California's Perspective on Concrete Pavement Preservation

Shakir Shatnawi,[1] Mary Stroup-Gardiner,[2] and Richard Stubstad[3]

ABSTRACT

The California Department of Transportation (Caltrans) has established a strong pavement preservation program to preserve existing pavements and delay rehabilitation. To implement this effort, Caltrans developed a 5-year pavement preservation plan with dedicated funding and established the Pavement Preservation Task Group (PPTG) consisting of over 22 subgroups, several of which apply to concrete pavement preservation specifically. The PPTG works as an advisory body to the California Pavement Preservation (CP2) Center located at the California State University in Chico.

This paper describes the major pavement preservation activities underway on pavement preservation of concrete pavements in California. In particular, it covers the following activities:

1. The development of the Maintenance Technical Advisory Guide (MTAG – 1) for Rigid Pavement Preservation.
2. The performance of diamond-grinding projects and the benefits of diamond grinding in life extension, ride quality improvement, and noise reduction.
3. The performance of dowel bar retrofits and the lessons learned from several projects.
4. The performance of full-depth slab repair, particularly with regard to the use of rapid strength concrete (RSC).

Caltrans plans for implementing pavement preservation on a more widespread basis within the State are also discussed, for both pavements in general and rigid pavements in particular.

THE MAINTENANCE TECHNICAL ADVISORY GUIDE FOR CONCRETE PAVEMENTS

The Maintenance Technical Advisory Guide (MTAG) – Volume II was developed for use by Caltrans and other pavement professionals by the PPTG and the CP2 Center. The first edition was developed in July 2006, followed by the development of the second edition in March 2008 (*1*).

[1] Shakir Shatnawi, Chief, Office of Pavement Preservation, California Department of Transportation, 5900 Folsom Boulevard, Sacramento, CA 95819; phone: 916-227-5706; email: Shakir.Shatnawi@dot.ca.gov

[2] Mary Stroup-Gardiner, Technical Director, California Pavement Preservation Center, College of Engineering, California State University, Chico, CA 95929; phone: 530-898-5963; email: MStroup-Gardiner@csuchico.edu

[3] Richard Stubstad, Applied Research Associates, Inc., 1111 Howe Avenue, Suite 540, Sacramento, CA 95825; phone: 916-920-9850; email: RStubstad@ara.com

Both editions focus on pavement preservation strategies for rigid pavements. The eight chapters of the second edition are as follows:

1. Introduction
2. Surface characteristics
3. Strategy selection
4. Joint resealing and crack sealing
5. Diamond grinding and grooving
6. Dowel bar retrofits
7. Isolated partial-depth repair
8. Full-depth repair including slab replacement

Training modules for each of the chapters were also developed, along with a separate module on distresses in concrete pavements.

Chapter 1 presents information on the pavement preservation concept, benefits of pavement preservation, and information on design and materials. Chapter 2 presents information on the most important surface characteristics (ride, surface texture and safety, noise, durability, and aesthetics) and why these factors are important. It also describes how each characteristic can be evaluated in the field. Chapter 3 describes the strategy selection process that should be followed to select the appropriate treatment for a given pavement with specific types of distress.

The remaining five chapters describe the concrete pavement preservation treatments most widely used in California. For each treatment, the purpose of the treatment as well as information on project selection, design, materials, specifications, and construction and inspection are presented. Limitations and troubleshooting guides are also included throughout.

A similar document exists for flexible pavement preservation as well.

For more detailed information on MTAG – Volume II, a complete copy of the rigid pavement document can be found on the Caltrans pavement maintenance Web site at www.dot.ca.gov/hq/maint/MTA_GuideVolume2Ridgid.html or on the CP2 Center's website at: www.cp2info.org/center.

DIAMOND GRINDING

Diamond grinding of concrete pavements in California, when properly timed and applied, has been found to be a very effective and low-cost pavement preservation technique. Arguably, it may well be the most cost-effective technique currently available for pavement preservation of jointed concrete surfaced pavements.

Diamond grinding of concrete pavements has been shown to result in the following benefits:

1. *Smoother pavement surfaces*—Diamond grinding is generally triggered by an unacceptably high level of roughness (International Roughness Index or IRI), oftentimes accompanied by some joint faulting, that has developed over the years. As applied in California, diamond grinding generally results in appreciably improved levels of pavement smoothness.

