The field inventory did reveal a potentially dangerous situation involving the use of wire rope clips and thimbles as a terminal end attachment. As discussed in the cable saddle section, a wire rope must have a proper bending radius. Proper diameter wire rope thimbles should be used with wire rope that is manufactured for flexibility. This usually means a larger number of wire in a strand, such as a 6 x 49 construction. Structural bridge rope that is 7 x 7 or 6 x 7 should not be used with thimbles and wire rope without recognition that this combination results in a 50 percent reduction in the bridge rope strength. Structural bridge rope has a large bending radius requirement. It is manufactured to be used with spelter or swaged sockets.

**Suspender Design and Installation**

The primary purpose of the suspenders is to transfer the walkway load to the catenary cables. The stiffening trusses distribute a point live load to several suspenders. This reduces the vertical oscillations of the walkway under non-uniform loading. The suspender design and installation had to meet several criteria; they had to be:

- Structurally sound.
- Vandal resistant.
- Minimum number of parts or connections.
- Have a vertical adjustment capacity.
- Practical to install under adverse conditions.
- Cost-effective with no adverse impact on public safety.

The first five would be easy to accomplish if it was not for the sixth criteria. The final suspender design is detailed on Plan Sheet 8 and Figure 16.

The suspender assembly utilized for the Pochuck Quagmire Bridge is more sophisticated, but at the same time simpler than suspender assemblies for similar bridges. Working top to bottom, as detailed on Plan Sheet 8, Figure 16, and photographs 59-62, the individual components are as follows:

- CM Big Orange Piggyback wedge socket clip attachment to the catenary cable.
- Flemish eye loop with a 1/2-inch extra heavy duty wire rope thimble and flemish sleeve.
- 1/2-inch 6 x 19 galvanized EIP IWRC wire rope.
- Muncy 1-inch thread stud, electro zinc galvanized, swaged to the 1/2-inch wire rope.
- 1 1/16-inch bore hole through 6-inch by 6-inch cross-stringer.
- 3-inch by 3-inch by 3/16-inch galvanized square washer.
- 1-inch bore galvanized square washer.
- Standard 1-inch square nut.
- 1-inch lock nut (not shown in construction photos).

A distinguishing feature is the vertical adjustment capability by utilizing the threaded stud.

Practical elements and concerns about vandalism became the determining factors in the suspender design rather than pure structural criteria. The number and 5-foot spacing of the suspenders was determined by the design of the cross-stringers. The design of the cross-stringers was in turn influenced by the size of the borehole.
Figure 16. Cross-stringer suspender detail.
required to pass the threaded rod. A 4-inch by 6-inch cross-stringer would have been sufficient from a loading perspective, but the project engineer was concerned about the long-term impact of the 1 1/8-inch bore hole. Would the 4-inch by 6-inch cross-stringer crack at the bore hole when the bridge shifted in the wind? This concern resulted in the 6-inch by 6-inch cross-stringers being specified for the suspenders. Slightly over-sizing the suspender bore hole had two benefits. The first ensured that the threaded rod would easily pass through even if the cross-stringer swelled if it became wet prior to assembly. This was a prudent precaution because the Pochuck Quagmire Bridge was eventually assembled in torrential rains. The second benefit was to allow a little play in the system so the cross-stringer would not split as the bridge shifted in the wind. Vandalism concerns determined the 1/2-inch 6 x 19 wire rope being specified. The 1/2-inch wire rope has a nominal breaking strength of 13 tons, which is far in excess of the 650 pound design load on each suspender. However, using a smaller diameter seemed to invite vandals to “snip” the critical connector. This is a prudent precaution for the Pochuck Quagmire Bridge location as it is in a relatively remote, unsupervised location yet accessible to a wide variety of users. Local youths were drinking beer and “recreating” at the site before the bridge was finished.

The upper end of the wire rope terminates in a Flemish loop, which is shown in photo 58. The Flemish loop is created by the galvanized heavy duty thimble and the crimped Flemish sleeve. The Flemish sleeve is the weak link of the suspender assembly in that it has a rated capacity of 2.4 tons. This is typical of the fact that connections are the “weak link” in a structural system. The Flemish loop was used in lieu of three wire rope clips typically used for this connection. Shown in photo 59 is the wire rope clip suspender connection of the Appalachian Trail Tye River Bridge.

