STATUS AND DEVELOPMENTS IN THE CONSTRUCTION OF PRESTRESSED CONCRETE RUNWAYS IN EUROPEAN AIRPORTS

Dipl. Ing. Fritz Klunker

Various methods for prestressing concrete pavements and their performances over the years are evaluated. The article gives the design criteria for prestressed concrete pavement and then recommends construction principles and procedures.

The search for technically perfect and, at the same time, economical solutions for reinforcing runways has led in the last years more and more to the use of post-tensioned pavements. However, as project specifications show, opinions still differ considerably on the correct design criteria and parameters. It is, therefore, desirable to hear more about the experience with prestressed runways in service at various airports to obtain a clear picture for an optimum design.

This paper, therefore, intends to show the developments in the construction of prestressed concrete pavements in Europe. They serve best to evaluate the problems inherent to the different designs.

In general, we can distinguish between two principal designs for prestressed pavements:

1. External prestress.
Jacks or wedges are used to compress straight runways without longitudinal prestress tendons against abutments at the ends.

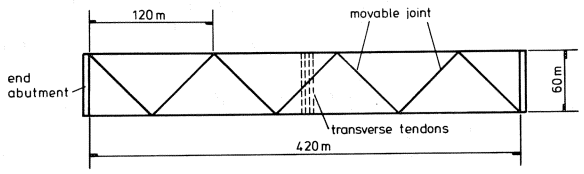
2. Methods using internal prestress include:

2.1. The longitudinal tendons are stressed in a stressing bed and then the concrete is poured in longitudinal strips. The transverse tendons are placed in sheathing ducts and stressed after the concrete of the entire runway has hardened.

2.2. Sheathed longitudinal and transverse tendons are stressed and grouted after the concrete has gained sufficient strength.

The method described under 1. was developed in France after 1945. The first pavement of this type was built at the Orly airport in Paris in 1946. The 420 m long, 60 m wide and 18 cm thick test slab was subdivided in a series of right angled triangles with their joints at a 45° angle to the longitudinal axis of the runway. Both ends of the runway were confined by fixed abutments. The slab was prestressed in transverse direction while the steel lined joints could move against each other. (Fig. 1)

Fig. 1. First prestressed concrete test section 1946 in Orly/Paris

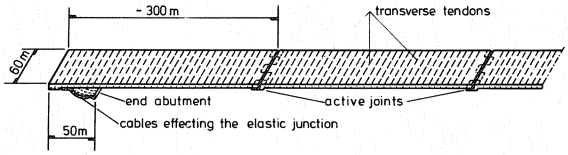


It was difficult to place the concrete in the triangles, since this could not be done by paving machines. The tendons started to corrode in the joints and failed after some time.

The above mentioned method was further developed in France and today the still existing runway at the Maison Blanche Airport in Algeria shows the following picture:

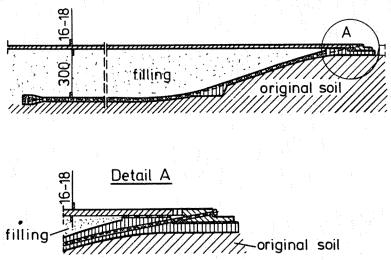
While several projects have used fixed abutments at the runway ends, at Maison Blanche elastic abutments were installed 3 m below the prestressed concrete slab for a length of about 57 m and then loaded with the weight of the backfill and the slab. (Fig. 2)

Fig. 2. Schematic view of the prestressed slab with elastic end abutments.



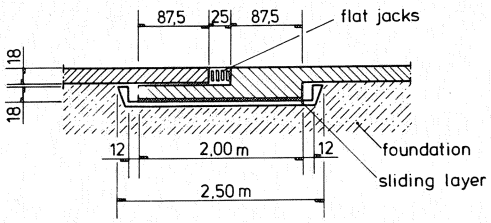
The tendons in the abutment are unbonded and retain the concrete runway slab. (Fig. 3)

Fig. 3. Sectional view of the prestressing joint at the abutment



Every 300 m there is an"active joint" with FREYSSINET flat jacks. (Fig. 4) Additional flat jacks were installed every 100 m and put under load together with the others. These temporary jacks were removed section by section after 3 to 6 months and then the blockouts filled with concrete. To compensate for the changes in length and in the compressive stresses in the slab resulting from creep and shrinkage, the jacks in the "active joints" were left in place and reloaded from time to

Fig. 4. Sectional view of an active joint.



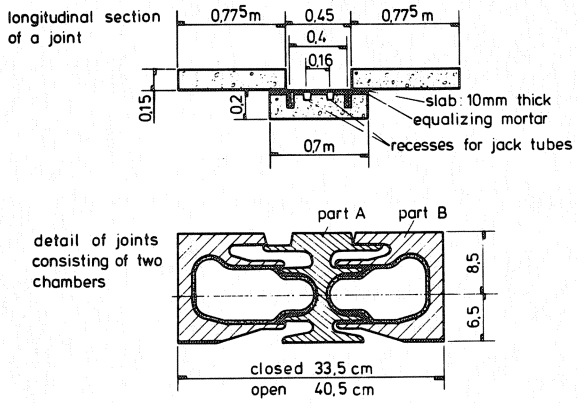
time even after the runway had been completed. (see references 1.)

