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Long-Life Asphalt Pavements

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Using innovative research and sound engineering principles to improve pavement structures, materials, and technologies.

The University of California Pavement Research Center (UCPRC) conducts research on pavements of all types, including concrete and asphalt. It has operated facilities at UC Berkeley since 1948 and at UC Davis since 2002, and also conducts research on California highways. Primary funding for the UCPRC is provided by Caltrans. Most of the UCPRC's work is done through the Partnered Pavement Research Center contract, whose mission is to apply innovative research and sound engineering principles to improve pavement structures, materials, and technologies through partnership between academia, Caltrans, and industry.

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Introduction

As traffic demand on existing pavements in the United States increases and funding becomes more constrained, efficient design of new and rehabilitated pavement sections incorporating long-life concepts will be increasingly important. Recognizing this, the California Department of Transportation (Caltrans) implemented its long-life pavement rehabilitation strategies (LLPRS) program in 1998. The program's goal is to rebuild approximately 1,740 lane-miles of high volume urban freeways with pavements designed to last 30-plus years with minimal maintenance. LLPRS projects were also intended to minimize total traffic delay and improve construction productivity and quality by performing the construction in 55-hour weekend closures or other extended closures instead of traditional 7- to 10-hour duration nighttime closures.

This heavily traveled section of I-710 near the Port of Long Beach, California, pictured below shows original 48-year old pavement on the right and rebuilt, long-life asphalt pavement on the left.

SOURCE: UNIVERSITY OF CALIFORNIA PAVEMENT RESEARCH CENTER

The most notable benefits of the innovative analysis, designs, materials, construction, and traffic handling that were developed to produce long-life pavements in California are lower life-cycle and user-delay costs. Under the Caltrans LLPRS program, potential use of long-life concepts for a project is triggered by the project's location and estimated future traffic. Other projects with special conditions will be considered on a case-by-case basis. These selection criteria were primarily aimed at urban freeways where these benefits are maximized. However, the potential for achieving the benefits of long-life rehabilitation on other types of projects has also been recognized and addressed through a number of changes in Caltrans' practice.

The term "long-life" is defined similarly for asphalt and concrete pavements. The Asphalt Pavement Alliance (APA) defines a perpetual or long-life asphalt pavement as "an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement" [1]. Tayabji and Lim provide a similar definition for long-life concrete pavement, with a long structural life and maintenance of ride and surface texture with minimal intervention and minor repairs, as the primary criteria separating long-life concrete pavements from conventional concrete pavements [2].

LLPRS concrete and asphalt projects have been constructed successfully in California. The first LLPRS project, constructed in 1998, involved successful replacement of a concrete truck lane on I-10 near Pomona with a new concrete lane in a 55-hour weekend closure using what would be later named Rapid Strength Concrete (RSC) [3]. Several other LLPRS projects where concrete truck lanes have been replaced with long-life concrete pavement have been completed, such as the two phases of the I-15 Devore project [4].

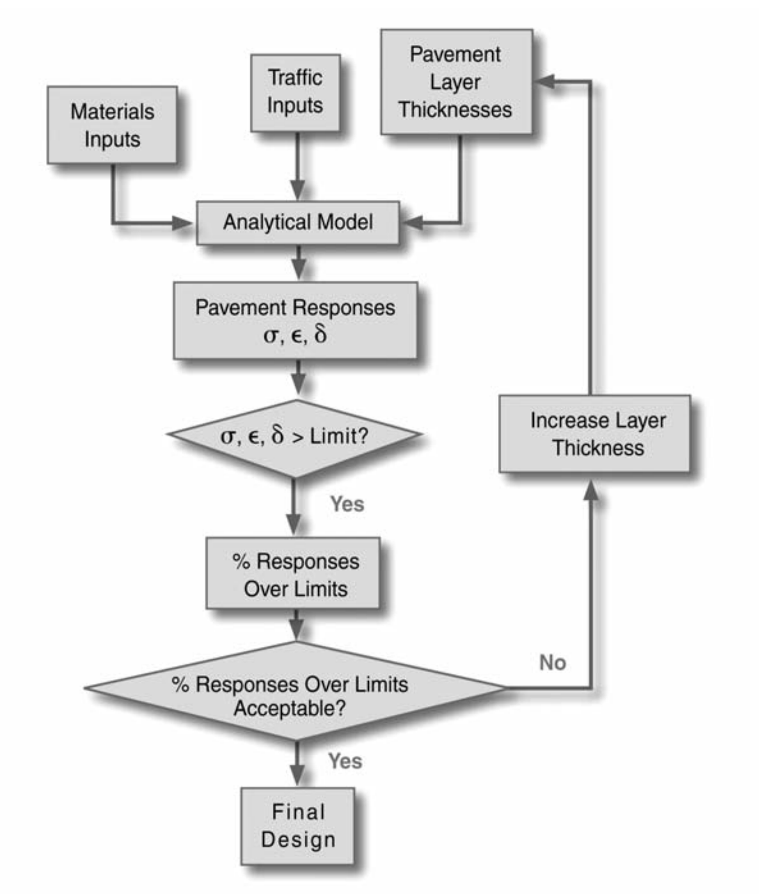
The first long-life asphalt pavement rehabilitation project was the rebuilding of a 2.7-mile section of I-710 in Long Beach, California in 2003 [5]. This portion of I-710 is the most heavily loaded highway in California, carrying truck traffic to and from the Ports of Long Beach and Los Angeles. Long-life asphalt pavements have been used successfully in many countries outside the United States. Some of the design concepts used on the I-710 project were based on previous experience in Australia [6], France, and the United Kingdom [7], and have also been used in Canada [8].

Based on lessons learned from the I-710 Phase 1 project, this article outlines five key elements that must be addressed in planning long-life asphalt pavements: design, materials and testing, communication, construction, and performance.

