CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING **March 2017**

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.	A survey contract requires determining local benchmark elevations following First Order procedure with the discrepancy between independent forward and backward levellings not exceeding ±4 mm $\sqrt{L}$ at 99% confidence level (with L in kilometres). A height difference is the average of the forward and backward levellings. Answer the following:		
	a) Derive an expression, based on the discrepancy and as a function of *L*, for the standard deviation of a height difference.	5	
	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 sight length (60 m) and balanced sight length (within 10 m) limitations of First Order levelling procedure, 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 be 88.5°.]	15	
	c) Discuss the typical observables and the sources of error (and how their effects are minimized) in the trigonometric leveling procedure in question b).	8	
	d) Discuss five important advantages of trigonometric leveling over the traditional precise differential leveling.	5	
2.	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. Answer the following:		
	a) Discuss briefly (providing the purpose and how often it should be done in each method) an important field calibration process that may be required prior to field observation.	6	
	b) What are the observables in the two methods?	3	
	c) Discuss the sources of errors (systematic and random) in the azimuth determination in both methods and how they are minimized (providing 5 sources of errors for each method).	10	
	d) Discuss one specific and unique application of each method.	2	
	e) What steps and corrections are required in each method to transform the determined azimuths to grid azimuths?	4	
3.	The system constant, z_0, of an EDM is to be determined without using the calibration baseline (with known lengths). Answer the following:		
	a) Explain how z_0 can be uniquely determined.	4	
	b) Explain how you can improve the uncertainty of z_0.	4	

4.	a) According to Donahue and others in their *Guidelines for RTK/RTN GNSS Surveying in Canada*, "working with a public or private Real-Time Network (RTN) can be a very precise and efficient way to perform cadastral and engineering surveys." What is RTN? How is it different from RTK? Discuss the issues (including how to solve them) that the surveyors must address a priori in preparation for RTN surveys. b) 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. c) A new point is tied to the geodetic control point A in b) using the same static surveying procedures. If the new point is 5 km away from the control point A whose published network accuracy is 0.030 m, determine the local accuracy and the network accuracy for the new point.	8 4 3	
5.	You are required to carry out a topographic survey of a proposed construction project site of about 5 ha (centered on Longitude 123˚W) with extensive above ground and underground utilities. The expected drawing scale is 1:500; ground elevations are to be shot at 15 m grid spacing and the final drawings must be delivered with a 0.25 m contour interval and must meet the NMAS Standards. Some of the specifications for the typical map standards, such as NMAS; ASPRS, Class I; and NSSDA standards are as follows: • For NMAS, the horizontal tolerance is 0.8 mm for map scales larger than 1:20,000 and the elevation should be accurate to within one-half a contour interval. • For ASPRS, the maximum allowable error (limiting RMSE) for X or Y coordinates of well-defined points for map of 1:500 is 0.125 m; and the elevation should be accurate to within one-third a contour interval. Answer the following: a) If the map meets NMAS standards, determine what vertical and horizontal accuracies should be reported according to NSSDA standards. b) If the map meets NMAS standards, determine if the vertical and horizontal accuracies satisfy the ASPRS Class I Map Accuracy Standards.	4 4	
6.	a) In a tunneling survey, it is required of the vertical control network that the maximum relative vertical positional errors between any survey points along the tunnel be within a tolerance of ± 5 mm. Interpret this tolerance and calculate the expected standard deviation of any survey point in the network, clearly stating your assumptions. Suggest the appropriate Canadian vertical control leveling order for this project, assuming the longest distance between any two points is 2.8 km. b) In the pre-analysis of a surface vertical network for a tunneling survey, describe how to determine error contribution, to the breakthrough error, due only to the proposed surface measurements.	7 4	
		100	

Some potentially useful formulae are given as follows:

$$Accuracy_x = 2.447 \times RMSE_x \qquad Accuracy_y = 2.447 \times RMSE_y$$

$$Accuracy_z = 1.96 \times RMSE_z \qquad CMAS = 2.1460 \times RMSE_x = 2.1460 \times RMSE_y$$

$$VMAS = 1.6449 \times RMSE_z \qquad \text{VMAS = CI/2}$$

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

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

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

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

$$\sigma_{X_n}^2 = \sum_{i=1}^{n-1} (Y_n - Y_i)^2 \sigma_{\beta_i}^2 + \sum_{i=1}^{n-1} \left(\frac{X_{i+1} - X_i}{\ell_i} \right)^2 \sigma_{\ell_i}^2 \qquad \sigma_{X_n}^2 = \sum_{i=1}^{n-1} (Y_{i+1} - Y_i)^2 \sigma_{\alpha_i}^2 + \sum_{i=1}^{n-1} \left(\frac{X_{i+1} - X_i}{\ell_i} \right)^2 \sigma_{\ell_i}^2$$

$$\sigma_{Y_n}^2 = \sum_{i=1}^{n-1} (X_n - X_i)^2 \sigma_{\beta_i}^2 + \sum_{i=1}^{n-1} \left(\frac{Y_{i+1} - Y_i}{\ell_i} \right)^2 \sigma_{\ell_i}^2 \qquad \sigma_{Y_n}^2 = \sum_{i=1}^{n-1} (X_{i+1} - X_i)^2 \sigma_{\alpha_i}^2 + \sum_{i=1}^{n-1} \left(\frac{Y_{i+1} - Y_i}{\ell_i} \right)^2 \sigma_{\ell_i}^2$$

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

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

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

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

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

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:

$$\Delta = \sigma_\Delta \sqrt{\chi^2_{df, 1-\alpha}} \qquad \Delta \le z_{\alpha/2} \sigma_\Delta \qquad \Delta \le t_{df, \alpha/2} \sigma_\Delta$$

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
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