Chapter 2
Overlay Design Process

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Abstract Bonded concrete overlays have been used for nearly 100 year to extend the life of pavements, concrete slabs, bridge decks or other structural slabs. First, this chapter describes material selection, for slabs on grade and pavements; joints; and construction procedures including steel placement, environmental effects, and curing. Secondly, the bonded concrete overlay (BCO) process is described: the steps required in project selection; design of the BCO; construction, and quality assurance with flow charts included to provide a graphical overview.

2.1 Purpose of Overlays

Bonded concrete overlays (BCOs) have been used since 1909. The primary purpose of overlays is to extend the life of a concrete slab or pavement, bridge deck or other structural slab. It has been shown [1, 2] that as the remaining life of a pavement decreases due to distress, e.g. cracking, spalling or punchouts, the life can be extended significantly by the use of a bonded concrete overlay. For a slab or pavement in good condition, a 25% increase in thickness can nearly double the stiffness, resulting in nearly a 50% reduction in flexural stress.

Other reasons for overlaying concrete pavements or slabs include:

- provide an improved frictional surface for pavements or bridges;
- provide a smooth surface for industrial floors or buildings;
- increase the elevation of the top surface to match an adjacent slab;
- provide a more durable wearing surface;

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- repair corrosion-damaged slabs or bridge decks with sound, durable concrete; and
- provide architectural features such as color or texture.

2.2 Materials Selection

2.2.1 Slabs on Grade/Pavements

2.2.1.1 Concrete

The cement content of the BCO concrete must be high enough to ensure that the available paste is sufficient to achieve bond at the interface, which eliminates the need for a bonding agent, and to meet strength and permeability requirements. Reduced paste requirements may be met by using well-graded aggregates. Some specifications mandate minimum cement content, e.g. 390 kg/m^3 for normal overlay concrete and 490 kg/m^3 for dense overlay concrete. Lower levels of cement are desirable to reduce cost, reduce heat of hydration and reduce shrinkage. Reduced cost and reduced heat of hydration may also be accomplished by using fly ash as cement replacement; the addition of fly ash also has the advantages of improving durability and, in many cases, ultimate strength.

The water-cement ratio is determined by strength and durability (permeability) requirements. Generally, a water-cement ratio of 0.40 will provide good durability and strength. One specification requires a water-cement ratio of 0.40 for normal overlay concrete and 0.32 for dense overlay concrete.

Aggregates should be selected for workability; aggregates should also have adequate durability for the intended application. The paste requirement may be reduced by improving overall aggregate gradation as suggested by Shilstone [3, 4] and Crouch [5]. Shilstone suggests incorporating an intermediate aggregate, and this may be particularly helpful when using steel fibers.

Admixtures will often include air entraining agent, which will help workability and improve freezing and thawing resistance. The use of fly ash may require greater dosages of air entraining agent to achieve the same percentage of entrained air. High range water reducers are often specified, and the amount should be based on trial batches. The addition or retarders in hot weather helps to preserve workability until the concrete can be placed and finished without affecting strength development.

2.2.1.2 Reinforcement

Steel reinforcing and steel and synthetic fibers have been used as reinforcement. Steel reinforcing has been used in the form of tied bars and welded mats.

Steel fibers have been used successfully in overlays to control cracks and to minimize drying shrinkage cracking. Normal steel fiber contents for steel fiber reinforced concrete are normally in the range of 1 to 2% by volume. The amount of fibers required to achieve the desired result will depend on the type of fiber based on its bond characteristics.

Synthetic fibers should be used at a minimum of 0.25% by volume; however, significant benefits have been obtained by using up to 1% volume.

2.2.2 Structural Slabs and Decks

2.2.2.1 Concrete

Overlays for structural slabs and decks are generally used to replace removed concrete since the slab or deck cannot tolerate additional dead load and still continue to carry the design live load. One of the main applications of overlays for structural slabs is to replace deteriorated concrete due to corrosion of the steel reinforcing. The original concrete is removed to a depth of about 25 mm below the steel, and the overlay is used to reinstate the original surface. Generally, very durable, low permeability concrete is specified. Guidelines similar to those outlined for pavements are appropriate for structural slabs. In addition, latex, e.g. styrene-butadiene, is often added (15% latex solids by weight of cement) to provide improved bonding, greater flexural strength and decreased permeability.

