23 CONSTRUCTION SURVEYING

Asterisks (*) indicate problems that have partial answers given in Appendix G.

23.1 Describe the types of construction projects where laser scanners are used.

From Section 23.2.1: Tunneling, sewer pipe placement, building construction, contour farming layout, horizontal and vertical alignments, and grading.

23.2 Discuss how line and grade can be set with a total station instrument.

From Section 23.9: At an occupied station, a backsight is taken with the instrument on a line of known azimuth and the direct to a required stake turned. The instrument is operated in tracking mode and a prism is placed on-line and adjusted in position to read the required horizontal distance, where the stake is driven. The stake can be set at its required elevation or marked as appropriate for the job.

23.3 Describe how a plumbing level can be used to ensure verticality in the construction of a tall building.

From Section 231.2.1: “The instrument shown in Figure 231.2 projects a visible laser beam a distance of 5 m below and 100 m above the instrument along the plumb line. These instruments are useful for alignment of objects in vertical structures. A similar type of single-beam laser projects a visible laser-beam at a selected grade–a device that is especially useful in aligning pipelines.” The instrument can be set under precisely laid out holes in each floor to ensure that verticality is maintained in the building.

23.4 In what types of construction is a rotating bean laser level most advantageous?

From Section 23.2.1, paragraph 4: “They expedite the placement of grade stakes over large areas such as airports, parking lots, and subdivisions, and are also useful for topographic mapping.”

23.5 Discuss how a laser is used in pipeline layout.

From Section 23.4, paragraph 7: “If laser devices are used for laying pipes, the beam is oriented along the pipe’s planned horizontal alignment and grade, and the trench opened. Then with the beam set at some even number of feet above the pipe’s planned invert, measurements can be made using a story pole to set the pipe segments. Thus, the laser beam is equivalent to a batter board string line. On some jobs that have a deep wide cut, the laser instrument is set up in the trench to give line and grade for laying pipes. And, if the pipe is large enough, the laser beam can be oriented inside it.”

23.6 What is a story pole and how is it used in pipeline layout?

From Section 23.4, paragraph 5: "A graduated pole or special rod, often called a *story pole,* is used to measure the required distance from the string to the pipe invert."

23.7 Where should stakes be set closer on the stake out of a pipeline and why?

From Section 231.4, paragraph 4: "Marks should be closer together on horizontal and vertical curves than on straight segments." Placing stakes closer together aids in defining the curve by reducing chord distances.

23.8 What information is typically conveyed to the contractor on stakes for laying a pipeline?

From Section 23.5, paragraph 2: "Information conveyed to the contractor on stakes for laying pipelines usually consists of two parts: (1) giving the depth of cut (or fill), normally only to the nearest 0.1 ft, to enable a rough trench to be excavated; and (2) providing precise grade information, generally to the nearest 0.01 ft, to guide in the actual placement of the pipe invert at its planned elevation."

23.9 A sewer pipe is to be laid from station 10+00 to station 12+50 on a −1.00% grade, starting with invert elevation 326.32 ft at 10+00 Calculate invert elevations at each 50-ft station along the line.

Station	Elevation (ft)
10+00	326.32
10+50	325.82
11+00	325.32
11+50	324.82
12+00	324.32
12+50	323.82
13+00	323.32
13+20	323.12

23.10* A sewer pipe must be laid from a starting invert elevation of 650.73 ft at station 9+25 to an ending invert elevation 653.81 ft at station 12+75. Determine the uniform grade needed, and calculate invert elevations at each 50-ft station.

Station	Elevation (ft)	grade
925	650.73	0.88%
950	650.95	
1000	651.39	
1050	651.83	
1100	652.27	
1150	652.71	
1200	653.15	
1250	653.59	
1275	653.81	

23.11 Grade stakes for a pipeline running between stations 0+00 and 5+64 are to be set at each full station. Elevations of the pipe invert must be 1168.25 ft at station 0+00 and 1162.05 ft at 5+64, with a uniform grade between. After staking an offset centerline, an instrument is set up nearby, and a plus sight of 4.06 taken on BM *A* (elevation 853.63 ft). The following minus sights are taken with the rod held on ground at each stake: (0 + 00, 5.51); (1 + 00, 5.67); (2 + 00, 5.03); (3 + 00, 7.16); (4 + 00, 7.92); (5 + 00, 8.80); (5+64, 9.10) and (*A*, 4.06). Prepare a set of suitable field notes for this project (see Plate B.6 in Appendix B) and compute the cut required at each stake. Close the level circuit on the benchmark.

