Governor Mario M. Cuomo Bridge

Pavement Condition Report

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Introduction

The recently completed Governor Mario M. Cuomo Bridge consists of two cable-stayed parallel structures with total length of 3.1 miles long. The bridge crosses the Hudson River east-west between Tarrytown and Nyack, New York, approximately 25 miles north of New York City. Each of the two structures consists of a 1,200-foot cable-stayed navigation span and side spans of 515-feet with common foundations and diverging (angled) towers, along with a series of 350-foot continuous, steel girder spans supported on seismic isolation bearings over reinforced concrete pier caps. The parallel structures provide 4 traffic lanes each and a bus lane. The westbound (WB) structure has a slightly wider deck (96' wide) than the Eastbound (EB) structure (87' wide). The WB structure includes a separate shared use pathway (SUP) for pedestrians and cyclists on its north side. The bridge is owned by the New York State Thruway Authority, is tolled and designed for a 100-year service life.

Daily vehicle count is estimated to vary from 140,000 to 165,000 per day with significant increases in heavy axle truck traffic reported over the past several years. The increase in truck traffic may be partly attributed to the bridge's significantly lower truck tolls compared to the NYNJ Port Authority's George Washington Bridge to the south. The truck count increase is notable because pavement experts worldwide have concluded that heavy axle vehicles (particularly when overloaded) contribute nearly all of the damage that affects flexible (asphaltic) pavement lifespans.

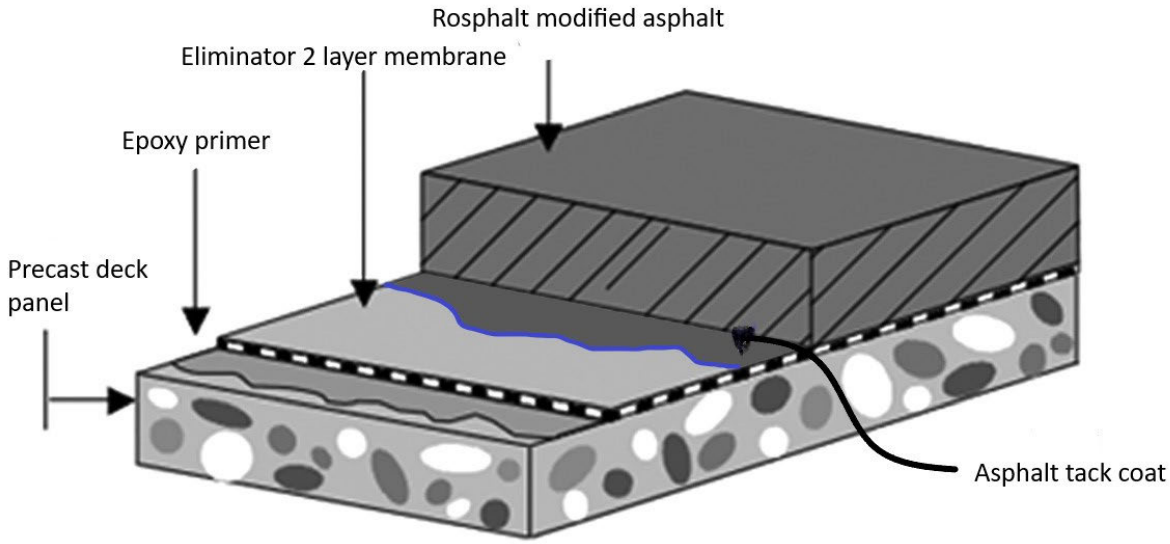
The bridge uses steel members to support reinforced [redacted] thick precast concrete deck sections reinforced with galvanized rebar (no post-tensioning is used except for the spans in the cable suspended structures). The approach span deck panels were produced by Unistress in Pittsfield, MA. The main and side span deck panels were produced by Fort Miller in Greenwich, NY. Top clear cover on the panels (over rebar) is specified as [redacted] (before finish milling).

The deck panels were installed with a composite design connection to the top flange of the girder and over [redacted]. The haunches were (temporary) open gaps that provide camber, superelevation and cross-slope fitment (adjustment) and are designed as an integral part of the structural composite design. After leveling the panels, a self-consolidating grout was pumped from the deck surface to fill the haunch space between the structural foam forms. Deck panels were designed with pre-placed vertical cut-outs (stud pockets) to accommodate shear studs on the girder. The transverse ends, spaced about [redacted] apart (and longitudinal sides) of each panel contained an open section of exposed galvanized steel reinforcing bar. After the end-to-end deck panel installation was complete, the open-end connections (gaps) between panels and the shear stud cutouts were grouted with concrete to complete the composite connection with the underlying steel and provide a continuous deck surface.

The WB structure was completed and opened first in September 2017. For one year, its deck was configured and used for 2-way traffic. During its first year of use, the WB deck area now used as the SUP carried live traffic (typically heavy axle) as WB lane 4. The eastbound (EB) structure opened a year later and in fall 2018, each span was transitioned to one-way traffic. In June 2020, the SUP opened to pedestrians and cyclists use.

The WB and EB decks were waterproofed and paved approximately a year apart, in the summers of 2017 (WB) and 2018 (EB). The deck surfacing consists of a continuous (seamless) sprayed polymethylmethacrylate waterproofing (PMMW) membrane applied in two layers following an epoxy primer immediately over the concrete, a hot applied asphaltic tack (bond) coat over the membrane, topped by a thermoplastic polymer modified dense graded asphalt pavement of 1.5" (nominal) thickness. In late spring 2020, the SUP asphalt pavement was topped with a blue tinted MMA polymer membrane in preparation for its current use by pedestrians and cyclists.

This report offers a preliminary condition survey focused on paving surface defects consisting of slightly elevated, circular raised mounds or blisters observed on the pavement surface. The blisters became a concern when the SUP was being prepared for its opening in late 2019. Similar blisters have been observed on the shoulders and roadways of both the EB and WB structures.



The June 2020 pavement inspection areas included: a) the SUP pavement and b) the pavement located on a portion of the traffic bearing lanes and shoulders pavement in both east and west directions. The following summary is based on on-foot visual inspections, nondestructive tests and core collection. A subset of the cores was selected for further third-party lab analyses based on location and the core quality as well as the testing type selected. These included tensile testing to evaluate the pavement bond to the membrane. Binder extraction and aggregate gradation analyses compared pavement conformance to project specifications. The nondestructive tests were performed using Impact Echo (IE) with results plotted by pavement location on color coded charts. Also included is an examination of previous test reports and review of a small portion of GPI's (QC inspection) daily work reports during pavement installation and other construction records and drawings.

