DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

14 AUG 2007

FROM: HQ AFCESA/CEOA
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SUBJECT: **Engineering Technical Letter (ETL) 07-6: Risk Assessment Procedure for Recycling Portland Cement Concrete (PCC) Suffering from Alkali-Silica Reaction (ASR) in Airfield Pavement Structures**

1. Purpose. This ETL provides guidance on evaluating the risk of recycling PCC affected by ASR (ASR PCC) and using this recycled material as base, subbase, fill, or drainage material within an airfield pavement structure, or using crack and seat or rubblization techniques with airfield concrete pavements suffering from ASR.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this ETL does not imply endorsement by the Air Force.

2. Application. The guidance in this ETL is optional.

2.1. Authority: Air Force policy directive (AFPD) 32-10, *Air Force Installations and Facilities*, and Air Force instruction (AFI) 32-1023, *Design and Construction Standards and Execution of Facility Construction Projects*.

2.2. Coordination: Major command (MAJCOM) pavement engineers.

2.3. Effective Date: Immediately.

2.4. Intended Users:

- Air Force MAJCOM pavement engineers
- Base civil engineers (BCE), RED HORSE, and other units responsible for design, construction, maintenance, and repair of airfield pavements
- United States Army Corps of Engineers (USACE) and Navy offices responsible for Air Force design and construction
- All designers and construction contractors building United States Air Force (USAF) airfield pavements.

3. Referenced Publications:

3.1. Air Force:

- AFI 32-1023, *Design and Construction Standards and Execution of Facility Construction Projects*, available at http://www.e-publishing.af.mil/pubfiles/

- AFI 90-901, *Operational Risk Management*, available at http://www.e-publishing.af.mil/pubfiles/
- AFPAM 90-902, *Operational Risk Management (ORM), Guidelines and Tools*, available at: http://www.e-publishing.af.mil/afpam90-902.pdf
- AFPD 32-10, *Air Force Installations and Facilities*, available at http://www.e-publishing.af.mil/pubfiles/af/32/afpd32-10/afpd32-10.pdf
- ETL 06-2, *Alkali-Aggregate Reaction in Portland Cement Concrete (PCC) Airfield Pavements*, available at http://www.afcesa.af.mil/ETL2006-2.pdf

3.2. American Society for Testing and Materials:

- ASTM C 1260-05a, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*, available at http://www.astm.org/

3.3. Innovative Pavement Research Foundation:

- IPRF 03-5, *Evaluation, Design and Construction Techniques for the Use of Airfield Concrete Pavement as Recycled Material for Subbase*, available at http://www.iprf.org/products/main.html

4. Acronyms and Terms:

AC	- asphalt concrete
AFB	- Air Force Base
AFI	- Air Force instruction
AFPD	- Air Force policy directive
AFPAM	- Air Force pamphlet
ASR	- alkali-silica reaction
ASR PCC	- PCC that is undergoing an alkali-silica reaction
ASTM	- American Society for Testing and Materials
BCE	- base civil engineer
DOD	- Department of Defense
ETL	- Engineering Technical Letter
FOD	- foreign object damage
GM	- silty gravel
GW	- clean gravel
MAJCOM	- major command
ORM	- operational risk management
PCC	- portland cement concrete
PCI	- Pavement Condition Index
POV	- privately owned vehicle
RED HORSE	- Rapid Engineers Deployable-Heavy Operations Repair Squadron
SM	- silty sand
USACE	- U.S. Army Corps of Engineers

USAF - United States Air Force

5. Objective. This ETL provides guidance and a framework for assessing the risk of incorporating recycled ASR PCC into an airfield pavement structure. Incorporating such reacting recycled material into the pavement structure can significantly reduce construction costs for new or reconstructed pavements. Use of fracture technology (e.g., crack and seat, rubblization) is becoming more common and popular for pavement rehabilitation. Several projects have used ASR-reacting concrete without any problems noted to date (i.e., differential swelling, pavement roughness, or strength loss attributable to ongoing ASR in recycled PCC). However, documentation of initial conditions, detailed study of the materials in question, and lack of long-term performance data make these results difficult to project to other locations and materials. IPRF Report 03-5, *Evaluation, Design and Construction Techniques for the Use of Airfield Concrete Pavement as Recycled Material for Subbase*, cautions engineers dealing with aggressive ASR in airfields to conduct a detailed benefit/risk analysis when evaluating project options. This ETL provides a basis for balancing the risks and benefits of recycling such material for a specific project for engineers wishing to apply a systematic approach to the decision-making process rather than proceeding solely on the basis of the lack of documented problems elsewhere.

6. Cautions. This ETL provides interim guidance and reflects consensus opinions on the best practices to assess the risk of including ASR PCC in USAF airfield pavements. This field of knowledge is evolving, and new data or research may eventually provide a better quantitative basis on which to assess the risk of airfield pavement construction with these materials. This ETL provides only a qualitative assessment of risk for recycling ASR PCC in base, subbase, fill, or drainage layers of an airfield pavement, or using crack and seat or rubblization techniques to convert the in-situ pavement into a base course to be overlaid with asphalt concrete (AC). It does not cover recycling ASR PCC as aggregate in a new PCC or AC, nor does it address alkali-carbonate reaction, a rarer alkali-aggregate phenomenon that has yet to be observed in any USAF pavements. If either of these recycling concepts is proposed, contact HQ AFCESA for guidance. Recycling PCC that is not undergoing ASR into the airfield pavement structure is a good and desired construction practice, as long as the recycled material is structurally sound and durable in its intended role.