Design

The design of long-life asphalt pavements is based on mechanistic-empirical concepts originally proposed by Monismith and McLean in 1972 [9][1]. These analytically-based design procedures are now used in a variety of applications including the construction of high-volume and low-volume pavements and the rehabilitation of flexible and rigid pavements [10]. This

FIGURE 1 Simplified Flowchart of Long-Life Asphalt Pavement Design



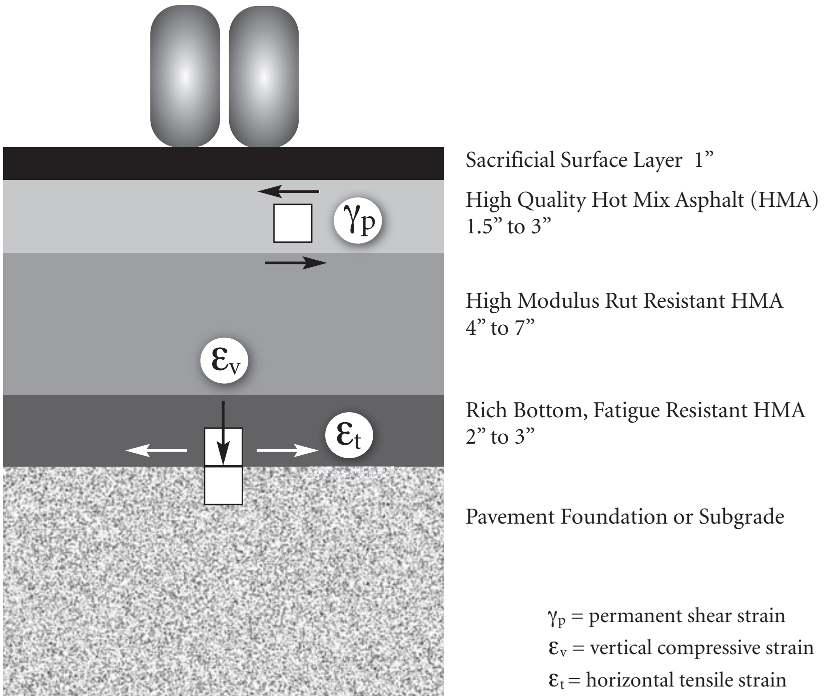
SOURCE: NEWCOMB ET AL. [11]

[1] For more information on California's transition to mechanistic-empirical pavement design, see Pavement Technology Update, vol. 3, no. 1.

design approach facilitates an engineering assessment of pavement responses to stresses, strains, and displacements generated from traffic loadings and the environment over the expected life of the pavement. A flowchart developed by Newcomb et al. [11], illustrating the basic elements in the design of long-life asphalt pavements, is shown in Figure 1.

The premise of a long-life asphalt pavement design is that structural distresses can be avoided if stresses, strains, and deflections are held below certain threshold limits. The primary distresses addressed in long-life asphalt pavement design are permanent deformation at the bottom of the pavement structure that contributes to surface rutting and bottom-up fatigue cracking. Rutting due to excessive traffic-induced shear stresses near the surface of the pavement is addressed through mix selection and testing. By limiting critical pavement strains to levels below which damage occurs, the structural integrity of the pavement should remain intact during its entire life. In addition to these primary distresses, the surface of the long-life asphalt pavement must be durable enough to require only periodic replacement after damage such as abrasion from traffic, raveling and top-down cracking while maintaining good skid resistance and free drainage to the shoulder. It should also be flexible enough to resist non-load associated thermal cracking in cold environments. The critical strains to consider in the mechanistic-empirical design of asphalt pavements and the desired characteristics of mixes in the long-life pavement structure are illustrated in Figure 2.

FIGURE 2 **Design Considerations and Structural Components of Long-Life Asphalt Pavement**



SOURCE: NEWCOMB ET AL. [11], MONISMITH ET AL. [15], HARVEY ET AL. [17]

Fatigue cracking typically occurs at the bottom of an asphalt pavement due to repeated high strains from heavy loads. One way to reduce these strains is to increase the thickness of the pavement structure. Shook et al. [12] showed that limiting the horizontal tensile strain at the bottom of the asphalt-treated layer can help control fatigue cracking. Nishizawa et al. [13] suggested limiting this tensile strain to less than 200 x 10^{-6} inch per inch (i.e., 200 $\mu\varepsilon$) while other researchers [14] suggested a more conservative limiting strain range of 70 to 100 $\mu\varepsilon$. A more robust approach [15] is to use Miner's Law of Cumulative Damage and compare the expected fatigue life of the asphalt mix from laboratory tests (N_{supply}) to the estimated traffic (N_{demand}) using the expression:

$$N_{supply} \geq M \times N_{demand}$$

where M is a reliability multiplier. A reliability level of 95 percent was selected for the design of the I-710 long-life asphalt pavement.

Another effective way to improve the fatigue resistance of the pavement structure is to introduce a stiff, durable, fatigue resistant layer at the bottom of the asphalt pavement and directly above the pavement foundation. This can be done by using a slightly higher than optimum asphalt content in a 2- to 3-inch thick asphalt mix layer, often referred to as a “rich bottom” layer. The primary purpose of the higher asphalt content is to enable compaction to lower air voids in the mix (less than three percent), resulting in significantly lower tensile strain at the bottom of that layer and improved durability and fatigue resistance of the layer [16]. Analyses for California pavements have indicated that the benefits of the rich bottom layer are insignificant when it is thicker than about 2- to 3-inches (50 to 75 mm) [17].

Rutting or permanent deformation due to traffic can occur in the pavement foundation (unbound base layers or subgrade) directly below the pavement structure or in the asphalt layers near the surface of the pavement. Full-scale accelerated pavement testing (using a Heavy Vehicle Simulator) on asphalt pavement over granular base and subbase on a clay subgrade (minimum R-value of 10, a high plasticity clay), indicates that rutting rates in the unbound layers are relatively low under thick asphalt layers, even when heavy overloads are applied [17]. Analysis has also indicated that limiting subgrade strain design equations, such as the Asphalt Institute and Shell Method equations are overly conservative for long-life asphalt pavement design with thick asphalt layers [17]. Structural rutting in the base and subgrade can be controlled by limiting the vertical compressive strain at the top of the subgrade. Earlier work by Monismith and McLean [9] and Santucci [18] suggested a limiting value of 200 $\mu\varepsilon$ to preclude structural rutting [19]. By increasing the thickness of the pavement structure and/or by increasing the stiffness of the pavement layers, the strain level can be limited.

