GMAT 3100

Surveying Applications and Design

Exam Preparation — Complete Study Notes & Question Answers

Exam: Tuesday 5 May 2026 | 9:50 AM | CE201 (Computer Lab)

2 hours + 10 min reading | 6 Questions | 45 Marks total

Exam Overview & Allowed Resources

The exam is computer-based in CE201. A USB will be supplied containing the exam paper (PDF), FIXIT software, and any required data sets.

Allowed software and resources:

- FIXIT — adjustment and least squares software
- Excel — calculations and data processing
- Word — writing your answers
- Topcon Office — survey software
- Calculators and drawing instruments
- Sketches can be drawn on paper supplied and photographed/inserted into your Word doc

Format: Answer all 6 questions. Questions are NOT of equal marks. Bullet point or table answers are acceptable.

Part 1: Short Answer Questions — Full Answers

These questions test breadth of knowledge across survey techniques. Answers should be concise and technically precise.

Q1. Theodolite Intersection — Can't Point Between Instruments

Q: If doing theodolite intersection surveys and you can't accurately point from one theodolite to the other, what can we do?

When direct mutual pointing is impossible (e.g. one instrument obstructs the other's line of sight), you can:

- Set up a target or prism near each theodolite that both instruments can observe. Use a small prism, retroreflective target, or even a plumb bob string as a mutual reference.
- Use a third reference point (control mark with known coordinates) visible from both stations, then compute the relative orientation of the two theodolites through coordinate geometry.
- Place a small lamp or LED target at each station so the other theodolite can sight to it from oblique angles.
- Use a coordinated free-stationing approach: each theodolite independently resects to known control, then the intersection computation uses absolute coordinates rather than requiring mutual sighting.
- Use a laser pointer on one theodolite to assist the operator at the other instrument in locating the correct direction.

▯ *Study Note: Theodolite intersection measures angles from two known stations to an unknown point. The geometry works best when the intersection angle at the target is between 30° and 150°. Avoid near-collinear setups.*

Q2. Pointing to Target Types — Prism on Pole vs Tripod vs Mark

Q: Is it better to measure directions by sighting to (A) a prism on a pole, (B) a prism on a tripod, or (C) a mark directly?

Ranking (best to worst accuracy): C > B > A

- C — Direct mark: Best accuracy. No centering error from a prism or target holder. The mark itself is the point. No target-setup eccentricity. Preferred whenever physically possible.
- B — Prism on tripod: Good. Tripods allow forced centering (tribrach), minimising centering error. The prism's constant offset is systematic and can be corrected. Better than a pole because there's no levelling/wobble error.
- A — Prism on pole: Lowest accuracy. Poles introduce centering error (operator holding), levelling error, and plumbing uncertainty — particularly significant at short distances where angular error is amplified.

▯ *Study Note: For high-precision work (e.g. ±1 arcsecond), always use tribrachs and forced centring systems. The distinction matters greatly at short distances — at 30m, a 2mm pole centering error = ~13".*

Q3. Total Station — Sighting a Mark That Is Obscured

Q: If you can't see a mark from your total station because it is obscured, what can you do?

- Free station / Resection: Set up elsewhere with a clear line of sight, then calculate your station coordinates from known control points.
- Traverse around the obstacle: Set up intermediate traverse points to carry coordinates to a new station with a clear view.
- Offset measurement: Measure to an accessible nearby point at a known offset from the target mark, then compute target position by geometry.
- Reflectorless EDM: If the mark is on a surface, shoot directly to the surface reflectorlessly — the mark doesn't need a prism.
- Use a prism on a pole held over the obscured mark (if accessible physically but not optically from the instrument).
- Intersection from two other stations that do have clear sightlines to the target.
- Use aerial / photogrammetric methods or a laser scanner to capture points inaccessible from any single ground station.

Q4. Measuring vs Setting Out — Which is More Accurate?

Q: Generally, which is more accurate: measuring coordinates of an existing mark, or setting a mark at a desired coordinate?

Measuring an existing mark is generally more accurate than setting out.

