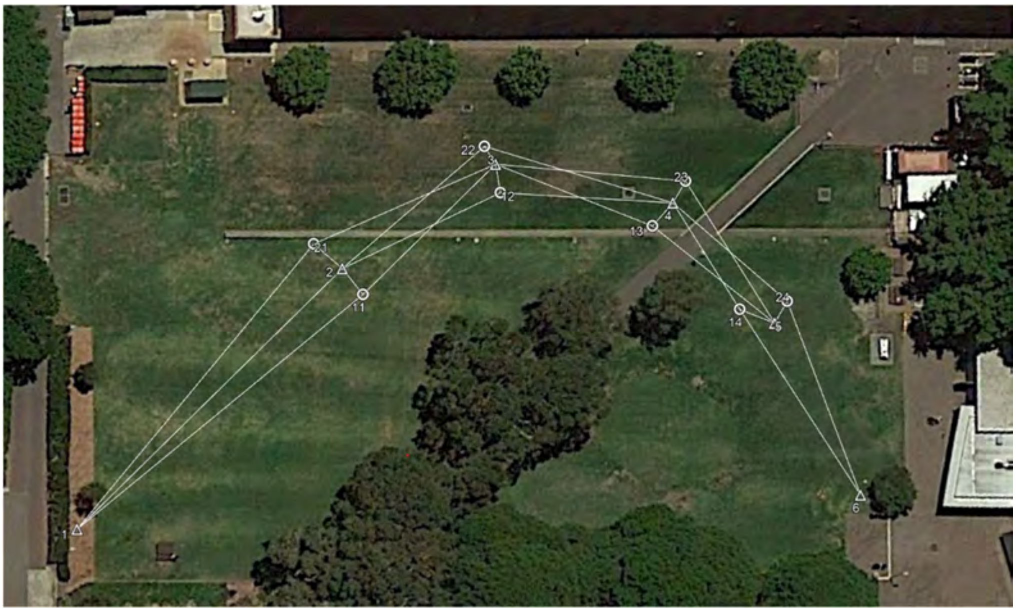


Fig. Approx locations of two 2023 imaginary student tunnels. Marks 11-14 in southern tunnel, marks 21-24 in northern tunnel.

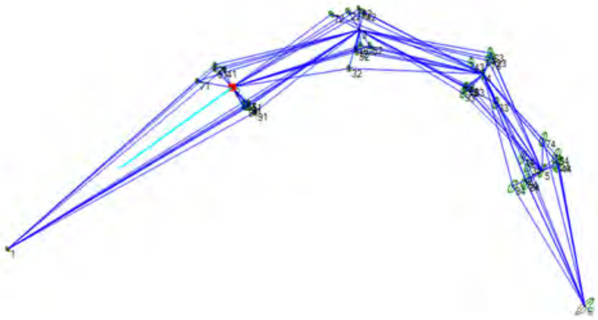
Description of students' fieldwork:
Set up a total station (usually robotic) at 4 locations close to the curve (i.e., inside a tunnel). Measure direction, horizontal distance, and height difference to 3 prisms from each set up. Locations are approximately as shown by the blue arrows in the figure. Students may choose to do manual booking of field observations or electronic recording and download, or both.

A variety of prisms might be placed on the wall marks so remember to change use the relevant prism constant. Multiple groups of students will occupy the site, so some groups setup inside the tunnel curve and other groups setup outside the tunnel curve – as though there were two imaginary tunnels but using the same prisms.

Calculations and report:
Given azimuth of line prism 1 to prism 2 (54° 14' 06") and height of centre of prism 2 (34.567m). Calculate the azimuth of line 5 to 6 and height of centre of prism 6 and their 95% CI. Calculations could be done onboard some instruments or in CAD. However, for this project a least squares analysis is required.

Report should include a summary of results, analysis of the precision of the results, and comments.

Feedback on Pollard to Robinson Wall Mark Tunnel Traverse
John Pollard and Tony Robinson were two former surveying lecturers who taught for many years in our school including survey camps. In 2023 I did a LS solution using 9 groups observations combined. There were 334 observations. From the set of all the observations, only a few were found to be outliers. The solution with 9 groups data combined gave: Azimuth 5 to 6 with 95% CI ± 36", and height of 6 with ± 0.9 mm 95% CI.



This tunnel exercise is (and has always been) marked primarily based on the accuracy of the survey.

The report and analysis should include comments on low redundancy numbers; the chosen standard deviations of input observations, especially the centring/pointing component for short direction lines; and how to improve the survey technique, eg simulations and or comments on sighting to 4 prisms instead of 3, using wall brackets for instrument, traverse observations between instrument setup sites, reversing the traverse and returning to the start, using standard prisms instead of 360°s, FL / FR and multiple arcs, placing wall marks on both sides of tunnel, direct distance measurement between wall marks with a tape, etc.

Surveyors using a total station with ATR and onboard calculations could determine the coordinates of their instrument by 'free stationing' (also called 3D resection with distances). Then calculate the coordinates of the next new target by radiation. Easy to do, but at the end of their survey they do not know the precision or accuracy of the final azimuth or coordinates of their final point. That is why we ask students to do a Least Squares analysis. In our project we also had the advantage of being able to compare 9 groups of data.

Even when using constrained centring and observing prisms directly I think it would be wise to use a standard deviation centring component for directions a little larger than zero, to account for errors in automatic pointing to a 360° prism. This would give the directions on very short lines larger standard deviations and that would reduce their effect on swinging the longer lines.

You will probably notice that if your starting coordinates are poor (no GNSS in the tunnel) then it might take many iterations to converge the Least Squares solution. That is due to the short lines and the geometry of the network making the orientation parameter particularly sensitive.

Assignment Q12. Control survey, deformation survey, or literature study

There are three questions supplied, do one question. It is intended that most students will do question A or question B. QA and QB need prior knowledge of least squares. As an alternative, students without sufficient least squares background may try QC. Note that QC needs considerable effort but is less intellectually challenging than QA or QB. Therefore the maximum mark that will be awarded for QC is likely to be lower than for QA or QB.

QA. The assignment involves the design and calculations for the improvement of the 2D component of the UNSW campus survey control network. The client wants to know the MGA coordinates of several marks on or near campus. These marks currently have large error ellipses. They are: [not relevant to this book now]

The full project would require surveys to the highest possible precision and accuracy given only the equipment that is currently available within the School. However, for this assignment students are **not** to do any precise measurements – just design the survey and use least squares simulation. You should describe any pre-processing calculations and pre survey calibrations or testing that might be required. That is, you are required to do the work a consultant surveyor would do before doing the survey measurements. You should analyse the problem and work out the best way of obtaining the required information.

The lecturer will be available as a consultant in this matter. Decide which equipment to use, estimate its precision, decide where to set up instruments, which lines to measure, and which UNSW campus marks to connect to. When designing your survey be aware of obstacles at the site. You should also be careful to not over do the survey with too many measurements.

The site constraints are that you are not able to occupy any of the roofs on UNSW campus, except you may design the survey assuming observations from the roof top pillars on K17 and H20 buildings are possible if you wish. Observations from ground level are allowed. You may take approximate measurements, e.g. with a HH GPS or scale off a campus map or Google Earth or similar, to get approximate coordinates of any new instrument locations and any other new survey points you wish to use. Students work in groups of 2. Both students are expected to contribute ideas to their group's survey design, to learn from the ideas raised by their partner, and to reach a consensus with one report per group.