This way the jacks keep the concrete slab in compression longitudinally and there are - except for the runway ends - no movements in the slabs because of varying temperatures. The temperature changes only cause a variation in the compressive stresses, while at the lowest possible temperature the concrete still should be under compression. With rising temperatures the compressive stresses increase and the abutments now have to take a considerable force, more than 300 Mp/lin.m. of the slab width. Of course, this calls for very heavy abutments and the properties of the subsoil are an important factor.

The critical influence temperature variations can have indicates that this system is more suited for areas with a fairly balanced climate, while repeated temperature changes are a disadvantage and can cause damage. In a greater, quick drop in temperature the compressive stresses decrease too far resulting in transverse cracks, while with sudden warmer temperatures the tendons in the abutments can be overloaded and yield. Especially critical points are the areas in contact with the wedges or jacks and other irregularities in the cross section. Even slight excentricities can cause the slab to warp or buckle.

This system was used in Central Europe for a number of prestressed slabs, especially road pavements, were subjected to compression this way. For prestressing the concrete slab against abutments also other systems have been used, such as, for instance, wedges or double wedges. These were precast concrete wedges with steel liners which were pressed into the gaps between slab sections by means of post-tensioning bars. Also various joint systems were tried in test slabs, as, for example, elastic pneumatic joints. (Fig.5) They allowed adjustments of the compressive stresses in the slab according to the variations in temperature. However, these adjustments are limited for economic reasons, since the structure should not be constantly dependent on the reliability of

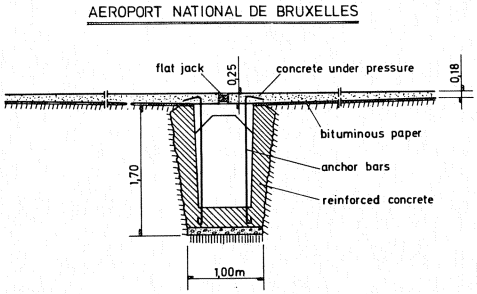
Fig. 5. Pneumatic joint consisting of two chambers.



a mechanical system and its maintenance. (see reference 3.) For all these systems the climatic conditions were not as favorable as those in the Mediterranean countries. But even the runway of MAISON BLANCHE is not free of defects such as those described above.

A specific example is the runway of the airport in BRUSSELS which had been designed by Prof. Paduart more than 20 years ago and was built in prestressed concrete. The runway is 3300 m long, 45 m wide and 18 cm thick. It is compressed in longitudinal direction against fixed abutments using flat jacks and then posttensioned in transverse direction. Every 330 m, similar to MAISON BLANCHE, there is an "active joint" situated above an access tunnel. The slab thickness is increased by 7 cm in this area and dowel bars anchor the slab to the tunnel base to prevent buckling. The flat jacks can be operated from the tunnel. (Fig. 6.)

Fig. 6. Cross section through active joint



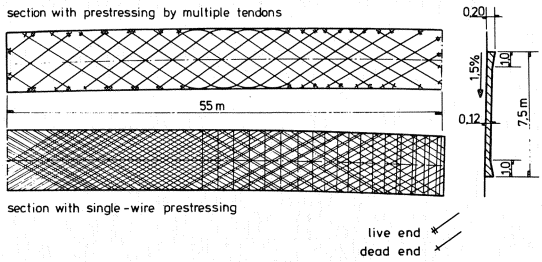
In between the "active joints" temporary joints were provided with a spacing of 110 m to operate additional flat jacks during the first few weeks after construction. Then these jacks were removed and the temporary joints filled with concrete.

How did this slab perform over the years? Well, to a certain extent the same symptoms appeared as in all concrete slabs compressed longitudinally between abutments by means of jacks. The concrete slabs creep under the compressive stresses. They lose the necessary compression at low temperatures and show transverse cracks. The opposite is the case in summer: with rapid large increases in temperature the longitudinal compressive stresses rise quickly leading to buckling of the slab and damage to the concrete in the area of the "active joints".

Table 1 shows a summary of posttensioned concrete slabs built in Western Europe between 1946 and 1960, a large part of which were road sections for test purposes. (see references 2.) Technical publications report the construction of prestressed test slabs in Czechoslovakia similar to the ones mentioned above. However, nothing is known about their present condition.