Reasons:

- When measuring, you observe the mark multiple times in different configurations (face left/right, multiple rounds), allowing statistical averaging and outlier detection.
- Setting out requires an iterative process — you place a mark, measure it, compute the error, adjust, and re-place — each iteration introduces new placement error.
- Physical placement errors (e.g. driving a peg, marking concrete) add mechanical imprecision that pure measurement doesn't have.
- In setting out, the final mark position depends on both the survey accuracy AND the marking/placement process.

Study Note: The ratio of setout accuracy to measurement accuracy depends on method and target type. For a total station, you might achieve ±2mm measuring, but ±5mm setting out due to physical constraints.

Q5. Coordinates on Featureless Surfaces — Boat Hull, Close Range Photogrammetry

Q: How do you get coordinates of points on the surface of a featureless object (e.g. boat hull) with theodolite intersection or Close Range Photogrammetry?

The problem: featureless surfaces have no natural targets to point to.

Solutions:

- Apply stick-on retroreflective targets (circular coded or uncoded): Bond temporary adhesive targets to the surface at measured/desired locations. These can be precisely sighted in theodolite intersection or automatically detected in photogrammetry.
- Use paint or marker dots at specific points of interest. These provide a definite point even if not as precise as a retro target.
- For Close Range Photogrammetry (CRP): Place coded targets (e.g. circular ringed targets) across the surface. Software auto-detects and matches them across images. Use a scale bar for absolute scale.
- For theodolite intersection: Place two theodolites on opposite sides. Operators simultaneously point to the same target dot and record horizontal and vertical angles. Coordinates computed by 3D intersection.
- Laser scanning: A scanner captures a dense point cloud of the surface without requiring individual targets — the shape itself is the data.

 Study Note: CRP is very efficient for this type of task. Software like Agisoft Metashape or PhotoModeler can achieve sub-mm accuracy for an object 3–5m in size. Key: good lighting, sufficient image overlap (~80%), coded targets for scale and orientation.

Q6. Gyro Theodolite — When to Use on Mine Baseline

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

- When there is no surface connection available (blind shaft mines), making it impossible to transfer azimuth optically from the surface.
- When accumulated traverse azimuth error over a long underground traverse requires independent checking or resetting.
- When the mine is expanding to new headings and a fresh, independent azimuth determination is needed rather than propagating existing traverse errors.
- Periodically as a quality control check on the entire underground control network — even if connection surveys are possible, a gyro provides an independent verification.
- After any suspected disturbance to the underground survey network (e.g. blast damage to marks, equipment incident).

- When legal or regulatory requirements specify independent azimuth determination (common for mine boundary surveys).

 Study Note: A gyro theodolite determines true north by measuring the precession of a spinning gyroscope under Earth's rotation. Typical accuracy: ±10" to ±20" for a Fennel-type gyro, ±5" for higher-end instruments. Much better than accumulating traverse error over several km of underground traverse.

Q7. Calibrating Reflectorless EDM on a Multi-Pillar Baseline

Q: How can you calibrate the reflectorless component of an EDM on a conventional multi-pillar EDM calibration baseline?

Standard EDM calibration baselines have pillars at known distances determined by prior adjustment. To calibrate the reflectorless component:

- Measure all inter-pillar distances with the conventional EDM using prisms (gives the baseline distances to high precision).
- Measure all inter-pillar distances using the reflectorless mode, pointing to the face of each pillar monument (or a flat painted surface on each pillar).
- Compare reflectorless readings against the known prism-mode distances. Differences reveal the zero error (additive constant) and any scale error of the reflectorless system.
- Solve for the reflectorless additive constant using the same least-squares pillar solution used for prism EDM calibration (Schödlbauer method or similar).
- Note: the reflectorless beam may not hit exactly the same point as the prism centre — account for the physical offset between prism position and pillar face using the known pillar geometry.

 Study Note: Reflectorless EDM typically has a different additive constant than the prism mode. Also, the angle of incidence on the target surface affects the measurement — perpendicular surfaces give best results.

Q8. Class 2 Laser Safety Precautions

Q: What are the safety precautions for using a Class 2 laser?

Class 2 lasers emit visible light up to 1mW. The eye's natural blink reflex provides protection for momentary exposure, but deliberate staring into the beam is hazardous.

