CHAPTER 5 DIAMOND GRINDING AND GROOVING

This chapter describes a treatment technique for restoring desired surface characteristics through diamond grinding and grooving. This chapter includes a discussion of design and specifications, project selection, and construction process. A project checklist and troubleshooting guide are also included in this chapter.

5.1 DESCRIPTION OF TREATMENT

5.1.1 Overview

Diamond grinding is one of the most cost effective concrete pavement restoration (CPR) techniques. It consists of "grinding" 3/16 to 1/4 inch (5 to 7 mm) of the surface of jointed plain concrete pavement (JPCP) using closely spaced diamond saw blades. The result is a level, smooth, and generally quieter riding surface. The closely spaced grooves left after grinding give the riding surface excellent texture and frictional properties.

The same technique and equipment is used for diamond grooving. However, while the purpose of grinding is mainly to restore ride quality and texture, grooving is generally used to reduce hydroplaning and accidents by providing escape channels for surface water. In terms of design, the main difference between grinding and grooving is in the distance between the grooves – about 6 times higher in the case of grooving. Figure 5-1 is a photograph of the pavement surface after grinding while Figure 5-2 shows the pavement surface after grooving.

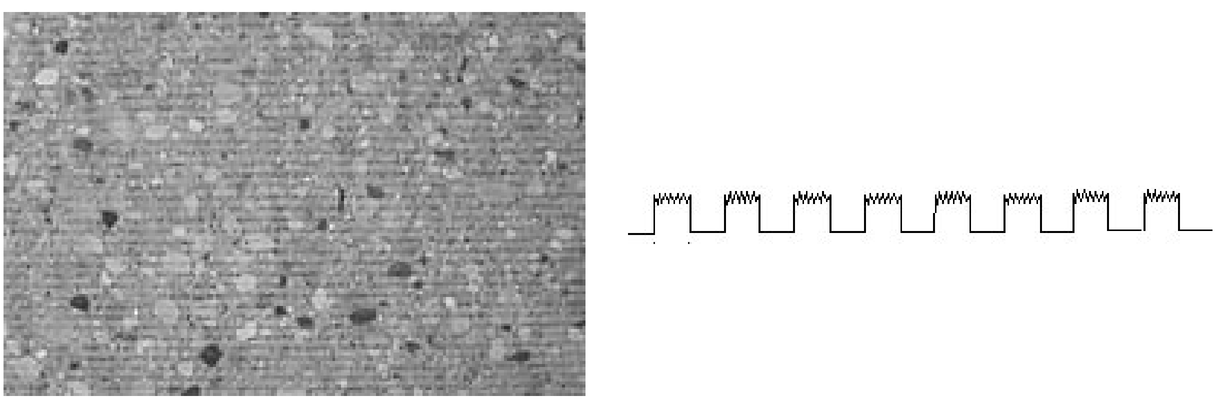

Figure 5-1 Concrete pavement surface after diamond grinding

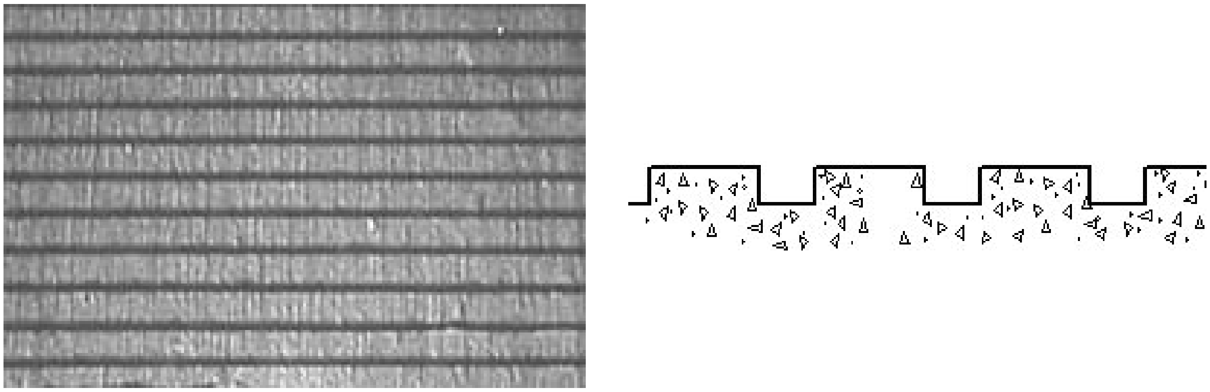

Figure 5-2 Concrete pavement surface after diamond grooving.

5.1.2 Purpose

Diamond Grinding

The most common reason for diamond grinding is to remove roughness caused by excessive faulting of pavement joints. However, if load transfer at the joints and cracks is not restored, faulting will most likely re-occur. Faulting at a joint is illustrated in Figure 5-3. A straightedge is used to measure the difference in elevation between the two adjacent slabs. In such cases diamond grinding can still be used as a short-term solution.

Figure 5-3 Faulting at a joint (FHWA, 2006)

Diamond grinding has also been proven effective in restoring smoothness and skid resistance on existing concrete pavements. On new pavements, it can be used to correct initial roughness due to construction problems and provide a uniform skid resistance and appearance. It is also being studied as a method for reducing noise generated by tire-pavement interaction (see Caltrans website http://www.dot.ca.gov/hq/oppd/pavement/qpavement.htm for the latest information).

It is important to recognize that diamond grinding can only be used to restore some of the functional characteristics of the pavement such as smoothness and skid resistance. If the pavement has structural or material deficiencies, diamond grinding will not repair or improve any of these defects. Diamond grinding should be used with discretion and only when needed, because it also reduces pavement thickness which can affect long-term pavement performance.

Diamond Grooving

Diamond grooving is a surface restoration procedure which can be performed on both PCC and hot-mix asphalt pavements. This procedure involves the use of diamond saw blades with a typical spacing of ¾ inch (19 mm) on centers to cut parallel grooves into the pavement surface. Grooving improves drainage characteristics of a pavement, as well as provides a surface with excellent breaking traction.

Caltrans requires the grooving blades to be 0.095 inch ± 0.005 inch wide, and they shall be spaced ¾ inch on center. The grooves shall be cut not less than ⅛ inch or more than ¼ inch deep (Caltrans, 2006).

Diamond grooving can be performed either transversely or longitudinally. Transverse grooving is not common on highway pavements due to construction difficulties (mainly traffic control), even though this technique provides the most direct drainage channel of water on the pavement. Longitudinal grooving to improve drainage characteristics is not as effective as transverse grooving, but it does provide a channel for water and produces a proper tracking effect on vehicles on horizontal curves, thus reducing skidding crashes.

