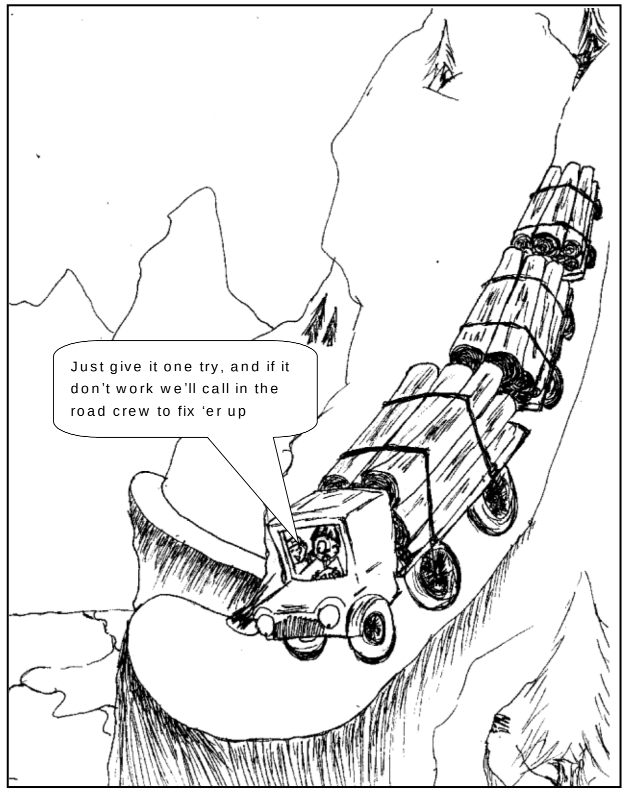
FRST 557

Lecture 9c

Switchbacks Vertical and Horizontal Design



Lesson Background and Overview:

Switchbacks are unique curves for several reasons. A switchback that truly reverses direction of the road by 180º does not have a point of intersection. The back and forward approach tangents are an infinite distance, parallel and separated by the distance of twice the curve radius. Because switchbacks are often located on fairly steep side hills, they require the incorporation of vertical design with the horizontal design to ensure that the switchback grade is within allowable standards.

Lesson Objective:

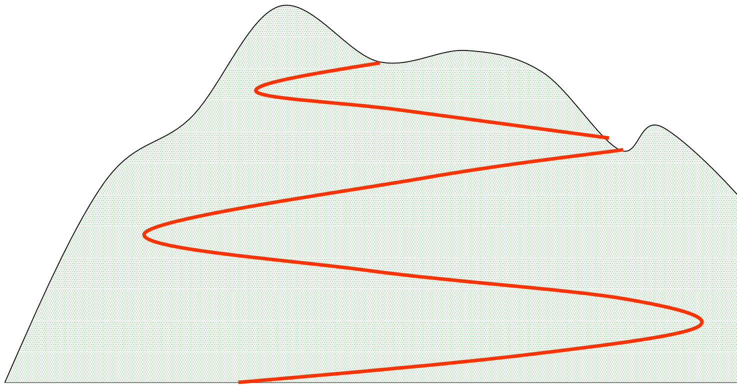
When you have completed this lesson and the associated assignment, you will be able to properly design and survey a switchback with proper vertical and horizontal alignment.

Lesson Preparation:

This lesson uses the principles of curve design as was covered in the previous lessons of this module.

What is a switchback?

A switchback is a curve that completely reverses the direction of a road. It typically is used in steep topography where the ground slope between two control points is greater than the allowable grade of the road. A switchback lengthens road to allow more gain in elevation while maintaining the allowable grade.



Switchbacks are not a desirable road feature and should be avoided if possible. They:

- reduce traffic speed
- result in high site disturbance due to large excavations & fills
- create a high road density
- are expensive to construct and maintain

What are some desired attributes of a switchback?

