

Redwood Water Tanks

National Park Service
U.S. Department of the Interior



Hawai'i Volcanoes National Park

Vanishing Treasures Program

Trip Report and Preliminary Treatment Recommendations



January, 2018

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Cover: One of the five remaining redwood tanks with the overhead pipe from the rain shed in the foreground.

Above: Close-up of one of the lugs that connect lengths of the steel retaining bands. Note the corrosion present in the lower band and on the threads of the upper.

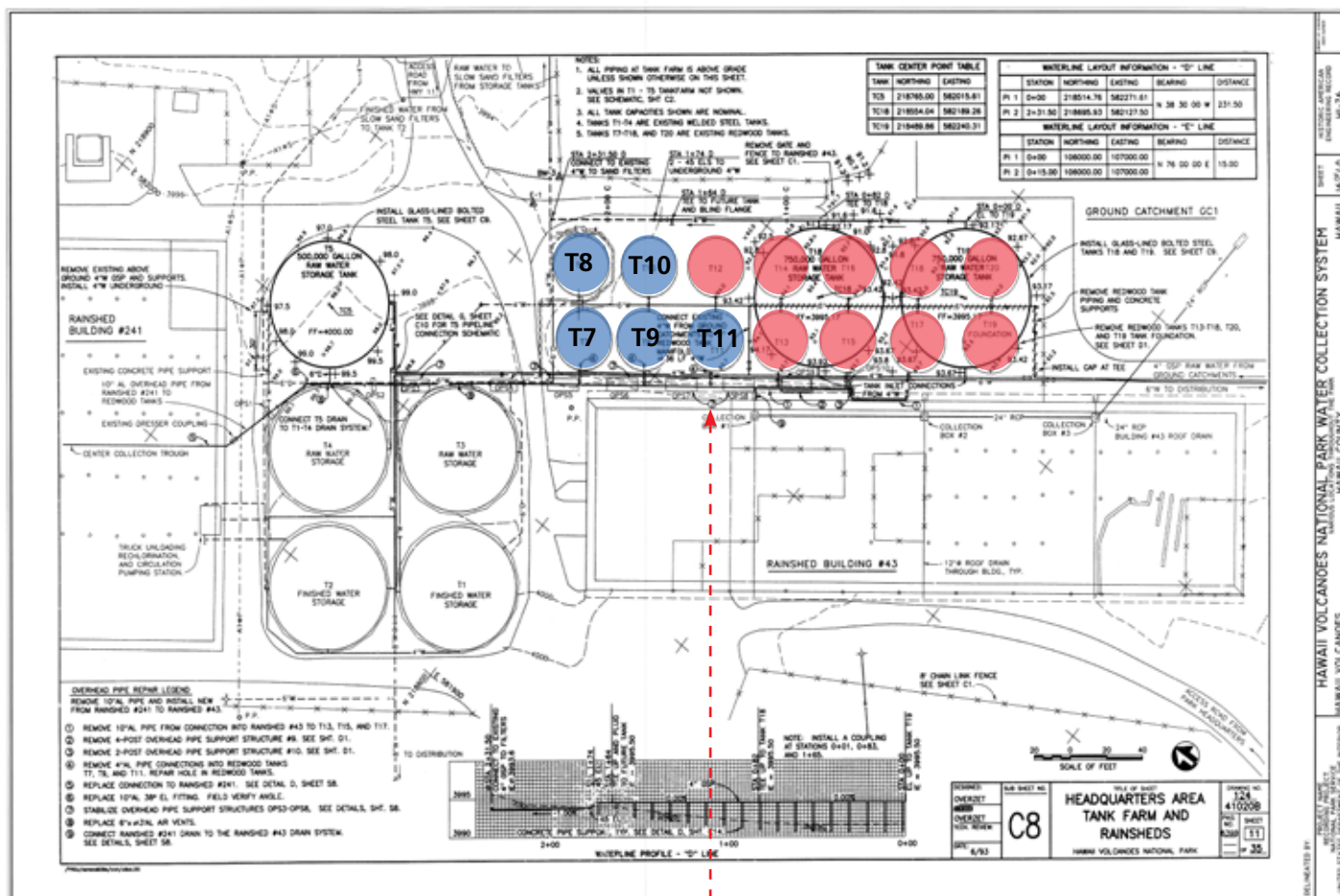


Figure 1a: Partial site plan of the tank farm and rain sheds showing the 14 historic redwood tanks arrayed in two rows at the top center. The five remaining tanks (T7 - T11) are shown in blue, while the tanks that were demolished to make way for larger metal tanks are shown in pink. Drawing from eTIC

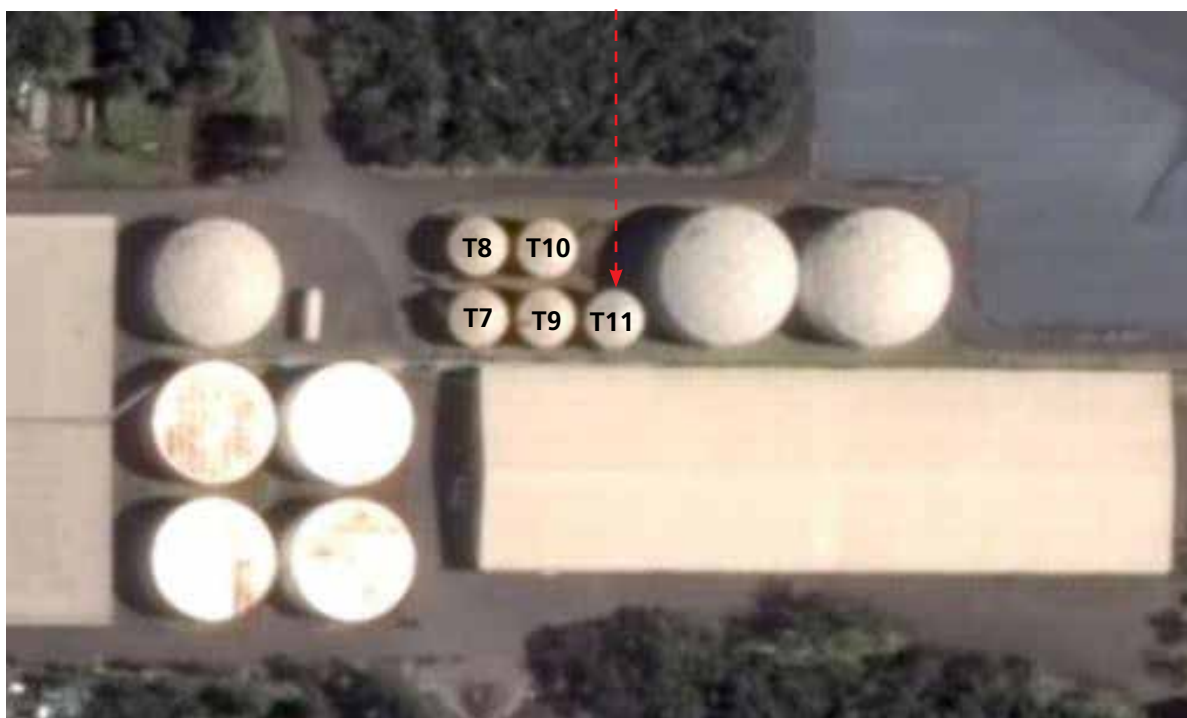


Figure 1b: Aerial view of the tank farm and rain sheds corresponding to the area included in the site plan in Figure 1a.