2.2.2.2 Reinforcement

Steel bars are normally used for structural slabs and decks. Often the original bars are adequate, although if significant reduction in cross section due to corrosion has occurred, the affected bars should be spliced with adequate anchorage length or replaced. In some cases when extensive replacement of reinforcing is required, corrosion resistant bars, e.g. epoxy coated steel, galvanized, or stainless steel may be considered for use in highly corrosive environments.

Fibers, steel or synthetic, may be used for crack control and to minimize shrinkage cracking.

2.3 Joints

2.3.1 Slabs on Grade/Pavements

Jointed slabs and pavements usually require that the joints in the original slab or pavement be reinstated which is time consuming and costly. Sawing the joints and applying suitable high elongation joint filler is one possible solution. In some cases it may be possible to clean the joints of debris and apply joint filler. If it essential to reinstate the dowels at joints to prevent faulting, precast joint units have been used by removing the concrete for approximately 600 mm on each side of the joint and installing the units which have dowels in place.

The overlays must be constructed to maintain the integrity of the joints. Saw cutting followed by application of suitable high elongation joint filler may be the optimum solution.

2.3.2 Structural Slabs and Decks

Joints in structural slabs and decks are expansion joints. In some cases the nosings at the joints of the original concrete have spalled and deteriorated and must be repaired. The concrete in the overlay at the joints must have the durability and toughness to resist the impact of vehicular traffic, where applicable, and one solution is to use very strong, impact-resistant concrete headers on either side of the joints to which the overlay can be butted.

2.4 Construction Procedures

2.4.1 Steel Placement

Research has shown that the reinforcing placed on the substrate of a 75-mm thick slab with a 75-mm overlay cast on the surface will achieve the same pull-out bond strength as reinforcing placed at mid-depth of a 150-mm thick slab; all bars failed in tension [6]. Placing the reinforcing on the substrate saves construction time and labor.

2.4.2 Environmental Effects

Weather conditions during construction of the overlay can be critical. Hot, dry climates cause the most problems because of the excessive evaporation of water from the concrete that often results. High evaporation rates during placements can result in plastic shrinkage cracking. Evaporation rate is a function of wind velocity, relative humidity, concrete temperature, and air temperature. An evaporation rate of 1 kg/m^2 or higher has been suggested as sufficiently high to cause plastic shrinkage cracking, but even lower values may cause problems. The evaporation rate can be estimated from published monographs [7, 8] or calculated from the equation.

The evaporation rate should be monitored through construction by the use of a weather station which measures the four factors that influence evaporation. If the threshold value of evaporation rate is approached, action should be taken: discontinue placement of the overlay or provide measures to reduce evaporation including improved curing methods.

Concrete temperature should be monitored throughout construction. Temperature at placement has been shown to have a significant effect on performance [9]. Pavements placed in high temperatures in the summer have been found to have poor performance based on such indicators as crack spacing and distress occurrence compared to pavements placed in cooler weather. Therefore, for best performance the BCO placement temperature should be kept relatively low to avoid high temperatures of hydration. The surface of the substrate should not be permitted to exceed a temperature of 50°C [9].

Another environmental issue that can be detrimental to the concrete performance is the temperature differential that occurs in the hours following placement. High ambient temperature differentials within 24 hours after placement may cause extensive thermal cracking; drops in temperature from the peak high temperature to the low temperature should not exceed 15°C [9]. The largest drops in temperature in the concrete are usually associated with concrete placements in the morning in hot weather, which leads to the maximum hydration temperature occurring in combination with the maximum ambient temperature in the afternoon, followed by a large reduction in ambient temperature during the night. The rapid cooling of the surface can lead to thermal contraction strains that exceed the capacity of the concrete at that young age. Weather forecasts should be consulted to determine if placement conditions will be likely to cause problems.

If any of the adverse environmental conditions described in this section occurs during the placement of the concrete, placement should be avoided unless the conditions can be offset by such measures as:

- cooling the aggregates or concrete;
- special curing methods discussed in a following section; or
- use of fly ash as cement replacement to lower the heat of hydration.

