HEAVY MOVABLE STRUCTURES, INC.
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Updating Portland Bridges with FRP

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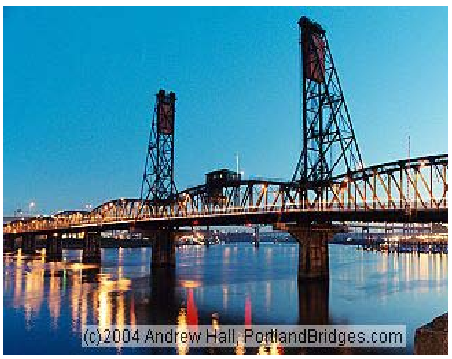
Willamette River Bridges

Portland Oregon is home to several beautiful and unique bridges. The Willamette River, which runs through the middle of Portland, divides the east and west regions of the City. There are eleven bridges that span the Willamette within the greater Portland area. Six of these bridges include a lift span for river traffic, all of which were built between 1910 and 1958.

Multnomah County is responsible for maintaining four of these movable bridges. The four structures were constructed with different lift span systems and different deck surfaces. In recent years, the decks have been replaced on all four of these structures. The following is a brief history of each of the four structures and the changes they have gone through over their life span:



Hawthorne: A six span steel truss structure with an overall length of 1383 feet including a 244 foot vertical lift span. The Hawthorne Bridge was originally built in 1910 for $511,216 with timber decking to limit weight. In 1945 the timber decking was replaced with steel grating, a more modern and better performing light weight deck. In 1998-99 The Hawthorne Bridge underwent a major renovation. During the renovation the 1945 grating was replaced with an updated grating system that provided better traction for vehicles, new paint and new wider sidewalks at a cost of $22 million, more than 40 times the original construction price tag.

Broadway: Originally built in 1913 for $1.6 million, spans 1736 feet with a 297 foot double leaf Rall Wheel bascule span. Like the Hawthorne, the Broadway bridge was built with timber decking to limit weight which was changed to steel grating in 1948. In 2005 the Broadway Bridge underwent a $28 million renovation that included new paint, sidewalks and replacement of the grating with Fiber Reinforced Polymer (FRP) decking. When originally constructed, the Broadway Bridge carried street cars from 1913 to 1940. In 2011 Portland's new street car system was returned to the Broadway Bridge which required cutting out and removing the two center lanes of FRP and replacing them with an FRP deck designed to accommodate new tracks.

Burnside: The only Willamette River Bridge in Portland built with design input from an architect whose influence can be seen in the Italian Renaissance towers and decorative metal railing. Built in 1926 for $4.5 million it has steel truss approach spans with a double bascule Strauss lift span. The deck was originally built 4 ½” thick with standard-weight concrete, and was replaced with 5 ¼” thick concrete with a special mix designed to minimize cracking in 2007. The added weight from the increased deck thickness required installing steel plates to the counter weights.

Morrison: The youngest of the four bridges was built in 1958 for $12.8 million, is a double leaf Chicago style bascule. The approach spans are steel truss spans that had light weight concrete decks. These were replaced with concrete filled steel grating and now have a microsilica concrete overlay. The lift span was originally built with steel grating to limit its weight. The grating was replaced with FRP decking in 2011-2012. The new deck weight was very close to the original deck weight and required only minimal increase to the counter weights.

This paper focuses on the ongoing innovation in bridge deck systems and the installation of FRP decking on the Broadway and Morrison Bridge bascule spans. For both of these deck replacement projects Multnomah County performed additional verification testing for load capacity and durability of the FRP material. Portland State University's (PSU) Civil Engineering program provided the laboratory test facility and published the final reports for the test findings of this research work. Multnomah County would like to recognize the excellent work performed by both the late Dr. Wendell Mueller PhD. and Dr. Peter Dusicka PhD. and their graduate students in this research work.