Background and Purpose

This trip report is the result of a site visit made on March 10, 2017, in response to a technical assistance request from Hawai'i Volcanoes National Park. The site visit, by Vanishing Treasures Historical Architect Randy Skeirik, was to provide guidance on the preservation of wood water tanks that had been used as a component of the Park's mid-20th century fresh water system, but have since been abandoned.

The Redwood Water Tanks

Acquired at various times after the conclusion of WWII, fourteen 80,000- to 100,000-gallon redwood tanks (*Figure 1a*) were installed in the headquarters area of Hawai'i Volcanoes National Park to store rainwater collected by an adjacent rain shed.

Eight 100,000-gallon war surplus tank kits were purchased on Oahu in February, 1947 and, according to the 1949 Superintendent's Report, three 80,000-gallon and one 100,000-gallon tanks were donated to the park by the Volcano House and moved from the Volcano House tank hill.

Specific entries from the 1949 Superintendent's Report include:

pg. 93 - Memo to Director:...(4) other large tanks were partially dismantled preparatory to moving them from Tank Hill to the approved site at the rain shed.

pg. 143 - Photo Caption:

(3) 80,000 gallon tanks and (1) 100,000 gallon tank removed from VH tank hill to be re-erected at rain shed.

pg. 144 - Photo Caption:

Photograph clearly shows (3) elevated tank foundations under construction for the previously reported 80,000 gallon tanks...all three 80,000 gallon tanks would have had to have been at the same height to operate together with the existing 100,000 gallon tanks; the elevated foundations are for the last (2) tanks erected on the outside row and the last tank erected on the inside row.

pg. 54 - Photo Caption:

The 80,000 gallon water storage tank in the background is complete except for roofing.

pg. 54 - Photo Caption:

Water storage tanks in park headquarters area. This part of the water plant consists of (12) 100,000 gallon tanks (3) 80,000 gallon tanks, and (3) 50,000 gallon tanks [under the rain shed].

As park needs grew, more water collection and storage capacity was needed, and nine of the 14 redwood tanks were demolished to make way for larger, metal tanks. (*See Figures 1a & 1b*) Additional metal tanks and a second rain shed were also constructed to the northwest of the original infrastructure. (*Figures 1a and 1b*)

Today, the remaining 5 redwood tanks (*Figure 2*) (4-100,000-gallon tanks and one 80,000-gallon



Figure 2: General view of the remaining redwood tanks. The tanks all hold 100,000 gallons except the tank on the front left which is smaller than the others, holding only 80,000 gallons.

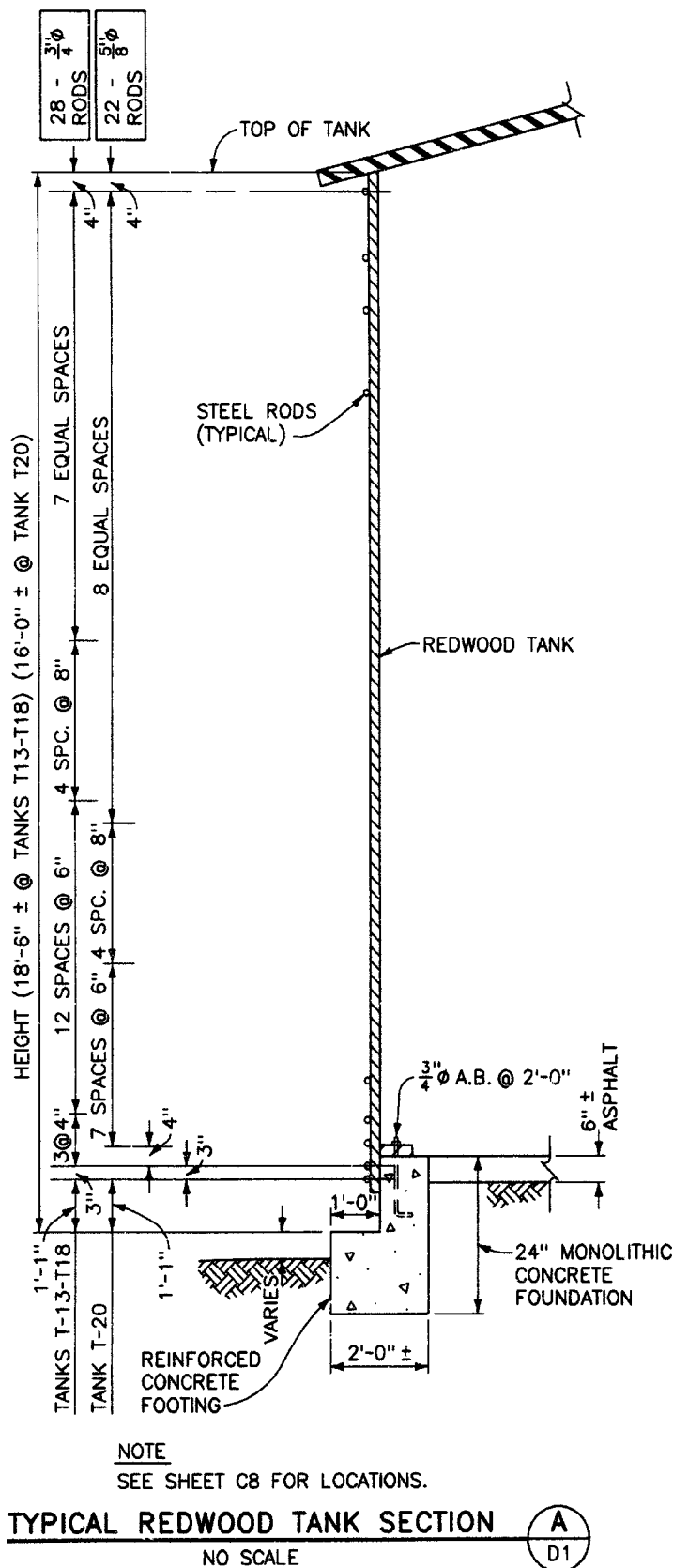


Figure 3: Cross section diagram through a tank wall shows the tank's concrete foundation and asphalt floor. The wall of the tank is composed of redwood staves bound together with steel rods. The tank is capped with a 12-sided corrugated metal roof.

tank) are no longer in use, and the park has considered demolishing them. However, because they are now considered historic, the VT Historical Architect was asked to assess the condition of the tanks, determine if it is possible for them to be preserved, and if so, to make recommendations for preservation treatments.

As it was only possible to examine the tanks from the ground, they were not inspected in detail. It was also not possible to inspect the insides of the tanks, so the following assessment and recommendations are based on a physical inspection of the exterior of the concrete foundations, the bottom six feet of the staves, and the lower steel bands. Based on this inspection, it appears the physical fabric of the tanks remains sound and that preservation and ongoing preservation of the tanks is possible.

In developing a preservation plan for these tanks, it is important to understand the dynamics of each tank as a system (Figure 3), and that the presence of water inside the tank is integral to the functioning of that system. Without the forces generated by the thousands of gallons of water typically stored in a tank, it is prone to failure and collapse.