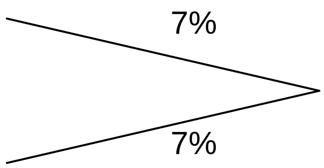
Because switchbacks are normally constructed in steep or otherwise unique situations for a special purpose, and because they often are constructed with the minimum possible radius:

- Grades should be reduced from that of the tangents to minimize braking requirement and to maximize vehicle control.
- Visibility needs to be maximized.
- Consideration should be made to providing for vehicles passing and possibly for stopping above the curve.

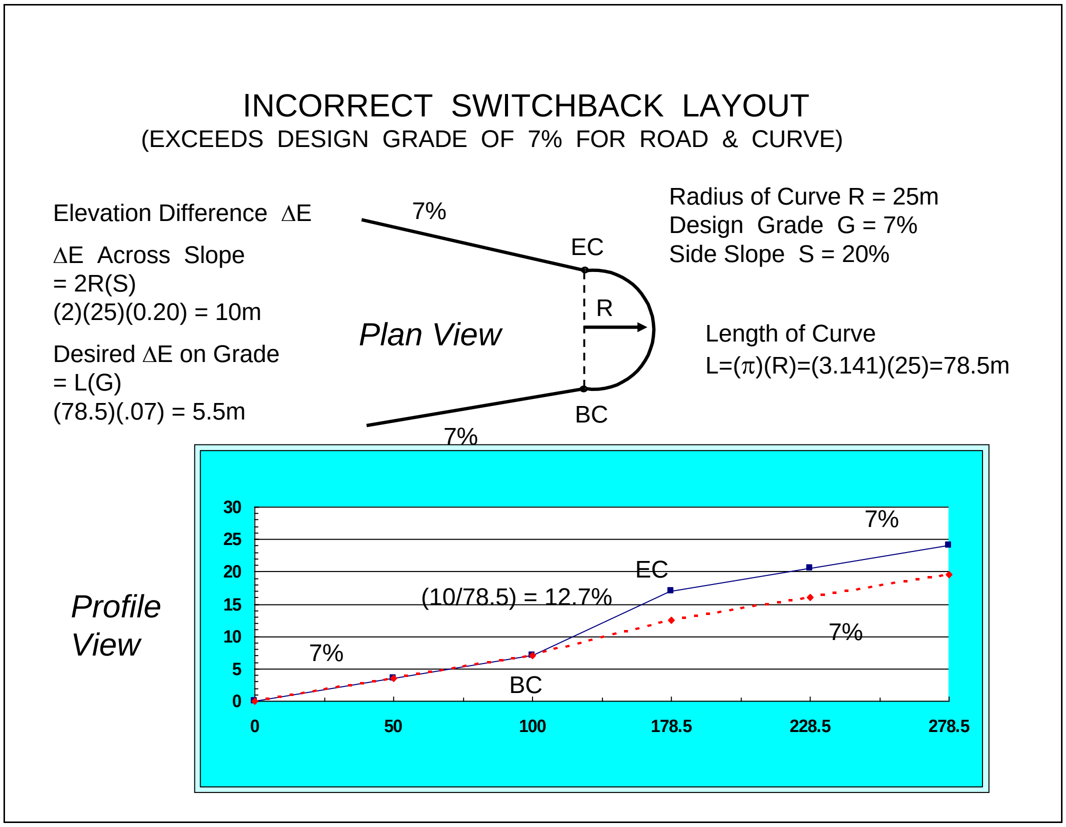
Proper provision for a switchback early in the curve design will save expensive work later.

What common mistake is made when designing a switchback?

Taking an example of a road being located on a 20% side hill, a reconnaissance line is located at 7% and reaches the desired switchback location and then reverses direction as illustrated. The desired switchback grade is also 7%.