					Grade:	-1.10%
Station	+Sight	HI	−Sight	Ground Elevation	Pipe Invert	Cut/Fill
A	4.06	1177.31		1173.25		
0+00			5.51	1171.80	1168.25	C3.55
1+00			5.67	1171.64	1167.15	C4.49
2+00			5.03	1172.28	1166.05	C6.23
3+00			7.16	1170.15	1164.95	C5.20
4+00			7.92	1169.39	1163.85	C5.54
5+00			8.80	1168.51	1162.75	C5.76
5+64			9.10	1168.21	1162.05	C6.16
A			4.06	1173.25		

23.12 If batter boards are to be set exactly 8.00 ft above the pipe invert at each station on the project of Problem 23.11, calculate the necessary rod readings for placing the batter boards. Assume the instrument has the same HI as in Problem 23.11.

Station	+Sight	HI	Rod Reading
A	4.06	1177.31	
0+00			1.06
1+00			2.16
2+00			3.26
3+00			4.36
4+00			5.46
5+00			6.56
5+64			7.26

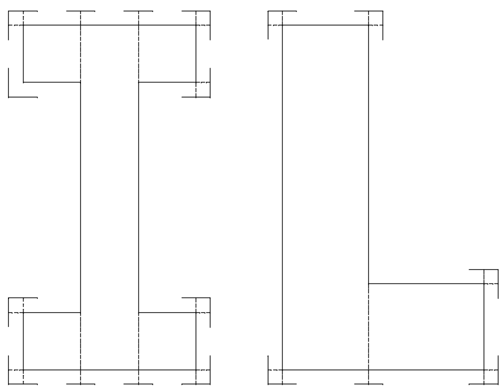
23.13 What are the requirements for the placement of horizontal and vertical control in a project?

From Section 23.3, paragraph 3: "The control points must be:

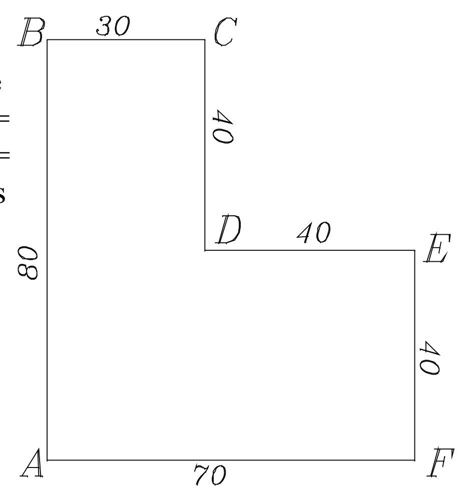
1. Convenient for use, that is, located sufficiently close to the item being built so that work is minimized and accuracy enhanced in transferring alignment and grade.
2. Far enough from the actual construction to ensure working room for the contractor and to avoid possible destruction of stakes.

3. Clearly marked and understood by the contractor in the absence of a surveyor.
4. Supplemented by guard stakes to deter removal, and referenced to facilitate restoring them. Contracts usually require the owner to pay the cost of setting initial control points and the contractor to replace damaged or removed ones.
5. Suitable for securing the accuracy agreed on for construction layout (which may be to only the nearest foot for a manhole, 0.01 ft for an anchor bolt, or 0.001 ft for a critical feature)."

23.14 By means of a sketch, show how and where batter boards should be located: (**a**) for an I-shaped building (**b**) For an L-shaped structure.



