CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING **October 2020**

Although programmable calculators may be used, candidates must show all formulae used, the substitution of values into them, and any intermediate values to 2 more significant figures than warranted for the answer. Otherwise, full marks may not be awarded even though the answer is numerically correct.

Note: This examination consists of 6 questions on 4 pages. **Marks**

Q. No	Time: 3 hours	Value	Earned
1.	The Canadian First Order levelling specifications require that the discrepancy between independent forward and backward levelling runs (at 95% confidence) is not to exceed ±4 mm $\sqrt{L}$ (with L in kilometers). Answer the following:		
	a) Derive an expression for the standard deviation of mean elevation difference of forward and backward levelling runs over a section of L km, and determine the numerical value for the standard of an elevation difference of one-way levelling run over a section of 1 km (you must show all necessary equations and assumptions for full marks).	7	
	b) Using modern total stations [angular accuracy of ± 1″ and a distance accuracy of ± 1 mm ± 1 ppm according to ISO Standards] has the potential for competing with traditional differential levelling. Assuming the total station is used in a trigonometric levelling procedure with imposed balanced sight length of 60 m, determine numerically (stating any assumptions made) whether the levelling result will satisfy the First Order specification. [Let the average zenith angle at each station to back sight target be 91.5° and to foresight target as 88.5°, and assume that the standard deviation of height difference of back sight and foresight targets at each setup is zero.]	15	
	c) Discuss the differences between loop and connecting traverse network surveys and explain specifically (describing the error sources) why ROM (ratio of misclosure) of one of the traverse surveys (identifying which one) will represent precision rather than relative accuracy of the survey.	6	
2.	It is a general requirement that the surveyor's total station equipment (the electro-optical type) be calibrated regularly on a government-certified calibration baseline that has known pillar coordinates. Ad hoc collinear array of points based on a series of tribrachs on tripods can be used to investigate some aspects of the total station equipment. Compare the use of a linear array to the use of a calibration baseline under each of the following considerations:		
	a) What quantities are measured in each case, giving an example for baseline of six points;	3	
	b) What corrections are applied in both cases, as "pre-processing" and why;	2	
	c) What quantities are estimated and statistically analyzed;	2	
	d) Typical equations showing how the calibration results will be used subsequently (defining the variables in the equations);	2	
	e) The three important advantages of baseline calibration over the linear array approach.	3	

3.	Answer the following: a) In two-epoch method of deformation analysis, what statistical test(s) must be performed on each epoch measurements and in the deformation analysis (naming the statistics and providing their purposes)? b) Surveyors usually claim that their geodetic level can be used as a geotechnical instrument such as a tiltmeter. Explain how, including the observables and necessary formulas in each case and two specific situations in which the use of one instrument is preferred to the other. c) What is orthometric height? Discuss one important disadvantage of orthometric height system.	5 8 5	
4.	In order to provide confidence in the area determination of an irregular quadrilateral lot ABCD in a flat topography, the surveyor has decided to measure the angles in the lot to a standard deviation of ±3″ and the distances to a standard deviation of ±0.002 m. The critical section of the lot is point C of the lot where the surveyor will measure lengths CB and CA, and angle BCA (θ_1). For pre-analysis, the approximate measurements made from a large-scale topographic map of the lot are CB = 72 m; CA = 125 m and $\theta_1 = 33^\circ$. With consideration for pointing, reading, centering and leveling errors, determine numerically if Leica TC2003 with angle-measurement standard deviation (ISO 17123-2) as 0.5″ and distance-measurement standard deviation (ISO 17123-4) as 1 mm + 1 ppm will achieve the designed standard deviations of angle and distance measurements (suggesting the number of sets of measurements required). Assume the instrument will be set up on a tripod with height above the setup point as 1.65 m and the centering will be done with laser plummet; and the centering error of each target will be 1 mm.	14	
5.	Explain the following: a) Precise point positioning (PPP) is becoming an attractive alternative to RTK in surveying. Explain three ways in which PPP is different from double-difference Real Time Kinematics (RTK) positioning (demonstrating your understanding of the two techniques). b) Discuss four of the important benefits of PPP technique compared to double-difference RTK technique. c) Explain the main objectives of calibrating and testing GNSS surveying systems and discuss the general concerns about the likely outcomes of the calibration and testing processes.	4 8 8	
6.	The allowable vertical breakthrough tolerance between two breakthrough points A and B in a tunneling survey is 0.012 m. The design of vertical control for the tunnelling survey is to follow the usual procedure of carrying out independent design of surface and underground vertical control networks. In the simulation of the underground network design based on minimal constraint least squares procedure, the 99% error of the elevation difference between points A and B is estimated as 0.010 m; similarly, for the surface network design, the covariance matrix for the two breakthrough points (in the order A and B) is given as $$C_{AB} = \begin{bmatrix} 4.0E-6 & 0.0 \\ 0.0 & 5.0E-6 \end{bmatrix} \text{m}^2$$ Interpret the meaning of the tolerance specified for the tunneling survey, use this interpretation to determine if the allowable vertical breakthrough tolerance is satisfied by the current design, and explain 2 approaches of minimizing the effects of refraction during the tunneling survey.	8	
		100	