The primary component of these tanks is the redwood staves that run the full height of each tank. The edges of each stave are slightly beveled so that they fit flush against the adjacent staves. (Figure 4) A watertight seal is achieved when the tank is

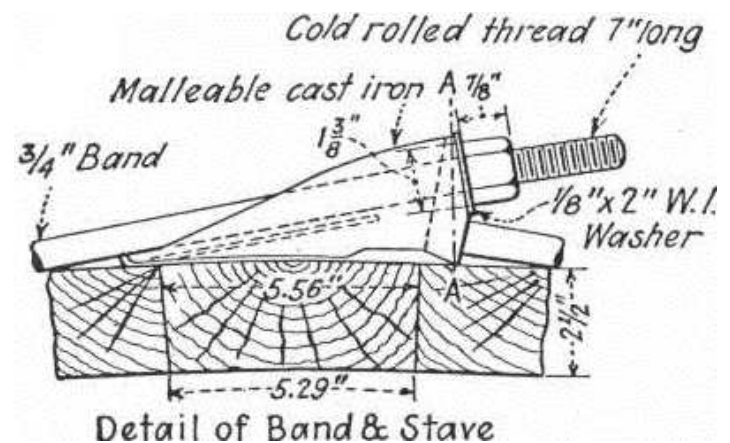


Figure 4: Cross section of typical wood tank or pipe construction showing how each stave is beveled (in this case 5.56" on the outside and 5.29" on the inside) to accommodate the curve of the tank or pipe. Also shown is a typical lug that is used to hold and tension the steel bands.

filled and the staves absorb water, swelling tightly against each other.

The structural capacity to resist the horizontal hydrostatic fluid pressure that is generated by the thousands of gallons of water contained in each tank is provided by a series of steel bands that encircle each tank and prevent the staves from being pushed outward.

The mild-steel bands on the HAVO tanks are either 3/4" or 5/8" inches in diameter and are formed from five individual sections that are threaded at each end and joined by steel lugs. (See Cover Page and Figures 4 & 5) Because the hydrostatic pressure is greatest at the bottom of a filled tank, the bands at the bottom are spaced more closely (six inches apart), with the spacing of the bands increasing as you progress up the tank, first to eight inches and finally to twelve inches at the top.

At ground level, a concrete footing both provides a firm foundation and holds the bottom end of the staves in place. (See Figures 3, 7, & 8) The bottom two bands, spaced only 3 inches apart, press the lower end of the staves against the foundation, effectively locking them in place. (See Figure 3)

At the tops, the staves rely on water pressure to push them outward and hold them tight against the upper bands. While it was not possible to examine the roof structure, it is likely that the roof framing and the outward thrust of the roof rafters are helping to hold the tops of the staves in place in the absence of water pressure in the now empty tanks.

Existing Conditions -General

A physical examination of the tanks from the ground indicated that they largely remain in good condition.



Figure 5: Close-up view of one of the lugs that connects the 5 sections of each steel band. The threaded connection with the nut (circled) allows the bands to be tensioned so that they compress the wood staves and resist the outward thrust of the water.

One significant exception is the mild-steel bands which are uniformly failing. Mild steel is not an alloyed steel and therefore does not contain significant amounts of anything other than iron. The lack of alloying elements, such as those found in stainless steels, means that the iron in mild steel is subject to oxidation (rust) if not properly coated.

Given the humid subtropical climate of HAVO coupled with the presence of corrosive sulfur dioxide from volcanic gases, the steel in the tank bands is showing significant corrosion, and in some places have rusted completely through. (Figure 6)

The black plastic that encases all of the steel bands may have been an attempt to "coat" the steel and protect it from corrosion, but given the ubiquity of the corrosion, this was obviously ineffective.

Existing Condition-Foundations

The reinforced concrete foundations are two feet thick at their base and extend eight to twelve inches below grade. One foot up from the bottom, the foundation steps back to become just one foot in thickness and continues up for an additional foot. (See Figure 3) "J"-bolts, which secure a 2 x 6 plate, are embedded in the top of the foundation. The purpose of the 2 x 6 plate is not clear, but, by swelling when wet, it may help to provide a water-tight seal at the point where the wood staves meet the concrete foundation.



Figure 6: The damp climate, coupled with the presence of sulfur dioxide from volcanic gases, has caused the mild-steel in the tank bands to corrode. Here the band has rusted completely through.

Despite some surface erosion, the concrete appears to remain in good condition. Soil deposition has raised the grade around the tank foundations, brining it up to and over the level where the foundations step back. This has allowed moss and/or grass to grow right up to the base of the tanks creating a situation where the end grain of the staves has become susceptible to prolonged exposure to moisture. (Figures 7, 8 & 9)

Because the tops of all the tanks must be at the same height in order for them to work as a system, the smaller 80,000-gallon tank (T8) has been placed on an earthen platform that is supported on the south by a low stone retaining wall. (Figure 10)



Figure 8: Changes in soil levels have covered the bottom halves of the footings allowing grass to grow right up to the base of the tanks.



Figure 9: Close-up of the base of a tank showing where soil had covered the foundation's step-back allowing grass to grow on top of the concrete. This condition can potentially accelerate the deterioration of both the wood staves and the concrete.



Figure 7: At the base of the tanks, the concrete footing steps back approximately at grade level. Soil deposition has both raised the grade around the tanks and allowed soil to accumulate on top of the footing, supporting the growth of both grass and moss. This will accelerate the deterioration of both the concrete footing and wood staves.



Figure 10: Tank 8 sits on an earthen platform retained by a rubble stone wall

Recommended Treatment-Foundations

Grade should be adjusted around the foundations to restore a condition like that shown in Figure 3, where the soil level is held below the level of the step-back. At the same time, it is important to slope the grade away from the base of every tank so that water will drain away from the foundations and not pool against the foundation. All accumulated soil, grass, and moss should be removed from the top of the step-back. This should be kept clear and clean so that the bottom ends of the staves are not exposed to additional moisture and can quickly dry when they are wetted.

Existing Condition-Staves

The staves form the wall of the tank, support the roof of the tank, and contain the water when the tank is filled. As such, staves are a primary structural component of the tank. (Figure 11) The



Figure 11: Close-up of tank staves and bands. Note that because the tank is empty there is no horizontal hydrostatic pressure to push outward and hold the steel bands in place. Nails have been used to prevent the bands from slipping down.

staves of the HAVO tanks, made from clear redwood, possess a natural decay resistance. When inspected from the ground, the accessible portions were found to be good condition with no apparent, significant issues. (Figure 12)

However, it has been reported by park staff that the staves have experienced deterioration on their inside faces. Because the 2017 inspection involved only an exterior assessment, this could not be confirmed. If true, it will be necessary to establish the full extent of the deterioration.

Recommended Treatment-Staves

As far as they could be inspected, the staves were found to be in good condition on the exterior. To keep them that way, the foundations should be cleared as previously described to help keep the staves dry and to allow them to dry more quickly when wetted.

Additionally, where moss, mildew, fungus, or lichens are growing on the wood (Figures 12 & 13),



Figure 12: Wood is most vulnerable to water penetration at the end grain, yet even in areas where grass was growing directly under the ends of the staves, an icepick would penetrate less than an eighth of an inch, indicating that the staves remain in good condition.