TABLE 1
Characteristics of San Gabriel Aggregate Used on I-710 Long-Life Pavement Project

Fraction	¾ inch (19.0 mm)	½ inch (12.5 mm)	⅜ inch (9.5 mm)	Rock Dust	Spec. Limits
LA Abrasion: Loss at 100 rev. (%) Loss at 500 rev. (%)	 8.6 34.2	 11.0 37.8	 11.0 37.8	 — —	 10 max. 45 max.
Specific Gravity	2.69	2.67	2.65	2.67	—

SOURCE: MONISMITH ET AL. [15]

Rutting near the pavement surface from heavy traffic is best controlled by carefully selecting quality materials and using good construction practices to produce an asphalt mix with high shear resistance. Because surface rutting is controlled primarily by the aggregate structure as opposed to the asphalt binder, the use of high quality crushed aggregate in a gradation that emphasizes mix stability is very important. Although the binder plays a secondary role, it should be stiff enough (consistent with temperature variations in the region where the pavement is being placed) to help resist rutting. Polymer modified asphalts should be considered for this rut resistant layer. Correctly selected polymer modified asphalts exhibit greater rutting resistance, although they do not necessarily have greater stiffness than conventional asphalts. Critical steps in developing a rut resistant pavement layer include testing the selected mix in the laboratory for shear resistance and using quality construction to ensure good compaction in the field.

Low temperature transverse cracking is a function of the binder flexibility and it is critical to select the proper asphalt binder for the climate region. Fortunately, the introduction of the Performance Grade (PG) system of grading asphalts has helped minimize this distress problem. Low temperature fracture tests on mixes can also predict transverse cracking at the pavement's surface [20].

The top surface layer of a long-life asphalt pavement must be designed for abrasion resistance and safety, because it is in direct contact with traffic and environmental elements such as rain and the sun's rays. High quality open-graded or gap-graded mixes are often used for this surface course. This pavement layer, which may be 1 to 2.5 inches thick depending on maximum aggregate size, climate conditions, and the number of lanes, is considered to be a sacrificial layer in a 30- to 50-year long-life asphalt pavement. Once its effectiveness is diminished (approximately every 10 to 15 years), it can be removed, recycled, and replaced with a new high quality sacrificial surface layer. Its foundation, the remaining long-life asphalt pavement structure, will continue to be sound and function as designed. Another advantage of the sacrificial layer is that many open-graded mixes can provide tire/pavement noise reductions when compared to dense-graded materials over most of their service life [21].

Materials and Testing

Selecting materials for a long-life asphalt pavement project should be consistent with quality control/quality assurance (QC/QA) guidelines, such as those used by Caltrans [22]. The use of high quality crushed aggregate with rough surface texture is particularly important for the rut resistant layer near the surface of the pavement structure as well as for the sacrificial surface layer, which must be abrasion and skid resistant. For example, a crushed river stone from southern California, identified as San Gabriel aggregate, was selected for the I-710 Phase 1 long-life project. Characteristics of the aggregate are summarized in Table 1. The gradation of the aggregate, shown on a 0.45 gradation chart in Figure 3, follows closely the maximum density line for a 0.75-inch (19 mm) nominal maximum size aggregate. This gradation meets Caltrans 2002 standard specifications.

Selecting asphalt binders for use in the pavement structure should be based on the temperature extremes expected at the project site. A conventional AR-8000 asphalt and polymer modified asphalt, designated as PBA-6a*, were chosen for the I-710 project. PBA-6a* contained a higher polymer level than the standard PBA-6a polymer modified asphalt specified by Caltrans. Polymer modified asphalt was chosen for its improved long-term durability and potential for improved rut resistance. An asphalt-rubber binder was used in the 1-inch open graded friction course (OGFC) placed on the pavement surface. Asphalt binders have been graded in California using PG specifications for conventional asphalts since 2006 [23] and polymer modified asphalts since 2007 [24]. The AR-8000 asphalt used originally on the I-710 Phase 1 project would grade as a

PG64-16 asphalt while the polymer modified PBA-6a* would be roughly equivalent to a PG64-28PM binder. Mixes containing these binders are shown in the design of the full depth replacement section of the I-710 project in Figure 4.

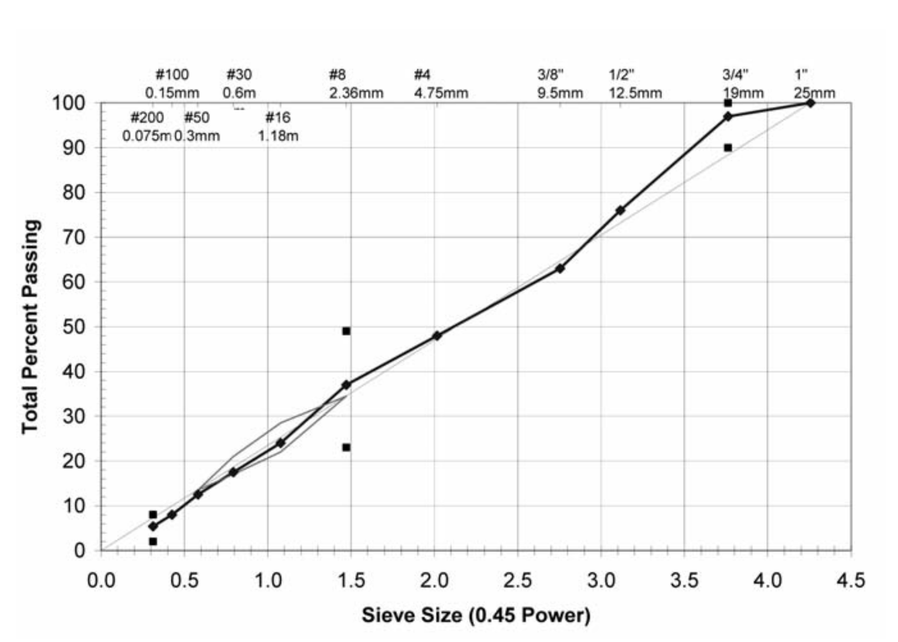
The initial binder content for the various pavement layers in a long-life asphalt pavement can be determined from standard mix design procedures such as Hveem or Superpave. These initial designs should be followed with more advanced performance tests to determine the final mix design that will meet expected traffic and climate conditions. In the case of the sacrificial surface layer, accepted design procedures for determining the binder content in an asphalt rubber or polymer modified open-graded or gap-graded mix should be used.

