Machine Driving of Wooden and Steel HIGHWAY GUARDRAIL POSTS under Adverse Conditions

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THE INSTALLATION of both wooden and steel highway guardrail posts by machine driving is an accepted procedure. However, there has been no information about the damage that might be done to the below-ground parts of these posts in driving. In talking with highway engineers in several states, we learned that a basic assumption is generally used: if the guardrail posts are undamaged above the groundline, we assume that there is no damage below the groundline.

The potential for damage is often present. For primary and interstate construction in West Virginia, only the top 27 inches of the roadbed always receives preparatory treatment. The top 15 inches is aggregate, which will cause no damage to either wooden or steel posts. Below the top layer is a 12-inch-thick subgrade, which is supposed to contain rocks no larger than 3 inches. There is no guarantee that larger rocks will not be used. The whole subgrade may be made up of 3-inch rocks, and there is no limit on rock size below the subgrade. Adverse driving conditions may damage both standard 6B8.5 steel posts that are driven to a depth of 33 inches and wooden posts that are driven to a depth of 36 inches.

In an exploratory study, we drove 32 wooden posts and 26 steel posts into a rock-filled base that was topped with limestone gravel and shale. We found that, though both post materials perform well, wood is superior to steel in resisting damage below the groundline.

The Study

Only posts suitable for the "strong" post guardrail systems—W-beam guardrail and median barrier systems, for example—were driven. Posts were purchased on the open market from companies that supply contractors in West Virginia. The steel posts were type 6B8.5, 6-inch web, 4-inch flange, 5 feet 9 inches long, and weighed 8.5 pounds per lineal foot. The wooden posts were 7-inch diameter, 6-foot long southern pine that had been pressure-treated with a water-borne salt preservative.

All posts were driven in a 65-year-old one-lane gravel road. Originally constructed for a large lumber company, the road had received continual though limited use as a part of the West Virginia secondary road system.

The road, constructed across a narrow flood plain, provided

Figure 1.—Wooden and steel guardrail posts were driven into an old roadbed. A trench was excavated so the posts could be examined in place.

three driving sites. Site I began on natural ground and ended with a sandstone rock fill at the edge of what had once been the stream channel. Site II was a built-up section between the old and present stream channels. Site III began on the other side of the present channel and ended in natural ground.

The general plan was to drive all posts on 3-foot centers to a depth of about 4 feet, backhoe a 5-foot deep trench along the sides of the posts, and examine the posts in place (fig. 1). The driving hammer was always raised to its maximum height before being released.

Two commercial post drivers with different hammer weights were used. On site I, we used a machine supplied by Murphy Industries of Sherman, Texas. This machine had a 950-pound hammer with an initial free-fall height of 8 feet to the top of a 6-foot post. On sites II and III, we used a driver supplied by Sterling Products, Inc., of Kingston, Pennsylvania. This machine came equipped with hammers weighing 800 and 1,200 pounds. Each hammer had an initial free-fall height of 8 feet to the top of a 6-foot post.

NOTE. Rate of installation was not a subject of this study. Wooden posts can easily absorb much higher impacts than those used in this study. Rate of installation is a function of such factors as hammer weight, method of hammer delivery (automatic or manual stroke operation), ease of post loading, post plumbing, and machine disengagement from a driven post. As shown in an earlier report, driving time is usually a small part of post installation time *(Gatchell 1967)*.

The evaluation of post damage was subjective, based upon comments from highway engineers. The basic categories used were: none, light, moderate, and severe. *None* was used when damage extended no more than 8 inches from the base and, for wooden posts, was no more than 1 inch deep. *Light* damage was more extensive but, in our judgment, would not impair the performance of the post as guardrail support. *Moderate* damage, which might cause rejection, included extensively bent flanges on the steel posts or long splits or gouges about an inch deep in the wooden posts. *Severe* damage, which would surely cause rejection of the posts, included extensive stripping of the flanges or curling or twisting of the web on the steel posts and extensive and deep splits in the wooden posts.