- Never deliberately stare into the beam or point it at eyes.
- Display appropriate laser warning signs at all entry points to the work area.
- Avoid reflecting the beam off specular (mirror-like) surfaces at eye height.
- Inform all personnel in the area that a laser is in use — bystanders, co-workers, public.

- Do not use optical instruments (binoculars, cameras without appropriate filters) to view the laser beam — these concentrate the beam and can cause injury even with Class 2.
- Follow the manufacturer's operating procedures and the relevant Australian standard (AS/NZS 2211.1).
- Appoint a Laser Safety Officer if required by site regulations.
- Consider using a Class 2 laser in areas away from aircraft flight paths and roads (laser glare risk).

Study Note: Class 1 = safe under all conditions. Class 2 = safe due to blink reflex. Class 3R = low risk but some hazard. Class 3B = direct viewing hazardous. Class 4 = fire hazard as well as eye/skin hazard.

Q9. EDM Through a Window — Effect on Distance

Q: Does EDM distance measurement through a window usually: A) give correct distance, B) measure too long, C) measure too short, or D) have an error approximately equal to the glass thickness?

Answer: B — measures too long (typically).

Explanation:

- Glass has a higher refractive index than air (~1.5 vs 1.0). Light travels slower through glass.
- The EDM measures the travel time of the light signal and converts it to distance using the speed of light in air. When the signal passes through glass, it slows down, so the measured time is longer, giving a longer computed distance.
- The extra apparent distance = thickness × (n_{glass}/n_{air} - 1) = thickness × ~0.5. So a 6mm pane adds about 3mm apparent distance.
- Multiple glass panes (double glazing) compound this effect.
- Tilted glass introduces additional complications (refraction, beam displacement).

Study Note: Answer D is tempting but wrong — the error is roughly HALF the glass thickness, not equal to it. This is the classic refraction-through-glass trap.

Q10 & Q11. Reflectorless EDM Through a Window

Q: How is reflectorless EDM distance measurement through a window affected?

- All the same refractive effects apply — the beam slows in glass, giving a longer apparent distance.
- Additionally, the window surface itself reflects a portion of the beam back to the instrument. The instrument may lock onto the window reflection rather than the intended distant target, giving a completely wrong reading.

- Dirty, scratched, or filmed windows scatter the return signal, reducing intensity and potentially corrupting the measurement.
- If the instrument does range through the window to the intended target, the distance will be slightly too long (same glass-thickness offset as conventional EDM).
- Best practice: avoid measuring through windows with reflectorless EDM. If unavoidable, verify by removing the window or comparing to a conventional prism measurement.

Part 2: Survey Design Questions — Full Answers

Survey Design 1: Fibreglass Boat Mould (3m × 1.5m × 1m, ±1mm precision)

Q: How would you survey a fibreglass boat mould to ±1mm precision? Draw a plan, discuss measurements, equipment, and expected accuracies.

Setup Plan Description

Set up two precision total stations or a coordinate measuring system in positions that provide good angular intersection geometry to all points on the mould surface. Stations should be positioned approximately 3–5m from the mould, at two different positions with ~90° angle between them.

Targets

- Affix circular retroreflective adhesive targets to all key points on the mould surface (intersections, curvature inflection points, edges, keel line, gunwale, bow and stern tips).
- Use at least 6–8 targets plus 3–4 reference targets on a rigid frame surrounding the mould to establish the coordinate system.

Equipment Options

- Option A — 3D Theodolite Intersection System: Two calibrated precision total stations (e.g. Leica TCA 2003, angular precision ~0.5"). Each operator simultaneously sights the same retroreflective target. Coordinates computed by intersection. Expected accuracy at 3m distance: ~0.3–0.5mm in X/Y, ~0.5mm in Z.
- Option B — Laser Tracker (e.g. Leica AT401): Single instrument, single-operator system. Tracks a retroreflective sphere (SMR) placed on each target location. Accuracy: ±10–20 µm over 3m. Exceeds requirement. Best choice if available.

- Option C — Close Range Photogrammetry: Multi-image photogrammetric survey with coded targets. Suitable for capturing all surface points efficiently. Accuracy ~0.1mm for this object size. Requires good lighting and camera calibration.