2.4.3 Curing

Proper curing procedures are necessary to avoid excessive moisture loss at early ages that can result in plastic shrinkage and loss in tensile strength capacity at the

Table 2.1 Recommended curing for bonded concrete overlays

Condition	Recommendation
Evaporation below 0.5 kg/m^2/hr	Membrane curing
Evaporation above 0.5 kg/m^2/hr but below 1 kg/m^2/hr	Membrane curing, plus evaporation retardant or fogging or wet mats, in place for 12 hours
Evaporation over 1 kg/m^2/hr	Membrane curing, plus wet mat curing or fogging or other approved methods, in place 36 hours
Temperature drop in next 24 hours less than 15°C below temperature at time of paving	Membrane curing
Temperature drop in next 24 hours more than 15°C below temperature at time of paving	Membrane curing plus wet mats for 36 hours, or other approved methods

surface. Curing should begin as soon after placement and finishing as possible to minimize loss of bleed water. Curing may be accomplished by:

1. Application of curing compound.
   For textured or tined surfaces the spray application should be applied from two directions to ensure that the entire surface is coated.
2. Application of membrane curing.
   Various liquid sealing compounds, e.g. bituminous and paraffinic emulsions, coal tar cut-backs, pigmented and non-pigmented resin suspensions, or suspensions of wax or non-liquid protective coating such as sheet plastics or waterproof paper, are used to restrict evaporation of water.
3. Curing blankets.
   A covering of sacks, mattings, burlap, straw, or other suitable paper is placed over the surface to reduce evaporation and to reduce the temperature reduction at the surface. When used to reduce evaporation the blankets are generally wetted.
4. Monomolecular film.
   Monomolecular films (MMF) are compounds that form a thin monomolecular film to reduce rapid moisture loss from the concrete surface prior to curing. Another curing method should be used after the evaporation retardant is sprayed on. Research has shown, however, that the use of MMF followed by application of curing compound does not consistently provide less evaporation than curing compound alone.

Table 2.1 summarizes recommended curing procedures for bonded concrete overlays.

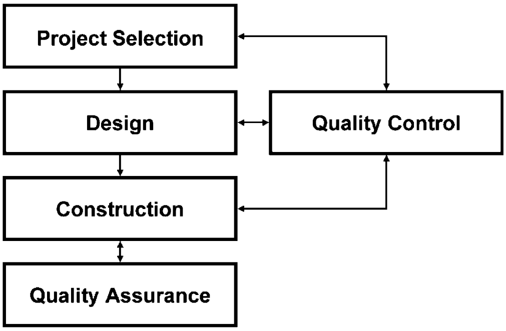

Fig. 2.1 BCO development process

2.5 The BCO Process

The BCO process is summarized in the flow chart in Figure 2.1. Each step of the process will be discussed.

2.5.1 Project Selection

The project selection involves several decisions as shown in the flow chart in Figure 2.2.

1. Need for rehabilitation, which is based on level of deterioration, age and increase in traffic loadings.
2. Availability of resources to the owner/agency with the responsibility for maintaining the highway.
3. Type of rehabilitation: overlay versus non-overlay.
4. Type of overlay if an overlay is selected. The overlay choices are portland cement concrete (PCC) and asphalt concrete. For PCC overlays the choice is between bonded and unbonded.
5. Timing and condition. A PCC overlay should be applied after structural failures have occurred but prior to functional failures at which time the pavement has reached a minimal level of serviceability. Figure 2.3 shows the pavement serviceability index (PSI) as a function of time and a hypothetical time at which structural failure and functional failure occurs.

Once the decision is made to construct a BCO, the next step is the design.

