CHAPTER 11 BONDED WEARING COURSE

11.1 OVERVIEW

A bonded wearing course (BWC) is a gap or open graded, ultra thin hot-mix asphalt (HMA) mixture applied over a thick polymer modified asphalt emulsion membrane. The emulsion membrane seals the existing surface and produces high binder content at the interface of the existing roadway surface and the gap or open graded mix all in one pass. The gap-graded and open-graded mixes provide an open surface texture to allow water to flow through the surface. BWC can be applied and opened to traffic quickly. Bonded wearing courses are primarily used in high traffic areas as a surface treatment over HMA and PCC surfaces. It can be placed over structurally sound pavements as a maintenance treatment, and may also be used in new construction and rehabilitation projects as the final wearing course.

The BWC polymer modified asphalt emulsion membrane seals the existing pavement and bonds the gap graded or open-graded mix to the surface. The thick nature of the membrane allows it to migrate upwards into the mix, filling voids in the aggregate and creating an interlayer of high cohesion that does not delaminate or bleed, when applied correctly.

The BWC gap and open graded mixes provide a stone on stone contact which is resistance to rutting within the mix. The finished mat has very high macro-texture properties, provides good skid resistance, and has a void structure that improves driving visibility by reducing back-spray and tire-splash. The void structure also reduces tire noise. The mix is generally laid two times as thick as the largest stone in the gradation; however, it may be placed thicker to correct minor surface irregularities and as thin as one and a half times the maximum aggregate size.

The BWC process can utilize any one of four different mix types. These include BWC Gap Graded, BWC Open Graded, Rubberized BWC (RBWC) Gap Graded and RBWC Open Graded. BWC Gap Graded consists of polymer modified gap-graded asphalt concrete over a membrane of polymer modified asphalt emulsion. BWC Open Graded consists of open graded polymer modified asphalt concrete over a membrane of polymer modified asphalt emulsion. RBWC Gap Graded consists of gap-graded rubberized hot mix asphalt (RHMA-G) over a membrane of polymer modified asphalt emulsion. RBWC Open Graded consists of open graded rubberized hot mix asphalt (RHMA-O) over a membrane of polymer modified asphalt emulsion.

This document provides an overview of:

- Materials used in construction of bonded wearing courses,
- Guidelines for project selection,
- Construction processes associated with bonded wearing courses,
- Troubleshooting guide to assist the field personnel, and
- Suggested construction field considerations.

11.2 DESIGN AND SPECIFICATIONS

11.2.1 Hot Mix Asphalt

This section provides an overview of materials used in the construction of bonded wearing courses. Bonded wearing courses are constructed using polymer-modified or rubber binders and gap-graded or open-graded aggregates. More detailed information may be found in the Standard Special Provisions SSP 39-700 (Caltrans, 2006c), SSP 39-710 (Caltrans, 2007b), and SSP 39-720 (Caltrans, 2007c).

Binder for BWC Gap Graded

Currently, there are two grades of binder approved in the Caltrans specifications for use in BWC Gap Graded construction. Table 11-1 lists the binder grades and the climatic regions where they are used. For the location of each pavement climatic region, please refer to the Highway Design Manual (HDM) Topic 615 "Climate" (Caltrans, 2006b). The binders vary in their degree of polymer modification, and their use corresponds to the climatic conditions encountered in California. In general terms, PG 76-22 PM is used in hotter climates, while PG 64-28PM is used in cooler climates. The requirements for these binders can be found in Section 92 of the Standard Specifications (Caltrans, 2006d).

Table 11-1 Binder Grades used in Pavement Climatic Regions for BWC Gap Graded

CLIMATIC REGION	PG BINDER GRADE
Desert	PG 76-22PM
South Coast Central Coast Inland Valleys North Coast Low Mountain South Mountain High Mountain High Desert	PG 64-28PM*

Note: (*) Use PG76-22PM on routes with 20 year ESAL's greater than 10 million (or TI of 12) and where slow moving standing traffic is expected

Binder for BWC Open Graded

The binder for BWC Open Graded is PG 58-34PM regardless of project location.

Binder for RBWC Gap Graded and RBWC Open Graded

The specifications for the rubberized asphalt binder are identical to RHMA-G under Section 39, "Hot Mix Asphalt" of the Standard Specification (Caltrans, 2006d). The base stock for the rubberized asphalt binder is chosen based on Design Information Bulletin (DIB) 86 (Caltrans, 2006a). The climatic regions and the appropriate base stock according to DIB 86 are listed in Table 11-2. RBWC is recommended for use only in those areas of California that frequently place rubberized hot mix asphalt.

Table 11-2 Based Stock used in Rubberized Asphalt (Caltrans, 2006a)

CLIMATIC REGION	BASE STOCK FOR RUBBERIZED ASPHALT
South Coast Central Coast Inland Valleys North Coast Low Mountain South Mountain Desert	PG 64-16
High Mountain High Desert	PG 58-22

Aggregate

The main properties of the aggregate used in BWC mixtures include gradation, shape, number of crushed faces, wear resistance and clay or deleterious material content.

All gradations can be used on high volume roads. Additional characteristics to consider, when choosing a gradation, are listed in Table 11-3. The ½ inch gradation is used where a thicker mat is desirable and where pedestrian or bicycle traffic are not a concern. Mat thickness should be a minimum of 1 inch. The 3/8 inch gradation is most widely used for urban, residential and business district roadways where pedestrian and bicycle traffic is a consideration. This can also be used on mainline travel ways with a minimum thickness of ¾ inch. The No. 4 maximum gradation is used for urban, residential, and business district roadways where pedestrian and bicycle traffic is a consideration. A minimum thickness of 5/8 inch is recommended because this gradation allows for some 3/8" material in the blend.

Table 11-3 BWC and RBWC Gradation Selection Characteristics

	GRADATION		
CHARACTERISTICS	1/2"	3/8"	No. 4[A]
Recommended Lift Thickness	1"	3/4"	5/8"
High Traffic	Excellent	Excellent	Good
City Streets	Excellent	Excellent	Excellent
Residential Streets	Good	Excellent	Excellent
Bicycle Traffic	Fair	Good	Excellent
Pedestrian Traffic	Fair	Good	Excellent
Noise Mitigation	Fair	Good	Excellent
Reflective Cracking Mitigation	Excellent	Good	Fair
Release to Traffic	Excellent	Excellent	Excellent

Note (A): No. 4 gradation only applies to BWC Gap Graded mix

The physical property requirements of the aggregate used in BWC mixtures are prescribed in the respective BWC and RBWC specifications. In mountainess environments with multiple daily freeze thaw cycles, it is recommended to only use BWC Gap Graded or RBWC Gap Graded. For BWC Gap Graded, use only the 3/8" or No. 4 gradation with the modifications for freeze-thaw areas as listed in the SSP. BWC Open Graded and RBWC Open Graded are recommended for use in areas that have frequent or heavy rainfall because their more open texture allows for more water to be removed from the pavement surface.