You may use any of UNSW control marks if you wish. Comment on whether you think the survey should be connected to the UNSW survey network (MGA) or not. Give reasons to justify for and against the connections. Consider the accuracy of the UNSW control survey network and of your high precision survey, also consider the benefits of a minimum constraint datum or of connection of the network to global coordinate location. Comment on how you guard against systematic and gross errors affecting your survey.

QB. This topic is done by individuals, not group work. Analyse the survey data in the FIXIT input file "Toon bridge survey three epochs.INP". The data is real from surveys of targets on a bridge. Three epochs of observations are supplied. Determine which points have moved significantly, how much they have moved and in which direction. Describe your analysis and your conclusions.

QC. This topic is done by individuals, not group work. Choose one of the one of the lecture topics or part of one of the lecture topics in this course. Or select one of the reference books listed in the course outline, or the Moodle class web material, or other books provided by Dr Harvey. Then see Dr Harvey to get approval to do this question. Each student doing this question must use a different reference source or topic.

Write a clear and concise summary of the topic or book or a chapter in it. You may scan figures from the book or find pictures on web and insert them in your report (with proper acknowledgement!) or redraw some of the figures in colour. The aim is to include important or useful information from the book, at a level that could be read by future year 3 students in this course. Do not plagiarise your material. Do not get someone else to write the report for you. You are going to be a professional who works ethically so we want you to act that way now.

It is relatively easy to collect masses of material and write a long document. It is more challenging to be able to summarise or condense the important matters to a limited word or page count. That is a useful skill for those people who have to apply for research grants, tenders for projects or similar when they are allowed only a limited space to make their argument. It is the quality of your writing and its content, not the length of the document that wins.

MOODLE QUIZ QUESTIONS

In this course there are sets of weekly questions managed through Moodle. Moodle calls them quizzes. Traditionally we would have called them tutorial questions. Feedback is built into the quizzes, and consultation with teacher is recommended. Students are allowed multiple attempts, usually within a 2-week period. Students are allowed to help each other with the questions, but not merely tell someone what the answer is. Both the giver and receiver of this help learn better by explaining the method to each other. The aim is to achieve mastery. To encourage students to attempt the questions small marks are awarded – typically 0.1 – 0.5 marks of the course, with a total of 10% for the term. A random audit system requires students to show their workings to the course coordinator during term. Students who perform poorly in the quizzes and workshops are recommended to discuss progress with the lecturer during the semester. Students are allowed multiple attempts at each question, so it is easy to cheat multichoice questions – simply try each option until correct. However, that is not a good way to learn.

Some of the quiz questions are based on past exam questions and are given elsewhere in this book. The following questions are in a random order. Some are easy, some take more effort. Some questions require written answers and sometimes drawings – they are mark manually by the teacher.

Many questions are multiple choice. In the following an equal sign (=) indicates the correct answer(s), tilde (~) the wrong answers, and # indicates feedback that is supplied in the quiz after a student enters their answer.

<u>Mini Pracs</u>

Select which of the following field exercises you have done:

□ Used a tripod based laser scanner to scan a scene that includes targets

□ Tested the alignment of the reflectorless EDM beam against the cross hairs and measured the beam width of the reflectorless EDM beam

□ Used at least 4 total stations, each with different operating systems

□ Set up accurately under a roof mark (not a prism) in a shaft that is about 20m high and measured the distance between floor and ceiling

□ Observed directions, ZAs, distance (prism and reflectorless EDM mode) through a glass door that is open, closed and at various angles to the line of sight

□ Used a motorised total station with built in Line of Sight (LoS) camera to point to target

□ Used a motorised total station with automated pointing and automatic reading of multiple arcs to prism targets

□ Used a motorised total station with remote controller to measure the join between two points that are not intervisible and to have the instrument track the prism

□ Set out a line of sight through a total station that is parallel to a wall by measuring offsets

□ Observed through a Wild T2 theodolite, with a parallel plate micrometer attached, to accurately measure small offsets from a line.

□ Visited the UNSW Mining school's 360° surround video 3D viewer to see and experience underground mining operations and conditions, both longwall coal mines and hard rock mines.

□ Used two high precision theodolites and scale bar, with the 3D intersection method, to precisely determine the length of a school ruler (or similar).

□ Determined the Additive Constant (AC) and Scale Factor (SF) of a total station in reflectorless EDM mode, on campus

□ Observed directions to a target in a very dark room

□ As part of a mini-Olympics determined the distance to a target for a throwing event, with instrument not on the starting position.

<u>High rise</u>

Write some brief notes with sketches that describe a few ways to transfer EN and H coordinates up through a high rise building during construction. You can write, or copy / paste into the answer box or attach a file.

<u>Methodology of Project Surveying</u>

You can type or paste you answer into the textbox or attach a document with your answer. Read all the class Moodle reference documents on Project Surveying Methodology. Then write a short (max 1 page) summary notes on at least one of them.

Are you spending enough time on this course to gain the desired learning outcomes?

<u>Revision</u>

Briefly explain MGA coordinates and why we use them.

Ethics 1

Which of the following are examples of unethical conduct by a Professional Surveyor?

Practicing without a relevant license/registration

Performing services beyond one's competency

Conviction of a crime

= All of the above

Feedback: All of the list are examples of unethical conduct by a Professional Surveyor. If it involves land boundary (cadastral) or mining surveying, he or she may be dealt with by BOSSI in NSW. That may cause Registration to be removed, and/or may face court, or some other action. If it is not a BOSSI matter, then membership of a Professional Institution such as ISNSW may be suspended, or other action taken.

[Based on https://practicequiz.com/q/which-of-the-following-are-examples-of-unethical-39007]

Ethics 2

What is the value of the following disclaimer? "Acme Surveyors assumes no responsibility for data supplied in electronic format. Such data is provided for convenience only and the recipient accepts full responsibility for verifying the accuracy and completeness of the data. The original hard copy of the data, which has been sealed and signed, shall constitute the official documents of record for working purposes. In the event of inconsistencies between the electronic data and the hard copy data, the hard copy data shall prevail."

A Allows the digital data to be altered by others.

= B Provides protection to the Professional Surveyor and his employer if the electronic data is altered by others prior to use.

The value of the disclaimer for data supplied in electronic format is that it provides protection to the Professional Surveyor and his employer if the electronic data is altered by others prior to use. The disclaimer establishes the limited validity of the electronic data provided. The disclaimer acknowledges that the data could be altered by others, and that the recipient is responsible for verifying completeness and accuracy.

C Answers A and B

D None of the above

[Based on https://practicequiz.com/q/which-of-the-following-are-examples-of-unethical-39007]

Automatic Target Recognition (ATR) Total Station Instruments

I have investigated the instrument specifications of at least two of the following instruments Leica TS60, Trimble S10, Topcon MS05AXii and Sokkia NET05AXii (or newer models). I have compared them and written some notes saying why I would recommend one of them. The aim of this question is to put you in the position of a survey company about to purchase a new instrument to do high precision surveying of a new project.