Lightweight Materials for Movable Bridge Decks

Steel grating decks

Steel grating decks provide a lightweight design that is structurally strong and durable offering a better option than timber deck materials. From the 1940's until recently steel grating was one of the only options available for a light weight deck for lift span bridges. These decks are relatively simple to construct and install at a reasonable cost. However, over time the surface of the grating tends to be worn smooth, becoming a potentially hazardous riding surface. Also, in Multnomah County’s experience, the welded connections within the steel grating and to the steel stringers have proven to be a weak point within the system, often requiring regular annual maintenance to repair.

New Deck materials

Advancements have been made with several materials that allow for many more options on the types of lightweight deck designs that can be used on lift bridges. The development of ultra-high performance concrete (UHPC) offers the possibility of achieving thinner cross sections that could result in lightweight concrete decks as light as steel grating decks. These concrete designs utilize high-strength cementitious and steel fibers with no coarse aggregate. They also include high strength steel reinforcing to keep the weight low. The reinforcing bars are made of a low-carbon chromium alloy steel which gives them much higher corrosion resistance compared to black bars. Since the deck is made of concrete, there is no need for an additional application of an overlay as with other developed deck systems. However, research on this type of system is still relatively new. For the Morrison Bridge project, Multnomah County felt that the amount of additional research that would be needed to develop enough confidence to move forward with this system would be too long and costly.

Another strong and lightweight material, aluminum, can be extruded into shaped sections that provide strengths capable of carrying vehicular loads on deck sections that also come in at about the same weight per square foot as steel grating decks. Multnomah County considered a Reynolds Metals Company aluminum deck section that weighs about 15 psf and is about 4.5 inches deep. Each panel section is connected to the adjacent panel with welds along the top and bottom of the panels. The top surface is overlaid with an epoxy gravel mix much the same as other similar deck systems. In the field, the panel sections are connected to the stringers by bolting the bottom flange of the panels. Aluminum has excellent properties for corrosion resistance. Galvanic corrosion protection between the aluminum deck and the steel stringers must be addressed with some type of material installed to separate the two, but this is relatively easy to achieve.

Another deck system on the market that could be suitable as lightweight alternative to the steel grid deck system is the Sandwich Plate System (SPS) developed by Intelligent Engineering in Europe. This design, as stated in its name, sandwiches a lightweight composite material between top and bottom steel plates. The thickness of the plates and the composite material can be adjusted to achieve the desired weight and depth for each application. This deck design provides a solid riding surface with a deck overlay similar to that of the aluminum deck system. The deck requires no field welding, with the panels being bolted down to the stringers. The cost of this system is comparable to other available deck systems. One disadvantage of this system, for the Morrison Bridge bascule span deck application, was that it would have required adjusting the stringer spacing to achieve the required weight. This was not an option in this case given the floor beam configuration.

After considering all of these options, Multnomah County decided that the best system for our applications was FRP.

What is FRP?

FRP is made by taking materials such as fiberglass or carbon fibers that have very high tensile strength and forming them into sections using various polymer materials with high compressive strength to create lightweight components capable of carrying heavy loads.

The first application of fiber reinforced materials may have been the addition of straw to mud to make higher strength bricks. In more recent times, short glass fibers were added to concrete to increase its strength. The development of FRP in the United States began after World War II. The first applications were in boat hulls and vehicle bodies. FRP also proved to be an excellent material for recreational applications such as fishing poles, tennis racquets, ski equipment and golf clubs. The first civil engineering application of FRP was a dome structure built in Benghazi, Libya in 1968. Further development of the pultrusion process generated the ability to create a variety of structural shapes allowing FRP to be used in more structural applications.

In bridge deck applications, pultruded composite decks were initially limited to pedestrian bridges. However, as materials improved and got stronger, carrying motor vehicle loads became a viable application for FRP.

Most steel decks on existing bridges are around 5 inches deep and weigh about 20 to 25 pounds per square foot. FRP panels can be pultruded to match the depths of existing steel decks. However, these pultruded panels as produced do not provide for a riding surface that is acceptable for vehicular traffic. To complete the panels as a new deck design they must be overlaid with an epoxy/aggregate mixture resulting in a suitable deck surface. Once the riding surface overlay is applied to the FRP deck, the weight per square foot comes in at around the same weight as a steel deck.