Measurements & Processing

- For theodolite intersection: measure face left and face right to each target from both stations. Average FL/FR pairs to eliminate horizontal and vertical collimation errors. Compute 3D coordinates by least squares intersection.
- Establish a local coordinate frame using the reference frame targets (x along mould length, z vertical, y transverse).
- Apply atmospheric corrections (temperature, pressure) to all EDM distances if applicable.
- Check residuals from redundant observations — any point with residual > 1mm should be re-observed.

Expected Accuracies

- Laser tracker: ±0.05–0.1mm — far exceeds requirement.
- Theodolite intersection: ±0.5mm — meets requirement with care.
- CRP: ±0.1–0.3mm — meets requirement.

Survey Design 2: UNSW Sundial Wall Azimuth

Q: How would you determine the azimuth of the face of the brick wall holding the UNSW sundial?

Approach

The face of the wall defines a plane. We need the bearing of the normal to this plane (i.e. the direction the wall faces). Two main methods:

Method A — Astronomical Azimuth (most accurate)

- Set up a precision total station (e.g. Leica TS30) on a stable tripod in front of the sundial wall, with a clear view of the sky.
- Measure angles to two or more clearly defined points on the wall face (e.g. corners of the sundial frame, nail heads, masonry features). These points define the wall plane direction.
- Perform a solar or stellar azimuth observation: observe the Sun using the solar filter method, or observe Polaris at elongation, to determine true north.
- The angle between true north (from astronomical obs) and the wall direction gives the wall azimuth.

Method B — GPS/GNSS Azimuth Transfer

- Establish two GNSS control points with precise coordinates (post-processed or RTK with base on a known mark).
- Set up total station on one control point, back-sight to the second (known azimuth).
- Turn angle to the wall face points to determine wall azimuth relative to the known control azimuth.

Measurements Required

- Horizontal angles to wall-face targets (FL and FR for each target, multiple rounds).
- Astronomical or GNSS azimuth determination.
- If the wall is not perfectly flat, measure at least 3 non-collinear points to fit a plane and compute the plane's strike direction.

Expected Accuracy

- Astronomical method: ±5–15" with careful solar obs — gives wall azimuth to ±10".
- GNSS transfer: ±5–10" depending on baseline length and GNSS quality.

Survey Design 3: White Cliffs Underground Motel (±100mm, 3D plan + lease boundary check)

Q: How would you survey an underground motel at White Cliffs to produce a 3D plan and check it is within lease boundaries? Accuracy required: ±100mm.

Challenge

No GPS/GNSS underground. Must transfer coordinates from surface. Confined spaces, irregular excavated walls, low ceilings.

Surface Control First

- Establish a surface control network using GNSS (RTK or static, connected to GDA2020) around and above the motel entry shafts.
- Determine precise coordinates of all entry points (shafts, adits) with ±20mm accuracy.

Underground Survey

- Transfer coordinates and azimuth from surface to underground via shaft plumbing (use a plumb bob or laser plummet down the access shaft) or optical azimuth transfer if a slant entry permits.

- Run a free-station traverse underground: set up total station at each station, resect to two or more known marks, then measure to walls, ceiling, floor, and next traverse station.
- Use a laser scanner (e.g. Leica BLK360 or FARO Focus) for efficient 3D capture of room geometry — especially effective for irregular carved surfaces. Multiple scan positions registered together by common targets or ICP.
- Mark key room features (doorways, room corners, pillars) with target stickers for precise coordinate determination.

Lease Boundary Check

- From the surface GNSS survey, determine the surface coordinates of lease boundary corners.
- Project lease boundaries vertically down to compare with underground room extents.
- ±100mm accuracy is achievable with careful total station traversing or scanner registration.

Output

- 3D point cloud of all rooms processed into a 3D plan (horizontal sections at room floor level, vertical sections through each room, 3D rendered model).
- Boundary check overlay showing any encroachment risk.

Survey Design 4: Kilauea Lava Surface Scanning (Response to Prof. Email)

Q: Email from Hawaii Institute of Geophysics asking about feasibility of using a terrestrial laser scanner 2–3m above a 2.5–4m lava surface patch, looking nearly straight down.