There is no correct choice of instrument in this question.

Geodesy

The following question is derived from the Earth Science Literacy Test, http://www.earth.nwu.edu/people/sethffest/test.html . It is edited and reproduced here because it is relevant to understanding some of the causes of deformation and some of the errors in survey measurements.

The effects of seasonal variations in temperature on built structures can cause deformation. What causes the seasons?

~ Earth is closer to the Sun in the summer

~ Rotation of Earth on its axis

~ The motion of the Sun around Earth

= Tilt of Earth's axis with respect to the plane of its orbit about the sun

~ Other

Light behaviour

The following question is derived from the Earth Science Literacy Test, http://www.earth.nwu.edu/people/sethffest/test.html . It is edited and reproduced here because it is relevant to understanding some of the apparent causes of deformation and some of the errors in survey measurements.

Why do objects seem distorted in a swimming pool?

= Because water refracts the light

~ Because water reflects the light

~ Because water is a liquid
~ Because of the movement of water/waves
~ Other

Ruler length
Process the 2004 students' indoor observations with T3000s to a school ruler. The data is supplied in my LS book, Monograph 13. The Fixit input file is available on the class Moodle site. How far apart are the two end markers (L and R) on the ruler?
~ 299.66 mm
= 399.66 mm
~ 399.66 m
~ 30 cm

Theodolite Intersection surveys
It is desired to point two theodolites such that the optical axes of both instruments are exactly aligned when pointing to each other. Describe the steps you would take to achieve this.

Hidden Point
Two prisms on an inclined prism pole (not moving) were observed from a total station. In the data below " Height" is the distance from the centre of the prism to the tip of the pole. Our convention is that prism 1 is closer to the tip than prism 2.

	"Height"	Direction	Slope distance	ZA
prism 1	1.300	30°45'50"	6.789	95°10'20"
prism 2	1.500	32°11'22"	6.888	94°55'44"

Centre of TS instrument axes is at ENH = 0 0 0 (not the ground mark). Calculate coordinates of the hidden point at tip of pole. If you are within 1 or 2mm of the values below, that is close enough for this exercise.
~ 1.432, 3.671, -1.300
~ 2.164, 5.824, 0.745
~ 5.824, 2.164, 0.745
= 2.164, 5.824, -0.745
~ None of the above # Show Bruce your working, so we can sort this out.

Intermediate results are:

	E	N	H	
Inst	0	0	0	
prism 1	3.458	5.810	-0.612	
prism 2	3.656	5.808	-0.592	
Distance prism 1 to 2 by TS observations:				0.198
	d	m	s	
Bearing 21	270	38	36.3	
ZA 21	95	50	51.4	

Method: Calc 3D coordinates of P1 and P2. Calc slope distance between P1 and P2, check it is close to 1.5-1.3m = 0.200m Calc bearing P2 to P1 and ZA P2 to P1. Use these bearing and ZA and a slope distance of 1.300m to 3D radiate coordinates of tip of pole from coordinates of P1.

Error in centring (plumbing)
A theodolite is set up on a tripod over a ground mark and observes directions to wall mark targets. The targets are 80 m from the instrument. What is the maximum allowed error in centring the theodolite over the ground mark to keep the error in the direction to less than 5 seconds of arc? Assume that there is no error in the pointing to the two wall targets.
~ 0.5mm
~ 1mm
= 2mm
~ 111mm
# Remember that a 1" change (or error) in direction causes about 1mm offset at 200m.

Recovery marks

Four recovery marks are placed about 6m from a survey control point and at the four cardinal directions (90° to each other). The ENH coordinates of these marks are known sufficiently accurately from previous surveys, so coordinates can be held fixed. An arc of directions is observed from a theodolite setup above the control point to the four marks with $S_{mean\ dir}$ = ± 3”. Calculate the approximate accuracy (±) of the point recovery measurement. [Optional further work: If there is a significant centring error what can be done about it? You may use FIXIT to do this by Least Squares simulation. Would measuring the slope distances as well (with a tape to ± 6mm precision) be beneficial?]

~ 0.01 mm
= 0.1 mm
~ 1 mm
~ 3 mm

Atmosphere effects and earth curvature

Which of the following relationships is correct if atmosphere effects and earth curvature are small enough to ignore? (Z = zenith angle; V = vertical angle; H = horizontal distance; S = slope distance; Δh = difference in height)

~ Δh = H cot V
~ H = S cos Z
~ Δh = H sin V
~ Δh = S sin Z
= H = Δh tan Z

3D Radiation

As part of a deformation survey a total station was set up at control point CP123. The EN coordinates of CP123 are (100.46, 531.21) and the reduced level (RL) of CP123 is 112.32 m. The height of instrument is 1.764 m. A prism on a tripod is observed at a target point and recorded electronically in the Leica GRE format as follows:

110026+00016 21.104+33537030 22.104+27327510 31.104+00030052

(That means: code 16, horizontal circle = 335°37 ’03.0”, vertical circle = 273°27’51.0”, slope distance = 30.052m). Corrections for atmosphere effects and earth curvature have been applied in the instrument. The height of prism above the target mark is 1.600 m. What is the RL of the target mark?

~ 1.980
~ 82.487
~ 114.136
= 114.300
~ 139.856

Trig Heights 1

Trigonometrical heighting observations in flat country made simultaneously from reciprocal stations A and B and provided reduced zenith angles as follows: A to B: 90° 00' 41" B to A: 90° 03' 35" The slope distance A - B was D_{AB} = 3229m. Assume k = 0.13 and R_E = 6371000 m (if you need them). What was the difference in height from 1 to 2?

~ -3.366
~ -2.004 # you forgot to change sign on the reverse observation.
~ -0.642
= +1.362
~ +3.366

You can use the " flat earth / vacuum " formula: ΔH = SD * cos ZA from each end and then take the mean to remove earth curvature and bending effects. Remember to use radians if in MS Excel, and that $\Delta H_{AB} = -\Delta H_{BA}$

Trig Heights 2

One-way trigonometrical heighting. The most accurate difference in height from an instrument at A to a wall mark at B may be computed from an observed zenith angle, Z, AND -

~ the horizontal distance at the instrument level using Δh = HD cotZ + (1-k)/2R
~ the ellipsoidal distance d_e> using Δh = d_e cotZ
= an observed slope distance S using $\Delta h = S \cos Z + S^2(1-k/\sin Z)\sin^2 Z/2R$
~ the horizontal distance reduced to sea level using Δh = HD cot ZA

Single line Atmosphere and Earth Curvature

Calculate the combined effect of earth curvature and k on Δh for a single line. Use the formula:

$$\Delta h = SD\cos ZA + \frac{(1 - k/\sin ZA)}{2R}(SD\sin ZA)^2$$

Data: SD = 345.000m, ZA = 91°23 '45, R = 6,364,940m

Find answers for Δh for 3 values of k, i.e. k = -1.0, k = 0.0, k = +1.0

= when k = -1.0 Δh = -8.385, when k = 0.0 Δh = -8.395, when k = +1.0 Δh = -8.404

~ when k = -1.0 Δh = -8.404, when k = 0.0 Δh = -8.404, when k = +1.0 Δh = -8.404

~ when k = -1.0 Δh = -330.631, when k = 0.0 Δh = -330.628, when k = +1.0 Δh = -330.626

~ when k = -1.0 Δh = -330.626, when k = 0.0 Δh = -330.626, when k = +1.0 Δh = -330.626

~ None of these

Intermediate values: SDcosZA =8.404, $(SDsinZA)^2$=118954, sinZA = 0.999703

Local Scale Parameter Model (LSP 1)

The following data applies to three questions LSP 1, 2 and 3.

