CANADIAN BOARD OF EXAMINERS FOR PROFESSIONAL SURVEYORS

C-3 ADVANCED SURVEYING

March 2023

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 5 questions on 5 pages. **Marks**

Time: 3 hours

Q. No		Value	Earned
1.	Leica/Wild Di1600 electro-optical distance measuring instrument (EODMI) is to be checked for its accuracy using a nearby government calibration baseline (of Heerbrugg design) of seven pillars with known mark-to-mark distances. The manufacturer's claimed accuracy of the instrument is 3 mm ± 2 ppm. Answer the following with regard to ISO 17123-4 calibration procedure:		
	a) Explain all of the necessary setting out properties of the baseline pillars according to Heerbrugg design, seven important Quality Assurance (QA) /Quality Control (QC) measures (including their purposes), and the field procedure (including the number and types of measurements made in the field) that you would recommend following in order to determine whether the EDM is capable of behaving as the manufacturer claimed.	16	
	b) Explain what reductions must be done on the measurements as "pre-processing" and why.	2	
	c) Explain four quantities that will be determined from the processing of the measurements and fully discuss the statistical tests that will be performed on the quantities in order to determine whether the EDM is capable of behaving as the manufacturer claimed.	6	
	d) Assuming the government-provided distances for the baseline are considered errorless and the reduced calibration measurements are to be adjusted by parametric least squares method, formulate one sample parametric equation for this problem with all the symbols used well defined, and explain how the calibration values will be estimated from the adjusted parameters.	4	
2.	a) A traverse is to be measured around a rectangular city block (ABCD) of 100 m by 200 m. The two 200 m sides are relatively flat while the other two have slopes of 20%. The equipment (total station or targets) would be set up on tripods with height of instrument or height of target of 1.600 m. Since this survey may extend over more than one session and only ground mark points will be occupied, forced centering cannot be assumed. The maximum allowable angular misclosure (at 99% confidence) of the traverse is 15″. With consideration for the effects of centering, leveling, pointing, and reading, numerically determine the conditions under which the misclosure will be satisfied using Leica TPS 802 total station instrument (assuming only the total station instrument is to be re-centered and re-leveled between sets). The Leica TPS 802 specifications are: standard deviation of an angle measurement (ISO 17123-3) is 2″; and compensator setting accuracy is 1″.	20	
	b) Discuss two important factors affecting accuracy of electronic (total station) coordinating systems in micro-geodetic network survey where sub-millimeter accuracy is usually desired (including in your discussion how these factors will affect micro-geodetic network survey results and the common procedures usually adopted in taking care of or minimizing their effects).	8	

3.	a) A local plane coordinate system was established at the collar of a shaft at latitude of 59°30′N (with grid convergence equal to zero). At a depth of 2km, a tunnel runs approximately in a westerly direction from the shaft. An open traverse follows the tunnel with stations along one side. Gyro-azimuths, based on a well-calibrated Gyromat 3000 automated gyro station, were measured at regular intervals in order to "control" the orientation of the tunnel. The specified accuracy of an azimuth determination with the equipment and procedures is ± 3″ and the average deflection of the vertical along the tunnel is -5". Apart from the internal corrections that are automatically done by the gyro station to the gyro measurements, explain two other important systematic corrections, with justification and suggestions of their numerical values (with calculation steps), that should be applied to the azimuths, observed at 4 km (westerly) from the shaft in order to convert it to a grid azimuth in the surface coordinate system. b) Clearly explain two major corrections usually applied to tape measurements in elevation transfer into an underground mine that are not normally applied when a tape is used to determine horizontal distances.	7 2	
4.	a) In a deformation survey, the datum-independent displacement vector ($\hat{d}$) and the corresponding cofactor matrix ($Q_{\hat{d}}$) for a monitored point as follows: $\hat{d} = \begin{bmatrix} dE \\ dN \end{bmatrix} = \begin{bmatrix} -0.013m \\ -0.006m \end{bmatrix}$ $Q_{\hat{d}} = \begin{bmatrix} 2.0323E-5 & 1.0665E-6 \\ 1.0665E-6 & 1.2796E-5 \end{bmatrix} m^2$ with the pooled variance factor as 0.518, the number of degrees of freedom for the pooled variance as 28 and the number of network points being considered for deformation analysis as 5. Determine the statistical significance of the displacement at this point at the significance level, α = 5%, assuming the a priori variance factor of unit weight is well known, and explain how you would have checked if the measurements in the two epochs involved are compatible before the deformation analysis. b) Discuss how a surveyor can use geodetic level as a geotechnical tiltmeter (explaining the observables, formulae involved, and one possible advantage over tiltmeter).	8 6	
5.	a) Precise point positioning (PPP) is becoming an attractive alternative to real-time kinematic (RTK) in GNSS surveying. Discuss four of the important benefits of PPP technique compared to double-difference RTK technique. b) GNSS system validation is one of the important GNSS field procedures that may be required prior to a GNSS control survey. Discuss briefly the key elements of the GNSS measurement validation procedure, purpose (including quantities to be validated), how often it is done, and explain a typical statistical test to check the external accuracy of the validation (including necessary statistical formulae with symbols well defined, and the expected degrees of freedom and confidence level).	8 13	
		100	

Some potentially useful formulae are given as follows:

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

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

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

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

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

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

$\alpha = \frac{\delta\Delta h}{s}$ where $\delta\Delta h = \Delta h_{12t2} - \Delta_{h12\,t1}$.

