SATISFACTORY AIRFIELD PAVEMENT PERFORMANCE IS NOT A FOREGONE CONCLUSION

By:
Raymond S. Rollings and Marian P. Rollings
Rollings Consulting, LLC
Beaufort, SC 29907
USA
Phone: (843) 770-9913
rollingseng@earthlink.net

and

James Greene
Air Force Civil Engineer Support Agency
Tyndall AFB, FL 32403
USA
Phone: (850) 283-6334
James.Greene@tyndall.af.mil

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ABSTRACT

The United States Air Force (USAF) owns and operates over 170 permanent facilites around the world with many more in use for temporary missions of various lengths. While design theory is a crucial aspect of USAF airfield pavement design, evaluation, and management, those issues that actually cause the most problems to the USAF are far more mundane. Typically, construction and materials are at the heart of most problems that lead to unsatisfactory performance or unexpectedly hign maintenance of USAF airfield pavements. However, design errors, when they occur, tend to be particularly costly. One must also recognize that human failures are usually a major aspect of these design, construction, and material problems. This paper examines recurring problems areas the USAF encounters with its airfield pavements, and iluustrates each area with specific examples. These problems occur regardless of whether the design, inspection, and construction are performed by the USAF, by other government agencies, or by engineers or contractors under contract to the government. Hence, no one group has a monopoly on airfield pavement problems. These recurring problems must be overcome before we can make use of the improved technology available today and before concepts like "long-life pavements" become a reality rather than simply a marketing jingle.

INTRODUCTION

Pavement construction has a vaunted history stretching back to our shared heritage of the ancient civilizations in locales like Egypt, China, Persia, Crete, Mexico, and Rome [1]. Airfield pavement design and construction has its specific origins in the exigencies of World War II, and the evolution of aerospace technology has continued to push its development ever since then [2]. Today, we have powerful analytical tools that allow calculation of a myriad of interacting factors upon our pavement structures, new testing technology such as that developed by the SHRP program that allow very sophisticated assessments of rheological behavior of our materials, and a steady stream of innovations such as GPS, laser controls, computerization, etc. that have revolutionized pavement construction.

Despite this long historical knowledge and experience base and all the sophistication of modern design and construction technology, those who must investigate and deal with airfield failures find business remains good; indeed, too good! How can this be? The authors would like to share their experiences with several recurring airfield pavement problem areas as experienced by the USAF and illustrate these problems with examples.

The USAF owns and operates approximately 170 permanent facilities around the world with many others used periodically for training, humanitarian relief, or combat operations [3]. This provides the USAF with the perspective of an agency that designs, builds, and maintains numerous airfield pavements under a variety of conditions worldwide. Procurement of design, construction, and maintenance activities on these airfield pavements includes in-house work by military and civilian organizations, use of other government agencies, such as the Army Corps of Engineers or Naval Facilities Engineering Command, and use of consultants, material producers, and contractors under a variety of contractual arrangements. Consequently, the authors feel the following observations are applicable to the broad arena of airfield pavements and are not limited to the military or any one specific agency, locale, contractual model, etc.

DESIGN

The design of an airfield pavement should provide the pavement cross section along with the requisite material and construction requirements for each component to support the required design aircraft loads in the environment within which the pavement is located. Environment is clearly the weather issues such as freezing and thawing appropriate to the area, but the design must also address all specific local issues such as types and availability of construction materials (e.g., coral as aggregate in the South Pacific, lateritic gravels in the tropics, permafrost in the high latitudes, or expansive subgrade soils), special durability problems (e.g., sulfates in the soils, alkali-reactive aggregates in portland-cement concrete, or stripping prone aggregates for asphalt concrete), and reasonably available skills and equipment for the locale to balance against cost of importing such. While much effort is expended in analytical stress calculation for thickness determination, an adequate airfield pavement design is very holistic effort incorporating many aspects of soils, materials, and the specific vagaries of local conditions.