Refraction corrections for open cut mine monitoring. Total station observations were made from pillar 5 to four points (1-4) with known coordinates on stable ground surrounding an open cut mine slope. All the observations were taken while the atmospheric conditions remained reasonably constant. All observations are mean of FL and FR. Point 6 was observed on the mine slope.

Pt	Easting	Northing	Height
1	3459.720	2116.780	626.120
2	4113.820	2178.360	634.060
3	3561.020	2010.340	541.780
4	4081.060	2008.910	540.060
5	3889.910	1506.070	602.910

DIRECTIONS			SLOPE DISTS			ZENITH ANGLES		
5	1	0°00’00”	5	1	747.384m	5	1	88°14’15”
5	2	53 34 54	5	2	709.290	5	2	87 29 59
5	3	2 02 54	5	3	605.148	5	3	95 48 41
5	4	55 58 30	5	4	541.612	5	4	96 40 28
5	6	33 14 35	5	6	594.410	5	6	91 15 29

Calculate the mean orientation correction to the directions, Ω mean scale factor to distances, F and mean angular correction to ZAs proportional to distance (in “/km) C where

$$\Omega = Bearing_{coords} - Direction_{obs} \quad \text{where } Bearing_{coords} = \tan^{-1}((E_i - E_5)/(N_i - N_5)) \quad \text{beware quadrant}$$

$$F = \frac{d_{coords}}{d_{msd}} \quad \text{where } d_{coords} = \sqrt{(\Delta E^2 + \Delta N^2 + \Delta H^2)}$$

$$C = (ZA_{coords} - ZA_{msd})/d_{coords} \quad \text{where } ZA_{coords} = \cos^{-1}(\Delta H / d_{coords})$$

= Ω = 324° 50’ 19.9”, F = 0.99998723, C = -79.8 “/km

~ Ω = 324° 50’ 19.9”, F = 1.00001277, C = -79.8 “/km

~ Ω = 324° 50’ 19.9”, F = 1.00001277, C = +79.8 “/km

~ Ω = 324° 50’ 19.9”, F = 0.99998723, C = -52.3 “/km

LSP 2

This question uses the same data as LSP 1 and continues the calculations. Calculate corrected observations from 5 to 6. Bearing, Slope Distance and ZA.

= Bearing = 358 04 54.9 Slope Dist = 594.402 ZA = 91 14 41.6

~ Bearing = 358 04 54.9 Slope Dist = 594.402 ZA = 91 14 14.1

~ Bearing = 358 04 45.9 Slope Dist = 594.420 ZA = 91 41 41.6

~ Bearing = 358 40 54.9 Slope Dist = 594.204 ZA = 91 14 46.1

LSP 3

This question uses the same data as LSP 1 and continues the calculations. Calculate the best coordinates for point 6.

= E = 3870.020, N = 2099.999, H = 589.996

~ E = 3870.002, N = 2099.999, H = 589.969

~ E = 3870.920, N = 2099.699, H = 589.896
~ E = 3870.028, N = 2099.990, H = 589.991

Directions through glass
Which of the following best describes horizontal direction measurement through a window or glass door? More than one option might be correct here.
~ causes the line of sight to deflect through a small angle so it has more effect on distant targets
offsets the line of sight by up to the thickness of the glass regardless of the distance to the target
has no effect on direction provided the glass is perpendicular to the line of sight
depends on the angle of the glass with respect to the line of sight and the glass quality
B, C and D are correct

EDM through glass 1
Does EDM distance measurement in prism mode through a glass door or window usually:
~ give correct distance
measure too long
~ measure too short
have an error in distance measurement approximately equal to the thickness of the glass

If line of sight is square to glass it will make distance too long by about the glass thickness, if glass is at an angle to line of sight, then more glass to penetrate and slightly bigger error, so B and D are correct. If you measure in reflectorless EDM mode or with a laser scanner through glass, you might get some results that need interpretation. Always best to avoid looking through glass if you can.

EDM through glass 2
Does EDM distance measurement in prism mode through a window perpendicular to the line of sight usually:
A) give correct distance
=B) give distance too long approximately equal to the apparent thickness of the glass
C) give distance too short approximately equal to the apparent thickness of the glass
D) not measure distance

If square to glass it will make distance too long by about the glass thickness, if glass is at an angle to line of sight, then more glass to penetrate and slightly bigger error)

EDM through glass 3
What is the effect on horizontal direction measurement through a window? More than one option might be correct here:
~A) cause the line of sight to deflect through a small angle so it has more effect on distant targets
=B) offset the line of sight by up to the thickness of the glass regardless of the distance to the target
=C) have no effect on direction provided the glass is perpendicular to the line of sight
=D) depend on the angle of the glass with respect to the line of sight and the glass quality?

Grid Convergence
Calculate the conversion of MGA grid bearing to true north for comparison with an azimuth from gyro-theodolite measurements using Morpeth, NSW data:

	E	N	(MGA zone 56)
T3	370946.251	6378192.178	
T4	370973.813	6378108.485	

Ans: Grid Convergence at T4 = ?, Azimuth from T4 to T3 = ?

~ GC = 44 ‘40”, Azimuth = 342°31 ‘ 00”
= GC = -44 ‘40”, Azimuth = 342°31 ‘ 00”
~ GC = 44 ‘40”, Azimuth = 342°15 ‘ 40”
~ GC = -44 ‘40”, Azimuth = 344°00 ‘ 20”
~ None of these options

See “grid convergence” in MGA technical manual, or Redfearn‘s formula and programs on GeoScience Australia‘s website. Grid convergence is an angle added to an azimuth to obtain a grid bearing: Grid Bearing = Azimuth + Grid Convergence. In the southern hemisphere, grid convergence is positive for points east of the central meridian (grid north is west of true north) and negative for points west of the central meridian (grid north is east of true north). In MGA central meridian is at E = 500000.

Gyro use

When should a gyro theodolite be used on a mine baseline?

~ Whenever you want # Not such a good choice. The instrument needs to be compared with known azimuth lines ie tested. Also, it would be expensive and inefficient to use on many lines. Generally only used occasionally to check for systematic drifts and gross errors.

~ On as many lines as possible # it would be expensive and inefficient to use on many lines. Generally only used occasionally to check for systematic drifts and gross errors.

~ On a mine baseline of known azimuth, before UG use # Yes that is a good thing to do, but you also want to test it again after the UG measurements.

= On a mine baseline of known azimuth, before and after each UG use

~ Tested at least once per year and after servicing # That is the general rule for EDM calibration. Yes, that is a good thing to do for gyros too, but regulations and standards recommend testing on a mine baseline of known azimuth, before and after each UG use.

