



Creegan+D'Angelo  
INFRASTRUCTURE  
ENGINEERS

---

Petaluma and Santa Rosa Railroad Trestle  
Limited Structural Assessment  
Petaluma, California

---



ENGINEERING YOUR SUCCESS

---

November 26, 2007

## Table of Contents

|   |    |
|---|----|
| 1. Executive Summary .....  | 1  |
| 2. Introduction and Background.....                                     | 1  |
| 2.1. Scope of Work.....   | 1  |
| 2.2. General Description of Trestle .....                               | 2  |
| 3. Trestle Field Assessment .....                                       | 5  |
| 3.1. Methodology.....   | 5  |
| 3.2. Field Evaluation .....   | 5  |
| 4. Structural Analysis.....   | 10 |
| 4.1. Pedestrian Load .....  | 10 |
| 4.2. Trolley Load.....  | 11 |
| 5. Rehabilitation Recommendations .....                                 | 12 |
| 5.1. General structural rehabilitation Recommendations.....             | 12 |
| 5.2. Component-Specific structural rehabilitation Recommendations ..... | 13 |
| 5.3. Future performance .....   | 14 |
| 5.4. Rehabilitation Costs.....  | 15 |
| 6. Limitations.....   | 16 |
| 7. Pile Rating, Cost Estimate Tables, and Drawings.....                 | 17 |
| Appendix A: Resistograph Plots.....                                     | 30 |

## **1. EXECUTIVE SUMMARY**

This report presents the results of Creegan + D'Angelo's evaluation of the 85-year-old, 500-foot-long historic timber railroad trestle located on the south bank of the Petaluma River, in downtown Petaluma. The purpose of the evaluation was to determine the adequacy of the trestle to carry a pedestrian load, or a trolley load. The evaluation consisted of observation of trestle components, nondestructive testing with a Resitograph, engineering analysis, development of rehabilitation schemes, development of rehabilitation construction costs, and preparation of this report.

Originally constructed to carry electric freight rail, the trestle is now out of service and access is prohibited. The trestle consists of two abutments and 35 bents typically constructed of five, vertical timber piles supporting a wood bent cap and built-up timber stringers. The stringers support wood railroad ties, steel rail, and outrigger members that support wood decking. The field observation and testing revealed that the trestle is deteriorating. Between bents 14 and 19 the trestle has displaced laterally away from the bank, possibly due to slope failure of the bank. Nearly all of the piles exhibit section loss in the intertidal zone, in some cases up to three inches from the original pile surface. Some piles exhibit decay at the tops of the piles where they meet the bent caps. Stringers are decayed at the interfaces of individual members. Bent caps are generally in good condition. Outriggers and decking were not observed from above, but are covered with decaying wood sheathing and are likely damaged.

Engineering analysis indicates that the trestle is currently not capable of supporting either the pedestrian load or the trolley load. Rehabilitation costs are estimated to be \$2.0 million and \$2.8 million to upgrade the trestle to pedestrian load-carrying capacity and trolley load-carrying capacity, respectively.

## **2. INTRODUCTION AND BACKGROUND**

### **2.1. SCOPE OF WORK**

Creegan + D'Angelo Consulting Engineers is part of a team retained by the City of Petaluma to evaluate the 500-foot-long historic railroad trestle located on the south bank of the Petaluma River, adjacent to downtown Petaluma. Other members of the team consist of Seth Bergstein of PAST Consultants, LLC, who performed an historic evaluation of the trestle, and Kevin Flynn of Flynn and Associates, who evaluated issues pertaining to the performance and behavior of the trestle's wood components. Their evaluations are contained in separate documents.

The scope of Creegan + D'Angelo's work was to evaluate the existing trestle for two load conditions, as follows: 1) Pedestrian load, and; 2) Trolley load. The evaluation consisted of field investigation of the condition of the existing trestle components, engineering analysis of the trestle under the two load conditions, development of rehabilitation schemes for the two loading conditions, preparation of construction cost estimates for the two schemes, and preparation of this report. As there was no geotechnical component to the project, geotechnical capacities of existing piles were

based upon the assumption that the piles are adequately founded for the two load conditions delineated above. Given that the trestle was designed for electric freight rail, this assumption is reasonable. Structural capacities of the piles were evaluated as described in the evaluation section of this report.

## **2.2. GENERAL DESCRIPTION OF TRESTLE**

The trestle is an approximately 500-foot-long timber structure constructed circa 1922 to carry electric freight rail load along the south bank of the Petaluma River adjacent to downtown Petaluma. The trestle is oriented in the east-west direction and extends from the end of Western Avenue east to the Petaluma Yacht Club. There is a floating boat dock of recent vintage north of the trestle that extends from the west end of the trestle at Western Avenue to a point beyond the east end at the Yacht Club building. A location map is shown in Figure 1, an aerial view of the trestle is shown in Figure 2, and an overall photograph is shown in Figure 3 below.