Some potentially useful formulae are given as follows:

$$v = \frac{Z_I + Z_{II} - 360}{2} \qquad \bar{z} = \frac{Z_I + (360 - Z_{II})}{2}$$

$$\frac{c}{\sin(z)} = \frac{Hz_I - (Hz_{II} - 180)}{2} \qquad \frac{t}{\tan(z)} + \frac{c}{\sin(z)} = \frac{Hz_I - (Hz_{II} - 180)}{2}$$

$$\textit{Corrected direction} = \textit{Measured direction} - \frac{(NR - NL) \times v''}{2 \tan z}$$

$$i_v = z - z' \text{ or } i_v = i \cos\alpha; \qquad i_T = Hz - Hz' \text{ or } i_T = \frac{i \sin\alpha}{\tan z}$$

Deformation: $\ell_2 - \ell_1 + V = Ad$; $\qquad d = \hat{x}_2 - \hat{x}_1$

$$F_c = \frac{\hat{d}^T Q_{\hat{d}}^{-1} \hat{d}}{\hat{\sigma}_0^2 u_d} < F(\alpha_0, u_d, df_p); \qquad F_c = \frac{\hat{d}^T Q_{\hat{d}}^{-1} \hat{d}}{\hat{\sigma}_0^2 u_d} < \frac{\chi^2_{\alpha_0, df = u_d}}{u_d}$$

$\alpha = \frac{\delta \Delta h}{s}$ where $\delta\Delta h = \Delta h_{12t2} - \Delta_{h12\,t1}$.

$\sigma_\alpha = \frac{\sigma_{\delta\Delta h}}{s}$ where $\sigma_{\delta\Delta h} = \sqrt{\sigma^2_{\Delta h1} + \sigma^2_{\Delta h2}}$

EDM:

$$n_a = 1 + \frac{(n_g - 1) 273.16 p}{(273.16 + t) 1013.25}$$ (for p in mb and t in °C)

$$N = (n-1) \times 10^6 \qquad \delta' = (N_{REF} - N_a) d' \times 10^{-6}$$

Standard pressure: 760 mmHg or 1013.25 mb; 0°C or 273.15 K

$$\hat{C} = \frac{M - (m_1 + m_2 + m_3 + m_4 + ... + m_n)}{n - 1}$$

Levelling: $\pm 3mm\sqrt{L} \qquad \pm 4mm\sqrt{L} \qquad \pm 8mm\sqrt{L} \qquad \pm 24mm\sqrt{L} \qquad \pm 120mm\sqrt{L}$

