

SOVIET PRECAST PRESTRESSED CONSTRUCTION FOR AIRFIELDS

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ABSTRACT

The Soviet Union used precast concrete slabs as routine pavement construction for roads and airfields and standardized the PAG-XVIII slab for airfields. These 2m x 6 m x 18 cm slabs are prestressed longitudinally and provide excellent load carrying capacity. In fact, an airfield in Uzbekistan supported intense US Air Force C-17 aircraft operations for several years without any structural distress. These slabs were even the thinner PAG-XIV slabs rather than the more robust PAG XVIII slabs (14-cm thick rather than 18 cm). Past history in the former Soviet Union found these precast, prestressed slabs to be structurally sound for aircraft operations and they also offered particular advantages for construction in adverse weather, rapid installation, maintenance on unfavorable soils, and construction in remote or environmentally sensitive areas. This paper will use the author's many years of experience with these slabs in Russia to describe the design, materials, construction, and performance of this precast, prestressed Russian concrete pavement technology that is little known in the West.

INTRODUCTION

Precast concrete construction for pavements has periodically been examined in the United States, but despite some perceived advantages, the increased cost and difficulty in matching smoothness achieved by cast in-place concrete pavements has limited US precast pavement technology largely to research evaluations and as a solution for a few specialized problems (e.g., 1, 2, 3, 4). Recently, innovations in construction technology have once again sparked US interest in precast concrete pavements (e.g., 5). In the Soviet Union, precast concrete pavement technology offered specific advantages for road and airfield construction in some circumstances and developed to be a standard solution for certain applications. This paper will describe Soviet precast technology used for airfields, USAF interest in Soviet precast airfield pavement, and recent enhancements to this technology.

BACKGROUND

The Soviet Union began building its first concrete airfield pavements in 1931-1932. These were constructed using unreinforced concrete hexagons 1.2-m (48-in.) long per side and 100- to 140-mm (4- to 5.5-in.) thick (6, 7). As aircraft became heavier, the hexagon length was increased to 1.5 m (60 in.) and thickness increased up to 220 mm (8.8 in.). An example of these hexagonal pavement slabs is shown in Figure 1. These unreinforced hexagonal slabs often had problems with rocking and spalling, and as modern concrete placement equipment became available after 1950, rectangular, cast in-situ pavement slabs became more common.

The Soviet precast concrete industry was well developed, and precast pavement construction continued to evolve as an alternative method to cast in-place concrete pavements in the USSR and allied nations. Soviet technical literature of the 1960s and early 1970s contains a number of descriptions of precast concrete road pavements as temporary roads, under heavy industrial traffic in the Donbass, on the Kiev-Odessa highway, in the Moscow area, and elsewhere with generally favorable assessments (2). In the airfield arena, reinforced concrete was recognized as superior to unreinforced, prestressed pavements were considered the best for efficient use of materials, but precast, prestressed pavements were considered particularly promising as the plant manufacture ensured high quality (6). Nevertheless, unreinforced concrete remained the most



Figure 1. Example of precast unreinforced hexagonal concrete slabs on an airfield (approximately WWII era pavement and still in use).

common airfield surfacing because of its simplicity of construction and technology despite a number of significant shortcomings (6).

Table 1 shows characteristics of standardized airfield precast slabs standardized for use in the USSR as reported in 1962 (8). By 1970 the PAG XIV precast slab was the standard approved slab for airfields and a number of plants were capable of production of such slabs (6). Since the end of the Cold War, this slab has been encountered several times by the US Air Force (USAF) when operating in areas previously dominated by the old Soviet Union. An example of a PAG XIV slab is shown in Figure 2. These slabs are 2 m x 6 m x 14-cm thick (80 in. x 240 in. x 5.6-in. thick). They are reinforced with a double layer of 12-mm diameter bars longitudinally and laterally and with mesh. Two lifting loops are exposed on each side of the slab. After placement, these are welded together (Figure 3), and the joint is filled with mastic. The longitudinal bars are pretensioned prestressed using an electrothermal method. This method leads to a 10 to 12 percent coefficient of variation in the prestress level. Concrete is specified to be grade 300 (28 day cube strength of 300 kgf/cm² or approximately 3,400 psi cylinder compressive strength), and prestress levels are reportedly 0.15 to 0.25 of the concrete strength. Sometime after reference 6 was published (1970), a thicker PAG XVIII slab (18 cm vs 14 cm, 7.2 vs 5.5 in.) similar to the PAG XIV was standardized for airfield use. The quality of precast slabs tended to be highest in the Moscow-St Petersburg areas and in plants dedicated to military construction.