SUP pavement history

The SUP was paved in summer 2017 with the same multi-layered system used on the traffic lanes of both structures. After vehicle traffic was transitioned from the old Tappan Zee bridge, the deck area slated to be used as the future SUP carried daily heavy axle traffic, functioning as the far-right WB lane from fall-2017 to fall-2018. Between fall-2018 and mid-2020, the SUP lane carried small quantities of construction vehicles and longitudinal concrete barriers.

The SUP includes 6 scenic outlooks (belvederes) measuring approximately 12 x 60 ft. The belvedere structures are cantilevered from the north face of the exterior girders. Each of the 6 belvederes has a unique architectural appearance using different substrates. The SUP walking surface approach to the belvederes consists of a slightly sloped cast-in-place transition taper on both sides constructed of cementitious hand placed grout. The transition tapers lead to a raised area for pedestrian resting and viewing which contain pavers to match the architectural elements related to a historic perspective of a specific belvedere. The belvederes were constructed after the SUP portion of the deck was closed to daily motor traffic (following the 2018 opening of the EB structure).

A review of the daily work reports and photos submitted during the early paving installation period reveals that haul truck tires, tires of a very heavy material transfer vehicle (MTV) and steel tracks of paving equipment were picking up tack coat on their wheels and tracks. The picking up resulted in stripping or tearing (removing) tire width and steel tread sized sections of black tack coat completely from the light-colored underlying waterproofing membrane (see next section).

The initial SUP pavement investigation was begun in late 2019 before the SUP opened for pedestrian/cyclist use. A visual inspection of the SUP asphalt surface revealed randomly scattered raised mounds or blisters. Some of the blisters were observed in multi-blister denser quantity clusters and other blisters were singular or dispersed. These blisters were predominantly circular, 3” to 8” diameter and the average height from the adjacent non-blistered pavement was estimated to be approximately 1/4”. None of the SUP blisters (in this stage of the investigation) were reported to be cracked or have holes that penetrated the paving layer.

Several cores were taken in blistered areas of SUP pavement and visually examined during this initial stage. In preparation for a blue colored MMA top coating, Safetrack SC by GCP/Stirling Lloyd, the SUP pavement surface was micro milled to provide a flat and even surface and eliminate the blisters. Within a week of the micro milling, the blisters began to re-appear. The blue Safetrack topcoat was placed on the SUP at 95 mils (2.4 mm) thick prior to its opening to pedestrians and cyclists in early June 2020.

Waterproofing and pavement details

Prior to the installation of waterproofing and pavement, the WB/EB precast concrete decks (including the grouted end-to-end connections between each panel) were milled at the request of the paving GC to flatness. The milling compensated for discrepancies in elevation between the deck sections. The milling removal was followed by a light shotblast to remove loose material from the concrete surface in preparation for a waterproofing membrane.

The first step of waterproofing used an epoxy primer, PAR1, from GCP/Stirling Lloyd at 100ft/gal or 15 mils thickness was applied to the shot blasted concrete deck as an adhesion layer prior to the waterproofing membrane. Following the epoxy primer, two layers of PMMW-based waterproofing manufactured in the UK, a proprietary seamless flexible membrane called Eliminator®, supplied by GCP/Stirling Lloyd, were sprayed over a GCP epoxy primer on the concrete deck in contrasting colors (yellow on bottom and gray on top). The minimum thickness of each coat was 60 mils. The specified minimum ASTM D4541 adhesion test of the membrane to the deck was 100 psi with failure in the concrete layer. Per the project specification, in banked curved areas where the cross-slope roadway sections are 5% slope or greater, the top (gray) layer of Eliminator was seeded with #8 trap rock using a broadcast rate of 0.75 lb/sq. ft. to optimize adhesion and shear values to the next layer, the tack coat. This trap rock may have also been broadcast in other areas.

Over the Eliminator, a GCP/Stirling Lloyd polymer modified, hot applied asphaltic tack coat, SA 1030, was sprayed at a coverage rate of 22 ft/gal. The project specification contains a special note within the Eliminator system specification (3.6.F): “Tack coat SA 1030 is heated and melted in a bitumen pot at 350-375°F. Heating above this temperature will degrade the product.” The tack coat has a minimum activation temperature of 200°F (the paving mix must be installed at temperatures exceeding 200°F for proper bonding to the waterproofing).

In some project photos, the paver is shown to be supplied directly from the delivering haul trucks (no shuttle buggy transfer vehicle). If tack coat pickup occurred in the areas where the haul trucks dumped directly to the paver, it is likely that in those areas, the paving will lack a good bond to the waterproofing layer because there is no opportunity to repair the tack in this scenario. Also, if the paver tracks picked up tack coat during paving operation, these disturbed pavement areas without tack will lack a good bond to the underlying waterproofing. The polymer modified asphalt pavement was applied over the tack coat in roughly the same order of installation (northern lanes first). The hot mix incorporated a dry powder thermoplastic proprietary binder additive called Rosphalt® 50LT, manufactured by Chase Corp. The polymer additive (2.5% of total hot mix by wt.) was combined with a dense graded aggregate mix with a nominal top size diameter of 9.5mm (3/8") using a standard asphalt binder (PG 64-22) at a design rate of 7.55% (of total hot mix wt.). The bridge deck paving mix design was performed by Tilcon (the owner of the paving plant and paving contractor) using a modified Superpave protocol to be compacted in place at ~1-2% air voids in accordance with New York State Thruway specifications for this special application. The Rosphalt modified paving mix incorporated ~5.2% (wt.) RAP (recycled asphalt pavement) as designed by its producing plant and paving contractor, Tilcon NY, of Riverdale, NJ. This is a relatively small percentage of recycled material content but if the recycled source is not consistent, it may contribute to pavement defects. The selected design binder content of the hot mix at 7.55% (wt.) is a relatively high use level of binder that aids compaction and fills air voids in the dense graded mix with the objective to render the pavement as an impermeable waterproofing layer. The small top size diameter aggregates of 3/8" allow a relatively thin layer of polymer modified pavement to be installed at 1.25-1.5" compacted thickness without crushing or rolling aggregates.

