SPECIAL DESIGN PROBLEMS AT USAF AIRFIELDS

R. ROLLINGS & M. ROLLINGS,
Rollings Consulting, LLC, USA, rollingseng@earthlink.net
J. GREENE & C. RUTLAND,
Air Force Civil Engineer Support Agency, USA,
James.Greene@tyndall.af.mil, Craig.rutland@tyndall.af.mil

ABSTRACT

The US Air Force has over 170 operational airfield facilities and missions that take them to all seven continents of the world. The special operational requirements of the Air Force and the breadth of environments in which it must operate has sometimes posed unique design requirements. This paper will examine a series of case studies of special design problems that had to be addressed or if not addressed, the impact of failing to adequately address these issues. The specific issues and case studies to be examined will cover

(1) Trafficability during construction
(2) Understanding site conditions
(3) Very soft reclaimed land
(4) Operations in perennially frozen conditions
(5) Sulfates and their unexpected impacts
(6) Material control to achieve desired performance
(7) Long life pavement concepts

1. INTRODUCTION

Pavement design often concentrates on calculations to determine pavement thickness. Numerous texts, professional papers, computer programs, and the like provide detailed methods of assessing load effects, calculating stresses or strains, relating these to material properties and performance, etc. Numerical modeling of pavements and calculation of pavement thickness is at the heart of classical pavement design. However, a complete airfield design must be a holistic assessment that incorporates the vagaries of the site condition, addresses environmental issues, and ensures the construction process meets the design assumptions.

In USAF experience, more problems arise from neglecting some of these other non-analytical aspects of pavement design than in conventional design calculations. This is certainly not to denigrate the importance classical design, as USAF experience suggests when there is a design error, it tends to be quite serious. However, in this paper, we would like to examine some examples from USAF experience of some of these other aspects of design that sometimes are neglected and which we have found to cause us periodic problems.

2. CONSTRUCTION TRAFFICABILITY

To be usable, a design must be able to be built. If there is some aspect of the design or the materials being used that will cause construction difficulty, this should be addressed in the design stage. If it is not, it will raise problems later in the construction and invariably cause delays and more expense during construction.

In the early 1990s, the USAF began mandating high capacity drainage layers of highly permeable open-graded materials. The contractor had the option of providing an unstabilized open-graded aggregates, the same aggregate with a smaller choke stone to stabilize the surface, or the layer could be stabilized with small quantities of cement of bitumen. Invariably the contractor would select and bid the cheaper open-graded aggregate. However, during construction this open-graded material was unstable and easily displaced under construction traffic. It required constant regrading and recompacting until it could be covered with the succeeding layer. This led to many complaints and claims. Today, the designer will normally specify that this be a stabilized open-graded layer simply to avoid these problems during construction.

The pavement cannot be built unless there is a sound foundation on which the contractor can work. Failure to address this during design and contract negotiations can often lead to problems. The design for the rehabilitation of the end of the runway at Patrick AFB, Florida required the removal of the existing concrete pavement and replacement with a somewhat thicker pavement. The subgrade here was a fine sand that is common along much of the southeastern U.S. coastline. The inexperienced contractor on this job was soon swamped with problems with forms that would not stay anchored and concrete delivery trucks bogged down in the treacherous fine sand. When the addition was just a few slabs short of being finished, the contract was terminated because over 90 percent of the slabs failed smoothness tests and the slab thickness varied in places by as much as +/- 50% of the design because of the rutting in the subgrade that was not corrected before concrete placement. A new contractor was brought in to remove and replace the concrete. His first step was to place a 100-mm base of crushed limerock to provide a sound foundation upon which he could work.

Approximately a year later, a design review was examining a proposed new concrete ramp at Hurlbert AFB, Florida that would be on an almost identical fine sand subgrade. A suggestion that the design include a base to provide construction mobility on the fine sands was hotly challenged by the designer as structurally unnecessary. His view was that since it was not needed structurally, if the contractor wanted to put one in for construction reasons, it would be at his on expense.

A contractor does not do anything at his expense. In such a situation, he would be forced to prepare his bid without a base course to win in the low-bid procurement environment. As soon as problems began, he would then file claims and invoke the differing site condition clauses. The USAF would eventually pay for the base course under such conditions - but would pay several times more in a claim situation than it would in a bid situation. The USAF directed the base course be included in the design over the protests of the designer just to avoid the construction dispute problems that were likely if the base was not included. The designer did not recognize that in the long run it was going to be simpler and cheaper to provide the contractor a workable design that is easy to build rather than one where there are hidden problems that will arise once construction begins.