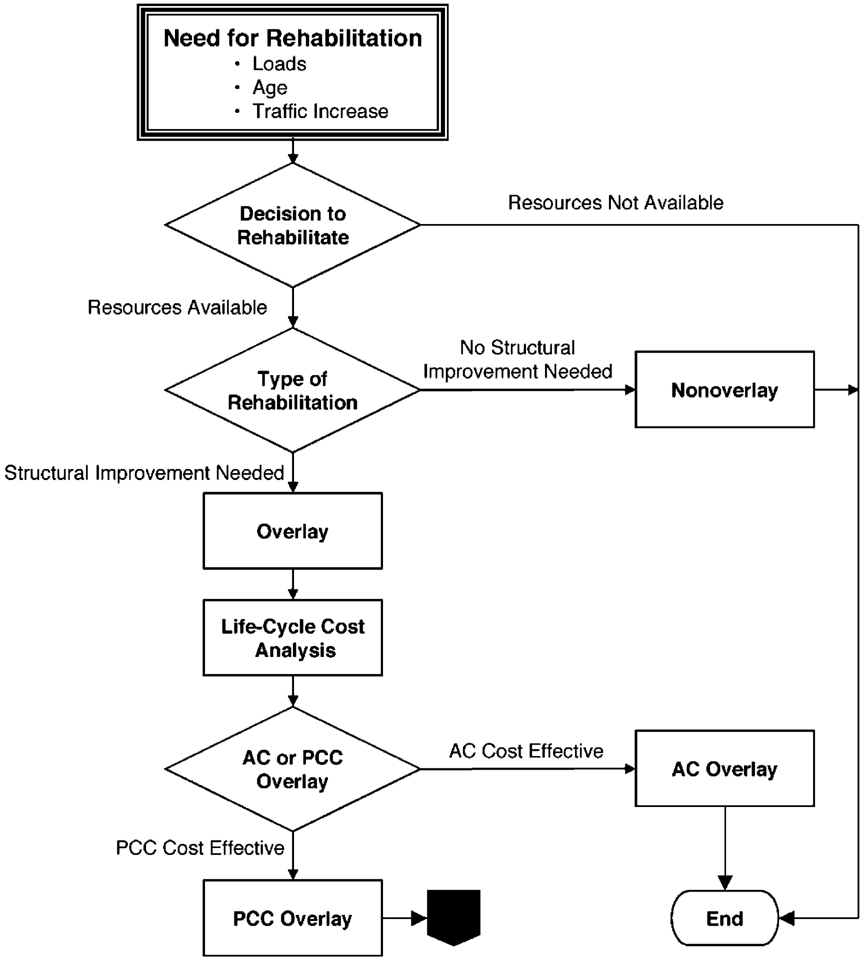

Fig. 2.2 Flowchart of the project selection stage

2.5.2 Design

The design decisions that must be made are:

- design period (overlay design life);
- traffic analysis; and
- remaining life of the original pavement.

The original pavement must be characterized, which usually requires:

- coring to determine modulus of elasticity, tensile strength, and thickness; and
- deflection testing.

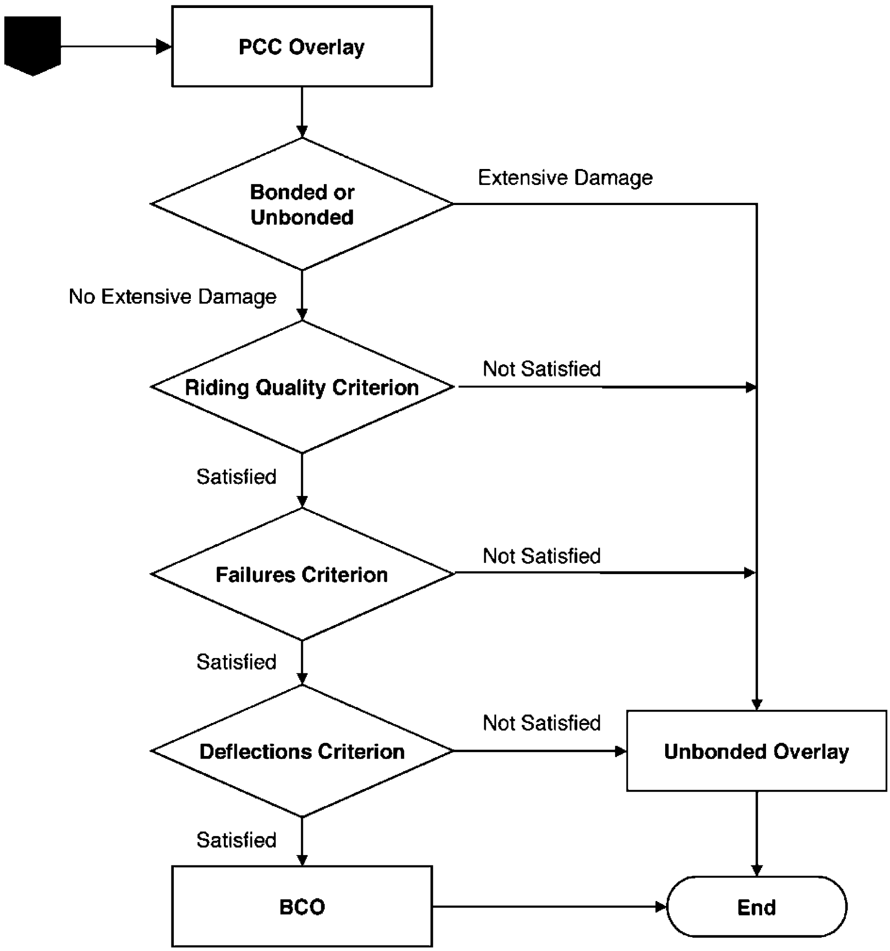

Fig. 2.2 Continued.

The thickness design is a function of:

- structural capacity of existing pavement; and
- structural capacity of BCO to fulfill future traffic requirements.