Diamond grooving should only be applied to pavements with sound structural and functional characteristics. Likewise, grooving should only be applied to pavement sections where wet weather crashes occur, not to an entire project except when the number of accidents throughout the project is significant.

5.1.3 Advantages

Diamond Grinding

When compared to other pavement restoration alternatives, diamond grinding has the following advantages:

- Cost effective – when balancing the cost of the CPR technique with the end result in terms of years of extended pavement life.
- Can be accomplished during off-peak hours with short lane closures and without encroaching into adjacent lanes.
- Pavements may be re-ground up to 2 or 3 times without significantly affecting the structural capacity of the pavement structure.
- Grinding in one lane does not require grinding of the adjacent lane which may have acceptable surface characteristics.
- Eliminates the need for taper which is required with overlay alternatives at highway entrances, exits, and side streets.
- Does not affect overhead clearances underneath bridges or hydraulic capacities of curbs and gutters on municipal streets.

Diamond Grooving

Some benefits of diamond grooving include:

- A cost-effective procedure for restoring surface texture. Diamond grooving provides a significant increase of the pavement's macrotexture.
- A proven procedure to reduce wet weather accidents by providing channels for the water to drain, as well as improving the frictional resistance to braking action through transverse grooves or by tracking vehicles within the grooves around curves on longitudinal grooves.

5.1.4 Limitations

Diamond Grinding

Some of the limitations associated with diamond grinding are:

- Faulting of the pavement joints will most likely reoccur if load transfer is deficient. If load transfer is not restored by other concrete pavement restoration techniques, such as dowel bar (load transfer) retrofit or undersealing, it will continue to cause problems.
- It does not correct any structural problems (e.g., slab cracking) or material problems (e.g., reactive aggregates).
- It reduces pavement thickness which could affect pavement fatigue performance. Grinding of concrete pavements to less than 8- or 9-inches [200-230 mm] in thickness is not advisable, because reduced pavement thickness will not provide sufficient structural capacity and will lead to pavement rupture and cracking under heavy vehicle loadings.

Diamond Grooving

The main disadvantage of longitudinal grooving is the "wiggle" (small lateral movements) that small vehicles and motorcycles may encounter while driven on grooved pavements. This problem can be mitigated by limiting the groove spacing to ¾ inch (20 mm) and using 0.125 in (3 mm) wide grooves (FHWA, 2004).

5.2 DESIGN AND SPECIFICATION

5.2.1 Terminology

The following terminology is used with diamond grinding and grooving:

- Depth – the depth of the saw cut grooves; sometimes also referred to as height.
- Land Area – the distance between consecutive grooves.
- Groove – the width of the saw cut groove or the width of the diamond blade.

The three terms are graphically illustrated in Figure 5-4:

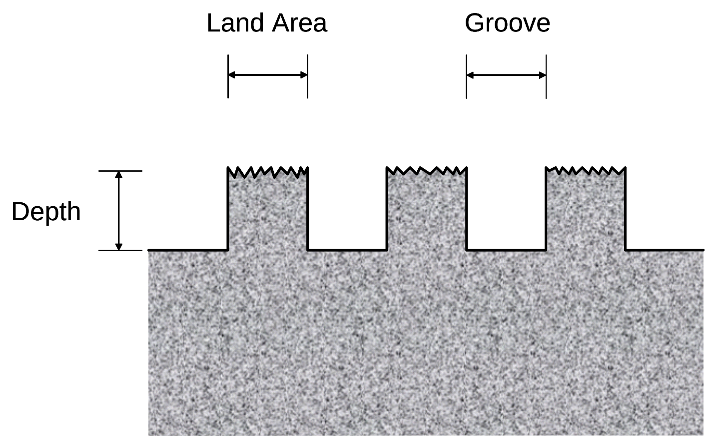

Figure 5-4 Diamond grinding and grooving terminology (FHWA, 2005)

5.2.2 Design Parameters

Diamond Grinding

The three design parameters shown in Figure 5-4 vary over a fairly narrow range of values. The groove is usually 0.10-0.13 inches (2.5-3.5 mm) wide with a depth of 0.05 to 0.2 inches (1.5 to 5 mm). The land area, however, was found to have an effect on the frictional resistance of the pavement. For optimum results, a higher land area or wider blade spacing is recommended for concrete pavements that contain softer aggregate such as limestone. For harder aggregates, a narrower blade spacing produces the best results.

The values recommended by the Federal Highway Administration (FHWA, 2005) and the Foundation for Pavement Preservation (FP^2) for the three design parameters are in general agreement with the values given in Table 5.1, which are typically used in California and described in Caltrans SSP 42-050:

Table 5-1 Typical values for diamond grinding design in California

Parameter	Value
Groove	0.08 – 0.12 inch (2 – 3 mm)
Depth	0.06 – 0.08 inch (1.5 – 2 mm)
Number of Grooves	55 to 60/ft (180 – 200 / m)

The contractor is normally given the option to select the number of blades best suited for the job. Although increasing the spacing between blades may improve the frictional characteristics of concrete pavement surfaces containing softer aggregates, light vehicles and motorcycles may experience vehicle tracking. Tightening blade spacing may reduce this type of effect (FHWA, 2004).

Diamond Grooving

Table 5.2 provides recommended dimensions for diamond grooving. These dimensions have proven to be the most effective for highways (FHWA, 2004).

Table 5-2 Recommended dimensions for diamond grooving design (FHWA, 2004)

Parameter	Value
Groove	0.125 inch (3 mm)
Depth	0.125 – 0.25 inch (3 – 6 mm)
Distance between Grooves (center to center)	0.75 inch (20 mm)

5.2.3 Specifications

The Caltrans specification for diamond grinding is SSP 42-050, “Grind Existing Concrete Pavement” and for diamond grooving is SSP 42-010, “Groove Existing Concrete Pavement”. Section 42 of the

Caltrans Standard Specifications includes descriptions for both grinding and grooving. This document can be downloaded at:

http://www.dot.ca.gov/hq/esc/oe/specifications/std_specs/2006_StdSpecs/2006_StdSpecs.pdf

In summary, the following performance criteria have to be met by the contractor for diamond grinding:

- The ground surface at transverse joints or cracks shall be tested with a 12-foot ± 2½ inch (3.5 m ± 0.06 m) long straightedge laid on the pavement parallel to the centerline with its midpoint at the joint or crack. The surface shall not vary by more than 0.01 feet (3 mm) from the lower edge of the straightedge.
- Cross-slope uniformity and positive drainage shall be maintained across the entire traveled way and shoulder. The cross-slope shall be uniform so that when tested with a 12-foot ± 2½ inch (3.5 m ± 0.06 m) long straightedge placed perpendicular to the centerline, the ground pavement surface shall not vary more than ¼ inch (6 mm) from the lower edge of the straightedge.
- After grinding has been completed, the pavement surface shall be profiled in conformance with the requirements of Section 40-1.10, "Final Finishing," of the Standard Specifications. Two profiles shall be obtained in each lane approximately 3 feet (0.9 m) from the lane lines. The average profile index shall be determined by averaging the two profiles in each lane. Additional grinding shall be performed, where necessary, to bring the ground pavement surface within the Profile Index requirements specified in Section 40-1.10, "Final Finishing," of the Standard Specifications.