Figure 13: As seen here, close proximity of vegetation, including grass, shrubs, and trees can create microclimates that prevent drying and encourage the growth of moss and fungus on the wood staves. The area around the tanks should be kept clear of vegetation and the grass should be kept short.

the surface should be cleaned with a 10% bleach solution using a natural bristle brush. In areas where regrowth is likely to occur, especially at their bottom ends, the staves can be treated with a liquid borate product such as Boracare. It will be particularly beneficial to treat the end grain of the wood, getting the wood to absorb as much of the borate as possible.

Because the staves are not painted, the borates are likely to leach out of the wood fairly quickly and the treatment may need to be reapplied as frequently as once a year. Monitoring for fungal growth or deterioration will help establish the frequency for which reapplication will be most beneficial.

Additionally, ultraviolet (UV) radiation will break down the lignin in the wood, resulting in surface loss. This is often expressed as “raised grain”. (Figure 14) While this was not observed to be a



Figure 14: Ultraviolet degradation is one cause of raised grain, as seen here.

major problem, some staves were showing areas of raised grain, and a more detailed inspection may reveal more evidence of this type of UV degradation.

If UV degradation is found to be a significant problem, there is a treatment that has been developed specifically for unfinished redwood that will protect it from UV radiation. (See Attachment 1) If, upon close inspection, significant surface loss is noted, it would be worthwhile to test this treatment on the tanks.

This UV protectant has only been applied in arid environments, where it has been found to last up to five years. Its longevity in a subtropical climate has not been established

For as long as the UV treatment does remain in place, it will also serve to prolong the effectiveness of the borate treatment because it will consolidate the wood’s surface, helping to prevent the borate from leaching out. For this reason, the UV treatment should only be applied after the liquid borate treatment.

On the interior, if decay is found but does not extend beyond the surface so that the staves are not structurally compromised, the condition could be addressed with an application of a liquid borate. This will help to prevent further decay and, because the inside face of the staves are protected from the weather, this should prove to be a relatively longterm treatment.

If some staves are found to be structurally compromised, it will be necessary to determine which staves in each tank are damaged and, since the exact form of the roof structure is not known, whether or not they are involved in supporting the roof structure. Since no damage is expressed on the exterior, and because the tanks will be preserved empty, it may be possible to retain the damaged staves that do not help support the roof. While the proper treatment cannot be determined until actual site conditions have been established, it may be possible to stabilize deteriorated, non-structural staves with an epoxy consolidant and leave them in place.

Deteriorated structural staves will need to be replaced or supplemented. Exact treatments cannot be recommended until actual conditions have been established, but replacement staves may

be available through the original manufacturer, International Tank and Pipe Co., or through salvage companies. Replacement staves should match the original in both size and species. A possible alternative would be to provide supplemental structural support on the interior of the tank where it would not be visible. The design of any supplemental supports would be dependent on actual site conditions and the structure of the roof itself.

The possible presence of deterioration on the interior of the tanks suggests that the tanks are not adequately ventilated. Because the tanks are being preserved empty, methods for venting the tanks to equalize atmospheric conditions inside and out should be explored - especially if interior deterioration is found. Currently, the tanks appear to only be vented through small (approximately 2 inch diameter) holes that are located in the soffit - one to either side of each roof hip. (Figure 15)

In order to improve ventilation, it would be ideal to create openings at the base of each tank and also at roof level to allow air to be drawn up through the full height of the tanks. It might be possible, for instance, to use a concrete core bit to create a number of holes in the foundation between the bottom of the staves and the point where the foundations step out. Connecting holes would need to be drilled down through the asphalt floor to connect with the foundation holes.

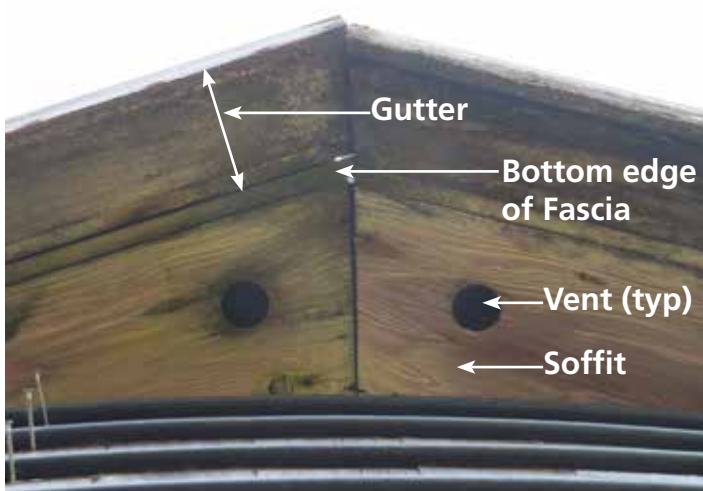


Figure 15: Looking straight up the outside of the tank, small holes can be seen in the roof soffit - one to either side of each roof hip. These appear to be the only means of exchanging air between the inside and outside of the tanks. This photo also shows the bottom of two intact sections of the wood gutter.

This would then let air in at the base. These openings would need to be screened to prevent the entry of animals and insects.

At the tops of the tanks, additional vents could be created in the soffits, or a minimally intrusive vent could perhaps be installed at the peak of the roof, or vents could be fabricated to run along the roof hips similar to a ridge vent. Like the vents at the base, these openings should be screened to prevent the entry of birds, animals or insects.

Existing Condition-Steel Bands

Five-part steel bands encircle each tank, spaced from 6 to 12 inches apart. (See Figures 3, 5, 6, 11 & 16) As already noted, many sections of the steel bands are in poor condition. The humid, sub-tropical environment coupled with the corrosive effects of sulfur dioxide from volcanic gases have had a devastating impact on the mild steel of the band sections, many of which have begun to corrode at multiple points around the circumference of the tanks (Figures 5, 6, 16 & 17).

Currently, on at least one tank, the two bottom bands - which are critical for holding the bottoms of the staves in place against the concrete foundation - have both rusted completely through. (Figure 17) While this tank appears to remain stable, the failed bands have the potential to structurally compromise this tank.



Figure 16: General view of tank bands showing areas of corrosion. Corrosion is widespread with a number of bands having rusted completely through. In addition, all of the threaded ends have corroded to the extent that the bands will need to be cut for them to be removed.



Figure 17: On one tank, both of the bottom two bands have rusted through. Because these two bands compress the staves against the concrete foundation, this tank may be structurally compromised. Compression at the bottom end of these staves should be reestablished as quickly as possible.

In addition, the threaded ends on all of the bands have corroded, making it impossible to turn the nuts that are used to tension or remove the bands. (Figure 5) As a result, in order to tension, or to remove and replace any band sections, they will have to be cut.

Despite the poor condition of the bands, the lugs all appear to remain in good condition and can be retained and reused, provided that they can be separated from the corroded bands without damage.

Recommended Treatment-Steel Bands

Each band is made from 5 separate, approximately 20-foot-long sections that are joined with bolted connections at steel lugs. (Figure 5) Concern has been expressed that when a band corrodes all the way through, it may snap, flying out from the tank with the potential to cause injury or damage. Because there is no water in any of the tanks, and therefore there is no outward pressure, the bands are no longer in tension and it is highly unlikely that they will snap. Instead, they will more likely just break apart and remain in place as long as the nails that are holding them remain intact.