There are several design procedures available for performing the design, but a discussion of the methods is beyond the scope of this chapter.

2.5.3 Construction

Some of the construction-related considerations are:

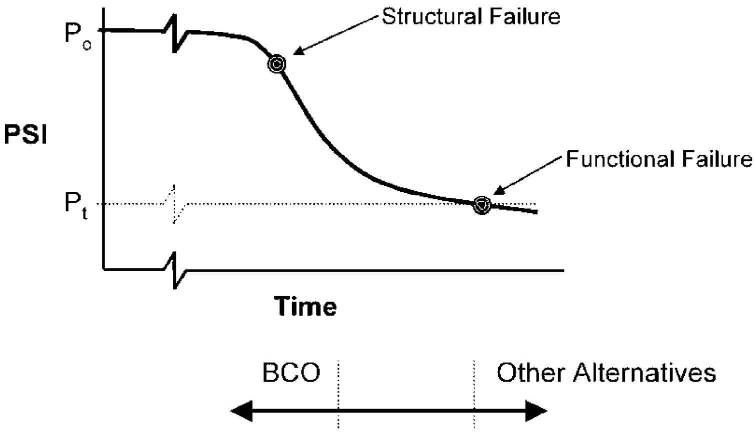

Fig. 2.3 Manifestation of structural and functional failure along the PSI curve

1. Materials and aggregates.
   Compatibility between the overlay and original pavement concrete is important, and the coefficient of thermal expansion and modulus of elasticity should be lower than the original concrete if possible. It has been found that aggregates used in the overlay should have lower thermal coefficients that can normally be obtained by using limestone materials.
2. Repairs.
   The original pavement must be repaired prior to overlay; the overlay will have no more integrity than the pavement to which it is bonded.
3. Surface preparation.
   The surface must be adequately cleaned, preferably by shot blasting using steel shot to a moderate roughness. The surface must be kept clean prior to placement of overlay concrete. Bonding agents are not necessary and should be avoided since they provide an additional step that can cause failure, e.g., a bonding agent that is allowed to cure prior to concrete placement, becoming a bond breaker [10].
4. Tied PCC shoulders.
   Tied PCC shoulders to the BCO provide slab edge support that in turn results in a reduction of stresses and deflections in the BCO and shoulder due to enhanced load transfer.
5. Critical weather conditions.
   Several research studies have shown that the following weather conditions during BCO construction may have adverse effects on the overlay performance [1, 9, 11, 12]:

   (a) It has generally been accepted that evaporation rates of $\sim$1 kg/m^2/h or more can lead to plastic shrinkage cracking which may lead to greater probability of delamination. It should be noted, however, that with the wide range of chemical and mineral admixtures currently being used the critical evaporation rate to initiate plastic shrinkage cracking might be much lower than 1.0 kg/m^2. Some transportation agencies now require weather stations on paving construction projects to monitor evaporation rate.

(b) Substrate surface temperatures $>50°C$ at concrete placement may lead to inadequate bonding.

(c) Daily temperature differentials of $>15°C$ (between the high ambient temperature on the day of placement and the low night temperature following) may lead to poor bonding.

6. Special.
   When evaporation rates approach or exceed the recommended maximum values, special curing, e.g., evaporation retardants, wet mats or fogging, should be required.

2.5.4 Quality Control/Quality Assurance (QA/QC)

A comprehensive QA/QC program is required to insure that the BCO provides the owner with a cost-effective pavement and results in a uniform, durable, safe, and low maintenance riding surface for the users. The program should include some or all of the following items:

- statistical sampling – samples from each subset of paving should be required;
- weather monitoring as described in the previous section relating to construction;
- materials tests;
- condition surveys of the completed BCO which includes sounding (to locate possible delamination) and mapping of cracks and other visible defects;
- pull-off tests (to determine bond strength);
- core tests; and
- deflection testing, e.g., falling weight deflectometer.

2.6 Conclusions

Bonded concrete overlays have many uses for highways, bridges and floors. There are many factors that must be taken into account in their design: material selection, joints, and construction procedures.

The use of bonded concrete overlays should be determined based on a rational project selection process, which considers the need for rehabilitation, availability of resources, type of rehabilitation, type of overlay and appropriateness of a BCO. The design should be conducted using a rational procedure to achieve the design life required by the owner. Construction considerations should include materials to insure compatibility of new and old concrete, repair of existing pavement, surface preparation, surface cleaning, weather conditions and special curing. A QA/QC program should be required to insure the quality of the finished BCO.

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