Typical Pultruded FRP Panel Section

In addition to being able to match the depth and weight of steel grate deck systems, FRP also offers some distinct advantages over their predecessors. Steel grating can become very slick in wet conditions, especially when mixed with oils and other deposits from passing vehicles. Over time as steel deck surfaces are worn smooth at the corners this becomes even more critical. With the overlay materials applied to FRP decks, the riding surface has a high coefficient of friction that is comparable to a concrete or asphalt deck surface. When the overlay is worn down and losses some of its traction, a new overlay can be applied at minimal cost to extend the life of the decking system, an option not available with steel decks.

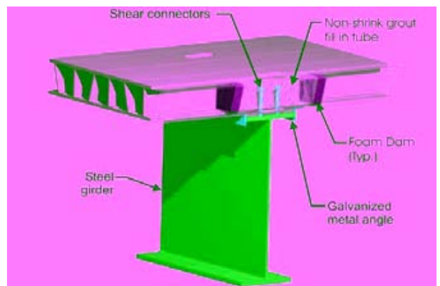
Because steel grating is an open deck system when they are used over waterways they allow rain water to wash through the deck directly into the river or stream below, carrying with it any dirt, oil or other materials deposited on the deck. With today's increased awareness of and sensitivity to environmental issues, FRP decks solid surface provide an excellent alternative because they allow all rain water to be collected and treated prior to release back into the environment.

Broadway Bridge Bascule Span Deck Replacement

FRP Options

The first Multnomah County Bridge to receive an FRP deck on its movable span was the Broadway Bridge in 2005. Of all available deck options listed above, Multnomah County determined that FRP would be the best solution for this particular application. Within the field of FRP deck systems, there were several to choose from. These can be broken into two general categories: (1) pultruded sections with hollow cells, and (2) honeycomb or foam-filled sections. For the Broadway project, the County selected Martin Marietta's pultruded DuraSpan Deck system with a 5-in deep section. The deck was connected to the steel stringers with steel studs welded to the tops of the stringers.

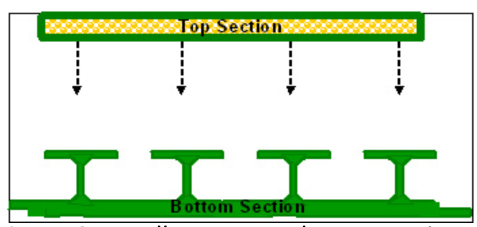
This type of connection required that holes about 4 inches in diameter be drilled through the top and bottom sheets of the deck panels. Each panel was then placed on the stringers with anchor studs sticking up into the deck section. The stud pockets were then filled with polymer grout securing the deck to the stringers. Polymer grout was also placed in one-inch gaps between the deck panels and the stringer flanges to give full bearing. The top of the deck was covered with a ¾-inch thick epoxy/aggregate overlay for the final riding surface.



Caption: DuraSpan Deck to stringer connection detail

Addition of Street Cars

Since original installation of the FRP deck in 2005, the Broadway Bridge has had streetcar tracks added. This modification required that the two center lanes of the original FRP deck be removed and new FRP decking reinstalled to accommodate the new tracks. ZellComp's 5" FRP deck was used for the replacement strips. The ZellComp deck system is very similar to the Martin Marietta deck in that it is also a pultruded section with hollow cores in the middle. However, the ZellComp deck is a two-part deck system with a top sheet that is screwed down to the bottom panels. Once assembled, the two deck systems have very similar cross-sections. By screwing down the top sheet, the ZellComp system eliminates the need for punching holes through the top sheets.



CAPTION: Zellcomp panel construction

Issues with FRP

The holes in the top sheets did prove to be an issue with the Broadway Bridge's original FRP deck installation. Connecting the deck panels to the stringers using grouted-in studs creates rigid points in the deck system. As the bridge expanded and contracted from temperature changes, cracks developed in the overlay at these rigid connection points. The cracks then allowed water to seep down into the open cells of the deck. At one point, the amount of water that was trapped within these cells created enough of a load increase that one bascule leaf was opening much slower than the other. The County then had to drill 5/8-inch holes through the bottom of the panels into each of the cells to allow water to escape. We soon learned that masonry bits were best for drilling these holes since steel or carbide bits would dull very quickly as they heated the glass fibers.