Additional information in terms of grinding equipment and operation is provided in SSP 42-050 and should be followed during construction.

5.2.4 Typical Item Codes

Typical Caltrans item codes for a diamond grinding project are given in Table 5-3.

Table 5-3 Typical item codes for a diamond grinding project

Item Code	Description
066145	Remove pavement markers
074017	Prepare water pollution control program
074020	Water pollution control
074042	Temporary concrete washout (portable)
120090	Construction area signs
120100	Traffic control system
128650	Portable changeable message sign
413111	Repair spalled joints
420201	Grind existing concrete pavement
420102	Groove existing concrete pavement
413114	Replace joint seal (existing concrete pavement)

Note: The Standard Special Provisions and the PS&E Guide must be followed for specific item codes proposed for the project.

Caltrans Standard Materials and Supplemental Work Item Codes can be found at the following web site:

http://i80.dot.ca.gov/hq/esc/oe/awards/#item_code

5.3 PROJECT SELECTION

Diamond Grinding

In the decision process, and depending on the pavement restoration problem to be addressed, the major questions to be answered are:

- Is diamond grinding going to solve the underlying problem?
- Is the pavement a good candidate for diamond grinding (i.e., no structural deficiencies)?
- What is the expected remaining service life of the pavement after diamond grinding?

Guidelines to help the designer find the answer to each of the above questions are provided in the following sections.

Diamond Grooving

Diamond grooving is typically applied to localized areas instead of an entire project length. Information on wet weather crashes, as well as surface friction data for the section to be restored, is needed to evaluate whether diamond grooving is the right treatment to be applied.

5.3.1 Applications

Question: Is diamond grinding a solution to the specific pavement deterioration problem you are looking to address?

Answer: Diamond grinding is known to improve the functional properties of jointed plain concrete pavements in many ways:

- Improves skid resistance and reduces the risk of hydroplaning (safety).
- Corrects wheelpath rutting caused by chain wear in cold climatic regions.
- Corrects faulting at joints and cracks if there are no voids at the joints.
- Corrects permanent slab warping at the joints.
- Corrects built-in construction or rehabilitation roughness.
- Improves drainage by correcting transverse slope.
- Reduces noise from tire-pavement interaction.

Faulting at Joints and Cracks

Excessive faulting of transverse joints and cracks is the most common reason for grinding jointed plain concrete pavements (JPCP). In general, several “ingredients” are necessary for faulting to occur: heavy traffic loads: Insufficient load transfer between adjacent slabs, free moisture in the pavement structure, and an erodible base or subgrade material. Under the action of traffic, moisture is ejected from beneath the leave slab, carrying fines from the base or subgrade material and eventually resulting in a void. The fines are usually deposited under the approach slab causing it to lift slightly. This mechanism of distress is illustrated in Figure 5-5 and was discussed in detail in Section 1.2.3.

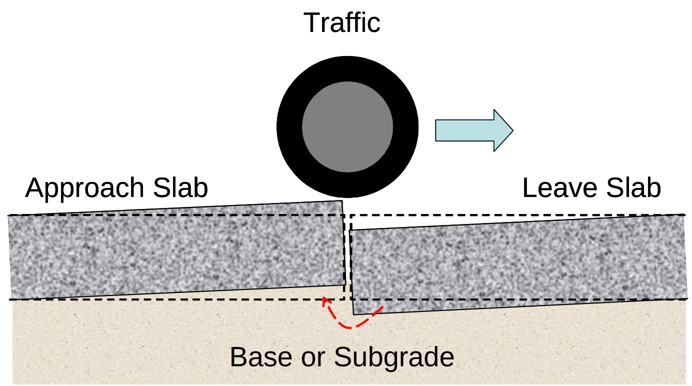

Figure 5-5 Faulting mechanism

Road users first notice faulting when the average difference in elevation between adjacent slabs (faulting) reaches about 0.1 inch (2.5 mm). This is where grinding for faulting is most likely justified and successful. In general, diamond grinding should be done before faulting reaches 0.16 inches (4 mm) or more. If the average faulting is greater than 1/2 inch (13 mm), depending on traffic level, the pavement may be beyond the window of opportunity for a successful diamond grinding project.

Slab Warping at Joints

In dry climates, slabs can become permanently warped at the joints. Long joint spacings and stiff base support may result in curled slabs that are higher at the joints than at mid-panel, resulting in a bumpy, rough ride. If there are no structural deficiencies, diamond grinding can be used to restore smoothness and level off the surface of warped slabs. In such cases, warping is not likely to re-occur.

Spot Grinding

If the surface of a newly constructed JPCP pavement does not meet smoothness specifications, diamond grinding can be used to eliminate construction induced (“built-in”) roughness. Depending on the specification requirements and cost-effectiveness, either full lane or spot grinding can be performed.

Work associated with partial- and full-depth slab repairs may also result in increased roughness, typically because of differences in elevation between the repair areas and the existing pavement. Diamond grinding can be used to blend repair areas with the original surface and restore ride quality. For widening projects, grinding of adjacent lanes may also be required.

Skid Resistance and Hydroplaning

Frictional characteristics of polished surfaces can be restored by diamond grinding. Increasing the macrotexture of the concrete surface the skid resistance is improved. In addition, diamond grinding provides directional stability by tire tread pavement-groove interlock.

The potential for hydroplaning is also reduced by grinding; for example the grooves in the pavement provide room for the water on the pavement.

Tire-Pavement Interface Noise

Tire-pavement noise is generally directly correlated with overall longitudinal roughness. Diamond grinding retextures worn and tined surfaces with a longitudinal texture, reduces roughness, and usually provides a quieter ride. For the latest information on quieter pavements, please see Caltrans website:

http://www.dot.ca.gov/hq/oppd/pavement/qpavement.htm

Restoring Transverse Slope

Diamond grinding can be used to restore the pavement cross-slope. For example, in areas where studded tires or tire chains are used, the surface of the pavement can be worn and need repair. This form of rutting increases the amount of water trapped in the wheelpaths during rainy weather, thereby creating hazardous conditions that involve decreased visibility due to spray and a greater possibility of hydroplaning. Diamond grinding can be used to remove wheel path ruts and reduce the possibility of hydroplaning.