2. *Longevity and life extension*—While the longevity of diamond grinding has been quantified, more effort is needed to determine the exact extended life benefits of grinding.

3. *Better skid resistance*—Diamond grinding generally restores an excellent level of skid resistance to the concrete pavement surface, resulting in increased safety for the traveling public.

4. *Improved noise levels*—Diamond grinding has also been shown to audibly reduce pavement–tire interface noise levels, as measured by on-board sound intensity (OBSI) noise measuring equipment.

5. *Lower agency costs*—Diamond grinding is one of the lowest cost—and oftentimes the most cost-effective—pavement preservation alternatives for concrete pavements.

6. *Lower user costs*—Diamond grinding improves fuel economy associated with driving on a smoother (i.e., lower IRI) pavement surface.

The following subsections quantify and explain the benefits of diamond grinding in more detail.

Smoothness and Longevity

A study carried out by Caltrans (*2*) found that the average roughness in terms of IRI before a planned PCC grinding project by Caltrans was 165 in/mi (2.61 m/km) before grinding and 93 in/mi (1.46 m/km) after grinding. Thus the average before / after IRI grinding ratio in California is 165.3 / 92.7 = 1.78. Moreover, this level of improvement (limited to California—mostly frost-free) results in an average treatment life of nearly 17 years before further rehabilitation or preservation (e.g., another grinding project, if feasible) is needed. These figures compare favorably with the reported national average longevity of a given grinding project of approximately 14 years (*3*). Moreover, since diamond grinding is almost always carried out on structurally sound (albeit having poor ride quality) concrete pavements in California in a timely manner, it is possible that the life extension of the pavement could be nearly as long as the treatment life itself.

Figure 1 shows the average decrease in IRI after diamond grinding based on 29 statewide projects within California. Figure 2 shows the various confidence levels associated with the statistics for these same 29 projects. Two forms of regression equations were fit to these data. While both provide good R^2 values, the exponential fit (Figure 1 and Figure 2) is recommended for use since it is unlikely that the progression of IRI will remain constant from cradle to grave, as the linear regression equations would imply.

For planning and design purposes, furthermore, it is recommended that the selected treatment life reliability level should be around 80 percent, which translates to about 14.5 years (see Figure 2)—perhaps slightly more for low- to medium-volume traffic roadways or slightly less for high-volume traffic roadways.

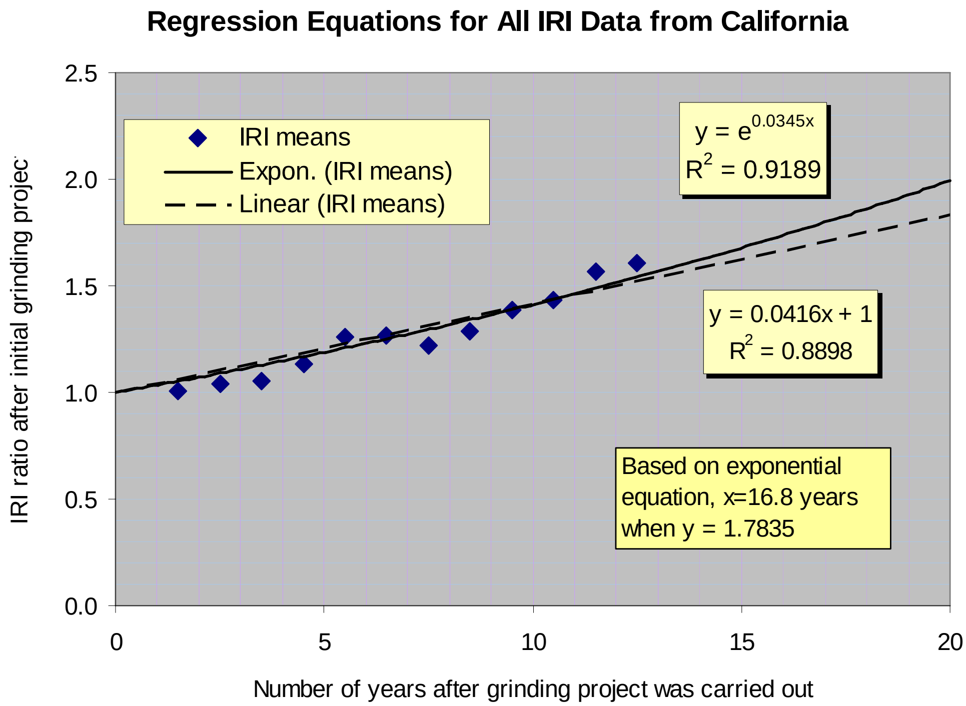

Figure 1. Change in the ratio of IRI over time as a function of the initial IRI after grinding (*2*).