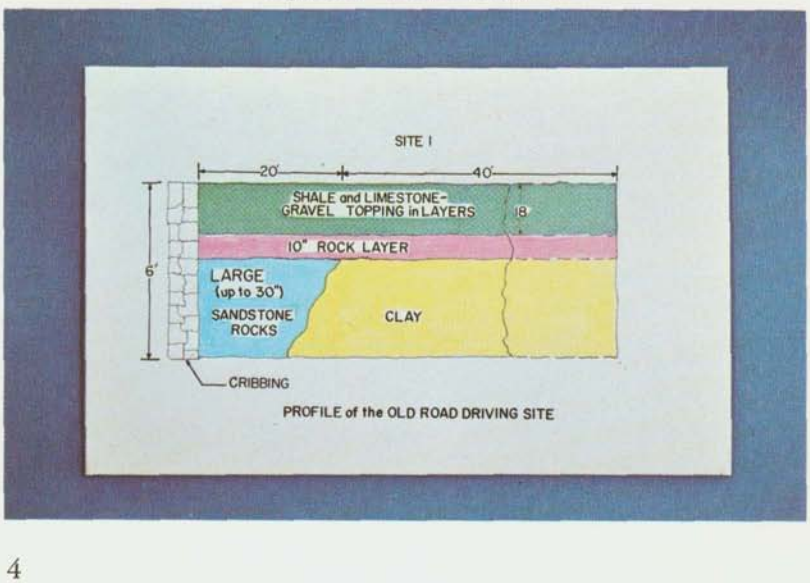
SITE I

Description

On site I (fig. 2) all posts were driven with a 950-pound hammer. Three wooden posts were driven into the rock base on one side of the road, and 10 steel and 7 wooden posts were driven on the other side. This arrangement of posts was made to allow easy access for the backhoe.

After digging the trench, we found that all of site I was topped with 15 to 18 inches of dry and highly compacted limestone gravel and shale in layers. We assumed that these layers were laid down over a long period of time as a part of road maintenance. A 10-inch-thick layer of small rocks had been placed between the clay base and the limestone and shale

Figure 2.—Profile of site I.



topping. This layer was not distinctly visible over the rock base. Extensive profile work in the clay base was not possible because the trench caved in shortly after being dug.

The three wooden posts and the first four steel posts had been driven into the sandstone rock base. Steel posts 5 and 6 were in a transition zone between the rock fill and the old stream bank. The other four steel posts and seven wooden posts were driven into the clay base.

Results

The seven wooden posts and the four steel posts driven into the clay base were undamaged, though a slight bending of the steel flanges was observed (table 1). This slight bending probably occurred in the 10-inch layer of rock between the clay base and the limestone-shale topping.

Table 1.—*SITE I: summary of post driving*

Post No.	Blows required, 4-foot depth	Type of base	Damage to post
	No.		
		STEEL POSTS	
1	12	Rock	Light
2	12	Rock	Severe
3	12	Rock	Light
4	19	Rock	Severe
5	11	Transition	None
6	15	Transition	Light
7	12	Clay	None
8	12	Clay	None
9	12	Clay	None
10	13	Clay	None
		WOODEN POSTS	
1	28	Rock	Very light
2	22	Rock	Very light
3	25	Rock	None
4	27	Clay	None
5	22	Clay	None
6	20	Clay	None
7	27	Clay	None
8	25	Clay	None
9	23	Clay	None
10	24	Clay	None

Figure 3.—The four steel posts and three wooden posts driven into the rock base of site I. The number of blows per post with the 950-pound hammer were (from left to right): steel post 1—12 blows; wooden post 1—28 blows; steel post 2—12 blows; wooden post 2—22 blows; steel post 3—12 blows; wooden post 3—25 blows; steel post 4—19 blows.