5.3.2 Project Evaluation

Question: Is the pavement a good candidate for diamond grinding?

Answer: Yes, if there is a need to restore ride quality and skid resistance and the pavement has not deteriorated so much that it is no longer cost effective to grind. However—if the existing pavement is structurally deficient, or suffers from durability problems such as alkali-aggregate reactivity, an overlay or reconstruction may be more appropriate.

Symptoms of Structural/Materials Deficiencies

- Severe drainage or erosion problems, as indicated by significant faulting (greater than ½ inch [13 mm]) or pumping, should be corrected prior to grinding.
- Significant slab replacement (10% of the lane) and repair may be indicative of continuing progressive structural deterioration that grinding would not repair.
- The presence of progressive transverse slab cracking and corner breaks indicates a structural deficiency in the pavement. Slab cracking, and the faulting of these cracks, will continue after grinding if load transfer is not restored prior to grinding.
- Rigid pavements suffering from durability problems, such as alkali-aggregate reactivity, should not be rehabilitated through grinding.
- Joints and transverse cracks with a deflection load transfer (usually measured with a Falling Weight Deflectometer) of less than 60 percent should be corrected in order to restore load transfer prior to diamond grinding.

Diamond grinding may still be used as a short-term solution to improve roughness and friction on a structurally deficient pavement until a more comprehensive repair or reconstruction of the pavement can be undertaken.

Window of Opportunity

Diamond grinding is a cost effective treatment when applied at the "right time, on the right project." If the treatment is applied too early or too late in the life of a project, its benefits may be diminished or the cost of the treatment may be unnecessarily high. The "window of opportunity" refers to the period of time during which diamond grinding will produce the expected benefits (significantly extending service life) at a competitive cost.

To better define the “window of opportunity,” triggers and limits are specified, usually in terms of faulting, roughness (IRI), skid resistance, or joint load transfer. Trigger values indicate when a highway agency should consider diamond grinding to restore ride quality. Limiting values for diamond grinding define the point when the pavement has deteriorated so much that it is no longer cost effective to grind.

Tables 5-4 and 5-5 provide trigger and limit values for diamond grinding recommended by FHWA (2006) for different types of pavements and traffic volumes. Caltrans is currently in the process of developing these values for pavement preservation.

Table 5-4 Trigger values for diamond grinding (FHWA, 2006)

	JPCP			CRCP		
Traffic Volumes*	**High**	**Med**	**Low**	**High**	**Med**	**Low**
Faulting, inches – avg. (mm – avg.)	0.08 (2.0)	0.08 (2.0)	0.08 (2.0)	N.A.		
Skid Resistance	Minimum Local Acceptable Levels					
PSR (not used in CA)	3.8	3.6	3.4	3.8	3.6	3.4
IRI in/mi (m/km)	63 (1.0)	76 (1.2)	90 (1.4)	63 (1.0)	76 (1.2)	90 (1.4)

*Volumes: High ADT>10,000; Med 3000<ADT<10,000; Low ADT <3,000

Table 5-5 Limit values for diamond grinding (FHWA, 2006)

	JPCP			CRCP		
Traffic Volumes*	**High**	**Med**	**Low**	**High**	**Med**	**Low**
Faulting, inches – avg. (mm – avg.)	0.35 (9.0)	0.5 (12.0)	0.6 (15.0)	N.A.		
Skid Resistance	Minimum Local Acceptable Levels					
PSR (not used in CA)	3.0	2.5	2.0	3.0	2.5	2.0
IRI in/mi (m/km)	160 (2.5)	190 (3.0)	222 (3.5)	160 (2.5)	190 (3.0)	220 (3.5)

*Volumes: High ADT>10,000; Med 3000<ADT<10,000; Low ADT <3,000

The general guidelines historically used for grinding include:

- The pavement needs a smoother ride for the traveling public (the Highway Design Manual uses an IRI of 160 in/mile [2.5 m/km]as threshold; CAPM starts at IRI of 150 in/mi [2.4 m/km]);
- Faulting is 0.1 inch (2.5 mm) or greater;
- Rutting is 0.1 inch (2.5 mm) or greater;
- Friction coefficient is less than 0.30;
- Projects with >10% slab replacement may not be cost effective;

- Joints with poor load transfer should be dowel bar retrofitted (this option results in a lower life cycle cost than other effective alternatives).

Other project specific factors, such as the hardness of the aggregate, may have a direct impact on the cost of grinding. Grinding a pavement with extremely hard aggregate (such as trap rock or river gravel) takes more time and effort than grinding a pavement with a softer aggregate (such as limestone, although not typically used in California).

In summary, the selection of a good candidate project for diamond grinding and concrete pavement restoration (CPR) in general involves both engineering and economics. The functional and structural condition of the pavement, the cost, and the timing of the treatment are all important factors to be weighed in the decision process.

5.3.3 Expected Lives of Treatments

Question: How many years of service life extension can be gained from diamond grinding?

Answer: Nationwide, the average life extension achieved through diamond grinding is estimated at about 14 years. In California, the numbers are even better, with an average of 16-17 years (Caltrans, 2005). However, note that the condition and age of the existing pavement can significantly affect the expected lifespan of a diamond grinding project.

A Caltrans-sponsored research study intended to better quantify the expected longevity or "survival" of diamond ground PCC pavements and the overall effectiveness under California conditions and construction practices was completed in 2005 (Caltrans 2005). The study found that nationwide, the average (50% reliability) longevity of a diamond ground project is around 14 years, or about 11 years at an 80% certainty (reliability) level.

Data were obtained from several statewide diamond grinding projects. Based on these data, a plot of the average expected increase in roughness with time was developed and is reproduced in Figure 5-6. The increase in IRI as a ratio of the initial IRI is used as a measure of pavement deterioration after grinding. A ratio of 1.78 is used as the trigger for rehabilitation. On the same plot, curves corresponding to the 70%, 80% and 90% reliability levels are shown.

As illustrated in Figure 5-6, the average life of the diamond grinding in California (i.e. a 50% reliability prediction) is 16.8 years, at an average IRI ratio of 1.78. At 80% reliability, the extension in service life is about 14 years. This study concludes that these results are quite reasonable, since the climatic conditions in California are comparatively favorable for longer-lasting rigid pavement performance.