Tilcon's Riverdale plant has both a drum plant (continuous feed) and a batch plant (batches are spaced ~ 1 minute apart) to manufacture asphalt hot mixes. Tilcon reportedly employed their drum style asphalt plant to produce the bridge deck hot mix. The drum plant is a newer design type of asphalt plant tends to offer improved consistency (compared to older design batch plants); particularly if placement rates are consistently high. Tilcon's plant is located about a 45-minute drive (by haul truck) west of the bridge.

The Rosphalt additive to the asphalt paving mix is expected to provide a more stable, rut resistant and fatigue resistant pavement. Proper installation and compaction of Rosphalt modified pavement requires high mixing (450°F) and high placement (400°F) temperatures compared to those of standard asphalt pavements which are installed in the 300-350°F range. Due in part to the special mix design and very narrow performance specifications, Rosphalt polymer addition is claimed to offer improved pavement lifespan. The Rosphalt modified paving was placed using a Caterpillar AP600D paver supplied by a Roadtec MTV (shuttle buggy) which occupied the adjacent lane along with the haul trucks delivering hot mix. Using this method of supplying hot mix to the paver, the paver is the only equipment in contact with the tack coat. An added benefit of the shuttle buggy is additional mixing prior to the conveyor to the paver which can help prevent segregation. However, in some cases (especially when a delay occurs), the hot mix can cool while it is stored in the MTV. This cooling before the paver adds to the compaction challenges of the fast-cooling thin cross section pavements on a bridge deck which are exposed to windier conditions and less thermal insulation than provided by on-grade paving installations (especially if the weather is cool).

Compaction was performed by 2 Bomag steel wheel compactors. In the early paving days of 2017, the compactors were operated in static mode (no vibration or oscillation) which is a commonly specified mode on bridge decks, as noted in Section 3 of the 4^{th} edition of the NY State Thruway Structures Design manual (3.1.2.4e). The prohibition of vibratory compaction on bridge decks is also specified in NYSDOT standard specifications. The specified use of static mode compaction as a standard on bridge decks is due to the concern that vibratory mode compaction can negatively impact the structural integrity of the deck (particularly at mid-span) and deck substructure. However, early daily QC reports indicated unsatisfactory in place pavement density results. To correct the low-density results, the compaction rolling methods were altered to allow closer placement (shorter distance) of rollers to the paver and the compacting steel wheel rollers converted from static to oscillation mode (a non-vertical vibration of the drum).

Several of the 2017 daily reports included pictures showing unintended pickup (removal) of sections of the tack coat by sticking to paving equipment tracks and tires. According to daily QC reports, the paving contractor began to use Paveforce, a Caterpillar brand of biodegradable solvent applied by spray bottle application on tracks and tires as a release agent to reduce the tire and track tack coat pickup. In other QC notes, soapy water or a water-based release agent was sprayed on tires to reduce pickup. The latter option, a detergent or surfactant diluted with water, is called for in the Eliminator project specification. Whether either of these materials was investigated or approved by the Engineer of Record is unknown.

Early paving QC reports also describe observations of excessive tack coat application in some areas. There is no mention of a remedial action to clear the excess tack coat in affected locations. Additionally, there are daily report references that (non-paving) construction traffic traversed tack coated areas prior to paving placement and that in some cases the tack coat appeared brittle and was damaged or stripped. It is questionable whether the areas of this type of pre-paving tack coat damage were inspected and repaired prior to paving.

The initial period of paving was performed during unseasonably hot weather which may have softened the tack coat to a nearly fluid state. This hot weather may have facilitated stripping. In some cases, the episodes of stripped tack coat were not resolved or repaired prior to the installation of the asphalt paving lift. Also unknown is the quantity and re-application frequency of the release agents used on tires and tracks assuming replenishment was necessary to prevent pick-up.

Visual observations (June 2020)

During the late nights and early morning days of June 22-26, 2020, several technical teams on foot examined the entire SUP pavement from [redacted] and the east abutment. Portions of the shoulder and bus lanes of both eastbound and westbound structures were also surveyed in the same fashion. The daytime high temperatures during the week of inspection were in the high 80’s to low 90’s °F, with minimal winds. Two (lead) inspectors led the investigation, recorded written and photographic records and directed other teams to perform: a) (non-destructive) sonic impact echo (IE) testing in specific locations and b) another team to remove 3” to 6” diameter cores for immediate visual inspection and subsequent lab analysis.

The lead inspectors focused on localized pavement areas which contained multiple randomly spaced and often clustered defects consisting circular shaped raised mounds (blisters). By walking backwards and facing the headlights of a following vehicle, the two lead inspectors could easily detect blisters by their contrasting shadows from the headlights of following vehicles. In a brief period on one day prior to sunset, the lead inspectors could discern the same blisters without the aid of headlights and darkness but they were less pronounced and more difficult to locate as the light contrast was lacking.

The lead inspectors surveyed blisters and maintained a written log ranking their numerical density and size and height severity identified by locations. The coring team was instructed to drill cores through the pavement to a depth of approximately ½" into the concrete deck so that the integrity and bonding of the layers including the membrane could be evaluated. All cores and core holes were immediately logged and reviewed by the lead inspectors prior to refilling (repairing) the core hole. Without exception, the cores that were centered within blistered domes were delaminated solely between the membrane and the asphalt paving at the level of the tack coat. No delamination of the waterproofing membrane or separation damage within the asphalt pavement layer was noted in any specimen other than some aggregate dislocation on the most severe blister edges. In several cores drilled in non-blistered areas, the core was removed in one piece and broken within the upper layer of the precast concrete deck beneath the membrane.

In both west and eastbound lanes, several of the blisters were noted to have vertical cracks in the dome area of 1-3" length. Cores taken in some of the cracked blisters indicated that the vertically oriented cracks penetrated to the level of the underlying membrane but did not pass through the membrane. Cracking of the blister dome areas appeared to be slightly more common in the eastbound lanes where the blisters appeared to have a shaved or abraded (lighter) appearance on their most elevated surface. This mystery (of differing blister appearance by traffic direction) was plausibly explained by a Thruway maintenance truck driver who stated that rotary snowplows were used on the eastbound lanes but not in the westbound lanes. The westbound lanes are adjacent to the enclosed glass viewing areas of the belvederes which could be damaged by the rotary plows' airborne snow and debris stream. In the westbound direction, only trucks with push blades (with non-damaging urethane bottom edges) are used.