The condition of the three wooden posts and four steel posts driven into the rock base is shown in figure 3. Wooden post 3 was undamaged, and damage to the other two wooden posts would not impair their performance. These results are consistent with our earlier driving experience, using a 1,400 pound hammer. As a general rule, when a wooden post hits an obstruction, it either stops or moves the obstruction.

The four steel posts driven into the rock base suffered light to severe damage. Steel posts 1 and 3 had only minor damage to the flanges and would probably perform adequately. Steel posts 2 and 4 would be unacceptable for guardrail support. The flanges of steel post 2 were stripped from the web. Steel post 4, which took 19 blows to get to grade, suffered separation and curling of the flanges and curling of the web. None of the wooden or steel posts was damaged above the groundline.

Steel posts 5 and 6, driven into the transition zone between the rock and clay bases, suffered minor damage to the flanges.

A significant observation is that the type of base did not affect the total number of blows (except for steel post 4, which suffered severe curling of the web). Further, there was little variation in the number of blows for each type of post. In the rock base, the three wooden posts averaged 25 blows per post, with a range of 22 to 28 blows. In the clay base, 7 wooden posts averaged 24 blows per post, with a range of 20 to 27 blows. Six steel posts required 12 blows per post for installation in the rock and clay bases. About three-fourths of the blows for each type of post were required to penetrate the dry compact top layers.

SITE II

Description

On site II (figs. 4 and 5) we drove lines of wooden and steel posts about 10 feet apart. Twelve wooden posts and 5 steel posts were driven with a 1,200-pound hammer. Five wooden posts and 11 steel posts were driven with an 800-pound hammer. Two of the 5 wooden posts were driven at the end of the steel post line. The use of the heavy hammer with wood and the light hammer with steel reflects currently recommended commercial practice.

At the time of driving (late October), which was preceded by an extended rainy period, the site was rather wet. The temperature was cool, and the relative humidity was high.

After backhoeing out the trench, we found site II to be much more variable than expected. The depths of the limestone-shale topping and the sandstone rock base along and between lines varied greatly. The severity of the conditions for the wooden posts was greater than those for steel. The rock base under the line of wooden posts was up to 9 inches deeper than that under the opposing position in the line of steel posts.

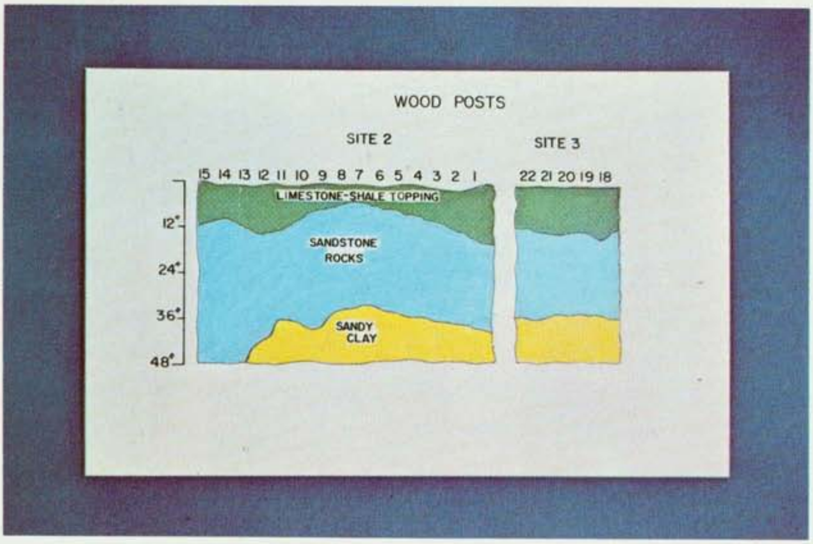


Figure 4.—Profile of sites II and III where wooden posts were driven. Numbers correspond to wooden posts as listed in tables 2 and 3.