The repeated load simple shear test at constant height (RSST-CH) can be used [25] to predict rutting. The simple shear test equipment is shown in Figure 5. Test results help the designer select the highest binder content (for durability) that permits the mix to carry the design traffic at a critical temperature[2] for the project site without exceeding a limiting rut depth of 0.5 inch (12.5 mm). Typically, a shear stress of 10 psi (69 kPa) is repeatedly applied to a test specimen, 6.0 inches (150 mm) in diameter and 2.0 inches (50 mm) in height, using a loading time of 0.1 second and a time interval between load applications of 0.6 seconds. The test is normally conducted for 5,000 stress applications or to a permanent shear strain of 5 percent, whichever occurs first. A representative relationship between permanent shear strain, γ_p, and the number of load applications, N, is shown in Figure 6. Repeated load triaxial tests can provide similar information when used with appropriate performance models and analysis.

Controlled strain fatigue tests can then be performed on representative mixes at the design binder content [26]. Fatigue tests are run on beam samples 2.5 inches (63.5 mm) wide by 2.0 inches (50 mm) high by 16 inches (400 mm) long. The load is normally applied sinusoidally in third point loading at a frequency of 10 hertz using the equipment shown in Figure 7. The majority of fatigue tests are run at ambient temperature, approximately 68ºF (20C), which is significantly lower than the temperature used for shear testing. Fatigue testing is performed at lower temperatures because fatigue cracking is expected to initiate near the bottom of the asphalt pavement layer rather than near the warmer pavement surface. When comparing fatigue results of different mixes, it is important to realize that mix stiffness influences the strains developed in the pavement under traffic loads. Therefore, laboratory fatigue results should be considered along with the thickness of the pavement structure in which the mixes are used to determine fatigue cracking performance of each mix. Typical fatigue test results for conventional and polymer modified asphalt mixes are shown in Figure 8 from the I-710 Phase 1 project.

Transverse cracking in pavements occurs in cold climates when rapid drops in temperature generate stresses in the pavement surface that exceed the tensile strength of the mix. Transverse cracks often extend across the full width of the pavement into the adjacent shoulders. Selecting the proper binder for surface mixes is critical because the binder plays a major role in resisting this type of distress. Using the PG system for grading asphalts in the United States has helped minimize low temperature transverse cracking. However, conventional asphalts may not be the best binder choice for surface mixes exposed to extreme weather conditions (cold winters and hot summers). Instead, modified asphalts, such as asphalt rubber or polymer modified asphalts, can provide the flexibility needed to withstand thermal stresses in cold climates and still maintain adequate stiffness to help resist rutting in a hot environment.

FIGURE 3 Aggregate Gradation Used on I-710 Long-Life Pavement Project

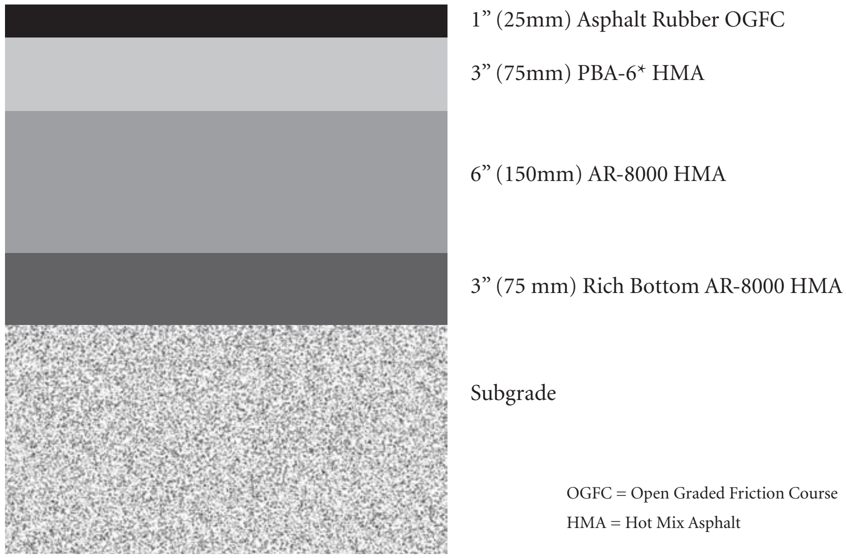


SOURCE: MONISMITH ET AL. [15]

[2] The critical temperature is defined as the temperature at a 2.0-inch (50 mm) depth where maximum deformation occurs near the tire edge. A critical temperature of 122ºF (50°C) was used for the I-710 project.

When designing a long-life asphalt pavement for cold temperature conditions, the asphalt mixes used near the pavement surface should be tested for low-temperature cracking resistance. The thermal stress restrained specimen test (TSRST), a direct tensile test, predicts the fracture temperature of a mix for a given cooling rate [27]. A schematic of the TSRST equipment and typical results from the TSRST are shown in Figure 9.