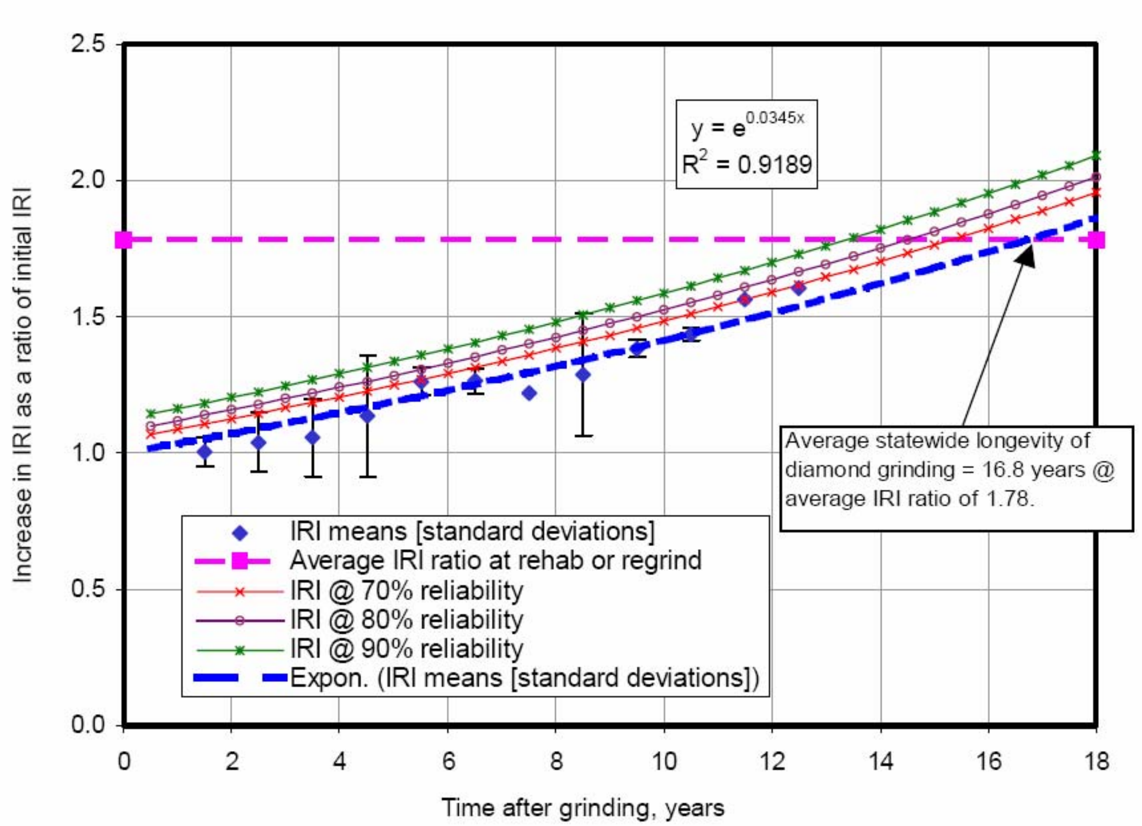

Figure 5-6 Reliability levels for the expected survivability of California diamond ground pavements (Caltrans, 2005)

Although the thickness of PCC slabs is reduced through grinding, a recent study shows that due to the increase in the strength of the concrete with time, the reduction in stiffness associated with the reduced thickness may not significantly affect the fatigue life of the pavement (Rao et. al 1999). In most cases, concrete pavements can be re-ground up to 3 times. However, caution must be made to avoid grinding the pavement too thin or when structural deficiencies occur.

5.4 CONSTRUCTION PROCESS

The construction process involves traffic control, the grinding or grooving process, and quality control & assurance of the finished pavement surface. Each of these aspects is discussed in this section of the guide. In addition, a description of diamond grinding and grooving equipment, strategies to insure productivity, and guidelines for the correct sequence of work when performing diamond grinding and grooving—in parallel with other CPR techniques—are provided.

5.4.1 Traffic Control and Safety

Typically, grinding and grooving are conducted on multi-lane facilities using a mobile single-lane closure, allowing traffic to be carried on the adjacent lanes. With proper work sequencing, the contractor can perform grinding and other CPR techniques while maintaining traffic on adjacent lanes and enabling the pavement to be fully opened to traffic during peak hours. When setting up traffic control, the following aspects should be considered (FHWA, 2005):

- Verify that signs and devices match the traffic control plan presented in the contract documents.
- Verify that the setup complies with the Federal Manual on Uniform Traffic Control.
- Insure that local agency traffic control procedures and use of devices are followed.
- Verify that the repaired pavement is not opened to traffic until all equipment and personnel have been removed from the work zone.
- Verify that signs are removed or covered when they are no longer needed.
- Verify that any unsafe conditions are reported to a supervisor (contractor or agency).

Depending on project location, size, and amount of work, one of the following types of traffic control alternatives may be considered:

- Complete roadbed closure
- Continuous lane closure
- Weekend closure
- Nighttime closure

A more detailed description on traffic control is provided in Section 1.5.4.

5.4.2 Equipment

A schematic of the grinding machine is presented in Figure 5-7. Actual grinding is done through the dual action of the grinding head: Rotation and pressure against the pavement surface. A front view of a typical grinding machine is shown in Figure 5-8. In Figure 5-9, the same machine is shown during grinding. The grinding head consists of closely spaced diamond blades. Typical blades are shown in Figure 5-10. In Figure 5-11 the cutting head (or grinding head) is shown with the diamond blades mounted. The cutting head typically has a width of 4 feet.