Figure 2. Example of PAG XIV precast airfield slabs (probably constructed early 1980s, still in service).

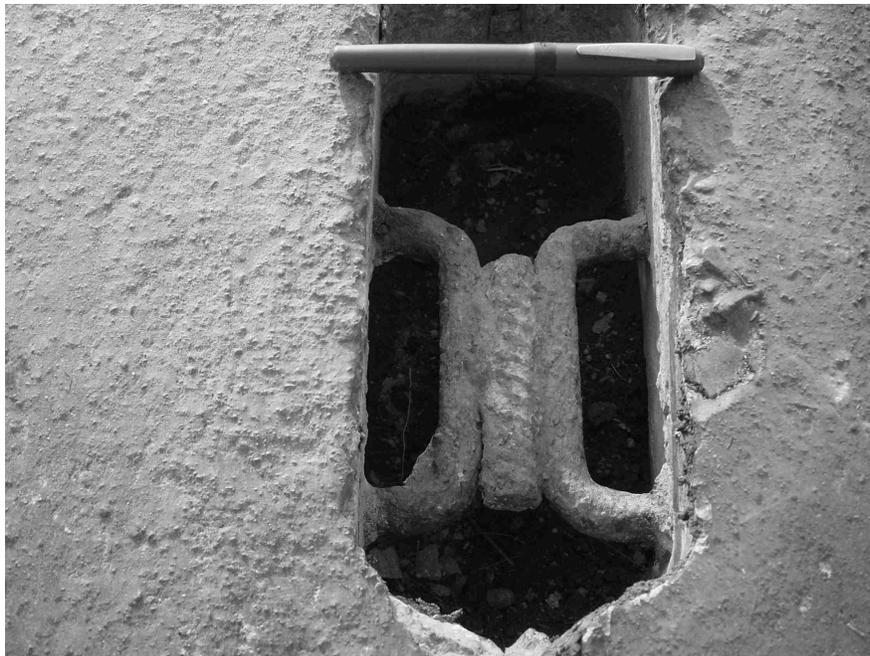


Figure 3. Example of welded lifting loops in joints. (mastic removed, pavement approximately 25 years old)

Table 1.
Soviet Precast Airfield Slabs Identified by Gerberg and Osipon in 1962.

Designation	Size (ft x ft x in. thick)	Weight (tons)	lb reinforcing/ft ² of slab
PAG III	6.6 x 13.1 x 5.5	3.1	2.43
PAG IV	6.6 x 13.1 x 5.5	3.1	1.74
PAG IX	10.5 x 19.7 x 5.5	7.4	1.09
PAG XIV	6.6 x 19.7 x 5.5	4.6	2.37
PAG XV	6.4 x 19.2 x 5.5	4.6	1.55
PAG XV-1	6.4 x 19.2 x 5.5	4.4	1.73

Notes: PAG IX biaxially prestressed with 400 psi longitudinally and 300 psi transversely. All others prestressed only longitudinally. Based on Table 35 in reference 8.

PRECAST AIRFIELD PAVEMENT TECHNOLOGY IN THE SOVIET UNION

Table 2 presents a set of recommended concrete airfield surfacings for different loads from 1970 (6). The precast prestressed PAG XIV slabs were suitable for a range of loads but not the heaviest loads. While biaxially prestressed concrete was recognized as superior to uniaxial prestress, most Soviet plants were set up only for uniaxial prestress manufacture. The precast slabs were deemed particularly advantageous for construction in freezing weather, rapid pavement construction, upgrades of existing facilities, and dealing with problems associated with expansive soils. For military airfields, they had the added advantage of being easily repaired following enemy attack if stockpiles of precast slabs were maintained on site (Figure 4). The precast slabs were designed according to the same concepts as other concrete surfaces (e.g., Winkler foundation, load stress calculation, factors for workmanship and loading effects, assessment of flexural resistance to cracking and prestress on allowable repetitions, etc.).

Table 2.
Suitability of Concrete surfaces for Soviet airfields.