Another issue that was a cause for concern on the original Broadway FRP deck was de-lamination of the overlay. The as-manufactured surface of pultruded FRP panels is very smooth and is not a good bond surface for the overlay. In order to achieve a good bond between the FRP panel and the overlay, the surface has to be sand blasted to expose some of the glass fibers and roughen the surface. However, prior to the panels being delivered to the job site, the manufacturer insisted on applying a non-skid coating to the top surfaces of the panels to avoid any slips or falls while workers were installing the panels. This non-skid coating had a very rough texture that served well as a bondable surface for the epoxy/aggregate overlay. However, after just a few months of service, we found that large areas of the overlay were experiencing severe cracking and delamination. An investigation into this problem revealed that the non-skid coating was not bonded well to the FRP in certain areas. For future FRP installations, we decided that we would not include the non-skid layer. This was just one more interface that had the potential for problems and we were better off without it. Deleting the non-skid layer would also allow for inspection of the FRP surface to insure that adequate preparation was made in blasting and cleaning the surface for a good bond of the overlay.

During installation of the new ZellComp panels on the Broadway Bridge along the streetcar tracks, all of the remaining original ¾”-thick overlay material on the Martin Marietta panels was removed and the whole bascule span deck surface received a new ½”-thick epoxy/aggregate overlay. Replacing the overlay allowed the County to remove the non-skid layer that was involved in delamination of the original overlay. Also, reducing the overlay thickness helped maintain bascule span balance after the steel streetcar rails were added.

The ZellComp deck design has a finished top surface of 4-foot by 8-foot FRP sheets that are screwed down to the panels below. The screws are countersunk into the ½-inch thick top sheet, but still protrude above the top of the panel about 1/4 inch. They are fully covered by the ½” overlay. At the interfaces between top sheets, small cracks are starting to appear. We are also seeing small areas of delamination and exposure of some of the screw heads. The problems we are seeing now are minor compared to the delamination we experienced with the original overlay on the DuraSpan, but we will need to develop solutions to the current problems in the near future.

Morrison Bridge Bascule Span Deck Replacement

Improvements needed at Morrison

The Morrison Bridge is the second bridge in the County's inventory of bridges with steel grid decks that was identified as a good candidate for a new deck surface. The Morrison Bridge is a six-lane bridge with a freeway ramp that feeds into the bridge from the east side. Given the open feel of the bridge, motorist speeds frequently exceed the posted 35 mph speed limit. The bridge was posted for “No Lane Changes” on the steel grid deck, as lane changes were a major cause of vehicles losing control on the worn smooth surface, especially in wet conditions. When the Broadway Bridge’s steel grating bascule span deck was replaced with FRP, the number and severity of accidents caused by motorists losing control on the span was reduced to zero. Achieving this type of safety improvement was one of our main goals for the Morrison project given its frequency of accidents.

In 2005 an SUV crossing the Morrison was going fast enough that when the driver hit the steel grating, they lost control of the vehicle and hit the railing hard enough that the vehicle went over the railing into the river. Operators on the Morrison Bridge have said, "On a wet day it is not a question of if there will be an accident, but when will the accident be?" The deck replacement on the Morrison Bridge was preceded, the year before, by a widening of the south sidewalk from 5 feet to nearly 15 feet. To achieve this widening, one to two feet were removed from each of the six 13-foot wide travel lanes, reducing them to 11 and 12 feet. There was concern that the narrower lanes would give drivers less recovery time if they did lose control, resulting in an increase in the number of accidents. Although there was no record of an increase in accidents, the County still felt the need to replace the steel deck as quickly as possible.

