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VERTICAL CURVES AND THEIR INFLUENCE ON THE
PERFORMANCE OF LOG TRUCKS

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INTRODUCTION

The problem of road location is becoming more important in the harvesting of the timber resource. As the easily accessible timber is removed, this problem increases. In the past, very little concern has been shown in determining the minimum length of vertical curve that a log truck could negotiate. With increasing cost of road construction, limiting topography, and more restrictive environmental constraints, reduction of the amount of fill or excavation required to construct long vertical curves may be desired. Since many forest roads are used mainly for hauling timber, there is a real need to determine what the limiting factors are.

The general rule of thumb has been to limit the minimum length of vertical curves to 100 feet, regardless of the geometry and capability of log trucks. This article attempts to consider all aspects, and to show mathematically how the dimensions of a truck determine what minimum length of curve is required.

There are three factors that will be considered important in this analysis:

1. log truck geometry,
2. length of vertical curve, and
3. algebraic difference of intersecting grades.

After a description of geometry and dimensions of a typical log truck, a general procedure is developed which can be used to analyze any situation, given certain dimensions of the truck and trailer. A Hewlett-Packard 9830 Programmable Calculator is used to generate a graph showing the algebraic difference of grades of a log truck and log load for various lengths of curves. Then, these values of algebraic difference of grades are used to determine the minimum length and maximum algebraic difference of grades for both sag and crest vertical curves.

Dimensions of log trucks are highly variable, depending on the make of truck and trailer, and on the lengths and diameters of logs being hauled. This necessitates a very general approach to the problem, so that any dimension can be applied.

The following dimensions and terms are required to analyze our problem, as illustrated in figure 1.

A = Distance between the front wheels and the center of the dual rear wheels of the truck.

B = Distance between the center of the dual rear wheels of the truck and the center of the dual rear wheels of the trailer.

C = Distance that the logs extend over the front bunk.

D = Distance between the top of the frame of the truck and the bottom of the logs at the front of the load.

X = Distance between the bottom of the logs and the point where the truck and trailer are connected together.

Y = Distance between the ground and the bottom of the trailer reach.

Two other dimensions that could be critical and are discussed later are:

Z1 = Distance between the front of the logs and the cab of the truck; and

Z2 = Height of the logs.

Several terms need to be defined: The *reach*, shown in figure 1, is a square or rectangular steel tube that connects the rear wheels of the trailer to the truck. It comes in various lengths, and can be adjusted by sliding it back and forth through the rear wheels. Originally, these reaches were made of wood and, therefore, were prone to breakage. With steel reaches, breakage is no longer a serious problem, even though they occasionally are bent.
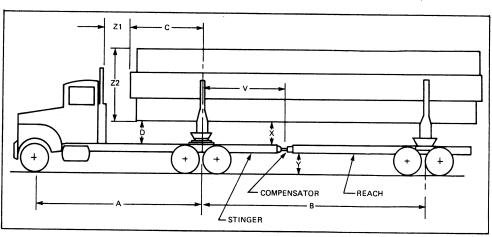

Figure 1. Log truck geometry and dimensions.

The *stinger*, as shown in figure 1, is an extension of the frame of the truck to which the reach is connected. The length of this stinger is an important factor in analyzing crest vertical curves. The distance from the center of the dual rear wheels to the end of the stinger (V in figure 1) is normally 9.5 feet; this distance has been determined to be the best for trailer steering and to enable the trailer to track better around horizontal curves.

The last term that needs to be defined is the *compensator*, also shown in figure 1. The compensator plays a very important role in enabling a log truck to negotiate both horizontal and vertical curves. It is attached to the front of the reach and consists of a steel cylindrical tube that is free to slide inside a housing. It is not restricted by a spring and will slide as necessary. The compensator is designed to allow a truck to turn without causing a stress to develop between the trailer reach and the stinger of the truck. As a log truck is being turned, the distance between the bunks (controlled by the log load) remains fixed, while the reach of the trailer has to lengthen. Thus, the compensator is designed to extend the distance necessary to allow for this lengthening.

Peerless Manufacturing Company[1] indicated that the distance a compensator can slide ranges from 43 feet to over 100 feet, depending on the particular truck configuration and length of logs being hauled. The compensator is not a limiting factor for trucks trying to negotiate vertical curves.