Statistics:

$$|\Delta| = \sigma_\Delta \sqrt{\chi^2_{df,\alpha}} \qquad |\Delta| \le z_{\alpha/2}\sigma_\Delta \qquad |\Delta| \le t_{df,\alpha/2}\sigma_\Delta \qquad \hat{\sigma} \le \sqrt{\frac{\chi^2_{\alpha,df}(\sigma)}{df}}$$

$$\sigma_{dp} = \frac{\sigma_p}{\sqrt{2n}} \qquad \sigma_{dp} = \frac{60}{M} \qquad \sigma_{\theta P} = \frac{\sigma_P}{\sqrt{n}} \qquad \sigma_{dr} = \frac{\sigma_r}{\sqrt{2n}} \qquad \sigma_{dr} = 2.5 \text{ div} \qquad \sigma_{\theta r} = \frac{\sigma_r}{\sqrt{n}}$$

$$\sigma_L = \sigma_v \cot z, \qquad \sigma_v = 0.2v'' \qquad \sigma_r = 2.5d'' \qquad \sigma_{\theta L} = \sigma_v \sqrt{\cot^2(Z_b) + \cot^2(Z_f)}$$

$$\sigma_i = \frac{(206265'')\sigma_{c3}}{S_1} \qquad \sigma_t = \frac{(206265'')\sigma_{c1}}{S_1} \qquad \sigma_{dc} = \frac{206265}{S}\sqrt{\sigma^2_{c3} + \sigma^2_1}$$

$$\sigma_c = \pm 0.5mm\text{/m} \times \text{HI (m)} \qquad \sigma_c = \pm 0.1 \text{ mm} \qquad \sigma_c = \pm 0.1 \text{ mm/m} \times \text{HI (m)}$$

$$\sigma_{\theta i} = (206265'')\sigma_{c3}\sqrt{\left[\frac{S_1^2 + S_2^2 - 2S_1S_2\cos\theta}{S_1^2 S_2^2}\right]}$$

$$\sigma_{\theta i+t} = (206265")\sqrt{\frac{\sigma_{c1}^2}{S_1^2} + \frac{\sigma_{c2}^2}{S_2^2} + \frac{\sigma_{c3}^2}{S_1^2 S_2^2}\left[S_1^2 + S_2^2 - 2S_1S_2\cos\theta\right]}$$

$$\sigma_P = \frac{45}{206265 \times M} S; \qquad \sigma_L = \left(\frac{\sigma_v}{206265}\right) S; \qquad \sigma_r = \frac{\ell}{2}\left(\frac{v_r}{206265}\right)^2$$

$$\sigma_d = \frac{S}{2R}\sigma_{k_h} \qquad \sigma_{ref} = \frac{S}{2R}\sigma_{k_V}$$

Table 1: Normal Distribution table (upper tail area):

α	0.001	0.002	0.003	0.004	0.005	0.01	0.025	0.05	0.10
z_α	3.09	2.88	2.75	2.65	2.58	2.33	1.96	1.64	1.28

Table 2: Chi-Square Distribution table (lower tail area)

α	0.025	0.05	0.10	0.90	0.95	0.975	0.99	0.995
Degrees of freedom								
1	0.001	0.004	0.016	2.705	3.841	5.024	6.635	7.879
2	0.051	0.103	0.211	4.605	5.991	7.378	9.210	10.597
3	0.216	0.352	0.584	6.251	7.815	9.348	11.345	12.838
11	3.816	4.575	5.578	17.275	19.675	21.920	24.725	26.757
12	4.404	5.226	6.304	18.549	21.026	23.337	26.217	28.300
13	5.009	5.892	7.041	19.811	22.362	24.736	27.688	29.819
14	5.629	6.571	7.790	21.064	23.685	26.119	29.141	31.319
15	6.262	7.261	8.547	22.307	24.996	27.488	30.578	32.801

Table 3: Table for Student-t distribution (α is upper tail area)

	t_α			
Degree of freedom	$t_{0.10}$	$t_{0.05}$	$t_{0.025}$	$t_{0.01}$
1	3.08	6.31	12.7	31.8
2	1.89	2.92	4.30	6.96
3	1.64	2.35	3.18	4.54
4	1.53	2.13	2.78	3.75
5	1.48	2.01	2.57	3.36
6	1.49	1.94	2.45	3.14
11	1.363	1.796	2.201	2.718
12	1.356	1.782	2.179	2.681
13	1.350	1.771	2.160	2.650
14	1.345	1.761	2.145	2.624
15	1.341	1.753	2.131	2.602