7. Background.

7.1. ASR is a complex chemical reaction between the alkalis present in PCC and certain, but not all, forms of silica in the concrete's fine or coarse aggregate. This reaction causes certain physio-chemical alterations of the aggregate and forms a gel that imbibes water and leads to internal swelling within the concrete. If sufficiently severe, the ASR can lead to widespread concrete cracking; popouts; spalling; an increase in concrete volume that damages adjacent non-reacting buildings, pavements, and utility systems;

and blowups or tenting of pavement slabs. Blowups from ASR on airfields are rare because of the thickness of the pavements. ASR is a slowly developing phenomenon, with damage within 5 to 10 years considered to be rapid and damage within 10 to 20 years considered more typical. The slowness of this reaction makes it difficult to test and assess pavements for ASR issues. Despite this slowness, once ASR symptoms develop, they can lead to ever increasing maintenance costs and may require premature replacement of the ASR-afflicted pavement.

7.2. The primary effects of ASR on most USAF airfields is an increase in maintenance to deal with the foreign object damage (FOD) hazards associated with defects such as spalling and cracking, and repairs to adjacent structures and pavements damaged by ASR swelling. When maintenance efforts can no longer keep pace with the ASR damage, complete pavement replacement is necessary. At least 20 USAF airfields have reported ASR damage on some of their airfield pavements. Consequently, the USAF has a significant volume of pavements that may be candidates for a risk assessment for recycling as outlined in this ETL. ETL 06-2, *Alkali-Aggregate Reaction in Portland Cement Concrete (PCC) Airfield Pavements*, provides more information on ASR, how to identify it, appropriate maintenance procedures for pavements with ASR, and procedures to avoid ASR in new airfield PCC pavement.

7.3. The construction cost of new or replacement PCC pavements may be substantially reduced if the existing concrete with ASR is crushed and recycled as base, subbase, fill, or drainage material within the replacement airfield pavement, or if crack and seat or rubblization rehabilitation techniques are used. In one existing USAF $50,000,000 runway replacement project, the projected savings of recycling the existing ASR PCC were approximately 10 percent of the total project cost. Rehabilitation techniques such as crack and seat or rubblization may also be appreciably quicker than conventional techniques and can reduce the time an airfield pavement is out of service. Since the USAF has a number of ASR-damaged PCC pavements, the potential savings across the USAF are very significant.

7.4. The arguments for allowing recycling of ASR PCC may be summarized generally in these four points:

7.4.1. The alkali-silica chemical reaction in these older pavements may have consumed most of the reactive constituents, and the damage may be over or nearly over.

7.4.2. In crushing or cracking and seating/rubblizing the ASR PCC, more volume is created between particles or in the network of cracks. Any future growth that occurs because of the ASR gel absorbing water can be accommodated within this increased open volume in the new structure.

7.4.3. Classical testing studies of ASR in concrete have examined the growth of laboratory specimens in terms of a few tenths of a percent expansion or less. Such miniscule volume changes have little practical effect in pavement structures (e.g., a 0.5-percent vertical expansion of a 12-inch-thick layer of recycled material would only be 0.006 inch, or less than 1/64 of an inch). The emphasis on ASR assessments for conventional concrete is to avoid cracking of the rigid concrete material. This is not an issue in crushed, unbound materials.

7.4.4. If the recycled ASR PCC is used at depth in a pavement structure, the overlying material would provide a compressive vertical load that might help counter any expansion.

7.5. Unfortunately, our knowledge of ASRs is incomplete, and well-documented laboratory and field trials of ASR PCC use in pavement structures are not available.

7.6. Concerns about recycling ASR PCC to counterbalance the points in section 7.4 include:

7.6.1. We are not able to predict when the ASR phenomenon is complete, nor are we able to examine a sample of concrete and determine if the reaction is complete or if it will continue. The technology to tell if or when the reaction is complete does not yet exist, but this is a topic of ongoing research.

7.6.2. The crushing or cracking of the existing ASR PCC does provide more volume for expansion, but it also makes the recycled material far more pervious than before. Past studies of military airfields in the southeastern and southwestern United States found that the moisture content in airfield pavements tends to increase after construction, often approaching 95 to 98 percent saturation in plastic materials. When the ASR-damaged PCC is recycled and placed within the pavement structure, far more moisture will be available to the recycled material because it is more permeable and in a wetter environment than when it was a surfacing material. Consequently, with more moisture available, the ASR process may get worse, accelerate, or restart.

7.6.3. If the recycled PCC continues to react, two possible adverse effects may develop. First, the increase in volume may lead to swelling of the recycled layer, with resulting surface upheaval and damage to adjacent structures and pavements. Secondly, the individual fragments of the recycled concrete containing aggregates and concrete matrix may break down as swelling within the fragments continues. This would tend to make a finer material over time: a clean gravel base that is classified at construction as a GW aggregate by the Unified Soil Classification System could deteriorate to become a silty gravel (GM) or gravelly silty sand (SM) material. This could lead to a loss in strength, especially when the material is saturated. It could also make the material more prone to pumping failures under rigid pavements, or it could make the material frost susceptible.