3. SITE CONDITIONS

The soils and conditions at a site are as Mother Nature provided them. The design must address these conditions and overly optimistic simplifications or wishful thinking about what one hopes the site conditions will be can be a recipe for disaster.

In one of the Air Force's first uses of the "design-build" approach for an airfield pavement, a concrete runway was to be extended. The bidders were provided borings in the project vicinity with gradations, Atterberg limits, and soil classifications plus a tabulated collection of design CBR values for various compaction and moisture conditions from past pavement projects at the airbase. Soils in this tabulation were predominately clays classifying as CL or CH by the unified soil classifications system.

The winning bid was $2 million lower than the next nearest bid. Shortly after award of the contract, the winner requested a $2 million increase in the contract award based on changed site conditions. The basis of the claim was worse soil subgrade conditions than anticipated in bidding the work. The contractor had based his design and bid on a subgrade CBR of 7 which had been selected as representative from the tabulated values and borings provided by the government. This was value was for a CL clay on one particular previous project and ignored the bulk of the data provided to the bidders. The project borings clearly revealed a 1.5m thick CH clays at the surface of the project area and other borings revealed the clay existed near the surface throughout the project area. The data provided clearly indicated that this CH clay would provide design CBR values in the 4 or 5 range and not the more optimistic 7 that the contractor had assumed. The contractor failed to recognize the critical soil material in the project area and based his designs on an optimistic guess at the soil strength.

A major expansion of an airfield in a remote and arid region of the Middle East required construction of a parallel taxiway and runway. The runway and taxiway ran along a level plain for some distance and then rose over a low ridge to the north. Surrounding the runway area were several low eroded hills and some barely discernable, low ridges. The surrounding ridges were typically covered with a thin mantle of residual silty gravelly soils developed on igneous rock. The design of flexible pavements for these features called for excavation to weathered rock followed by 200-mm subbase of local silty gravel (CBR of 50), 150-mm base course of crushed stone (CBR of 100) and 100 mm of asphalt concrete surfacing. The weathered rock foundation was assigned a design CBR of 20 (normally the maximum subgrade design allowed in USAF airfield pavement design guidance) and was expected to be actually quite a bit better than that.

Within a few years of completion, the runway and taxiway were closed to logistical aircraft because of severe rutting in the southern ends of the taxiway and runway. More detailed investigation [1, 2] found that the level plain where the southern portion of the runway and taxiway were located was actually a playa - a dry desert lake bed. Rather than a foundation of weathered rock, the pavement here sat on over 10 m of lacustrine deposits of silt and clay with a near surface water table. Rather than a CBR of 20, the real CBR of these wet fine-grained materials was on the order of 4 or 5. Figure 1 illustrates the difference between the designer's view of the site and the real site conditions.

A design, no matter how sophisticated, must accurately assess the true soil and support conditions if it is to provide usable results.

4. RECLAIMED LAND AND VERY SOFT SUBGRADES

The construction of new runways on over 200 hectares of reclaimed land in the Seto Inland Sea for the US Marine Corps Iwakuni Air Station, Japan, is the firstUS Department of Defense airfield to be built on reclaimed land in recent times. However, in civil aviation several major airports have been built on reclaimed land in the last several decades. With increasing competition for available space, future airfield work, both military and civil, can be expected to make use of reclaimed land as the foundation for future airfield pavements.

These soft sediments pose particularly challenging geotechnical problems as they settle are prone to massive settlements after placement. This invariably requires complex analytical assessments of settlement and special designs are needed to speed settlement and to accommodate long-term settlements. For example, Kansai International airport, Japan, which is built on reclaimed land, is predicted to settle 12 m over 50 years and in 2001 had settled 11.5 m [1].