Type of Concrete Surfacing	Category of Load					
	I	II	III	IV	V	VI
Cast in-situ prestressed PCC	+	+	+	-	-	-
Reinforced PCC	+	+	+	+	+	-
Precast prestressed slabs of plant manufacture	-	+	+	+	+	-
Unreinforced concrete	-	-	-	-	+	-

Notes: Based on tables 26 and 27 of reference 6

+ suitable

- not recommended

Load Categories

I - Four-wheel gear with 144,000 lb load at 142 psi

II - Four-wheel gear with 121,000 lb load at 142 psi

III - Four-wheel gear with 88,000 lb load at 142 psi

IV - Single wheel gear with 66,000 lb load at 142 psi

V - Single wheel gear with 12,000 lb load at 85 psi

VI - Single-wheel gear with load of 11,000 lb at 57 psi

Depending on the airfield location, local soils and drainage conditions, type of loads, and specific surfacing requirements, a base course will be needed under all rigid pavements; only under the most favorable subgrade soil and climatic conditions would a base not be used (6). Soviet pavement philosophy saw sand as the simplest base for concrete pavements as it provided improved working conditions, low coefficient of friction, uniformity of support, good drainage, economical, and widely available (6). The base should be composed of clean, medium to coarse sands with less than 4 to 7 percent of the particles finer than 0.05 mm. The upper limit on 0.05-mm sized particles is for coarse sands in moderately wet areas and the lower limit is for medium sands in wet areas. Alternately, crushed stone and gravel mixtures can be used when pumping of fines from underlying fine-grained soils into the base is not a problem. Also, soils and aggregates can be bound with bitumen or portland cement to provide a bound base. The thickness of the sand or gravel base might vary from 4 to 6 in. on sandy subgrade soils to 10 to 20 in. on fine-grained soils depending on the climate.



Figure 4. Precast slabs stockpiled at previous Soviet military airfield to be used for rapid runway repair. Note this is not one of the standard precast slab designs discussed in the paper.

Placement of precast pavement slabs for airfield construction as described in reference 8 proceeds as follows:

1. Truck cranes remove slabs from their transporter (railroad flatbed, truck, etc.) into piles not more than 5 or 6 slabs high and with wooden spacers between slabs (see Figure 4 for an example view of the spacers). Approximately 100 to 130 slabs should be unloaded per crane per shift.
2. The slab edges are primed with mastic.

3. The slabs are transported to the paving site by truck when the sand base is ready. This base should be prepared to a smoothness tolerance of +/- 3mm (1/8 in.). If a bedding layer of cement-sand is to be used this is usually mixed on site with the sand moisture not exceeding 5 or 6% and the slab should be placed on this material within 4 or 5 hours of mixing.
4. The slab is lifted from the truck with a crane and lowered vertically onto the sand base without horizontal movement. Elevation tolerance between adjacent slabs should not exceed 5 mm, and joints should not be more than 15-mm wide. Load is released from the crane cable for 20-30 seconds, and then the slab is raised again to check that intimate contact is made between the slab and its foundation. Any irregularities are corrected in the sand surface, and the process is repeated perhaps as many as 3 or 4 times until a good fit is made between slab and foundation and tolerances are met.
5. After two slabs are unloaded the crane is positioned on them to continue work and the tolerances are checked again.
6. After a 10 to 15 m section of slabs has been placed, they are rolled with a pneumatic or a vibratory roller.
7. To avoid the repeated lifting and lowering of the slab, some jobs have used a vibrating unit placed on the slab to level and seat the slab and improve contact. This greatly speeds the operation over the trial and error lifting and lowering approach described in section 4.
8. The lifting loops are welded together. Good welding techniques are mandatory. If the spacing between the bars is 4 mm or less, they are welded together in a single weld. If the spacing is greater than 4 mm, then a reinforcing bar whose diameter is 3 to 4 times greater than the gap is placed on the lifting loops and two welds are made (see Figure 4 for an example of this). The welded connection is then trafficked with 2-3 passes of a fully loaded MAZ-200 or YaAZ-210 truck. Any broken welds are rewelded. The gap where the loops have been welded is cleaned and then filled with mastic.

USAF OPERATIONS AND SOVIET PRECAST SLABS

With the end of the Cold War, US interests led to the USAF operating from or contemplating operating from airfields that had the Soviet-era precast prestressed slabs as part or all of their airfield pavements. This poses a number of interesting technical challenges:

1. The USAF bases its airfield pavement structural design and evaluation on a Westergaard-edge loaded analytical model formulation, load transfer between slabs by appropriately designed joints, and a fatigue curve based on field performance in full-scale accelerated traffic tests (9, 10). The dimensions of the PAG XIV-type slabs do not meet the assumptions of a semi-infinite slab used in Westergaard formulations. Hence the bending is more related to one-way bending of a beam on an elastic foundation formulation rather than classical Westergaard models using two-way slab bending. For this reason, a Westergaard-based analysis would tend to underpredict stresses in the slab and fail to recognize the increased importance of the supporting foundation in carrying the load.