7.6.4. There is no accepted method of projecting the behavior of laboratory specimens to anticipated field behavior. This is a particular problem with durability tests such as those performed to study ASR problems.

7.6.5. Classical studies of ASR have dealt with bound materials that have tensile strength to resist internal swelling. When PCC is crushed for recycling, it exists as a granular medium that no longer has inherent tensile strength to resist swelling. Consequently, while the PCC is in a bound state, it resists swelling, which may be a fraction of a percent, but when the PCC is crushed and placed as particulate matter, the potential for swelling may increase.

7.6.6. Reliable data on if and how much recycled ASR PCC may swell in the field is not available. A different chemical durability problem involving reactions between sulfates and components of PCC (sulfate attack) uses laboratory tests with expansion measurements of tenths of a percent, which is the same order of magnitude used with ASR laboratory specimens. At Holloman Air Force Base (AFB), a sulfate-resistant concrete airfield pavement was crushed and recycled as a well-graded base and fill material. This material underwent sulfate attack, with resulting heaving of overlying asphalt and concrete pavements, and damage to building foundations and walls, and to utility and drainage structures. Both ASR and sulfate attack are water-driven reactions, but the sulfate attack chemical reaction is totally different than ASR; therefore, the Holloman AFB case provides no insight into whether recycled ASR PCC will continue to react. It does, however, illustrate that a crushed, dense-graded recycled concrete placed in a pavement structure did swell sufficiently to cause significant damage. ASR and sulfate attack reactions are in the same order of magnitude for volume change. Hence, one should be cautious of dismissing the potential for a crushed, well-graded material to swell significantly from chemical-induced volume changes, whether from ASR, sulfate attack, or other volume-change reaction.

7.6.7. If a recycled ASR concrete is placed as an open-graded drainage layer within the pavement, deterioration of individual particles of recycled material may lead to blockage of the drainage layer and may result in settlement as smaller particles settle into a more compact arrangement after deterioration.

7.7. As is illustrated in sections 7.4. through 7.6., there is simply no answer to the question of whether or not ASR PCC will continue to react when recycled in the pavement structure, and if it does react, what the effect on the pavement will be. The prudent course is to recognize that adverse reactions are possible, and then one may assess the risk of recycling these materials.

8. USAF Operational Risk Management (ORM) Program.

8.1. AFI 90-901, *Operational Risk Management*, establishes the requirement to integrate and sustain ORM throughout the Air Force. AFI 90-901 defines ORM as "a decision-making process to systematically evaluate possible courses of action, identify risks and benefits, and determine the best course of action for any given situation." Air Force pamphlet (AFPAM) 90-902, *Operational Risk Management (ORM) Guidelines and Tools*, provides detailed guidance on how to carry out an ORM assessment. This ETL provides guidance on how to implement an ORM assessment of using recycled ASR PCC within a USAF airfield pavement structure.

8.2. The potential benefits of interest are reduction in initial construction costs and/or more rapid construction for the airfield pavement in question. The risk is possible future closure of the airfield pavement while maintenance, or even complete reconstruction, is carried out to deal with possible damage to the pavement should the ASR continue in the recycled PCC.

8.3. Based on past experience with disruptions caused by materials swelling within the pavement, the most likely symptoms of problems with recycled ASR PCC would be surface distortions. The past experiences on which this theory is based were sulfate attack on recycled PCC, sulfate attack on stabilized materials, and volume change of various waste products that were used in pavement. These events were not ASR related, but they do illustrate what may happen with unexpected volume change within the pavement structure. For rigid pavements, the damage may appear as unevenness between slabs and/or cracked slabs (Figure 1). Repairs would typically consist of grinding the surface or removing and replacing affected slabs. For flexible pavements, the damage is often localized swelling (Figure 2); in some cases, it becomes a linear raised or humped area. This damage can resemble a giant mole burrow across the pavement. The swelling may preferentially run along joints, where there is more water ingress. The repair is usually to cut out and patch the heaved areas. If the recycled material is in a drainage layer, deterioration of the material may result in surface settlement and depressions. Other potential problems are frost heave in seasonal frost areas, localized loss of strength and shear failures, and pumping on rigid pavements. If adverse deterioration occurs in the recycled material, the affected pavement feature would have to be closed and repaired. This might take a week or more, depending on the exact nature of the problem, and might be necessary annually or even more often, or only every few years. While the anticipated damage, if adverse reactions occur, would require possible annual closure and repair of the feature, lasting a week or more, in two instances volume change occurring in materials within the runway structure led to complete removal down through the affected material and reconstruction (Tampa civil airport due to expansive steel slag in the base course and a Laughlin AFB auxiliary field that experienced sulfate attack of a lime-stabilized base).

8.4. These are the basic steps of an ORM assessment:

1. Identify the hazards.
2. Assess the risk.
3. Analyze risk control measurements.
4. Make control decisions.
5. Implement risk controls.
6. Supervise and review the process.

