

CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING

March 2026

Although programmable calculators may be used, candidates must show all formulae used, the substitution of values into them, and any intermediate value 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

Q. No	Time: 3 hours	Value	Earned
1.	a) According to the “Performance Standards for the Practice of Professional Land Surveying” in a Province, it is required under certain sections that coordinates shall be accurate to 0.05 m at 95% confidence level in urban areas. After a cadastral survey in an urban area, a licensed member obtained, after least squares adjustment of the 2-D network of 5 points with degrees of freedom of 11, the following covariance sub-matrix was obtained for property marker A: $C_{\hat{A}} = \begin{bmatrix} 3 & 1 \\ 1 & 2 \end{bmatrix} cm^2$ Determine if the survey complies with the regulation at marker A, assuming the a-priori variance factor was known. Show your answers in the form of out-of-context ellipse with all the steps of your calculations. b) The standard deviation expected for a GNSS baseline determined using static surveying procedure can be estimated as $\sigma_{baseline} = \sqrt{2\sigma_s^2 + a^2 + (k \times ppm)^2}$	10	
	where $\sigma_s = 0.0015$ m, is the receiver setup error; $a + k ppm$ is the receiver manufacturer’s specified accuracy with $a = 5$ mm and $k = 1$. Check if the misclosure of the baselines measurements of 0.07662 m is acceptable at 95% confidence level assuming the total length of the loop is 50,000 m with 5 baselines involved (with each baseline measured independently).	5	
	c) Given a Leica DNA03 digital level [24× magnification, compensator setting accuracy = $\pm 0.3''$, $\sigma_{ISO} = \pm 0.3$ mm] with matching invar rods, explain (with some numerical substantiation) whether the level is suitable for First Order levelling (where σ_{ISO} is the standard deviation per 1 km of double run levelling according to ISO 17123-2). Test the suitability of the instrument with regard to the following Canadian specifications for First Order leveling using optical mechanical instruments: sensitivity of 10"/2 mm, magnification of at least 32× and the discrepancy between independent forward and backward leveling runs not to exceed [at 95% confidence level] $\pm 4mm\sqrt{k}$ with k in km.	11	
2.	a) Describe two total station axial errors that can be eliminated or minimized within the range of the dual-axis compensator and explain how to test in the field for the existence of each of the errors.	6	
	b) 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.	6	

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 measurement set and in the deformation analysis stage (naming the statistics and providing their purposes)? b) Clearly explain the main problem of deformation analysis based on isolated (local) coordinate system.	5 2	
4.	a) According to Donahue and others in their <i>Guidelines for RTK/RTN GNSS Surveying in Canada</i>, “working with a public or private Real-Time Network (RTN) can be a very precise and efficient way to perform cadastral and engineering surveys.” Describe RTN and provide a checklist of your considerations in the general planning of an RTN survey. b) Discuss briefly the purpose of GNSS field procedure validation usually required prior to a major GNSS campaign and explain a typical statistical test to check if a validation procedure is passed (including necessary statistical formulae with well-defined symbols, and the expected degrees of freedom and confidence level).	10 6	
5.	a) The system constant, z_0, of an EDM, is to be determined on the baselines with unknown lengths. Explain with the aid of a suitable sketch how z_0 can be uniquely determined. b) Provide four important Quality Assurance (QA) /Quality Control (QC) measures (including their purposes) that you would recommend following for a successful calibration of an EDM. c) The scale factor and its standard deviation are some of the quantities estimated for an EDM during its calibration procedure. Clearly explain the statistical tests that are required on each of these quantities and why.	4 8 4	
6.	Answer the following regarding correlation survey in an underground mine. a) If the entrance into the mine is through an adit, suggest an appropriate type of correlation survey and explain (with clear reasons) 3 main sources of error in the survey. b) Explain why the effects of centering errors are critical in Weiss quadrilateral method of mine correlation surveys using one total station instrument. Clearly explain how you will minimize these effects.	4 4	
7.	A closed-loop horizontal traverse of 4 points is to be run in a flat and homogeneous terrain using Leica 802 total station with specified standard deviation of 2" according to ISO 17123-3 Standard. Assume each traverse leg is approximately 100 m long; the included angle at each traverse point is approximately 90°; the targets and total station are to be centered on tripods using tribrachs with optical plummets; heights of targets and instrument are to be set at 1.6 m and the included angle at each traverse point is to be measured in one set. With consideration for leveling, centering, pointing and reading errors at each setup point, determine if the traverse will satisfy the allowable angular misclosure of 15" at 95% confidence level.	15	
		100	