Consequently, existing USAF airfield pavement design and evaluation manuals, nomographs, and computer programs would fail to accurately analyze these Soviet-era pavements.

2. The welded loops in the slabs obviously play a role in obtaining and maintaining slab alignment, but it is less clear that they provide load transfer in the classical manner assumed in conventional USAF airfield analysis.
3. The USAF design procedure for prestressed pavements mandates biaxial prestressing in order to obtain post-cracking moment distribution that allows design in the plastic range (11). The failure mode in this design concept is negative moment cracking in the slab surface and is intended for very large expanses of prestressed pavements and requires biaxial prestressing. The uniaxial prestressing encountered in the PAG XIV-type slabs represents a very different circumstance. This prestress in the longitudinal direction will help to counter the higher bending stresses in that direction. The conventional reinforcing in the transverse direction will help keep cracks in that direction closed. This mixture of prestressed and conventional reinforcing is similar to a partially-prestressed concrete concept (12) rather than conventional USAF prestress design. However, the USAF has no information on how this partially prestressed pavement slab will perform under aircraft sized loads for these slab dimensions.

In order to learn more about the behavior of PAG XIV-type slabs to aircraft load, a joint study is being conducted by the Air Force Civil Engineering Support Agency (AFCEA) and Air Force Research Laboratory (AFRL) at Tyndall AFB, FL and the Army Engineer Research Development Center (ERDC) at the Waterways Experiment Station, Vicksburg, MS. This study will include accelerated traffic tests during the summer of 2007 of 2m x 6m x 14-cm thick slabs on two subgrade support conditions and two wheel loads representative of a logistical aircraft and a tactical aircraft. The slabs are prestressed longitudinally with nominal 500 psi prestress and conventionally reinforced transversely. While these test slabs are roughly modeled on the PAG XIV slabs the USAF has encountered in several places, the actual details of such slabs remain uncertain and US materials and manufacturing methods will lead to differences between the actual Soviet slabs and the test slabs. The purpose of the testing is to get insight into the behavior under aircraft loads of thin relatively narrow uniaxially prestressed slabs and to develop possible structural analysis concepts for these types of pavements.

As a preliminary analysis approach, the investigation team is basing structural calculations on the ISLAB 2000 finite element computer program that models the surface slab with 2D bending elements and the subgrade support with Winkler-type springs. It can incorporate a second layer of 2D bending elements to allow more detailed analysis of the slabs over an existing pavement or stabilized layer. Cracking will be assessed using the conventional military field fatigue criteria (9) and simple superposition of flexural strength and prestress will be assumed to resist cracking in the longitudinal direction. Allowable deflection criteria will be based on work done before for thin steel-fiber reinforced airfield pavements (13).

The USAF has operated extensively from only one airfield with precast Soviet-era slabs which matched the descriptions of the PAG XIV slabs. The climate and soil conditions were generally favorable and the precast slabs had been placed over a previously existing 8-in. thick concrete pavement about 20 or 25 years before. Thin sand and sand-cement mixture were used as a bedding layer between the precast slabs and the underlying pavement in different areas of the airfield. After extended C-17 operations there was no sign of cracking or damage to the slabs. However, the C-17 did break the welded loops and there was some creep of the slabs allowing the center-crowned runway to open a number of inches in some places along the centerline joint (Figure 5). When the above described analysis approach was used with this pavement and the underlying pavement and foundation were analyzed by using a single high modulus of subgrade reactions (i.e., spring constant, k), the analysis showed rapid cracking of the slabs which had not occurred in the field. When the option to analyze the precast surface slab and underlying pavement as separate layers was used with the spring constant representing only the base and subgrade the results were more realistic. That analysis predicted initial cracking in the slabs to be well past the actual applied C-17 traffic which was consistent with the observed lack of cracking. Nuances of modeling decisions have a major influence on the outcome of the analysis.



Figure 5. Opening of the centerline joint on a crowned runway thought to be due to breaking of loop welds under heavy C-17 traffic.