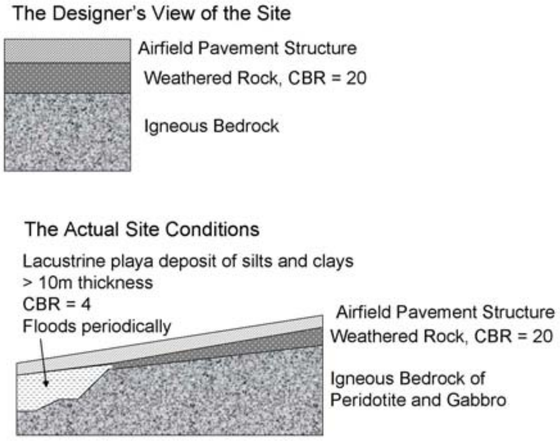

Figure 1 - Difference between designer's concept of the site and actual site conditions

Very soft sediments such as dredged material and phosphate waste clays often are initially more fluid than solid and often comprise the reclaimed land used for airfield, port facilities, etc. Classical geotechnical approaches based on Terzaghi 1-D consolidation theory handle such materials poorly and more robust approaches using finite strain concepts provide better estimates of settlements [2, 3, 4, 5]. When airfield pavements must be built on such sediments, customary geotechnical approaches may be inadequate, and specialists in site improvement and settlement assessment are mandatory.

5. PERMAFROST

The need for military airfields in Alaska, northern Canada, and Greenland during World War II and the ensuing Cold War led to a number of facilities being constructed on permafrost. From experience it was learned the only effective way to deal with permafrost was to keep the permafrost from melting. To accomplish this required thick layers of non-frost susceptible material over the permafrost so the active layer of thawing would never reach the perfmafrost. It was also learned that maintaining the surface organic layer as an insulator was generally prudent. If ice-rich permafrost melted large settlements invariably resulted.

Thule and Sondestrom Airbases were built in Greenland in 1951 and 1942 respectively and both were expanded at various times. The thaw depth in unimproved areas at both bases varied from 1.2 to 2.4 m, and Thule was somewhat colder than Sondestrom (mean annual air temperature of -11^{o}C versus -4^{o}C). Pavement designs at Thule AB required a minimum of 2m of non-frost susceptible fill and base course. During a 1952 expansion of the runway, this was changed to 1 m. There was pronounced subsidence in the thinner sections within a year. Subsidence developed also in two areas of the thicker pavements. Studies during 1953 and 1954 found that painting the pavement surface white lowered surface temperatures about 5^{o}C and reduced thaw penetration about 0.6 m. These studies recommended minimum pavement thicknesses of 2.4 m for future construction and painting the pavement surfaces white. Melting of the ice-rich permafrost below the inadequately thick existing pavements has led to perineal settlement problems requiring repeated repairs. The painting of the runway appears to have allowed the depth of the permafrost to rise below the runway creating a dam for subsurface water flow. This is thought to have been a contributor to massive surface flooding of the airfield in 2002. In 1992, design of a proposed reconstruction of the runway considered use of insulation to prevent permafrost melting but it was rejected as too costly because of the depth of excavation needed to protect the insulation from damage from aircraft loads. Experience at Sondestrom was similar to Thule. Pavements were 1- to 1.9-m thick and the underlying ice-rich permafrost melted with widespread resulting settlements. Galena Air Force Base, Alaska is located on the banks of the Yukon River and was in an area of discontinuous permafrost. Melting of a section of discontinuous permafrost resulted in an 820-m long depression in the center of the runway.

Today, Thule Airbase, Greenland is the only active USAF airfield on permafrost. Experience at various bases on permafrost during World War II and the following Cold War emphasize that it is critical to protect the permafrost from melting after the pavements are in place. Trying to economize and use thinner pavements, as was done several times, results in ongoing maintenance problems for the life of the facility.

6. SULFATES AND DURABILITY ISSUES

Sulfate attack is a well known and extensively documented durability problem with portland-cement concrete. Calcium and alumina from the portland cement, sulfate which may be present in the environment, water, aggregates, or as a contaminant, and water combine to form the expansive mineral ettringite. Ettringite formation is accompanied by an increase in volume that leads to concrete deterioration. To prevent this reaction, sulfate-resistant cements (US Types II and Type V cement) are specified BY THE

Ddesignerwhen concrete will be exposed to sulfates. Sulfate-resistant cements develop their resistance to sulfate attack by reducing the allowable amount of alumina in the cement; thereby removing one of the necessary ingredients for ettringite formation.