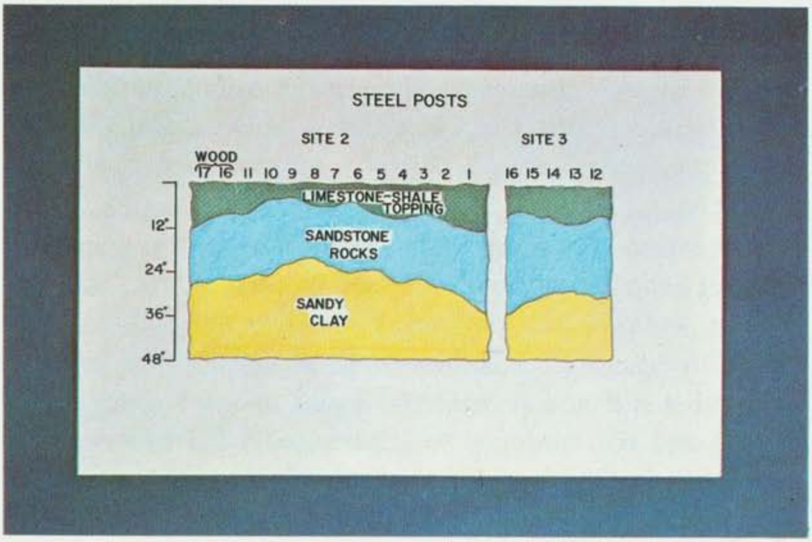


Figure 5.—Profile of sites II and III where steel posts were driven. Numbers refer to posts as listed in tables 2 and 3.

Results

Except for wooden posts 14 and 15, all posts penetrated the rock fill and ended in a clay base (table 2). Variations in the depth of the rock layer made comparisons difficult between the 800- and 1,200-pound hammer weights and between the wooden and steel posts.

We observed little damage or difference in the severity of damage to steel posts driven with the 800- and 1,200-pound

Table 2.—*SITE II: summary of post driving*

Post No.	Depth of topping	Depth of rock layers	Hammer weight	Blows required	Damage to post
	Inches	*Inches*	*Lbs.*	*No.*	
		STEEL POSTS			
1	16	20	1200	9	None
2	14	18	1200	10	Light
3	13	18	1200	17	Moderate
4	12	16	1200	11	Light
5	17	14	1200	10	None
6	3	22	800	21	Moderate
7	4	22	800	14	None
8	5	21	800	10	None
9	3	14	800	11	Light
10	3	21	800	12	Light
11	10	24	800	14	Moderate
		WOODEN POSTS			
1	20	24	1200	18	Light[1]
2	16	24	1200	24	Light[1]
3	14	24	1200	30	None[1]
4	10	24	1200	29	None
5	10	23	1200	27	None[1]
6	8	24	1200	25	Moderate[1]
7	8	23	1200	18	None[1]
8	6	22	1200	16	None
9	8	23	1200	23	None[1]
10	8	22	1200	28	Severe
11	14	24	1200	19	None
13	18	20	800	41	None
14	9	40+	800	53	Light[1]
15	18	40+	800	72	None[1]
[2]16	8	17	800	26	None[1]
[2]17	16	14	800	22	Light[1]