FIGURE 4 Full-Depth Replacement Section on I-710 Long-Life Pavement



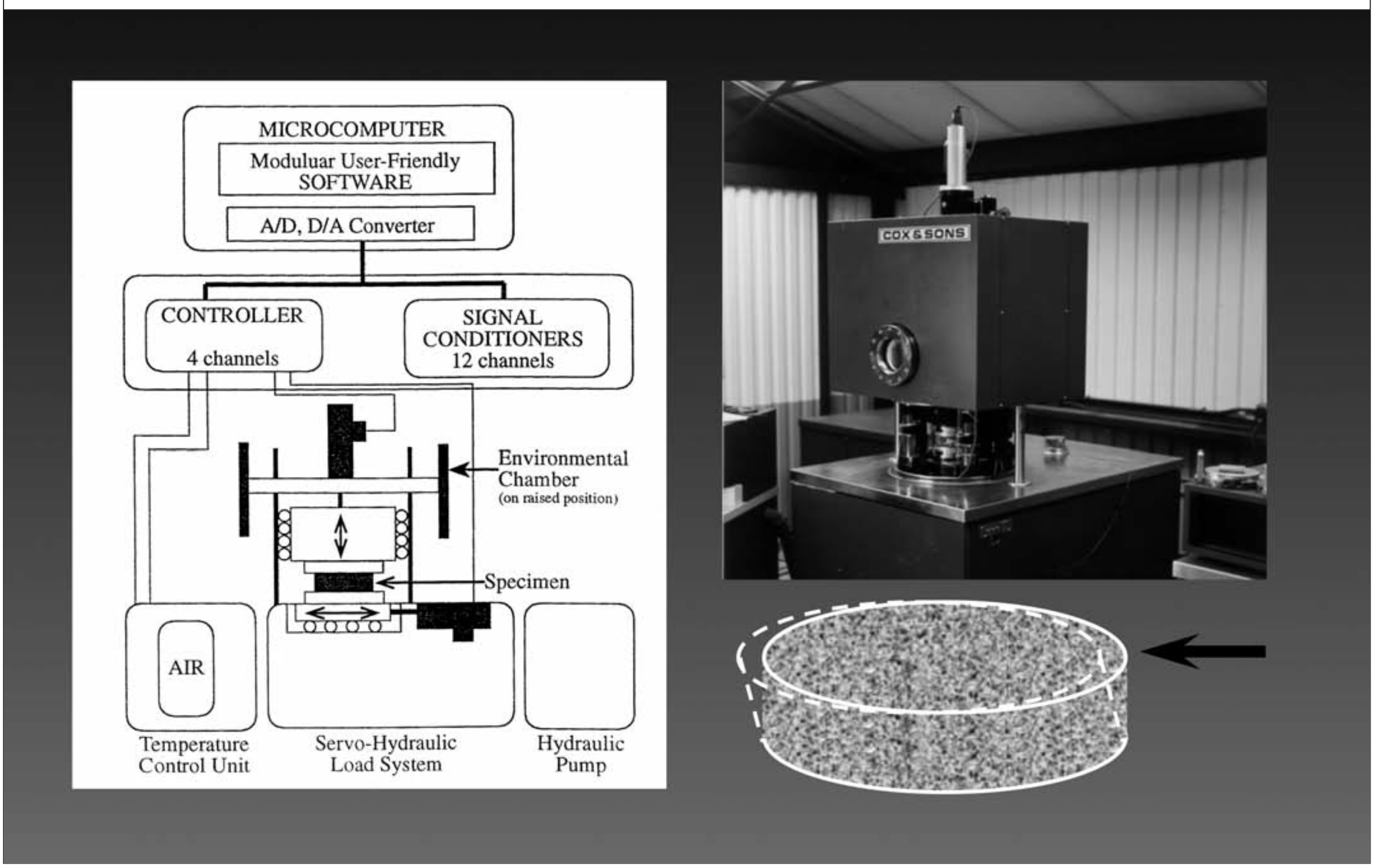
SOURCE: MONISMITH ET AL. [15]

Communication

Effective communication is vital to the success of a long-life asphalt pavement project.

A pre-bid meeting should be held with all potential contractors and suppliers to inform them of the increased testing and unique construction requirements needed to

FIGURE 5 Repeated Load Simple Shear Test Equipment



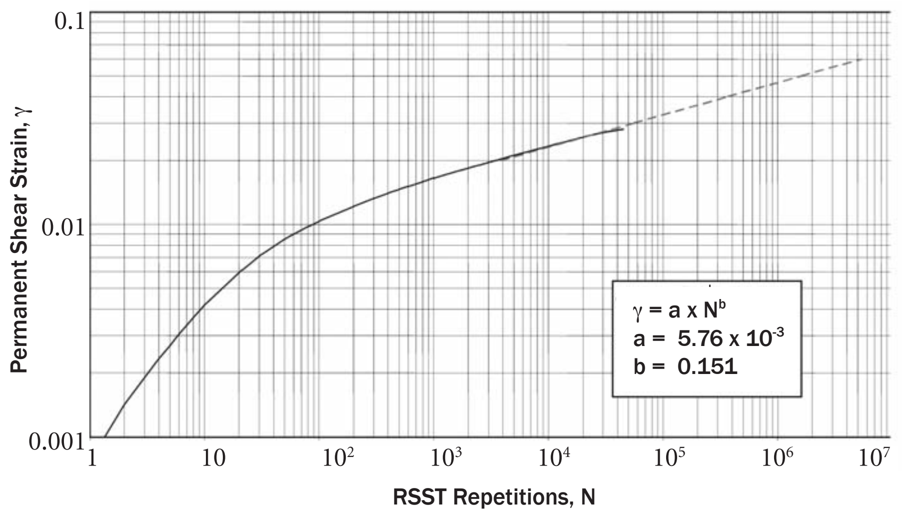
SOURCE: SOUSA ET AL. [25]

produce a long-life asphalt pavement compared to a conventional pavement. Based on this information and individual contractor limitations and constraints, some contractors may elect not to bid on the project.

Once the contract has been awarded, a pre-construction meeting should be held with all stakeholders, including representatives from the specifying agency, material suppliers, contractor/subcontractors, academia (if participating),and traffic control agencies. The purpose of this meeting is to clarify expectations for all parties involved and plan a rough schedule for the testing, construction, traffic control, and performance evaluation phases of the project. Another important aspect of the meeting is to develop and communicate the partnership role among industry, agency, and academia (when involved).

Public outreach is also an important consideration for any long-life pavement project. Communicating to the public through media outlets such as newspapers, radio, and television, and through phone canvasses, the internet, and social media about construction closures and alternate routes can significantly reduce traffic delays and related road user costs. These messages need to begin well in advance of the scheduled project so that the general public and businesses in the area have sufficient time to react and alter their travel pattern.

FIGURE 6 Permanent Shear Strain versus Load Applications in RSST-CH at 50° C on 4.7 Percent Binder PBA-6a* HMA



SOURCE: MONISMITH ET AL. [15]

Construction

Long-life asphalt pavement construction is similar to strict quality-controlled conventional pavement construction. Attention to detail, a commitment to quality, and timely feedback of test results will help ensure a well-performing pavement structure. Key factors to focus on during construction are uniformity during mix production and placement, optimum compaction of all pavement layers, avoiding mix segregation, and insuring a strong bond between asphalt layers.

A standby hot mix asphalt (HMA) plant should be available in case production interruptions develop at the primary plant during very high mix production periods. For example, 15,000 tons of HMA were produced during a 55-hour weekend closure on the I-710 Phase 1 project. Uniform mix production at the plant, uniform delivery of mix to the job site, and uniform mix placement all contribute to the construction of a quality pavement. The use of material transfer vehicles, where feasible, can help minimize thermal variations in the mix during placement.

