following reasons:

• Turnbuckles are easily vandalized and are high maintenance.

• More wire rope clip connections and connections in general are needed.

The White Mountain Forest Service Bridges use a U-bolt to make the stringer connection, as shown in photo 69. This provides a limited vertical adjustment capability. The White Mountain Bridges have a distinct design feature in that the suspenders are a steel rod with a welded loop at either end. The loop connects to the bridge clamp at the top and the stringer U-bolt at the bottom. While the White Mountain Bridges appear to be very successful, this method may have the following limitations:

• Manufacturing the steel rod to the correct length is difficult and time consuming.

• There is little or no long-term adjustment capability to account for wood shrinkage or cable stretch.

• The rigid steel rods transfer walkway oscillations to the catenary cables more readily than the wire rope suspenders.

The combination of longer threaded U-bolts, bevel cut on the stringer underside, and a Flemish sleeve connection would give a designer the ability to specify adjustability, walkway slope, and cradle all at the same time.

A Practical Lesson – “The Hard Way”

The installation of the piggyback clips provided a hard-learned lesson, which is applicable to other projects. The catenary cables and suspenders were fabricated by Mr. Dick Doran, an internationally known wire rope expert, of Doran Sling. As was the case with almost everyone who came in contact with the project, Mr. Doran became interested in the project on both a professional and personal level. He provided a wealth of practical information. The project specifications called for the catenary wire rope to be cut in the shop and the spelter sockets attached. The suspenders would be fabricated to the varying correct lengths and mounted on the primary catenary at calculated locations. The entire prefabricated assembly would then be reeled on an oversized spool and transported to the bridge site for installation. Due to their interest in the project, as well as keeping the accelerated construction schedule going, GPU Energy volunteers offered to pick up the cable early and mount the suspenders in the field. This would be done while the prefab of the bridge walkway was proceeding at Wawayanda State Park. The suspenders were not mounted in the shop. Out in the field (in 6 inches of mud and pouring rain), it was discovered the seat of the 1-inch piggyback clips would not snug up to the 1-inch wire rope. This would have been a minor problem in the Doran shop, but out in the
field, it was another story. There was no power nor the right power tools. All the material had been accepted from the fabricator and was onsite. The work crew was waiting and ready to work. The field solution was to flip the piggybacks and to “burn” off the tops of the tines. The reader should compare photos 58 and 60 to the detail on Plan Sheet 8. This modification required shaving 168 tempered steel tines. Some 40 saw-zal blades later, the reversed piggybacks fit. This points to several old adages.

- Measure twice – cut once.
- Plan your work – work your plan.
- Be prepared – field modifications can be expected.

With the suspenders attached to the primary cable, the cables were placed in the cable saddles, tension applied, and hoisted up. The cable work assumed the distinctive parabolic profile of single-span suspension bridges, as shown in photos 70 and 71.

The primary cable and the 42 vertical suspenders assumed the correct geometry shown in photos 70 and 71. This was due to the advance design work and then a fine-tune design to fit as-built conditions. As is the case with the majority of single-span suspension bridges, the primary cable between the towers was designed as a symmetrical equal tangent parabolic curve. The reader should not assume that suspension bridges are limited to symmetrical equal tangent single spans. One is referred to the “Wire Rope Engineering Handbook” for information on the stresses and geometry of a variety of suspended cable configurations.

The basic mathematical characteristics of a parabola were used to design and fabricate the suspender lengths. Figure 17 (page 65) is a simplified sketch of the bridge profile shown on Plan Sheet 1. As on Plan Sheet 1, the suspenders are identified A to K depending on their location. Figure 18 (page 65) is a further simplification showing the mathematical relationship between the chord, tangents, tangent offsets, and the parabolic curve. Two useful basic properties of a parabola allow one to calculate the suspender lengths. The properties are as follows:

- The parabolic curve bisects a line joining the midpoint of the chord and the intersection of the tangents at the ends of the chord. The distance from the vertex to the curve and from the vertex to the chord are equal and called the middle ordinate distance. This distance is called “e” among engineers, and in the case of suspension bridges is also the “sag.”
- The distance from the tangent to the curve varies as the square of the distance along the tangent from the point of tangency to the chord midpoint.
Referring to Figure 18, the distance from the tangent to the curve at point “z” is as follows:
Distance \( zw = (3/4)^2 e = 9/16 e \)

**Figure 17.** Sketch of Pochuck Quagmire Bridge in profile showing parabolic curve relationships.

**Figure 18.** Symmetrical equal tangent parabolic curve mathematical relationship.
These basic relationships allow one to calculate the suspender lengths. In the case of the Pochuck Quagmire Bridge, the walkway had an upward camber rise of 3.5 percent. It was important to identify the 42 suspender lengths between two converging bridge elements — the downcast parabolic cable and the rising walkway. The suspender detail, Figure 19 and Plan Sheet 8, indicates the only variable of the suspender assembly to be the length of the 1/2-inch 6 x 19 galvanized EIP IWRC. It was critical to be aware that in the suspenders the minimum length of 1/2-inch 6 x 19 EIP IWRC allowed between the Flemish sleeve and the swaged threaded rod was 12 inches. This is a wire rope industry standard. This determined the overall length of the center K suspender of the Pochuck Quagmire Bridge, which in combination with the tower heights and walkway slope, established the sag or “e” of the main cable.