The remainder of this ETL will provide guidance on implementing those ORM steps for a specific project where designers are contemplating the use of recycled ASR PCC.

Figure 1. Example of Differential Heaving on a Rigid Pavement Caused by Volume Change in Underlying Base and Fill Layers

Figure 2. Example of Localized Heaving in a Flexible Pavement Caused by Volume Change in the Underlying Base Course

9. Identify the Hazard.

9.1. Section 7.6. summarizes the potential adverse outcomes possible if recycled ASR PCC is used within the airfield pavement structure, and sections 7.4. through 7.7. emphasize the uncertainty of the results of recycling ASR PCC. No reliable prediction of the results is available to the USAF decision maker at this time—nor is any research ongoing within the Department of Defense (DOD) to provide an answer in the near future. Hence, present decisions will have to be made with incomplete information.

9.2. Basically, the potential hazards are that the recycled ASR PCC within the pavement structure may increase in volume, causing disruption to the pavement surface and adjacent pavements and structures, and/or individual fragments of the recycled material may break down, leading to potential loss in strength, frost susceptibility, pumping under rigid pavements, and settlement.

10. Assess the Risk.

10.1. Assessment of Risk. AFPAM 90-902, *Operational Risk Management (ORM), Guidelines and Tools*, suggests that risk be assessed on a combination of hazard severity and probability of occurrence.

10.2. Hazard Severity Categories. Hazard severity categories suggested in AFPAM 90-902 are *catastrophic*, *critical*, *moderate*, and *negligible*. The definitions are in terms of effect on mission, Airman death or injury, and system loss or damage. For an airfield pavement, the hazard severity will be a combination of mission degradation and system damage. As a baseline, the hazard severity for this ETL assessment of the use of ASR PCC within the airfield pavement structure will be *critical*. This presumes that a major airfield pavement feature, if damaged, would require extended closure of the affected airfield pavement for repairs and would constitute a major impediment to the flying mission and significant damage to the pavement system.

10.3. Hazard Severity Rating. Which specific pavement feature is involved (e.g., runway at an airfield with only one runway versus a runway at an airfield with parallel runways) will play a role in determining the hazard severity rating. An adjustment on hazard severity for specific airfield conditions will be made later in the analysis.

10.4. Probability of Occurrence. The probability of occurrence is particularly difficult to assess because we are uncertain of the results. The rating guidance in AFPAM 90-902 that seems most useful in this case is:

1. Frequent: Continuously experienced
2. Likely: Occurs regularly
3. Occasional: Occurs several times in the life of the system
4. Seldom: Can be expected to occur in the life of the system
5. Unlikely: Unlikely, but could occur in the life of the system

If one considers the "system" in question to be all USAF airfield pavements containing recycled ASR PCC, then there are various arguments to support a case for *occasional*, *seldom*, and *unlikely* probability ratings. Unfortunately, no current research or test information conclusively identifies the "right" answer. Certainly, there are some slow reacting and not very reactive aggregates that can probably be recycled safely. There are also certainly some very reactive aggregates (colloquially termed "hot" aggregates) that one should be very hesitant to recycle. For this ETL, we will use *seldom* as the probability of occurrence as a reasonable base estimate of the situation. Later, adjustments will be made for adverse site conditions and specific ASR characteristics of the concrete.

10.5. ASR PCC Risk Assessment. Figure 3 shows the risk assessment matrix from AFPAM 90-902, with a suggested risk priority list (i.e., a risk level with a 10 is more serious than one with an 11, etc.). For recycling ASR PCC in the airfield pavement with a probability of occurrence of *seldom* and a hazard severity of *critical*, the initial average risk level assessment would be *medium* (block 11 with yellow highlighting). This means that if one considers the average USAF-wide prospect of recycling ASR PCC within the airfield pavement structure, then it would be a medium risk. In sections 10.6 through 10.8, this initial average risk assessment will be modified for specific site considerations.

			Probability				
			Frequent	Likely	Occasional	Seldom	Unlikely
			A	B	C	D	E
Severity	Catastrophic	I	1	2	6	8	12
	Critical	II	3	4	7	11	15
	Moderate	III	5	9	10	14	16
	Negligible	IV	13	17	18	19	20
			Risk Levels				

Risk Levels: Extremely High - 1, 2, 3
High – 4, 5, 6, 7, 8
Medium – 9, 10, 11, 12, 13
Low – 14, 15, 16, 17, 18, 19, 20

Figure 3. Risk Assessment Matrix Reflecting the Probability of an Event and the Severity of the Event (AFPAM 90-902)

10.6. Hazard Severity Adjustment for Site-Specific Pavement Features. The selection of a hazard severity level should be made in conjunction with base operations personnel and the airfield manager. The initial hazard severity selection of *critical* was based on anticipation that the closure of the feature for repairs would have a significant impact on the flying mission. This would be the expected result if a runway or primary taxiway had to be closed for a week. If alternative pavements are available to carry out the mission, such as a parallel runway or alternate ways to route taxiing aircraft, then the hazard severity could be reduced to *moderate* and the overall risk level would drop to *low*. On the other hand, if the pavement in question is the only instrumented runway at a base with frequent bad weather, then the impact of closure could be very serious, and a hazard severity rating of *catastrophic* might be warranted, raising the risk level to *high*. Special areas such as intersections of runways and taxiways may require special consideration because closure of these pavements for repair would affect two pavement features. For minor pavements such as ramps or ladder taxiways, the impact of closing these areas for a week might be minor, and a hazard severity of *negligible* could be appropriate. Each project needs to have its hazard severity level adjusted individually to reflect the actual impact that a pavement failure would have on the base's flying mission.