Mine Surveying 3D tunnel calculations (a)

Calculations are required for a **hypothetical** rescue of people, including the site‘s mine surveyor, who are trapped underground in a NSW south coast mine. For the purposes of this question assume we are to drill directly to their location with no offsets.

Data: People are located at P and the best estimate of their location, based on nearby wall markings and their last known location, are given below. Coordinates are on MGA, zone 56. There is a nearby ‘tunnel ‘ containing a centreline traverse with roof marks at A and B. The coordinates of A and B are also given in the table below. Ground surface in this area is about 30m above AHD and the geoid height (N) in this area is 20m. For this site, the Geoscience Australia web site spreadsheet calculates the grid convergence = -01°18'37.298" and the combined SF = 1.0001440

Pt	East m	North m	Height m
P	290164.	6147793.	9223.
A	289982.214	6147475.257	9209.691
B	290192.161	6147882.103	9232.040

One option is to drill vertically from the surface at D. Determine the coordinates of D that could be used to set out a drill rig. Describe how you would locate point D by survey. How far would you have to drill down (describe any assumptions or additional measurements you make)?

= 807 m
~ 827 m
~ 787 m
~ 9193 m
~ 9223 m

If you are going to drill vertically down from D to P, then the E and N coordinates would be the same as P. For height you need to think about the datum used and whether geoid is relevant or not. Underground heights have a base 10000m below 0 AHD.

Mine Surveying 3D tunnel calculations (b)

Use the same data as in part (a) question above. What is the bearing from A to B? What is the azimuth of AB from true north? What is the grid distance AB and what is the slope distance AB.

~ brg 27 17 43.2, Az 28° 36 ‘ 20.2, grid dist 457.822, slope dist 457.757
= brg 27 17 43.2, Az 28° 36 ‘ 20.2, grid dist 457.822, slope dist 458.302
~ brg 27 17 43.2, Az 25° 59 ‘ 05.9, grid dist 457.822, slope dist 457.757
~ brg 27 17 43.2, Az 25° 59 ‘ 05.9, grid dist 457.822, slope dist 458.302

Mine Surveying 3D tunnel calculations (c)

Use the same data as in part (a) question above. Another option is to drill from A to P. If a survey instrument is set up 1.50m below the roof mark at A, then what are the bearing, zenith angle and drilling slope distance (not the grid distance) to P. Why would you require the bearing AB?

~ Brg 29°46‘28.5”, ZA 87°40‘59.1”, slope dist 366.017
~ Brg 29°46‘28.5”, ZA 87°40‘59.1”, slope dist 366.069
= Brg 29°46‘28.5“, ZA 87°40‘59.1“, slope dist 366.316
~ Brg 27°17‘43.2“, ZA 28°36‘20.2“, slope dist 458.302

This is part of a past exam question. Another question that could be asked about this problem is about the shortest distance from the tunnel line AB to P and where on the line AB you would start the drilling to P. For slope distance you need a real distance at the site, ie local. Not an MGA grid distance. So convert the grid distance from coordinates to a horizontal distance. That is done using the CSF in the reverse process that you normally have HD * CSF = GD. Then combine HD with delta H of the line to get slope distance. This question focusses on the difference between local and grid coordinates and their consequences.

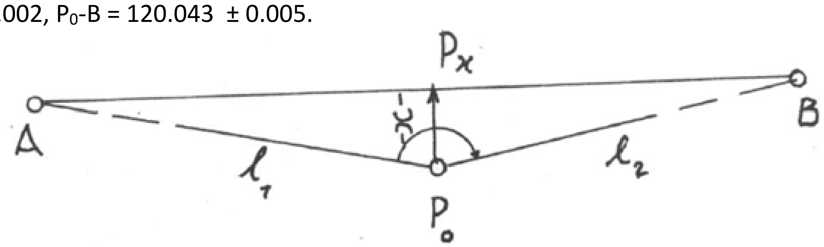
Roof marks

Describe how you can accurately centre a theodolite or total station under a roof mark in an underground tunnel with a constant and strong wind in it.

Do not use a plumb bob unless you shield it from the wind e.g. inside a pvc pipe and use heavy weight. Use optical or laser plummet that ‘sees’ upward, or theodolite with diagonal eyepiece, or total station with line of sight camera or laser light and ZA set to 0.

Shift to On line

A surveyor lined up a station P_0 near a line A-B for a ‘ranging in job‘ and observed: Y = A-P_0-B = 179° 56' 23.6" ± 3"; P_0-A = 46.391 ± 0.002, P_0-B = 120.043 ± 0.005.



How much did he have to shift P_0 to get on line?

= 0.035 # Based on a FIXIT solution or by solving the triangles
~ 0.058
~ 1.834
~ 33.449

Total station coordinates

A properly adjusted total station , when levelled, will measure in which of the following reference systems?

~ a celestial coordinate system
~ an orbital system
~ a geocentric, terrestrial coordinate system
= a topocentric, terrestrial coordinate system
~ none of the above

There are some total stations that can be set to an alternative coordinate system, such as defined by XYZ coordinates of targets which are not aligned with local vertical direction. This can be useful for Tunnel Boring Machine guidance and other applications.

Angular units

Angular units - {

= one radian is about 57.3 degrees
~ converting degrees to radians requires multiplying the angle by π (pi)
~ a radian is a number which applies only to a circle of the radius r = 1

~ there are about 306264 seconds of arc in 1 radian
# There are about 206264 seconds in a radian and old surveyors used that knowledge in their calculations before they had computers.

Standard deviation

If the standard deviation of the direction 101 to 102 is ±10", and the standard deviation of direction 101 to 103 is ±10", then the standard deviation of the angle deduced from these two directions (i.e. angle 102 - 101 - 103) is about (to nearest ")

~ ± 10"
= ± 14"
~ ± 15"
~ ± 20"
~ None of the above

By law of propagation of variances

Direction offsets

If a theodolite/ total station direction is precise to ±0.5“ what displacement does this represent at a target 50m away (to one decimal place of a mm)?

= ± 0.1 mm
~ ± 0.2 mm
~ ± 0.5 mm
~ ± 1.0 mm

Two lines in 3D

Two lines in 3D As part of the design of a new structure two straight pipes are to be placed near each other. It is important that the two pipes are not too close to each other. The coordinates of the two ends of the centreline of each pipe are given below.

	From			To		
	E	N	H	E	N	H
Pipe A	1116.5	3420.0	60.0	1111.0	3434.0	52.2
Pipe B	1110.5	3424.5	51.9	1117.5	3437.5	59.0

Calculate the shortest distance between the centrelines of the two pipes. Calculate the coordinates of the two end points of this shortest join line.

= Distance = 0.373, End point on pipe A: 1112.822 3429.362 54.784 End point on pipe B: 1113.106 3429.340 54.544
~ Distance = 0.373, End point on pipe A: 12.822 29.362 4.784 End point on pipe B: 13.106 29.340 4.544
~ Distance = 11.331, End point on pipe A: 1112.822 3429.362 54.784 End point on pipe B: 1113.106 3429.340 54.544
~ Distance = 11.331, End point on pipe A: 16.5 20.0 10.0 End point on pipe B: 17.5 37.5 9.0

Underground traverse - 2 shafts

Underground traverse - 2 shafts During an underground survey between a wire in each of two shafts, A and E, the following traverse data on an assumed azimuth were obtained:

Line	Bearing	Distance(feet)
AB	94° 21′ 04.8″	393.728
BC	80 02 30.0	264.810
CD	61 49 05.0	334.817
DE	336 54 49.5	112.497

The above ground grid coordinates of A and E, from resection, were found to be:

	E (m)	N (m)
A	556 821.63	447 219.42
E	557 098.39	447 300.38

Transform the partial coordinates into the grid coordinates for each station. (This question is adapted from: Advanced Engineering Surveying by Shepherd). Think about how to solve this problem. If you need help the feedback built into this question gives more details (after you attempt it).