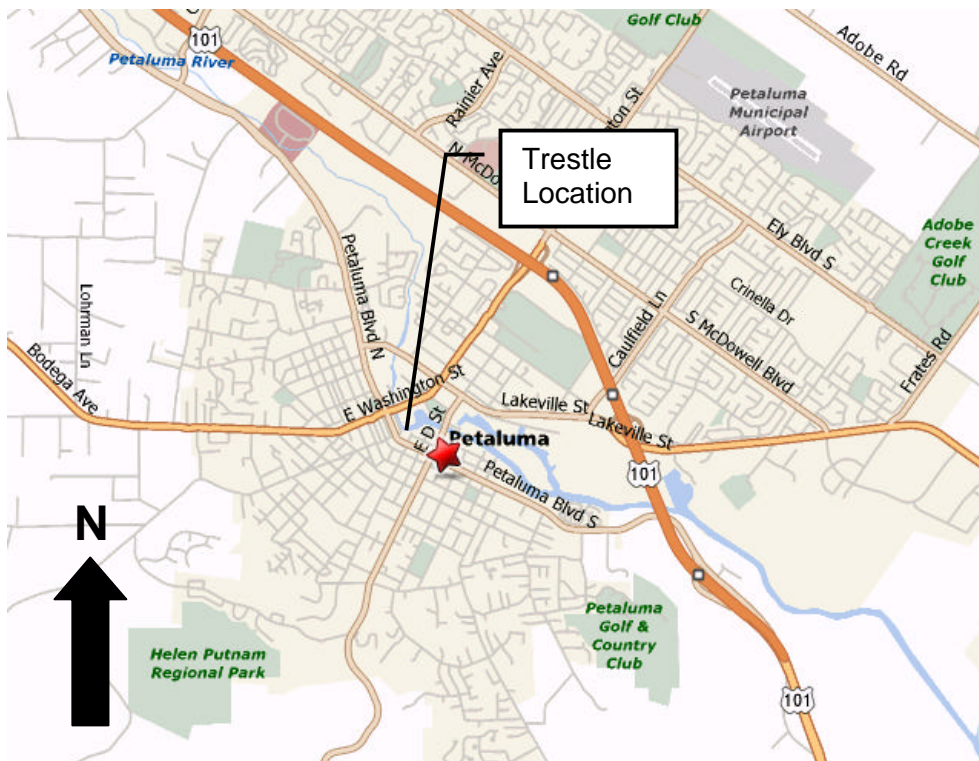


Figure 1: Location Map

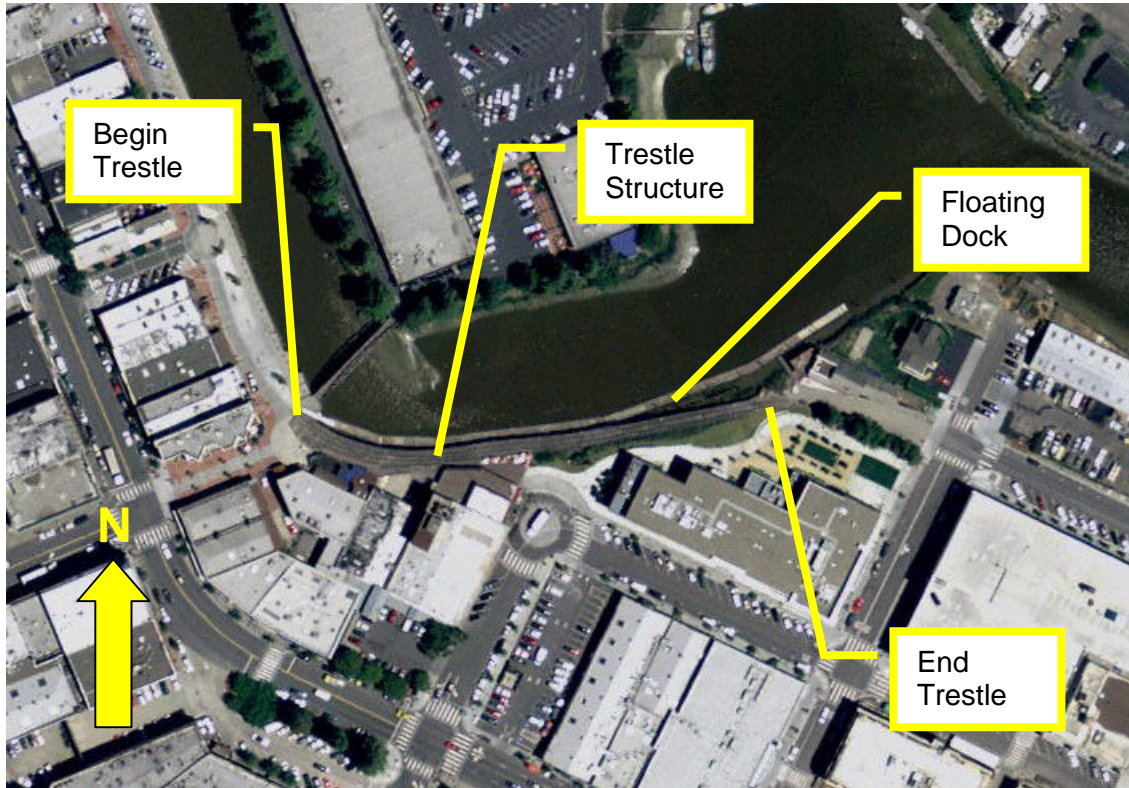


Figure 2: Aerial View of Trestle



Figure 3: Trestle Overview, Looking East

The structure consists of two abutments with 35 pile-supported bents in between that support deep, built-up timber stringers. The bents are spaced approximately 10 to 16 feet apart, and typically consist of five vertical piles supporting a bent cap. Piles typically range from approximately 12 to 14 inches in diameter, supporting an approximately 12 inch by 14 inch timber bent cap, oriented in the flat direction; a drift pin connects the pile to the bent cap. The piles are redwood, while the bent caps and stringers appear to be Douglas-fir. The bents are located adjacent to and over the bank and the piles are subject to inundation from the tidally influenced river. Refer to Drawing 10 at the end of the text for a depiction of a typical bent; a photograph of a typical bent is shown in Figure 4 below.



Figure 4: Typical Bent (Bent 29, looking east)

Each bent is diagonally braced with two members measuring approximately 4 inches by 8 inches, inclined at approximately 30 degrees, attached to the bent cap and the piles. There is one diagonal on each side of the bent. At the base of the diagonals are two horizontal braces of approximately the same dimension, one on each side of the bent.

Exposure of the pile/mud interface varies, depending upon the tide and location along the trestle. In some locations on the east end of the trestle the pile/mud interface is likely exposed most of the time, and submerged only at high tide, whereas at other locations at the west end of the trestle the pile/mud interface is submerged even at low tide.