The lead inspectors directed the IE test team to record their data in limited areas of predominant blister density. Additionally, the IE team tested several areas without defects to determine whether the analysis would match the visual findings (of no defects). During a portion of the subsequent nights following the previous night's IE testing, the lead inspectors referred to color coded charts generated by the IE test team from the previous night's analysis and were able to match locations by geographic landmarks and measuring tape (or surveyor wheel) distances. Allowing for small measurement discrepancies, the IE pictorial images generally matched the blister locations detected by visual inspection. Due to the spacing limitations of the 6"x12" grid of IE recording, a portion of visible blisters were not detected. The undetected blisters were ostensibly located between the direct mechanical (spot) impacts of the IE test machine.

On two nights, several belvedere transition tapers were visually inspected as well as sounded by hammer to detect and record areas of delamination. Portions of the cast-in-place concrete transition tapers were not apparently sealed and/or bonded to the underlying concrete and were noted to rock in place when weight was shifted from one side to the other. Several transition tapers had water immediately underneath and when rocked, the underlying water flowed to the transition taper periphery and was pumped out to the longitudinal end of the taper. Drainage scuppers are present on the high (uphill) side of the belvederes but were not installed on the low side (this item is detailed in the bridge deck design drawing notes). As a result, water from snow melt and rain is more likely to pond in the low side of the transition taper areas.

A design drawing dated Nov 6, 2018 (H12ER-01 A7101) shows that during the belvedere construction, the asphalt pavement and waterproofing membrane are removed along with a thin cross-section of the top surface of precast concrete deck in the belvedere transition tapers and raised flooring areas to partially accommodate the greater combined thickness of the inset mortar bed and the raised walking surface pavers. The same drawings include a note which states that the builder shall apply a waterproofing membrane system in the belvedere area. A liquid spray membrane, Laticrete Hydroban, is called out on the same drawing to be applied on the surface of the concrete deck in the belvederes where the paving and top surface of the deck was removed to provide vertical space for the mortar bed underlying the pavers.

The lead inspector team could not view the top surface of the SUP Rosphalt polymer modified asphalt surface course due to the blue coating cover membrane that had been recently installed prior to the opening of the SUP. As a result, we could not evaluate the appearance of this pavement and whether it displayed segregation or other paving defects. Within the shoulders and far right traffic lanes of the driving lanes, if we ignore the presence of blisters, the pavement surface appeared to be consistently in excellent condition. The pavement surface appeared very uniform and without distresses, cracks, raveling, segregation, patched areas, rutting or shoving. There was no separation seen in the longitudinal joints and no obvious evidence of paver stop/starts which would appear as transverse anomalies. The lead inspectors drove across the bridge at highway speeds in Thruway heavy trucks and cars. The riding surface was very smooth in both vehicle types. Limiting considerations for the observations above are: a) these observations were compiled during late night and early morning hours with less-than-optimal lighting and b) the visual inspection and related core sampling and tests were conducted on a small portion of the traffic lanes.

Several discussions occurred during this survey regarding the blisters noted on the driving lane and shoulder areas. A pertinent question arose: Do the blisters disappear under heavy traffic and/or reappear when the affected lane is closed to traffic? One of the Thruway technical staff supporting this inspection who viewed the deck many times in daytime and nighttime commented: “the blisters are depressed by heavy traffic and may reappear more prominently after there is no traffic in that lane”. During the June inspection, we could visually discern blisters within 1.5-2 hours of no traffic in the lane as there was always a time lag between the closing of a lane and the timing of our visual inspection.

Comparing the observed pavement condition on the cable suspended deck sections versus the pier supported approach deck sections, the suspended deck areas displayed noticeably fewer blisters and blister clusters than quantity observed on the pier supported approaches. The pronounced differential in blister totals/square area was the same on both EB and WB structures. The blister quantity differential between cable and pier supported decks was noted both visually and in the IE surveys.

A detail not included during the June SUP or traffic area inspection is the horizontal longitudinal connection between the westbound shoulder edge vertical concrete barrier and the underlying concrete deck surface. The raised concrete area immediately under this barrier is at the same elevation as the asphalt paving surface on either side. If there is a cold joint gap between the deck and the vertical barrier, it’s possible that water could pass through horizontally to the SUP side of the barrier since the roadway’s design incorporates a 2% transverse slope to the sides. Alternately, if the pavement is not well sealed at the vertical edge joint on either the roadway or SUP side of the raised concrete base, water, salts and debris can flow into the joint and potentially under the pavement and the membrane of the SUP.

Pavement core specimens

In addition to 7 cores obtained from the SUP in January 2020, 22 cores were taken on the SUP and the shoulder/right lane areas of eastbound and westbound directions during the week of June 22, 2020. After visual inspection of each core, Advance Testing Company, Campbell Hall, NY, was directed to further analyze 3 cores removed in January and 9 cores removed in June. A portion of the tested cores including those with and without blisters were subjected to tensile tests for adhesion of the Eliminator membrane to the asphalt pavement surface. In a separate series of tests, most of the submitted cores Rosphalt modified pavement layers were treated by solvent extraction to verify mix design conformance to project specifications.

The January and June cores were drilled using water flushed diamond bits with diameters of 3, 4 and 6”. During both time periods of core extractions, the coring contractor was instructed to drill approximately ½” beneath the membrane into the deck surface. The core extraction objective was that the cores would be broken within the upper structural concrete layer—this was typical when a skilled coring technician executed the removal. The core locations were predominantly in the middle or edge areas of blisters. In the cores taken from raised blister locations, delamination occurred predominantly within the tack coat layer or adjacent zone of the base level of the Rosphalt pavement. No cores displayed visual delamination of the membrane from the concrete deck surface. No cores contained voids in the middle or top elevations of the 1.5” pavement layer.

Test method ASTM D4541 was selected to measure the pull off strength (tensile bond strength) of the Eliminator membrane to the surface of the Rosphalt modified asphalt pavement layer. This test evaluates the bond of the polymer modified tack coat which is the spray applied bonding layer between the Eliminator membrane and the asphalt pavement layer. If the core was removed from a blistered or raised area (as opposed to a non-defect location), the lab did not alter its test procedure. To prepare the core for tensile testing, the lab milled off concrete that remained on the bottom of the Eliminator membrane to provide a flat bonding surface for the 20 mm dolly. After applying the steel dolly to the membrane surface with a high strength epoxy adhesive, the adhesive was allowed to cure for 24 hours. Prior to pulling off the dolly, the circumference of the adhered dolly was predrilled with a small coring bit through both layers of the membrane to the asphalt layer so that only the dolly surface area was measured for tensile value. Five cores provided nine tensile results with a range of 204-494 psi. These tensile results exceed the 100-psi project specification with most failures occurring within the expected layer of the tack coat.