10.7. Probability Adjustment to Reflect the ASR of the Existing Pavement. The development of ASR in concrete is a complex function of aggregate characteristics, cement chemistry, and environmental conditions. The initial probability rating of *seldom* assumes a moderately reactive PCC pavement that is to be recycled. Such a pavement will typically begin to show significant ASR symptoms at an age of 10 to 20 years. These symptoms will include extensive cracking and relatively modest volume changes that will develop spalling at joints, extrusion of joint sealant, and minor displacement of adjacent structures, such as jamming of grates in trench drains and small upheaval of asphalt concrete shoulders. Patching probably has been frequent in the 15- to 20-year range. When considering older pavements that may be 30 or 40 years old, past maintenance records and Pavement Condition Index (PCI) assessments should help develop an estimate of how severe the ASR has been on the specific PCC. The probability of occurrence in Figure 3 should be adjusted to the left to *occasional* for highly reactive pavements and to the right to *unlikely* for pavements showing low levels of reactivity. These descriptions can be used to help classify highly reactive and low reactivity pavements:

10.7.1. A highly reactive pavement will show symptoms of ASR less than 10 years after placement and may require patching within this period. Figure 4 shows minor ASR cracking on a pavement at Holloman AFB. The damage is not severe now, but it occurred 5 years after placement. This specific pavement required patching at 8 years of age to reduce FOD hazards. This pavement would be rated as highly reactive because ASR symptoms and repairs began less than 10 years after placement. Pavements that show large volume changes, even if they did not appear until the 10 to 20 year point, should also be considered as potentially highly reactive. Figure 5 shows examples of heaving of AC that suggests serious potential problems if the adjacent ASR PCC were recycled into an airfield pavement structure. Figure 6 shows differential displacement of several inches between slabs that are undergoing ASR at Kirtland AFB, and also shows a repaired AC area adjacent to a PCC section that has expanded several inches. These photographs suggest a highly reactive material. When contemplating recycling an existing ASR PCC pavement that began showing symptoms early in its life (10 years or less) or that shows large volume change potential, it would be prudent to consider this material highly reactive and raise its probability rating to at least *occasional*.

Figure 4. Minor ASR Cracking in 5-Year-Old Pavement (Left Photograph); Patching Needed 3 Years Later (Right Photograph). Because of the early development of ASR symptoms in this Holloman AFB pavement, it would be considered a highly reactive pavement.

Figure 5. Examples of Damage to Adjacent Asphalt from ASR-Induced Expansion in Adjacent PCC Pavement. This suggests of a highly reactive pavement.

Figure 6. Examples of Large Volume Changes Suggesting Highly Reactive ASR Pavements. On the left, two pavement slabs are displaced by several inches. On the right, the PCC has grown from the visible joint in the AC and damaged the adjacent pavement. An AC repair patch to the damaged AC from this growth is visible to the left of the PCC.

10.7.2. Some pavements that develop ASR do so only after a long time and may develop only mild symptoms. Maintenance for ASR issues on such pavements has probably been minimal or nonexistent. Figure 7 shows an example from Travis AFB where the pavement is over 25 years old. ASR cracking remains relatively tight, with minimal raveling and spalling, and with only modest displacement of the asphalt shoulder. In this case, lowering the probability rating of using this PCC in a recycled application to *unlikely* would be reasonable.

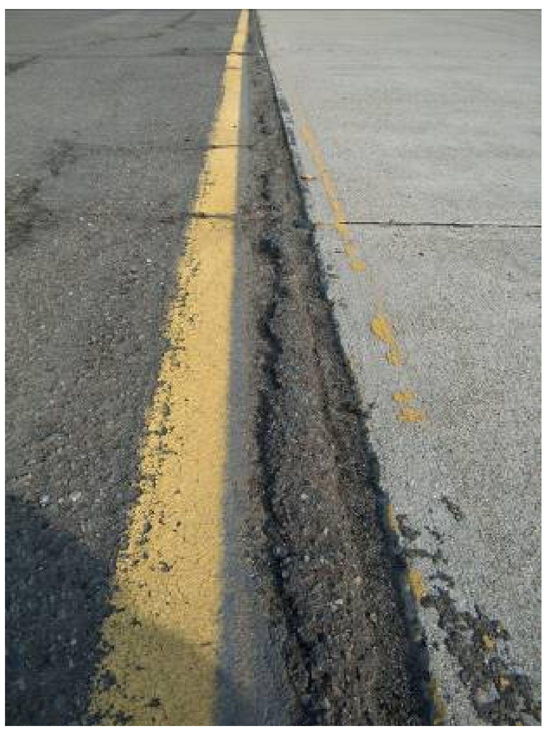

Figure 7. Example of Low Reactivity ASR at Travis AFB. Cracking is generally tight, with minor FOD issues in this pavement that is over 25 years old. Small volume change has caused minor upheaving of the AC shoulder. The only maintenance on this ramp has been sweeping to minimize the hazard cause by the slow generation of FOD.