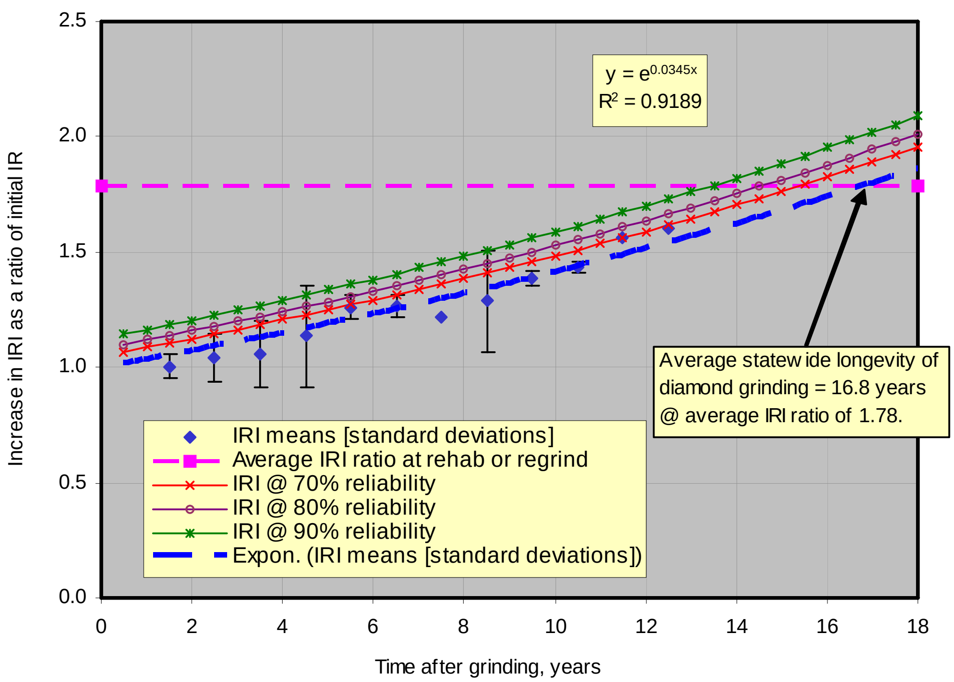

Figure 2. Reliability levels for the expected survivability of California diamond-grinding projects (*2*).

Skid Resistance and Noise Properties

It is a well-known fact that grinding of a concrete pavement generally improves skid resistance, in many instances substantially. For example, changes in skid resistance due to diamond grinding of longitudinally tined concrete test sections were monitored and reported by the Arizona Department of Transportation (*4*). Table 1 shows the results of a diamond grinding study carried out in the Phoenix area (the percentage improvement for any given test section due to grinding is shown in parentheses in the After Grinding columns).

Friction is typically denoted by the Friction Value or the Coefficient of Friction using a Standard Test Method (ASTM or other), and is defined by:

Friction Value = F/L

where: F = frictional resistance to motion in the plane of the pavement–tire interface;

L = tire load force perpendicular to the pavement–tire interface.

Table 1
Friction Values and Percentage Improvement in Skid Resistance Due to Diamond Grinding (*4*)

	Friction Values (% Improvement)					
	Before Grinding			After Grinding		
Test Section	Lane 1	Lane 2	Lane 3	Lane 1	Lane 2	Lane 3
1	0.52	0.55	*	0.65 *(+25%)*	0.63 *(+15%)*	*
2	*	*	0.56	*	*	0.66 *(+18%)*
3	0.49	0.51	*	0.69 *(+41%)*	0.69 *(+35%)*	*
4	*	*	0.53	*	*	0.67 *(+26%)*

* Denotes an empty cell.

The test sections shown in Table 1 were all new (with longitudinal tining—the same surface texture used in California) before grinding. Therefore, the improvement in skid resistance due to diamond grinding is likely to be even better for older PCC pavements, many of which exhibit polished and exposed aggregate. As indicated in Table 1, the increase in friction values and, therefore, skid resistance ranged between 15 percent and 41 percent, with an overall average improvement for the six sections tested of 27 percent.