The aggregate specifications are provided to obtain desired mix properties. For example, the mixture is intended to interlock and develop a shear-resistant pavement surface; hence, crushed particle faces are essential. The gap and open-graded aggregate creates voids in the aggregate, which ensure the correct void level in the mix. Flat or elongated particles reduce texture depth and are to be avoided. The aggregate should also be wear resistant (low wear value in CT 211) and low in clay content (high Sand Equivalent value using CT 217).

Mix Design

The performance of a bonded wearing course depends on the quality of the materials and how they interact during application, rolling, and after opening to traffic. This is heavily dependent on the mix design. The following sections provide a summary of the mix design considerations.

11.2.2 BWC Gap Graded

The amount of polymer modified asphalt binder to be mixed with the aggregate for gap-graded polymer modified asphalt concrete shall be determined by the Contractor using the surface area calculation in Asphalt Institute MS 2 (Table 6.1). Using a 1/2", 3/8", or No. 4 maximum gradation, the optimum binder content shall be established based on an estimated film thickness minimum of 10 microns. Film thickness is calculated based on effective asphalt content. The tensile strength ratio (TSR) is a minimum of 70 as determined by a modified California Test 371. The vacuum saturation portion of the test procedure is modified to account for the gap gradation. If the test results show the minimum tensile strength ratio of the untreated HMA mix to be less than 70, an antistrip treatment, such as lime or liquid, is required and the quantity of the additive should produce a tensile strength ratio of at least 70. The plasticity index of the aggregate blend under California Test 204 is used to determine the appropriate type of antistrip treatment. If the plasticity index is between 4 and 10, either dry hydrated lime with marination or lime slurry with marination can be used. If the plasticity index is less than 4, liquid antistrip, dry hydrated lime without marination, dry hydrated lime with marination, or lime slurry with marination can be used. To complete the mix design with the antistrip treatment included, the appropriate lab procedure is used as listed in the SSP (Caltrans, 2006c). The TSR requirement can be waived by the DME.

11.2.3 BWC Open Graded

The mix design requirements for BWC Open Graded are based on "open graded asphalt concrete" found in Section 39 of the Standard Specifications (Caltrans, 2006d). Using a 1/2" or 3/8" maximum gradation, the optimum bitumen content (OBC) is determined by California Test 368. The aggregate blend should be treated with an antistrip treatment unless the DME waives the requirement.

11.2.4 RBWC Gap Graded

The mix design requirements for RBWC Gap Graded are based on the RHMA-G in Section 39, "Hot Mix Asphalt" of the Standard Specifications (Caltrans, 2006d). Using a 1/2" or 3/8" maximum gradation, the optimum bitumen content is determined by California Test 367 following exceptions as listed in the specification. The tensile strength ratio (TSR) is a minimum of 70% as determined by modified California Test 371. The vacuum saturation portion of the test procedure is modified to account for the gap gradation. If the test results show the minimum tensile strength ratio of the untreated HMA mix to be less than 70, an antistrip treatment, such as lime or liquid, is needed that will produce a tensile strength ratio of at least 70. As discussed above, the plasticity index of the aggregate blend under California Test 204 is used to determine the appropriate type of antistrip treatment. If the plasticity index is between 4 and 10, either dry hydrated lime with marination or lime slurry with marination can be used. If the plasticity index is less than 4, liquid antistrip, dry hydrated lime without marination, dry hydrated lime with marination, or lime slurry with marination can be used. To complete the mix design with the antistrip treatment included, the appropriate lab procedure is used as listed in the SSP (Caltrans, 2007b). The TSR requirement can be waived by the DME.

11.2.5 RBWC Open Graded

The mix design requirements for RBWC Open Graded are based on the RHMA-O section in Section 39 of the Standard Specifications (Caltrans, 2006d). Using a 1/2" or 3/8" maximum gradation, the optimum binder content (OBC) is determined by California Test 368 except that the OBC determined by CT 368 is multiplied by a factor of 1.2. The aggregate blend should be treated with an anti-strip treatment unless the DME waives the requirement.

11.2.6 Polymer-Modified Asphalt Emulsion Membrane

The polymer modified emulsion membrane is designed to give high flexibility and bonding over the range of climactic conditions in which bonded wearing courses are placed. This emulsion is manufactured using conventional means.

Specifications are based on standard emulsion specifications such as, stability, binder content, viscosity and torsional recovery. Application viscosity is important; as the material should be thin enough to be easily sprayed at the correct rate, but thick enough not flow away and form a continuous membrane. The residual properties indicate polymer presence and the base asphalt grade used. The polymer modified asphalt emulsion used is specially formulated for all BWCs and RBWCs. Cooler conditions call for higher residual penetration, while warmer climates require lower residual penetration. Additionally, the emulsion is designed to break rapidly after spraying to ensure that no water is trapped. The gap-graded or open-graded nature of the mix allows water to escape, thus promoting breaking of the emulsion.

11.3 PROJECT SELECTION

11.3.1 Distress and Application Considerations

While a bonded wearing course is a flexible pavement surface, it is not considered a structural layer at the typical placement thickness of less than 1 inch. A BWC is a viable application for treating structurally sound, worn pavements and has shown some ability to retard reflection cracking due to its membrane and gap or open-graded aggregate structure. BWC's are used on both flexible and PCC pavements to correct non-structural surface defects such as skid resistance, noise dampening and splash-and-spray control. They are typically selected for use when speed of construction and user delays are concerns. Table 11-4 outlines the allowable surface distress' on which a BWC can be placed. Note that the definitions of pavement condition in Table 11-4 are taken from SHRP Manual P-338 (SHRP, 1993).

Table 11-4 Distress Severity or Extent That Can Be Treated With a BWC (Koch, 1998)

PAVEMENT TYPE	CRACKING	PATCHING/ POTHOLES	SURFACE DEFORMATION	SURFACE DEFECTS	JOINT DEFICIENCIES
AC	1. Longitudinal & Transverse (Medium) 2. Block (Moderate) 3. Edge (Moderate)	Patches: Moderate Potholes: Moderate	Rutting: <0.5 in Shoving: No	Bleeding Moderate Polished Agg: OK Raveling: Severe	N/A
PCC	1. Corner Breaks (Moderate) 2. Materials Related Distress (Low) 3. Longitudinal (Moderate) 4. Transverse (Moderate)	N/A	Studded tire Or chain wear (Low)	Map cracking and scaling: < 12 yd^2 to 120 yd^2	Spalling: Moderate
Note: For PCC, a BWC will not treat blowups, pumping, faulting of joints, or crack widths > 3/8 in					

11.3.2 Performance

Bonded wearing courses have been estimated to last 7 to 12 years (Oliver, 1999; PennDOT, 2002; Wonson, 1997) or 6 to 10 years on PCC pavements that are 30 or more years old (Corley-Lay, 2007). The main method of failure is surface wear; that is, the surface oxidizes and is abraded over time. Premature failure occurs from placement on pavements with high deflections and cracked surfaces, base failures and delamination which occurs when placed on dirty or poorly prepared surfaces.