Draft Email Response

Dear Professor,

Thank you for your enquiry about using terrestrial laser scanning for characterising pahoehoe and a'a lava surface textures at Kilauea.

The short answer is: yes, a terrestrial laser scanner would be well suited to this application, and the geometry you describe (scanner 2–3m above, near-nadir pointing) is workable with some important considerations:

- Scanner suitability: Phase-based scanners (e.g. Leica RTC360, FARO Focus) work well at close range. Time-of-flight scanners (e.g. Leica P50) are also suitable. For 2.5–4m patches at 2–3m range, you will get point densities of several hundred points per square metre easily.

- Geometry: Near-nadir scanning is fine for flat-lying lava. For a'a with steep block faces, some shadowing will occur — multiple scan positions or a tilted mount will help capture all facets.
- Mounting: The scanner can be mounted on a surveying tripod (most have a 5/8" thread). You may need a tall tripod or overhead frame structure. Ensure stability — any vibration degrades point accuracy.
- Accuracy: For this range, a modern scanner achieves 1–3mm point accuracy, which will clearly resolve texture variations from 5mm to 1.5m scale as you describe.
- Practical considerations: Lava surfaces absorb laser energy (dark colour, rough texture) — this reduces range but at 2–3m is not a problem. Highly vesicular surfaces may give noisy returns — multiple scan positions help.
- Processing: Register multiple positions with ICP or common targets. Output a gridded DEM or mesh for roughness analysis. Software such as CloudCompare (free) or Leica Cyclone handles this well.

I would be happy to discuss this further or provide recommendations on specific scanner models.

Kind regards,

Survey Design 5: Designing a Deformation Monitoring Survey

Q: How would you design a survey for deformation monitoring?

Step 1: Understand the Problem

- What is being monitored? (Dam, building, embankment, mine subsidence, landslide, tunnel convergence)
- What is the expected magnitude and rate of movement?
- What accuracy is required? (Typically 1/5 to 1/10 of the expected movement)
- What is the monitoring frequency? (Continuous, daily, seasonal)

Step 2: Control Network Design

- Establish reference (datum) points far from the deforming structure — assumed stable.
- Use free network adjustment or minimum constraint with the reference marks.
- Minimum 3 datum points for full 3D network; check datum stability between epochs.

Step 3: Object Points

- Establish monitoring targets on the structure at locations likely to show maximum deformation (crest, toe, abutments, corners).

- Use forced centring prisms, tiltmeters, strain gauges as appropriate.

Step 4: Measurement Technique

- Total station: precision angular and distance measurements to retroreflective prisms. Suitable for cm to sub-mm precision.
- GNSS: continuous or periodic position. Suitable for large-scale, slow deformation. Sub-cm to mm with long observation sessions.
- Terrestrial laser scanning: full surface change detection. Detects unexpected deformation patterns not covered by discrete prism points.
- Tiltmeters, inclinometers, extensometers: continuous automated monitoring for rapid events.

Step 5: Statistical Analysis

- Compare coordinates epoch-to-epoch using congruency testing (global and point-wise).
- Use F-test (global) and t-test (point-wise) to determine if displacements are statistically significant.
- Report displacement vectors with 95% confidence ellipses.

Part 3: Discussion Questions

Discussion 1: Roof Marks vs Wall Marks in Mine/Tunnel Traversing

Q: Should we continue to use roof marks, or should we use wall marks and free stationing/resections?

Traditional Roof Marks Approach

- Marks on the roof (ceiling) of the tunnel connected by plumb wires or laser — instrument set up under the marks.
- Advantage: marks are out of traffic path, less likely to be disturbed.
- Disadvantage: poor intersection geometry (all points nearly collinear in plan), difficult instrument setup under mark, propagates azimuth error quickly.

Wall Marks + Free Stationing Approach

- Marks on walls at convenient height; instrument positioned freely and resected to multiple known wall marks.

- Advantage: better geometry (wider angular spread), multiple observations improve precision, instrument can be set up anywhere practical, redundancy allows error detection.
- Disadvantage: wall marks more exposed to damage from traffic; free station computation required.