Test method ASTM D2726 (bulk specific gravity) was applied to the Rosphalt modified asphalt layer on 11 cores prior to solvent extraction. January cores (on SUP only) and June cores (SUP plus shoulder and right lane of EB and WB structures) were included. With one exception (2.84%), the air void percentage of these specimens ranged from the high 1% to low 2% of the Rosphalt modified pavement. These results indicate good correlation with the original mix design and show uniform results throughout the different areas cored. The consistent low voids in this range in combination with a 9.5 mm nominal aggregate and high binder content contribute to a pavement layer of very low permeability that is essentially another layer of waterproofing. Additionally, the small nominal aggregate size, dense grading and high binder content are less susceptible to fatigue damage versus standard dense graded pavements (typically used in on-grade applications) of larger nominal aggregate diameter (12.5 mm or 19 mm) with air voids in the 3.5-5% range and binder content of ~5.5% (wt.).

Test method ASTM D2172 (solvent extraction of bituminous paving mix) was also applied to the same 11 cores. Two of the January 2020 cores (taken from the SUP) showed a higher binder content exceeding 9%. The remaining 9 cores from the SUP, shoulders and right-side traffic lanes averaged 7.76% binder. The thermoplastic Rosphalt additive is composed primarily of organic content, so it should be extracted along with the asphaltic binder, which leads to an expectation of an extracted binder content higher than 7.55%. The statistical spread in binder weight percentage in the extraction procedure can be partly attributed to the small sample size of the pavement in the cores provided.

After extraction and calculation of the binder content by wt. %, the ASTM D2172 test also provides clean aggregate from each core specimen which then is re-sieved to determine gradation. The gradation test results of all individual cores were within specified design limits in all sieve sizes from 3/8" to 200# (mesh). The sampled cores were in consistent conformance on gradation and with the exception of the 2 January 2020 SUP cores, the binder content was slighter higher than the original mix design.

Impact Echo testing

Olson Engineering (Wheat Ridge, CO) participated in the June 22-26, 2020 SUP and roadway inspection and survey supplying a technical team of two to operate their test instruments. Olson's survey methods and data were summarized in their November 3, 2020 draft report. Their team operated a proprietary design hand-propelled Sonic Survey Scanner similar in size and shape to a 3-wheel jogging stroller. Two non-destructive evaluation (NDE) methods were evaluated by the Olson team to detect and map the presence of delaminations (or voids) between the Rosphalt pavement and the concrete deck. One of the two test methods was determined imprecise in this application, so it is not discussed here.

The Impact Echo (IE) testing and subsequent modeling analysis produced mapped data which appeared to match the location and areas of delamination identified by visual inspection as blisters on the pavement surface. A portion of the (previous night's) IE test results were provided in color-coded maps on printed records during the June inspection period. In two instances (separate nights), the lead inspectors compared blister visual measurements with Olson's IE blister maps using deck landmarks the following nights. In both cases, the IE maps agreed with visual blister locations.

The IE testing procedure is designed to provide a condition survey based on ASTM C1383 (Std. test method for measuring P-wave speed and thickness). Olson's IE test rig uses multiple small solenoid driven pistons mounted on the circumference of a nylon wheel. The small diameter pistons deliver a low strain impact on the pavement surface approximately 6" apart (longitudinally in the direction of rig travel). A sensor (displacement transducer) adjacent to the piston records the differential (lower frequency, higher amplitude) resonance of the delaminated areas compared to the well bonded areas of pavement. Location and resonance data for each impact is compiled real time on a laptop mounted near the rig's handlebars. While the longitudinal data points were 6" apart, the lateral distance between data points was 12". The 12" transverse spacing was discussed and determined by the inspection group personnel as a compromise based on the time requirements to collect the IE data across the SUP and traffic lanes using multiple longitudinal passes at a slow walking speed of ~ 2 mph.

The two lead inspectors walked the SUP and a large portion of the EB/WB traffic/shoulder lanes. They were typically far ahead of the Olson IE survey crew which proceeded at a slower rate due to slower walking speed and multiple passes. Several traffic bearing areas were not visually inspected in detail (both EB and WB) including a higher proportion of the central suspended span lanes because the blister counts and clusters were noticeably fewer on the suspended spans than similar lane areas on the east and west approaches of both EB and WB structures.

The lead inspectors selected and marked off pavement areas as they proceeded ahead on their visual inspection for the trailing Olson team to later perform their IE survey. In most cases, a portion of the most concentrated or densely clustered areas of blisters were selected and subjected to further IE data logging. The pavement areas surveyed and subsequently mapped by Olson using IE consisted of Rosphalt pavement with the exception of item #4, which is of cementitious construction:

1. 6 partial span sections on SUP, 10 partial span sections on WB shoulder and rt. lane and 4 partial span sections on EB shoulder and rt. lane; and
2. 2207 linear ft in SUP, 1261 linear ft WB shoulder and rt. lane and 688 linear ft of EB shoulder and rt. lane; and
3. 13,470 sq ft of SUP, 12,867 sq ft of WB shoulder and rt. lane and 7,360 sq ft of EB shoulder and rt. lane; and
4. Two 12' x 5' cementitious transition tapers on the SUP at the Tides of Tarrytown belvedere.

Table 3 of Olson's draft report summarized their findings of blister defects by span number and pier location in the pavement areas surveyed. Due to the grid size and pattern, and the average blister diameter (assumed to be 6"), Olson estimated that approximately 40% of the blisters were not detected due to their location falling between the impact taps of the wheel mounted pistons. To counter the misses, their IE data was subjected to multiple Monte Carlo simulations. The simulations are dependent upon average blister diameter so recalculating at a 5" diameter could reveal a significant increase in missed defects. The simulation corrected blister areas as a percent of total area surveyed by location averaged: SUP (2.6%), WB (2.57%) and EB (2.45%). The range of % blister area on a per surveyed section varied from 0.5% to 5.9% which converts to non-delaminated or well-bonded pavement areas (per section) of 94.1% to 99.5%.

There are 6 unique belvedere features on the WB structure's SUP. Each belvedere has 2 mildly sloped transition tapers (one on each side) that are ~12 feet long. These cementitious longitudinally sloped transition tapers transition from the SUP pavement elevation to a slightly higher elevation to match the infill floor elevation of the belvederes. On several belvedere transition tapers, water has been observed under the sloped transition taper (above the underlying concrete deck). Under and adjacent to some transition tapers, ponded water could accumulate and be slow to dissipate due to lack of nearby scuppers. Significant portions of the transition tapers may be unbonded and separated from the deck as evidenced by the effects of a person's foot pressure induced slab rocking and resultant water pumping at the taper edge.