The main performance benefits associated with using a BWC are improved skid resistance, reduced traffic noise, improved pavement condition rating and ride quality, spray reduction, and reduced impact of reflection cracking. Figures 11-1 and 11-2 show how the characteristics of a BWC compare with those of other mixture types (Oliver, 1999; PennDOT, 2002; Caltrans, 1998). The figures indicate that a BWC retains good skid resistance characteristics over time and that it is comparable to other wearing courses that provide good skid resistance characteristics. The skid resistance of a BWC varies with increasing speed in a manner similar to stone mastic asphalt as shown in Figure 11-2.

Noise level has been measured to decrease 6.7dB (Corley-Lay, 2007). This is a noticeable improvement to the human ear. This is a similar reduction to Quiet Pavement Pilot Program (QPPP) in Arizona, which reported an average noise reduction of 5 dB in residential neighborhoods (FHWA, 2005).

Pavement condition rating (PCR) and ride quality, measured as International Roughness Index (IRI), were assessed on 4 jointed concrete pavements which were overlaid with BWC. All of these projects had positive improvement in both PCR and IRI regardless of initial condition of the pavement as listed in Table 11-5 (Corley-Lay, 2007).

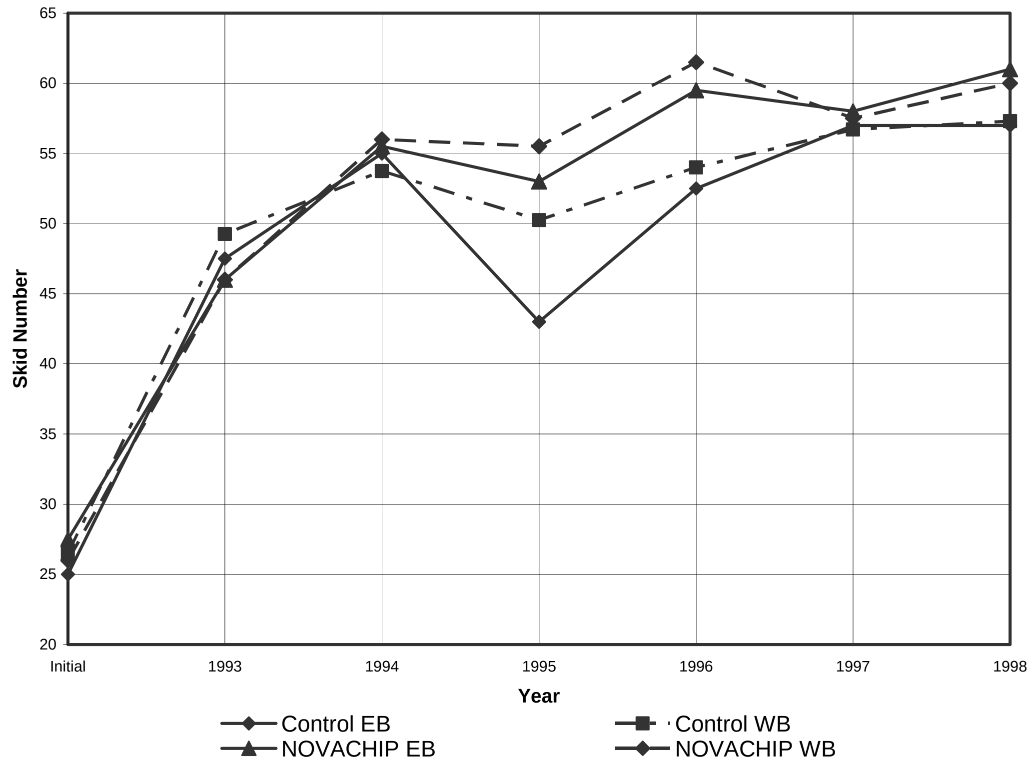

Figure 11-1 Change in Skid Resistance Over Time (Commonwealth PennDOT, 2002)

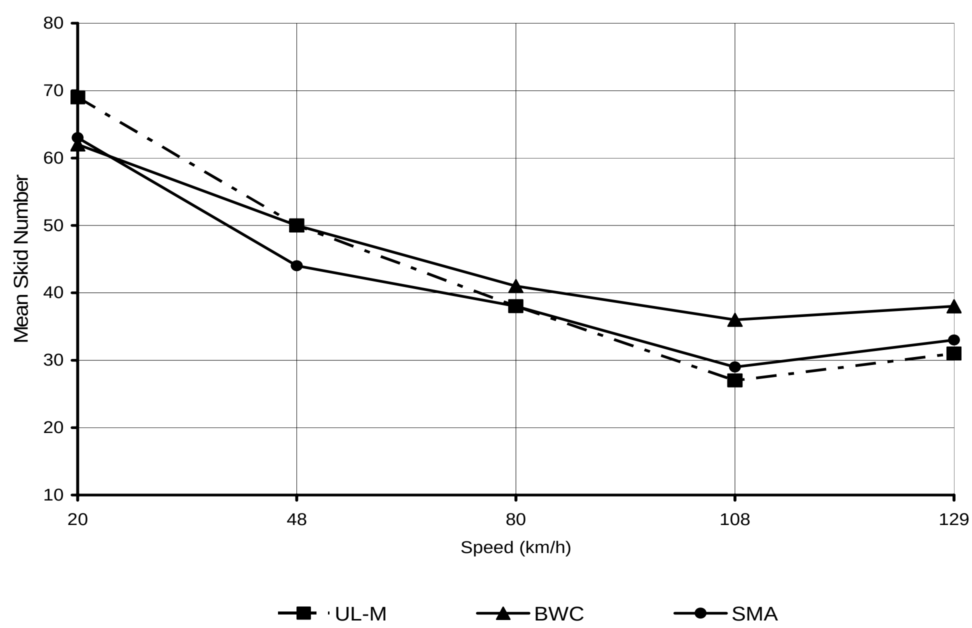

Figure 11-2 Change in Skid Resistance with Speed (Oliver, 1999)

(UL-M is Ultra Thin Polymer Modified HMA – 1 in (25mm))

Table 11-5 Summary of PCR and IRI results for BWC over JCP sections (Corley-Lay, 2007)

SITE	PRE-PCR	INITIAL Δ PCR	POST BWC PCR RATE OF DECLINE (PTS/YR)	PRE-IRI	Δ IRI (DECREASE)	POST BWC IRI RATE OF INCREASE (PTS/YR)
I-40 Burke Eastbound	64.1	35.9	0.83	189.1	103.1	2.1
I-40 Burke Westbound	63.8	36.2	2.47	182.9	99.6	2.1
US 1 Cary	<30.1	>65		201.3	85.4	
I-440 Raleigh Inner	36.6	63.4	3.5	115.2	34.4	1.26
I-440 Raleigh Outer	11.4	88.5	3.2	115.0	32.4	0.54
I-95 Johnston Northbound	33.0	62.0		150.7	62.6	
I-95 Johnston Southbound	37.5	58.2		123.9	40.0	

It can be seen that BWCs rate well in comparison to other surface treatments. The data listed in Table 11-6 has been collected from 2 sources (Oliver, 1999; Holleran, 2001). Splash and spray are important surface characteristics and may be measured in various ways. One method is by hydraulic conductivity. This is done by pressing a special cylinder against the road surface and measuring conductivity. A high number represents faster drainage. Table 11-6 shows the results of hydraulic conductivity tests performed on four surface treatments. As the results indicate, gap-graded BWC had the second highest drainage characteristics of the four surface treatments types tested. Open graded asphalt concrete (OGAC) had the highest drainage characteristic. When spray splash or lateral drainage of the wearing course is a primary concern, BWC Open Graded should be used.