FRP still the best option

Although the County encountered some problems with the Broadway deck replacement, the consensus was that FRP was still the best option for the Morrison project. When sections of the original Martin Marietta deck were removed from Broadway for the streetcar project, these panels were examined closely and found to be in the same condition as when they were when first installed more than five years earlier, without loss of section or deterioration of strength.

At the start of the Morrison project, The County again looked at the various options for FRP to determine if there were better alternatives. The County concluded that decks with hollow cells were preferable to decks that had any type of honeycomb or foam-filled cells, as water will find a way into these cells and they must be free-draining to avoid any overload due to collected rain water.

This left us with the only two options on the market, the Martin Marietta DuraSpan Deck and the ZellComp deck. While weighing the pros and cons of these two designs, the possibility of modifying the ZellComp deck caught our attention. The existing Morrison steel grating deck was a very lightweight deck at less than 20 psf. It was also only 5 inches deep. The Martin Marietta and ZellComp FRP decks are 5" deep before the epoxy/aggregate overlay goes down. With the overlay thickness added, some modifications would be required at the ends of the bascule span to achieve the proper grade to match the existing approach decks.

CAPTION: Testing of modified deck design

We asked ourselves “What if we eliminated the top sheet and flipped the ZellComp panels over?” This would significantly reduce the weight of the new deck as well as lower the profile by 1/2 inch, making it much easier to match the existing grade. The County presented this design change to Dan Richards of ZellComp to get his opinion. He agreed that this was a viable option given that the spacing of the stringers on the Morrison deck is only 3'-10". Some testing would need to be done to determine the load capacity of this configuration. Both ZellComp and the County did some mock-ups with this configuration and subjected them to loads that would take them to failure. Both sets of test data concluded that these panels had the capacity to handle vehicle live loading on the Morrison Bridge. The next question to answer was fatigue life. What kind of life expectancy could be achieved with the modified deck design?

Following testing standards

There are no set AASHTO standards for determining fatigue life of FRP components. Back in 2000 a committee called HITEC was assembled consisting of approximately 20 transportation experts from the academic field as well as from both Federal and state DOT's. This group was to help establish standards for testing and verifying the appropriate applications of FRP materials in transportation design. For fatigue testing, 1.5 times the HS loading was given for the test load, which was to be run for 2 million cycles. This standard is significantly different than AAHSTO fatigue loading for regular decking, which allows for 75% of HS load plus Impact load of 15%. The AASHTO formula gives a wheel load of 13.8 kips for HS20 loading whereas the HITEC formula gives 24 kips for that same wheel load. When testing the new panel configuration at Portland State University (PSU), we elected to use the HITEC criteria for fatigue loading. The panel failed in flexure at approximately 1.5 million cycles, well below the required 2 million. At this point we began to question the validity of this high level of loading as a reasonable approach for testing fatigue loading on FRP. The question was, how did HITEC determine this standard for fatigue testing? We decided that the best source of answers would be to contact members of the HITEC committee. This was in 2010, ten years after the committee had been formed. A list of all the members of the committee was available; however, much of the information was old and out of date. Most of the committee members could not be reached, but we were able to contact a couple of the members and learned that the committee no longer existed. The best we could find out about the test criteria was that it was not based on anything other than the collective engineering judgment of the committee members.

Given that the test values for the HITEC approach were so significantly different than for the AASHTO methods, we elected to do all future testing based on AASHTO procedures. However, at this point it was too late to conduct additional testing on the modified configuration of the deck design in time to get acceptance for the Morrison project. With failed test results for the modified design, we had no choice but to go back to the original configuration.

Since the modified design of the ZellComp deck was no longer an option, we were back to considering both ZellComp and Martin Marietta. The County ran one additional fatigue test at PSU on both the Martin Marietta and ZellComp decks simultaneously. Both deck systems were constructed and placed side by side with the load actuator applying one wheel load to each of the two panels. Each panel was subjected to the same load and the results showed that both panels had comparable fatigue life. These two systems were both considered acceptable options so rather than selecting one system and sole sourcing it for this project, we elected to write the specifications to allow for open competitive bidding between the two. Once Martin Marietta learned of this, they withdrew their interest in bidding on the job.