The bents typically support two stringers, five feet on center, each consisting of three, sistered heavy timber beams approximately 8 inch wide by 17.5 inch deep that are bolted together. As revealed by visual inspection, individual beam members appear to span two bents; the joints of adjacent individual beams are probably staggered. Stringers are attached to the bent caps with vertical bolts. The stringers support approximately 8 inch by 8 inch square railroad ties spaced approximately one foot on

center, with every fourth tie bolted to the stringers below, and 3.5 inch by x 7.25 inch outriggers approximately four feet on center that support 1.5 inch by 9 ¾ inch decking and a metal framed, cable handrail. The ties support steel rails that are centered over the stringers. Most of the deck is covered by wood panel sheathing. A series of Douglas-fir fender piles approximately four feet on center is attached to the north side of the trestle.

### **3. TRESTLE FIELD ASSESSMENT**

#### **3.1. METHODOLOGY**

At the request of the City of Petaluma, the existing trestle was to be evaluated under pedestrian loading (100 psf) and trolley loading (80 kips). This evaluation consists of the following components:

1. Field evaluation of the existing condition of the structural members.
2. Engineering evaluation of the existing trestle to carry pedestrian and/or trolley loads.
3. Recommendations for modification of the trestle if the existing trestle is not sufficient to carry pedestrian and/or trolley loads.

#### **3.2. FIELD EVALUATION**

##### **3.2.1. Field Evaluation Methods**

The field evaluation consisted of visual examination of trestle components, and limited nondestructive testing of trestle components. Field evaluation occurred on August 7, August 27, and August 28, 2007.

Visual inspection can reveal areas of damage to the structural components, with such causes as fungal activity (decay), activity of insects or marine borers, fire damage, mechanical damage (such as from impact), and chemical damage (such as from crystallization of salts within the wood). Visual inspection was generally limited to areas that could be observed from the floating dock on the north side of the trestle, areas accessible from the bank, and several areas where a 26-foot-long scaffold stage was placed beneath the trestle. In general, the western two-thirds of the north side of the trestle can be observed from the dock (the dock is close to the trestle on the west side, but is increasingly distant from the trestle at the eastern side). In general, the eastern half of the south side of the trestle can be observed from the shore of the Petaluma River, whereas the western half of the south side of the trestle is generally inaccessible due to an existing retaining wall and a boardwalk and deck adjacent to the trestle. The top of the trestle was not accessed because it appeared to be unsafe. Piles were rated visually, as explained in more detail below. Pile ratings are shown in Drawings 2 through 5 located at the end of the text.

Nondestructive testing conducted by Creegan + D'Angelo consisted of Resistograph testing of a limited number of structural components. The Resistograph is an instrument

that advances a small-diameter, spade-tipped drill bit at a constant rate into wood. The resistance of the bit to rotation (torque) is measured and recorded electronically, as well as on a paper strip. Higher rotational resistance is associated with sound wood, and no rotational resistance is associated with decayed or damaged wood and voids within the wood. Objects within the wood (such as nails, spikes, or drift pins), growth rings, orientation of grain, and wood species can influence the rotational resistance and/or advancement of the bit. Seventy-one resistograph tests were performed on piles, bent caps, stringers, ties, and outriggers. Locations of resistograph testing are shown in Drawings 6 through 9 at the end of the text. Appendix A contains the resistograph plots. The number on the plot is referenced in the drawings.

### 3.2.2. Overall Trestle Observation

The top of the trestle had deteriorated wood sheathing covering a majority of the railroad ties and outriggers. From approximately bent 14 to bent 19, an approximately 70 to 80 foot distance, the trestle appeared to deflect laterally away from the bank, toward the centerline of the river. The piles in this location were inclined, and the deflection of the track and trestle was clearly visible from the top of the trestle. Low tide revealed a wood retaining wall in this location that appeared to retain a portion of the bank. It may be possible that movement or failure of the retaining wall resulted in lateral loading on the piles near the mud line, causing the trestle to move away from the bank. Reportedly, movement of an existing deck attached to the trestle may have contributed to lateral movement of the trestle. In general, the top of the trestle appeared to be approximately level.

### 3.2.3. Structural Piles

Visual inspection revealed that most of the piles have suffered some loss of cross section. Piles were categorized visually as "Good," "Fair," "Poor," and "Beyond Poor;" refer to Table 4 at the end of the text for a summary of pile visual ratings, and Drawings 2 through 5 at the end of the report for a graphic representation of the visual rating of the piles. In general, piles classified as good suffered no apparent damage or section loss. Piles identified as fair suffered section loss up to approximately two inches from the original surface of the pile. Piles identified as poor suffered section loss greater than approximately two inches, to approximately three inches from the face of the pile. Piles that appeared to exhibit a severe amount of section loss, including having holes that passed through the entire cross-section, were categorized as beyond poor. There were four piles that were rated "good," two rated "beyond poor," 118 rated "fair," and 49 rated "poor." Pile section loss appeared to occur near the top of the range of high tide (high tide as observed during the dates of the field inspections, which fluctuated as much as 6.1 and 6.3 feet on August 27 and August 28, 2007, respectively). Section loss was typically characterized by "necking down" to the minimum diameter and then transitioning back to a larger cross section. The condition of a typical pile with cross-section loss is shown in Figure 5 below.



Figure 5: Typical Pile Cross Section Loss – Bent 6 (nearest pile rated “fair”)  
Beyond the bent is a concrete pile associated with the deck adjacent  
the Mill building. Bent 6 is a four-pile bent.

It should be noted that the majority of piles were not immediately accessible to the observers, and as such the visual evaluation was carried out from the shore or the dock. Accordingly, these classifications should be understood to be a rough, quantitative evaluation made from as far as 15 to 20 feet away. Additionally, while some of the piles were visible from the mud line to the bent cap during low tide, others were not; that is, portions of some of the piles were submerged, even during low tide, and the entire pile was not visible. Piles were not visually inspected below the mud line. The lower portions of many piles that were exposed only at low tide exhibited a significant degree of marine growth, as shown in Figure 6 below.



Figure 6: Typical Marine Growth (Bent 16)

At the tops of the piles, some degradation of the surface and end grain decay was observed, and the wood fibers had become friable. In many locations, wood shims, sometimes consisting of plywood, had been installed between the bent cap and pile top. At some locations the tops of the piles did not appear to be level, and the bent cap was bearing on only a portion of the top of pile.

