CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING **June 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.	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; b) What corrections are applied in both cases, as "pre-processing" and why; c) What quantities are estimated and statistically analyzed; d) Typical equations showing how the calibration results will be used subsequently (defining the variables in the equations); e) The three important advantages of baseline calibration over the linear array approach.	3 2 2 2 3	
2.	Answer the following with regard to deformation monitoring and analysis. 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) Discuss one important disadvantage of orthometric height system and explain why surveyors prefer the system to leveled height (uncorrected differential leveling height) system (demonstrating also that you know the differences between the two height systems).	5 8 9	
3.	In order to provide confidence in the area determination of an irregular quadrilateral lot ABCD in a flat topography, the surveyor has designed 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 θ_1 = 33°. 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	

4.	The standard deviation of Leica DNA03 digital level with invar staff is specified as 0.3 mm/km double-run according to ISO17123-2 standard. Answer the following (clearly providing all necessary equations of problems, error propagations, and good sentence explanations of steps involved, for each of the questions). a) Determine the expected standard deviation of misclosure of forward and backward leveling runs over a 400-m section using the instrument and show numerically if the leveling will satisfy the Canadian special order leveling specification, $\Delta = 3\sqrt{L}$ mm (at 95% confidence). b) Determine the expected standard deviation of elevation difference per set up (**Note:** the sight distance for leveling for ISO standard procedure is 30 m) c) The Leica DNA03 digital level was calibrated according to ISO standard17123-2 as 0.5 mm/km double-run based on least squares adjustment with degrees of freedom of 15. Determine if the level is still consistent with the manufacturer's specified value at 95% confidence level (clearly providing null and alternative hypotheses, statistic, test and conclusion).	9 4 5	
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. d) As part of GNSS job specifications for a GNSS survey project, a fixed baseline of approximately 16,697 m in length (between control points A and B) was observed using static surveying procedures with specified accuracy of 5 mm + 1 ppm. The differences between the observed and fixed baseline components are 0.0074 m, 0.0013 m, 0.0050 m respectively for ΔX, ΔY, ΔZ components. If the setup error of 0.0015 m is assumed for each receiver, determine if the surveying procedures are acceptable at 95% confidence level.	4 8 8 4	
6.	The allowable vertical breakthrough tolerance between two breakthrough points A and B in a tunneling survey is 0.010 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 standard deviation of the elevation difference between points A and B is estimated as 0.005 m; similarly, for the surface network design, the covariance matrix for the two breakthrough points (in the order A and B) is given as $$C_{AB} = \begin{bmatrix} 2.895E-6 & 1.298E-6 \\ 1.298E-6 & 4.165E-6 \end{bmatrix} \text{m}^2$$ 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.	10	
		100	

Some potentially useful formulae are given as follows:

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

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

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

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

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 $\delta\Delta h = \Delta h_{12t2} - \Delta h_{12\,t1}$.

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

EDM:

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

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

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:

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

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

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

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

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

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

$$\sigma_{\theta i+t} = (206265'') \sqrt{\frac{\sigma^2_{c1}}{S_1^2} + \frac{\sigma^2_{c2}}{S_2^2} + \frac{\sigma^2_{c3}}{S_1^2 S_2^2}\left[S_1^2 + S_2^2 - 2 S_1 S_2 \cos\theta\right]}$$

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

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

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