Deck Installation

Conway Construction Company of Ridgefield, Washington was awarded the Morrison Bridge deck replacement contract with a low bid of $4.2 million. ZellComp supplied the FRP deck material at a bid price of $1.8 million which included the material and installation. The overlay material was another $170,000, for a total deck cost of just under $2 million not including the cost of the new steel stringers. The total deck area was just over 17,000 square feet, giving us a cost figure of about $115 per square foot for the new deck.

It was required that the bridge remain open to traffic throughout the project. However, we were able to reduce the roadway to one lane in each direction. This allowed us to move traffic to the north half of the bridge while working on the south, then flipping it around to complete the other half. The new decking was installed on one quarter of the bascule span at a time. The old steel grid deck was cut into sections and removed with the stringers below still attached. The old stringers as well as the sides of the steel grid decking were coated with lead-based paint, so full containment was required to prevent any debris from entering the river.

The two-part ZellComp deck system allowed us to bolt the bottom of the FRP panels to the steel stringers with a 1/8”-thick layer of neoprene padding between the two surfaces for protection of the softer FRP material. Once all the FRP panel sections were bolted down, the ½”-thick top sheet was screwed to the top flanges of the panel beams. Each hole was predrilled with a countersink for the screw head.

Problems encountered

Prior to bidding the job, ZellComp switched from Creative Pultrusions to Strongwell for production of the pultruded panels. Martin Marietta and ZellComp previously had both used Creative Pultrusions to produce their panels. Given that there was a possible conflict of interest when both were looking at bidding on this job, ZellComp elected to make the switch to Strongwell for their panel production.

Martin Marietta and ZellComp each owned their own dies for producing their particular panel configuration. However, the mix design for the various materials that went into the production of the panels was a proprietary design owned by Creative Pultrusions. In order for ZellComp to use Strongwell to produce their panels, they needed to develop an independent mix design. Strongwell, working with Zellcomp developed their unique mix of ingredients for the new panels to be produced at Strongwell.

When the first ZellComp panels were delivered, the County noticed that several of the panels had cracks that ran, in many cases full-length, along the corners between the webs and the flanges. In some cases, cracks were observed in both the top and bottom of the panels. This was cause for serious concern for the County. The specifications called for no cracks or other imperfections in the panels. ZellComp and Strongwell assured the County that these cracks were not structural, but only cosmetic, and would not adversely impact the performance of the panels. This was not enough for the County to feel confident that there would not be immediate or future problems with the panels. The County requested that destructive testing be done on one of the panels that exhibited the worst cracking to determine if indeed there was no reduction in capacity.


CAPTION: Cracked FRP Panels

Additional Testing

Not only was the ultimate load capacity of the cracked panel an issue, but the long-term life expectancy of the panel was also in question. Both of these issues had to be addressed in testing the panels. The County returned to PSU to set up and perform testing of these panels. ZellComp also performed independent ultimate load testing on the panels and determined that there was no reduced capacity. After reviewing the test results that County was please with the performance of the test specimen, but needed to complete our own testing before reaching any conclusions.

In order to determine if the cracks had any effects on the panels' capacity, we wanted to isolate the cracks during testing. Part of the panel that was selected for testing was cut into individual "I" shaped sections. Four independent sections were made in this configuration. Two had the identified cracks within them and two were free of any cracks or other noticeable defects. Two sections (one with a crack and the other without) were tested with the crack in the bottom of the test set-up such that it would be in tension under bending loads. The other two sections were tested with the crack located in the top such that it would be under compression. These specimens were tested to ultimate load in three point bending.

In addition to this testing, we did a non-destructive test on a full panel section with the crack located directly under the load point to compare with previous tests performed on non-cracked panels produced by Creative Pultrution. Test conditions were similar but not exactly the same. The two tests had some common characteristics, which included the panels being previously fatigue tested and each having the load placement within the critical location for the particular panel. However, there were significant differences in the tests including manufacturer, presence of cracking, location of the load (one being on an exterior beam versus the other on an interior beam), and several differences in geometry of the panels. Thus, these tests were used to compare cracked and un-cracked post-fatigue panel strength with the caveat that the results would provide only an estimation of the actual panel strength due to the differences mentioned.