DEVELOPMENT OF THE GRAPH

To determine the restrictions that a vertical curve puts on a log truck, it is necessary to calculate the absolute algebraic difference of grades that a log truck makes as it moves through a vertical curve. The maximum algebraic difference of grades occurs when both the front and rear wheels of the log truck are in the vertical curve. Figure 2 shows the determination of the difference in grades by calculating the mid-ordinate E and the vertical distances Y1 and Y2 at the horizontal distances A and B from the vertical point of intersection of the curve. The distances A and B correspond to the distance between the front and rear wheels of the truck and the distance between the rear wheels of the truck and the trailer wheels, respectively. The assumption is that for grades of 20 percent or less, the horizontal distance of A and B are nearly equal to their slope distance.

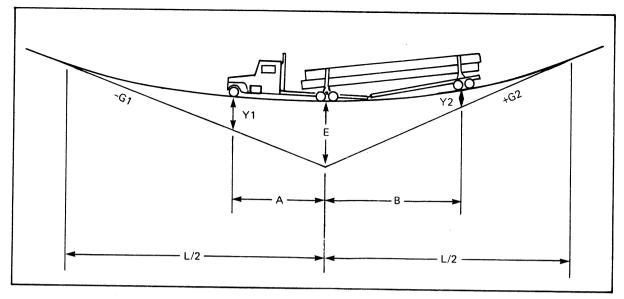[1]Telephone Conversation; Peerless Manufacturing Company; May 12, 1976.

Figure 2. Front and rear wheels in vertical curve.

Given the length of vertical curve and intersecting grades, the values described can be generated using the following equations:

$$E = (G2 - G1) \times L/8$$

$$Y1 = (L/2 - A)^2 \times (G2 - G1)/(2L)$$

$$Y2 = (L/2 - B)^2 \times (G2 - G1)/(2L)$$

Note that A, B, and L must all be in dimensions of stations (1 station = 100 feet). With these values, the grades of the truck and log load are determined by the difference in elevation between the front wheels of the truck and its rear wheels and the difference in elevation between the rear wheels of the trailer and the rear wheels of the truck, divided by the respective lengths A and B.

With this information, the truck and tractor geometry graphs shown in figure 3 are developed. The horizontal axis is the algebraic difference of intersecting grades, and the vertical axis is the algebraic difference of grades of the log truck and log load. The length of the vertical curve varies from 0 to 100 feet.

In the example provided,

A = 16' and B = 24'.

For analyzing a log truck with different dimensions, it is necessary to generate a new graph. A program for generating graphs (figure 3) using the Hewlett-Packard 9830 Programmable Calculator has been included as Table 1.
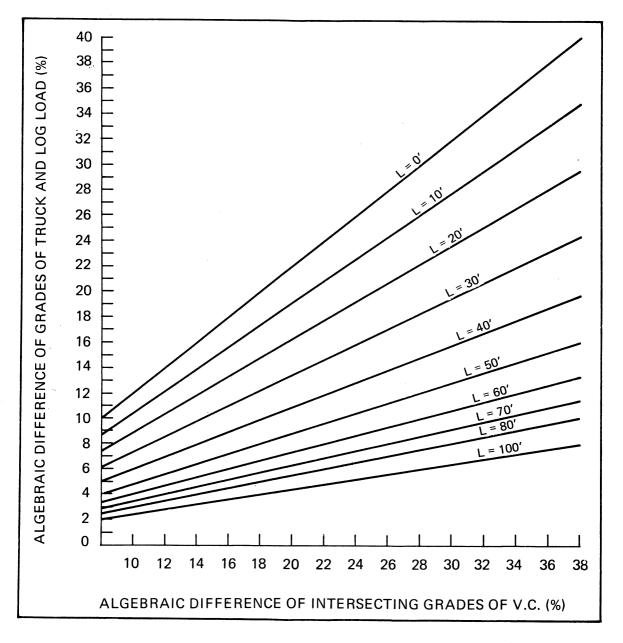
Figure 3. Truck and trailer geometry as a function of vertical curve geometry.

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There are two dimensions that are important when looking at sag vertical curves:

    (1) Distance that the logs extend over the front bunk of the truck; and

    (2) Height that the logs ride above the frame of the truck.

The height of the logs above the frame of the truck will vary, but generally will not be less than 1.3 feet. The distance that the logs extend over the front bunk is highly variable and depends on the length of the logs and the way they are loaded. Since the distance between the front bunk and the cab of the truck is approximately 11 feet, the overhand and is usually 8 feet and should never be greater than 10 feet. In the example, if 34-foot logs were being hauled, and the distance between bunks was 24 feet, then approximately 8 feet of log would be extending over the front bunk.