A field comparison of the crack conditions and water permeability of HMA pavement sections treated with a BWC and an open graded friction course (OGFC) in southern Nevada shows that BWC reduces the impact of reflective cracking (Sebaaly, 2007). After 6-years in service, the BWC surface shows significantly less raveling than the OGFC surface. The cracks on the BWC surface are significantly narrower and experience significantly less deterioration than the cracks on the OGFC surface. The BWC membrane provides an effective barrier to moisture penetration through the reflected cracks, thus, reducing the impact of reflective cracking on the performance of HMA pavements. Figures 11-3 and 11-4 demonstrate the difference in the cracking. Another field study shows that reflection cracking appears after a few years on jointed concrete pavements, but the cracks remain narrow and of low severity (Corley-Lay, 2007).

Table 11-6 Hydraulic Conductivity as an Indication of Spray Reduction Characteristics (Oliver, 1999)

MATERIAL	HYDRAULIC CONDUCTIVITY (s^{-1})
0.55 in Stone Mastic Asphalt	0.03
½ in BWC Gap Graded	0.06
0.4 in UL-M	0.01
½ in OGAC	0.12

Figure 11-3 The UTACS cracks remained the same width all through-out the core, except at the membrane which remained sealed although the crack had reflected to the surface (Sebaaly, 2007).

Figure 11-4 The bottom lift of the existing HMA layer is not cracked and the crack on the top layer is very wide at the interface. The crack in the OGFC layer is V shaped, indicative of raveling (Sebaaly, 2007).

Caltrans has placed BWC projects since 2001 in a variety of climates and traffic loadings. These projects total almost 600 lane miles. Figures 11-5, 11-6, 11-7, and 11-8 provide a sampling of the projects placed to date.

Figure 11-5 District 7 Rt. 103, BWC Gap Graded, Constructed in 2005

Figure 11-6 District 6 Rt. 99, The northbound lanes, or right-hand side, are BWC Gap Graded and the southbound lanes are RBWC Open Graded. Constructed in 2005

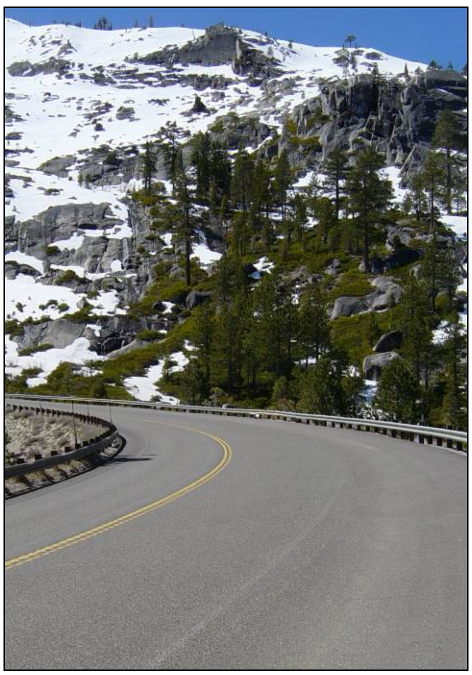

Figure 11-7 District 3 US 50, BWC Gap Graded Alpine mix, Constructed in 2002

Figure 11-8 District 10 I-5, RBWC Open Graded, Constructed 2005

Relative Cost Effectiveness

The oldest projects in the United States, placed in 1993 and 1994 in Pennsylvania, Texas and Louisiana, are still performing well after 14 years. The oldest project in California, placed in 1998, is exceeding the County of Los Angeles' expectations. There has been no observed delamination. Additionally, no maintenance activities have been required on the BWC section of roadway for the past 9 years.

In 2007, BWC total project prices averaged $12 per square yard with the range being between $9 and $14. The high end of this range was seen on projects with limited work windows. Due to the influence on production and the thin application of the HMA, the allowed project work window has one of the largest impacts on project cost. For example, the typical production rate for BWC is 125 tons per hour. On one 2007 project, the contractor was able to pave 1500 tons/day due to a generous work window from 5:00am – 5:00pm. The most expensive projects had work windows that only allowed for 6 hours of production, 11:00 pm until 5:00 am. The contractor still has to pay for an eight-hour shift with only six hours of production. Other factors that influence costs for BWC projects include; materials used, night work vs. day work, quantities, lime treated aggregates, size of project, trucking, and the project location.

Furthermore, BWC is a one-pass process which reduces user delays compared to equivalent two pass processes, such as hot applied chip seal that is followed by an asphalt rubber overlay. User delay costs are included in Life Cycle Cost Analysis. The Caltrans' B/C module estimates user delay costs at $0.17 per delayed minute per car and $0.46 per delayed minute per single unit or combination truck (Caltrans, 2007a).

11.4 CONSTRUCTION

The main components of the construction process include:

- Safety and Traffic Control
- Equipment Requirements
- Mix Production and Handling
- Surface Preparation
- Application Conditions Required
- Application of BWC
- Opening to Traffic

Section 11.5.2, "Suggested Field Considerations", at the end of this chapter, provides a series of tables to guide project personnel through the important aspects of constructing a BWC.

11.4.1 Safety and Traffic Control

Traffic control is required both for the safety of the traveling public and the personnel performing the work. It is also used to ensure the new surface is compacted and allowed to cool to below 160°F prior to reopening the surface to traffic.

Traffic control should be in place before work forces and equipment enters onto the roadway or into the work zone. Traffic control includes placing construction signs, construction cones and/or barricades, flag personnel, and pilot cars required to direct traffic clear of the maintenance operation. For detailed traffic control requirements, refer to the Caltrans project specifications and the Caltrans Code of Safety Operating Practices (Caltrans, 1999).

11.4.2 Equipment Requirements

Equipment requirements for constructing a BWC are found in the appropriate SSPs (Caltrans, 2006c; Caltrans, 2007b; Caltrans, 2007c). The most significant requirement is that the binder application and hot mix spreading function are combined into a single unit. The following section describes the specialized unit while the subsequent sections discuss other equipment requirements.