From the isolated "I" section tests, the results showed a reduction of capacity of 16.6% with the crack in the tension region and 15.8% when the crack was in compression. When the cracked panels were tested as part of a complete system, we estimated a reduction of about 8% when compared to the Creative Pultrution test sample.

Fatigue test results showed no reduction in capacity over the cycle life and there was no visible damage to the panel. Based on the completed test results, the County concluded that, although there may be some minor reduction in capacity, the cracked panels are still capable of performing as intended for the design purpose with no significant risk.

CAPTION: FRP Panel with web voids

The next set of panels to be delivered had two panel sections with voids within the webs of the panels. This condition also was out of specification and raised the issue again as to whether these panels should be installed or not. We did not have the option of doing further testing to determine the effects these voids might have, as there were no more replacement panels available. It would also be several months before new panels could be produced if these panels ended up being rejected or destroyed through testing. The risk that is posed by this type of void in the panels is that under bending load the web could buckle and create a weak spot. Though there most likely would not be an immediate failure, fatigue could be an issue in a relatively short time period.

The first option presented by ZellComp was to sandwich the webs with FRP sheets on either side of the voids. This would require drilling holes into the webs which would not be ideal, but better than the voids. Then one of the County inspectors came up with the idea of filling the cells next to the web voids with grout. This would provide resistance against buckling of the webs and offered a rather inexpensive fix that was easy to install and required no holes being drilled into the panel webs.

The final set of panels that were delivered was free of any voids or cracks. It appeared that Strongwell was able to identify the causes of the problems and correct them for the final production.

Addressing deck cracking

The next issue we had to deal with was the potential for cracking in the overlay at the joints between top sheets on the FRP panels. In an attempt to prevent this overlay cracking, our design specifications required addition of a face sheet over the FRP panel top sheets. This face sheet was installed in the field by placing dry fiberglass sheets on a layer of liquid epoxy resin and rolling the surface to saturate the glass and work out any air bubbles in the process. This approach to prevent cracking between panel tops was a process that was new for both the contractor and the manufacturer. There was a learning curve to the process, especially for working out the air bubbles. Following installation of the face sheet on the first quadrant of the bascule span, we required the contractor to go back after the face sheet epoxy had set and grind out several air bubbles that remained. Once we reached the second quadrant, the methods used by the contractor were much improved and the air was removed from the face sheet without additional grinding.

Since the Morrison project was completed in early 2012, we have discovered that several of the screw heads holding the panel top sheets in place have cut their way through the face sheet and the overlay. It appears that the screw heads are so much more rigid than the FRP and overlay material that the pressure from passing tires flexes enough that the edges of the screw heads act like knives and cut circular holes up through the overlay. We are also seeing several locations where the overlay is cracking over the edges of the panel top sheets. The face sheet helps to minimize this cracking as we are seeing less of it on Morrison than we had on Broadway, but a better method of dealing with this type of cracking still needs to be developed.

The overlay was applied in a two-layer broadcast procedure of mopping on the epoxy resin and broadcasting the aggregate onto the resin. The two layers provide a total thickness of 3/8 of an inch. This is half the overlay thickness that was applied to the Broadway Bridge's original FRP deck. The main reason for this thin 3/8" overlay was the weight limitation for the Morrison bascule span. The Morrison steel grid deck weight was less than 20 pounds per square foot, whereas the Broadway's grid deck was 26 pounds per square foot. Morrison's new FRP deck with the final overlay came in at very close to the original weight of the steel grid deck. The amount of additional counterweight required to achieve the proper span balance was minimal.

Conclusion

Although Multnomah County's experience with FRP decking has not been trouble free, we are pleased with its performance to date and feel that we have made good choices for our situations. The problems that we have had to deal with have been relatively minor, and with some modifications they can be resolved. FRP is a corrosion-free material that is lightweight and high strength. For Multnomah County, it is an ideal replacement material for our old and failing steel grating decks.