As a log truck travels through a sag vertical curve, the distance between the front end of the logs and the frame of the truck decreases. This decrease is a function of the algebraic difference of grades of the truck and log load and the distance that the logs extend over the front bunk. For example: if the total algebraic difference of grades of the truck and log load was 10 percent and the extension of the logs over the front bunk was 8 feet, then the amount of movement of the front of the logs downward would be:

$$\text{Movement} = \frac{(\text{Extended length over front bunk})}{x} \; (\text{total sum of grades divided by } 100)$$

or

$$\text{Movement} = (8 \text{ ft}) (10\%)/(100) = 0.8 \text{ ft}$$

By considering the 1.3-foot clearance between the front of the logs and the frame of the truck as the controlling factor, the critical algebraic difference of grades of the truck and the log load for logs extending 8 feet over the front bunk can be determined as follows:

$$\text{Critical total sum of grades} = (\text{clearance}) \times (100 \text{ divided by extended length over the front bunk})$$

or

$$\text{Total sum of grades} = 1.3 \text{ ft} \times 100/8 \text{ ft} = 16\%$$

A total algebraic difference of grades of greater than 16 percent could cause damage to the frame of the truck.

With this value of 16 percent, the various combinations of lengths of curves and algebraic differences of grades can be determined as shown in figure 3. The graph shows that a curve length as short as 50 feet and an algebraic difference of grades of 40 percent could be used before the logs would hit the frame of the truck. From this, it can be concluded that there is no real problem with sag vertical curves restricting the physical performance of a log truck. The truck's ability to pull steep grades, instead of curve length, will be the limiting factor. Also, a vertical curve with a length of 50 feet or less would be very difficult to maintain.

Two other dimensions were considered on sag vertical curves:

    (1) the height of the load, and
    (2) the distance between the front of the logs and cab of the truck.

The height of the load has the same effect as the distance that the logs extend over the front bunk, in that the top of the load will move toward the cab of the truck for some given geometry. For example: if the height of the load was 6 feet and the algebraic difference of grades of the truck and log load was 10 percent, then the top of the load would extend 0.6 feet toward the cab of the truck. Normally, this will be no problem because a distance of at least 2 feet is maintained between the front of the logs and the cab of the truck. It could certainly be a factor if the logs were positioned improperly on the truck and the resulting distance between the load and truck cab was less than 1 foot.

ANALYSIS OF CREST VERTICAL CURVES

The critical dimensions of a log truck when analyzing crest vertical curves is the length of the stinger and the vertical distance between the end of the stinger and the bottom of the logs. The length of stinger on most log trucks is 9.5 feet. The vertical distance between the end of the stinger and the bottom of the logs will depend on the length and diameter of the logs being hauled. The vertical distance at the bunk is 1.3 feet, the same as the vertical distance between the front of the logs and the frame of the truck. However, this vertical distance is decreased due to the deflection or sag of the logs over the unsupported length between bunks and natural sweep or crook of the logs.

To determine what the deflection is, the following formula can be used:[2]

$$\text{Deflection} = \frac{q\,x}{24\,E\,I}(L^3 - 2\,L\,x^2 + x^3)$$

where

    q = uniform loading on the bottom layer of logs,

_____

[2] Mechanics of material by Timoshinko and Gere.

L = total length between bunks,

x = length of stinger,

E = modulus of elasticity for species of timber being hauled,

and

I = moment of inertia for a circular section.

For coastal Douglas fir logs of 12 feet average diameter and 24 feet between bunks, the amount of deflection was 1-1/2 feet. If the unsupported length between bunks was 30 feet, the amount of deflection is .25 feet. The longer the unsupported length between bunks and the smaller the log diameter, the greater the deflection.

In addition to log deflection, sweep of a log will also reduce the vertical clearance between the end of the stinger and the bottom of the logs. For purposes of determining critical vertical curve lengths and algebraic sums of intersecting grades in this article, a vertical clearance of 1 foot will be used.

As a log truck travels through a crest vertical curve, the end of the stinger will be forced upward toward the bottom of the logs. The amount of movement is a function of the algebraic difference of the grades of the truck and log load and the length of the stinger of the truck. For example: if the algebraic difference of the grades of the truck and log load is 10 percent and the length of the stinger is 9.5 feet, the vertical movement of the end of the stinger will be: 9.5' x 10%/100 = 0.95', very close to the recommended clearance.

Again, using the graph in figure 3, a 50-foot vertical could be designed, but the algebraic difference of intersecting grades could only be 25 percent. Thus, the crest vertical curve is more restrictive to the performance of a log truck than a sag curve.