Of course, the considerations for roads are different from the ones for runways, especially because of the slab width being limited to 7.5 m. The resulting problems will be discussed later. Still another solution using a diagonal posttensioning shall be mentioned. It could be of interest for further research and testing, especially for posttensioned pavements with relatively small width, i.e. for highways. Here begins the transition to internal prestress. (Fig. 7)

Fig. 7. Internal prestressing with crossed tendons



Amongst the solutions under point 2. first the prestressing bed shall be discussed. Here the longitudinal tendons are placed without a sheathing duct. The abutments for the various sections are spaced up to 700 m apart and the longitudinal tendons between them are prestressed. The transverse tendons are placed with sheath-

ing ducts and then the concrete is poured in 7.50 m wide strips. After the concrete has set it will behave just like in any other regular reinforced slab, this is, transverse cracks can occur when the temperature drops. The prestress load in the tendons is transferred to the concrete by bond which becomes fully effective only with the increasing strength of the concrete. A too early transfer will cause slippage. Only after the concrete of the entire area between the abutment has hardened sufficiently can the tendons be released to transfer the prestress load to the concrete. This is where the problems occur using this method. When the tendons are released too late transverse cracks may have already formed; if they are released too early slippage occurs and the prestress force is not effective in those slab areas. The failures in the beginning were carefully corrected and the method improved. So, for example, additional strip footings with steel profiles were provided every 100 m in the 700 m long section between abutments where the tendons were provided with steel straps to increase the bond and to anchor them in the steel profiles.

The advantage was that the concrete did not have to be poured and hardened in the entire slab section. After the concrete had reached sufficient strength the wires in the individual subsections could be cut at an early time to transfer the prestress force to the concrete. Of course, the wires were cut in the joint gaps in a carefully predetermined sequence and only after testing of the concrete strength. This runway, only 16 cm thick, is now in service for more than 15 years, however, its live load and the loading frequency are much less than on commercial airports.

The method of internal prestress mentioned under 2.2. uses tendons with sheathing ducts in longitudinal and transverse direction which are stressed against the concrete after it has hardened. Just as for the methods described before, it is essential that the concrete slabs are not bonded to their substructure, that they can move freely in both directions and that temperature changes can cause only stresses resulting from friction between slab and bedding.

Before going into structural details and the construction sequence the questions of loading and the design of prestressed concrete slabs shall be discussed. (see references 3.) In general, the wheel loads and tire pressures of the various aircraft types are well known. However, the distance between the wheels is so small that their forces influence each other and increase the loads in the slab. For many years, therefore, a "single wheel load" of 100,000 lbs (45 Mp) has been used for the design corresponding to a LCN value of 100. This number used to consider a tire pressure of about 8 kp/cm2, while today a Boeing 747 has a tire pressure of about 13.5 kp/cm2. A new single wheel load lower than the aforementioned 45 Mp could be calculated considering this difference.

The formula for it is:

$$\frac{Q_1}{Q_2} = \frac{F_1}{F_2} \times 0.27 \qquad (1)$$

where:

Q_1 initial single wheel load with contact area F_1

F_2 new contact area

Q_2 single wheel load corresponding to F_2 causing the same bending moments in the slab

With Q_2 and F_2 a straight line can be drawn in a graph and intersected with the LCN-curve. However, it should be noted that in certain areas of the runway where high dynamic loads from the running engines must be superimposed on the maximum static loads, an impact factor of 1.2 has to be considered.

For this reason it seems to be appropriate not to change the original number of 45 Mp for single wheel loads.

The moments and resulting stresses due to live loads have been calculated in the past using the improved formula by Westergaard:

$$= 0.0547 \frac{P}{h^2} \left[\left(\frac{b}{l}\right)^2 - 10.186 \ln \frac{b}{l} + 3.714 \right] \qquad (2)$$

The basis for it was Schleicher's formula for a circular plate on elastic bedding. In spite of using a reduction factor the calculations had too conservative results because of the assumption of a too large depression under the load area. In case the load distribution in the slab shall be evaluated more accurately by considering the individual landing gears, it is recommended that the moment influence charts by Pickett & Ray be used.

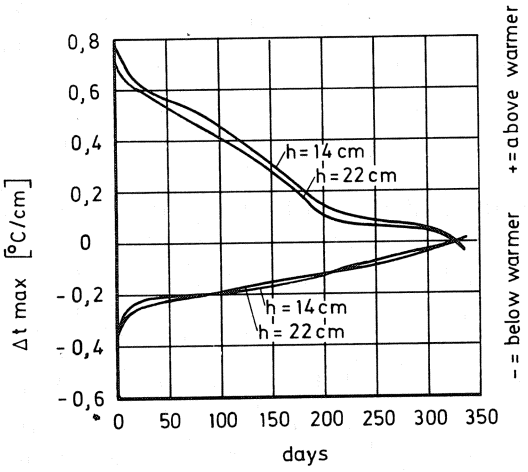
For the stress calculation in regular concrete runways on a compacted substructure the multilayer theory developed in the United States has been accepted in the past years. It allows the evaluation of the influence of the load supporting layers on the stresses in the concrete slab. For posttensioned concrete slabs with internal prestress it has to be considered that, because of the small friction between slab and ground, only vertical loads can be transmitted and that the prestress force in the slab influences the size of the load distributing area. Computer programs for the stress calculation using the multilayer theory already exist and preparations are being made to consider the special properties of prestressed slabs.