Nevertheless, the corroded bands will need to be replaced and eventually all of the remaining bands will rust through and require replacement. Replacement is particularly urgent for the tank

that has lost both of its bottom two bands (Figure 17) because this may structurally compromise the tank. These bands should be replaced as quickly as possible. Replacement bands are available from the original manufacturer, National Tank and Pipe Company (now International Tank and Pipe Company) of Clackamas, Oregon.

As noted above, in order to preserve the tanks, it will be critical to maintain tight compression of the staves at the base. This is accomplished by tightly fastening the bottom two bands, pressing the staves between the bands and the concrete foundation.

It will also be important to create some form of compression ring on the interior of each tank at the top end of the staves (see *Recommended Treatments-Roof*, below) and to then provide compression against this ring using a tightened band around the outside of the tank. By compressing the staves at the top and the bottom of each tank, the staves will be locked in place, holding the tanks together and preventing collapse.

Because the tanks no longer contain water, multiple, closely spaced steel bands are no longer necessary. Because strength in tension is not required by the majority of the bands on an empty tank, alternatives to expensive, and vulnerable, mild steel bands may be available. For instance, because the bands on these tanks are covered with black plastic, it may be possible to replace all of the non-structural bands with black plastic tubing. A firm called Netafim produces a black polyethylene tubing is both UV and acid resistant, and that can withstand heat, direct sun and harsh chemicals. It is available in 3/4 and 1 inch tubing diameters that should closely match the diameter of the plastic housings on the existing bands and it comes in coil lengths of up to 1000 feet. (<http://www.netafimusa.com/greenhouse/products/system-components/polyethylene-tubing/>)

A short length of threaded rod (preferably stainless steel) could be epoxied into each end of each section of tubing to receive the tensioning nuts, thereby closely replicating the appearance of the existing bands. If the hollow tubing proves too insubstantial, it could be filled with something like sand to provide additional weight.

While the majority of the bands can be replaced with non-functional replicas, it will be critical

to have functioning steel compression bands in place at the top and bottom of each tank, and to have perhaps three additional lightly tensioned steel bands equally spaced between those top and bottom bands.

Finally, where non-functional bands are used, they will not be in tension around the tank so they will tend to slip down. The problem of loose bands is currently addressed by supporting the bands with nails driven into the staves at regular intervals. (Figure 11) In places where the nails have come loose, the bands have begun to slip downward. (Figure 18)

While the nails currently in use are not overly intrusive when viewed from a distance, it may be possible to find something that will hold the bands more securely yet be less visible. One possibility could be black plastic coated nail straps similar to the one shown above. The black plastic coating on the nail straps would blend with the black plastic on the bands, helping to reduce their appearance. Nail straps are available from companies such as Dottie. (<http://catalog.lhdottie.com/viewitems/nail--straps/plastic-coated-nail-straps>). (Figure 19) Whatever type of fastener is ultimately used, galvanized metals should be avoided since



Figure 19: In place of shiny silver nails, something like this black plastic coated nail strap could be used to less conspicuously lock the bands in place.

the zinc in the galvanizing will react with chemicals in the redwood and stain the wood. Stainless steel and aluminum are the preferred metals to use for fasteners in redwood.

Existing Condition-Roofs

Each tank is covered by a 12-sided pyramidal roof. (Figure 20) Without access to ladders or scaffolding, it was only possible to assess the roofs from the ground or with photographs. Further, without access to the interiors of the tanks, there is no way to know the nature or condition of the roof structure. Cross section drawings of the tanks (Figure 3) only show the roofs conceptually without any hint of their actual construction.

A visual inspection from the ground revealed white-finished corrugated aluminum panels with matching white metal hip caps. At least one of the tanks, Number 7, has a hatch in the roof to provide access to the interior of the tank. (Figure 21) It stands to reason that the other tanks also have roof hatches, but they were not observable from the ground.



Figure 18: Without the swelling and outward pressure that result from filling a tank with water, the circumference of an empty tank will shrink, releasing pressure on the steel bands. Where the nails supporting the bands have failed, the lugs and bands are slipping downward (arrows).



Figure 20: Each tank has a 12-sided pyramidal roof that is covered with white corrugated metal panels. The tanks originally had wood gutters, sections of which remain on some tanks.



Figure 21: Tank 7 has an access hatch through the roof to provide entry to the tank interior. Logically every tank would need such a hatch. It may be that other hatches are not visible because they are closed (this hatch is open), and/or because they were not located in a position where the viewing angle allowed them to be seen from the ground. The corrugated aluminum roofing panels appear to be a light gauge and some may be working loose (circled).

Viewed from the ground, the corrugated aluminum roofing panels appear to be a relatively light gauge and, in some cases, the edges and corners appear to be coming loose. (Figure 21)

Some tanks retain sections of their original wooden gutters. (Figure 22) As can be seen in Figure 15, the wooden box gutters were installed directly against the fascia of the roof's eave. The gutter sections that remain are in poor condition, are choked with debris, and are supporting healthy vegetative growth. (Figure 22) On at least two tanks, the gutters have detached and are dangling



Figure 22: Some tanks retain sections of the original wood gutters. What remains is in poor condition, is choked with debris, and is supporting healthy vegetative growth. Visible here is the gutter's "downspout" (circled). As might be expected, the rain that fell on the tank roofs was also collected and channeled into the tanks.



Figure 23: The remaining gutters are in poor condition and some, as seen here, are detached and dangling precariously above the ground.

precariouly. (Figure 23) The "downspouts" from the gutters (See Figure 22) drop only a few inches before making a 90-degree turn to conduct the rainwater into the tanks.