It is well documented that good compaction (higher density) results in improved fatigue resistance of the mix. Rut resistance in the upper layer of the pavement structure also relies on good compaction. Construction practices that focus on good compaction at longitudinal joints will help reduce permeability at this critical portion of the mat and avoid moisture infiltration and damage.

Mix segregation, especially with coarse aggregate mixes, can occur during production, transport, or placement. Segregation in the finished mat can produce a permeable mix, which can lead to water infiltration and subsequent moisture damage. Care in stockpile management, proper loading of transport vehicles, and continuous uniform feed into the paving machine during placement will help minimize segregation problems.

The importance of a strong bond between pavement layers has been demonstrated at the National Center for Asphalt Technology (NCAT) test track [28] and in Heavy Vehicle Simulator testing at the University of California Pavement Research Center (UCPRC) [29]. When a tack coat is not used, fatigue cracking can actually be initiated at the interface between asphalt pavement layers and result in premature failure of the pavement structure. Hot asphalt or asphalt emulsion is an effective tack coat. For pavement rehabilitation projects, milling, in combination with a tack coat, can enhance the bond between an overlay and the existing pavement surface.

UCPRC, with support from Caltrans and a four-state consortium, which includes Caltrans, Washington Department of Transportation (DOT), Minnesota DOT and Texas DOT, has developed a powerful planning and scheduling software tool for large scale rehabilitation projects [30]. The program, Rapid Rehab (previously referred to as CA4PRS), helps agencies optimize construction schedules, produce savings in personnel and construction costs, and reduce overall road user delay due to construction closures. Caltrans has trained more than 700 of its district engineers and technical personnel to use Rapid Rehab. This scheduling/ traffic analysis tool has been used on several major rehabilitation projects throughout California, including the long-life concrete project on I-15 in Devore and the I-710 long-life asphalt pavement project in Long Beach.

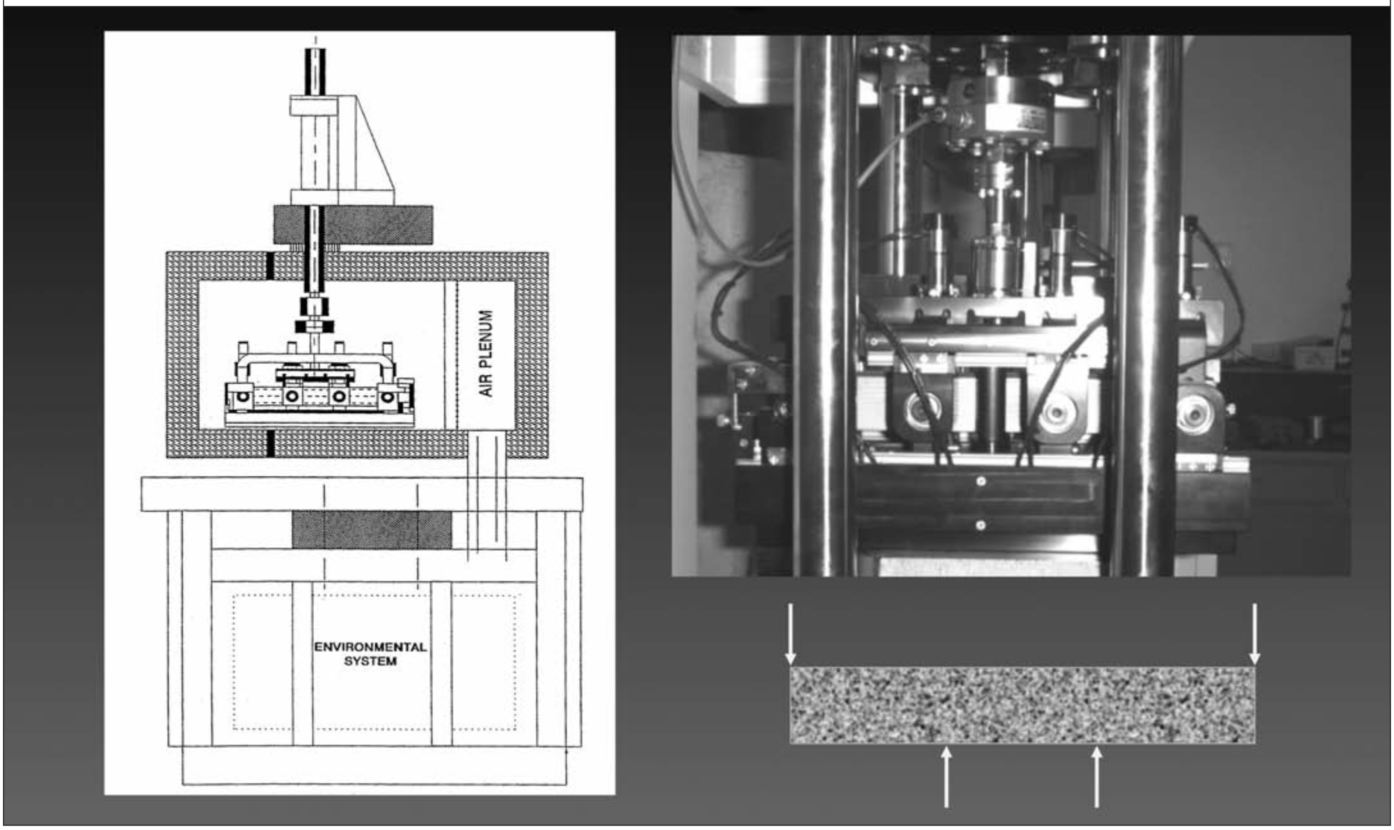
Performance

Long-life asphalt pavements should be monitored periodically to evaluate the structural integrity of the pavement. Surface distresses, such as top-down cracking, thermal cracking, rutting, and raveling should also be tracked in order to replace the sacrificial surface course before it is no longer effective. Performance reviews of existing long lasting pavements outside of California have shown that well-designed and well-constructed asphalt pavements can withstand a wide range of traffic conditions over a long time period with only periodic maintenance of the sacrificial surface layer.

For example, Baker and Mahoney [31] reported on the performance of asphalt pavement sections with a thickness between 6 and 19 inches on I-90 in the state of Washington. None of the sections, which ranged from 23 to 35 years old, had ever been rebuilt for structural reasons. The age at first resurfacing averaged 18.5 years west of the Cascades mountain range and 12.4 years on the eastern side.