Resistograph testing was performed on a number of piles and other components, as indicated in Drawings 2 through 9. The resistograph testing performed in regions of reduced cross-section suggested that in these regions, the wood still appeared sound. That is, section had been lost, but what remained has load-carrying capacity. Resistograph testing at the tops of some of the piles revealed that at several locations, the piles did not appear to have lost cross section, but the wood had reduced capacity due to decay.

#### 3.2.4. Fender Piles

Fender piles and associated structural members at the trestle level were examined from the dock. These piles are Douglas-fir, and appeared to have been treated with creosote; at the tops of some piles was weathered metal flashing, most likely installed to protect

the end grain from water infiltration and decay. Some fender piles had cables attached; reportedly, some fender piles had begun to lean away from the trestle and toward or over the adjacent dock following a dredging operation in the river, and the City used cables to pull the fender piles back toward the trestle and away from the adjacent dock. Fender piles exhibited section loss similar to that of the structural piles. Structural members attached to the trestle adjacent the tops of the fender piles were significantly deteriorated or missing, and the connections of the fender piles to the trestle exhibited deterioration. Resistograph readings on two fender piles suggested that while the exterior appeared sound, there may be some capacity loss in the interior.

### 3.2.5. Bent Caps, Stringers, and Ties

Bent caps, stringers, and ties appeared to be in good condition. As was the case for the piles, access to stringers and bent caps was limited, and visual observation was made from the dock, scaffold stage, and/or the bank. In many cases, only portions of these components were visible, and inspection was made from distances on the order of 15 to 20 feet away. Resistograph readings on bent caps and ties were made from below, and generally confirmed that these members retain much of their original load-carrying capacity. Incision marks typical of pressure treating were visible on some of the bent caps.

Resistograph readings of stringers revealed that while these members appeared sound from the exterior, there was some decay at the interior surfaces where the individual 7.5" X 18" stringers are sistered together, as shown in Figure 7. It is likely that water travels down the joint surface between stringers and does not evaporate, providing an environment for decay. The Resistograph readings suggest that up to several inches of the interior stringer member may be decayed at each interface. Incision marks typical of pressure treating were visible on some of the stringers.

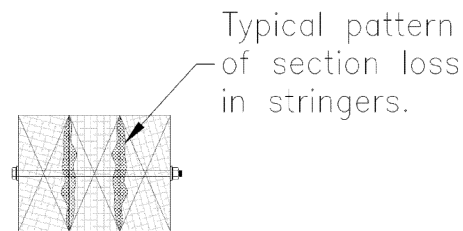


Figure 7: Typical Stringer Damage

In one location, sounding (striking the stringer with a hammer, and listening to the sound of the impact, and qualitatively gauging the rebound of the hammer) performed by Kevin Flynn indicated a potential hollow spot beneath the face of a stringer that visually appeared undamaged. Multiple strikes with the hammer broke through the face of the stringer to wet, decayed wood.

### 3.2.6. Summary of Inspection Findings

Load-bearing piles in general exhibited some section loss, generally less than three inches from the surface, for a loss in diameter of up to six inches. For a twelve-inch diameter pile, a two inch loss all around amounts to a loss of approximately 55 percent of the cross-sectional area, and a three inches loss all around amounts to a loss of 75 percent. However, the remaining section of pile at the location of section loss registered resistance on the resistograph and appears able to carry load. The tops of some piles registered low resistograph readings, suggesting decay and loss of load

carrying capacity, but did not exhibit section loss. Friable wood fibers were also evident on some of the piles. Based on the limited inspection performed as part of this study, bent caps appeared to be in acceptable condition. Stringers appeared to be in good condition visually, but resistograph testing indicated that there was decay at the joints between sistered members. The fender pile system appeared to be in fair to poor condition, with damage to the connections between the trestle and fender piles, and some decay in the interiors of the piles and section loss similar to that found on the structural piles. The inspection program also revealed that visual inspection alone is not sufficient to determine the level of deterioration of the wood components, as some damage was hidden from view and exposed via Resistograph testing.

#### **4. STRUCTURAL ANALYSIS**

The trestle was evaluated for two gravity loading conditions, as follows: 1) pedestrian loading; and 2) "trolley" load, specified as 80 kips (1 kip = 1000 lbs).

##### **4.1. PEDESTRIAN LOAD**

Because the trestle is a bridge structure originally designed for electrified rail, it falls into a gray area between modern structural codes. For loading on pedestrian bridges, and pedestrian loading on sidewalks of vehicular bridges, Caltrans typically assigns an 85 psf live load. For pedestrian walkways and regions of egress loading or areas of uncontrolled public assembly, the current building code, the 2001 California Building Code (CBC), assigns an unreducible live load of 100 psf. Given that the trestle could conceivably function as an uncontrolled assembly area, the higher, 100 psf live loading was used for the evaluation. The structure was checked for gravity loading under combined dead and 100 psf live loads, using the CBC load combination of Dead + Live loading, and allowable wood stresses consistent with the CBC.

The performance of a structural component can be expressed in terms of demand/capacity ratios (D/C ratios), which is the structural force or deflection demand on a member caused by the design load, divided by the force or deflection capacity of the member, as determined by the code. Components with D/C ratios less than 1.0 are considered acceptable, and those with D/C ratios greater than 1.0 are considered deficient.

A summary D/C force ratio for the trestle components under pedestrian loading is shown in Table 1 below. The larger of shear or bending moment demand capacity ratio for a particular member is shown.