Recommendation: Wall Marks + Free Stationing

- Modern total stations with auto-targeting and robotic capability make free stationing efficient and fast.
- The significantly better geometric strength of wall-mark configurations leads to smaller error ellipses (as shown by the Shepherd & Jarosz 2003 research — 81×11mm vs 65×17mm at Point 4 for comparable survey configurations).
- Preferred equipment: robotic total station with auto-target recognition (ATR), e.g. Leica TS60 or Trimble SX12. ATR allows the instrument to automatically find and point to prisms, reducing operator error and speeding up observations.

Discussion 2: Ethics — Missing Traverse Angle

Q: Ethics scenario: A party chief tells you to insert a fictitious angle (56°41'24") into the field book to fill in a missing traverse angle. What is your most ethically correct response?

This is professional misconduct and must not be done.

The ethically correct response:

1. Politely but firmly decline to write a fictitious observation into the field book. Explain that you cannot record data that was not observed.
2. Bring the problem to light professionally: inform the party chief that the angle was missed and the field work must be repeated for that angle, or the traverse must be revised.
3. If the party chief insists, escalate to the project surveyor or manager.
4. Under no circumstances sign or submit a survey that contains fabricated observations.

Why this matters:

- Surveyors are licensed professionals with legal obligations to record observations truthfully.
- Fabricated data could compromise the integrity of the final survey result, leading to incorrect property boundaries, construction errors, or safety risks.
- Professional indemnity insurance typically does not cover deliberate data fabrication.

- In Australia, falsifying survey records can result in loss of licence and legal liability.

� Study Note: The sum of interior angles in a 7-sided polygon = (7-2) × 180° = 900°. The recorded sum is 843°18'22". The 'calculated' missing angle = 900° - 843°18'22" = 56°41'38", NOT 56°41'24" as suggested by the party chief. This discrepancy of 14" indicates the remaining measured angles may also contain errors — another reason not to simply fill in the angle.

Part 4: Key Study Notes by Topic

Local Scale Parameters

Local Scale (LS) accounts for the difference between distances measured on the ground and those represented on a map grid.

- Grid Distance = Ellipsoidal Distance × Point Scale Factor (K)
- Ellipsoidal Distance ≈ Horizontal Distance × (1 - h/R) where h = height above ellipsoid, R = 6400km
- Combined Scale Factor (CSF) = K × (1 - h/R)
- 1 ppm change = 1mm per km

� Key Point: Local Scale is useful when working over small areas to avoid constant CSF corrections — use a single average scale for the project area.

Deformation Surveys — Statistical Tests

- Global test (F-test): Are any points significantly displaced between epochs? Tests the overall network.
- Point-wise test (t-test or Baarda's data snooping): Which specific points have moved significantly?
- Significance level α typically 0.05 (95% confidence).
- Confidence ellipses show the uncertainty in position — displacement must exceed the combined uncertainty to be significant.

✔ Key Point: A displacement is significant if it exceeds approximately 2.5× the standard deviation (95% confidence, 2D).

Underground Surveying — Azimuth Transfer

- Gyro Theodolite: Determines true north independently of traverse. Used at shaft bottom to give absolute azimuth.

- Optical Plumbing: Transfer surface azimuth and coordinates down shaft via plumb wires.
- Weisbach Triangle: Geometric construction to transfer azimuth from surface control through a shaft using wire observations.

✔ Key Point: Gyro uncertainty ±10–20" needs to be compared against accumulated traverse azimuth uncertainty when deciding when to use gyro.

Network Adjustments — Free Network

- Free network (minimum constraint) adjustment: does not fix any points. Solves for the 'inner solution' by holding the centroid and orientation of the network constant.
- Produces error ellipses showing internal precision of the network, independent of external datum errors.
- Used in deformation monitoring to compare epochs without the fixed datum affecting the results.
- Variance Factor (VF) = v^T P v / (n - u) — should be close to 1.0 if the model is correct.

Reflectorless EDM & Laser Safety

- Reflectorless EDM measures distance to any surface without a prism — uses high-intensity laser (typically Class 3R or 3B).
- Accuracy typically ±2–5mm at short range, worse at longer range or on dark/angled surfaces.
- Main error sources: surface angle of incidence, surface albedo, beam size (footprint averaging).
- Class 2 laser (≤1mW, visible): protected by blink reflex. Do not stare into beam.
- Class 3R (≤5mW): slightly higher risk, avoid viewing with optics.

