CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING

October 2018

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 7 questions on 4 pages.

Time: 3 hours

Q. No		Marks: Value	Marks: Earned
1.	a) Briefly describe 3 theodolite errors whose effects on a horizontal circle reading will not change when the telescope direction is changed horizontally with the zenith angle reading locked, and explain how these effects can be minimized.	4	
	b) Clearly explain how a theodolite can be checked in the field for plate bubble error.	2	
	c) Explain one method of checking (in the field) if a theodolite has a standing axis error. How will you minimize the effect of this error on horizontal direction measurements?	3	
	d) Explain the procedure for calibrating a total station for the effects of tilting and collimation errors, providing appropriate supporting formulae and a discussion on how the calibrating parameters are determined internally by the total station.	5	
2.	Your company has recently purchased a Sokkia B20 automatic level with the following manufacturer's specifications: • Standard deviation for 1 km double run leveling (according to ISO 17123-2) is ± 0.5 mm (with micrometer); • Magnification is 32×; and compensator setting accuracy is ± 0.3". Answer the following with regard to the level:		
	a) Explain clearly what is meant by "1 km double run leveling" and the relevance of ISO 17123-2 statement in the specifications.	4	
	b) If the level is to be used in a survey, determine the expected standard deviation of a height difference measurement in a set-up with a sight distance of 60 m.	4	
	c) If the level is to be calibrated according to ISO 17123-2, what quantities will be estimated and what statistical testing can be done a posteriori (clearly providing null and alternative hypotheses, test statistics and possible conclusions with all symbols defined)?	10	
3.	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)?	5	
	b) What is the main problem of geometrical deformation analysis with regard to absolute monitoring networks?	2	
	c) Leica DNA03 geodetic electronic level with invar rod has a manufacturer's specified accuracy of 0.3 mm per km double run (according to ISO 17123-2 specification). Assuming an ISO standard sight length of 30 m, calculate the achievable precision (in arc seconds) if this level is used as a "long base" tiltmeter between two benchmarks that is 60 m apart, through repeated levelling (clearly explaining all steps and derivations of formulas involved).	6	
	d) Discuss the important limitations in using terrestrial laser scanners in deformation monitoring surveys.	2	

4.	a) A Leica TCRA 702 total station (accuracy specifications according to ISO 17123 for angle as 2″, distance as 2 mm ± 3 ppm and compensator setting accuracy as 0.5″) is to be used to measure a height difference (ΔH) between a total station setup point and another point Q. In this process, the slope distance d_S, the zenith angle z, height of instrument (HI) and the height of reflector (HR) will be measured in order to determine ΔH. If the error in ΔH (at 99.7% confidence level) is not to exceed ±15 mm, determine the expected standard deviations in measuring HI and HR, assuming balanced accuracies with approximate values of the measurements as z = 100°, HI = 1.6 m, d_S = 200.0 m, and centering error of target and instrument is to be 2 mm each. b) Discuss 3 important benefits of two-dimensional network design and clearly explain what quantities are solved for in the First-Order Design (FOD) and the Second-Order Design (SOD) problems.	15 5	
5.	a) 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 specified tolerance for the tunneling survey and then use this interpretation to determine if the allowable vertical breakthrough tolerance is satisfied by the current design. b) Clearly explain four approaches for taking care of the effects of refraction in tunneling surveys.	9 4	
6.	The two commonly used methods of precise azimuth determination are based on the use of Global Navigation Satellite System (GNSS) and gyrotheodolite/gyro station equipment (e.g. follow-up method). Answer the following: a) GNSS validation procedure and the gyro station calibration for the alignment constant are the important field calibration processes commonly required prior to field observation. Discuss briefly these calibration processes (providing simple explanation of the procedure, the purpose and how often it should be done in each method). b) What steps and corrections are required in each method to transform the determined azimuths to grid azimuths (specifying the type of azimuth determined in each method)?	6 4	
7.	Two survey crews A and B measured the length of a horizontal baseline using the same EODMI instrument (with precision ± 3 mm ± 2 ppm and the reference refractivity as 281.949). Crew A measured the whole baseline and obtained the overall length of the baseline (corrected wrongly for meteorological condition using refractivity of 300.000 instead of the correct value of 305.520) as 1799.921 m. Crew B measured the baseline in two equal sections (with each section measured independently) and obtained the meteorologically corrected overall length of the baseline as 1799.931 m. Answer the following, assuming each of the crews was able to center their instrument to an accuracy of 0.8 mm and their target to 0.8 mm. Determine if there is any significant difference (at 99% confidence level) between the two lengths obtained by crews A and B.	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: $\pm 3mm\sqrt{L}$ $\quad \pm 4mm\sqrt{L}$ $\quad \pm 8mm\sqrt{L}$ $\quad \pm 24mm\sqrt{L}$ $\quad \pm 120mm\sqrt{L}$

Statistics:

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

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

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

$$\sigma_i = \frac{(206265'')\sigma_{c3}}{S_1} \qquad \sigma_t = \frac{(206265'')\sigma_{c1}}{S_1} \qquad \sigma_{dc} = \frac{206265}{S} \sqrt{\sigma_{c3}^2 + \sigma_1^2}$$

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

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

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

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

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