In addition to the stresses from live loads the stresses resulting from the temperature gradient, that is the difference in temperature between top and bottom of the concrete slab, have to be considered. The slab wants to warp under heat, but is bent back by its own weight causing tensile stresses. The formula for this is:

$$\sigma_{\Delta_T} = \frac{E_b \alpha_t . \Delta_t}{2 \cdot (1 - \mu)} \qquad (3)$$

For a warmer temperature on the top of the slab, that is tensile stresses in the bottom of the slab, in Central Europe a coefficient of 0.9° C per cm slab thickness is used. For colder temperatures on top (as, for example, from a thunderstorm or hail) the coefficient is 0.45°C per cm. These numbers are not uncontested and there are areas where they may be lower as, for example, in case of the airport Amsterdam/ Schiphol near the ocean. Recording the temperature gradients during one year with no extreme temperatures shows a variation of 0.8 to -0.4 where the higher values apply to the thinner slabs. (Fig. 8)

Fig. 8. Influence line for positive (above warmer) and negative (above colder) temperature gradient.



For a structural analysis, therefore, these values are justified if special conditions do not allow less stringent assumptions. (see references 4.)

In regular reinforced pavements the concrete itself in the uncracked stage can carry these tensile stresses with the reinforcing steel carrying no load. In case a crack has formed, the reinforcing steel, because of the low reinforcement percentage, cannot carry the tensile force and yields. Different, however, is the situation with prestressed concrete, where the reinforcement helps to increase the carrying capacity. Live loads and temperature gradients cause bending moments in a prestressed concrete slab. A safety factor of 1.25 against reaching the allowable stresses in the concrete applies to these loads.

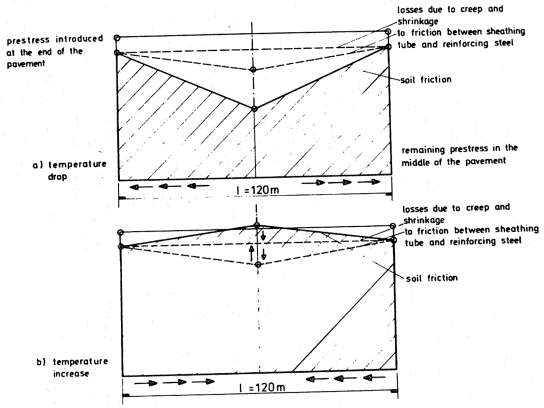
The prestress force in the center of the slab is not the same as the one introduced at the ends. The force decreases from the losses in the concrete due to creep and shrinkage as well as from friction in the sheathing ducts. This reduction can be calculated by precise formulas and can also be measured exactly during posttensioning by dynamometers.

Of utmost importance is the friction between the concrete slab and the subgrade. If there was no friction, the slab would immediately follow fully each temperature variation in the center fiber of the slab. For each degree Celcius increase in temperature the gap in the joint between two 100 m long slab sections would decrease by 1 mm, and increase for 1 mm at a temperature drop of 1° C.

For a temperature variation of +45° to -20° C in the concrete slab a movement of 65 mm is caused at the joint. Different types of aggregate and a varying moisture content of the concrete have only a negligible influence. Most important, however, is the condition of the subgrade surface together with the installation of an anti-friction layer, as, for example, paper or plastic foil. While in Central Europe friction factors of μ = 1.0 to 0.6 are assumed - the higher factor applies for the first movement of the newly built slab - in the United States factors of μ = 0.2 to 0.4 are used. To justify these values the bituminous levelling membrane has to be very smooth: the deviations along a 4 m long straight edge may not exceed 4 mm. Also a layer of levelling concrete slipformed with a finisher can guarantee these low values.

Friction causes tensile or compressive loads in the slab depending on rising or falling temperatures in the concrete. The stress distribution in a 120 m long pavement section is illustrated in Figure 9.

Fig. 9. Stress distribution in a 120 m long pavement section.



The prestress force introduced at the edges of the slab will be decreased by creep and shrinkage and the losses from friction in the sheathing ducts increase towards the center of the slab. The same applies for friction on the subgrade which reaches its maximum in the center of the slab. During falling temperatures the slab wants to contract, the resistance from the soil friction causes the prestress force to decrease in the center of the slab. On the other hand, soil friction increases the effect of posttensioning in the center of the slab when the slab temperature rises.