Figure 19 is the sketch and an example of the step-by-step procedure used to calculate the Pochuck Quagmire Bridge suspenders. The author has refrained from presenting specific calculations in this case study, but a number of people have asked that this procedure be detailed. The reader should also refer to the bridge profile and suspender detail. Suspender F on the east side of the south cable shall be the example.

- Tangent Elevation at Suspender F = 427.80 - (30.13)(.6546) = 408.08
- Distance from the tangent point @ F to the underside of the 1-inch wire rope is:  
  
  \[(30.13/55.24)^2 e = (.2975)(18.08) = 5.39\]

- Elevation of underside of cable = 408.08 + 5.39 = 413.47
• Elevation of the underside of the bevel cut 6-inch x 6-inch stringer is determined by the platform
  elevation and the run/rise of the walkway:
  
  \[ 405.66 + (30.13)(3.5\%) - \frac{5.5\"}{12\"/ft} = \text{Elevation 406.26} \]

• Elevation of the top of the F threaded stud:
  
  \[ 406.26\"+(5\frac{1}{2}\"+ 19 19/16\"//12\"/ft) = \text{Elevation 408.35} \]

• Length of wire rope from top of threaded rod to the inside crest of the flemish loop wire rope
  thimble (see suspender detail) is as follows:
  
  \[ \text{Elevation 413.47} - (1.86\"//12\"/ft) - \text{Elevation 408.35} = 4.965' \]

• Wire Rope Length of Suspender F = 4.965' = 4’-11 9/16”

This 7-step calculation was performed 84 times — 21 times for each suspender pair to “rough out” the
  design; 21 times for the final design and to provide an estimate of the 1/2-inch wire rope needed; and 42
times to customize each suspender for the as-built conditions of the towers and saddles. Doran Sling and
  Assembly was provided with a “cut sheet” that identified the suspender lengths to within 1/16-inch. The
  suspenders were fabricated to this tolerance. Each suspender was identified by its correct location, for
  example, south cable, east side – F Suspender. A secure, weatherproof tag was used to distinguish each
  suspender. To make the field fabrication even easier, the project engineer had the suspender locations and
  spacing marked on the main cables at the Doran shop. This was calculated by applying the length of curve
  equation on page 50 to the as-built tower dimensions and distributing the distance evenly between the suspend-
  ers. For example, the south cable suspender spacing was as follows:

• Suspender Spacing = \[ \ell \left(1 + \left[ \frac{8}{3} \right] e^{2} - \left[ \frac{32}{5} \right] e^{4} + \left[ \frac{256}{7} \right] e^{6} \right) \div \left( \text{# of suspenders} + 1 \right) \]

• Spacing = 110.47 \[ 1 + \left[ \frac{8}{3} \right] \left[ \frac{18.08^{2}}{110.47^{2}} \right] \left[ \frac{32}{5} \right] + \left[ \frac{18.08^{4}}{110.47^{4}} \right] + \left[ \frac{256}{7} \right] \left[ \frac{18.08^{6}}{110.47^{6}} \right] \]

= \left( \frac{110.47 \times 1.0675}{22} \right) = 5.36

All this time-consuming measuring and “number crunching” would pay dividends in the time it would save in
  the aerial assembly and “tuning” of the bridge.

Aerial Bridge Assembly

All the planning, measuring, and prefabrication led to the aerial connection of the seven prefabricated bridge
  sections. This is shown in photos 72-77. The sections were hoisted via “come-along” winch hoists, as
  shown in photos 72-74. The pair of top overhead 9/16-inch structural strand guylines, (shown in photo 10,
  page 22), that run from top of tower to top of tower serve two purposes: first as guylines and secondly as a
  cable runway for the pulley sheaves used to pull the bridge panels into place. This is shown in photo 74. It is
  very important to recognize that during the aerial maneuvering of the 1500-pound bridge sections, the weight
  of the individual bridge sections was carried by the overhead 9/16-inch structural strand. The workers’ fall
  protection lines were connected to the main catenary cables. If the bridge sections dropped for whatever
  reason, the workers would not be carried down with it. When the bridge section was in the correct position,
  the male-female elements of the truss chords were bolted together. The weight of the bridge section was