Paving Unit

The paving unit used for the construction of a BWC is a specially designed and constructed machine. Figures 11-9 and 11-10 show the two models that are currently used by contractors. Note that the spray bar is located behind the paver's tracks, so that the polymer modified asphalt emulsion membrane is applied right in front of the augers. Thus, the emulsion film is not damaged by wheels or crawlers. Figure 11-11 shows a close up of the spray and spreading functions of a BWC paving unit, and Figure 11-12 shows a freshly laid BWC.

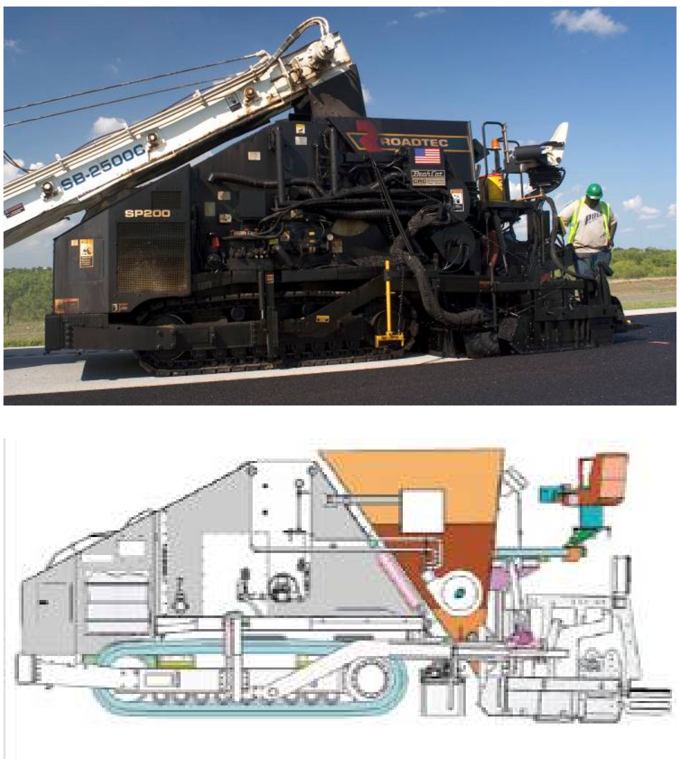

Figure 11-9: Roadtec Spray Paver (Roadtec, 2005)

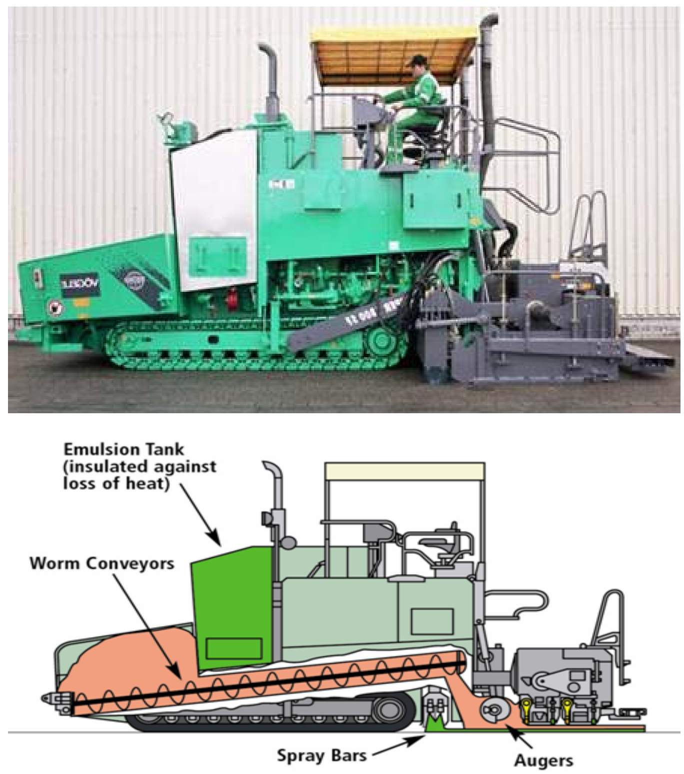

Figure 11-10: Vögele Spray Paver (Vögele, 2004)

- The paving unit pushes the truck carrying the hot mix asphalt.
- The mix drops into a hopper of the paving unit.
- The mix is transported via an auger to a screed.
- The emulsion membrane is sprayed just in front of the screed and the mix is laid on top.

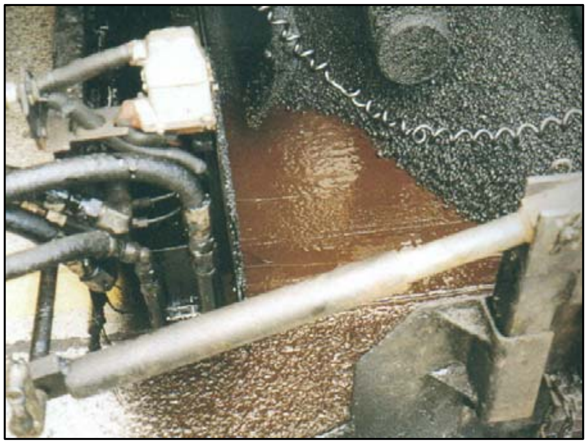

Figure 11-11 Emulsion Membrane and Mix Spreading (Alverez, 1992)

Figure 11-12 Freshly Laid BWC (Alverez, 1992)

11.4.3 Material Transfer Vehicle

A Material Transfer Vehicle (MTV) is not required for construction, but it is highly recommended. It can be beneficial in creating smoother ride with its ability to create a more continuous paving operation. Additionally, it helps keep mix temperature high during cool weather paving such as at night.

It is recommended that a MTV used on BWC projects have the following characteristics:

1. Able to remix the BWC to eliminate truck end segregation, minimize temperature segregation and deliver a uniform BWC to the paver.
2. Be a self-propelled machine totally independent of the paver.
3. Have a high capacity truck unloading system to receive BWC from the haul units.
4. Have a minimum 25 ton on board BWC surge capacity to minimize paver start/stops and maximize trucking efficiency.
5. Be equipped with a pivoting paver loading conveyor able to swing 55 degrees to either side to allow off-lane paving.
6. Paver hopper:
    a. Equipped with a hopper insert, with a minimum capacity of 7 tons.
    b. Hopper insert: Mass flow design to deliver remixed BWC directly to the paver conveyor system.

Rollers

Compaction of a BWC is required. Only static and steel drum type rollers should be used. The rollers must be at least 126 pounds to 172 pounds per linear inch of drum width and must conform to the Caltrans Standard Specifications Section 39-5.02, "Compacting Equipment" (Caltrans, 2006d). Compaction must conform to Caltrans Standard Specifications Section 39-6.03, "Compacting" (Caltrans, 2006d) and shall consist of two coverages. The first before the temperature of the mat falls below 240°F and the second before its falls below 200°F. If necessary, more than 2 coverages may be ordered by the Engineer when rolling bonded wearing course patches or joints. Rolling of the gap-or open graded mixture is intended to seat the aggregates and to provide a smooth surface. There are no in place density requirements when rolling bonded wearing course mixes.