23.15 A building in the shape of an L must be staked. Corners *ABCDEF* all have right angles. Proceeding clockwise around the building, the required outside dimensions are *AB* = 80.00 ft, *BC* = 30.00 ft, *CD* = 40.00 ft, *DE* = 40.00 ft, *EF* = 40.00 ft, and *FA* = 70.00 ft. After staking the batter boards for this building and stretching string lines taut, check measurements of the diagonals should be made. What should be the values of *AC, AD, AE, FB, FC, FD,* and *BD?*



$AC = \sqrt{80^2 + 30^2} = 85.44\,\text{ft}$

$AD = \sqrt{40^2 + 30^2} = 50.00\,\text{ft}$

$AE = \sqrt{40^2 + 70^2} = 80.62\,\text{ft}$

$FB = \sqrt{80^2 + 70^2} = 106.30\,\text{ft}$

$FC = \sqrt{80^2 + 40^2} = 89.44\,\text{ft}$

$FD = \sqrt{40^2 + 40^2} = 56.57\,\text{ft}$

$BD = \sqrt{40^2 + 30^2} = 50.00\,\text{ft}$

23.16* Compute the floor area of the building in Problem 23.15.

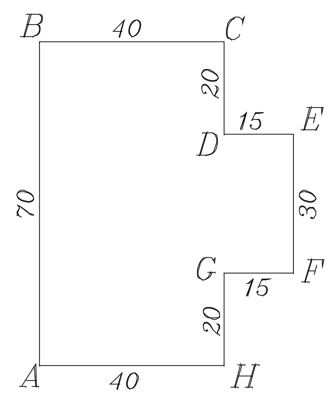
Area: = 30(80) + 40(40) = **<u>4000 ft²</u>**

23.17* The design floor elevation for a building to be constructed is 332.56 ft. An instrument is set up nearby, leveled, and a plus sight of 6.37 ft taken on BM *A* whose elevation is 330.05 ft. If batter boards are placed exactly 1.00 ft above floor elevation, what rod readings are necessary on the batter board tops to set them properly?

2.86 ft

Station	+Sight	HI	−Sight	Elev
A	6.37	336.42		330.05
			2.86	332.56

23.18 Compute the diagonals necessary to check the stakeout of the building in Figure 23.8.



$$AC = BH = \sqrt{40^2 + 70^2} = 80.62\,\text{ft}$$

$$BE = AF = \sqrt{55^2 + 20^2} = 58.52\,\text{ft}$$

$$BF = AE = \sqrt{50^2 + 55^2} = 74.33\,\text{ft}$$

$$BD = AG = \sqrt{40^2 + 20^2} = 44.72\,\text{ft}$$

23.19 Why is it necessary to design a street with a grade that is at least 0.50% between block corners?

From Section 23.7, paragraph 16: "Streets need a minimum 0.50% grade for drainage from intersection to intersection, or from midblock both ways to the corners. They are also crowned to provide for lateral flow to gutters. Drainage profiles, prepared to verify or construct drainage cross sections, can be used to locate drainage structures and easements accurately. An experienced engineer when asked a question regarding the three most important items in highway work, thoughtfully replied "drainage, drainage, and drainage."

23.20 Where is the invert of a pipe measured?

From Section 23.4, paragraph 5: "the *invert* (flow line or lower inside surface) of the pipe"

23.21 Discuss the importance of localizing a GNSS survey.

From Section 23.10, paragraph 3: "As discussed in Sections 15.8 and 19.6.6, care must be taken to ensure that points located using GNSS are placed in the same reference frame as the project coordinates."

23.22 Explain why slope intercepts are placed an offset distance from the actual slope intercept.

From Section 23.7, paragraph 7: 'They are usually offset 4 ft from the construction limits to protect them from destruction during the construction process."

23.23 What information is normally written on a slope stake?

From Section 23.7: The minimum information is the amount of cut (C) or fill (F) from the ground at the stake to the centerline subgrade elevation, distance from the stake to the centerline, and the value of the cut or fill slope.

23.24 Discuss the advantages of combining digital elevation models with design templates in staking out highway alignments with a data collector.

From Section 23.7, paragraph 14: "Total station instruments, with their ability to automatically reduce measured slope distances to horizontal and vertical components, speed slope staking significantly, especially in rugged terrain where slope intercept elevations differ greatly from centerline grade. When the data collector allows the user to input the design template (see Section 26.3), it can rapidly determine the positions of the slope stakes using field observed data."