To further investigate this transition taper issue, the Olson team performed a detailed IE survey of both transition tapers leading to the Tides of Tarrytown (the belvedere closest to the east approach). The Tides of Tarrytown east transition taper showed delamination of ~63% (of total transition taper area) and the west transition taper of ~18% from the IE survey. Additionally, the lead investigators sounded the transition tapers on the Tarrytown belvedere in addition to the farthest west belvedere transition tapers (Fish & Ships) with a hammer in several areas to confirm suspicions of large delaminated areas.

Origins of pavement blisters

The Rosphalt modified asphalt pavement is bonded to the Eliminator membrane with an adhesion layer provided by a polymer modified asphalt tack coat. The 120 mill (3 mm) thick double layer of Eliminator waterproofing above the concrete and below the pavement is not permeable to liquids or gases. Additionally, the cured and cross-linked Eliminator membrane also has a relatively low surface energy, which means that the Eliminator surface is difficult to wet out (adhere to) in this application where the bond between the membrane and next layer must be strong. The Rosphalt modified wear course pavement is similarly designed to provide low permeability with its high binder content and small aggregate nominal size resulting very low air voids that are not inter-connected.

Comparing the multiple layers composed of polymeric and asphaltic composition between the concrete deck and the Rosphalt pavement, the layer with the lowest tensile strength is the tack coat. Higher ambient temperature significantly softens the tack coat as well as decreases its tensile strength. The tack coat layer would be the predicted location of failure if it was possible to tensile test an extracted core longitudinally end-to-end, that is, from top (paving layer) to bottom (upper surface of concrete deck). Following are factors that could negatively impact the pavement bond to the Eliminator membrane:

1. the tack coat is not properly applied to the Eliminator,
2. solids (dust, blowing debris) or liquids (including water from construction equipment (including vehicle A/C condensers) or oil or other spilled lubricants contaminate the tack coat,
3. the tack coat is missing or has been stripped (ripped away or left in place but delaminated) by equipment tires or tracks,
4. the pavement application falls below the tack coat activation temperature (200°F),
    a. segregation within the paving box that allows some of the mix to cool in the less sheared dead areas (including corners) can lead to occasional drops of (cold) hot mix
    b. in newly placed areas requiring repair prior to compaction, manually shovel placed additional hot mix can be relatively cool,
5. overheating the tack coat in the melting pot causes oxidation damage,
6. large diameter aggregate segregation at the base of the pavement causing air voids which reduce the contact area to the tack coat.

In the foregoing examples, the Rosphalt pavement layer may be unbonded or poorly bonded due to lack of surface wetting because the viscous Rosphalt modified binder in the paving mix is unlikely to migrate to the Eliminator interface in locations where the tack coat is missing or not able to function as an intermediate adhesive. However, missing, failed or solids contaminated areas of tack coat may not be a sole direct cause of elevated blisters, particularly on a sealed and rigid concrete deck.

Trapped water or organic liquids or oils and lubricants remaining on the tack coat at the time of paving often can directly lead to defects including blisters that appear at a later time. Black tack coat (and asphalt pavement) surfaces are excellent infrared (heat) absorbers and can reach 180°F, particularly on a hot, sunny day. Water and organic liquids/contaminants with lower flashpoints, on a hot day, generate vapor pressure which can't escape downward through the membrane and can't escape upwards through the hot, thermally softened low void pavement. The resulting trapped vapor pressure build-up can lead to formation of a blister which usually appears in the early days or weeks after paving in partial relief of local stresses. If trapped water and/or other volatile liquids are the cause of singular or multiple blisters following several thermal cycles, often there is a visible vent hole in the near center region of the raised dome. However, no small diameter vents were observed on any of the thousands of blisters. Additionally, new blisters formed on the SUP in spring 2020 after the surface was leveled by micro-milling.

After the current WB structures opened to traffic in fall of 2017, the SUP served as the farthest right traffic lane, carrying some of the heaviest axle traffic for one year. After the EB structures opened, the SUP carried miscellaneous a small amount of construction vehicles during the belvedere construction period. In fall 2019, the blisters were noticed on the SUP pavement and in spring 2020, micro-milling was performed to re-level the SUP in preparation for a final blue MMA polymer topcoat. Within a week after the topcoat was installed, the blisters re-appeared. However, the probability that volatile liquids were the sole cause of blister re-appearance after 2-1/2 years seems unlikely as slow dispersion due to the many interim thermal cycles would be expected to cause losses of trapped volatile liquids over this extended period.

What factors might explain the lower quantities of blisters on the cable suspended spans versus the approach spans? The WB and EB structures were paved about 1 year apart, yet the right shoulders and bus lanes of both structures have similar blister quantities in the surveyed sections. Additionally, the suspended central and side spans contain lower blister quantities than the pier supported approach structures on both sides and in both directions.

Perhaps the approach concrete decks are subject to different strains/stresses and movement axes than the suspended deck sections. A partial explanation for differential effects is displacement variances through daily temperature cycles and structure changes relating to aging. Other contributing elements may include: concrete shrinkage, settlement over the haunched girder flanges, movement locally over the bearings and vertical and skew displacement related to thermal expansion in the longitudinal direction as local and larger scale factors which affect cyclic movements potentially causing strain/stress cycles on the pavement.

A construction procedure that could differentially impact the pavement in the suspended vs. approach structures is the oscillation form of vibration used by the paving steel drum compactors [redacted].

Recommendations

Identify areas of the bridge deck at high risk of either freeze-thaw or (salt-induced) corrosion damage. For example, if there is known water leakage from the westbound driving lanes to the SUP due to the cold joint underlying the longitudinal concrete barrier walls, that could be addressed with silicone sealant (either Dowsil 888 or 890sl) as a high priority. This water can accelerate degradation of the architectural surfaces in the belvederes, particularly in areas with insufficient drainage. Additionally, if the vertical SUP pavement edge joint at the barrier is unsealed, water and salt (from the roadway) could penetrate below the waterproofing membrane and cause delamination. A quick survey of the SUP in a golf cart during a rain storm could help identify the most heavily impacted areas in the event only limited area repairs are possible.