Table 1: Pedestrian Load Demand/Capacity Ratios

| Component                          | Undamaged, full section | Reduced Section           |
|------------------------------------|-------------------------|---------------------------|
| Decking                            | 0.44                    | N/A                       |
| Outrigger                          | 0.77                    | N/A                       |
| Stringer                           | 0.38                    | 0.57 (assume 2/3 remain)  |
| Bent Cap                           | 0.36                    | N/A                       |
| Pile (14" diameter)                | 0.07                    | 0.24 (2" loss all around) |
| Pile (12" diameter)                | 0.13                    | 0.54 (2" loss all around) |
| Minimum Pile (6.8 inches diameter) | N/A                     | 1.0                       |

The table of D/C ratios above indicates that currently, the trestle is incapable of carrying the pedestrian load. However, as indicated in the table, the limiting components are piles with a reduced section diameter of approximately seven inches or less. The primary gravity load-carrying piles are the middle three piles, with the exterior piles contributing very little to the vertical capacity. Accordingly, with repair to a relatively small number of piles, the pedestrian loading can be accommodated. Other members would likely require rehabilitation, as discussed further in Section 5.

#### 4.2. TROLLEY LOAD

The trolley load specified by the City of Petaluma for this analysis is 80 kips. A worst-case wheelbase dimension was assumed for analyzing the stringers. The original electrified rail design loading is not known. While there is a nationwide standard for freight rail design (the AREMA code), there is no uniform standard for light rail (electrified passenger rail). Accordingly, the California Building Code allowable stress values for wood were used for analyzing the members; these values are similar to those used by Caltrans for vehicular bridges. According to the AREMA code and to the Caltrans Bridge Design Specification (which is the typical design code for new vehicular bridges in California) no impact factor is applied to live loads on wood bridges. Accordingly, no impact factor was used in this analysis for the trolley load, and only a dead load and live load combination was used. A pedestrian load of 100 psf, acting on the decking outboard of the track, was assumed to occur concurrently with the trolley load.

A summary of D/C force ratios for the trestle components under trolley loading is shown in Table 2 below. The larger of shear or bending moment demand/capacity ratio for a particular member is shown.

Table 2: Demand/Capacity Ratios

| <b>Component</b>             | <b>Undamaged, full section</b> | <b>Reduced Section</b>              |
|------------------------------|--------------------------------|-------------------------------------|
| Decking                      | 0.44                           | N/A                                 |
| Outrigger                    | 0.77                           | N/A                                 |
| Stringer                     | 0.81                           | 1.22 (assume 2/3 remain)            |
| Bent Cap                     | 0.54                           | N/A                                 |
| Pile (14" diameter)          | 0.20                           | 0.51 (2" loss from face, 10" diam.) |
| Pile (14" diameter)          | 0.20                           | 1.15 (3" loss from face, 8" diam.)  |
| Pile (12) diameter           | 0.28                           | 1.15 (2" loss from face, 8" diam.)  |
| Minimum Pile (8.3" diameter) | N/A                            | 1.0                                 |

As indicated above, D/C ratios for stringers and piles with reduced cross sections are greater than 1.0 and are thus unacceptable. Currently, the trestle is inadequate for the 80 kip trolley load. Significant repair would be required prior to applying a trolley load, and is discussed in Section 5.

## **5. REHABILITATION RECOMMENDATIONS**

### **5.1. GENERAL STRUCTURAL REHABILITATION RECOMMENDATIONS**

The trestle is over 80 years old, and the structural components have experienced deterioration, as revealed by limited visual inspection and nondestructive testing. The investigation performed by Creegan + D'Angelo is an appropriate first step in evaluating the trestle, and is consistent with the level of evaluation required for a Historic Structure Report. However, if the City or another entity pursues reopening the trestle for pedestrian or trolley loading, additional investigation of the primary structural members will be required in order to determine if specific structural components are to be rehabilitated or repaired. More thorough observation, including quantifying the original and reduced pile section diameters, and testing of all of the primary structural components, will likely be required. Additional investigation could include a dive pile survey to examine portions of piles that are not exposed during low tide; this survey could be performed in conjunction with other work, described below.

The trestle appears to have deflected laterally between bents 14 and 19; a survey would indicate if this deflection extends beyond the bents listed above. As part of a rehabilitation program, the cause of the trestle deflection should be determined, and mitigated. A geotechnical investigation of the river bank in this area would be required, and it is possible that a bank stabilization program consisting of a new retaining wall system would be required. Bents in this area will likely need to be removed and replaced.

Reportedly, dredging operations in the channel have affected the stability of the fender pile system adjacent to the trestle. Because the fender pile system is not intended to carry vertical load, it is possible that these piles were not driven very far into competent material and are thus more susceptible to damage from dredging than are the structural piles. However, given that the fender pile system is only a few feet from the outermost trestle pile, it may be possible that dredging operations have affected the load-carrying

capacity of the structural piles as well. Load-testing on a limited sample of structural piles would help quantify existing pile adequacy, and could be performed in conjunction with pile replacement between bents 14 and 19.

For both the pedestrian and trolley load conditions a seismic evaluation of the trestle will be required. The seismic performance of the structure will likely be highly dependent upon the load-bearing capacity of the piles, skin friction developed between piles acting in tension and the surrounding material, and the fixity or resistance to rotation of the base of the piles. This determination will require geotechnical investigation of the soil beneath the trestle, and of the existing piles.

## **5.2. COMPONENT-SPECIFIC STRUCTURAL REHABILITATION RECOMMENDATIONS**

Rehabilitation of specific trestle components is discussed below. A summary table of rehabilitation steps for pedestrian and for trolley loads is included at the end of Section 5.

### **5.2.1. Fender Piles**

The connection of the fender pile system to the trestle has experienced significant deterioration, and reportedly, individual fender piles have recently pulled away from the trestle and been pulled back into position and supported with cables by City of Petaluma personnel. It is likely that as individual connections continue to deteriorate, individual fender piles will continue to separate from the trestle; this may be a hazard to users on the adjacent floating dock or boaters nearby. If the fender pile system is desired for aesthetic or historical reasons, it is likely that a majority of the fender piles will need to be replaced. Otherwise, the fender pile system may be removed to ameliorate the potential hazard associated with leaning piles. The floating dock adjacent to the trestle prevents boats from striking the structural piles, negating the need for the fender pile system.