Another study carried out by Caltrans (*5*) showed similar benefits for sound or noise emissions from the tire–pavement interface. Such emissions are the primary source of audible noise emanating from high-speed roadways.

A measuring technique has been developed to accurately measure tire-pavement noise levels, called on-board sound intensity or OBSI. A typical setup using dual microphones to measure OBSI pavement–tire interface noise level is shown in Figure 3.

Figure 3. OBSI microphone setup—two-probe system.

Currently, there is no Standard Test Method for measuring OBSI. However, methods are currently under development at both ASTM and AASHTO using the two-microphone setup shown in Figure 3.

Typically, decibels (dB) are stated in terms of a weighted average value, called dB(A) or dBA, which covers the so-called *A-weighted* range of audible frequencies to the human ear. Audible sources of typical noise using two methods of measuring sound levels are shown in Figure 4.

Differences between before- and after-grinding OBSI levels on various freeways in California are shown in Table 2. These differences have been shown to be noticeable, meaning easily perceptible to the human ear, whether one is riding in a vehicle or is not moving but is within earshot of the roadway.

Note that OBSI levels are measured only some 5 in. (127 mm) from the source of the noise, i.e., from the tire–pavement interface as shown in Figure 3, and are thus wildly exaggerated compared to what a person would hear inside a typical vehicle or in the proximity of a high-speed roadway. Accordingly, the OBSI values shown in Table 2 should be used for comparative purposes only, not to ascertain the true dBA level heard by the traveling (or nearby) public. The main point to be made is that diamond grinding significantly reduces noise levels resulting from high-speed concrete roads, such as freeways and tollways.

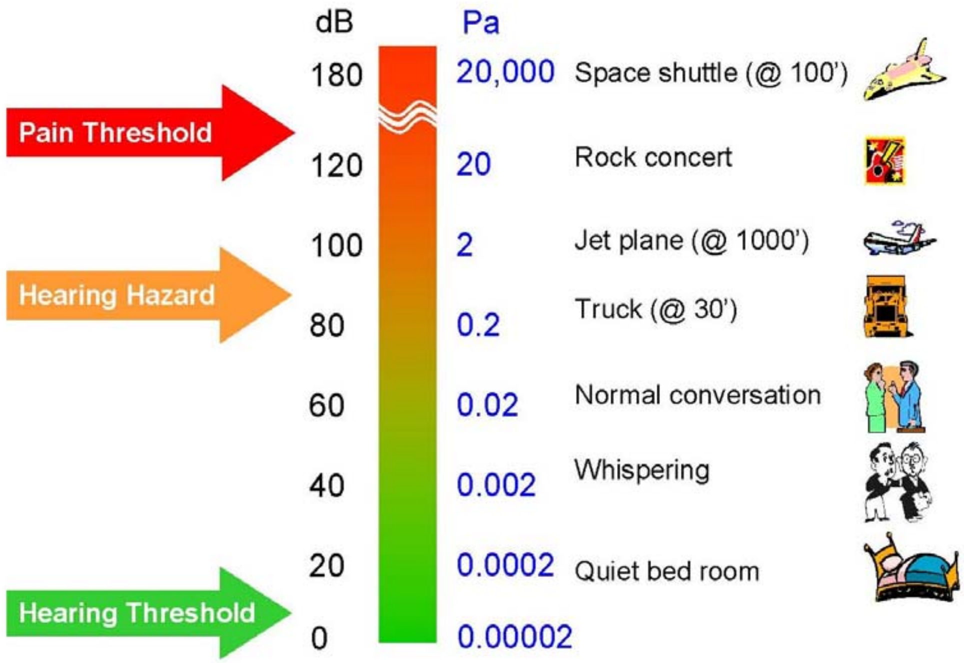

Figure 4. Conversion from sound pressure to perceptible noise levels and typical examples of dB(A) levels at normal distances from various sound sources (*6*).