In USAF experience, design is relatively rare as the primary cause of an airfield pavement problem; however, when it does occur, it tends to be a severe problem. Design problems may arise simply because basic criteria and assumptions in design aids are not understood (e.g., see Rollings and Rollings [4]), the designer simply does not understand that airfield design is dramatically different from highway design (e.g., the consultant who converted B-747 traffic into equivalent 18-kip single axle loads), or the designer is unqualified (e.g., recent airfield runway plans signed and sealed by a mechanical engineer rather than a civil engineer). Modern computer programs make pavement design appear simple to those without experience and tempt them to try their hand at it rather than paying for someone more qualified to undertake the task. However, failure to understand site conditions and the limitations this imposes is probably the most common major design error in our experience.

Design of a runway and parallel taxiway for a major Middle Eastern airfield expansion during the 1980s illustrates how failure to understand site conditions can cause major problems. Contract administration for this project was under the Army Corps of Engineers, design was by a US consultant, and construction was by a joint venture of a US and host nation contractor. The site is remote, difficult, and more detail is available elsewhere [5].

The runway and parallel taxiway start on a low plain in the south and rise onto a gentle ridge to the north. The subgrade is a thin layer of residual gravel classifying as a GM under the unified soil classification system over parent igneous bedrock. The design called for excavation through the thin mantle of residual soil to weathered rock upon which the flexible and rigid pavement structures would be founded. This weathered rock was assigned a design CBR of 20.

This site was subject to two floods during construction, was closed several times by flooding after construction, and within 10 years suffered major structural failure that required complete reconstruction of areas of the runway and taxiway and installation of a major drainage system. While the situation here is complex (5), Figure 1 illustrates the fundamental mismatch between the designer's view of the site and the actual conditions. The level plain upon which southern portions of the runway and taxiway rested was a playa or dry desert lake bed. In this region, the subgrade strength was only 20 percent of that assumed by the designer (and which was appropriate for the weathered rock further to the north on the ridge). Premature structural failure was the result of this design error and misunderstanding of the site. Periodically, the playa would also fill with water from the infrequent storms, and the runway would be closed until evaporation or slow infiltration of the water into the fine-grained soils would again allow the runway to be reopened.

DETAILS

The airfield pavement designer is responsible for preparation of design documents, specifications, and project plans. These items comprise numerous details ranging from spacing between joints, types of joints, materials to be used, layer thicknesses, material properties, etc.

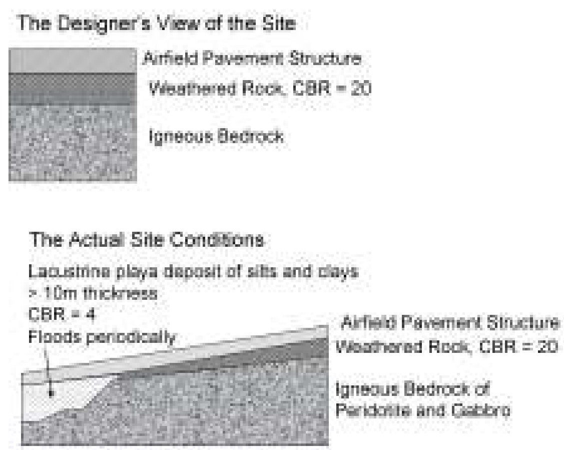

Figure 1. Contrast Between Designer's Concept of Site and Actual Site Conditions.

guidance in official design documents, guide specifications, industry standards, and similar sources provide assistance in preparation of these documents, but ultimately the designer is responsible for all that goes into or that fails to go into the project plans as well as the design and specification documents. Much of this work is tedious, and one can be tempted to rush through them or assign them to more junior personnel. However, many projects have been ruined by some overlooked detail.

Let us look at an example. Some nine years after construction of a 12-in. thick concrete parking ramp at an Air Force base in the southeastern US, there was extensive damage to a major trench drain (Figure 2). Damage included surface spalling, cracking approximately 15-in down in the concrete trench walls, broken trench anchor bolts, surface unevenness, and jammed grates. A structural engineer from the original design agency visited the site and concluded the damage was due to (1) excessive loads being applied by the surrounding concrete ramp, (2) too stiff of a joint filler in the expansion joint between the trench and the ramp that allowed these loads to be transferred, and (3) use of the ramp by occasional C-130 and C-5 aircraft that overloaded the trench drain.