Laser Scanning Key Points

- Phase-based scanners: faster, shorter range (typically up to 70m), better for indoor/close work.
- Time-of-flight scanners: longer range (up to 1000m+), suitable for large civil structures, slower.
- Key parameters: point density (pts/m²), accuracy (σ per point), scan time, range.
- Registration: aligning multiple scan positions. Methods: target-based (precision), ICP (iterative closest point, for surfaces).
- Useful for: as-built surveys, deformation monitoring, heritage recording, volume calculations, tunnel profiling.

High-Rise Building Surveys

- Verticality: measure with precision total station using angles or offsets at multiple levels. Compare to design plumb line.
- Tiltmeters: permanent electronic sensors for ongoing monitoring of structural tilt.
- Settlement monitoring: precision levelling to floor benchmarks at multiple epochs.
- Floor levelness: profiling with digital level or laser level.
- Wind/thermal sway: GPS or accelerometers for dynamic monitoring.

✔ Key Point: High-rise structures sway and experience thermal expansion — surveys should account for time of day and wind conditions. Measure in stable morning conditions where possible.

Hydrographic Surveying Summary

- Determines water depths and bed morphology of water bodies.
- Equipment: echo sounder (single or multibeam), GNSS for position, motion sensor for vessel pitch/roll/heave.
- Single beam: one depth per ping along a profile line.
- Multibeam: swath coverage — 100–150° swath width, full seabed coverage.
- USVs (Unmanned Surface Vehicles): allow surveys in shallow/dangerous areas. GPS autopilot for accurate lane keeping.

✔ Key Point: Vertical reference (chart datum) critical — must account for tides, water level variations. In Australia, LAT (Lowest Astronomical Tide) commonly used as chart datum.

Astronomy / Azimuth Determination

- Solar observation: measure hour angle or altitude of Sun + compute azimuth from ephemeris. Needs accurate time (GPS disciplined clock), lat/lon.
- Polaris observation: near north celestial pole. Azimuth correction from tabulated east/west elongation values.
- GPS azimuth: long baseline between two GPS receivers gives bearing. Accuracy depends on baseline length.
- Gyro theodolite: mechanical gyro finds north from Earth's rotation. Best underground method.

Part 5: Key Formulas Reference

Formulas provided on the exam sheet — understand what each term means.

Formula	What It Means / When To Use
$\Delta H = SD \cdot \cos(ZA) = HD/\tan(ZA) = D \cdot \cot(ZA)$	Height difference from slope distance (SD) and zenith angle (ZA). Three equivalent forms.
$H_B = H_A + HI - HT + d \cdot \cot ZA \cdot$(refraction correction)	Full reciprocal trigonometric levelling formula. HI = height of instrument, HT = height of target.
Grid Dist = Ellip Dist × K	Apply point scale factor K to convert from ellipsoidal to grid distance.
CSF = K × (1 - h/R)	Combined Scale Factor for converting ground distance to grid.
Ellip dist ≈ Horiz dist × (1 - h/R)	Height correction: reduces ground distance to ellipsoidal.
1 ppm = 1mm/km	Quick check: 10ppm error on 5km = 5mm.
VF = vTPv / (n-u)	Variance factor from adjustment. Should be ~1.0. VF>>1 = model problems or blunders.
F = SD_coords / SD_msd	Scale factor in network — ratio of coordinate-derived distances to measured distances.

Part 6: Final Exam Tips

- Read all questions first during reading time — allocate time based on marks.
- For survey design questions: always state the problem requirements first, then justify your equipment and method choices.
- Draw clear sketches — label everything (stations, targets, sight lines, scale bars).
- Use FIXIT for any adjustment calculations (free network, traverse adjustment, deformation analysis).
- Show all working in Excel if numerical calculations are required — name your cells clearly.
- For ethics questions: be direct. State what is wrong, why it is wrong, and what the correct action is.

- Answer in the context of Australian standards where relevant (GDA2020, MGA, ARR, AS/NZS).
- Budget time: 45 marks in 120 min = ~2.7 min/mark. A 10-mark question = 27 minutes maximum.

Good luck — you've got this!