Other Equipment

Other required equipment includes sweepers for cleaning the pavement before application and hand tools such as rakes, shovels etc.

11.4.4 Mix Production and Handling

Standard hot mix facilities and storage bins may be used for BWC mix production, as outlined in Caltrans Standard Specifications 39-3.04, "Mixing" and Section 39-3.01 "Storage", respectively (Caltrans, 2006d). The only special requirements are that the mixing temperatures for a BWC Gap Graded shall not exceed 350°F and storage time shall not exceed 8 hours. The requirements of the other BWC and RBWC are prescribed in the respective specifications. A drain down test should be performed to ensure binder does not drain out of the mixture. All mixing plants must be calibrated to California Test Method CT 109. BWC mixes may be treated with an anti-stripping agent or lime if required, but the District Materials Engineer must approve this.

11.4.5 Surface Preparation

Cracks greater than $^1/_4$ inch wide should be filled or sealed prior to application see Chapter 4 (Crack Sealing, Crack Filling, and Joint Sealing) of this document. The use of over-banding methods of crack sealing is not recommended for this treatment as this method can leave strips that reflect through the finished pavement. All repairs necessary to bring the pavement to the minimum requirements listed in Table 11-9 must also be performed prior to the application of the BWC.

Manhole covers, drains, grates, catch basins, and other utility services must be covered prior protected from the application of the BWC. Covering the services with construction paper or roofing felt can do this. Any surface irregularities deeper than 1 inch should be filled with dense graded hot mix before applying the BWC. Prior to application, the pavement should be swept with a rotary broom equipped with metal or nylon broom stock.

11.4.6 Application

Application of a BWC requires the use of a specialized paving unit described above in Section 11.4.2. Additional details specific to placing bonded wearing courses are discussed in the following paragraphs.

Conditions Required

A BWC may be applied on damp, but not wet, surfaces. The minimum air and pavement temperature requirements are dependent on the type of asphalt binder used. PG 64-28PMs should be placed at temperatures above 45° F, while PG 76-22PMs should be placed at temperature above 50°F. PG 58-34PMs and asphalt rubber binders should be placed above 55° F. The placement temperature may be reduced to 50°F with approval of the Office of Flexible Pavements in METS. No freezing conditions are allowed in the first 24 hours as the polymer modified asphalt emulsion membrane requires about one day to fully cure. If the water in the emulsion freezes, it may rupture the bond between the pavement and the new mix.

Polymer Modified Asphalt Emulsion Membrane

The emulsion applicator is part of the paving equipment and applies the polymer modified emulsion membrane at a temperature between 120° and 180°F at an average rate of 0.20 gal/yd^2. The application rate should be adjusted according to the surface being covered according to tables included in the respective BWC and RBWC specifications (Caltrans, 2006c; Caltrans, 2007b; Caltrans, 2007c). For more absorbent, textured or badly pocked pavement surfaces, the application rate is increased. The application rate is reduced for smooth or flushed AC pavements. Typically PCC pavements require less emulsion membrane than AC pavements.

If the screed extension is outside the spray bar width, the polymer modified emulsion membrane will need to be applied manually to coat the pavement between the end of the spray bar and the end of the screed. Care should be taken to ensure the correct application rate in such circumstances. The spray bar should be calibrated and able to be adjusted to within ± 10% of the design application rate. Coverage of the pavement must be even and uniform and, as such, it is important that there are no plugged nozzles on the spray bar.

Paving

Good paving practice should always be followed when constructing a BWC. Windrowing and pick up machines are not allowed for constructing bonded wearing courses. The trucks servicing the paving unit should operate in a smooth manner, causing no bumps and allow paving to proceed continuously to create a smooth ride.

The minimum delivery temperatures are very critical to successfully place BWCs and RBWCs. Minimum temperature guidelines specified in the respective specifications need to be followed. Placement should not be allowed if BWC and RBWC temperatures behind the screed fall below 285°F due to the propensity of the freshly laid mat to result in shadowing, dragging and raveling.

Longitudinal joints should be straight or correctly aligned to the curvature of the roadway, and should occur only at the edge or center of a traffic lane and never in the wheel paths. Unlike traditional paving, miscellaneous areas, turn lanes, and handwork areas should be paved before paving main line.

Variable width shoulders with a cross slope or grade break in excess of 3% may require different paving techniques. A shoulder backing machine has proven to be very successful using the BWC material. Depending on the project, it can be used to meet grade by paving the main line and then the shoulder or the shoulder and then the main line. Figure 11-13 illustrates this process on State Route 84 near Half Moon Bay.

Figure 11-13 Paving the shoulder of Rt. 84 with BWC Type O using a shoulder backing machine in 2007.

At the start and finish of the work, the existing flexible pavement should be cut out to a depth of 1.2 in and tapered back a distance of 10 ft to provide a key for the new surfacing. For PCC, the mix should be rolled over at the start and finish of the work. The end of each run should be squared off at the point where feathering commences, and the feathered material should be cut out before the next run is started. Figure 11-14 illustrates the method for making transverse butt joints between runs. Handwork should always be minimized.

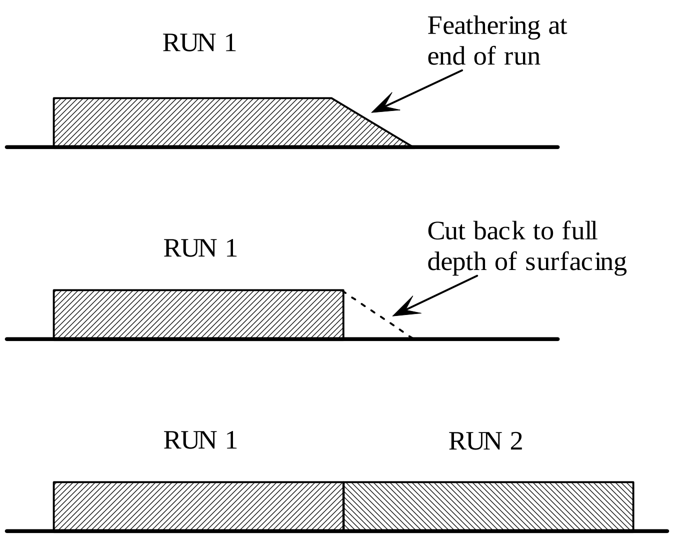

Figure 11-14 Making Transverse Butt Joints (Lobaugh, 1997)

Rolling

A minimum of one steel drum tandem roller is required for compacting a BWC. **Rollers must be operated in static mode only.** Usually two passes using 126 pounds to 172 pounds per linear inch of drum width roller is sufficient to properly seat the aggregates. Rolling must be carried out before the temperature, at mid layer of the mix, falls below 200°F (Caltrans, 2006c). Figure 11-15 shows roller positions relative to the paver.