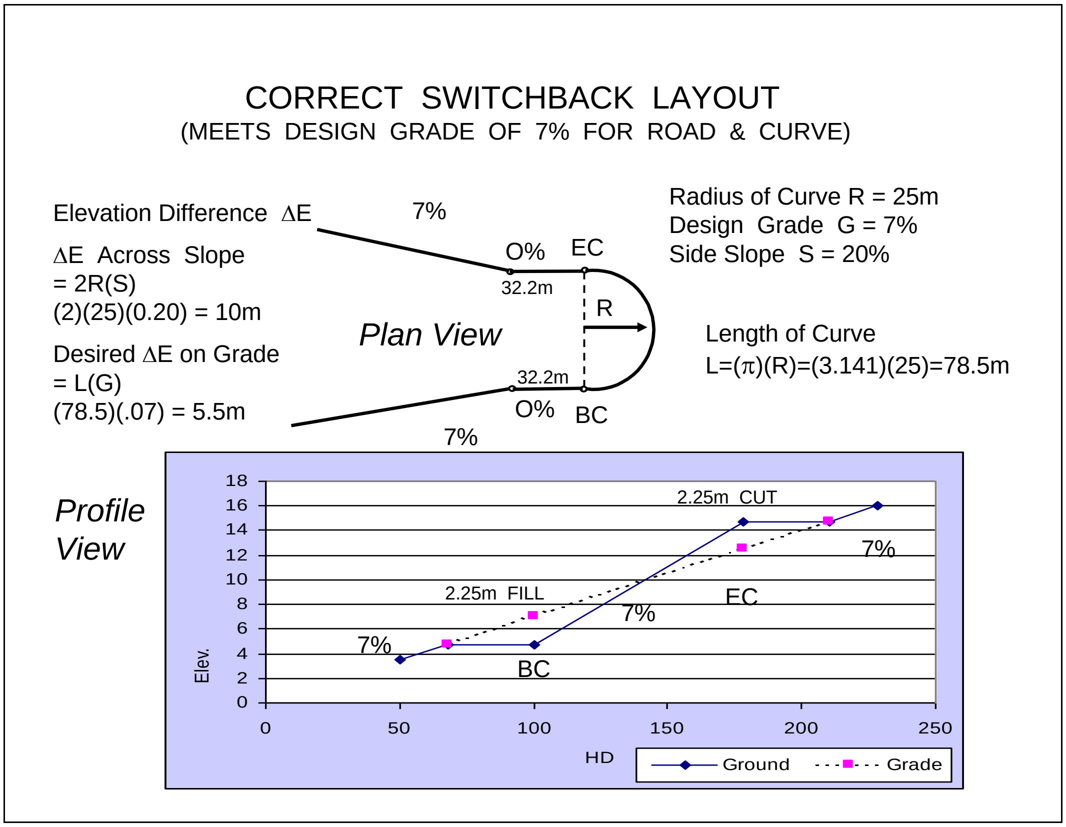
An attempt to locate the switchback inside the tangents (as would usually be done with a curve) would produce the following results. Note that, for consistency in the switchback illustrations, the curve is illustrated as if I = 180° rather than a lesser intersection angle.



A curve of 78.5m length climbing at 7% can only climb an elevation difference of 5.5m. The actual elevation difference is 10m.
If no consideration is made for the vertical design, a 25m-radius curve as illustrated would result in an inability to construct the road to the 7% standard because of an excessive elevation difference between the BC and EC.

How is this corrected?