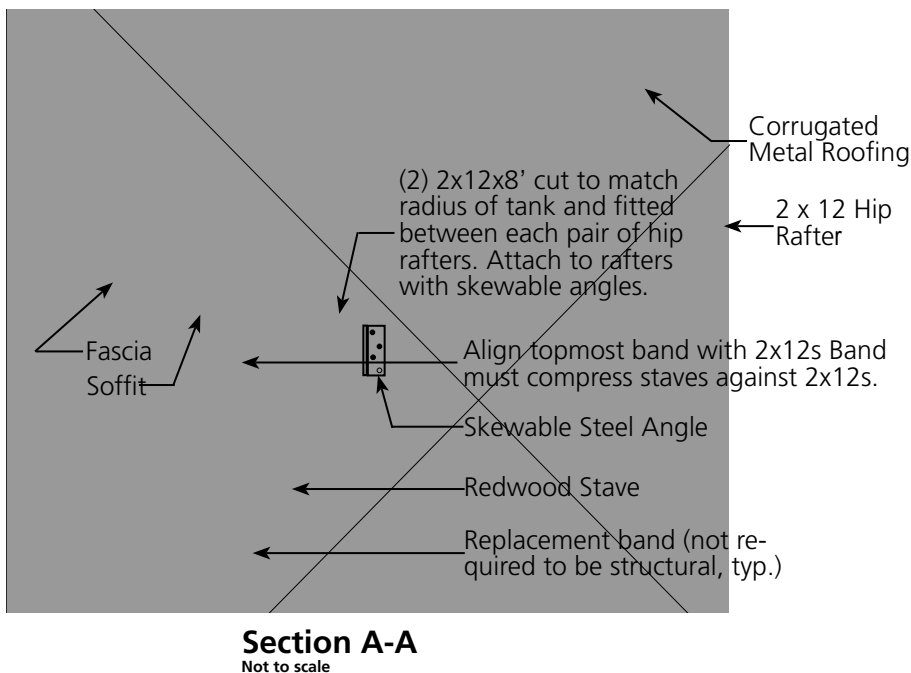
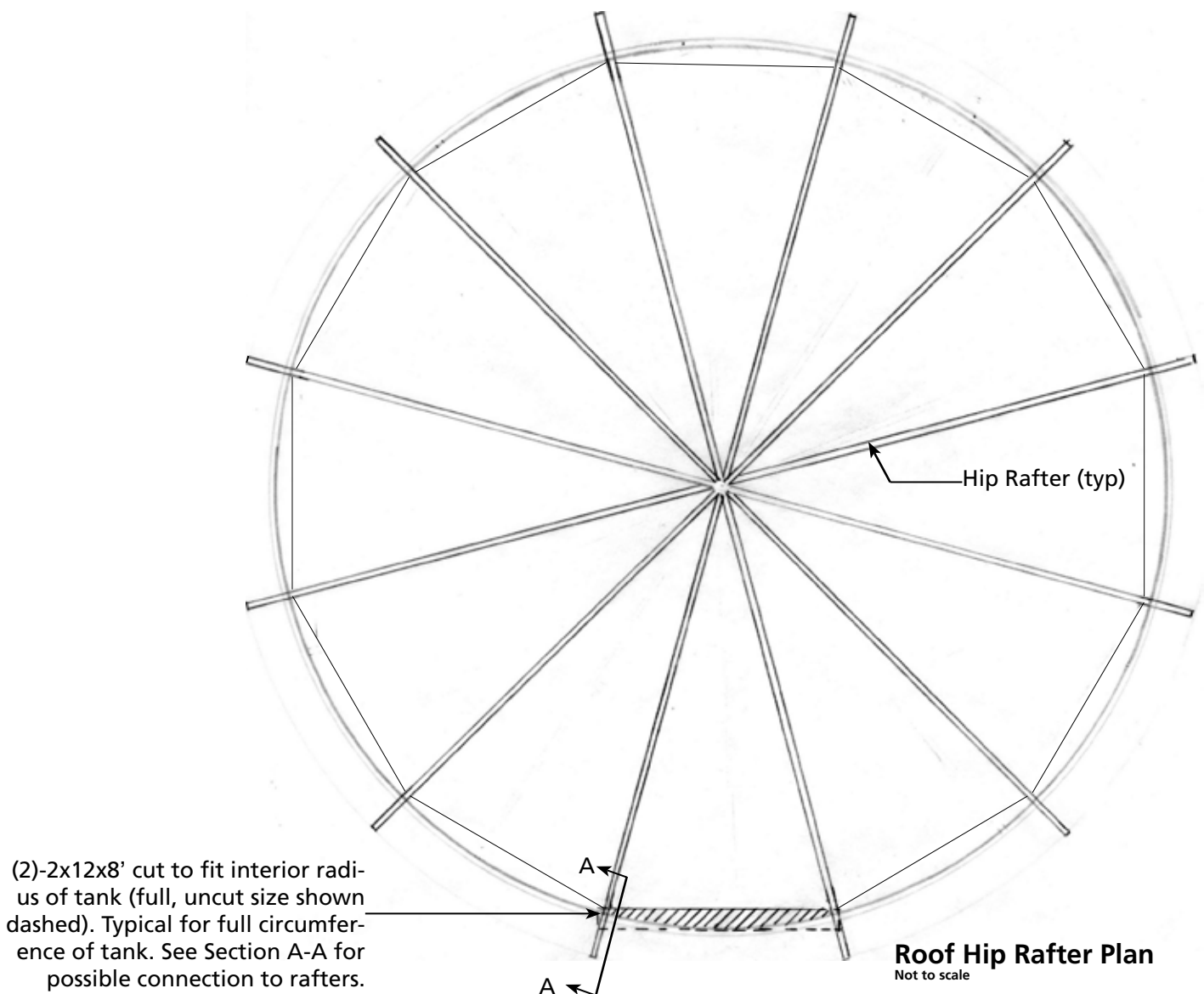
Recommended Treatments - Roof

To help with the long-term preservation of the tanks, it will be important to maintain the tank roofs to keep rain water out of the tanks so that the interiors stay dry. To that end, the roofs will require regular inspection and maintenance to repair damage and deterioration as it occurs. Venting to allow interior and exterior atmospheric conditions to equalize will also be important.

With the tanks preserved empty, it will also be critical to assure that there is adequate outward pressure on the tops of the staves to prevent them from collapsing inward. (Figure 24) Because all sloped roofs develop an outward thrust, it should be possible to use the roof structure to help achieve this objective.



Figure 24: Although a smaller tank in a different location, this clearly illustrates what can happen to an empty tank. With no water in the tank, there is no outward pressure on the staves. As the staves dry and shrink, gaps will open between the staves and, once there is enough space for one stave to fall inward, the rest will quickly follow.



Figures 24a & b: Figure 24a (top) shows a hypothetical roof framing plan - based on the assumption that 2x12 hip rafters are used. It is impossible to surmise the nature of the framing between the hip rafters. Figure 24b (left) illustrates how the rafters may relate to the stave wall of the tank. If possible, 2x12s could be cut to match the radius of the tank and installed inside the tank between the hip rafters. These should align horizontally with the topmost steel band in order to compress the tops of the staves.

Hypothetical Roof Framing and Conceptual Design for Installation of a Compression Ring at the Top of the Tank - no scale

Because these tanks have not collapsed, they may already have some internal structure that is providing the necessary outward thrust. Without the ability to inspect and assess the tank's interiors and roof framing, it is impossible to know.

If they do (See Figure 25), no changes may be required. If they do not, then support (a “compression ring”) should be added that will provide an outward force to counter the inward force from the topmost steel band on the outside of the tank. This will effectively sandwich the tops of the staves between the band and the newly installed compression ring, locking them in place. (See Figure 24b)

Without knowing the exact construction of the roof framing, it is impossible to create a specific design for this internal compression ring - if it is needed. Figures 24a and 24b serve to illustrate the concept, and may serve as a point of departure for a design based on the actual conditions. All of the internal framing should be inspected, and necessary repairs made, before adding any additional framing.

With the staves safely locked in place, either by existing framing or by the new compression ring, the existing roofing should be systematically inspected for loose and damaged panels. These should be reattached, repaired, or replaced as necessary.

The roof hatch on each tank should be located and inspected. All hatches should be watertight,



Figure 25: Although a scale model, this shows a tank with both a conical roof and framing that is flush with the top of the tank. Framing of this type, if it exists in the HAVO tanks, would help to prevent the inward collapse of the staves.



Figure 26: The effects of “splash” are clearly visible here. The line of gravel on the ground that runs along the base of the tank shows where the water from the roof hits the ground. That water splashes back against the bottom of the tank, wetting the bottom ends of the staves. This allows moss and fungus to grow on the wood, leading to deterioration.

be firmly attached, and have a mechanism for latching them in the closed position. All deficiencies, in any of these areas should be addressed.

