CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING **October 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 7 questions on 4 pages. **Marks**

Time: 3 hours

Q. No		Value	Earned
1.	Considering the new development in modern theodolites, such as Robotic Total Station (compared with the old optical mechanical theodolites, such as Wild T1A theodolite), explain 5 important points on how the skills required of surveyors in operating the old optical mechanical theodolites are modified in operating modern total station (stating in each point the skill in operating specific aspect of the old optical mechanical theodolites and how the skill required in doing the same with modern total station has changed).	10	
2.	Leica Distomat DI1600 EDM equipment was calibrated over Surrey EDM six-point baseline in BC. The constant correction for the EDM is assumed to be equal to zero and the manufacturer's stated accuracy is 3mm ± 2ppm. The published mark-to-mark baseline distances (*p*) and the calculated mark-to-mark distances corrected for meteorological conditions (*m*) are fitted by least squares adjustment to a linear regression $p = C + Sm$, where C is the EDM constant correction and S is the scale factor. The *m* and *p* values are based on all the possible combinations of one-way distances among the baseline points. The following least squares adjusted quantities were obtained: $1\text{-}S$ = -3.01 ppm; $\hat{\sigma}_S$ = 1.05 ppm; C = 0.70 mm; $\hat{\sigma}_C$ = 0.77 mm. Answer the following:		
	a) Test if $\hat{\sigma}_S$ is compatible with the manufacturer's claimed scale factor error at 95% confidence level.	6	
	b) Test if the scale factor correction ($1\text{-}S$) is significantly different from zero at 95% confidence level.	5	
3.	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 slope of the terrain (covered with the same material) be +1.5°.]	15	
	c) Discuss five important advantages of trigonometric levelling over the traditional precise differential levelling.	5	

4.	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. b) 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). c) What steps and corrections are required in each method to transform the determined azimuths to grid azimuths?	6 10 4	
5.	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	
6.	Answer the following with regards to deformation monitoring and analysis. a) What is the *observation differencing* approach? Explain the conditions under which this approach may be used and discuss two disadvantages of the approach. b) Discuss the important limitations in using terrestrial laser scanners in deformation monitoring surveys.	6 2	
7.	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 levelling 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:

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

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

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

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

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

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

Deformation: $1_2 - 1_1 + V = Ad$; $\qquad d = \hat{x}_2 - \hat{x}_1$

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

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

EDM:

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

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

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:

$$\Delta = \sigma_\Delta \sqrt{\chi_{df,\alpha}^2} \qquad \Delta \le z_{\alpha/2}\sigma_\Delta \qquad \Delta \le t_{df,\alpha/2}\sigma_\Delta$$

$$\hat{\sigma} \le \sqrt{\frac{\chi_{\alpha,df}^2(\sigma)}{df}}$$

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