Within the grouted tile areas of the SUP belvederes, there is reported evidence of water infiltration. If possible, prior to onset of cold winter weather, the grouted areas should be protected with a clear penetrating (silane) sealer according to Thruway specifications. Both the silicone sealant and penetrating sealer applications do not require high levels of skill and could be quickly executed by Thruway maintenance personnel.

The sloped transition taper approaches to the SUP belvederes have been observed to have significant delamination (using NDE methods discussed above) and underlying water is evident. These areas should be continually inspected for damage until more information about their construction method and material sources is available. Then a repair procedure could be developed. One permanent potential repair is epoxy injection to displace water and air in conjunction with vertical stainless-steel pins to the substrate.

SUP and traffic deck sections with a higher blister count should be noted and tracked by a visual survey conducted on foot yearly. Over a period of several years, it should be possible to determine if these defects are either: a) in a near steady state equilibrium or b) if the pavement is noticeably deteriorating differentially in the heavily blistered areas versus the less densely blistered areas.

Conceivably the blisters found in the SUP could be considered primarily as a cosmetic issue with the assumptions that the raised areas do not lead to slip/fall/tripping hazards or allow water to accumulate below the pavement and cause further delamination damage due to freeze/thaw movement. However, the blistered areas on the driving surfaces, in particular the more heavily blistered lanes bearing the highest axle load traffic, could be subject to accelerated wear. The higher wear (particularly in the heavy axle lanes) may result from a combination of fatigue damage resulting from vertical deflections (between raised blisters and underlying membrane) due to cyclic loading as well as shear damage in curves and locations where braking is most common.

Use of a rotary snow plow auger is suspected of slowly abrading the raised blisters on the Eastbound lanes, in particular, the far right (bus) lane and shoulder areas. In several areas, the shaved blisters have cracked near the top of the blister possible due to the mechanical shock of colliding with the steel rotating auger blade. On winter storm days with low snow totals, relying primarily on bladed snow removal (especially if the blade has a polyurethane polymer bottom wear edge), should reduce this type of damage.

Increases in heavy axle traffic counts have been shown in numerous tests worldwide as a primary cause of accelerated pavement degradation. In particular, pavement experts agree that overweight trucks contribute damage that is a logarithmic function of the amount overweight. If weigh in motion data can be collected and documented accurately, the next step would be to implement and enforce. If enforcement is difficult due to political or other reasons, signage warning of weigh in motion detection capability might still provide a limited benefit.

Is there a viable procedure to potentially reduce the number of blisters in a given area of the deck without replacing pavement? Micro-milling was performed on the SUP (prior to the top coating) and the blisters were not observed for a short period. However, the blisters returned to the milled areas shortly afterwards, so we can infer this option to be non-viable. The milling procedure is not able to cause a rebonding of the tack coat to the Eliminator assuming this layer is where the blister separates from the underlying membrane. The Stirling Lloyd tack coat (if present in the blistered area) must be heated to at least 200°F to activate it. If the bridge technical staff has interest in performing a small area test next year, an IR heater planer could be mobilized to the bridge deck with the objective of reheating the 1.5” pavement and the underlying tack coat to at least 225°F. With the relatively thin pavement layer, thorough heating to the tack coat layer should occur relatively rapidly. Compaction could be reapplied in very close proximity to the heater using a rubber-tired roller for better meshing at the tack coat level.

Repairs

I. CRACK REPAIR

Cracks should be repaired promptly to prevent water from entering and remaining in the cracks. Longitudinal cracks may occur in asphalt pavements if the deck substructure allows excess movement, or if trucks are frequently severely overweight. Transverse (latitudinal) cracks are uncommon but may appear as gaps seen adjacent to underlying joints or may result from broken blisters. Cracks (or gaps) should be filled with a very low viscosity epoxy polymer that will penetrate, cure and structurally seal to the full depth. Hot-applied asphalt sealers and solvent containing materials should not be used.

EQUIPMENT
Clean mixing vessel
Slow speed drill motor with mixing paddle
Long handle rubber squeegees (blade can be bent in a "v" shape to direct material into crack)
Air Compressor

MATERIALS
100% Solids (0 VOC) Fast Curing Epoxy Penetrating Sealer, Kemko® 186 Epoxy Healer/Sealer or equivalent

SPECIFICATION	TEST METHOD	REQUIREMENT
Color	Visual	Clear
Viscosity	ASTM D2393	75 cps max.
Tensile Strength	ASTM D 638	48 mpa (7000 psi) min.
Tensile Elongation	ASTM D 638	4% min.
Gel Time @ 23ºC	ASTM D 2471	15 minutes max.

Bagged, dry, 30 mesh Silica Sand

METHOD OF REPAIR
1. Perform repair when deck temperature is above 10 °C
2. Remove as much as possible all dirt or debris from the crack with compressed air.
3. Mix sealer components in clean vessel for three minutes minimum with slow speed drill fitted with mixing paddle, pour sealer and flood crack with sealer. Push excess sealer back and forth over crack with rubber squeegee so that sealer completely fills crack and crack remains full. Continue application of sealer until the crack will accept no more sealer. Remove any excess or puddles of sealer.
4. Broadcast silica sand over deck areas that appear wet from sealer within 30 minutes of initial application of sealer. (Sand will provide skid resistant surface until light epoxy film and sand wear off under traffic.)
5. Allow a cure time of 3-4 hours before opening to traffic (shorter on warm days and longer on cool days).
6. Note: if the volume and length of the crack(s) is (are) very limited, it may be convenient to mix

the epoxy in paper coffee cups and apply with a disposable syringe directly into the crack without covering the adjacent surface.

II. SPALLS AND GOUGES

Gouges are usually the result of heavy sharp objects falling on the pavement, or rigid objects dragged on the pavement. Spalls can occur adjacent to joints or cracks. The damage due to gouges or spalls is generally not full depth. The following method uses extremely durable materials and should provide a chemical resistant, non-melting, well bonded, impermeable repair.

EQUIPMENT
Pavement Saw
Chipping Hammer
Mortar Mixer 20 Liter Capacity
Stiff Brush
Screed
Trowels
Hand Tamping Tools

MATERIALS
The low modulus 100% solids (0 VOC) liquid epoxy asphalt, Kemko 2490, or equivalent, should meet the following requirements:

SPECIFICATION	**TEST METHOD**	**REQUIREMENT**
Color	Visual	black
Viscosity @ 23º C	ASTM D 2393	3500 max
Tensile Strength	ASTM D 638	15 mpa (2200 psi)
Tensile Elongation	ASTM D 638	60-80 %
Gel Time @ 23ºC	ASTM D 2471	25 minutes min.
Structural rating	ASTM C881, Type III, Grade 1	Passes

Aggregate
Same gradation and source as used in original bridge paving (see note 7 below) unless repair depth is less than 1” high. A smaller top size aggregate must be used for repairing pavement depths of less than 1”. The aggregates must be clean and dry (less than 0.2% wt moisture).