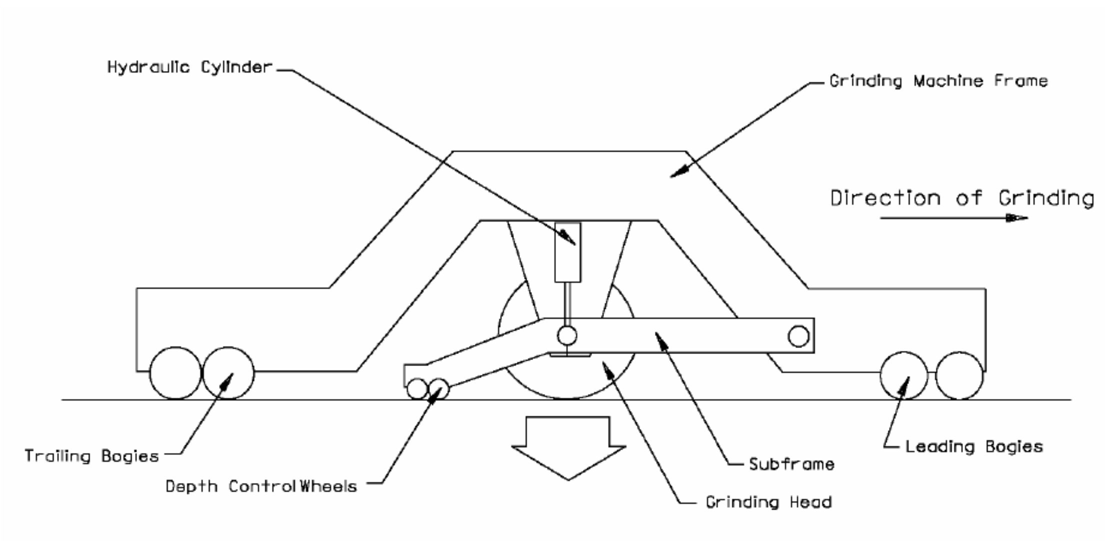

Figure 5-7 Schematic of grinding machine (MnDOT, 2005)

Figure 5-8 Typical grinding machine, front view (Courtesy of Caltrans)

Figure 5-9 Grinding process (Courtesy of Caltrans)

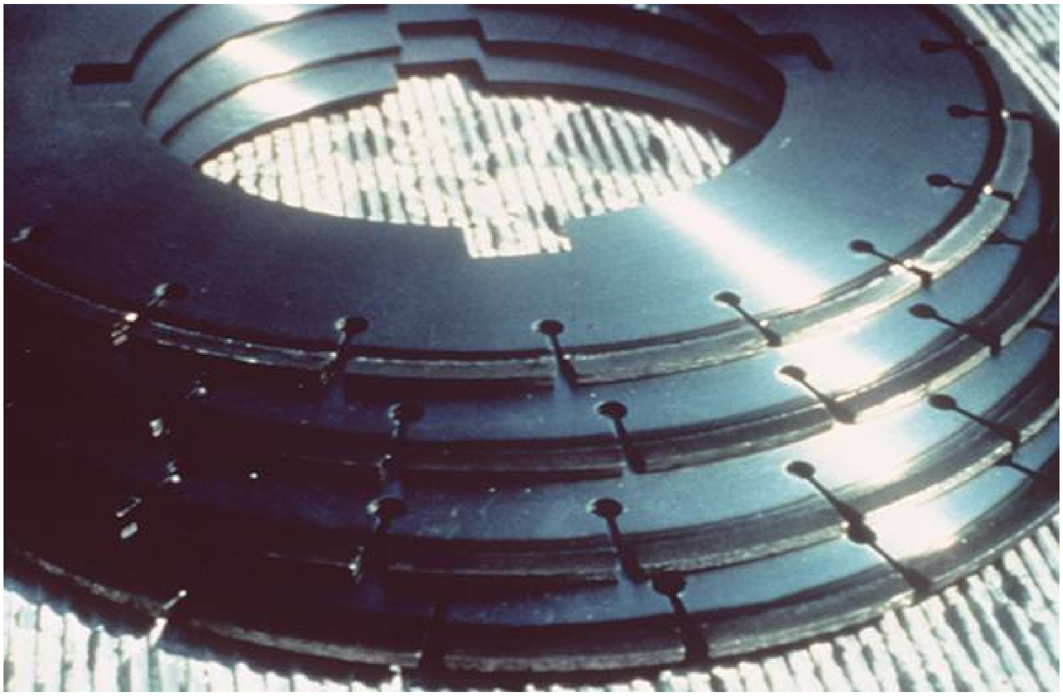

Figure 5-10 Diamond blades (Courtesy of Caltrans)

Figure 5-11 Typical cutting head (Courtesy of Caltrans)

In general, three or four passes of one or more grinding machines are necessary to cover the entire width of a lane. The desired texture is produced using a spacing of 50 to 60 blades per foot (165 to 200 blades per meter). The texture of the pavement surface after diamond grinding is shown in Figures 5-12 and 5-13.

Figure 5-12 Pavement surface after diamond grinding (Courtesy of IGGA)

Figure 5-13 Pavement surface texture behind grinding head (Courtesy of Caltrans)

5.4.3 Productivity

According to the American Concrete Pavement Association (ACPA), the ride and frictional qualities of the finished surface are not significantly affected by the direction of grinding (ACPA, 2000). However for best results, grinding should be started and ended perpendicular to the pavement centerline and maintained parallel to the centerline between the starting and ending points. To the extent possible, grinding should be performed continuously along a traffic lane for the entire lane width, including lane lines.

The width of the cutting head is generally about 4 feet (1.2 m). To grind the entire width of one lane, more than a single pass of the grinding equipment will be required. It is recommended that the overlap between adjacent passes be no more than 2 inches (50 mm). To increase productivity and minimize traffic closures on large projects, several machines are usually used together to allow an entire lane width to be covered in one pass.

Grinding equipment should have a long reference beam so the existing pavement can be used as a reference. By blending the highs and lows, excellent riding quality can be obtained with a minimum depth of removal. Generally, it is required that a minimum of 95 percent of the area within any 3 ft by 100 ft (1 m by 30 m) test area be textured by the grinding operation.

Immediately after grinding, thin fins remaining from the area between saw blades generally remain on the finished surface. These fins should break free easily with one or two passes of a roller or under normal traffic. If this doesn’t happen, the grinding head may be excessively worn or the blade spacing may need to be reduced.

5.4.4 Slurry Removal

Disposal of portland cement concrete pavement grooving or grinding residue shall be in conformance with the provisions in Section 42, "Groove and Grind Pavement," of the Caltrans Standard Specifications and the special provisions. The Contractor shall include water pollution control measures to address the handling of the grinding pavement residue within the Storm Water Pollution Prevention Plan or Water Pollution Control Program, as specified in "Water Pollution Control" of the special provisions (SSP 42-600).

5.4.5 Sequencing Work

Diamond grinding is usually performed in conjunction with other repairs. The sequence in which the repairs are performed is very important. Typically, slab repairs (full or partial depth) and load transfer restoration are performed first. If edge drains are in need of retrofit, they should precede slab repairs. Diamond grinding should be performed after spall repairs and slab replacements to ensure uniform smoothness and frictional properties of the existing and repaired pavement. The only component of the pavement that may be affected by grinding is the sealing of joints and cracks. For this reason, crack and joint sealing should be performed after grinding is completed. A schematic of the sequence of CPR techniques, as recommended by the FHWA and FP^2 is presented in Figure 5-14 (FHWA, 2005).