10.8. Probability Adjustment to Reflect Local Moisture Conditions. ASR is a moisture-driven reaction. Unfortunately, even in arid desert environments, ample moisture content is available to trigger and sustain ASR activity in conventional concrete. If the proposed recycled ASR PCC is to go into a pavement structure that has historically experienced at least seasonally wet conditions, it would be prudent to increase the probability of occurrence one level (e.g., from the base of *seldom* to *occasional*). This high moisture exposure may result from conditions such as a high groundwater table; a perched groundwater table; capillary rise from a near-surface water table; condensation of water vapor; poor or blocked drainage; or thaw periods in seasonal frost areas. Even in arid regions, local geologic conditions such as basins, playas, or sabkhas can seasonally result in a high water table near or above the natural ground level. On the other hand, if conditions are likely to be dry and stay dry within the pavement structure, a reduction in the probability of occurrence from *seldom* to *unlikely* might be warranted. Traditionally, military airfield pavement design has allowed a reduction in pavement thickness for favorable moisture conditions when the annual rainfall is less than 15 inches and the water table is permanently deeper than 15 feet. Such rainfall and water table conditions may be used as indicators that a reduction in the probability of occurrence for adverse reactions in recycled ASR PCC.

10.9. Summary of Risk Assessment. The general initial average risk assessment for recycling ASR PCC within a USAF airfield pavement structure as base, subbase, or fill, or as part of a crack and seat or rubblization rehabilitation technique is *medium*. This is based on a hazard severity rating of *critical* and a probability of occurrence of *seldom* in the risk assessment matrix in Figure 3. This initial average risk assessment must then be adjusted for specific site conditions. Consultations with operational and command elements should adjust the hazard severity rating as appropriate for the specific criticality of the pavement feature being analyzed (section 10.6.). The probability of occurrence may also need to be adjusted for specific site conditions such as particularly high or low alkali-silica reactivity in the concrete being recycled (section 10.7.) and particularly wet or dry conditions (section 10.8.).

11. Analyze Risk Control Measures. Generally, the only option available to control the risk, other than outright rejection of recycling the ASR concrete into the pavement, is to find ways to limit the probability of occurrence or to mitigate the likelihood or extent of adverse effects if the recycled ASR concrete deteriorates. These are some possible mitigation methods:

11.1. Limit the thickness of the recycled material. If only a limited thickness of approximately 6 inches of the material is used, then likely adverse effects will be reduced. Also, the deeper the material is in the pavement, the less significant any adverse effects will likely be.

11.2. Blend the recycled ASR concrete with other aggregates or materials that are not suffering from ASR. This approach is simply diluting the potentially reactive material.

11.3. Limit the available water. Trying to limit water from the pavement traditionally has proven easier in concept than in practice. Water arriving as vapor, as condensation on the underside of surfaced areas, through capillary processes, or by infiltration seems to find a way into pavements to cause problems. Attempts to control moisture access to the pavement for other moisture-related problems such as D-cracking, frost damage, and sulfate attack have generally had a poor record of success. Although conceptually sound, this is not a recommended mitigation method simply because it is difficult, if not impossible, to accomplish in the field.

11.4. Test the material proposed for recycling. If the material to be recycled shows no deterioration and no swelling in a vigorous laboratory test, it would be reasonable to lower the probability of occurrence by one rating (e.g., from *seldom* to *unlikely*). Unfortunately, there is no accepted test method or criteria to evaluate the potential deterioration in the ASR concrete proposed for recycling. The tests used to most accurately assess conventional concrete for ASR (or at least those thought to most accurately do this) run for 1 or 2 years before an answer is available. Usually this is useful for research but not for construction. To get timely results, laboratory tests are often run under accelerated test conditions, which usually means under more extreme temperatures and under severe saturation or chemical exposure conditions. The results of such tests are available sooner, but how these results relate to field conditions is unclear. Such accelerated test conditions may trigger reactions that would never appear in the field. Nevertheless, some reasonable testing may provide additional insight into the probability of adverse deterioration. Potential tests are under research, but there is no currently accepted standard test or criteria. Any proposed test or criteria should be evaluated and either accepted or rejected on a case-by-case basis. HQ AFCESA may be consulted for assistance if needed. If testing is proposed to aid in evaluating the recycling of ASR PCC into an airfield structure, the following testing guidelines should be met:

11.4.1. The actual concrete proposed for recycling should be used in the testing. Tests from other locations or previous tests at the same air base are not a substitute.

11.4.2. A qualified concrete petrographer should be part of the analysis team examining and evaluating the test specimens.

11.4.3. The proposed concrete should be crushed to the proposed gradation for its use in the field and test specimens compacted to the expected field density.

11.4.4. The samples should be exposed to soaking under conditions of elevated temperature in a high alkali solution such as outlined in American Society for Testing and Materials (ASTM) C 1260, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*.