A USAF pavement evaluation team later took cores of the joint and found a much simpler explanation. The coring found that the expansion joint material extended to only a depth of 12 in. and not the full depth of 15 in. The joint at the trench edge was a thickened edge joint 15-in. thick, and it appears the contractor had procured expansion board material appropriate for a 12-in. thick pavement used through most of the ramp. Neither the designer, contractor, construction crews, or agency inspectors noted this discrepancy during construction, or they failed to recognize its significance. In effect, there was no expansion joint as the ramp concrete

Figure 2. Example of damage to nine-year old trench drain in a USAF ramp.

bore directly on the trench drain at the lower depths and the damage is consistent with a missing or ineffective expansion joint. There are other examples at USAF bases where coring has found the expansion joint did not extend full depth of the pavement, and similar damage has arisen in those cases also.

CONFORMANCE WITH SPECIFICATIONS

Typical specifications contain extensive detail, and much of it represents past practice, concepts (both correct and incorrect) about how work should be done or what materials should be used, requirements added trying to avoid some specific bad performance observed in previous projects, and details about materials to be used. Issues about whether work and materials conform to specifications are at the heart of many construction disputes. There is always lively debate about whether specific specification requirements are needed or reasonable. Yet many specification requirements are present for very good reason and can be ignored only with risk.

Recently, the USAF had major failures of two very large aircraft parking ramps in a seasonal frost area. Investigations indicated the cracked slabs involved in the failure were due to differential frost heave. The base course was slightly out of specifications and averaged approximately 7 percent passing the No. 200 sieve rather than being 5 percent or less as had been specified. It seemed inconceivable to many that such a minor variation, almost uncontrollable and unidentifiable on a big project, could not be the cause of so much damage!

The mechanism for the differential frost heave was thought to spring from isolated leakage and saturation of the base in some areas but not in others adjacent to the saturated zone. Large quantities of water from deicing aircraft ran across these ramps and entered the unsealable joint between the PCC ramps and AC shoulders. Eventual freezing of this wetter base along the outside edge of the ramp is believed to have led to heaving and cracking. The following year, water entered the base from the newly cracked slabs and the damage progressed to the next row of slabs. Cracking was also observed wherever water could leak through poorly sealed joints or cracks in the ramp concrete surfaces.

To investigate if the small error in allowable percent fines in the base could cause significant heaving, specimens of the base course aggregate with varying amounts of material passing the No. 200 sieve were subjected to a laboratory frost heave test (ASTM D 5918). The results of this testing are shown in Table 1. Clearly, even small variation in the contents of fines cause major effects in frost-susceptibility of base course aggregates. The tight requirements for non-frost susceptible material are justified and must be enforced during construction.

Table 1.
Heave Rates of a Base Course with Varying Fine Content.

Fine Content	Heave Rate, mm/day	Frost-Susceptibility Classification
1%	4	Low
2.5%	5	Medium
3.5%	11	High
4.5%	22	Very high

MATERIAL QUALITY AND DURABILITY

The materials used in airfield pavements must be of such quality that they can stand up to the loading conditions and be durable under the anticipated environmental conditions. While this is easy to say, the actual tests we use to examine durability (e.g., sulfate soundness or LA abrasion) are often only poorly correlated to field performance. Despite this well known weakness, we often make major decisions on accepting or rejecting materials based on inferior testing technology and understanding. Complex durability issues like alkali-silica reaction or durability under freezing and thawing conditions are not explained by simple tests. And then too often, the better quality materials are too expensive or are inconvenient to obtain so a cheaper more available material is substituted with assurances that it will be adequate.

In the buildup prior to the last Gulf War, a military engineering unit designed and built a large slip-formed concrete airfield ramp at a Middle-Eastern base. This was a high-priority effort, and time was crucial. Concrete was procured for this construction from local sources by a major US contractor responsible to the US for providing in-theater support. Initial problems in concrete placement were linked to a poor concrete mixture and adjustments were made in the mixture proportions that allowed placement to proceed. The job was finished quickly and was deemed a success.