23.25 Describe how control can be brought quickly into a deep open-pit mine?

From Section 231.9, paragraph 5: "In the resection procedure, a station whose position is unknown is occupied and the instrument's position determined by sighting two or more control stations (see Sections 11-7 and 11-10). This is very convenient on projects where a certain point of high elevation in an open area gives good visibility to all (or most) points to be staked. As noted, two or more control points must be sighted. Measurements of angles, or of angles and distances, are made to the control stations. The microprocessor then computes the instrument's position by the methods discussed in Sections 11-7 and 11-10."

23.26 What are spads and how are they used in mine surveys?

From Section 23.8, paragraph 3: "Later setups are made beneath spads (surveying nails with hooks) anchored in the ceiling."

23.27 A highway centerline subgrade elevation is 635.22 ft at station 12+00 and 630.98 ft at 17+00 with a smooth grade in between. To set blue tops for this portion of the centerline, a level is setup in the area and a plus sight of 6.19 ft taken on a benchmark whose elevation is 632.08 ft. From that HI, what rod readings will be necessary to set the blue tops for the full stations from 12+00 through 17+00?

HI = 638.27 g = −0.85%

Station	Subgrade Elevation	Rod Reading
12+00	635.22	3.05
13+00	634.37	3.90
14+00	633.52	4.75
15+00	632.68	5.59
16+00	631.83	6.44
17+00	630.98	7.29

23.28* Similar to Problem 23.27, except the elevations at stations 12+00 and 17+00 are 1713.35 and 1707.10 ft, respectively, the BM elevation is 1710.84 ft, and the backsight is 5.28 ft.

HI = 1513.32 g = –1.14%

Station	Subgrade Elevation	Rod Reading
12+00	1503.55	9.77
13+00	1504.69	8.63
14+00	1505.83	7.49
15+00	1506.98	6.34
16+00	1508.12	5.20
17+00	1509.26	4.06

23.29 Discuss the checks that should be made when laying out a building using coordinates.

From Section 23.6, paragraph 3: "Measuring the distances between adjacent points, and also the diagonals checks the layout."

23.30 What are the jobs of a surveyor in a project using machine control?

From Section 23.11, paragraph 2: "Using machine control, the surveyor's role in construction surveying shifts to tasks such as establishing the project reference coordinate systems, creating a DTM (see Section 17.14) of the existing surface for the design and grading work, managing the electronic design on the job site, calibrating the surveying equipment with respect to the construction site, and developing the necessary data for system operation."

23.31 Describe the procedure for localization of a GNSS survey.

From Section 23.10, paragraph 3: "As discussed in Section 15.9, sufficient project control known in the local reference frame must be established at the perimeter of the construction project. Then prior to staking any points, the GNSS receiver must occupy this control and determine their coordinates in the WGS 84 reference frame; these are GNSS coordinates. Using the project coordinates and the GNSS coordinates, transformation parameters (see Section 19.6.6) are computed so that the GNSS-derived coordinates can be transformed into the local project reference frame. It is important that this transformation occur only once in a project and include important control in the transformation. That is, if a benchmark on a bridge abutment was used to design a replacement structure, then this benchmark should be included in the localization process regardless of its location in the project. The localization process should only occur once during a construction project to avoid the introduction of varying orientation parameters caused by random errors. Once the localization is accepted, the transformation parameters should be distributed amongst the various GNSS receivers involved in the project."

23.32 Why is localization important in a GNSS survey?

From Section 23.10, paragraph 2: "The localization process, discussed next, transforms this set of low accuracy GNSS coordinates into the project control reference frame eliminating the inaccuracies of the autonomous base station coordinates."

23.33 How should finished grades be established in machine control projects?

From Section 23.11, paragraph 4: "However in finished grading, a robotic total station or laser level is required. As previously mentioned, one manufacturer has combined a laser level with the GNSS receiver to provide millimeter accuracies in both horizontal and vertical location."

23.34 What is the minimum number of horizontal control points needed to establish finish-grades using a robotic total station on a machine-controlled project that is 3 mi in length?

16 control stations; $\frac{3(5280)}{1000} = 15.84$

23.35 What is the minimum number of control points needed to guide machines using a GNSS receiver on a machine-guidance project that is 3 mi in length?

1 control station; $\frac{3(5280)\left(\frac{12}{39.37}\right)}{10000} = 0.48$

23.36 Do an article review on an application of machine control.

Independent study.