11.4.5. These tests should continue for not less than 30 days. Longer tests would be more persuasive than shorter ones.

11.4.6. Any sign of swelling should result in an increase in the probability of occurrence rating by at least one level (e.g., from *seldom* to *occasional*). Because of the severity of the test and the uncertainty of how well it represents field behavior, it is probably only appropriate to raise the probability rating one level.

11.4.7. Any change in gradation or weakening of fragments should be assessed by the analysis team petrographer and design engineer. They should assess if the deterioration of the fragments would have an adverse effect. For example, production of sand-sized particles for a base under a rigid pavement would have little or no impact on pumping potential, but generation of large quantities of material passing the No. 200 sieve might very significantly increase the potential for pumping in the pavement.

11.4.8. If the tests show no potential for swelling and no degradation of the material under these severe test conditions, the probability of occurrence may be reduced one rating.

11.5. Other miscellaneous factors may affect the risk. Some pavement designs, such as asphalt surfaces, are easier to maintain for minor pavement surface problems where one could simply mill and overlay. The coarser fractions of crushed materials generally have fewer weak particles and contaminants, so some beneficiation of the recycled concrete may be feasible by removing the finer fractions. General stockpiles of potentially recyclable PCC that comes from multiple projects may be hard to control and assess. For airfield paving projects, it is prudent to have specific knowledge of the origin and condition of the PCC proposed for recycling.

12. Make Control Decisions.

12.1. The available risk control options are fairly limited. One may reduce the amount of recycled material susceptible to deterioration by using it in thin sections or by blending it with non-reactive materials; however, this may reduce the economic benefit of the recycling. Attempts to control moisture access to the recycled material are probably impractical and overly optimistic. Hence, this is not recommended as a control measure. Finally, while one can run tests to try to assess the reactivity of the proposed material, no accepted tests or criteria are currently available for this purpose. The answers from such tests are perhaps best thought of as suggestive rather than conclusive. The assigned initial average probability of occurrence rating of *seldom* is thought to be a reasonable and not overly conservative estimate based on current knowledge. One should reduce this probability rating only with caution.

12.2. AFPAM 90-902 defines risk as the probability and severity of failure or loss from exposure to various hazards. The hazard in question is deterioration of ASR PCC recycled within the airfield pavement structure that could lead to damage, closure, and periodic repair of the airfield pavement. It is possible, although probably a remote possibility, that the pavement would have to be closed, the pavement including all recycled ASR PCC would have to be removed, and a replacement pavement would have to be built. The loss that might be suffered by the USAF includes increased maintenance costs, repair or replacement costs, and the impact of closure of the airfield pavement for repairs or replacement.

12.3. Essentially, all risks of recycling ASR PCC in a USAF airfield pavement will be borne by the USAF. It is unlikely that any damage will be visible within the one-year contract warranty period normally provided by contractors on airfield pavements. Therefore, if adverse deterioration does occur, neither the designer nor the contractor are likely to be held liable for any loss suffered by the USAF for using recycled ASR PCC. When evaluating potentially optimistic predictions from designers, contractors, material producers, or their consultants, one should remember that they are exposed to no risk if there is an adverse reaction.

12.4. The benefit of recycling ASR PCC in the pavement structure is economic. By recycling ASR PCC, it may be possible for the USAF to significantly reduce construction costs or, in some cases, speed construction. The USAF also has a significant quantity of ASR-affected airfield pavements that need or will need to be rehabilitated. If they cannot be recycled, then there is also a significant cost in disposing of the material.

12.5. The crux of the issue is whether the cost savings that may be realized are adequately balanced by the possible need to close airfield pavements for maintenance, repair, or replacement if deterioration continues in the recycled material. This has a potential major impact on the flying mission at a USAF air base, an impact that is probably far more critical than the actual cost of any maintenance, repair, or replacement project.

13. Implement Risk Controls.

13.1. The decision to use or not use ASR PCC in an airfield pavement structure impacts many parties at the base and MAJCOM. If ASR PCC is proposed for recycling, crack and seat, or rubblization, the pavement designer should prepare a risk assessment as outlined in this ETL and submit it to the BCE for approval. The BCE will coordinate with affected base-level organizations and submit the coordinated risk assessment package to the MAJCOM pavement engineer for MAJCOM concurrence and approval. Each MAJCOM may establish unique requirements for coordination and approval.

13.2. As a general rule, the risk assessment for recycling ASR PCC into a USAF airfield pavement should probably offer significant economic benefit and be in the low risk assessment category to be viable. It is critical that this risk assessment be based on judgment of actual conditions and not be driven by project pressures and budgets. AFPAM 90-902 offers good advice on trying to balance natural inclinations to sometimes be overly optimistic with similar tendencies to be overly conservative. This is a classic case requiring mature professional judgment and balance in arriving at a reasonable assessment. And with this assessment, there are unknowns and risks regardless of the decision.

13.3. While this ETL applies specifically to USAF airfield pavements, the general methodology may be used for any pavement; however, pavements such as roads, streets, and industrial and privately owned vehicle (POV) parking lots are not USAF mission critical elements. Hence, far more latitude in recycling ASR PCC is possible for these applications than is possible for a USAF airfield pavement.