### **5.2.2. Structural Piles**

Most structural piles have experienced section loss, and some have experienced deterioration at the tops of some piles. As indicated in the demand/capacity ratio tables, some piles with reduced cross section will be inadequate for pedestrian or trolley load. Replacing an individual pile, or two or more piles within one bent, is challenging because there is not sufficient clearance to drive new piles between existing piles. It will likely not be possible to remove existing, damaged piles and install new ones in the same location for a number of reasons, as follows: 1) it may not be possible to completely remove existing piles. The piles may break during pulling, or there may be significant tension resistance such that it is not cost effective to mobilize equipment to remove them, and 2) piles are typically driven into undisturbed soil or rock strata. Driving piles into an area where there was an existing pile may compromise the capacity of the new pile. Accordingly, new bents can be constructed between existing bents in locations where existing piles are inadequate. Alternatively, it may be possible to add reinforcing steel and concrete around a damaged pile to repair it (concrete jacket). The tops of piles that have experienced end-grain decay will require repair, which could involve removing the

top of the pile and inserting an additional cap beam. The cap could be limited to the damaged pile, or extend over several damaged piles if they are adjacent to each other. Lastly, the tops of a number of piles do not fully support the bent caps, as the tops are not level; shimming caps will be required to ensure an adequate bearing surface for the bent caps.

#### 5.2.3. Bent Caps and Stringers

Bent caps appeared to be sound, and unless future testing and inspection indicates otherwise, it is anticipated that these members are adequate. Stringers exhibited decay at the inner 7.5"X18" member, and at the interfaces of this member with the outboard members. This deterioration will continue. While the calculations indicate that the stringers are adequate for the pedestrian load case, they are likely inadequate for the trolley load case. One method of repair would be to remove the rail and ties, remove and set aside the stringer components, and replace the stringer with a steel wide-flange section. Stringer components could be placed outboard of the steel to conceal it, but would not contribute to the load-carrying capacity. The wood stringer components could facilitate attaching railroad ties and outriggers to the stringers.

#### 5.2.4. Decking and Outriggers

The decking is weathered and its condition beneath the plywood is unknown. It is assumed that all the decking will need to be replaced. The outriggers appeared to be undamaged from below; however, the tops of the outriggers were covered with decking and/or sheathing and so their condition beneath these elements is unknown. Because a different railing system will likely be installed if the trestle is to be used for pedestrian or trolley load, it has been assumed that the outriggers will likely need to be replaced to support a new rail.

### **5.3. FUTURE PERFORMANCE**

The mechanisms causing deterioration of the structural components are ongoing, and will continue without mitigation. Areas sensitive to moisture infiltration and fungal attack, such as the stringer member interfaces, and the tops of the piles, will continue to degrade. Piles will likely continue to experience section loss from marine borer attack. The rate of deterioration is nonlinear in a number of aspects. As regards the loss of pile cross section, a linear rate of marine borer attack (as measured from the surface of the pile) results in an exponential rate of cross section loss, because the cross-sectional area of the piles is a function of the square of the diameter. Additionally, with treated members, deterioration is slow until the outer, treated shell of the wood member is breached, after which deterioration of untreated material occurs at a faster rate. At the interior of the redwood piles, extractives in the heartwood that retard decay are water soluble, and provide less protection against decay as time passes. Given the large number of variables, it is difficult to estimate the remaining life of the structure. In its current use (no load) and without mitigation, the trestle components will continue to deteriorate, but collapse is not eminent.

As indicated above, the trestle will require rehabilitation for pedestrian and trolley uses. Both uses require, at a minimum, global mitigation from bents 14 to 19, new decking and outriggers, some new ties, and pile repair. Given the effort and expense involved in this work, it is assumed that a rehabilitation program to stop deterioration of the structure would be undertaken. Ongoing deterioration of the piles could be mitigated by wrapping the piles with band-secured plastic wrapping. The wrapping would extend from the underside of the bent cap to one to two feet below the mud line. The wrapping deprives decay and marine agents of oxygen, thus inhibiting these mechanisms. Pile wraps could last fifteen to twenty years or more before they need to be replaced. Stringers and bent caps can be treated with fumigants to prevent decay. These are injected via new boreholes in the members. Fumigants would likely need to be reapplied at five-year intervals.

#### **5.4. REHABILITATION COSTS**

As part of the scope of work, Creegan + D'Angelo developed estimates of structural rehabilitation cost for the pedestrian and trolley load conditions. The extent of damage was extrapolated from limited nondestructive testing in order to generate cost estimates. This extrapolation affects the number of piles to be repaired and or replaced, the number of other structural components to be repaired or replaced, and the extent of bank stabilization. It was also assumed that heavy timbers for the rehabilitation could be obtained. Construction costs are highly variable, and can be affected by the number of contractors bidding on a job, the price and availability of materials (in this case, large timber members, concrete, reinforcing steel, pile wrapping material), the strength of the local economy and the number of local construction projects being built, the size of the project, unique aspects of the job, access, and client/owner requirements. In particular, limited interest from contractors, reflected in a small number of bidders on the project, could significantly increase the construction cost, from 50% to possibly 100% or more. Additionally, price escalation could be significant; that is, the price could increase 5 to 10 percent annually from the current cost. Cost estimates are shown in Tables 5 and 6 at the end of the text.

Additional work may be required for pedestrian or trolley load, possibly including, but not limited to, construction of additional egress "bridges" from the trestle, signaling, crossing arms, and the like. Such costs are not included in the estimates. Environmental studies, mitigation, and permitting costs may be required for construction in the waterway; such costs are not included in the estimates.

Tasks associated with trestle rehabilitation for pedestrian and trolley load conditions are shown in Table 3 below.