Figure 2 shows an example of sulfate attack on a cement-stabilized base course at Holloman AFB, New Mexico. Type V cement was used for the stabilization of the local fine-grained soil, but sulfate resistant cements are ineffective under these conditions. In the high pH environment typical of stabilization, alumina in the soil's clay minerals is highly soluble and is released into the pore water. This provides the necessary alumina for ettringite formation, and the low-alumina content Type V cement provides no protection. An identical chemical process occurs with lime-stabilized materials, and a USAF runway with a lime-stabilized base in Texas had to be reconstructed because of sulfate attack. At present, there is no reliable military guidance on allowable sulfate exposure levels or conditions for lime or portland-cement stabilized materials or on adequate protective measures [6}.

Figure 2 - Swelling caused by sulfate attack on cement-stabilized taxiway base course at Holloman AFB, NM.

Another project at Holloman AFB used 0.6 to1.5 m of crushed recycled portland-cement concrete as fill and base course under two aircraft hangars and adjacent ramps and taxiways [7]. Even though this concrete was made with Type V cement and had existed for over thirty years as an aircraft apron without reacting, it is now undergoing sulfate attack with resulting heaving of overlying pavements and floors and cracking of building walls. This problem is still under investigation, but preliminary conclusions are that when the concrete is crushed additional alumina reaction sites are exposed, permeability is greatly increased allowing ample water access to support ettringite formation, and when placed under buildings and pavements, the moisture content increased compared to previous exposure conditions as a concrete pavement. At present the USAF and Corps of Engineers suggest not using recycled concrete in applications where it will be exposed to sulfates.

7. MATERIAL CONTROL

If the materials used in an airfield pavement design fail to meet the requirements placed in the project specifications by the designer, the performance of the pavement may be sorely compromised.

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 - 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

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). 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. These aggregate popouts posed a safety risk and operations from the ramp were severely affected.

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.

It is simply imperative that the materials used in airfield pavements meet the performance and durability requirements set forth by the designer.

Figure 3 – Popouts from unsound aggregate

8. LONG-LIFE PAVEMENT CONCEPTS

Langley AFB is the oldest USAF base in continuous use and dates back to 1917. A current project is replacing a runway at Edwards AFB that has been in service for over 50 years. Clearly the USAF needs to take a long term view of its pavement infrastructure. Past approaches have emphasized a low initial cost, low-bid approach to materials and construction, and a nominal twenty year life for the pavement. However, there is certainly a need now for the USAF to consider designing and building airfield pavements intended to last longer and to be more cost effective. Two recent conferences in the US reflect this growing interest in adapting US pavement philosophy to embrace concepts of designing and maintaining pavements for much longer lives than we have traditionally considered [8, 9].

An assessment of the problems facing the USAF in implementing long-life pavement concepts for concrete airfield pavements found that much of the difficulty lay in assuring the materials used in pavements would meet these requirements and in achieving the necessary quality of construction to provide long life [10]. The USAF is presently periodically encountering shortened pavement life because of poor material control or poor construction and these must be fixed before long-life pavement concepts can be achieved in the field. Basic USAF airfield design concepts are probably compatible with long-life concepts, but there would be some improvements that would require investigation. Certainly, high initial investment pavements such as prestressed concrete pavement might well become more attractive when considered for a 50 year or longer life.

Adapting USAF asphalt concrete airfield pavement design approaches to long-life concepts would face a similar struggle to achieve the needed quality in materials and construction as with portland-cement concrete airfield pavements. The USAF has generally relied on, and been well served by, building flexible airfield pavements with relatively thin asphalt surfaces on high quality crushed stone base courses. In considering the challenge of designing for a life several times greater than present practice it may prove necessary to use thicker asphalt surfacing. If one plans to achieve long life by only periodic surface maintenance of the asphalt concrete, then the asphalt surface must be thick enough to avoid fatigue cracking on the bottom of the asphalt layer. Ideally, the design would see top-down cracking develop, which could be maintained by surface milling and replacement with new asphalt concrete, rather than fatigue cracking at the bottom which would necessitate removing and replacing the whole asphalt concrete layer.

9. CONCLUSIONS

An airfield pavement design must be structurally sound and environmentally durable. This paper has illustrated non-traditional issues that may impact design based on USAF experiences. Some lessons learned from a USAF perspective include:

1. The designer needs to be sure that the pavement design and materials provide workable construction surfaces for the contractor. Several times this has been the issue at the heart of some construction disputes and claims in USAF airfield pavement construction.