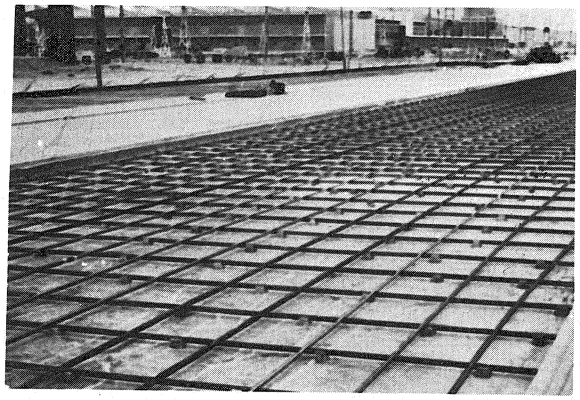
For a stress evaluation in longitudinal direction of a runway only the lowest

value of the prestress load in the center of the slab is of importance. To reliably prevent transverse cracks the prestress load there shall never be less than 10 kp/cm2. Of course, the stress computation always has to consider the most unfavorable load combination possible where the compressive force reduced by the losses from creep and shrinkage, friction in the sheathing ducts and friction in the soil still has to carry the moments resulting from the live loads. The same design considerations apply for the transverse direction. Because of the short width of a runway compared to its length the soil friction losses are smaller normally resulting in a lesser degree of prestress in the transverse direction.

The technically best and most economical solution is when the tensile stresses from live loads and temperature as well as the remaining compressive stresses are at their allowable limits. Then only the section length and the degree of prestress are the remaining variables but not the slab thickness.

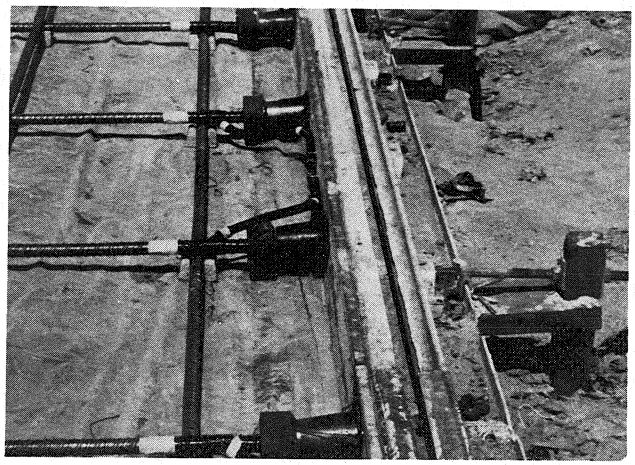
After discussing the characteristics and the design of a prestressed concrete runway, the construction principles shall be reviewed. The required accuracy in levelling the substructure can only be achieved on top of a consolidated layer where a smooth bituminous curing membrane is sprayed onto a cement treated base. The antifriction layer should be either highway paper or plastic foil on top of which the longitudinal and transverse tendons with their sheathing ducts are installed. The concrete cover underneath the ducts shall be at least 3 cm. The weight of the fresh concrete deflects the ducts together with the tendons. Therefore, the tendon crosspoints shall be supported in as short intervals as possible to avoid friction losses from duct deflections. (Fig. 10)

Fig. 10. Bar tendons of a pavement



In case the transverse tendons do not penetrate the lateral bulkheads, the sheathing ducts have to be carefully sealed to prevent the entry of grout and may need to contain a dummy bar to avoid deformations. (Fig. 11)

Fig. 11. Transverse tendons with anchorage bell and pocket former



The optimum section length is about 120 m and the width 7.5 m according to the dimensionsof regular road finishers. A slab thickness of 18 cm has been proven as adequate and has been used for most commercial airports. Military airports use 16 cm thick slabs for the same kind of loads and they have performed without damages for decades. For lighter aircraft 14 cm thick slabs have been used and for overlay slabs even 12 cm only.

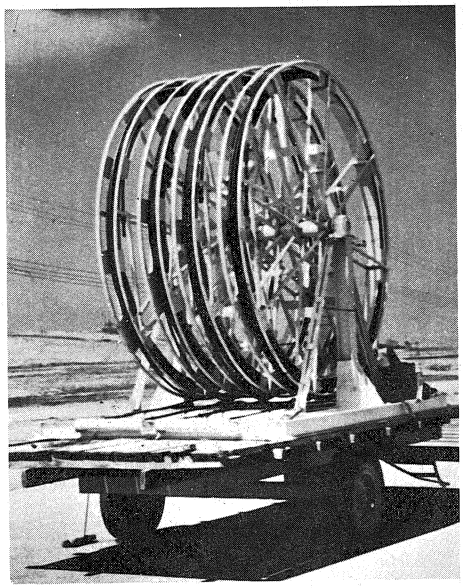
This construction method also allows skew edges, curves with a 50 m radius as well as convex or concave transitions between gradients.