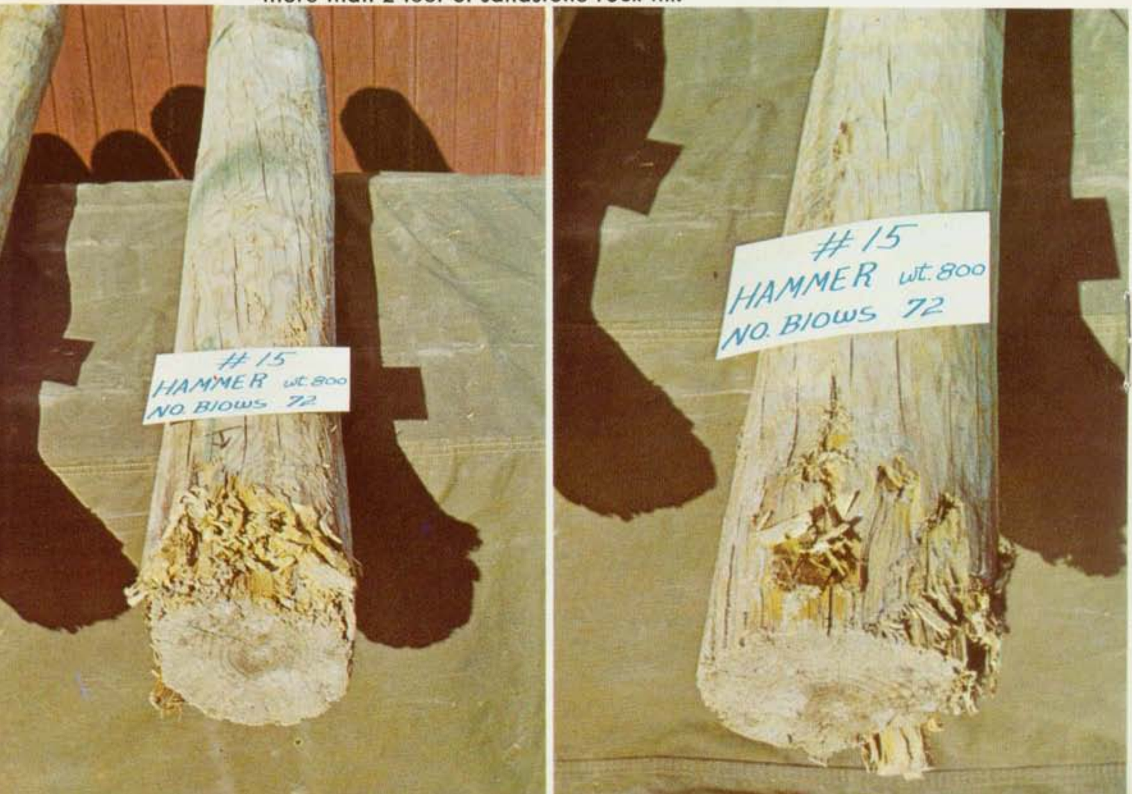
[1]Knots within 3 to 12 inches of bottom of post prevented or minimized damage.
[2]Driven at end of steel post line after steel post 11.

hammers. However, those driven with the 1,200-pound hammer penetrated about 5 inches less rock fill. We saw repeated examples of sandstone rocks that were cleanly broken by the posts. Damage was limited mostly to bending of flanges.

Steel posts 3, 6, and 11 might not have been suitable for guardrail support because of extensive flange damage. The other 8 posts should have been acceptable.

Of the 15 wooden posts driven on site II, posts 6 and 10 were significantly damaged. Damage was in the form of splits resulting from wedge-shaped rocks that had been driven into the base of the posts. We believe that wooden post 6 would have been serviceable because the damage was in that portion of the post that was completely treated with preservative. Post

Figure 6.—Two views of wooden post 15. Knots located within 4 inches of the base minimized the severity of damage that could have resulted from driving through more than 2 feet of sandstone rock fill.



10 had splits along its sides that may have penetrated to untreated wood in the center, and therefore this post was considered to be severely damaged.

The presence of knots within 3 to 12 inches of the base of a post is recommended to minimize the potential for splitting. Splits stop at the knots. Furthermore, on either side of the knot, the grain is not straight but is curved around the knots. This curving of the grain also tends to terminate splits. For example, wooden post 15 (fig. 6) required 72 blows with an 800-pound hammer to be driven into more than 2 feet of sandstone rock fill. Because knots were located about 4 inches from the base, damage to the post was superficial. The value of knots in reducing the severity of damage was observed on 11 of the 17 wooden posts driven on site II.