Table 3: Rehabilitation Task Comparison

| <b>Pedestrian Load</b>                      | <b>Trolley Load</b>                               |
|---|---|
| Detailed evaluation of (E) components       | Detailed evaluation of (E) components             |
| Geotechnical study of possible bank failure | Geotechnical study of possible bank failure       |
| Geotechnical study of (E) piles             | Geotechnical study of (E) piles                   |
| Mobilization                                | Mobilization                                      |
| Remove and dispose of rail, deck            | Remove and dispose of rail, deck, ties, stringers |
| Remove fender pile system                   | Remove fender pile system                         |
| Remove bents in global failure area         | Remove bents in global failure area               |
| Bank stabilization                          | Bank stabilization                                |
| New bents in global failure area            | New bents in global failure area                  |
| Repair tops of piles                        | Repair tops of piles                              |
| Pile concrete jacket                        | Pile concrete jacket                              |
| New decking, handrail                       | New stringers                                     |
| Pile wrap                                   | New decking, handrail                             |
| Fumigant treatment                          | Pile wrap   |
|   | Fumigant treatment                                |

Rehabilitation for pedestrian load is estimated to cost \$2.0 million, and rehabilitation for trolley load is estimated to cost \$2.8 million. These costs are for upgrades to carry gravity loading, and do not include ongoing inspection and maintenance costs.

It was assumed that all piles rated “beyond poor” and approximately half of the piles rated “poor” that carry significant load would be jacketed for the pedestrian load, and that all of the piles rated “poor” and one half of those rated “fair” that carry significant load would be jacketed for the trolley load.

**6. LIMITATIONS**

This evaluation was based on available information provided by the City of Petaluma, information retrieved by PAST Consultants during the historical research phase of the project, field observation, field observations made by Kevin Flynn and Associates, and limited nondestructive testing performed by Creegan + D’Angelo. The level of detail and testing was commensurate with the level of investigation required for a Historical Structure Report. Assumptions were made about the material strength of the wood observed in the field. These assumptions will affect the trestle load-carrying capacities calculated as part of the evaluation. Additionally, there was no geotechnical study performed as part of this evaluation, and assumptions about the geotechnical pile capacity are described above. As noted above, additional study will be required if the trestle is to be loaded with either the pedestrian or the trolley load.

**7. PILE RATING, COST ESTIMATE TABLES, AND DRAWINGS**

Table 4: Pile Visual Rating

| Bent Number   | Pile A | Pile B | Pile C | Pile D | Pile E | Pile F | Pile G |
|---------------|--------|--------|--------|--------|--------|--------|--------|
| Abut 1        | Fair   | Fair   | Fair   | Fair   | Fair   |        |        |
| 2             | Fair   | Fair   | Fair   | Fair   | Fair   |        |        |
| 3             | Fair   | Fair   | Fair   | Fair   | Fair   |        |        |
| 4             | Poor   | Poor   | Fair   | Fair   | Poor   |        |        |
| 5             | Fair   | Fair   | Fair   | Fair   | Poor   |        |        |
| 6             | Fair   | Fair   | Fair   | Fair   |        |        |        |
| 7             | Fair   | Poor   | Poor   | Fair   | Fair   |        |        |
| 8             | Fair   | Fair   | Fair   | Fair   | Fair   |        |        |
| 9             | Fair   | Fair   | Fair   | Poor   | Poor   |        |        |
| 10            | Fair   | Fair   | Fair   | Poor   |        |        |        |
| 11            | Fair   | Poor   | Poor   | Fair   | Poor   |        |        |
| 12            | Beyond | Fair   | Fair   | Fair   | Poor   |        |        |
| 13            | Fair   | Fair   | Fair   | Fair   | Beyond |        |        |
| 14            | Fair   | Fair   | Fair   | Poor   | Poor   |        |        |
| 15            | Fair   | Fair   | Poor   | Fair   | Poor   |        |        |
| 16            | Poor   | Fair   | Fair   | Fair   | Poor   |        |        |
| 17            | Fair   | Fair   | Fair   | Poor   | Poor   |        |        |
| 18            | Fair   | Fair   | Fair   | Fair   | Fair   |        |        |
| 19            | Fair   | Fair   | Fair   | Fair   | Fair   |        |        |
| 20            | Fair   | Fair   | Fair   | Fair   | Poor   |        |        |
| 21            | Fair   | Fair   | Fair   | Fair   | Poor   |        |        |
| 22            | Fair   | Poor   | Poor   | Poor   | Fair   |        |        |
| 23            | Fair   | Fair   | Poor   | Fair   | Poor   |        |        |
| 24            | Good   | Fair   | Poor   | Poor   | Fair   | Fair   | Fair   |
| 25            | Fair   | Poor   | Fair   | Fair   | Fair   |        |        |
| 26            | Poor   | Fair   | Poor   | Fair   | Fair   |        |        |
| 27            | Poor   | Poor   | Fair   | Fair   | Fair   |        |        |
| 28            | Fair   | Poor   | Poor   | Fair   | Fair   |        |        |
| 29            | Poor   | Fair   | Fair   | Fair   | Poor   |        |        |
| 30            | Fair   | Fair   | Fair   | Poor   | Fair   |        |        |
| 31            | Poor   | Fair   | Fair   | Fair   | Poor   |        |        |
| 32            | Fair   | Poor   | Fair   | Poor   | Poor   |        |        |
| 33            | Fair   | Fair   | Fair   | Good   | Poor   |        |        |
| 34            | Fair   | Fair   | Fair   | Fair   | Poor   |        |        |
| 35            | Good   | Good   | Fair   | Fair   | Fair   |        |        |
| Abut 2        |        |        |        |        |        |        |        |
| <b>Totals</b> | 35     | 35     | 35     | 35     | 33     | 1      | 1      |
| Good          | 2      | 1      | 0      | 1      | 0      |        |        |
| Fair          | 26     | 26     | 27     | 26     | 13     | 1      | 1      |
| Poor          | 6      | 8      | 8      | 8      | 19     |        |        |
| Beyond        | 1      | 0      | 0      | 0      | 1      |        |        |





**APPENDIX A: RESISTOGRAPH PLOTS**



---

To: Diane Ramirez, City of Petaluma

From: Chris Delp

Date: 11/16/07

Subject: **Petaluma and Santa Rosa Railroad Trestle Limited Structural Evaluation**