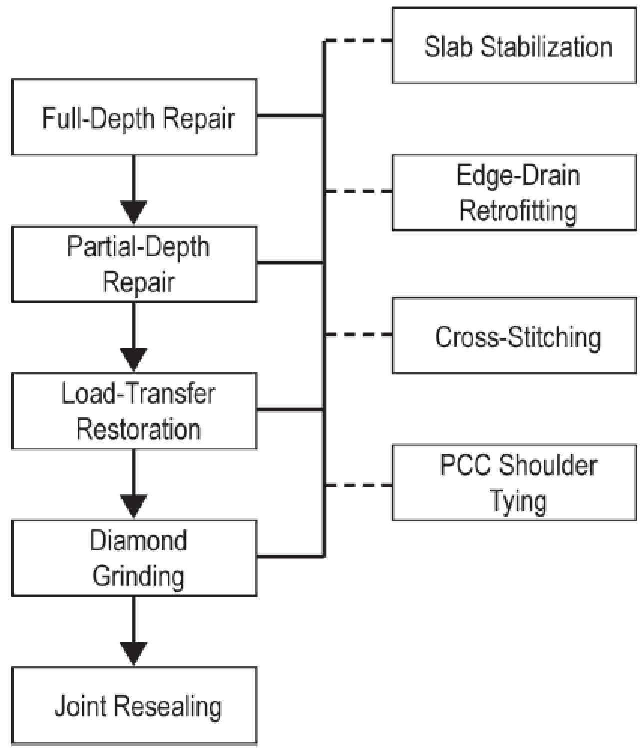

Figure 5-14 Sequence of repairs in the concrete pavement restoration process (FHWA, 2005)

5.4.6 Job Review - Quality Issues

The quality of diamond grinding is called acceptance testing, which is usually assessed through measurements of roughness and/or skid resistance after grinding is completed.

Roughness

The terms roughness, smoothness and ride quality are used interchangeably to describe how the pavement compares to an ideal pavement with a perfectly smooth surface. The most commonly used profile measuring device for grinding operations is the California profilograph, which is used by Caltrans, but several other different devices are available and may be used. It is common to make profile measurements before and after grinding to better quantify the benefit of grinding. The equipment used in acceptance testing should be the same as that used in the initial evaluation and should be specified along with procedures to be followed in acceptance testing as described in Section 5.2.3.

Skid Resistance

Pavement skid resistance can also be used to asses the quality of diamond grinding. Skid resistance values obtained after diamond grinding can be compared to values obtained prior to grinding to document improvements.

Nationally, skid resistance is generally measured using either a standard ribbed tire (ASTM E 501) or a standard smooth tire (ASTM E 524). Caltrans measures surface skid resistance with the California portable skid tester following California Test Method 342 (5). Note that pavements with harder aggregates such as granite will maintain adequate surface friction longer than pavements with softer aggregates.

Slurry Disposal

Disposal of residues from the grinding or grooving operation should be in conformance with the provisions described in Section 42, "Groove and Grind Pavement," of the Caltrans Standard Specifications and Standard Special Provisions 42-600. Water pollution control measures or a water pollution program should be developed to address the handling and disposal of grinding residue.

5.5 PROJECT CHECKLIST AND TROUBLESHOOTING GUIDE

The project checklist and the troubleshooting guide, included in this section, provide important information which can help solve difficulties and improve performance in diamond grinding and grooving repairs. The project checklist describes important aspects of a grinding project, such as preliminary responsibilities, material and equipment requirements, project inspection responsibilities, and cleanup responsibilities, all of which should be considered in order to promote a successful project. The troubleshooting guide describes common problems encountered during the project and their solutions.

5.5.1 Project Checklist

The following checklist was primarily based on guidelines from the FHWA Pavement Preservation Checklist Series (http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=351) and the FHWA/NHI Course: Pavement Preservation Design and Construction of Quality Preventive Maintenance Treatments.

Preliminary Responsibilities	
Document Review	✓ Bid/project specifications and drawings ✓ Special provisions ✓ Agency requirements ✓ Regulatory agency requirements/permits ✓ Traffic control plan ✓ Equipment specifications ✓ Material safety data sheets (if required for concrete slurry)
Project Review	✓ Verify that pavement conditions have not significantly changed since the project was designed. ✓ Joints and transverse cracks sustaining severe faulting (equal to or greater than ½ in. [13 mm]) or displaying evidence of pumping (e.g., surface staining or isolated wetness) are potential candidates for load transfer restoration with dowels prior to diamond grinding. ✓ Verify that structural repairs are completed in the proper sequence (Figure 5-14).
Equipment Inspections	
Diamond-Grinding Machine	✓ Verify that the diamond-grinding machine meets requirements of the contract documents for weight, horsepower, and configuration. ✓ Verify that the blade spacing on the diamond grinding cutting head meets requirements of the contract documents. ✓ Verify that the vacuum assembly is in good working order and capable of removing concrete slurry from the pavement surface.
Profilograph or Profiler	✓ Verify that the profilograph or pavement profiler meets requirements of the contract documents.

	✓ Verify that the unit has been calibrated in accordance with manufacturer's recommendations and contract documents. ✓ Verify that the profilograph operator meets requirements of the contract documents for training/certification.
Others	
Weather Requirements	➢ Air and/or surface temperature should meet minimum agency requirements (typically 35 °F [2 °C] and rising) for diamond-grinding operations in accordance with contract documents. ➢ Diamond grinding shall not proceed if icy weather conditions are imminent.
Traffic Control	✓ Verify that signs and devices match the traffic control plan presented in the contract documents. ✓ Verify that the setup complies with the Manual on Uniform Traffic Control Devices (MUTCD) and the California Supplement to the MUTCD. ✓ Verify that the repaired pavement is not opened to traffic until all equipment and personnel have been removed from the work zone. ✓ Verify that signs are removed or covered when they are no longer needed. ✓ Verify that any unsafe conditions are reported to a supervisor (contractor or agency).
Project Inspection Responsibilities	
Alignment	✓ Verify that diamond grinding proceeds in a direction parallel with the pavement centerline, beginning and ending at lines normal to the pavement centerline. ✓ Verify that the transverse slope of the ground surface is uniform to the extent that no misalignments or depressions that are capable of ponding water exist. Project documents typically have specific measurable criteria for transverse slope that must be met.
Texture	✓ Verify that diamond-grinding results in a corduroy texture extending across the full lane width and complying with contract documents. ✓ Verify that texturing cut into the existing pavement surface is in accordance with texturing requirements presented in the contract documents. ➢ Verify that each application of the diamond ground texture overlaps the previous application by no more than the amount designated in the contract documents, typically 2 in (50 mm). ➢ Verify that each application of the diamond ground texture does not exceed the depth of the previous application by more than the amount permitted in the contract documents, typically ¼ in (6 mm). ✓ Verify on a daily basis that diamond-ground texture meets smoothness specifications.
Residues	✓ Verify that concrete slurry is adequately vacuumed from the pavement surface and is not allowed to flow into adjacent traffic lanes. ✓ Verify that the grinding residue is handled in conformation with Caltrans SSP 42-600 and not discharged into any area forbidden by the contract documents or engineer. Concrete slurry from the grinding operation is typically collected and discharged at a disposal area designated in the contract document.