However, shortly after placement major popouts began appearing (Figure 3). As Murphy's law would dictate, the aircraft models slated to use the ramp in upcoming operations were those that are the most susceptible to foreign object damage (FOD) from ground debris such as these popouts.

Figure 3. Example of Extensive Popouts on a New Airfield Ramp in the Middle East.

An examination of the aggregate used in this construction found it to be totally unsuitable for use in concrete. The rapid appearance of the popouts was foreordained by the use of a substandard local aggregate. It had been deemed more convenient to use the local aggregate and avoid the delay of shipping in appropriate quality aggregate to the locale. After all, this was a rush expedient military construction job. However, the headaches these popouts caused the USAF proved to be far greater than any savings in time or money that had been realized.

CONSTRUCTION

Poor quality construction is a common and recurring complaint. While often the responsibility for such justly lies with the contractor, there are other times when poor specifications, difficult site or environmental conditions, or owner-dictated actions, changes, or last-minute requirements plays a role in poor quality construction. Sometimes, it can be the dominant role.

To examine how the owner's actions can play a role in construction quality issues, let's examine a runway at a USAF airbase in Germany. This particular runway had been resurfaced with asphalt concrete in 1999. At the beginning of the winter of 2005-2006, faint cracks and raveling were observed in this 7-year old pavement (Figure 4). By the end of the winter deterioration was much more evident and worrisome. Tests found the penetration value of the asphalt cement (tested with German DIN similar to ASTM D9) in samples from deteriorated areas was 12 and that from nearby areas without visible damage was 28 to 29. Cracking can appear in asphalt concrete pavements when the penetration falls below 30 and is often serious when the penetration is below 20 [6]. Hence, the observed deterioration is consistent with past knowledge and the test results. Significantly, other areas of the runway report penetration values that suggest deterioration will begin in new areas soon. Normally, asphalt pavements at this base last 15 or more years before aging problems like cracking and raveling appear.

Figure 4. Aging Damage in the Form of Cracking and Raveling on a Runway in Germany.

Coring found the damage was limited to only the upper surface lift of asphalt concrete. All other tests indicated the gradations, compaction, asphalt content, etc. should have provided better life than this. Overheating the asphalt concrete at the time of construction remains as the only phenomena that could explain this premature aging of the pavement. Since control of the asphalt temperature is a contractor responsibility, one would normally conclude the premature aging and deterioration of the runway were caused by the contractor's poor construction practices.

This situation is more complex, however. The 1999 rehabilitation of the runway that envisioned only a simple mill of a few surfaces inches of an existing asphalt concrete followed by an overlay turned into a major challenge when water trapped in the thick underlying asphalt layers caused widespread blistering of the new overlay as it was being placed [7]. An innovative design modification using a vapor collection layer eventually allowed the overlay to be placed without blistering. Because this was a NATO-funded project, approval for this modification had to be obtained from the appropriate headquarters committee in Brussels. For three weeks of beautiful construction weather in August, the contractor sat idle while the matter got on the approving committee's agenda and was eventually approved.

The final lift of asphalt concrete was placed in October when the weather was turning cold, and asphalt placement would normally be suspended. The final installation of the runway lights actually occurred during a snowstorm. The contractor undoubtedly increased asphalt temperatures in an effort to cope with cold placement conditions.

Yet he had no options. The runway had to be opened. It was the only instrumented runway on the base and without this runway, the airbase would have not been operational for much of the winter – simply an unacceptable situation. The problem arose because changed site conditions caused a redesign of the project. This was then compounded by slow approval of the necessary changes by the owner. In the end, the only way the contractor could finish the project under the adverse environmental conditions was to use poor construction procedures that would lead to premature failure of the runway. In this case, inadequate initial site investigation and slow owner approvals are the fundamental causes of the construction deficiency.