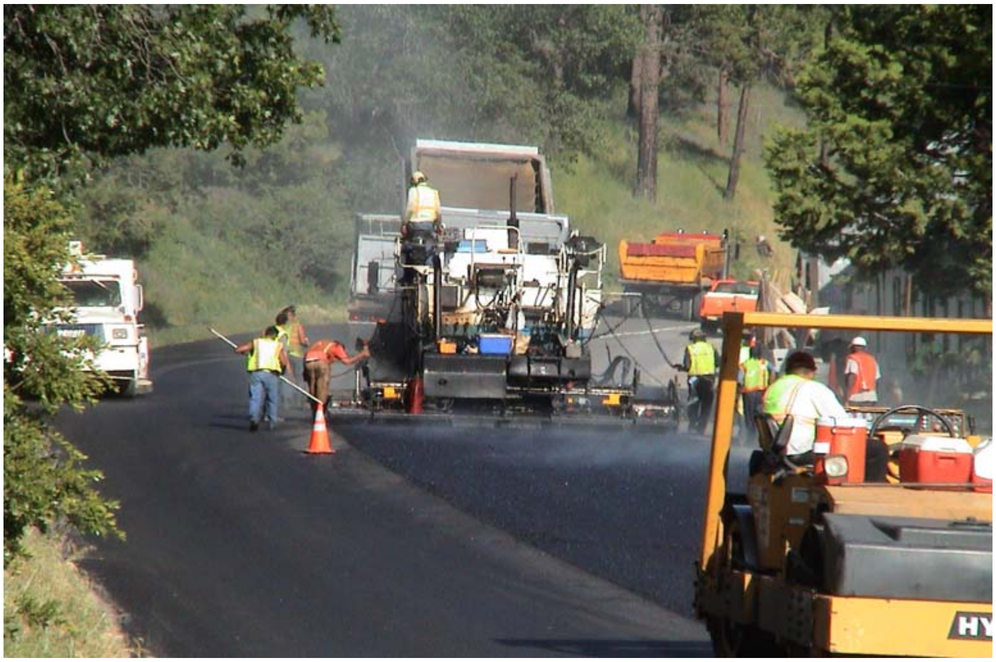

Figure 11-15 Roller Position During Application (Alverez, 1992)

11.4.7 Opening to Traffic

Traffic can be allowed onto the new surface once rolling is completed and the mix temperature has fallen below 160°F. BWC is typically opened to traffic within 15 minutes of placement. RBWC may need to be sanded. If sanded, it is typically opened to traffic within 20 minutes or 30 minutes without sanding. Typically, no post sweeping is required unless the mix begins to ravel or the road is sanded.

11.5 TROUBLESHOOTING AND FIELD CONSIDERATIONS

11.5.1 Troubleshooting Guide

This section provides information to assist the maintenance personnel with troubleshooting problems that may arise when applying a BWC. Table 11-7 lists some commonly encountered problems and their recommended solutions.

Table 11-7 Common Problems and Related Solutions

PROBLEM	SOLUTIONS
SURFACE WAVES	▪ Ensure the head of material in front of the paver screed is at the correct height and does not fluctuate (i.e., rise and fall). ▪ Ensure the screed is not worn or set incorrectly. ▪ Ensure the mix is not too stiff or has not fallen below 285°F. ▪ Ensure the dump trucks do not bump the paving unit as this can cause long frequency waves resulting in increased pavement roughness. ▪ Ensure grade control equipment (if in use) is functioning properly
WASH BOARDING	▪ Slow roller down.
TEARING	▪ Ensure the paving unit is being operated correctly. ▪ Ensure the mix is not too cold (i.e., below 285°F) or too stiff. ▪ May be fixed by adjusting the degree of crown and ensuring mix temperature is correct. ▪ Ensure application is not too thin
NON UNIFORM TEXTURE-SEGREGATION	▪ Ensure the mixture is not separating in the hopper or during transportation. ▪ Ensure the paving unit is set up properly. ▪ Ensure the mix temperature is at least 285°F. ▪ Check the mix design for poor grading. Adjust if necessary.
SCREED MARKS	▪ Ensure the paving unit is set up correctly and that the screed in not worn or dirty. ▪ Ensure the mix temperature is at least 285°F. ▪ Check the mix design for poor grading. Adjust if necessary. ▪ Ensure mix is in specification.
ROLLER CHECKING & MARKS	▪ Ensure the roller does not cause a wave in the mat in front of the roller (i.e., mix too hot). Wait until the mix cools further. ▪ Check the mix design for too much asphalt in the mix, or too much middle size sand in the gradation. Adjust design if necessary.
BLEEDING & FAT SPOTS	▪ Ensure the mix temperature is not too hot (greater than 350°F). ▪ Check the mix design for too much asphalt or for too coarse an aggregate grading. Adjust design if necessary. ▪ Ensure there is no moisture in the mix or on the pavement. ▪ Ensure the tack coat application rate is not too high for the surface to which it is applied. Tight, smooth surface require less tack coat than do more open surfaces. Reduce application rate on existing surfaces that exhibit bleeding. ▪ Ensure spray bar equipment is operating properly. ▪ Ensure aggregates are dry before mixing with asphalt in the hot mix plant, that pavement is not bleeding, that pavement is dry, and that mix is correctly designed for traffic and aggregate.

Table 11-7 Common Problems and Related Solutions (cont.)

PROBLEM	SOLUTIONS
DELAMINATION	▪ Ensure adequate tack coat is applied. ▪ Ensure the mix is above minimum application temperature (285°F). ▪ Ensure the mix is not below the minimum compaction temperature (200°F). ▪ Ensure the existing pavement surface temperature is above the minimum (i.e., 45°F) before paving. ▪ Ensure the surface is cleaned immediately before paving. ▪ Ensure roller drums are not dirty and have working spray systems.
POOR TRANSVERSE JOINTS	▪ Ensure butt joints are properly constructed.
POOR LONGITUDINAL JOINTS	▪ Ensure proper joint construction practices are followed, especially when compacting thin layers.
EXCESSIVE RAVEL	▪ Ensure the mix design meets project specifications, particularly that the mix contains sufficient binder. ▪ Ensure compaction is carried out above the minimum temperature (i.e., 194°F).

11.5.2 Field Considerations

The following field considerations are a guide to the important aspects of applying a bonded wearing course. The tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size, and some topics may need attention from several staff members. The field supervisor should be acquainted with its contents.