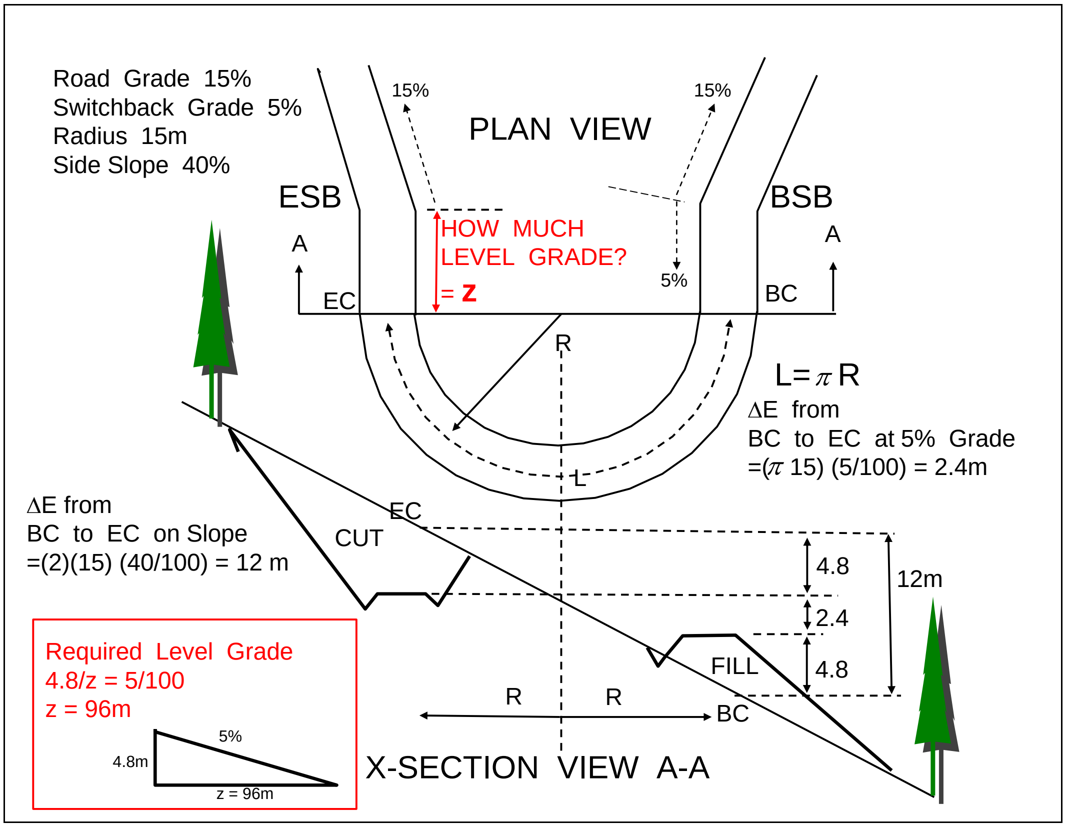
Considering the vertical design illustrated here, it is recognized that the length of the switchback must be increased so that ΔE=10m can be gained at a 7% grade.
The curve (L=78.5m) climbs only 5.5m (at 7%), therefore the curve must be extended by a sufficient length to gain the 4.5m shortage.



If equal length approach and exit tangents are added to the curve at a 0% grade, the 4.5m elevation can be gained in an additional total of 4.5/G=64.3m which is divided in two to be added equally before the BC and after the EC.
In order to maintain the 7% grade when constructed, the final road would be on a fill at the lower end of the switchback and in an excavation of the upper end.

