bridge will appear level. This will account for stretch in the catenary cable or elongation in the cable under high temperatures. Either condition could result in a “sag” in the walkway, if it was built level. The original design specified a 5 percent camber. This was revised when handicap accessibility became a design goal. ADA limits walkways to a maximum slope of 8 percent. If the slope is between 5 and 8 percent, intermediate level 5-foot long rest platforms are required every 30 feet. Constructing these on the bridge would have been difficult. Designing the camber at 3.5 percent eliminated the need for the intermediate level platforms. Using 3.5 percent also allowed for a margin of error in construction as well as assurance that the walkway slope would not exceed 5 percent even on the coldest days when the cables contract. The camber also plays a role in the interface between the bridge walkway and the tower platforms at either end. The camber results in a vertical load component that forces the walkway end to “sit down” on the platforms. This makes for a smooth ramp transition.

Cable Saddles

The catenary cables pass over the tops of the towers via the cable saddles, which are detailed on Plan Sheet 6, photo 51, and Figure 8. The saddles support the cable, change its direction, and in a perfect theoretical world would be a frictionless connection. This concept is important in the tower design. A frictionless saddle will transmit only axial loads to the tower, as opposed to a horizontal load that would result in bending moments. A column or pole is much stronger in axial compression than bending. Large bridges

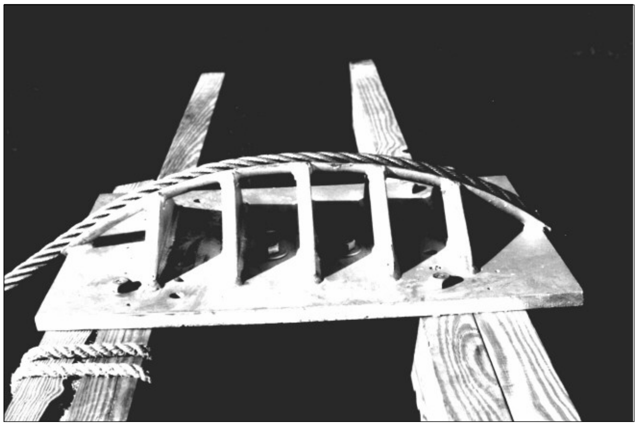

Photo 51. West tower - north pole cable saddle. *Photo courtesy of Mr. Tibor Latincsics.*

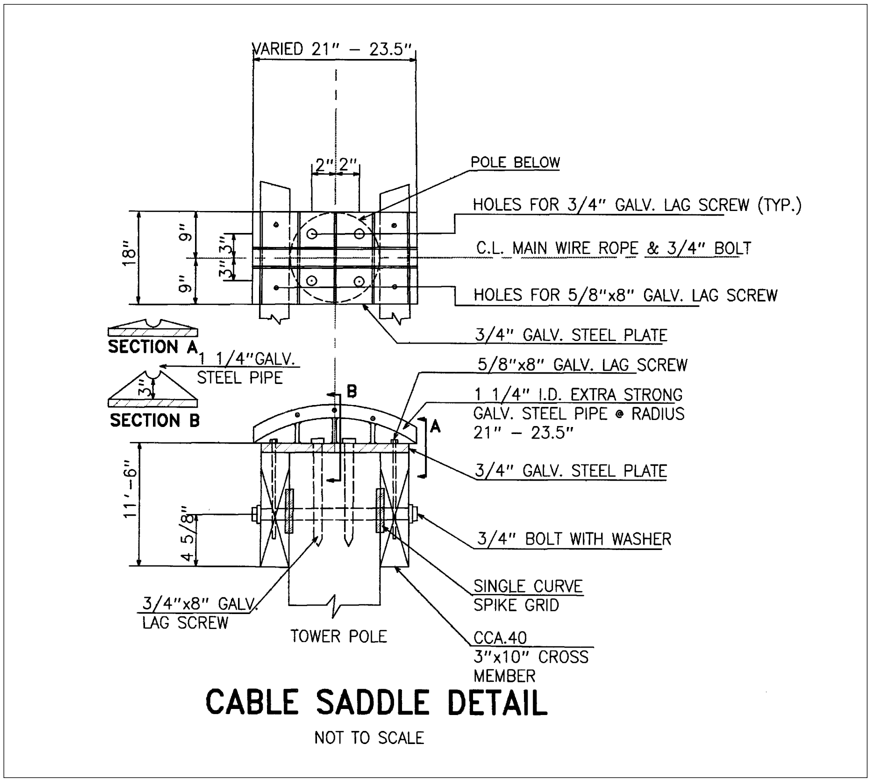

Figure 8. Cable saddle detail.

support their cable saddles on a nest of rollers. The original design concept for the Pochuck Quagmire Bridge envisioned a ball bearing axle mounted grooved sheave for the cable supports. The field inventory by the project engineer indicated that split pipe saddles utilized by the USDA Forest Service have a long history of adequate service. The cable saddle on the 1972 Tye River Bridge and the 1992 Kimberly Creek Bridge are identical. The cable saddles detailed in Figure 8 and photo 51 were substituted for mounted sheaves to simplify the design and installation. The saddles are made of 3/4-inch galvanized plate steel. A side benefit of the zinc plating is that it made the saddles very smooth, almost frictionless. Future project planners are advised that such custom galvanizing is expensive, but may be well worth it, because of less rusting of steel that is exposed to the weather.