Table 2
Pre- and Post-Grind OBSI Values From Six Projects in California (*5*)

Site No.	Route Designation	County	Pre-Grind OBSI (dBA)	Post-Grind OBSI (dBA)	Post-Grind Reduction (dBA)
1	SR-60	San Bernardino	105.1	103.9	1.2
2	I-15	Riverside	103.9	101.8	2.1
3	I-5	Orange	104.0	101.3	2.6
4	I-405	Orange	104.4	102.0	2.5
5	I-5	Kern	103.2	100.0	3.2
6	I-5	Sacramento	104.7	100.3	4.4
Average			**104.2**	**101.5**	**2.7**

Agency and User Costs

While agency and/or user costs of maintaining and using a pavement are difficult to quantify precisely, it is obvious that the longer the time between treatments, the lower the agency costs are to maintain the roadway. Furthermore, diamond grinding is a comparatively low-cost pavement preservation technique, with an expected life cycle of—on average—nearly 17 years in California (*2*).

Even more importantly from a roadway user perspective, it has been shown that pavements with a lower (smoother) IRI contribute to lower user costs. Vehicles use less fuel when driving on smoother pavements, plus vehicle maintenance costs are reduced since a smooth pavement has a tendency to cause automobile and truck parts to last longer (eg. brakes, suspension, steering, tires, etc.).

Annual fuel cost savings have been estimated to be as much as $25,000 per lane-mile, for trucks only, for the average ground PCC freeway pavement in California (*7*). Keep in mind that these cost savings are based on 2002 fuel costs and do not include other user costs, vehicle delay costs during construction, and passenger vehicle costs at all. Thus the actual user cost savings will be considerably higher than the $25,000 per lane-mile indicated in the referenced 2002 Caltrans report (*7*).

Recalling that a diamond grinding project generally lasts 17 years or so in California, the *current* approximate cost of diamond ($30,000 per lane-mile) pales in comparison to the savings achieved in fuel costs of more than $25,000 per year during the first half of the 17-year design life, or at least $210,000 over the expected life of the treatment.

It can be concluded that diamond grinding is a cost effective and easy-to-carry-out method of pavement preservation for concrete pavements—as long as the pavement programmed for diamond grinding qualifies as a candidate for this procedure.

Determining If a Concrete Pavement Is a Candidate for Diamond Grinding—or Not

There are certain pavement distresses or conditions that should *preclude* the use of diamond grinding as a rehabilitation alternative, including the following:

1. Lack of structural integrity (e.g., voids under joints from pumping, excessive slab cracking, or progressive cracking over time).

2. Poor load transfer across transverse joints as indicated by excessive faulting, voids, or large differential deflections.

3. Spalling or other damage due to alkali–silica reactivity.

4. Freeze–thaw damage, including D-cracking (generally confined to freeze–thaw zones, which exist but are relatively uncommon in California).

5. Soft aggregates in the PCC slab, such as limestone, that are prone to polish (this may be overcome by widening the spacing of the grinding blades).

None of these distresses would be remedied by diamond grinding alone, and the problem would likely continue to cause pavement failure a short time after grinding. While such precluding factors are certainly considered under present Caltrans guidelines, this consideration is not yet based on any truly objective criteria or measurable threshold values to indicate the most optimum timing to carry out diamond grinding.

Still, even without a formal process for selecting a project for diamond grinding, it is seen that Caltrans achieves an average 17-year life cycle for diamond-grinding projects. Based on this, future pavement preservation initiatives in California will certainly utilize this very effective pavement preservation strategy to an even greater extent in the future.

DOWEL BAR RETROFITS

Poor load transfer across transverse joints was listed above as one of the factors that should preclude the use of diamond grinding. Dowel bar retrofit (DBR) rectifies poor load transfer and can be used in combination with diamond grinding. DBR (see Figure 5)—if properly carried out—can be a very effective pavement preservation strategy. This approach can be used to remedy poor joint load transfer, thus rendering a diamond grinding project feasible—barring any other precluding conditions in the above list.

Figure 5. Dowel bar retrofits at a transverse joint (*8*).

This strategy can be very successful when properly designed and constructed. For example, an extensive project in 1999 along the I-10 freeway in Los Angeles County, California, proved to be a very successful DBR project prior to grinding (see Figure 6). Excellent materials and workmanship, together with an adequate time window before opening to traffic, were achieved throughout the project. By 2008, a mere 2 percent of the 22,000 dowel bars (11 per joint) have shown some signs of distress—some 9 years after the fact. Many other successful DBR projects have also been constructed in California since the early 2000s.