5.5.2 Troubleshooting Guide

The following guide summarizes some of the common problems encountered during the grinding or grooving process. It also includes typical causes of these problems and possible solutions.

Problem	Causes and solutions
"Dogtails" (pavement areas that are not ground due to a lack of horizontal overlap).	Causes: • These are primarily caused by weaving during the grinding operation (IGGA/ACPA, 2001). Solution: • Maintaining the required horizontal overlap (typically 2 in [50 mm] maximum) between passes and steady steering by the operator will avoid the occurrence of dogtails.
"Holidays" (areas that are not ground).	Cause: • Isolated low spots in the pavement surface. Solution: • Lower the grinding head and complete another pass. Typical specifications require 95 percent coverage for grinding texture and allows for 5 percent un-ground isolated areas.
Poor vertical match between passes.	Cause: • Inconsistent downward pressure. This is often obtained when unnecessary adjustments to the down-pressure are made. Solution: • A constant down-pressure should be maintained between passes to maintain a similar cut depth. A less than 0.12 in per 10 ft (3 mm per 3 m) vertical overlap requirement is often required (IGGA/ACPA, 2001).
Too much or too little material removed near joints.	Causes: • Expansion joints or other wide gaps in the pavement can cause the cutting head to dip if the leading wheels drop into the opening. • Slabs deflecting from the weight of the grinding equipment can cause insufficient material to be removed. Solutions: • Wide gaps can be temporarily grouted to provide a smooth surface. • If slabs deflect from the weight of the grinding equipment, lowering the grinding head may help, but stabilizing the slab or retrofitting dowel bars may be a better alternative (IGGA/ACPA, 2001).
The fins that remain after grinding do not quickly break free.	Cause: • This could be an indication of excessive wear on the grinding head, but most likely it is the result of incorrect blade spacing. Solution: • The grinding head should be checked for wear before or after each day of operation. If the cutting blades are not worn, the blade spacing should be reduced.

Problem	Causes and solutions
Large amounts of slurry on the pavement during grinding.	Cause: • Most likely this indicates a problem with the vacuum unit or skirt surrounding the cutting head. Solution: • If large amounts of slurry are left on the pavement, or slurry flows into adjacent traffic lanes or drainage structures, the surface grinding operations should be stopped. Inspect the equipment and make necessary repairs.
Lack of horizontal overlap.	Cause: • As with grinding operations, this is primarily caused by weaving during the grooving operation. Solution: • Lack of horizontal overlap or weaving during grooving operations may cause lighter vehicles and motorcycles to experience increased vehicle tracking. Maintaining the required horizontal overlap between passes and steady steering by the operator will avoid the occurrence of this problem.
Isolated areas with inconsistent groove depth.	Cause: • Isolated low spots in the pavement surface. Solution: • Although the effects of variable depth grooves are less readily apparent to traffic (no dip in the pavement surface is created), a uniform depth is desirable to ensure the intended drainage characteristics. The grooving head may need to be lowered in areas known to contain isolated low spots.
Inconsistent groove depth near joints.	Causes: • Expansion joints or other wide gaps in the pavement can cause the cutting head to dip if the leading wheels drop into the opening. • Slabs deflecting from the weight of the grooving equipment can cause insufficient material to be removed. Solutions: • Wide gaps can be temporarily grouted to provide a smooth surface. • If slabs deflect from the weight of the grooving equipment, lowering the grooving head may help, but stabilizing the slab or retrofitting dowel bars may be a better alternative.
Large amounts of slurry on the pavement during grooving.	Cause: • This indicates a problem with the vacuum unit or skirt surrounding the cutting head. Solution: • If large amounts of slurry are left on the pavement, or slurry flows into adjacent traffic lanes or drainage structures, the surface grooving operations should be stopped. Inspect the equipment and make necessary repairs.
Light vehicles and motorcycles experience vehicle tracking:	Cause: • Interaction between tire and pavement surface. Solution: • Reduce the spacing between the blades.

5.6 KEY REFERENCES

American Concrete Pavement Association, 1994. *Slab Stabilization Guidelines for Concrete Pavements*, Skokie, IL, 1994.

American Concrete Pavement Association and International Grooving and Grinding Association, 2000. *Diamond Grinding and Concrete Pavement Restoration*, Concrete Pavement Technology, 2000.

American Concrete Pavement Association, 2006. http://www.pavement.com/PavTech/Tech/Fundamentals, 2006.

Caltrans, 2005. *The Effectiveness of Diamond Grinding Pavements in California*, Sacramento, California, May 2005.

Caltrans, 2006. *Standard Specifications*, Publication Distribution Unit, Sacramento, California, May 2006.

Federal Highway Administration, 2004. *Pavement preservation design and construction of quality preventive maintenance treatments*, National Highway Institute Course 131103, November 2004.

Federal Highway Administration and the Foundation for Pavement Preservation, 2005. *Pavement Preservation Checklist Series, No 7, Diamond Grinding of Portland Cement Concrete Pavements*, Publication No. FHWA-IF-03-040, August 2005.

Federal Highway Administration, 2006. *Concrete Pavement Rehabilitation Guide for Diamond Grinding*, http://www.fhwa.dot.gov/pavement/concrete/diamond.cfm, 2006.

Minnesota Department of Transportation (MnDOT), 2005. *State Aid Concrete Pavement Rehabilitation (CPR) Best Practices Manual*, Report No. MN/RC – 2005-33, Research Services Section, St. Paul, Minnesota 55155, September 2005.

Rao, Shreenath et al, 1999. *Longevity of Diamond-Ground Concrete Pavements*, Transportation Research Record No. 1684, Transportation Research Board, Washington, D.C., 1999.

Stahl, Kirsten, 2006. *PCC Pavement Preservation and Maintenance*, Presentation at the Southern California Pavement Preservation Conference, Diamond Bar, California, May 2006.