An important design element of the cable saddles is to provide the proper bending radius for the type of wire rope being used. The minimum bending radius varies with wire rope diameter, type of steel wire in the rope, and the construction of the wire rope. A rule of thumb is that the bending radius should be 400-600 times the diameter of the outer wires of the outer strands of the wire rope. The minimum bending radius of 6 x 25 wire rope varies from 13 to 15 inches, with the larger the better. A bending radius of 21 inches was utilized for the Pochuck Quagmire Bridge saddles. The bending radius of the Pochuck Quagmire Bridge saddles meets the recommendations of the wire rope industry. Too small a bending radius subjects a wire rope to excessive bending stresses with the resultant fatigue of individual wires. The wires adjacent to the core of the rope are affected first. This condition is impossible to detect.

The bending radius of the saddle is also an important element in determining the radial pressure on the wire rope. The freebody figure of the towers on page 51 shows that for equilibrium to be achieved, the horizontal component of the loads in the catenary and backstay cables must be equal. The downward vertical component of the cable loads are counteracted or supported by the tower and foundation system. The bearing surface between the wire rope and the saddle must be of sufficient area so the radial pressure exerted does not exceed the allowable bearing of either material. In this application, the wire rope is the weaker of the two and becomes the determining design element. The radial pressure 6 x 25 wire rope is rated for one to two thousand PSI. Using the lower value required a bearing length of 22 inches for the Pochuck Quagmire Bridge. Twenty-five and a half inches or more of bearing surface was provided.

The last major element of the saddle design is the groove diameter or “seat” of the actual saddle. As shown in photo 51, a 1 1/4-inch extra strong steel pipe was cut in half and bent to the proper radius. The half pipe saddle keeps the wire rope in its proper location. It is important that the diameter of the groove or “seat” be only slightly larger than the diameter of the wire rope. Grooves that are too large do not provide the proper support the wire rope requires. If the wire rope is not properly supported, it may deform to an elliptical shape compromising the strength.

In summary, if the cable saddles do not have the proper bending radius, bearing surface, or groove diameter, the wire rope is negatively impacted. The full strength of the wire rope will not be available. From the field inventory, it appears that excluding the USDA Forest Service bridges, proper bending radius and bearing surface are often overlooked in trail bridge designs. These omissions are compensated for by the large number of safety factors utilized with wire rope. Another problem the inventory revealed is that in order to reduce the up and down oscillations of walkways, which do not have stiffening trusses, some bridge maintainers clamp the wire rope to the cable saddle. This is a very poor idea! This will transfer a horizontal overturning load to the bridge tower. In many cases, the towers may not have been designed for this loading.

Once the poles and cross arms were installed, the project engineer measured the final dimensions and provided customized shop drawings of the cable saddles for each individual pole top to R.S. Phillips Steel. The project was fortunate in that R.S. Phillips Steel, a well-known steel fabricator, is located in Vernon Township, New Jersey. The customized details for each non-uniform pole top ensured that the saddle fasteners lined-up with the center of the cross arms and quarter points of the poles as well as providing maximum bearing surface. As the pole heights varied in elevation by 2.4 inches from bank to bank, the project engineer designed the apex of all four saddles to match in elevation by varying the radius of the bent pipe saddle. The saddles were to be attached to the poles via 3/4-inch lag screws and 5/8-inch bolts. Once driven, there was no room for adjustment, given the bore and bite of such large connectors. In anticipation of this, the project engineer had #12 nail bore holes drilled into the saddles to allow the saddles to be tacked down, checked, and then the major fasteners driven.

The project engineer arrived 10 minutes after the stalwart volunteers started work on October 5, 1995, the night of the saddle installation. By that time, the energetic and enthusiastic volunteers had installed the east tower saddles, driving the major connections first. Unfortunately, they confused east and west and installed the west saddles on the east tower. This is an example of communication problems that can be expected in a complex project, for which all the planning and detailed plans cannot prevent. The end result is that the cable saddles vary in elevation by 5 inches from one side of the river to the other. This shifted the sag low point 2.5 inches from dead center. This is not visible by eye. The subsequent change in the suspender lengths was accommodated by the built-in adjustment capability. See the suspender detail on Plan Sheet 8 and photographs 58-61. To ensure a good connection of the saddles to the towers, the top cross arms were doubled up, and 5/8-inch through bolts into the cross-braces were substituted for the 5/8-inch lag screws. A profile view of the installation of the saddle on the west tower is shown in photo 51 (page 45).

Catenary Cable Geometry

When suspended between two supports, a uniformly loaded wire rope assumes the shape of a catenary curve. The specific shape of the catenary curve is established by the sag-span ratio. The sag-span is the ratio between the sag of the wire rope to the span between the supports. The dilemma facing bridge engineers is that the larger the sag for a given span and loading, the lower the tension load in the cable. However, the reduction in the cable tension load (or cable size) comes at the expense of taller towers. The benefit in reducing the cable diameter within the safety factor of 4 to 5 is not just the cost savings in the cable, but also the cost savings in the multiple suspender attachments. Economics is very much an element of good engineering. Structural-practical economic criteria place most bridge sag-span ratios in the 1/8 to 1/12 range. For example, the Bear Mountain Bridge sag-span is 1/8, the Brooklyn Bridge is 1/12.5, the George Washington Bridge is 1/10.75. The USDA Forest Service Bridges at Jackson River is 1/10.0 and the Pemigewasset River is 1/13.0. The Pochuck Quagmire Bridge has a high sag (17.75 feet) to span (110.20 feet) ratio of 1/6.2. This is beneficial and allowed the use of 1-inch wire rope for the design loading. In lightweight pedestrian bridges, excessive sag should be avoided because it can lead to excessive side sway in the bridge.

A combination of physical constraints established the sag-span ratio of the Pochuck Quagmire Bridge. They were as follows:

- Donated 40-foot long Class I SYP transmission poles.
- Required 6 feet embedment of the pole.
- 57-foot wide Pochuck Creek.
- 25-foot clearance to eroding banks.
- Clearance to the 100-year flood level.
- Minimum practical suspender length at the cable lowpoint.