Some potentially useful formulae are given as follows:

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

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

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

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

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

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

EDM:

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

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

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

Map Accuracy:

$$\text{Accuracy}_x = SE \times \sqrt{\chi_{df, 1-\alpha}^2} \quad \text{Accuracy}_y = SE \times \sqrt{\chi_{df, 1-\alpha}^2}$$

$$\text{Accuracy}_z = SE \times z_{1-\alpha/2} \quad \text{CMAS} = SE \times \sqrt{\chi_{df, 1-\alpha}^2} \quad (SE = \text{RMSE})$$

$$\text{VMAS} = CI/2 \quad \text{VMAS} = SE \times z_{1-\alpha/2}$$

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

Collimation correction due to collimation factor C: $C \times (\sum_1^n d_{BS_i} - \sum_1^n d_{FS_i})$

$$\Delta \bar{h} = \frac{\Delta h_f - \Delta h_b}{2} \quad \Delta = \Delta h_f + \Delta h_b \quad \sigma_{\Delta h} = \sigma_{ran} \sqrt{L}$$

Statistics:

$$\chi^2 = \frac{s^2(df)}{\sigma^2} \quad \Delta = \sigma_\Delta \sqrt{\chi_{df, \alpha}^2} \quad \hat{\sigma} \leq \sqrt{\frac{\chi_{\alpha, df}^2(\sigma)}{df}} \quad \Delta \leq z_{\alpha/2} \sigma_\Delta$$

$$\Delta \leq t_{df, \alpha/2} \sigma_\Delta \quad y = d\hat{x}^T C_{d\hat{x}}^{-1} d\hat{x} \quad y \leq \chi_{1-\alpha, df}^2$$

$$\sigma_{dp} = \frac{\sigma_p}{\sqrt{2n}} \quad \sigma_{dp} = \frac{60}{M} \quad \sigma_{\theta p} = \frac{\sigma_p}{\sqrt{n}} \quad \sigma_{dr} = \frac{\sigma_r}{\sqrt{2n}}$$

$$\sigma_{dr} = 2.5 \text{ div} \quad \sigma_{\theta r} = \frac{\sigma_r}{\sqrt{n}} \quad \sigma_L = \sigma_v \cot z, \quad \sigma_v = 0.2v'' \quad \sigma_r = 2.5d''$$

$$\sigma_{\theta L} = \sigma_v \sqrt{\cot^2(Z_b) + \cot^2(Z_f)}$$

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

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

$$\sigma_{\theta t} = (206265'')\sigma_{c3}\sqrt{\left[\frac{S_1^2 + S_2^2 - 2S_1S_2\cos\theta}{S_1^2S_2^2}\right]}; \quad \sigma_{\theta t} = 206265\sqrt{\left(\frac{\sigma_{c1}}{S_1}\right)^2 + \left(\frac{\sigma_{c2}}{S_2}\right)^2}$$

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

Refraction Error: $d\delta = 8'' \frac{PS}{T^2} \left(\frac{dT}{dx}\right)$ T = (273.15 + t°C); p (mb) and S (m)

Error Ellipses:

$$C_{\hat{x}} = \begin{bmatrix} s_x^2 & s_{xy} \\ s_{xy} & s_y^2 \end{bmatrix} \quad \lambda_1 = \frac{1}{2}(s_x^2 + s_y^2 + R) \quad \lambda_2 = \frac{1}{2}(s_x^2 + s_y^2 - R)$$

$$R = \left[(s_x^2 - s_y^2)^2 + 4s_{xy}^2\right]^{1/2} \quad a_s = \sqrt{\lambda_1} \quad b_s = \sqrt{\lambda_2}$$

$$a_{95} = k_{95}a_s \quad b_{95} = k_{95}b_s \quad k_{95} = \sqrt{\chi_{df,1-\alpha}^2} \quad \beta = \arctan\left(\frac{s_{xy}}{\lambda_1 - s_x^2}\right)$$

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