Normally, short crest vertical curves can be eliminated on main haul roads by increasing the amount of excavation. The problem of short crest vertical curves occurs most frequently at the intersection of spur roads with the main haul road. A large change of grade can occur in a very short distance due to limitations in topography. Crest vertical curve limitations should be considered when designing haul and spur road intersections.

CONCLUSIONS

In designing forest highways and high use recreation roads, safe visibility, comfort and appearance must be considered when designing vertical curves. In logging road design, the ability of trucks to negotiate vertical curves is of importance. By keeping vertical curves as short as possible, the fill

required on sag curves can be reduced with lower construction costs. In mountainous regions, the topography of the land may limit the length of curve.

The general conclusion is that sag vertical curves can be as short as 50 feet and algebraic difference as great as 40 percent before they become critical to the performance of log trucks. A vertical curve shorter than 50 feet would be difficult to maintain with a road grader. The ability of log trucks to pull sustained grades of 20 percent and greater will be more restrictive than the length of vertical curve. The compensator has been discussed and is not considered a limiting factor on either sag or crest vertical curves.

Close attention should be paid to the proper design of crest vertical curves. They will be more critical than sag vertical curves because the deflection and natural sweep of the logs decreases the clearance between the bottom of the logs and the end of the stinger. The algebraic difference in the grades of the truck and log load should never be greater than 10 percent. The result could be damage to the stinger or reach, or the stripping of the load from the front bunk. A possible remedy would be to raise the bunk height. New graphs would have to be developed if the truck dimensions were different than the ones covered in this article.

Table 1. Program for generating truck and trailer geometry graphs.
(Hewlett-Packard 9830)

```
10   DEG                                   340   P=0.4
20   SCALE 10,40,0,40                      350   IF P=0.4 THEN 360
30   XAXIS 0,2,10,40                       360   FOR L=P TO 0 STEP -0.1
40   YAXIS 10,1,0,40                       370   FOR G1=5 TO 20
50   DISP "INPUT A, IN STATIONS";          380   G2=G1
60   INPUT A                               390   Y1=((((L/2)-A) ↑2)*(G2+G1))/(L*2)
70   DISP "INPUT B, IN STATIONS";          400   IF L/2 <= A THEN 520
80   INPUT B                               410   E=(G2+G1)*L/8
90   FOR L=1 TO 0 STEP -0.1                420   I=(G1*A)
100  FOR G1=5 TO 20                        430   J=(G2*B)
110  G2=G1                                 440   G3=(I+Y1-E)/A
120  E=(G2+G1)*L/8                         450   G4=(J-E)/B
130  Y1=((((L/2)-A) ↑2)*(G2+G1))/(L*2)     460   G=G3+G4
140  Y2 =((((L/2)-B)↑2)*(G2+G1))/(L*2)     470   H=G1+G2
150  IF L/2 <= B THEN 260                  480   PLOT H,G
160  I=(G1*A)                              490   NEXT G1
170  J=G2*B                                500   PEN
180  G3=(I+Y1-E)/A                         510   NEXT L
190  G4=(J+Y2-E)/B                         520   FOR L=0.3 TO 0 STEP -0.1
200  G=G3+G4                               530   FOR G1=5 TO 20
210  H=G1+G2                               540   G2-G1
220  PLOT H,G                              550   E=(G2+G1)*L/8
230  NEXT G1                               560   I=(G1*A)
240  PEN                                   570   J=(G2*B)
250  NEXT L                                580   G3=(I-E)/A
260  IF B  = 0.3 THEN 300                  590   G4=(J-E)/B
270  IF B  = 0.3 THEN 280                  600   G=G3+G4
280  IF B  = 0.25 THEN 320                 610   H=G1+G2
290  IF B  = 0.25 THEN 340                 620   PLOT H,G
300  P=0.6                                 630   NEXT G1
310  IF P=0.6 THEN 360                     640   PEN
320  P=0.5                                 650   NEXT L
330  IF P=0.5 THEN 360                     660   END
```
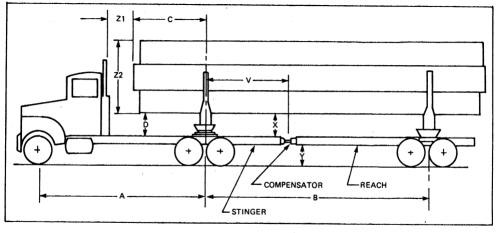
Figure 1. Log truck geometry and dimensions.