~ B: 556 941.16, 447 208.74 C: 557 020.84, 447 221.65 D: 557 111.66, 447 268.42
~ B: 556 941.16, 447 208.74 C: 557 020.65, 447 221.84 D: 557 111.42, 447 268.66
~ B: 556 941.74, 447 208.16 C: 557 020.84, 447 221.65 D: 557 111.42, 447 268.66
= B: 556 941.16, 447 208.74 C: 557 020.84, 447 221.65 D: 557 111.42, 447 268.66 # Well done :-)
~ None of this list

Our Surveying Computations (UNSW GMAT2500) textbook may help with this question. The methodology used in cadastral surveys is similarly applied to this underground survey problem. It is about determining a swing of bearings and possibly a scale of distances. See Section 7.2 and 7.6 Q3. Here is some more help. I could just send you a worked solution, but you will not learn the topic as well as sorting it out yourself. A drawing might help if it was animated, or you saw it being drawn - not just the final figure. Here is a description of the method.
The distances in feet can be multiplied by 0.3048 to convert them to metres. Or leave them as feet and get a SF close to 0.3048 later. I prefer to convert them to m. The above ground coordinates in m are from a resection (or they could be from GNSS or from a control survey). If the wire shafts are assumed to be perfectly vertical and position transferred accurately, then the EN coordinates underground are the same as their coordinates above ground.
Calculate the bearing and distance between A and E using the resection coordinates.
Calculate the bearing and distance between A and E using the underground traverse data. This can be done several ways. One way is to treat it as a misclose problem starting with 0,0 (or anything else) as the coordinates for A.
Calculate the difference between the two bearings (A to E). That is the amount of swing (bearing addition) that needs to be applied. In this data set the swing is less than 1 degree (but in other data sets it might be a larger number). Add this swing to each of the underground bearing lines. Think about whether it is + or -.
Next compare the two distances between A and E. Are they only a few mm different? If so, you might ignore it. If not so small, then calculate the ratio. That is a scale factor to apply to each of the underground distances.
Now you have new bearings and distances for the underground traverse. Start at the EN coordinates of A and calculate the traverse through B C D to E. Check that the coordinates of E match with what they should be (that is the starting given values of E).

Weisbach Triangles

The following observations were made as part of a correlation survey using the Weisbach triangle method. At the surface, the clockwise angles were made to a reference line AB, which had a Grid bearing of 208" 08' 20". Observed values ABY = 92° 22' 26", BY = 2.42 m, ABX = 92°35'38", YX = 3.18m Underground clockwise angles were made from a reference line CD which lies to the south of the wires X and Y. DCY = 170° 56' 30", DCX = 170° 58' 22", CX = 2.84 m
Assuming that all the angles were measured with a standard deviation of ± 3" and the lengths ± 0.01 m, calculate the most probable value of the bearing of the underground reference line CD and its standard deviation. You may use FIXIT or do the calculations and propagation of variances long hand. You may assume the distances AB and CD are long, perhaps use 100m for them both in your calculations. (Source and worked solution: Advanced Engineering Surveying by Shepherd)

= 129° 59' 11 " ± 7.26"
~ 129° 59' 11 " ± 52.7"
~ 309° 59' 11 " ± 7.26"
~ 309° 59' 11 " ± 52.7"
~ None of these options

Here is a FIXIT input file for the question. Try to generate your own before reading or copying this. If still struggling then try to understand what this file is doing before you copy it.

```
TITLE      Weisbach Tutorial Question GMAT3100
TITLE      Assume centring and ppm is +- 0, angles are +-3" so dirns are 3/rt2 = 2.12"
COMMENT           Dis       ppm       Dir      cent      H
DSD              10.0       0.0       2.1       0.0      10.0
COORDINATE    1                            147.1611      888.1807
COORDINATE    2 EN                         100.0000      800.0000
COORDINATE    3                            102.0849      798.7713
COORDINATE    4                            104.8135      797.1382
COORDINATE    5                            107.2489      795.6773
COORDINATE    6                            183.8687      731.4168
AZIMTUH       2    1       28  8 20.00
COMMENT     Assume backsight is 100 m away, it does not matter what it really is.
H DISTANCE    2    1            100.00
```

```
DIRECTION     2    1         0  0  0.00
DIRECTION     2    3        92 22 26.00
DIRECTION     2    4        92 35 38.00
DIRECTION     5    6         0  0  0.00
DIRECTION     5    3       170 56 30.00
DIRECTION     5    4       170 58 22.00
H DISTANCE    2    3              2.4200
H DISTANCE    3    4              3.1800
H DISTANCE    5    4              2.8400
H DISTANCE    5    6             100.00
JOIN          5    6
```

Laser scanning notes

Write answers to each of the questions:

- What are the safety concerns when using lasers?
- What are the main advantages of laser scanners compared to other survey measurement techniques?
- What are some limits or constraints of using laser scanners?
- What instrument specifications would you consider most important when purchasing or hiring a laser scanner?

reflectorless EDM and Automatic Target Recognition

Write answers to each of the following questions:

- List and briefly describe several error sources that may occur in reflectorless EDM (i.e. non prism mode EDM)
- Describe how you would test and how you would calibrate reflectorless EDM.
- If you do a conventional EDM calibration in prism mode on an established multi-pillar baseline, does that mean the reflectorless EDM is OK too? Why?
- Describe possible error sources in total station automatic target recognition.

Total stations

I have used at least three different models and manufacturers of total stations. Each instrument has a different operating system. {TRUE/FALSE}

Boat mould

Write an answer to the following question. A mould has been constructed to produce fibreglass boats 3m long, 1.5m wide, and 1m deep. It is intended to measure the coordinates of several key points on the mould to sub millimetre precision. Draw a plan showing the location of equipment and targets. Discuss the measurements and processing required, type of equipment and expected accuracies.

Instrument supply

Contact a survey instrument supply company or their website. Obtain information about high precision survey equipment and attachments, including purchase and or hire costs ($A) and expected accuracies.

Height of instrument

Write a description of 2 or 3 different methods to determine height of instrument accurately (±1mm) for a total station set up over a ground mark. Comment on the accuracy you expect to achieve using approximate calculations and estimates of the measurement precisions.

1) Measuring ZA to a levelling staff (see Bruce’s Least Squares monograph for calculations) on a nearby BM with known RL.
2) ZA and reflectorless EDM observations to nearby survey marks (possibly wall marks) with known RL
3) Careful use of a special tape measure that attaches to a tribrach and has built in height of instrument may not be much better than ± 1 mm.
4) Observations to permanently mounted prisms with known heights.
5) Perhaps you can think of another method?