SITE III

Description

On site III (figs. 4 and 5), we drove a line of five wooden posts with the 1,200-pound hammer and a line of five steel posts with the 800-pound hammer. This site provided the greatest resistance to driving. As on site II, the wooden posts were driven under more severe conditions than were the steel posts; the rock base for the wooden posts was up to 10 inches deeper than that for the steel posts.

Results

Although site III offered the greatest resistance to driving (average of 30 blows per wooden posts), four wooden posts driven with the 1,200-pound hammer were undamaged, and one suffered only very light damage. The rocks in site III were smaller, rounder, and more tightly fitted than those in the other two sites (table 3).

Even though there was up to 10 inches less rock on the steel post side, three of the five steel posts driven with the 800-pound hammer were damaged. The damage ranged from light to severe. Post 15 had severe twisting of the web and flanges. Post 16 had curling of the web and separation of the flanges from the web.

Table 3.—*SITE III: summary of post driving*

Post No.	Depth of topping	Depth of rock layers	Hammer weight	Blows required	Damage to post
	Inches	*Inches*	*Lbs.*	*No.*	
		STEEL POSTS			
12	10	20	800	15	None
13	10	20	800	13	None
14	13	15	800	18	Light
15	13	18	800	16	Severe
16	10	23	800	16	Moderate
		WOODEN POSTS			
18	12	23	1200	33	None
19	14	23	1200	29	None[1]
20	13	25	1200	40	Light
21	13	26	1200	25	None
22	13	26	1200	23	None

[1]Knots minimized damage.

CONE FORMATION AT THE BASE OF BLUNT WOODEN POSTS

During machine driving, a flat-bottomed wooden post tends to form a cone of compressed material on its base (fig. 7). Cones were clearly visible in site II. The centers of the cones were made of limestone and shale with concentric conical layers of other materials on the outside (fig. 8). These cones were often present after the post was driven through 2 feet of sandstone rock fill. A sleeve of material from the top layers was often clearly visible around these posts. This sleeve was thickest near the groundline and tapered in toward the bottom of the post.

There are two major benefits to these cones. One is the reduction in resistance that would normally be associated with a cross-section 7 or more inches in diameter. The effect is similar to driving a pointed post.

The second major benefit is the protection the cone provides to the base of the post. The top layers generally will be composed of small pieces (1 inch or less) of topping, which do not cause damage. If a post with a cone beneath is driven onto a

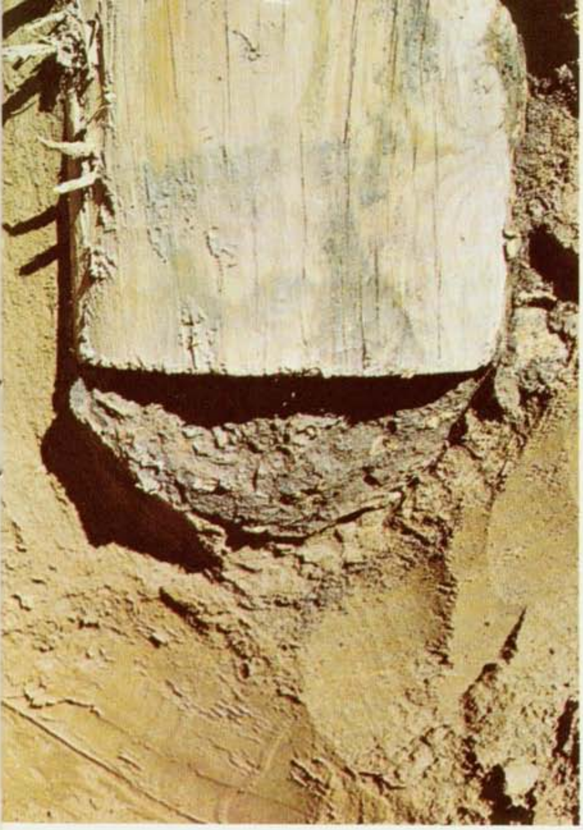


Figure 7.—Cones of compressed top-layer material form at the base of flat-bottomed wooden posts. These cones reduce the resistance of the post to driving and help protect the bottoms of the post from damage.