WORKMANSHIP

The USAF has had an inordinately large number of portland-cement concrete pavement projects that developed spalling at early ages. This spalling developed anywhere from a few days to within a year of placement and varies from extensive large spalls to thin raveling-type spalls (Figure 5). The flyers consider debris from pavement spalls a serious source of potential foreign object damage to jet aircraft engines so development of spalling is a major safety concern in the USAF.

A review of 12 different incidences of early age spalling on USAF airfields found the predominant cause was poor construction techniques that may be augmented by contributions from poor materials, inadequate curing, or operational activities [8]. Typical construction techniques leading to spalling problems include hand repair of excessive edge-slump during slipforming, adding water to the surface to ease finishing, and excessive finishing of the surface. Such activities lead to nondurable paste being left on the pavement surface and to elevation differences between adjacent slabs. Then traffic, environmental effects, snow clearing, etc. rapidly develop spalling on the new pavement.

Unfortunately, there is no simple answer to solving this problem. Much depends on the craftsmanship of the paving crew and the professionalism of the paving superintendent on site. Continuous government inspection is seldom available anymore, and prohibitions against poor

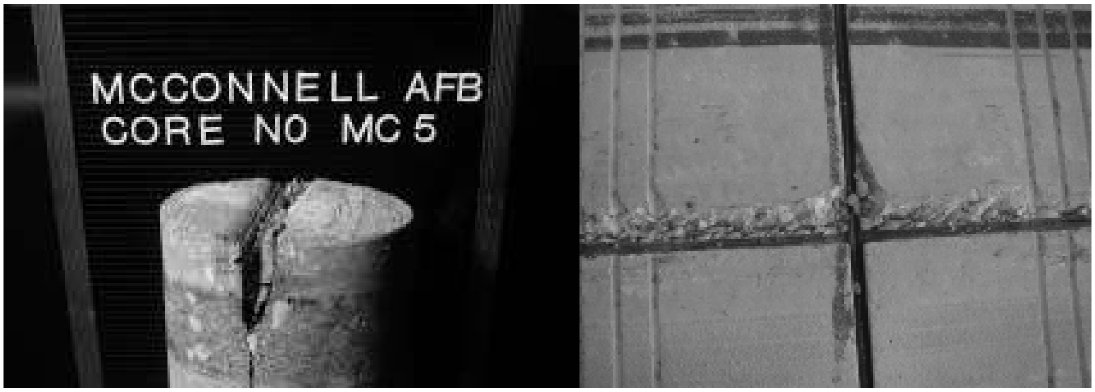

Figure 5. Examples of Early-Age Spalling at USAF Airfields (Left: Core from Runway Joint at McConnell AFB, KS, Right: Runway Centerline Cannon AFB, NM).

practices in the project specifications will not be effective unless embraced by the paving crew in the absence of government oversight. The USAF has mandated use of well-graded aggregate gradations in their airfield portland-cement concrete pavements hoping that requiring use of a mixture that is more easily placed, consolidated, and finished will lead to fewer poor construction practices in the field. The Air Force Institute of Technology has annual classes for USAF civil engineering personnel on pavement design and construction, and the causes of early-age spalling are presented to students. In a parallel effort, the Army Corps of Engineers Transportation Systems Center of Expertise has been conducting workshops for government inspectors and contractor personnel immediately prior to major airfield paving projects. These workshops include discussions of the early-age spalling problems and the role of proper construction practices in avoiding them. Some engineers have begun mandating beveled joint edges hoping to reduce the incidence of spalling, but opinions on the efficacy of this beveling remain mixed. Early-age spalling has been reduced by these various efforts, but the problem continues to reoccur and has not been solved.