As noted above in the section on wood staves, venting opportunities at the roof level should be explored. Hip vents, or a vent at the roof peak would provide the best ventilation and should be incorporated, if possible. Otherwise, methods for discretely increasing the size of the soffit vents should be explored.

Finally, the gutters should be restored. Without gutters, rainwater will run directly off the roof, hitting the ground at the base of the tanks. This water will splash back against the wall of the tank, contributing to the deterioration of the concrete foundation and wetting the bottom ends of the staves. (Figure 26) Wetting the staves in this way will encourage moss and fungal growth on the wood, leading to deterioration of the bottom ends of the staves.

In order to preserve the historic appearance, the new gutters should be constructed of wood, although pressure-treated wood attached with screws might be a good alternative to untreated wood and nails. Additionally, the gutter should be lined with metal with soldered connections to create a waterproof liner that will protect and preserve the wood.

Along with the restoration of the gutters, downspouts must be created to conduct the water down to the ground and away from the base of

the tanks. Given that the original “downspouts” directed the water into the top of each tank, an alternative must be found since we will want to keep the interiors of the tanks dry.

One possibility may be the creation of an internal downspout, using the route of the original downspout down from the gutter and into the tank, but then continuing a pipe down to the floor of the tank to connect with an existing drain. (Figure 27) It may also be possible to use an existing pipe that runs the full height of the exterior of the tank. (Figure 27) Either of these alternatives would preserve the historic appearance of the tanks while also providing an effective method of preventing splash and preserving the bases of the tank staves. Any solution will require that the new downspout be adequately sized to carry all of the water collected.

Conclusion

As noted above, the recommendations presented here were developed based only on an inspection of the tanks from the ground. The tops of the tanks, their roofs, and their interiors were not accessible. Actual conditions, especially those of the roof structure, may be very different from those conjectured here. Therefore, it is important to understand that some of these recommendations may not be applicable, and others may need to be adapted to meet actual conditions.

Nevertheless, treatments such as grade adjustments, cleaning of mold and fungus, and borate treatments, as well as replacement of critical steel

bands can and should proceed as quickly as possible.

In all cases, the intent should be clear that the objectives are to preserve as much of the original fabric as possible, to preserve the existing/historic appearance of the tanks, and to use appropriate substitute materials when it is in the best interest of the resource. All work should meet the Secretary of the Interior’s *Standards for Preservation*. (See Attachment 2)



Figure 27: Existing internal drains or exterior pipes could be utilized in place of a traditional downspout to carry the water collected by the gutters down to the ground. How this is accomplished will need to be determined on-site, based on actual conditions.



Attachment 1: UV Protectant

Note: Reference to removal of existing finishes is not relevant in this case.

Redwood Preservation at Scotty's Castle Death Valley National Park

**School of Engineering, University of Vermont
Cooperative Agreement No: H8W07060001
Task Agreement No: J8W07070030**



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Project partners include:
Curation, Death Valley National Park
Atlas Material Testing Solutions
Conservation Associates
Vanishing Treasures Program (NPS)

DAMAGE TYPOLOGY: SUBSTRATE

SURFACE EROSION

Exposure to UV light results in the breakdown of the lignin matrix of wood, resulting in a loss of surface coherence, increased friability, and erosion. Earlywood is especially susceptible to erosion, and the process is often accompanied by detachment of wood fibers that appear as little "hairs" on the wood surface.



Fig. 1

In Fig. 1, wood surfaces exposed to sunlight are noticeably eroded while shaded surfaces are smooth and largely intact. Under magnification, damage to the wood structure and disgregation of wood fibers from the surface are evident (Fig. 2). In Fig. 3, erosion is pronounced around the system of small checks that has developed on the end grain, as well as along earlywood layers of the wood surface.



Fig. 2



Fig. 3

Weathering of wood is characterized by chromophoric (color) changes at the surface.

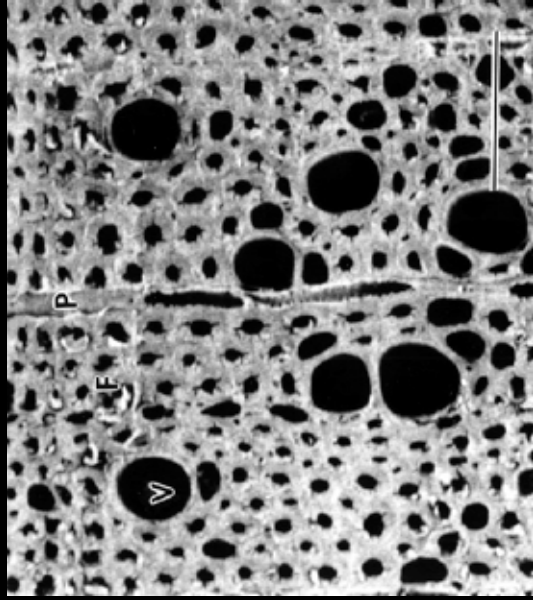
As the lignin is changed by exposure to light, the chemical byproducts are chemically unstable and dissolve readily in water.

Small amounts of water are enough to wash away the deterioration products on the surface, exposing new wood to light so that the process continues.

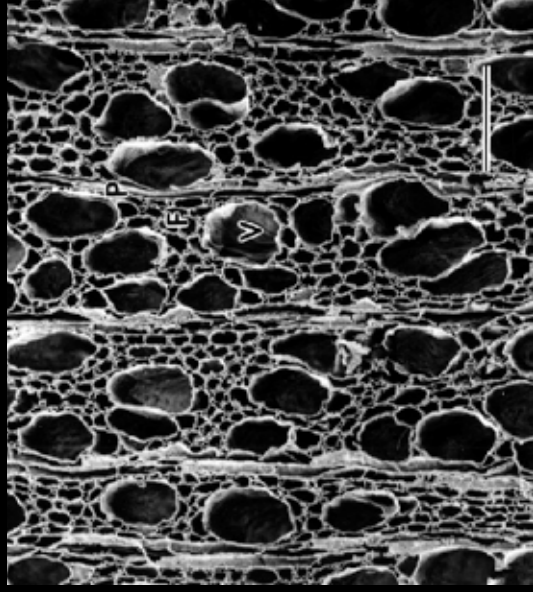
Several strategies exist for the clear or semitransparent finishing of wood including:

- Consolidant treatment to improve surface resistance to weathering
- Use of inorganic pigments (semi-transparent deck stains) that absorb
- The addition of UV stabilizers to clear coatings

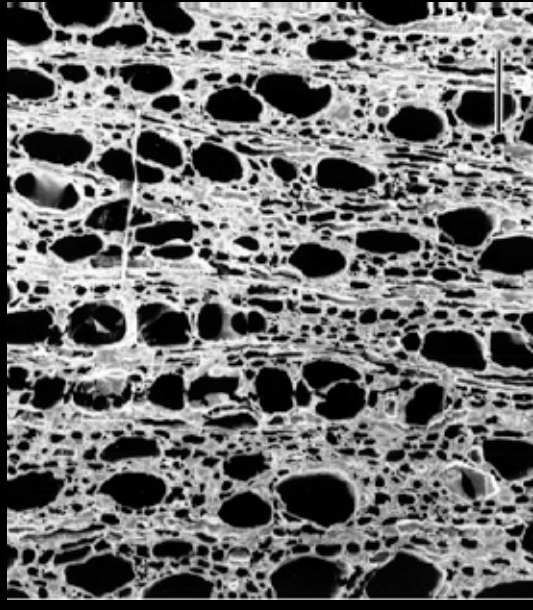
Stabilizers in these finishes include absorbers that convert light energy to caloric energy or heat, and HALS that trap radicals formed by photo-degradation. In this project proprietary finishes were tested, as was Butvar B-98 (a polyvinyl butyral used primarily in object conservation applications for its mechanical properties, depth of penetration, light and heat stability, and reversibility/re-treatability).