13.4. Once the pavement has been finished, the BCE should implement a monitoring program to watch for adverse behavior. At least annually, the BCE should have the pavement visually inspected by a knowledgeable pavement engineer who should walk the entire scope of the project. The BCE should have at least 9 transverse elevation profiles and 3 longitudinal elevation profiles run when the project is finished and annually thereafter. The pavement engineer should judge whether any adverse behavior is developing from the use of the recycled ASR concrete. The elevation profiles, along with the pavement engineer's visual assessment and his or her analysis of the profiles, should be maintained in a permanent file for the facility.

14. Point of Contact. Recommendations for improvements to this ETL are encouraged and should be furnished to the Pavements Engineer, HQ AFCESA/CEOA, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32408-5319, DSN 523-6334, commercial (850) 283-6334, e-mail AFCESAReachbackCenter@tyndall.af.mil.

James D. Frishkorn, Colonel, USAF
Director of Operations & Program Support

2 Atchs
1. Example of a Risk Assessment
2. Distribution List

EXAMPLE OF A RISK ASSESSMENT

A1.1. BACKGROUND. An airfield has a runway that displays ASR damage consisting of moderate cracking and spalling, moderate shoulder upheaval, and damage to airfield lights. The damage began appearing as a network of fine cracks approximately 6 years ago, and the pavement is now 18 years old. The base has a parallel runway. The runway is located in an area where the water table often rises within the pavement structure during the spring thaw period. If the existing ASR PCC can be crushed and recycled as base course for the new pavement, large savings are possible.

A1.2. SETTING THE INITIAL AVERAGE RISK LEVEL ASSESSMENT. The initial average risk level assessment is *medium*, block 11 (reference paragraphs 10.2., 10.4., and 10.5.).

			Probability				
			Frequent	Likely	Occasional	Seldom	Unlikely
			A	B	C	D	E
Severity	Catastrophic	I	1	2	6	8	12
	Critical	II	3	4	7	11	15
	Moderate	III	5	9	10	14	16
	Negligible	IV	13	17	18	19	20
			Risk Levels				

Risk Levels: Extremely High - 1, 2, 3
High – 4, 5, 6, 7, 8
Medium – 9, 10, 11, 12, 13
Low – 14, 15, 16, 17, 18, 19, 20

A1.3. ADJUSTING FOR HAZARD SEVERITY. (Reference paragraph 10.6.) The base agrees that because there is a parallel runway, the hazard severity can be reduced to *moderate* to give a risk assessment of *low*, block 14.

			Probability				
			Frequent	Likely	Occasional	Seldom	Unlikely
			A	B	C	D	E
Severity	Catastrophic	I	1	2	6	8	12
	Critical	II	3	4	7	11	15
	Moderate	III	5	9	10	14	16
	Negligible	IV	13	17	18	19	20
			Risk Levels				

A1.4. ADJUSTING FOR ASR REACTIVITY IN THE EXISTING PCC. (Reference paragraph 10.7.) The PCC shows the expected reactivity. The development of ASR at 10 to 20 years after PCC placement and moderate levels of damage are consistent with the original definitions. No adjustment is needed for alkali-silica reactivity in the existing PCC. The risk level assessment remains as *low*, block 14.

A1.5. ADJUSTING FOR MOISTURE CONDITIONS. (Reference paragraph 10.8.) Because of the seasonally wet conditions, it is prudent to increase the probability rating to *occasional*, giving a risk level assessment of *medium*, block 10.

			Probability				
			Frequent	Likely	Occasional	Seldom	Unlikely
			A	B	C	D	E
Severity	Catastrophic	I	1	2	6	8	12
	Critical	II	3	4	7	11	15
	Moderate	III	5	9	10	14	16
	Negligible	IV	13	17	18	19	20
			Risk Levels				

Risk Levels: Extremely High - 1, 2, 3
High – 4, 5, 6, 7, 8
Medium – 9, 10, 11, 12, 13
Low – 14, 15, 16, 17, 18, 19, 20

A1.6. ADJUSTING FOR RISK CONTROL MEASURES. (Reference section 11.) No risk control measures using blending or thin sections are desired to maximize potential cost savings. There is insufficient time for tests to be run before the contract has to be awarded. Hence, no further adjustments are to be made, and the risk level assessment remains as *medium*, block 10.

A1.7. MAKING THE FINAL DECISION. This guidance is offered by AFPAM 90-902:

> All identified benefits should be compared to all identified costs. . . . Balancing costs and benefits may be a subjective process and open to interpretation. Ultimately, the balance may have to be determined by the appropriate decision authority.

In this case, the question that the decision-making authority must make is whether a *medium* risk, with the attendant possible airfield pavement closure costs, is sufficiently counterbalanced by the possible savings. Such decisions must be made on a case-by-case basis, and there is no generic answer to such questions.

Note: Had moisture not been an issue so that the probability remained at *seldom*, and had tests been run that showed no swelling and no degradation (paragraph 11.4.), the probability would have dropped to *unlikely*, which, with the *moderate* severity level, would have given an overall risk level assessment of *low*, block 16. This is significantly better than the *medium* risk level assessment (block 10) rating in the example and would make using the recycled ASR concrete much more attractive.

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