More examples

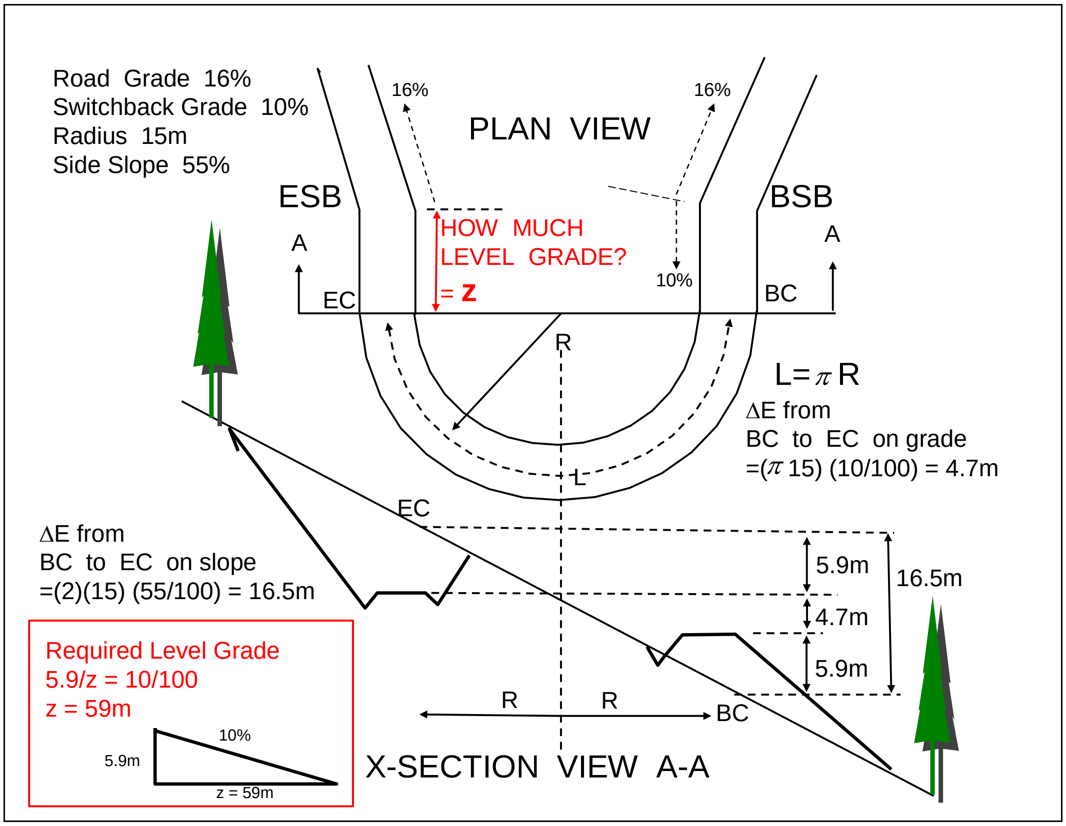
Although topography and more sophisticated considerations may be added to this design problem, we will continue to consider a few more examples with the equal length approach and exit extensions. **We will also assume that the objective design grade is maintained through the entire extended switchback from BSB (beginning of switchback) to ESB (end of switchback).**



In this example the elevation difference between BC and EC is 12m.
The curve, at 5% grade will climb only 2.4m, which means that the P-Line 0% entry and exit extensions must supply sufficient length to climb 9.6m.

Each extension will provide for one half of this difference (4.8m) and at a grade of 5%, each extension will be 96m in length.

Although not covered here, more detailed planning might consider designing in a horizontal and vertical curve at the BSB and ESB. An experienced road planner might also design for a different grade for the extensions.



This example illustrates a steeper side slope, a smaller radius curve and a compromised steeper curve grade.

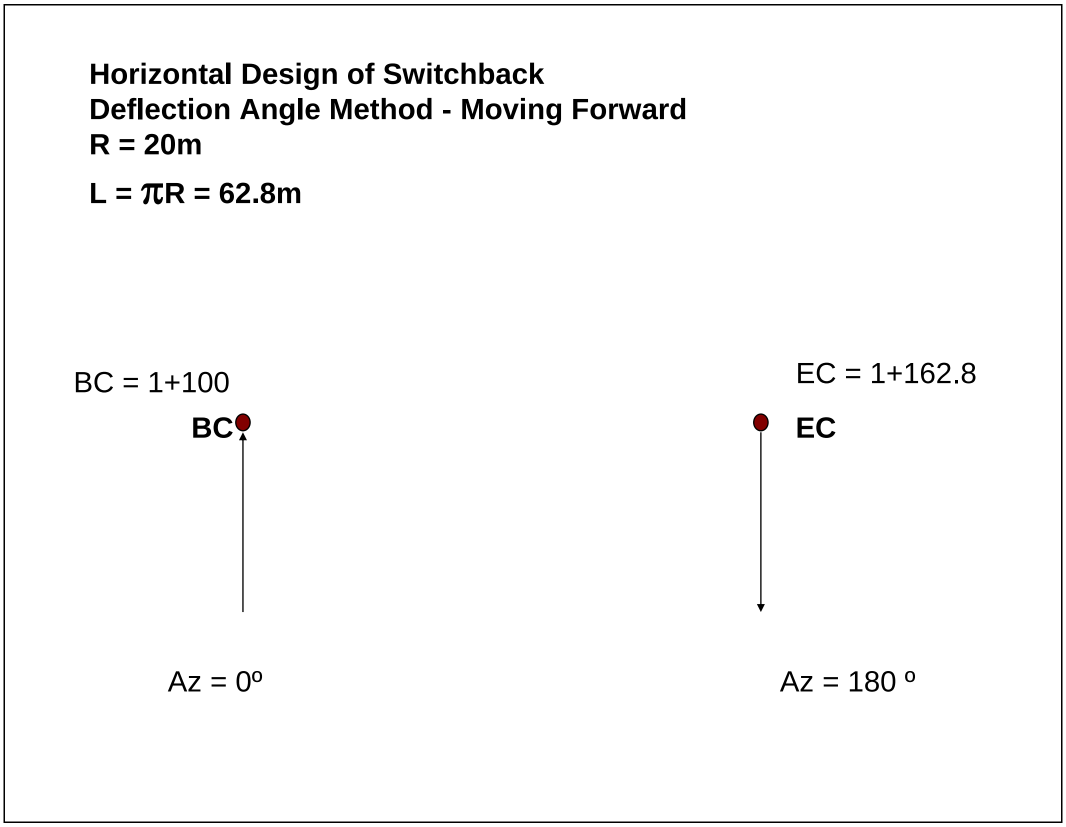
Level P-Line entry and exit extensions of 59m each would be constructed at 10% grade as would the curve. The constructed cut and fill at the centerline of BC and EC are equal at 5.9 meters.This example as illustrated would result in a sudden 6% grade change at BSB and ESB. The vertical curve needed at these points would take part of each extension.