The I-710 Phase 1 long-life asphalt pavement in Long Beach has been monitored and tested since its construction. Field measurements during the first five years of traffic include surface skid resistance, profile, rut depth, deflection. Visual condition surveys were performed as well. Laboratory testing included shear and flexural fatigue testing. Results show performance that meets or exceeds expectations for the first five years of its life [32]. The design traffic for this pavement was 200 million equivalent single axle loads (ESALs). Asphalt is 12 inches thick in the full-depth asphalt replacement sections beneath the overpasses, and 8 inches thick in the asphalt overlays placed on cracked and seated concrete sections. Based on the success of the I-710 project, Caltrans is working with UCPRC to design and construct two additional long-life asphalt pavement sections on I-5 in northern California: one near Red Bluff and the other near Weed.

FIGURE 7 Controlled Strain Fatigue Test Equipment



SOURCE: TAYEBALI ET AL. [26]

Selected layers of these pavement structures will contain up to 25 percent reclaimed asphalt pavement (RAP). The same design principles and laboratory performance tests used to evaluate materials for the I-710 project are being used for these long-life asphalt pavement sections.

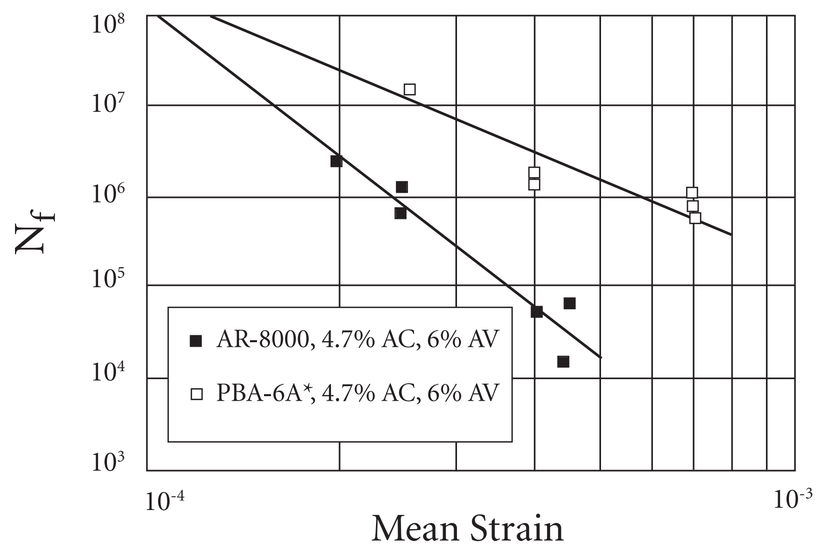
Benefits

Long-life asphalt pavements can offer several advantages over conventional asphalt pavements. The most noteworthy benefits include lower life-cycle cost and lower user-delay costs.

Life-cycle cost can be lower with long-life asphalt pavements because major structural pavement repairs or reconstruction are postponed. The greater initial cost can be more than offset by the reduced maintenance and rehabilitation costs for roads carrying very high traffic volumes. A well-designed and constructed long-life asphalt pavement will have adequate load-carrying capacity to delay failure from fatigue cracking, structural or surface rutting, and low temperature transverse cracking. The only planned maintenance for long-life asphalt pavements is periodic replacement of the surface layer.

Lee et al. [33] recently examined three different pavement design alternative scenarios used on highway projects at the time of the I-710 Phase 1 project to evaluate cost-effectiveness for the project and the benefit-cost ratio for the research and development it used, based on information applicable to its time of planning and design. The study used software tools originally developed for construction productivity analysis of Caltrans' concrete and asphalt long-life rehabilitation projects [4, 34] to estimate construction schedules and traffic delay for the alternatives. Life-cycle cost analysis (LCCA) was used to estimate cost-effectiveness for that 2003 project. The pavement alternatives examined were long-life asphalt concrete pavement (ACP) consisting of a combination of

FIGURE 8 **Typical Fatigue Test Results for Conventional and Polymer Modified HMA (N_f = fatigue life)**



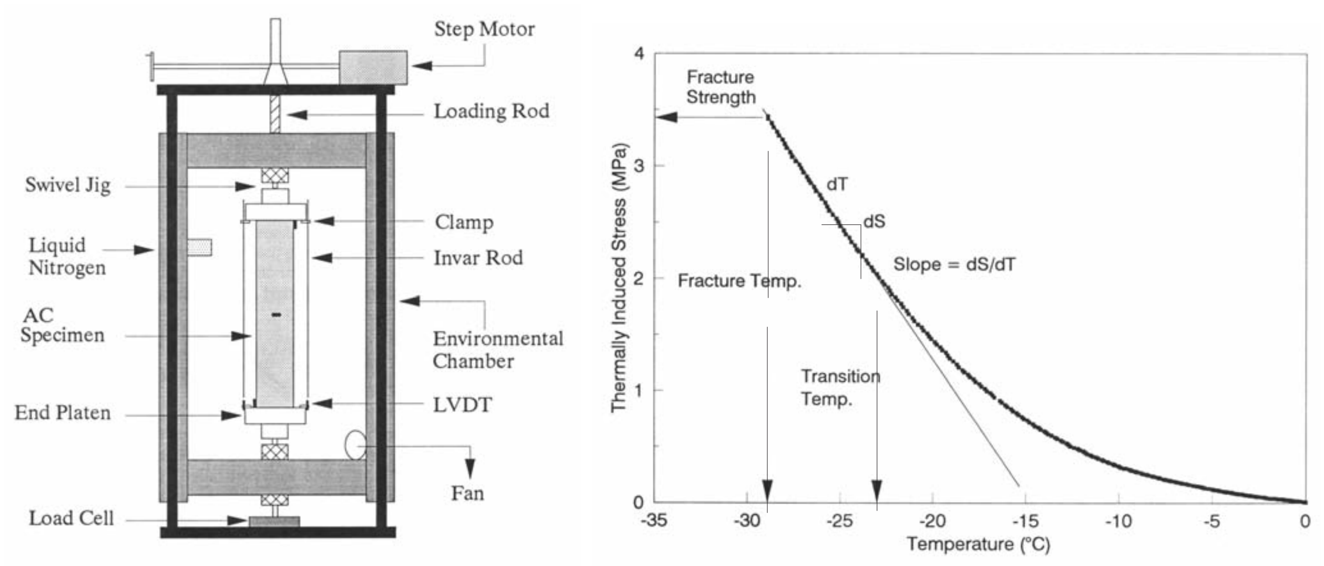
SOURCE: MONISMITH ET AL. [15]