Healthy cell structure



Weathered & deteriorated
cell structure



Consolidated with B-98

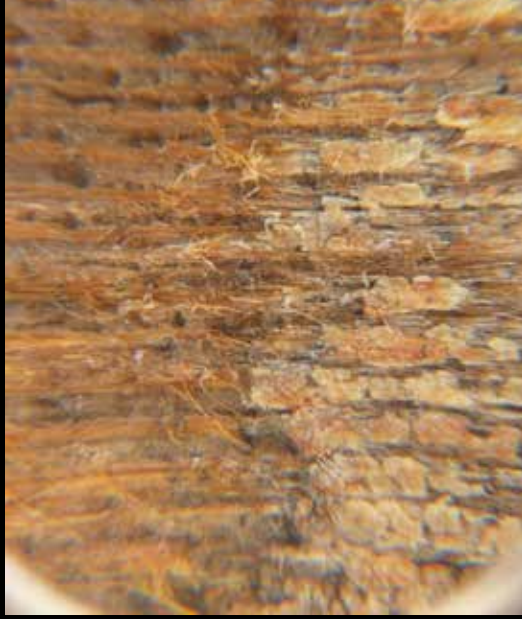
At Scotty's Castle, where the existing coating(s) had failed completely, application of the consolidant resulted in visible improvement of the surface.

Dry cleaning (with a nylon-bristle brush) left a surface relatively free of old varnish, but disgregated as the result of UV exposure.

The consolidant treatment resulted in the binding of detaching wood fibers to the surface. Note that the surface displays preferential erosion of earlywood layers.



Before varnish removal



During varnish removal



After consolidation

In the early stages of failure, embrittled coatings develop cracks that admit water to the substrate, promoting dimensional instability associated with changes in moisture content, and subsequent detachment of the coatings.

The consolidant fills these cracks, reducing moisture infiltration.

The consolidant can be effectively removed without adversely affecting the existing coatings by carefully selecting solvents (for mixing and cleaning) that do not dissolve the original varnish(es).



Before consolidation



After consolidation



After B-98 removal

Treatment Procedures: Cleaning

1. Dry Brushing

Remove loose varnish and debris with a coarse, nylon bristle brush. Brushing should be in the direction of the grain.



2. Acetone Spray*

Remove loose varnish that does not come off readily with a brush by applying acetone through a low-pressure spray bottle. Once the acetone has dried, brush away the varnish with a nylon brush. Again, brush in the direction of the grain. Repeat as necessary.

**This method of cleaning is only appropriate where the existing finish has failed and must be removed entirely.*

Treatment Procedures: Cleaning

4. Wet Cleaning

Loose embedded dirt, bird droppings, mildew and other accretions can be removed with water and a coarse nylon-bristle brush used in the direction of the grain. To remove mildew, use a 2% Vulpex solution in water and rinse thoroughly.



Treatment Procedures: Consolidation

Make sure surface is free of dust, debris and loose fibers.

Dry-brush bare wood or vacuum/sponge varnished surfaces.

Cut in any hardware using a trim brush. Any B-98 that is inadvertently applied to metal hardware can be removed with ethanol.

Coat the wood evenly with the consolidant. Add a heavier application to any areas that are particularly dry.

Allow B-98 to dry for 30 minutes before applying the second coat.



Treatment Procedures: Consolidation

Consolidant: 3.5% B-98 (g/ml) in Ethanol (ETOH) w/ 8% Tinuvin 5151 by vol of B-98

- B-98 260ml (or 70g)
 - Ethanol (ETOH) 2000ml
 - Tinuvin 20.8ml
- A. Add dry B-98 slowly to ethanol (ETOH) and mix thoroughly (do not let the B-98 clump)
 - B. Allow to sit for 30 minutes
 - C. Add Tinuvin and mix thoroughly.



Redwood Preservation at Scotty's Castle, Death Valley National Park

In considering the feasibility of using the treatments described in this report in other contexts, it is important to recall the process architectural conservators followed in designing the treatments, and to apply them appropriately to different sites with different materials and conditions. It should not be assumed that the treatments developed here can be uniformly applied at any site. Instead any treatment at future sites should be preceded by:



- Condition assessment, to understand the deterioration conditions that candidate treatments will need to address
- Finishes analysis, to determine which of the existing finishes are to be preserved
- Resin selection, to select treatment products that will address deterioration without compromising historic finishes
- Treatment testing, to determine whether and how treatments can be applied to minimize adverse impacts to historic materials
- Pilot testing, to solve problems posed by field implementation of the treatments and to establish the desired treatment aesthetic

Attachment 2: Secretary of the Interior's Standards for Preservation

Preservation as a treatment

When the property's distinctive materials, features, and spaces are essentially intact and thus convey the historic significance without extensive repair or replacement; when depiction at a particular period of time is not appropriate; and when a continuing or new use does not require additions or extensive alterations, Preservation may be considered as a treatment.

Standards for Preservation

1. A property will be used as it was historically, or be given a new use that maximizes the retention of distinctive materials, features, spaces and spatial relationships. Where a treatment and use have not been identified, a property will be protected and, if necessary, stabilized until additional work may be undertaken.
2. The historic character of a property will be retained and preserved. The replacement of intact or repairable historic materials or alteration of features, spaces and spatial relationships that characterize a property will be avoided.
3. Each property will be recognized as a physical record of its time, place and use. Work needed to stabilize, consolidate and conserve existing historic materials and features will be physically and visually compatible, identifiable upon close inspection and properly documented for future research.
4. Changes to a property that have acquired historic significance in their own right will be retained and preserved.
5. Distinctive materials, features, finishes and construction techniques or examples of craftsmanship that characterize a property will be preserved.
6. The existing condition of historic features will be evaluated to determine the appropriate level of intervention needed. Where the severity of deterioration requires repair or limited replacement of a distinctive feature, the new material will match the old in composition, design, color and texture.
7. Chemical or physical treatments, if appropriate, will be undertaken using the gentlest means possible. Treatments that cause damage to historic materials will not be used.
8. Archeological resources will be protected and preserved in place. If such resources must be disturbed, mitigation measures will be undertaken.

The Guidelines for the Treatment of Historic Properties illustrate the practical application of these treatment standards to historic properties.

<https://www.nps.gov/tps/standards/treatment-guidelines-2017.pdf>

The Guidelines for the Treatment of Cultural Landscapes apply these treatment standards to historic cultural landscapes.

<https://www.nps.gov/tps/standards/four-treatments/landscape-guidelines/index.htm>