Initially, about 22 years ago heat-treated Sigma steel St 125/140 with diameters of 10.2 and 12.2 mm was used for the tendons. The bars were cut to length on the site and then the threads were rolled on. In the last years threadbars were used instead. They had the advantage that the bar has only to be cut to length and no special threads have to be rolled on. Especially suited is the 16 mm diameter Threadbars St 145/160 which can be shipped in coils of 2.8 m diameter and can be easily protected for ocean shipment. After cutting the threadbar to length it can be pushed mechanically into a continuous sheathing duct and then coiled again for transportation to the site. (Fig. 12)

Now a comment to the old question: bar or strand, grouted or unbonded. The discussion has to concentrate here on the special topic of thin, large slabs with construction joints. Tests at the Technical University of Munich in this respect have proven that grouted tendons clearly provide a higher stiffness and better load distribution than unbonded tendons.

A comparison of bar and strand had similar results. The test slab using strand experienced larger deformations at the beginning of the dynamic tests and under the maximum test load. Also, the gap at the bottom of the joint was found

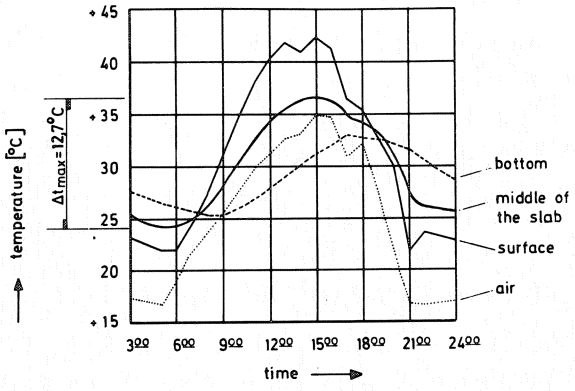
Fig. 12. Longitudinal tendons with Sheathing wound up for transport



to be considerably wider in the case of strands than when using threadbars. How far any economy in using strands can compensate for their different behaviour cannot be answered here.

The slab should be poured with a speed of at least 30 m/h, that is a 120 m long strip shall be poured and vibrated within 4 hours at the latest. (see references 4.) The concrete hardens and, depending on the ambient temperature, reaches a strength of 150 kp/cm2 within 20 hours. (Fig. 13)

Fig. 13. Temperature history on a summer day - slab thickness 22 cm



At this time the first partial posttensioning has to be applied to avoid cracks due to the temperature drop at night. The setting cement gives off its hydration heat, the maximum of which is only reached after 24 to 36 hours. It is, therefore, clear that the temperature drop in the early morning hours of the first night represents a danger for the slowly hardening concrete slab and that a first partial posttensioning is needed to take a step against it. After 2 to 3 days the prestress force has to be increased to 80% of its final value. Only after all strips of a pavement have been poured and gained sufficient strength can the full prestress load be applied. At this time also the transverse tendons are posttensioned in one operation and then all tendons are grouted.

Special attention should be given to the design of the joint between two prestressed concrete slabs. First, on top of a concrete foundation, a blockout, about 1 m wide is left between slabs. The edges of both adjacent slabs rest on this foundation because the live loads have to be transferred without impact across the joint, while the shear forces have to be carried safely to the substructure. The joint itself compensates for the length changes in the slab due to temperature variations.

It should be remembered that for two 120 m long slabs this difference in length can amount to 78 mm considering a possible temperature change from +45°C to -20°C. Although initially this number is not reached because of the friction on the ground, after a longer service time and certain temperature changes it appears that the joint indeed must be designed for these maximum movements.

For the transfer and carrying of the shear forces the foundation strip appears to be indispensable as dowels alone may not be sufficient considering the large possible movements. The longitudinal prestress in the 1 m wide blockout on top of the foundation strip, however, can be omitted without disadvantage.

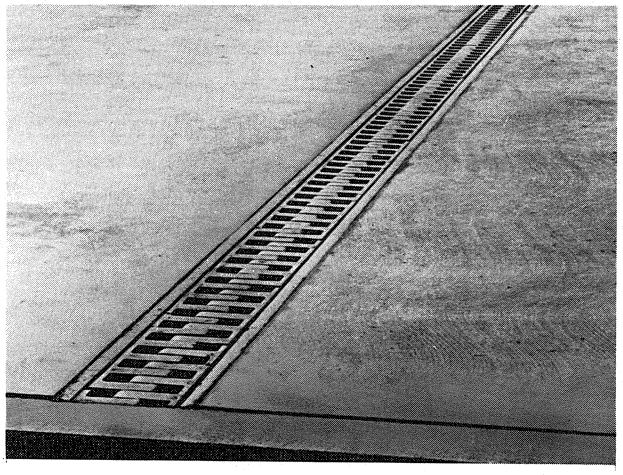
To avoid repetitions, the various joint designs shall not be discussed here again. However, in case an entire pavement shall be posttensioned in both directions, two solutions shall be shown here.