crack-seat-and-overlay (CSOL) and full-depth asphalt concrete (FDAC) under bridges, a standard-life ACP also consisting of CSOL and FDAC; and a long-life portland cement concrete pavement (PCCP). Results from the LCCA study, summarized in Figure 10, showed that the long-life ACP alternative used on the I-710 project had the lowest life-cycle costs over the 60-year analysis period. The combined life-cycle agency cost for the long-life FDAC and CSOL scenario used on the I-710 Phase 1 project was $33.2 million for the long-life ACP alternative, $37.8 million for the standard ACP alternative, and $50.4 million for the long-life PCCP alternative.

These LCCA results for the I-710 Phase 1 project are based on costs for various pavement rehabilitation types as of 1999 through 2003, a discount rate of four percent as used by Caltrans for LCCA cost-benefit analysis, and expected maintenance and rehabilitation scenarios developed from a number of California sources. Costs for the asphalt layers in the long-life ACP alternative were increased over the costs of conventional asphalt to reflect the use of polymer modified asphalt and rich bottom layers. The cost of the long-life PCCP alternative used in the I-710 LCCA calculations was substantially increased over normal PCCP construction because of the need in the 55-hour weekend closures to use Rapid Strength Concrete mix that achieved required flexural strength within 12 hours.

The results from the LCCA are specific to that project and time. Factors that can be expected to change over time and for other projects include material costs, differences in cost inflation rates between asphalt and concrete, the need for innovative materials to meet structural and construction closure requirements, changes in project configuration (e.g. the ratio of truck lanes needing lane replacement relative to passenger car lanes not needing rehabilitation), other project-specific factors, and different discount rates. LCCA is an important consideration in every phase of developing a project and should be performed using project-specific information and current and projected future costs.

FIGURE 9 Thermal Stress Restrained Specimen Test (TSRST) and Typical Test Results



SOURCE: KANERVA ET AL. [27]

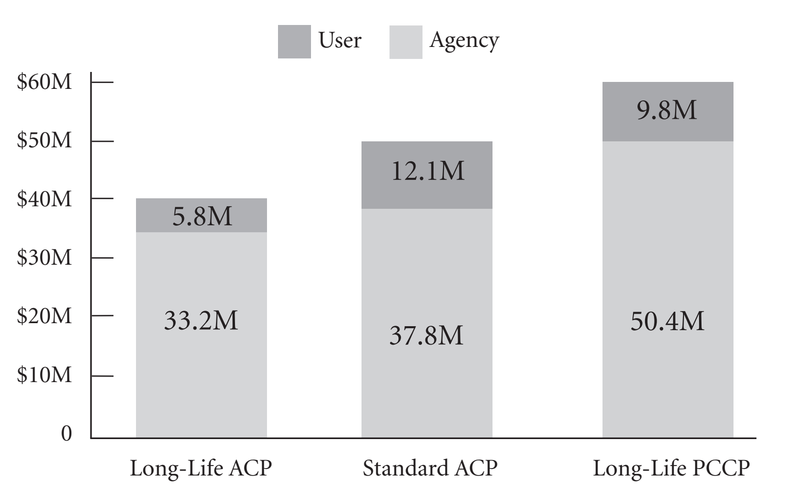
User-delay costs are lower for long-life pavements because minor surface rehabilitation can be done within short work windows or during off-peak traffic hours. Fewer user-delays translate into less frustration for the traveling public and reduced costs for transporting goods. The LCCA study by Lee et al. [33] showed user costs of $5.8 million for the long-life ACP alternative, $12.1 million for the standard ACP alternative, and $9.8 million for the long-life PCCP alternative, as shown in Figure 10. These results indicate that although both long-life alternatives would have impacted both day and nighttime traffic within the limited number of 55-hour closures, the total traffic delay cost was calculated to be less than many repeated nighttime closures for the standard ACP alternative.

Summary

Long-life asphalt pavements can be more cost-effective than conventional asphalt pavements. Successful implementation of long-life asphalt pavements relies on key elements that must be addressed including design, materials and testing, communication, construction, and performance monitoring.

The emergence of mechanistic-empirical design procedures in the 1960s and later development of performance tests under the Strategic Highway Research Program (SHRP) in the 1990s provide engineers with the tools necessary to design and construct long-life asphalt pavements. Testing of materials used in various layers of the pavement structure focuses on limiting critical strains to preclude fatigue cracking, rutting, and low temperature transverse cracking. The surface layer of a long-life asphalt pavement is designed to be durable, skid resistant, and free draining for safety. The surface layer, typically open-graded or gap-graded asphalt mix in California, also serves as a thin sacrificial layer. Once its effectiveness is lost, this layer can be easily removed and replaced with another high quality sacrificial layer

FIGURE 10 Life-Cycle Cost Comparisons for I-710 Phase 1 Alternatives Using Data Applicable to 1999 through 2003.



SOURCE: LEE ET AL. [33]

without jeopardizing the integrity of the underlying long-life asphalt pavement structure.

Effective communication among all stakeholders is vital to the success of a long-life asphalt pavement project. Pre-bid and pre-construction meetings help all parties understand their responsibilities. Communication with the public about road closures and alternate routes helps reduce traffic delays and road user costs.

Construction of a long-life asphalt pavement demands the best QC/QA procedures available with special emphasis on attention to detail and timely response of test results to contractors on the job. Powerful planning and scheduling tools, such as the Rapid Rehab program used by Caltrans, help optimize construction schedules, minimize costs, and reduce road user delays.

Periodic evaluations to document performance are an essential element of any long-life pavement project. Life-cycle cost analysis should be used to select the most economical design for each project using project-specific input, and current cost data. Construction scheduling and traffic analyses can be performed using the Rapid Rehab software to help provide input to LCCA.

Reduced life-cycle cost and user-delay costs are important benefits of long-life asphalt pavement alternatives when compared to standard asphalt pavements.

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