CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING **October 2016**

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 8 questions on 5 pages. **Marks**

Q. No	Time: 3 hours	Value	Earned
1.	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. c) A facility on the construction project site was located to 0.25 m horizontal accuracy (one standard deviation) by GPS. Determine if the positional accuracy of the GPS survey is better than that of the topographic map, assuming the map meets the NMAS standards.	 4 4 2	
2.	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) Given from the least squares adjustments based on the *coordinate differencing* approach, the datum-independent displacement vector ($\hat{d}$) and the corresponding cofactor matrix ($Q_{\hat{d}}$) for a monitored point, clearly explain (including important steps, assumptions, formulae, and quantities needed and how to extract them) how you will statistically determine that the monitored point has not moved significantly. c) Explain how you will define the datum for the least squares adjustment of each epoch of measurements (based on the *coordinate differencing* approach) by external minimal constraints and iterative weighted similarity transformation methods (assuming the deformation network is a trilateration network). d) Discuss the important limitations in using terrestrial laser scanners in deformation monitoring surveys.	6 5 3 1	

3. Explain the following:

a) Real-Time Kinematic (RTK) GPS has become another tool for the cadastral surveyors. Explain (with regard to base station location and a case where an important cadastral detail is located where there is no visibility to the sky) the practical issues in using this tool for cadastral surveying (your explanation should include suggestions on solution approaches to the issues). (12)

b) 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. (8)

c) One of the sources of error in precise GNSS surveying is observing heights of GNSS antennas above survey stations. Explain why heights of antennas are needed and how they are measured for best accuracy. (3)

4.

a) A leveling instrument that has not been used for over 15 years is to be used for a survey project. The manufacturer claims, following DIN 18723 [or ISO 17123-2], that the equipment has a standard deviation of ±0.2 mm over 1-km double-run leveling. Since there is no record of any testing or calibration of this particular instrument, explain six important quality assurance/quality control measures (with an explanation on why each measure is important) and the field procedure (including the configuration of the test line, number and types of measurements made in the field) that you would recommend following in order to determine whether the level is capable of behaving as the manufacturer claimed. (10)

b) Explain the quantities that will be determined from the adjustment of the measurements, and the statistical tests (hypotheses, test statistics, etc.) that will be performed on some of the quantities in order to determine whether the level is capable of behaving as the manufacturer claimed. (5)

5. To obtain accurate horizontal direction measurements to elevated points with a theodolite, it is important to correct the measurements for the effect of horizontal axis of the theodolite not being horizontal.

a) The following circle readings were recorded when observing to an elevated point P with a theodolite. The readings were obtained with the dual compensator on and then taken again when the dual compensator is off, as shown in the following table.

	Compensator On	Compensator Off
Average Horizontal circle reading in face I and face II	25°23′15″	25°23′35″
Average Zenith angle reading of face I and face II	60°59′00″	60°59′30″

Determine the amount (in arc seconds) by which the vertical axis of the theodolite is inclined to the direction of gravity and calculate the horizontal angle between the plane containing the inclined axis and the direction to point P. (4)

b) Discuss two possible reasons for the horizontal axis of a theodolite not being horizontal when the theodolite is leveled and centered on a point. (2)

c) Clearly explain how a theodolite can be routinely checked in the field for the two sources of errors discussed in question a) (i.e. to find out if the theodolite has these errors). (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 ± 15 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	
7.	A recently repaired gyrotheodolite (e.g. GAK1) is to be used for orientation transfer in an underground mine. A number of control points in a local plane rectangular coordinate system were already established near the shaft of the mine so that surface observations reduced to the horizontal would be in the mapping plane. Explain clearly what procedure you would follow (including corrections to be applied and an explanation on the reasons for the corrections) in order to determine the accurate grid azimuths (in this local coordinate system) at a horizontal drift running approximately in a westerly direction at a level of 1000 m below the surface. Assume that the gyrotheodolite setup point is close to the shaft and the transit (time) method of gyro observations will be adopted.	8	
8.	Last July, a crew was to lay out a 1500 m distance from one survey marker to set a second survey marker. Even though the temperature was + 30°C, they did not apply a meteorological correction but simply used the display value of "1500.000". You have just measured between the two markers and the uncorrected display, using the same electro-optical EDM instrument [± 3 mm and ± 2 ppm; group refractive index: 1.000294497, manufacturer refractive index number or refractivity is 282.106] and reflector, is "1500.095" with an ambient temperature of - 20°C. Determine the current distance between the markers now and whether there is a significant difference, at 90% confidence between the distance now compared to last July, assuming standard atmospheric pressure.	8	
		100	

Some potentially useful formulae are given as follows:

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

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

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

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

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

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

$$i_v = z - z' \quad \text{or} \quad i_v = i \cos\alpha \, ;$$

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

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

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

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

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

EM Waves:

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

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

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

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

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