On the other hand, there have been reports of dowel bar retrofit distresses in some projects in California. These distresses appear to be related to materials or workmanship in the rather demanding process of dowel bar retrofitting. An example of one of these distressed projects is on I-5 in Orange County. In this project, it appeared that the grouting material was not properly consolidated (vibrated) between the edge of the slot and the dowel bar (see Figure 7), and there were many locations of misaligned dowels.

Figure 6. Successful dowel bar retrofit project on I-10 in Pomona, CA (*9*).

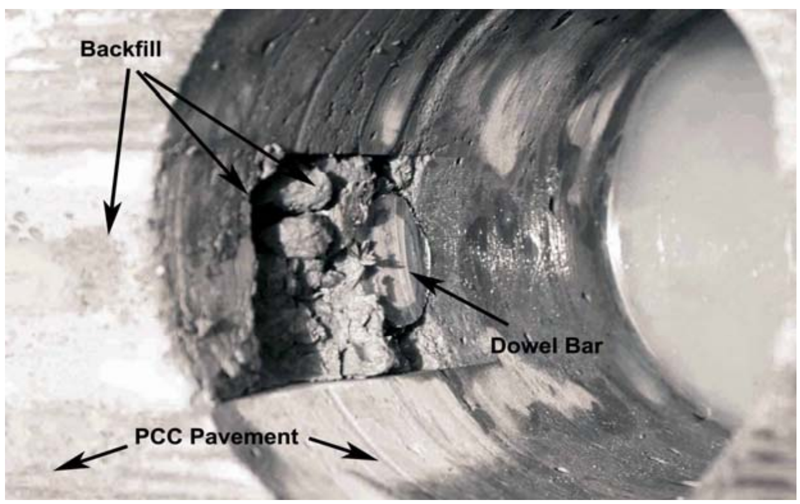

Figure 7. A poorly performing dowel bar retrofit on I-5 in Orange County (*10*).

In other instances of premature failure, it has been found that the dowel bar slots were not thoroughly cleaned prior to placing the backfill material, thus resulting in an inadequate bond between the backfill and the original concrete. There were instances where the dowels were misaligned because inexperienced contractors did not use gang-saws and had a hard time retaining the correct dowel bar alignment.

Dowel bar retrofits are best suited for pavements that are structurally sound but still exhibit low load transfer at joints and/or cracks. Pavements with little remaining structural life, as evidence by extensive cracking (more than 10 percent stage 3 cracking) or with high-severity joint defects are not good candidates for DBR.

In summary, there are five major factors to consider when evaluating a potential project for DBR (*1*):

- Structural condition of the slabs [should be good or better].
- Structural condition of the base [should exhibit low falling-weight deflectometer (FWD) deflections].
- Measured load transfer efficiency [< 60 percent as measured by an FWD].
- Magnitude of faulting [> 0.10 and < 0.5 in. (2.5–13 mm)].
- Condition of joints and/or cracks [moderate severity spalling or better].

Finally, and most importantly, good materials and workmanship and adequate time allowed before opening to traffic are mandatory. DBR retrofits, when warranted, are generally followed by grinding to restore smoothness properties.

FULL-DEPTH SLAB REPAIR

Full-depth slab repairs, or replacements, are used when isolated slab distresses are too severe to warrant other forms of pavement maintenance and preservation. Full-depth repairs may be used with or without followup diamond grinding, depending on the overall pavement condition and the remaining life expectancy of the untreated pavement. A typical photo of a removed slab prior to a slab replacement panel is shown in Figure 8.

Full depth slab repair involves full-depth and -width slab removal followed by cast-in-place replacement of slabs (or partial-length slabs) in an existing pavement. Typically the minimum length requirement is 6 ft (1.8 m); however, when repair areas are closely located it may be more cost effective to substitute a larger area—usually the full length of the original slab. Guidelines associated with full-depth slab repairs, such as reestablishing joints, etc., are detailed in the Caltrans *Slab Replacement Guidelines* document (*11*).

Figure 8. A full-depth concrete slab replacement project (*11*).

Full depth slab repair can address a wide variety of distresses, including transverse cracks, longitudinal cracks, joint spalling, and blowups. According to the FHWA (*12*), Table 3 shows the typical distress types and severity levels where full-depth repairs should be applied.