The USAF must be able to determine if existing airfields using Soviet-era precast slab can structurally support anticipated operations. This cannot be done with existing USAF pavement design and evaluation tools, and more robust analytical tools and new criteria are needed for this task. Current studies and tests are aimed at accomplishing this objective. In some cases the USAF traffic is more severe than that for which these designs were originally envisioned to support as in Table 2 (e.g., the C-17 often operates with a gear load of a quarter-of-a-million pounds and tactical aircraft often have tire pressure more than twice as high as that shown in

Table 2. In addition, military operations will often continue past conventional civilian concepts of design failure in the pavement. Most of the precast pavements that the uSAF is encountering are older pavements built between WWII and perhaps the early 1980s. Hence, the older Soviet writings on the topic (e.g., 6, 7, and 8) probably provide the best insight on the pavements actually being encountered in the field.

INNOVATIONS AND RUSSIAN EXPERIENCE

Crushed granite is the preferred aggregate for these precast prestressed slabs in Soviet experience. At a precast plant in Kirov, load tests on precast prestressed slabs made with gravel found that flexural cracks that formed under the test loads failed to close after unloading. These cracks should have been closed by the prestress forces. Use of crushed gravel did not solve the problem. Hence, the quality of the aggregate plays a significant role in behavior of these structural systems.

The first author also developed enhanced designs for these precast prestressed slabs using enriched limestone materials, essentially a quarry waste product that normally finds little use in construction. Some 500 slabs (1.75m x 3.0 m x 0.16m) were produced at Moscow Precast Concrete Plant No. 10 during September and October 2003 using this concept. These slabs were used as reusable temporary access roads for building construction, often in terrible muddy conditions under heavy truck traffic with no complaint of inadequate performance or slab failure. The key is optimizing the limestone material in the concrete mixture to both use an economical waste material and improve flexural strength that in turn improves the slab load capacity. This concept was patented with the US Patent Office (US 7,004, 673 B2 Feb 28, 2006).

The paper's first author spent most of his career working in Russia working in the precast industry and with the precast pavement industry there before emigrating to the US. During this career, he observed that the precast prestressed pavement slabs performed well in a variety of often very demanding circumstances. For example, western Siberia is the heart of the Russian gas and oil region, and construction here is difficult. The land is either a great swamp or is tundra; the weather is severe; construction seasons are short; there is almost no existing infrastructure; and it is remote. Precast prestressed slabs were the key to successful road building in this region to support oil and gas operations. Slabs for this construction were manufactured in plants in Moscow and elsewhere in European Russia and shipped to this region for construction. The first author served as Chief of Laboratory for concrete, reinforcement, and precast members and had ample opportunity to observe and analyze the behavior of these precast pavements in Western Siberia. Such experiences lead him to conclude that the advantages of precast prestressed concrete pavement have yet to be exploited in the US. For example:

1. Precast pavement systems can be manufactured outside of disaster areas and shipped by rail or truck into the disaster area such as Hurricane Katrina. Then they can be used to restore transportation arteries, build temporary access or parking areas, etc.
2. They are a natural solution for temporary roads in wetlands or other sensitive ecological or historical areas.

3. They are a recoverable, reusable resource for industrial applications such as oil well drilling or mineral exploitation that allow the natural environment to be restored upon removal.
4. In areas where expansive soils exist or where highly compressible soils exist (e.g., port facilities over dredged material), precast systems have the ability to be periodically taken up and allowing grade corrections to be made, and then they can be relaid.
5. Industrial and transportation arteries in Alaska face many of the same challenges that precast pavement systems solved so well in western Siberia. Similarly, rapid construction of roads in remote areas such as will be required by new border facilities can make use of these concepts.
6. Precast pavements also will allow the US to exploit its famous abilities to mechanize systems for enhanced quality and to take advantage of the economies of scale.

CONCLUSIONS

This paper has examined evolution of precast pavement technology and airfield applications in particular in the Soviet Union and more recently in Russia. Use of such technology has developed more extensively in the old Soviet Union than it did in the US for a variety of climatic, geographic, social, and political reasons. As US interest in precast pavements is again rising, this Russian experience provides a timely aid. Certainly, the US has not exploited the potential for precast pavements yet.

As the international political climate changes, the USAF has found that it needs to operate from airfields constructed with Soviet-era precast prestressed slabs. These represent a considerable departure from conventional concrete pavements found in Western Europe and North America, and existing USAF guidance on structural design and evaluation is inadequate for such pavements. Consequently, a test program is underway to better understand these pavements, their critical behavior modes, and how they should be evaluated for USAF operations.

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