Constructed Switchback

Even well engineered switchbacks such as the one pictured here must be closely supervised during construction. The tendency is to not sufficiently cut and fill according to the design and to over-steepen the curve.

How is the horizontal switchback curve designed?

Because of trees, brush, and other obstacles often found in forest surveying, the Moving Forward Method is probably the most frequently used method.
For the experienced surveyor, an understanding of this method can facilitate establishing an adequate curve during reconnaissance or P-Line surveys, thus saving later revisions. This is accomplished with quick calculation of the 0% approach tangent, memorized deflection angles for the minimum radius switchback, and paced in distances.



The horizontal design of a switchback is like any other curve except that, with no Point of Intersection (PI), the value of the Intersection/Central angle (I) is considered to be 180º.

Because of the small radius, it is often preferable to measure shorter arc (or chord) lengths. Increments of 5 meters will usually make the two units identical, when rounded to a decimeter.

Horizontal Design of Switchback

$i_n = (180\ \lambda_n) / (\pi R)$ $d_n = (i_{n-1} / 2) + (i_n/2)$ $c_n = 2R\sin(i_n /2)$

Curve Design Table - Deflection < Moving Forward					
Station	λ	Central < i	c	d	Azimuth
		0.0			0.0
1+100 BC					
	5.0	14.3	5.0	7.2	7.2
1+105					
	5.0	14.3	5.0	14.3	21.5
1+110					
	5.0	14.3	5.0	14.3	35.8
1+115					
	5.0	14.3	5.0	14.3	50.1
1+120					
	5.0	14.3	5.0	14.3	64.4
1+125					
	5.0	14.3	5.0	14.3	78.7
1+130					
	5.0	14.3	5.0	14.3	93.0
1+135					