Table 3
Typical Distresses Addressed by Full-Depth Repairs
for Jointed Concrete Pavement (*12*)

Distress Type	**Severity Levels That Require Full-Depth Repair**
Transverse cracking	Medium, High
Longitudinal cracking	Medium, High
Corner break	Low, Medium, High
Spalling of joints	Medium[1], High
Blowup	Low, Medium, High
Reactive aggregate spalling	Medium[1], High
Deterioration adjacent to existing repair	Medium[1], High
Deterioration of existing repairs	Medium[1], High

[1] Partial-depth repairs can be optionally used if the deterioration is limited to the upper one-third of the pavement slab.

A wide variety of materials are available for full-depth slab repairs. The selection of a suitable material will depend on the project's environmental, design, and funding requirements along with desired performance. While these slab repair materials include conventional portland cement concrete (PCC) mixtures and bituminous materials, rapid-strength concrete (RSC—also known as fast-setting hydraulic cement) is most often used in California due to the need for early opening to traffic, most commonly by the early hours of the following morning.

Slabs constructed using RSC mixtures are generally opened to traffic in less than 4 hours after casting. RSC mixtures are designed to develop a flexural strength in excess of 400 lfb/in^2 (2.75 MPa) within 4 hours. This requirement was developed using finite element analysis and is based on the fact that if the slab is subjected to traffic prior to obtaining this minimum strength, the durability and life expectancy of the slab will likely be compromised.

RSC cement mixtures have performed very well in California, indicating both excellent concrete design and construction practices (*13*). A total of 15 statewide projects were surveyed by Caltrans recently for premature distresses on RSC slab replacements. The results were excellent (see Figure 9), with less than 2 percent of the surveyed slabs showing any significant surface distresses. Where distresses were observed, shrinkage cracks were the most prevalent distress type.

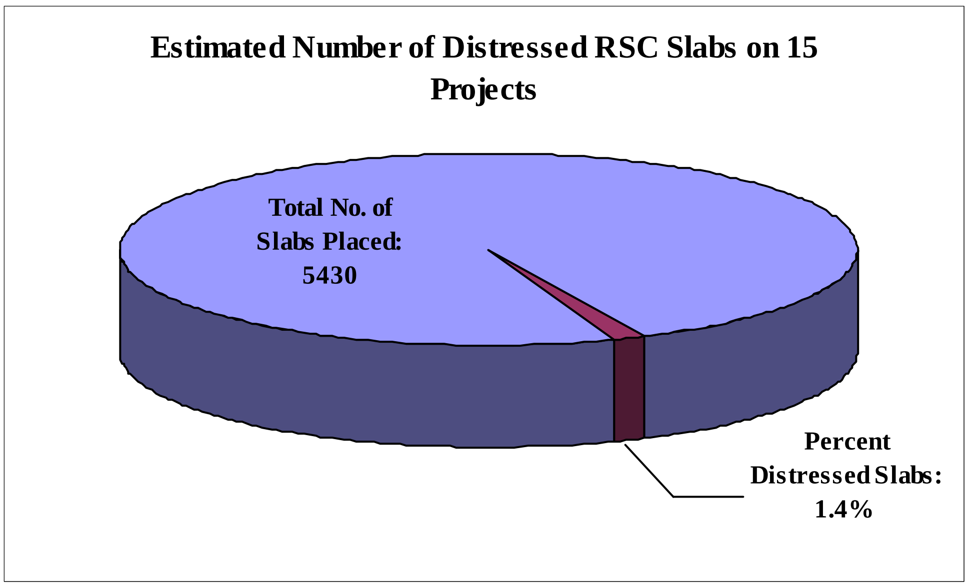

Figure 9. Percent distressed slabs on surveyed RSC projects (*13*).

Detailed construction guidelines to assist contractors in the proper use of RSC were published by Caltrans in January 2004 (*11*).

PERTINENT PAVEMENT PRESERVATION ISSUES AND RECOMMENDATIONS

The preceding sections have outlined Caltrans experience with various rigid pavement preservation strategies. It should be emphasized that the concept of "preserving rigid pavements as rigid" should be the motto of concrete pavement preservation. There is a need to refine and determine the appropriate pavement preservation tools to determine the right fix at the right time.

Examples of issues that have been implemented and will need to be explored further:

- Determine the optimum timing and utilize the remaining life concept in pavement preservation. There is an optimum time for each strategy depending on appropriate threshold values and the remaining life of the existing pavement. For example, DBRs should not be used on a project near the end of its performance life.