Bayesian LS

Find a small control survey or traverse measured at a project site (eg Morpeth_trav.inp in Bruce's LS monograph) Process the data in FIXIT using conventional and Bayesian approaches. All solutions use the same observation data (except the additional coordinate point observation) and default standard deviations. Comment on the differences between the output and discuss the special features of each of the methods. Write a brief report summarising the results.

Freenets

Complete the following task and document the results.

Use your survey camp control survey data (or a textbook data set, or a data set from your work experience). Calculate a free net solution in FIXIT (or other LS software). Compare the coordinates, VF and residuals to those of a minimum constraint solution. Also compute a Freenet without observations to any distant targets (if there are any) and compare results.

Accuracy in construction surveys

Accuracy in construction surveys Generally, it is more accurate to setout (place) a new mark at desired coordinates than measuring coordinates of an existing mark. {TRUE/FALSE}

= FALSE

Caspary Deformation data

Complete the set of questions based on dam deformation data from Caspary (2000) www.sage.unsw.edu.au/sites/sage/files/SAGE_collection/MonographSeries/mono11.pdf . Details about this question are in the Deformation Class notes and the data is in three input files also on Moodle:

CASPARYepoch1.INP, CASPARYepoch2.INP, and CASPARYepochs 1&;2.INP

#There is not a single correct answer. Some of the answers depend on what you decide to do in the earlier steps. Each student's answer to this question is often marked manually by the teacher.

Coordinate transfer in buildings

Write some notes that describe a few ways to transfer EN and H coordinates up through a high rise building during construction. Include sketches.

Curved tunnel

Write notes that answer these questions: A tunnel 3m wide is to reach a certain point, at which it must be directed to follow a 30m radius curve to turn the tunnel through an angle of 82°. Describe how you as the surveyor would arrange to have this achieved. What is the longest traverse line that could be used (approx). The two tunnels so connected by the 30m radius circular curve eventually consist of two straights each 100m long. How would you arrange to carry an accurate bearing very accurately round this curve?

Have you drawn a sketch to help visualise the problem? How does your answer compare with the following feedback for this question.

The longest traverse line would go from a bracket on a wall on the outside of the curve and pass nearly tangentially to the wall on the inner side of the curve. You can get an approximate value by using right angle triangle geometry. The method requires simple Pythagoras calcs with the outer and inner diameters. It is the sort of rough calculation you would use when designing your survey. Of course the actual traverse line would be shorter (if both ends are on the curve) so that you line of sight was not too grazing of the inner wall, and that your instrument mounted eg on a bracket, would be offset from the outer wall. If your traverse points were not both on the curve, but one was on the straight you might get a different number. Also, in real tunnels you would probably have transition (spiral) curves too. In an exam I would be considering the method you were using and some comments. Accurate carrying of the bearing for the short lines would try to minimise centring errors, eg using wall brackets instead of centering above or below a ground or roof mark. Can you think of other considerations?

Differences Underground

Write some notes that explain the main differences between surveys on the surface of the earth and surveys in underground mines. Include safety issues and equipment used as well as survey control procedures.

Hydrographic Surveying or Olympics or Astronomy measurements

Write an answer to the following past exam paper question: Briefly describe the survey measurement and analysis aspects of both:

a) Hydrographic surveys of the seabed of a coastal port.

b) Surveys of Olympic Athletic Field events.

c) What aspects of past surveyor's astronomy measurements might be useful in future surveying applications?

Do not leave this to the night before the exam. That is when you rest yourself. Of course, just copying some previous student's answer won't help you much - you know that.

Hydro: echo sounder, ultrasound, sonar, single beam travel over sea floor, or multibeam like 'laser' like sonar scanning, consider water density salt fish temp pressure etc, tides, GPS position of boat and orientation, INS, channels, clearance under vessels, effects of dredging, tides, and difference between MHWM and AHD datums.

Olympics: quick real time computer linked results, specifications, checks for gross errors, 100m track etc not short but a little long OK, throwing events: radiate point and starting point calculate join, 360° prism near bottom of pole, train field hands, jumping events and swim pool etc: perpendicular distance, heights by ZA, level ground, marathons need distance over undulations and around arcs not straight-line distances, …

- The measurements cannot be wrong → need redundancy i.e. for javelin have two TS taking observations to each throw.
- The measurements must be calculated, confirmed and presented pretty much in real.
- Need equipment that can be proven to be calibrated and correct → how/when will you do the calibration, is there a standard that can be adhered to.
- Is the equipment safe to use around lots of people → check laser ratings for the modes that will be used for the survey.

In class we discuss the importance of accurate surveys of sporting events for young people too. It is not just for world champions. A gross error in setting out (eg a 100m track) that gives a person a false impression of their ability (they think they have broken records) has consequences.

A student wrote: There are two main types of survey in this area – preparatory and instantaneous measurement. Preparatory surveys include setting out race tracks, or measuring pool lengths to check it complies with international regulations. Time taken is not as crucial for this type of survey, however accuracy is very important. Surveys must account for any atmospheric (or water) corrections that need to be applied to measurements taken. For example, the need for water corrections could be removed by using a hidden point pole to measure the position of a touch pad in a pool. Measurements of a 400m track must be thoroughly checked, and the surveyor must be familiar with what is required for the project to satisfy the requirements, for example which part of the start line to measure to in order to get the correct distance. More difficult preparatory surveys include those needed for a marathon, as it is a very long distance to accurately cover using traditional survey methods. For this, alternate methods need to be considered, such as a calibrated bicycle, or car-mounted laser scanners which can detect a painted line on the surface of the road.

Instantaneous measurements also need to be very accurate, as world records may be at stake, however these types of survey do not have the luxury of time. Examples of this include javelin throws or long jump, where the athlete's result must be accurately measured or calculated and is then displayed to the crowd.

[Blooper: Swimming pool is not an athletics field event.]

One student's answer about astronomy use: Blooper: "If you're on a ship with a theodolite and the receiver breaks? You could in the future find your position in the ocean to an accuracy of 30m!" {Reading ZAs with a theodolite on a moving platform is not reliable. If you lock the compensator you can get ZA with respect to the platform, but not the real ZA that you need for astronomy}. A better answer might be that experience at observing moving targets (like stars moving across the field of view) and observing at night or in very dark conditions to a target that is not a prism and you cannot see your cross hairs / reticule.

Construction surveys

List several issues that a surveyor has to deal with when doing a survey for the construction of a new bridge with large spans and high pylons.

Construction surveys

Write an answer to this past exam question: A new bridge is going to be built over a floodplain on the NSW coast.   The bridge project will span several years. The process from a survey involvement perspective will be a control survey, then Digital Terrain Modelling surveys for final design and to produce details survey plans and 3D models of the site, cadastral boundary surveys, construction set out surveys, as-built (WAEx) surveys, and ongoing deformation monitoring surveys after completion. There will be many different surveyors involved. The MGA combined scale factor for the site is 0.999603.   Some details of the bridge: 3.5 kilometres long, maximum clearance is 15m above the flood plain; 93 piers; the prefabricated slabs for each span are very heavy and move the bridge pylons/piers during placement; and each span is 34m in length. The bridge is not a straight line in plan view.   Describe the important survey considerations that have to be planned and specified by the project's survey manager dealing with construction survey parts of the project.
#Ref: Paper by Bruce Harvey about Bridge construction and MGA scale factors.