Figure 8.—Section of cone formed at the base of wooden post 16. Center of the cone is made up of limestone and shale from the top 8 inches of the site profile. In the outer inch of the cone, concentric layers of other materials can be seen.

large rock, the cone must squeeze from between the post and rock before the rock can damage the post. However, each blow tends to move the rock. We believe that the protection provided by the cone is one major reason for the excellent performance of wooden posts under adverse conditions.

The Dynamic Interactions of Machine Driving

On site I, about three-fourths of the total number of blows were required to penetrate the top 15 to 18 inches of dry compact limestone gravel and shale. The total number of blows for each type of post was independent of the site base (sandstone rock fill or clay). On site II, cones of compressed top-layer material were found on the bases of wooden posts even after the posts had been driven through 2 feet of sandstone rock fill. On site III, which provided the greatest resistance to driving, wooden posts were undamaged. The base of site III was made up of smaller, rounder, and more tightly fitted rocks than the other two sites. What do these results tell us?

Post-driving is a dynamic process, and the reaction that occurs when the hammer hits the post depends on many factors and their interactions. The driving energy available increases with each succeeding blow, for about 40 percent more energy is delivered per stroke when the post has been driven in 3 feet than at the beginning of driving. Therefore we should expect a greater depth of penetration per blow at the end of driving than at the beginning.

When a rock in the base is hit, we assume that we are point-loading in most cases. That is, the rock will not be in contact with the entire cross-section of the post. Under point-loading, the forces acting on this rock become very great. The tendency will be to either move or break the rock or to damage the post.

Consider what happens when a steel post is driven. The I-shaped cross-section of the 6B8.5 steel post has an area of about 2.6 square inches and a perimeter of about 30 inches. In comparison to wood, the small cross-section is of distinct advantage in reducing the chances of hitting obstacles. But more important, perhaps, this cross-section requires relatively little displacement of aggregate for insertion.

The side surface area of the steel post is about 25 percent greater than that of a 7-inch wooden post. Resistance due to rubbing of the sides against gravel or rock can therefore be greater with the steel post.

During driving, the web of the steel post is restricted from bending or twisting by the flanges. However, the flanges are under no such restraint at their edges. The energy delivered by the driving hammer is concentrated on an obstruction by the small cross-section. In soft rock fills, such as used in this study, this concentrated loading will often break up such rocks, and the posts will pass on by. For obstacles that resist breaking, the steel post must either move the rock or become deformed. In this case, the small cross-section becomes a disadvantage. Our experience shows that the flanges are rather easily bent or twisted. Detection of this damage from observing the driving action above ground is not possible. Because deformation of the web is restricted by the flanges, damage to the web requires an excess number of blows.

When a wooden post is driven, the major consideration is displacement of the substrate. We believe the following happens. With the first few blows, the top layers are compacted beneath the post. Shearing of the topping around the post is likely. When compaction is no longer possible, cone formation begins. In profile, the cone is a wedge that compresses the substrate down and to the sides. The result is a flow of material from the base to the sides. This material is more highly compacted than that further away from the post. The result is a tightly fitted post.

The cone is considered the major reason why wooden posts, with 15 times the cross-sectional area of steel posts, took only twice as many blows to install with the 950-pound hammer on site I. The action is similar to driving a pointed post.

Another factor is the side surface area of the post. As mentioned above, the side surface area of steel is about 25 percent greater than that of a 7-inch wooden post. When considering the influence of side surface area, we must also compare the properties of the post materials. In comparison with wood, steel is uncompressible. Wood fibers can be compressed or deformed, thus minimizing the resistance to the rock.

How can the cones penetrate the rock layers? The reasons for this are not clear. It is possible that, during impact, the cones exert compressive forces that start the displacement of rocks not yet in contact with the cones. Rocks that cannot be displaced will, of course, destroy the cones.