The intention of these tables is not to form a report, but to highlight important aspects and components of the BWC construction process. Some information is product-specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	▪ Is the project a good candidate for a bonded wearing course? ▪ How much rutting is present, depth and extent? ▪ How severe and what type of cracking exists? ▪ Is crack sealing needed? ▪ Is the pavement surface waterproof? ▪ How much bleeding or flushing exists? ▪ Is pavement raveling or oxidized? ▪ What is the traffic level? ▪ Is base sound and well drained? ▪ Is surface water splash-and-spray a problem? ▪ Is pavement strengthening required? ▪ Review project for bid/plan quantities.
DOCUMENT REVIEW	▪ Application specifications. ▪ Mix design information. ▪ Special provisions. ▪ Construction manual. ▪ Traffic control plan (TCP).
MATERIALS CHECKS	▪ Have the aggregates been sampled and tested? Do they meet the requirements set forth in the Standard Special Provision? ▪ Has the binder for the mix been sampled and tested? Does it meet the requirements set forth in the Standard Special Provision? ▪ Is the mix produced by an approved source? ▪ Has a full mix design has been performed for the mixture? ▪ Has the mix been tested? Is the mix within specification? ▪ Has the polymer modified asphalt emulsion membrane been sampled and tested? Does it meet the requirements set forth in the Standard Special Provision?
PRE-SEAL INSPECTION RESPONSIBILITIES	
WEATHER REQUIREMENTS	▪ Have air and surface temperatures been checked at the coolest location on the project? ▪ Do air and surface temperatures meet agency requirements? ▪ Is rain expected before or during paving operations? ▪ Are freezing temperatures expected within 24 hours of the completion of any paving runs?
DETERMINING APPLICATION RATES	▪ Agency guidelines and requirements are followed. ▪ Rut filling and leveling course requirements is a separate item and rates have been calculated or estimated to properly re-profile roadway. ▪ Has a full mix design been done? ▪ Are emulsion membrane application rates correct for the pavement surface? ▪ More emulsion may be required on roads with porous surfaces and less for those with flush surfaces or PCC surfaces.

SURFACE PREPARATION	▪ Is the surface clean and dry? Has it been swept? ▪ Have areas with oily residue been scrubbed? ▪ Have all pavement distresses been repaired? ▪ Has the existing surface been inspected for drainage problems? ▪ Have all utilities been raised and masked? ▪ Has project been laid-out to ensure the best possible results?
EQUIPMENT INSPECTIONS	
BROOM	▪ Are the bristles the proper length? ▪ Can the broom be adjusted vertically to avoid excess pressure?
APPLICATION EQUIPMENT	▪ Has the machine been calibrated to accurately spray the correct amount of membrane? ▪ Are all spray tips clean and free of blockage? ▪ Is there a double or triple overlap of spray fan? ▪ Is the paving unit clean and operating correctly? ▪ Are flow gates clear, set at the right height, and functioning properly? ▪ Are conveyors and augers functioning properly? ▪ Is the flow system (manual or automatic) operational? ▪ Are material levels in the auger chamber of the paving unit set correctly? ▪ Do the screed heaters work? ▪ Is the screed clean and properly set? Is the angle of attack correct? ▪ Is the automatic leveling system working and correctly set? ▪ Is the paver speed correct for correct thickness and angle of attack? ▪ Are the screed strike offs clean and providing a uniform mat?
EQUIPMENT INSPECTIONS	
ROLLERS	▪ Are appropriate rollers being used? Do they comply with the requirement set forth in the Standard Special Provisions?
MATERIAL DELIVERY VEHICLE	▪ Do dump trucks or live bottom trailers properly match up with the paving unit?

CALIBRATION OF EQUIPMENT	▪ Are all machines properly calibrated? ▪ Who carried out calibration? ▪ Has documentation has been provided?
PROJECT INSPECTION RESPONSIBILITIES	
TRAFFIC CONTROL	▪ Do the signs and devices used match the traffic control plan? ▪ Does the work zone comply with Caltrans requirements? ▪ Flaggers do not hold the traffic for extended periods of time? ▪ Unsafe conditions, if any, are reported to a supervisor? ▪ Signs are removed or covered when they no longer apply?
EMULSION MEMBRANE APPLICATION	▪ Has the emulsion temperature been checked? ▪ Are high winds expected? Will the expected weather conditions delay the breaking of the emulsion? ▪ Has emulsion application spray bar been checked for blocked nozzles? ▪ Has application rate been checked? ▪ Is the application even and does it cover the entire pavement? ▪ Is the application in accordance with relevant CT guidelines?
PROJECT INSPECTION RESPONSIBILITIES	
LAY DOWN OF BWC GAP GRADED MIX	▪ Has a test strip been successfully laid and compacted? ▪ Is the surface dry (damp is OK)? ▪ Is the mix temperature correct? ▪ Is the paving unit progressing at a uniform speed? ▪ Are the hopper, augers, and screed operating correctly? ▪ Is the screed set at the correct height? ▪ Is the mat being tamped uniformly and is the mat a uniform thickness? ▪ Are height adjustments minimal? ▪ Are height adjustments allowed sufficient times to be effective? ▪ Is the mat uniform looking? ▪ Are edge lines and joint overlaps neat and straight? ▪ Is the job stopped if problems persist?
ROLLING MIX	▪ Is the surface temperature of the mat correct at beginning of rolling? ▪ Is the roller being operated at the correct speed? ▪ Is the mat uniform looking? ▪ When making transverse joints, are they rolled from the cold side first? ▪ Are longitudinal joints rolled from the hot side first? ▪ Are edge lines and joint overlaps neat and straight? ▪ Is the job stopped if problems persist?

TRUCK OPERATION	▪ Do truck operators avoid driving over mat? ▪ Do truck operators allow the paving unit to push the truck? ▪ Are changeovers of dump trucks smooth, causing no bumping of the paving unit?
LONGITUDINAL JOINTS	▪ Are joints matched properly? ▪ Are joints flat and smooth? ▪ How far does the end gate of the paving unit overlap the previously placed lane ($^1/_2$ inch max)? If not, excess material should be raked off. ▪ Is excessive raking avoided? Minimal raking of the longitudinal joint should be done. ▪ Are longitudinal joints rolled from the hot side of the joint first? ▪ Are the joints straight and compacted? ▪ Ensure no gaps!
PROJECT INSPECTION RESPONSIBILITIES	
TRANSVERSE JOINTS	▪ Transverse joints should be avoided and should be used only at the end of paving or when problems occur in laying. ▪ Is the mat uniform up to the joint? ▪ Is excessive raking avoided when forming the joint? ▪ Is the joint compacted transversely? If there are restrictions, is the joint compacted longitudinally? ▪ Is the joint tight and well compacted and close to invisible?
BROOMING	▪ Does brooming occur shortly before placement of the bonded wearing course?
CLEAN UP	▪ Is all loose mix removed from the traveled way? ▪ Are any spills cleaned up?
OPENING THE MIX TO TRAFFIC	▪ The traffic travels slowly — 24 mph or less—over the fresh mat? ▪ Are reduced speed limit signs used? ▪ Are all construction related signs removed when opening to normal traffic?

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