- Determine the structural integrity of cement treated bases. For example, several attempts were made on the 710 Freeway in the Los Angeles basin to determine the integrity of the base to help determine the most appropriate design strategy using FWD and backcalculation techniques. This proved to be difficult to determine in advance without the use of more costly, destructive test methods.

- Ensure that asphalt concrete as an alternative slab replacement strategy is used as a temporary measure only until a viable rigid pavement strategy can be implemented. The use of asphalt concrete to replace distressed slabs is detrimental to the adjacent slabs because it creates a free edge effect and can cause accelerated deterioration of the adjacent slabs.

- Determine the economic benefits of rigid pavement preservation. One of the major issues for decision makers is quantifying the benefits of preservation as compared to rehabilitation alternatives.

- Use nondestructive test methods to help determine the most appropriate strategies. Nondestructive methods need to be refined for use in pavement preservation. For example, there is a need to determine the support conditions under the slab and detect voids more reliably so that preservation treatments can be applied more successfully.

- Use of RSC in California has become a standard strategy and will continue to be used as such. However, more effort will be needed to address shrinkage.

- The use of precast and prestressed concrete panels will become a standard strategy in urban areas. This technique has been shown to be successful when properly constructed.

- Use a treatment design life of approximately 14 years for most diamond grinding projects is recommended, not the 17-year, statewide average, treatment life.

- Investigate the use of second- and third-generation concrete grinding to mitigate noise, skid resistance, and loss in ride quality.

- Another technique that needs to be investigated further is crack and joint sealing and the proper techniques to achieve the best performance.

- Investigate the use of polyester concrete as a backfill material in DBRs. Laboratory tests have shown a stronger bond with the existing concrete results from the use of polyester concrete.

- Use analytical methods to determine the benefits of pavement preservation to complement actual performance data. This is needed to bridge the existing gap between theory and practice as well as the current lack of adequate performance data.

REFERENCES

1. *Maintenance Technical Advisory Guide, Volume II — Rigid Pavement Preservation, Second Edition.* Caltrans Division of Maintenance—Office of Pavement Preservation, Sacramento CA, 2008.

2. *The Effectiveness of Diamond Grinding Concrete Pavements in California*. Caltrans Materials and Testing Services—Office of Rigid Pavement Materials and Structural Concrete, Sacramento CA, 2005.

3. Rao, Yu, Khazanovich and Darter, *Longevity of Diamond-Ground Concrete Pavements.* TRB, Transportation Research Record No. 1684. Washington, DC, 1999.

4. Scofield, *SR202 PCCP Whisper Grinding Test Sections*. Arizona DOT Construction Report, Phoenix AZ, 2003

5. *Effect of Diamond Grinding on Noise Characteristics of Concrete Pavements*. Caltrans Materials and Testing Services—Office of Rigid Pavement Materials and Structural Concrete, Sacramento CA, 2008.

6. Rasmussen, Barnhard, Sandberg, and Miller, *The Little Book of Quiet Pavements.* FHWA, Washington DC, 2007.

7. *Smoothness Specifications for Concrete Pavements in California*. Caltrans Materials and Testing Services—Office of Rigid Pavement Materials and Structural Concrete, Sacramento CA, 2002.

8. *WSDOT Projects—Photos.* The Washington Department of Transportation—I-5 South 317th Street HOV Direct Access, Tacoma WA, 2005.

9. *Rigid Pavement Preservation on I-10.* Caltrans District 7, Pomona CA, 1999.

10. *Dowel Bar Condition Assessment.* Caltrans Materials and Testing Services—Office of Rigid Pavement Materials and Structural Concrete, Sacramento, CA, 2005.

11. *Slab Replacement Guidelines.* Caltrans Materials and Testing Services—Office of Rigid Pavement Materials and Structural Concrete, Sacramento, CA, 2004.

12. *Full-Depth Repair of Portland Cement Concrete Pavements*. Pavement Preservation Checklist Series, Federal Highway Administration, Washington DC, 2005.

13. *Field Evaluation of the Performance of Rapid Set Concrete Panel Replacements.* Caltrans Materials and Testing Services—Office of Rigid Pavement Materials and Structural Concrete, Sacramento, CA, 2008.

DISCLAIMER