The Flemish loop offers the following advantages:

- Vandal resistant.
- Strong.
- Cost-effective.
- Arrives prefabricated - fewer small parts to accidentally drop into the river.
- Less long-term maintenance.
- Better looking - professional end product.

However, the Flemish loop does not have the in-the-field adjustment capability of simple wire rope clips. This adjustment capability is provided by the threaded rods at the lower end of the Pochuck Quagmire Bridge suspender assembly.

Photos 58 and 60 show the CM Big Orange Piggyback clip that provides the interconnection between the suspender and catenary cable. Also provided are three photographs of alternate connections used on other bridges inspected in the author’s inventory. A comparison of these four structurally acceptable alternatives provides an interesting contrast of practical elements and costs. All costs are presented in 1996 dollars.

This shall be discussed later. One should be aware that using a Flemish loop requires accurate calculation of suspender lengths.
the catenary cable. The number of parts required are minimized. The piggybacks cost $22.50 each. Photo 61 shows the method used on the Tye River Bridge. Although the bridge was originally built in 1972, the walkway and suspender assemblies were replaced in 1992 because several suspenders had corroded to the point of being unsafe. The connection consists of a 1-inch Crosby drop forged wire rope clip and a 7/8-inch screw pin chain shackle. The cost for this connection hardware is $35.98. The cost is so high because individual chain shackles are a specialty item. One might ask, “Why not connect the flemish loop with just the wire rope clip and eliminate the shackle?” This would result in the two wire ropes rubbing against one another every time the bridge is loaded or the wind blows. Such a wear point could lead to long-term problems.

The third alternative, as shown in photo 62, was used on the Jackson River Bridge in Virginia. It is a 1-inch wire rope clip and chain shackle in concert with a half open swage socket. This is a good connection, which addresses the vandalism and maintenance problems of numerous wire rope clips. The cost is $59.08.

The fourth alternative, which is a bridge clamp, is shown in photo 63. This particular one is on the Lincoln Woods Trail Bridge off the Kangamangus highway in White Mountain National Forest. They are also used on other suspension bridges built by the USDA Forest Service in the White Mountains. The bridge clamps cost $108 each and are a specialty item having a long delivery time. Ignoring the cost-benefit ratio, it is the best wire rope connector. The cost of the four alternatives, if used for the 42 Pochuck Quagmire Bridge suspenders, is as follows:

- Pochuck Quagmire Bridge piggybacks (42) ($22.50) = $945
- Tye River clip and shackle (42) ($35.93) = $1,511
- Jackson River swage socket (42) ($59.08) = $2,481
- White Mountain bridge clamp (42) ($108.00) = $4,536

The cost-benefit ratio suggests that the bridge clamp is the best option for long-term durability and safety.
The $4,536 cost and long delivery time required for the bridge clamps was not within the project scope. Such a cost would have been 13 percent of the total project budget. A long delivery time would have doomed the project, which depended on accelerated construction during a narrow construction “window” in the Pochuck Quagmire. The Pochuck Quagmire Bridge piggybacks meet the six design criteria listed at the beginning of this section.

The next major element of the suspender assembly is the connection to the 6-inch by 6-inch cross-stringer. This was performed by swaging a 30-inch long, 1-inch diameter threaded stud to the 1/2-inch wire rope. The threaded stud is shown in photos 64 and 65, Figure 16 on page 59, and detailed on Plan Sheet 8. The swaged threaded stud provides another vandal proof simple connection. A swage connection is a very structurally sound connection developing 95 to 100 percent of the wire rope strength. The threaded stud was simply threaded through a 1 1/8-inch vertical bore hole in the cross-stringer.

This provides two major benefits.

- The threaded stud provides a vertical adjustment capability to fine tune the bridge camber. This capability should not be used as a reason not to accurately calculate the various suspender lengths.
- As shown in photo 64 and Figure 16, by beveling the underside of the 6-inch by 6-inch cross-stringer to the slope of the bridge camber, the bridge walkway is automatically set to the desired slope. In this case that was 3.5 percent. The suspender hangs vertical (plumb) and the 3-inch by 3-inch bearing washer is perpendicular to the suspender and flush to the beveled underside of the cross-stringer.

These two design components saved a significant amount of time in the bridge construction. Photo 68 on page 63 shows an alternative to the threaded rod used on the Tye River Bridge – a turnbuckle connected to an eyebolt. This alternative is not as desirable as the threaded rod for the
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...