Job No.: 207003.00

---

Response to comments:

This memorandum accompanies the final report for the Petaluma and Santa Rosa Railroad Trestle Structural Evaluation. Comments (*italicized*) and responses are indicated below:

From City of Petaluma, California, Memorandum to Seth Bergstein and Reinhard Ludke, dated 10/31/07:

*Additionally, we would like to request a summary of the differences between this engineering analysis of the trestle and the previous 2002 CSW report provided to you. Please send a brief email/memo explaining the similarities and differences in what was done for each report and what the differences in the conclusions are.*

The CSW report appears to consist of an evaluation of the existing trestle and three schematic designs and costs for complete trestle replacement. Regarding the evaluation of the existing trestle, it appears that CSW took borings to determine the diameter of the existing piles. The capacity of a pile is a function of its unsupported length, pile diameter, and mechanical properties of the wood. It appears that CSW evaluated the effect of the reduced diameter of the pile on pile capacity, and also assumed that the mechanical properties of the wood were low, and concluded that the piles needed rehabilitation. CSW determined that the extent of deterioration would make rehabilitation of the existing piles infeasible.

For the Creegan + D'Angelo report, the mechanical properties of the wood were evaluated with nondestructive testing. The nondestructive testing indicated that while the cross-section of pile had been reduced, the mechanical properties of the wood that was remaining had not been significantly reduced, and that some of the piles were capable of carrying load. It appeared to Creegan + D'Angelo that piles that required rehabilitation could indeed be jacketed with concrete; a reinforced concrete jacket of sufficient thickness should be capable of carrying the required load. Detailed design would be required to determine the thickness of the jacket; if the jackets of adjacent piles interfered with each other, two or three piles could be jacketed together.

*Limited Structural Assessment Report, Tables 5 & 6: Public Works, along with Marianne Hurley, is concerned about the small difference (\$2M to \$2.8M) between the pedestrian load and trolley load. Is the handrail item for one side of the trestle or two? Does this item take into consideration the portions of the trolley that are not up against a deck or other solid surface?*

Regarding the “small” difference in cost between the pedestrian and trolley load rehabilitation schemes, note that the primary difference between the repair schemes is the number of piles to be jacketed. Decking and handrail replacement, removal of the fender pile system, and complete bent and stringer replacement in the area where the trestle has moved laterally near the mill building, are the same for each scheme. Accordingly, the primary difference in cost reflects additional jacketing for the trolley load. There is a 40% difference in cost between the schemes. Of course, if two new structures were designed, one each for pedestrian and trolley load, the cost of the trestles would likely be significantly different from each other, as the trolley-loaded trestle would be significantly more robust. Hypothetically, if all of the members of the trestle were undamaged with the exception of the fender pile system, and the area where the trestle has moved laterally, the cost to repair for either pedestrian or trolley load would be the same (remove the fender piles, and replace some bents where the trestle moved laterally) and there would be no difference in repair costs. Conversely, if all the members of the existing trestle were significantly deteriorated and replaced or repaired in kind (keeping the historical fabric, etc.) for pedestrian and/or trolley load, the cost of the repair would be the same for either load case because the repair for each case would be identical. Thus the difference in repair costs can range from zero to something greater, depending upon the nature of the damage.

For the purposes of the cost estimate it was assumed that there is handrail along both sides of the trestle for the entire length. However, it should be noted that whether or not a handrail was included for both sides of the trestle is a relatively minor issue compared with the other issues associated with repair cost, as discussed below. The handrail was combined with new decking for the cost estimate; if the handrail is broken out individually, the cost for a handrail on one side of the trestle is likely less than 2% of the overall construction cost. The cost estimate is an estimate, based upon a level of damage that was extrapolated from a limited number of tested members to all of the trestle members. Furthermore, in the absence of a geotechnical evaluation, it was assumed that the bearing capacity of piles is such that they are still capable of carrying trolley load (or trolley load plus the weight of the concrete jacket). The cost estimate is based on schematic-level repair schemes. Preparing detailed plans for repair, resulting in a more accurate cost estimate, was beyond the scope of our retention. A seismic evaluation (which would require geotechnical information) may precipitate additional work that is not reflected in the construction costs. Performing work in the river may require environmental permitting, the cost of which could be highly variable and the determination of which is beyond the scope of our retention. Determination of additional work required for pedestrian or trolley use, such as additional access “bridges” to provide additional egress, addition of signals and crossing arms, etc., was beyond the scope of our work.

Moreover, it should be noted that even with a complete set of construction documents to be bid upon, the construction cost can be highly variable, and can be affected by the number of contractors bidding on a job, the price and availability of materials (in this case, large pieces of wood, concrete, reinforcing steel, pile wrapping material), the strength of the local economy and the number of local construction projects being built, the size of the project, unique aspects of the job, access, and client/owner requirements. There may be a limited number of contractors

capable of performing the work. If there are only one or two bidders, it may be possible for the construction cost to be 50 to 100% greater than the estimate.

In the report we have expanded the discussion of the limitations of the cost estimate in section 5.4.

From Email from Diane Ramirez to Seth Bergstein and Chris Delp, 11/5/07:

*1. In the C+D report, tables 5&6, one line item is described as "global failure area". What is the "global failure area"? And does the scope & price include 5 piles, sway bracing and pile caps for each unit?*

The global failure area refers to the area adjacent to the Mill Building where the entire trestle has moved laterally. This note has been added to the cost estimate. The price to replace the bent includes all of the components of the bent.

*4. By John Fitzgerald's telling, the lateral movement in the tracks was not solely caused by the sliding of the soil along the bank, but that the piers for the deck adjacent to the trestle moving with the bank and therefore the deck attached to the piers and additionally the edge of the deck pushed on the deck of the trestle and caused the lateral movement.*

Please note that the report stated "it is possible" that the failure of the retaining wall caused the trestle to move laterally. This language has been changed to "it may be possible." Also, the phrase "reportedly, movement of an existing deck attached to the trestle may have contributed to lateral movement of the trestle" has been added.