Directions and Regulations

Read* the latest version of the Survey and Drafting Directions for Mine Surveying and made a brief summary of some of its contents.

* You don't have to read every word, just see what things are covered and read some parts that interest you.

Registered Mining Surveyor

Write some notes that outline the role of a Registered Mining Surveyor in underground and surface mining operations.

Toon Bridge analysis

Analyse the survey data in the input file "Toon bridge survey three epochs.INP ". The data is real from surveys of targets on a bridge. Three epochs of observations are supplied.   Determine which points have moved significantly, how much they have moved and in which direction.   Describe your analysis and your conclusions in a brief report.

Some of the things that I would like you to include in your report: How good were the starting coordinates?   What types of observations were used?   Are there many outliers?   What is a typical value for SE (standard deviation of E coordinate) and SH for the sphere targets and our check point 12?   SN is not so important for this survey.   Add some JOIN lines to the FIXIT input file, eg sphere 6, 1506 to 2006 and 1506 to 2506 etc.   Has there been statistically significant movement of some of the spheres?

A future question

My teaching ended just as artificial intelligence (AI) started making its presence felt in the field of assessment. One new question I might set now is to take one of my existing exam questions, and find an AI answer with ChatGPT or similar, then to provide students with the question and AI answer and ask them to critique the answer. Is it correct, how could it be improved?

`

Humorous Exam and Assignment Answers

It takes a lot of concentration and effort to mark exams and assignments. We all make mistakes sometimes. I have found some of the mistakes to be humorous. Why is slapstick comedy funny eg when an actor slips on a banana skin? Apparently, it is due to our relief that it did not happen to us. I did not start recording these when I started teaching, if I had done that the list would be longer.

" I'll do the calcs posthumously " [meaning at night?]
" … looking for the closet port " [closest]
" … taking massages from clients " [messages]

Q. List safety issues that need to be considered when doing underground mining surveys.
A Student's answer: DBYD [Dial Before You Dig, on a deep underground mine? or before digging the mine??]

Q. List special survey equipment used in tunnel and underground mining surveying. Do not include total stations, levels, tripods and other equipment that is used in common above ground surveys in your list.
A Student's answer: circumferentor [a very old and approximate instrument for angle measurement in cadastral surveys 100 years ago?]

Q. Briefly describe the survey measurement and analysis aspects of Hydrographic surveys of the seabed of a coastal port. A Student answer: "Hydrographic surveying is to do with measurements of clittoral features." [a littoral zone is a region near a shore]

An answer about a question on laser scanning. Remove sound from the data [noise]. … used prisms as targets.

High Buildings: You can plumb up through the floor using specially created survey voids allowing you to ensure verticality. You know that if it is vertical, it has a bearing of 0 degrees and thus there is no coordinate change in Eastings or Northings, only in height. [I think they mean ZA= 0]
One method of transferring Easting and Northing coordinates from ground level up to each floor is to do a level run on the interior of the building. [How do you get E N from a level?]
During construction of each floor placement of a Reference Mark has to be consistent i.e. directly above the point below. This can be done with a Disto during the addition of a new level. [I think that might not be accurate enough]

Laser scanning: If class 4 then access to site should be limited. [It can cut metals if its class 4 laser!]
Mine rescue calcs: Zenith will also change as a result of arc to chord. The grid bearing will change underground throughout distance, as there are deflections of vertical.
Zenith angle = grid bearing – grid convergence [azimuth]
Gyro theodolites are calibrated with respect the Earth's magnetic field and calculations of mean oscillation against this magnetic field. [gyros measure with respect to the earth's rotation axis and true north, not magnetic]

From some of my other courses:
In a survey camp report about control survey "design a control network that would later be sued" [used]
H&S form in GMAT2500… qualifications: "Undertaking the curse of GMAT2500" [course]

In a cadastral surveying assignment:
Before … conducting the survey … viewing the DP is detrimental in order to locate which reference marks are available on the street to be measured. [I think it is essential. DP is a Deposited Plan of cadastral boundary survey]

Q. Describe the steps you would take prior to field survey.
… Check the closest public toilets …

In a report about Least Squares analysis of their data "will show up as an outlier if there are gross eroors."

b = 0.024m = 0.24
… = 0.09m = 9.00 mm
… = 0.004 m = 0.040 mm

Input file for control survey

```
COMMENT    <fr> <to><arc> ddd mm <secs ><sdv sec   >
DIRECTION   909  801    1 366 10 35.0
```

…

Describe … danger circle in 3 point resections…
Ans: ... the points shot to are too close together, which results in a bad skull factor. To avoid this take shots to points spread out this will ensure a god skull factor and accurate results. [good, scale? in this exam students used MS Word to type their answers! Scale factors are not involved. Generally points close together may result in a danger circle.]

In a thesis: … this error is not significant enough to hinder tits usage …

Survey computations with MS Excel spreadsheet (this one is sad). Question asked to calculate traverse angular misclose then other things after that. The correct answer is -8". Student said:

	DD	D	M	S
misclose	-0.002222222	-1	0	3592

in their spreadsheet then wrote on the paper misclose = -1° 0' 3592" Doesn't that look ODD to you? Where is the common sense and understanding? The student had done the prior work correctly, just 'blew' it at the last step.

How many rows in the B matrix? 2 x 6 = 16

By checking the distances to see any typos/gross errrors, it was found that…

A student in a lab class told me: "my motto is due today = do today"

Typed in an exam… This can lead to things such as gross error being pissed or ...

A year 4 thesis student at a meeting discussing his progress said " I just found that our library has a lot of surveying books" [He had spent so much of his time in computer lab, that he had not visited our library until year 4. This has become much more common since internet searching became available.]

At Berry survey camp, standing behind a fence looking at a paddock they need to traverse through, a student asked, "Are they cows or bulls?" [I suggested they don't try to milk a bull…]

What does clockwise mean?

What do you do if your additive constant (EDM) is negative? Are my calculations wrong or how do I apply it?

The best "excuse" I ever got from an undergraduate student (and he didn't even ask for special treatment):
Lest you think that I have just been putting my feet up and relaxing since I did my last exam on 18 November, I've actually been fully occupied with long neglected home maintenance, my son's wedding last weekend and I'm currently in the middle of two weeks flying training for the Navy …!

THE END

From where did I get the ideas for these questions? Some of the questions are real emails or enquiries from surveyors and former students. Some of the questions are based on my own consulting surveys. Some of the questions were inspired by conference presentations by surveyors about projects they have worked on. Sometimes I wake in the middle of the night with a new idea. Sometimes I think of new questions while riding my bicycle to and from uni.

When you do an exam there is a time limit. You do your best in the time you have. If you had more time, you might have done more or better? I have had limited time to compile this book too. My time is up so I stop now.

If you have read all the way through this book – well done! I hope you get to apply your knowledge to real, interesting, and challenging surveying projects.

Acknowledgements
Jean Rüeger provided many valuable comments about a draft version of this book. Thank you Jean. I also thank the many students who have supplied answers to the questions and participated in class discussions and fieldwork.