HUMAN AND CONTRACTUAL RELATIONS

Animosity Between the Parties. Karl Terzaghi [9] wrote a classic paper discussing the competing views and inherent discord between the owners, design engineers, field construction engineers, and contractors. His biting observations ring as true today as they did 49 years ago. Current examples illustrating this incompatibility between the views of the parties abound. At one military facility in the Great Plains, the government construction department forbade the government design department to even come on the construction site. In another case, the government design engineer adamantly refused to agree to a base course under a rigid airfield pavement because the manual did not require a base on this subgrade. The owner pointed out that two years before on similar soils at a nearby base, construction had bogged down in the fine sands because of poor trafficability. The design engineer remained unswayed. If the contractor needed a base course to build the pavement he could provide it at his own expense, it wasn't going in his design since the manual did not require it. Fortunately, this would be overruled by the owner, but too often there is an atmosphere of open warfare between the disparate parties involved in concrete pavement design and construction.

Fraud and Corruption. These are not new problems in construction. McCullough [10] describes the well-documented corruption and fraudulent substitution of below-strength steel cable in the Brooklyn Bridge in 1878. Fraud and corruption in construction continue today. The U.S. military mandates every lot of joint sealant used on military airfield concrete pavements has to be individually tested by an independent laboratory because certificates of conformance to specification by the manufacturer were found to be totally unreliable. In some cases, over 80 percent of the samples of manufacturer-certified materials failed to meet the specification tests. In a similar vein, Emmons et al [11] noted that only 15 percent of 46 concrete repair materials that were advertised by their manufacturers as expansive, non-shrinking, or shrinkage- compensating actually tested as low-shrinkage materials. Fraud exists and is a real problem in construction, but this is not news to anyone. We must be aware of its possibility and take steps to prevent it.

Inspection. The importance of skilled personnel and independent inspection of construction remain fundamental. The distinguished late New York engineer Jacob Feld noted in his pioneering text on failures [12] that a 1903 editorial in *Engineering News Record* noted the need for concrete work to *be under the constant supervision by skilled foreman, architects or engineers* and a 1918 editorial published by the American Railway Association concluded that

> *The one thing which these failures conclusively point to is that all good concrete construction should be subjected to rigid inspection. It should be insisted upon that the Inspector shall force the Contractor to follow out the specification*s *to the minutest details ... It is believed that only by this kind of inspection is it possible to guard against the failure of concrete structures.*

Feld [12] observed *so the 1903 editorial advice still held in 1918, and the lesson was not learned and is still not learned.* We may simply extend Feld's observation that the lesson remains unlearned in 2007.

Contractual Relations. The USAF desires quality from airfield pavement construction while the contractor must do the minimum possible to eke out a profit under the low-bid system. These are incompatible objectives for the same job. Design-build approaches that are becoming more common for military airfield pavements compound these problems even further as one sees both the design and construction portions of the effort subjected to intense scrutiny to maximize profit and minimize cost. There are alternate procurement methods that try to provide some recognition of best value, but such efforts in the pavement field tend to founder within the constraints of existing bureaucracy.

Low-bid approaches to procurement generally required by law for government agencies are not conducive to getting the highest quality materials and work- factors that are fundamental to achieving long-life pavements. Alternate procurement methods that have been tried such as *design-build*, *request for proposal*, or *best value contracting* have yet to live up to their promise. Recently, a government agency tried using a contractual business model from the environmental cleanup arena that essentially contracted with a qualified A-E firm to rapidly design and build a new runway for the USAF with negligible government input, insight, or on-site personnel. Part way through the construction, a visit by the USAF pavement engineer from the Major Command that was to inherit the runway led to removal and replacement of over a mile of defective concrete, extensive surface grinding and repair, and a three year warranty on repair surface defects. The business model used was inappropriate and the agency plans to never use it again for airfield pavement procurement.

CONCLUSIONS

This short review of typical USAF airfield pavement problems reveals that our primary problem is human shortcomings for which there are not technical answers. While technology will continue to provide ever better and more clever tools and materials, the full benefit of these will never be realized until our human shortfalls are addressed. A sophisticated design with space-age materials built using the most automated construction processes can easily founder from simple human frailties to which we are prone. To fight these we need to remember the fundamental issues, be conscientious in addressing details, check and inspect all work and materials, use interlocking checks and balances between owners, designers, and contractors, and develop contractual methods that emphasize quality of materials and construction that is fairly compensated.

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