METHOD OF REPAIR
1. Saw cut around perimeter of damaged area to the depth of the damage.
    a. If the damaged area is very large, a a small milling machine can be used with care taken to stay at least 4 mm above the Eliminator membrane.
2. Remove all loose material.
3. Clean surfaces of area to be repaired by sandblasting, grinding or vigorous wire brushing. The optimum surface profile is roughly approximate to 60 mesh sandpaper.
    a. Note: if the repair area is no longer protected by a layer of membrane or membrane is damaged or loose, then carefully cut and remove membrane that is no longer fixed to the concrete deck.
4. With stiff brush, apply prime coat of neat (no aggregate included) epoxy binder to completely

cover all surfaces of the repair, including vertical faces of saw cut.

5. To make an epoxy repair mortar: mix proper amounts of both A and B components for 2 minutes, then add aggregate using approximately 12% by weight of epoxy binder.
6. For small repairs, a drill mounted Jiffy type mixer works fine in a 5-gallon bucket (note that Jiffy mixers will likely require a more fluid mix with more binder). For larger repairs, a "Kol" type (http://www.mixall.com) or mortar mixer provides the best shear and will work best with drier mixes. Do not use a concrete mixer for epoxy blends.
7. Aggregate must be dry and clean with the same gradation as was used in the original pavement. The minus 200 sieve size portion of the aggregate may be omitted to make mix more workable. The binder content may be adjusted between 12% and 16% to make the mix easier to install, but do not use more binder than is necessary to provide good workability. More binder allows a self-leveling mix and less binder will require a trowel finish and possibly requires additional compaction.
8. To accelerate cure in order to minimize traffic delays, the aggregate may be pre-heated to 40 °C. Excessive heating shortens the working time of the mixed components as the viscosity of the epoxy increases more rapidly.
9. Place the mixed epoxy mortar in the repair area and screed flush with the surrounding pavement. Compact with hand tools.

III. Large Areas - Pavement Replacement

If a vehicle or spilled fuel burns on the pavement, the amount of damage depends on the duration and intensity of the fire. Fires of short duration may cause only superficial damage at the surface and may not require repair. Fires of long duration may cause damage beyond 5 mm in depth. Long duration fires or burning spilled fuel usually damage areas that are larger than spalls or gouges. The repaired area should consist of a hot mixed asphalt pavement with a maximum 9 mm (3/8") top size aggregate dense graded mix with mix design air voids less than 3.5% (to preserve impermeability—no inter-connected voids).

EQUIPMENT

- Set of maintenance hand tools: shovels, rakes, brooms, squeegees, etc.
- Special heated tools: Irons, preferably of the continuously fired type; kerosene torches (weed burners); heated roller, preferably of the continuously fired type; surface heater, of a type which does not impinge flame directly on pavement such as an IR heater planer
- Stove or electric band heater, capable of heating a five-gallon pail of asphalt binder (part BIX) to at least 130° C.
- Pavement saw

MIXING EQUIPMENT

For job-site mixing, 3-6 cubic feet cement concrete or mortar mixers may be employed providing the mixing chamber, bearings, packing, etc., will permit at least limited operation at 130-150° C. Portable mixing vessels (tanks, drums, pails depending on amount to be mixed) for blending the binder and aggregates.

- Platform scale to weigh binder and aggregate when repair materials are field mixed.
- For larger areas, mixtures can be prepared in a conventional batch plant.
- Long stem or infra-red thermometers to measure temperature of the binder and aggregate.

SPREADING EQUIPMENT

Use self-propelled bituminous material spreaders capable of spreading hot bituminous paving mixtures without tearing, shoving or sousing and producing a finished surface which can be compacted to conform to the grade and smoothness of the original overlay.

MATERIALS

Aggregate source and gradation as specified in the job mix formula for original bridge pavement (see note 6 below). Asphalt binder PG70 or higher, preferably polymer modified. If alternate aggregates must be used, basalt aggregate is preferred but granite is acceptable.

METHOD OF REPAIR

1. For large area damage deeper than 25 mm (1")
2. Saw cut with vertical faces around perimeter of locations to be replaced to form rectangular areas. If disbonding is noted at the freshly cut edge, the boundary of the patch should be extended until tightly adhering overlay is encountered. Any oil-soaked or otherwise defective material found under the overlay should be removed and replaced with hot asphalt concrete mix.
3. Remove all damaged pavement and all good pavement to a depth of at least 25 mm.
4. The area should be swept clean of loose aggregate and the edges blown free of dirt. Any moisture should be dried off, with a torch or weed blower if necessary
5. Prime with Kemko 2490 or equivalent epoxy binder. Apply two-component bond coat using stiff brush to apply uniform thin coat which also covers the vertical edges of the existing pavement.
6. Mix and place and compact asphalt concrete as specified in NYS Thruway Structures Design Manual, Section 3. Aggregate gradation and source can be the same or similar to that used in the original surfacing with the exception of substituting a (higher temperature rated) polymer modified PG70 or greater binder in lieu of the Rosphalt additive. RAP should not be considered for repair mix uses.
    a. An alternate impermeable paving mix for 1.5" or less thickness pavement repairs could be found in the FAA P-401 specification, with a job mix formulation based on gradation 3 (3/8" or 9 mm nominal top size).
7. For field mixes in portable mixers without aggregate drying and screening facilities, it is necessary either to charge a suitable cold aggregate combination to the mixer and heat with a kerosene torch or else prepare suitable hot, dry aggregate at a central plant and deliver to the job site. Such aggregate should be heated to at least 175°C to compensate for heat losses during stockpiling and transport to the mixer. It is necessary to warm the mixer with at least one waste batch of aggregate before attempting to prepare asphalt concrete with portable equipment.
8. Slightly over-fill cavity so that paving mix can be adequately compacted.
9. **Compact with pneumatic (rubber tired) roller first**, followed by steel roller.
10. If overfilling results in a raised section in the pavement, mill repaired area flush to adjacent pavement.