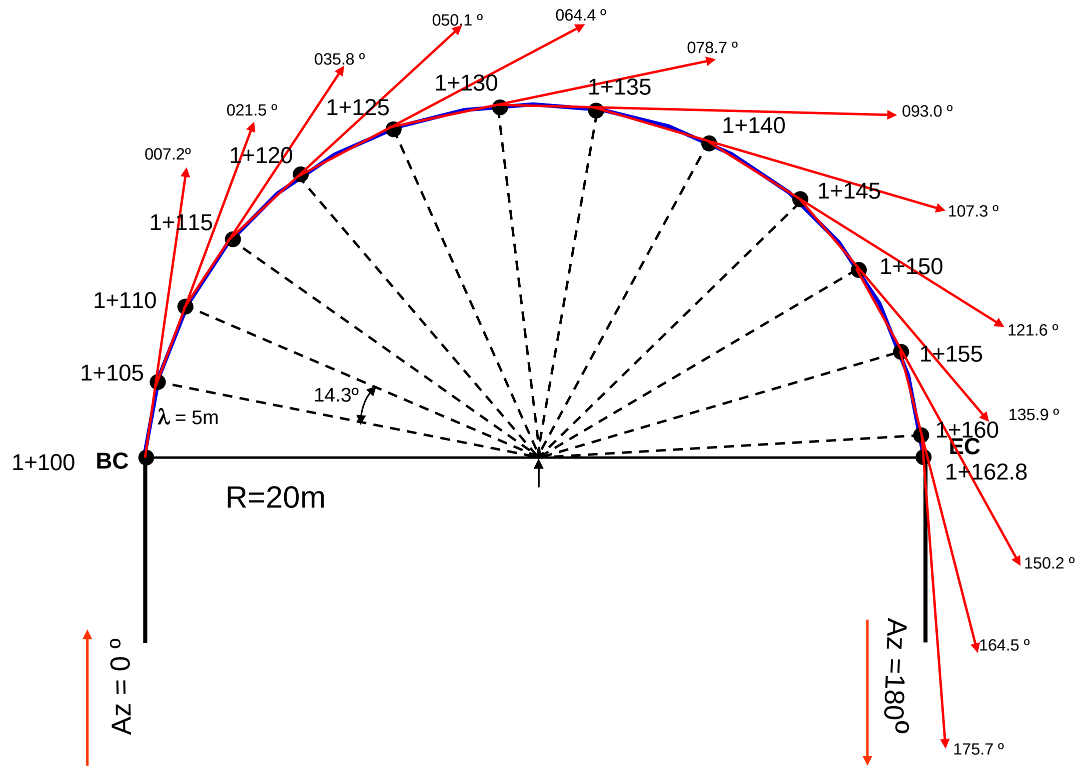
Horizontal Design of Switchback - continued

$i_n = (180\ \lambda_n) / (\pi R)$ $d_n = (i_{n-1} / 2) + (i_n/2)$ $c_n = 2R\sin(i_n /2)$

Curve Design Table - Deflection < Moving Forward					
Station	λ	Central < i	c	d	Azimuth
		14.3			93.0
1+135					
	5.0	14.3	5.0	14.3	107.3
1+140					
	5.0	14.3	5.0	14.3	121.6
1+145					
	5.0	14.3	5.0	14.3	135.9
1+150					
	5.0	14.3	5.0	14.3	150.2
1+155					
	5.0	14.3	5.0	14.3	164.5
1+160					
	2.8	8.0	2.8	11.2	175.7
1+162.8					
	0.0	0.0	0.0	4.0	179.7
					Correct to 180.0

Note that in this example, there is an accumulated rounding error in the azimuth. This is common and is less than the level of precision of the instruments normally used to measure these angles.

Horizontal Design of Switchback – Moving Forward



The L-Line survey is completed in the same way as the deflection angle moving forward method as used in Lesson 5d. The other methods of curve design can also be used for switchbacks.

How do I handle variations in topography?

There are two key objectives in designing a switchback:

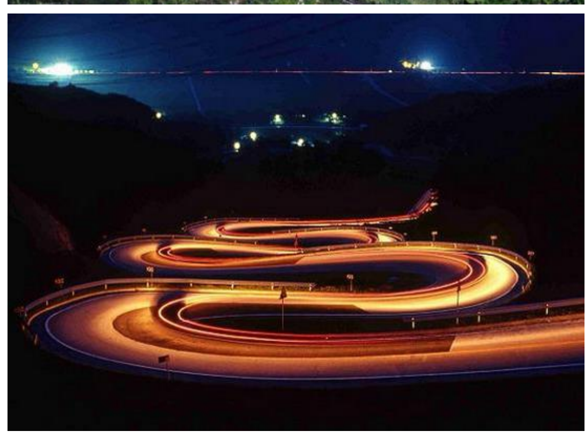
1. The horizontal length of the structure (from BSB to ESB) must be sufficient when matched with the difference in elevation from BSB to ESB so that, when constructed, the road will have the design grade. ($\left(\frac{\Delta E}{(L+2Z)}\right) = G$
2. As close as possible, the volume of earth in the excavation should balance the volume of fill.