The first one is the so called "finger-joint". The slab edges at the blockout are lined with steel channels to which the cast iron finger structure is bolted on. (Fig. 14) The experiences differ. At one airport even after a 15 year service no difficulties were encountered at all, while another airport experienced broken fingers allowing the entry of foreign matter.

In a more recent design heavier steel sections were used for the joint and the longitudinal tendons were extended over the 1 m wide blockout. A special jack in the remaining gap was used to stress this tendon section.

Occasionally, problems can result from closing the blockouts with concrete, especially when the concrete is too stiff and does not fill all the voids. Here is a good application for high early strength concrete with fluidifiers which allow less reliance on a careful vibrating. With suitable tests and selection of materials the same strength as in the rest of the

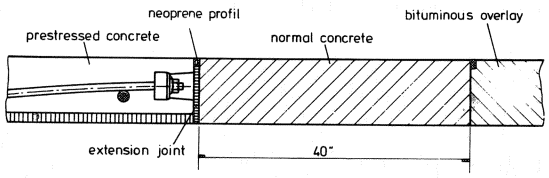
Fig. 14. Plan view of finger joint



pavement can be reached in a very short time.

One problem should still be mentioned; the longitudinal joints in prestressed pavement slabs. In a runway with a width of 45 m movements of 15 mm can occur in the joint between slab and shoulder, in addition to the longitudinal movements of 39 mm near the transverse joints. Certainly these are theoretical maximum values, but even the best hot sealing compound embrittles through the years and requires frequent repairs. A better solution is to pour a strip of regular concrete between the prestressed pavement and the bituminous shoulder with a neoprene filled running joint. The joint next to the shoulder is filled with regular sealing compound. (Fig. 15)

Fig. 15. Cross section prestressed concrete slab - normal concrete strip - bituminous shoulder.



The drainage of prestressed runways and taxiways has no other problems or difficulties than regular concrete pavements. On the contrary the missing filler in the joints, especially in the longitudinal construction joints allows a fast runoff for the rainwater. To a certain extent water can enter the expansion joint. The surface of the foundation strip has the same gradient as the slab itself, so that the water can runoff towards the edges. A plastic pipe passing through the foundation into the ground allows the water to drain off.

The runways and taxiways built in Germany using the DYWIDAG Posttensioning System during the years 1956 to 1961 were not placed on a firm substructure but on a well compacted antifrost layer with a modulus of foundation support of $k \geq 8$ kp/cm2. Extensive field and laboratory tests were performed to determine if, because of later consolidation or settlements in the gravel layer, cavities underneath the slab had formed.

Some of the results shall be mentioned here:

1. At static loading of the slab with the design load a considerable difference shows up between measurements and the computation; the measurements are lower than calculated. This demonstrates that the Westergaard design method still contains a considerable safety factor.
2. Loadtests in the center and at the edge of the slab, that is at the longitudinal construction joints, show only small differences in the deflection. This means that the carrying capacity of prestressed pavements, although they are poured in strips, can be assumed as uniform in all areas.

Consequently, a concrete slab posttensioned with this system can take much higher live loads than designed for without permanent damage.

Concrete slabs are always only as good as the areas near the joints, that is, the less joints the better the condition of the runway. The maintenance of the joints in regular concrete pavements requires additional work. They have to be refilled and broken loose filler material has to be removed. In certain, not too long, intervals the joint filler has to be completely exchanged. This work has to be done during the night between takeoffs or during shutdowns and is most unwelcome.

As mentioned before, prestressed concrete runways are maintenance free and have been in service for 15 years without repairs. This is an impressive proof of their quality and an important plus in the economic considerations of the combined costs of construction and maintenance.

It should be added here that choosing a posttensioned slab in most cases results in savings in the substructure. The uniform carrying capacity of the slab, the better load distribution to the substructure and soil, as well as the perfect seal against water from the top entering the ground underneath allow for a simpler substructure and thinner foundation layers. For this reason not only the costs for various kinds of concrete slabs alone should be compared, but the entire struc-

ture consisting of slab and foundation.

Finally, the problems in prestressed road pavements should be discussed. It is certain that difficulties are encountered when using external posttensioning with abutments under the road surface. This method is only applicable for straight sections. For horizontal curves as well as for convex and concave curves between gradients another system has to be used. The same is true for the stressing bed method; it is also limited to straight sections. Only the last method described above using posttensioning tendons allows any geometric road design without technical difficulties.

These can be found in another area. While for a runway section 120 m long and 45 m wide the ratio between length and width is 2.67:1, it is 16:1 for a road section with the standard dimensions 120 m x 7.5 m or, at best, 13.33:1 for a section 120 m x 9.00 m.

The end anchorages of the short transverse tendons have an increased influence on the material and labor costs.

This resulted in the considerations to replace the transverse tendons by regular reinforcing steel or to provide a longitudinal center joint. The results known from such projects are not very encouraging. In some cases longitudinal cracks formed, even where the longitudinal prestress force had been increased considerably to compensate for the missing transverse tendons.