Summary & Discussion

Both wooden and steel posts driven under adverse conditions perform well, but wood is superior to steel in resisting damage. Of the 26 steel posts driven, 4 were moderately damaged and 3 were severely damaged. Of the 32 wooden posts driven, 23 were judged to be undamaged. Only 2 wooden posts were found to be moderately or severely damaged. This favorable comparison for wood was true even though the driving conditions for wood were generally more adverse than those for steel.

The superiority of wood is the result of its mechanical properties and of post-soil interaction during driving. Wood is extremely strong in compression parallel to the grain. One post took 72 full blows with an 800-pound hammer without damage to the top or bottom. Another post took 40 blows with a 1,200-pound hammer and suffered only very light damage.

Cones of compressed top-layer material beneath flat-bottomed wooden posts reduce the energy required for insertion and protect the bottom of the posts. The presence of knots within 3 to 12 inches of the base of a wooden post further minimizes any damage that might occur.

The results on site III suggest that wood will perform even better in comparison with steel if harder rocks are found in the base. If rocks resist breaking and do not have wedge-shaped edges, the wooden posts will displace them without suffering damage.

Damage below the groundline brings up questions about the performance of guardrail systems. How often do adverse conditions occur? If we install posts on 6-foot 3-inch centers, and a severely damaged post is bracketed by two undamaged posts, how important is the damage? If a steel post is severely bent, how much damage can it sustain and still perform? If the galvanizing is scratched off during driving, what is the effect of rusting rate on rate of loss of strength? Creosote-treated wooden posts may have a service life of over 40 years. What is the effect of cracks in the treated shell of wooden posts that are located below the groundline on the rate of loss of strength?

We cannot assume that posts undamaged above the groundline are also undamaged below. None of the posts used in this study was damaged above the groundline. Also, because all posts require the same number of blows to drive, we cannot assume

Figure 9.—Six steel posts on site I required 12 blows each for insertion. Damage ranged from none to severe.

that all posts are either damaged or undamaged. Driving wood onto wedge-shaped rocks can cause splits.

Six steel posts (fig. 9) on site I each received 12 blows with a 950-pound hammer. Damage ranged from none to severe. Damage to the flanges of steel posts occurs relatively easily and is not detectable from above-ground observations of the driving action.

Conclusions

This study must be considered exploratory. We used only one wood species: southern yellow pine. Other species may perform better or worse than this material. We would expect Douglas-fir to perform as well, and many of our dense hardwoods such as red oak might perform better.

We evaluated these posts in only one type of rock-filled base: sandstone. This is a relatively soft type of rock. We assume that, had the rocks been harder and less resistant to fracture, the wooden posts would suffer less damage and the steel posts more damage than that found in this study.

We concluded that:

- The type of guardrail post should be carefully specified, depending on soil conditions. Ease of installation has little to do with performance. In soft soils, wooden posts may be preferred because of their larger soil-bearing surface. In rocky soils, wooden posts may be preferred because of their ability to resist damage. Adversely, wooden posts will occasionally disturb the berm where steel posts will not. On certain types of granular fills, steel posts may be preferred because of the minimized displacement of fill and the resulting minimized chance of severe site disturbance.

- Wooden posts are superior to steel in resisting damage below the groundline.

- The driving action causes no damage to the tops of wooden posts.

- Wooden posts should have a blunt bottom because, as they are driven, a cone of compressed top-layer material forms at their base. This cone acts as a wedge, which reduces the energy required to drive and protects the bottom of the post from damage.
- Wooden posts should be cut so that knots are located between 3 and 12 inches from the base to minimize the severity of damage.

Reference

Gatchell, Charles J. 1967. A WAY TO REDUCE HIGHWAY GUARDRAIL COSTS: MACHINE-DRIVING OF WOODEN POSTS. USDA Forest Serv. Res. Paper NE-81. 19 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa.

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