If contours are not perfectly parallel, the curve portion of the switchback could be slightly more or less than 180 degrees. This could happen if the controlling ΔE is between the BC and EC and the survey approaches both need to be at zero percent. If the controlling ΔE is between BSB and ESB, then the planned Azimuths can be followed. In the latter case, one or both of the approaches may not be 0%, but because the ΔE and L+2Z are as planned, then G will also work out.

And a last word

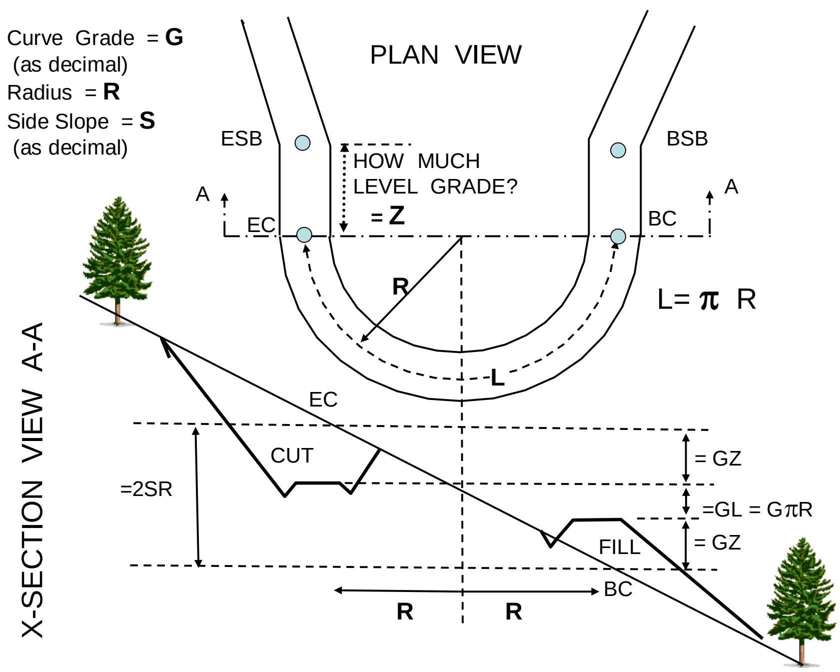
By understanding the vertical design of switchbacks, and by remembering the deflection angles for minimum radius curves, switchbacks can be paced in during reconnaissance and/or surveyed in during the P-line traverse. Some experience in this area can save costly L-line surveys later.



SWITCHBACKS (supplemental)

In addition to the curve layout, switchbacks need to consider the problem of reducing the steep road grade that result from having to turn the road directly down slope in the curve. This is accomplished by providing for a break in the surveyed grade before and after the curve portion of the switchback. The following illustration and table provide some guidelines for determining the length (Z) of level (0%) surveyed grade to provide for a switchback grade of 8%. This example produces a constant grade (G) from BSB to ESB.



The formula used to determine Z is:

$$Z = \frac{SR}{G} - \frac{\pi R}{2}$$

Extension (Z) of Switchback Curve to Produce an 8% Road Grade

Curve Radius R	Side Slope (S)													
	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%
16	2.9	6.9	10.9	14.9	18.9	22.9	26.9	30.9	34.9	38.9	42.9	46.9	50.9	54.9
18	3.2	7.7	12.2	16.7	21.2	25.7	30.2	34.7	39.2	43.7	48.2	52.7	57.2	61.7
20	3.6	8.6	13.6	18.6	23.6	28.6	33.6	38.6	43.6	48.6	53.6	58.6	63.6	68.6
22	3.9	9.4	14.9	20.4	25.9	31.4	36.9	42.4	47.9	53.4	58.9	64.4	69.9	75.4

Consideration must also be given to the vertical curve design. Sufficient road length is needed for transition of the grade of the switchback approaches to the grade of the switchback.