Another major difference between prestressed road and runway pavements is in the size of the live loads. For airport pavements wheel loads of 18 to 20 Mp and combined loads of 45 Mp are used for the design; trucks can bring wheel loads of 5 to 6 Mp and double that in case of dual tires.

Earlier it was explained that the basis for an optimum design is a balanced proportion between principal and secondary stresses. This is not the case here any more for the relationship of live load moments to the other stresses. There are limits to a reduction in the posttensioning force or to an increase in the strip length because of the friction on the ground and the posttensioning force remaining in the center of the slab. Also a reduction of the slab thickness to 15 cm or less cannot be recommended. It will be quite difficult to find a technically perfect solution for a prestressed road slab which can compete economically with regular reinforced concrete pavements. A diagonal posttensioning as described and illustrated before would probably have the best chances. Possibly, some institution interested in further developments will carry the costs or at least the additional costs for a test pavement.

In the meantime 3.3 Million m2 of posttensioned concrete slabs for runways and parking areas have been built successfully all over the world using the DYWIDAG Posttensioning System. It should be considered here, that initially no specifications or guidelines existed for these pavements. They had to be developed from experience. The fact that most of these projects were won in fierce competition with conventional pavements shows clearly that the best technical and economic solution was always searched for and found.

It does not decrease the success of this development to admit that in the search for the limits in the reinforcement percentage, soil friction and other difficulties and failures have been encountered which, however, have been overcome today.

It can be reported here with special pride that last year a test pavement was built on one of the busiest airports in the United States using the method described above. As far as published, the measurements and tests conducted had very favorable results and the condition of the slab lives up to the expectations. Consequently, more of these pavements are expected to be built in the future, especially since there is a considerable need to catch up with this technical development.

Table 1. Summary of concrete pavements built in Western Europe between 1946 and 1960

Location	Function	Year of constr.	Area m2	Thickness cm	Prestressing Method
Germany					
Mergelstetten	Federal Highway (Bundesstrasse)	1953	2,700	15	tendons
Speyer	country road (Landstrasse)	1954	10,000	20	tendons
Wolfsburg	access way	1957	16,200	16	tendons
Dietersheim	Federal Highway (Bundesstrasse)	1959	6,750	16	tendons
several airports	runway and taxiway	1956	800,000	14 to 16	tendons
Koeln-Wahn	runway and taxiway	1960	300,000	18 to 20	tendons
France					
Luzancy	Federal Highway (route nationale)	1946	270	16	diagonal tendons

Location	Function	Year of constr.	Area m2	Thickness cm	Prestressing Method
France					
Esbly	Federal Highway (route nationale)	1949	285	15	diagonal tendons
Servas	Federal Highway (route nationale)	1952	2,050	12	external prestressing with jacks
Orly I	runway	1947	25,200	16	tendon
Orly II	apron	1953	10,750	18	external prestressing with jacks
Maison blanche	runway, taxiway	1954	146,000	18	external prestressing with jacks
		1961	106,000	16	
Fontenay-Tresigny	Federal Highway (route nationale)	1959	17,800	12 to 15	different
Belgium					
Brussels	road	1947	560	10	tendons
	road	1958	3,000	10	tendons
	airport	1960	153,000	18	external prestressing with jacks
Zwartberg	road	1960	24,500	8 to 12	external prestressing with elastic joints
Austria					
Salzburg	autobahn	1959	12,000	16 to 20	external prestressing with wedges
Vienna	city road (Stadtstrasse)	1956	950	20	external
Wien-Schwechat	runway, taxiway	1954	12,000	20	external prestressing bed and jacks
		1959	100,000	15	
Netherlands					
Amsterdam-Schiphol	taxiway	1950	16,000	14	tendons
different sections	Federal Highway	1957	2,200	12 to 15	prestressing bed
Leiden	autobahn	1960	8,000	12	prestressing bed
Switzerland					
Wildegg	by-street	1955	2,000	12	external prestressing with wedges
Naz	country road	1955	2,000	12	external prestressing with jacks
Moeriken	country road	1956	3,300	15	external prestressing with wedges
Neuchatel	country road	1960	5,000	15	external prestressing with elastic joints
Boudry	country road	1960	14,000	15	external prestressing with jacks
England					
Crawley	road	1950	720	15	diagonal tendons
London	apron	1951	360	16	diagonal tendons

Location	Function	Year of constr.	Area m2	Thickness cm	Prestressing Method
England					
Buckingham-shire	road	1951	350	15	tendons
Essex	road	1952	400	15	tendons
Woolwich	road	1952	1,200	15	tendons
Port Talbot	road	1954	6,000	15	diagonal tendons
South Walls	road	1954	2,700	15	diagonal tendons
Gatwick	apron	1957	6,000	13	tendons

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