2. A specific pavement design is based on an image or concept of what the site support conditions will be. If the designer’s concept does not match the site realities, expensive failures are likely.

3. As economics and lack of space drive us to build on particularly poor site conditions, such as reclaimed land, our conventional geotechnical solutions may provide overly optimistic predictions. As the problems become more difficult, the assistance of specialists knowledgeable in the issues and robust theoretical tools are needed.

4. Some site conditions, such as the permafrost in the examples cited in this paper, may mandate expensive solutions. Attempts to short cut these will seldom work, and expensive failures and maintenance are likely to result.

5. Certain problems such as sulfate attack on portland-cement concrete have well-established technical solutions. However, when we change the application to cement-stabilization of clayey soils or recycling concrete within the pavement structure, our

standard solutions fail to provide protection in this new application.

6. Materials used in the airfield pavement structure must be sound. Even small deviations from the specifications, such as for the fines in non-frost susceptible bases cited here, can have unfortunate consequences. Under the press of time, one may grasp at a poorer quality material, as with the concrete aggregate at the Middle Eastern airfield cited here, only to find that soon one is saddled with ongoing maintenance and operational headaches that overshadow the savings in time that was originally achieved.

7. As we begin to embrace concepts of long-life pavements the importance of materials and construction quality become the key to success or failure. Once one begins to design pavements with a view to long term performance, new design concepts and types of pavements may become more attractive than they have been in the past.

ACKNOWLEDGMENTS

Support of the Air Force Civil Engineer Support Agency in preparing this paper is gratefully acknowledged. Thanks are also due to our colleagues in the military airfield pavements community whose experience, ideas, and discussions provide the background of this paper. The opinions expressed here are those of the authors alone and do not reflect any official government position, policy, or opinion or that of any other individual.

REFERENCES

1. American Society of Civil Engineers. (2001). “Airport Expansion Proceeds Despite Rapid Sinking,” *Civil Engineering*, Vol. 71, No. 3, pg 10.

2. Palermo, M. R., J. E. Clausner, M. P. Rollings, G. L. Williams, T. E. Myers, T. J. Fredette, and R. E. Randall. 1998. “Guidance for Subaqueous Dredged Material Capping,” WES TR-DOER, USAE Waterways Experiment Station, Vicksburg, Mississippi.

3. Rollings, M. P. 1994. “Geotechnical Considerations in Dredged Material Management,” *Proceedings, First International Congress on Environmental Geotechnics*, International Society for Soil Mechanics and Foundation Engineering and the Canadian Geotechnical Society, Edmonton, Alberta, Canada, pp. 21-32.

4. Townsend, F. and M. McVay. 1990. “State-of-the Art, Large Strain Consolidation Predictions,” ASCE *Journal of Geotechnical Engineering*, Vol. 11, No. 2, pp 222-243.

5. Schiffman, R., V. Pane, and R. Gibson. 1984. “The Theory of One-Dimensional Consolidation of Saturated Clays: IV. An Overview of Nonlinear Finite Strain Sedimentation and Consolidation,” *Proceedings ASCE Sedimentation, Consolidation Models*, American Society of Civil Engineers, San Francisco, California.

6. Rollings, R., J. Burkes, and M. Rollings. 1999. “Sulfate Attack on Cement-Stabilized Sand”, ASCE *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 125, No. 5, pp. 364 - 372.

7. Rollings, R., M. Rollings, T. Poole, G. Wong, and G. Gutierrez. 2006. “Investigation of Heaving at Holoman AFB, New Mexico,” ASCE *Journal of Performance of Constructed Facilities*, Vol. 20, No. 1, pp 54-63.

8. Auburn Universtity. 2004. *Proceedings, International Symposium on Design and Construction of Long Lasting Asphalt Pavements*, Auburn, Alabama.

9. Federal Highway Administration. 2006. *Proceedings, International Conference on Long-Life Concrete Pavements*, Chicago, Illinois.

10. Rollings, R. and J. Greene. 2006. "U.S. Air Force Perspective on Long-Life Concrete Airfield Pavements," *Proceedings*, *International Conference on Long-Life Concrete Pavements*, Chicago, Illinois.