$\sigma_\alpha = \frac{\sigma_{\delta\Delta h}}{s}$ where $\sigma_{\delta\Delta h} = \sqrt{\sigma^2_{\Delta h1} + \sigma^2_{\Delta h2}}$

EDM:

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

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

Statistics:

$$|\Delta| = \sigma_\Delta \sqrt{\chi^2_{1-\alpha, df}} \qquad |\Delta| \le z_{1-\alpha/2} \sigma_\Delta \qquad |\Delta| \le t_{df, 1-\alpha/2} \sigma_\Delta \qquad \hat{\sigma} \le \sqrt{\frac{\chi^2_{1-\alpha, df}(\sigma)}{df}}$$

$$y = d\hat{x}^T C_{\hat{x}}^{-1} d\hat{x} \qquad \chi^2_{\frac{\alpha}{2}, df} \le \frac{(df) s^2}{\sigma^2} \le \chi^2_{1-\frac{\alpha}{2}, df} \qquad F_{1-\frac{\alpha}{2}, df_1, df_2} \le \frac{s^2_{01}}{s^2_{02}} \le F_{\frac{\alpha}{2}, df_1, df_2}$$

$$y < \chi^2_{u, 1-\alpha} \qquad a_{(1-\alpha)100\%} = a_{st} \sqrt{\chi^2_{1-\alpha, df}} \text{ or } a_{(1-\alpha)100\%} = a_{st} \sqrt{2F_{1-\alpha, df1, df2}}$$

Error propagation:

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

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

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

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

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

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

$\sigma_d = \dfrac{S}{2R}\sigma_{k_h}$ $\sigma_{ref} = \dfrac{S}{2R}\sigma_{k_V}$

$\ell = f(x)$ $C_{\hat{x}} = \sigma_0^2\left(A^T PA\right)^{-1}$ $P = Q^{-1}$

$s_{\Delta x}^2 = s_{x_1}^2 + s_{x_2}^2 - 2s_{x_1x_2}$ $s_{\Delta x\Delta y} = s_{x_1y_1} + s_{x_2y_2} - s_{x_1y_2} - s_{y_1x_2}$ $s_{\Delta y}^2 = s_{y_1}^2 + s_{y_2}^2 - 2s_{y_1y_2}$

$\lambda_1 = \dfrac{1}{2}\left(s_{\Delta x}^2 + s_{\Delta y}^2 + R\right)$ $\lambda_2 = \dfrac{1}{2}\left(s_{\Delta x}^2 + s_{\Delta y}^2 - R\right)$ $R = \left[\left(s_{\Delta x}^2 - s_{\Delta y}^2\right)^2 + 4s_{\Delta x\Delta y}^2\right]^{1/2}$

$a_s = \sqrt{\lambda_1}$ $b_s = \sqrt{\lambda_2}$ $a_{95} = k_{95}a_s$ $b_{95} = k_{95}b_s$

$k_{95} = \sqrt{\chi^2_{2,1-0.05}}$ $\beta = \arctan\left(\dfrac{s_{\Delta x\Delta y}}{\lambda_1 - s_{\Delta x}^2}\right)$

Map projection and Reductions:

Meridian convergence: $\gamma = \dfrac{d\tan\phi\left(1-e^2\sin^2\phi\right)^{1/2}}{a}$ a = 6378137 m; e = 0.081819191

or $\gamma = L\left(1+\dfrac{L^2}{3}\left(1+3\eta^2\right)\cos^2\phi\right)\sin\phi$

where $\eta^2 = e'^2\cos^2\phi$; $e'^2 = 0.006739496780$; $L = \left(\lambda - \lambda_0\right)$ (in radians); λ_0 is the longitude of the central meridian; and ϕ is the latitude of the given point.

$\alpha = A - \eta\tan\phi$ where $-\eta\tan\phi$ is Laplace correction

Horizontal Control Survey:

a = C(d +0.2) cm [where d is distance in km; C = 2 (First Order); C = 5 (Second Order)]

Vertical Control survey:

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

Map Accuracy Standards:

$Accuracy_x = SE \times \sqrt{\chi^2_{df,1-\alpha}}$ $Accuracy_y = SE \times \sqrt{\chi^2_{df,1-\alpha}}$

$Accuracy_z = SE \times z_{1-\alpha/2}$ $CMAS = SE \times z_{1-\alpha/2}$

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

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
28	15.308	16.928	18.939	37.916	41.337	44.461	48.278	50.993

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