CONCEPTS FOR THE SELECTION OF PAVEMENTS FOR RUNWAYS, TAXIWAYS, AND APRONS OF LARGE SIZE AIRPORTS

Otto G. Koch, Wladimir K. Chebrat and Giulio de Gasparre
Hidroservice — Engenharia de Projectos Ltda.
Sao Paulo, Brazil

1 - TYPES OF PAVEMENTS

The main objective in the design of pavements for large airports is to utilize all the technical resources and experience available from all over the world, with the purpose of guaranteeing the longest possible life span to the pavements.

Such undertakings involve great financial investments and it must be assured, when selecting the type of pavement, that its useful life span will be longer than the time estimated for the amortization of the invested capital. Consequently, it should be usable for many years with a minimum of maintenance expenses and without need of major repairs.

Asphalt and cement concrete are the basic material used to date for construction of runways and taxiways; cement concrete has been generally utilized on apron construction.

The use of asphalt concrete for construction of aprons and runway thresholds was quickly discontinued due to the following causes:

a) Low resistance to fuels which are often spilled at aircraft parking and refuelling points.

b) Low resistance against stresses transmitted by tires of maneuvering aircraft, especially on landing or take-off, the latter being the most critical situation because the aircraft are fully loaded.

Another world-wide determining factor for discontinuing such type of pavement is the influence of climatic conditions on the life of the asphalt concrete paving.

As a matter of fact:

a) In cold climates, due to the occurence of snow and ice, pavement surfaces are subject to mechanical and chemical treatment in order to guarantee their serviceability. Such treatments are: removal of snow by snow plows which, in turn, transmit stresses affecting pavement quality, and covering of unremovable ice layers with sodium chloride, to avoid aircraft skidding. A saline solution is formed, which attacks the asphalt with spring temperature rise and consequent defrosting.

b) In hot climates, high temperatures on the pavement surfaces soften the asphalt layers which deform under the loads of aircraft wheels and form grooves, hollows and bumps. Besides changing the surface levels, fractures and fissures may arise allowing the infiltration of rainwater and wearing out the grade and subgrade, thus causing much greater damage.

In the two cases above, the influence of climatic conditions causes repeated and expensive maintenance services, and in more critical and frequent cases, requires the reconstruction of pavement sections which, in turn, may cause airport shutdowns with severe economic consequences.

These are the main reasons why there has been a world-wide tendency to discontinue the use of asphalt concrete in construction of runways and aprons and to increase the use of cement concrete.

To this date, the following rigid type cement concrete pavements were studied, tested, or built on runways and aprons:

a) Rigid pavement of plain cement concrete, with contraction and expansion joints in two orthogonal directions.

b) Rigid pavement of partially reinforced and discontinuous cement concrete, with contraction and expansion joints in two orthogonal directions.

c) Rigid pavement of continuous reinforced cement concrete, with construction joints.

d) Rigid pavement of prestressed concrete, with special joints.

2 - BASIC CONCEPTS FOR PAVEMENT DESIGN OF AIRPORT RUNWAYS AND APRONS

The main consideration in the design of runways and aprons is the weight of aircraft.

Since the 1930's, aircraft weights have constinuously increased. Such continuous increases will, probably, not last forever, but they will continue to occur in the foreseeable future.

In fact, the air transport development in the last 15 years shows that there exists a direct relation between the relative level of international air traffic and the number of seats offered by aircraft in service. Basing on experience of the recent past and by a simple extrapolation of aircraft capacity up to the year 2000, it was found to be economically feasible to build aircraft with 1,000 - 1,200 seat capacity.

Such aircraft would have a 500 to 600 tons maximum weight in the subsonic and 500 to 700 tons in the supersonic range.

Therefore, in determining the general concepts and principles for the design of a new runway, taxiway or apron, it is logical to establish the weight of a "project aircraft" as 650 tons, 600 tons of which are distributed between the main landing gears and 50 tons in the nose landing gear.

Through the experience obtained on airport runways, designed and built in the 1960's, and continuously subject to strengthening and repairs due to unforeseen stresses caused by increasing air traffic demand, one should account on new runway and apron design for the probabilities of aircraft weight increases for at least the next 20 years, as a basic concept for design load estimation.

However, the aircraft maximum weight concept by itself is not enough for pavement dimensioning. What also matters, is the distribution of such load through the landing gear, that is, the definition and concept of the aircraft "typical landing gear".

The main purpose in defining the landing gear configuration is to make possible a better distribution of the load through the adequate choice of the number of wheels, and the size and pressure of tires, in order to cause smaller stresses in the pavement.

However, there are obviously technical and aircraft design limitations, making a great number of wheels impracticable and the use of larger size wheels impossible because their dimensions would be prohibitive. Tire pressure is also limited by technical and safety reasons.

A maximum load of 25 tons per wheel is assumed when determining the "typical landing gear". This will require a 4-truck landing gear, each truck supporting 150 tons and mounted in a manner similar to the landing gear of the Boeing 747 or US-SST, except that each truck will have six wheels instead of four. (See figure 1).

The second design consideration is the analysis of fatigue stress, which is fundamental for long life pavement design. The fatigue,which a rigid flexible pavement is subject to, is a function of the number of times aircraft wheels roll over it, supporting their maximum load.

The fatigue effect is studied, both for flexible and rigid pavements, not for the "typical design landing gear", but for a gear which may induce lesser magnitude stresses in relation to the weight carried, and yet will cause greater wear on the pavement in view of the cumulative effect of wheel weight and frequency of operations.

Therefore, the existing and foreseen aircraft up to the year 2000 can be divided into three groups, in function of aircraft total weight, tire/pavement contact pressure, and maximum weight per wheel. The following table shows aircraft weights and loads.

Group	Aircraft Type	Total weight (Tons)	Contact Pressure (kg/cm^2)	Maximum Load Per Wheel (Tons)
I	Boeing 737/100	44.39	9.43	10.24
	Boeing 737/200C Advanced	52.66	11.17	12.00
	Boeing 727/100	77.20	11.66	17.50
	BAC-111/500	45.45	10.90	10.21
II	Boeing 727/200	94.40	11.60	22.00
	Boeing 707/120B	117.10	11.95	13.60
	Boeing 707/320C	152.50	12.68	17.50
	DC-8/63	162.39	13.70	19.25
	DC-10/30	253.11	11.60	23.00
III	Boeing 747 B	353.20	13.00	20.60
	L-500	390.77	14.76	22.00

By analyzing these groups in function of the three factors which, combined with the number of operations, determine the pavement fatigue, one reaches the conclusion that the first group need not be considered since the maximum load per wheel shows values lower than those of the 2nd and 3rd groups.

In order to determine the number of roll overs, that is, the number of stresses on the pavement, it is necessary to know the number of predicted accumulated aircraft movements until the year 2000. This number is due to the total predicted number of passengers, the utilization and sizes of the aircraft, and the airport location and importance. Also, because of the fast development of civil aviation, a safety coefficient of about 1.15 should be adopted.

As an example, beginning in the year 1968 and checking 1975, 1980, 1985, 1990 and 2000 for one of Brazil's International Airports, an estimate on the number of yearly movements for each type of aircraft was made in function of each class of passengers, and taking into consideration domestic, transfer and international flights.

The accumulated values up to the year 2000, were as follows (1.15 safety coefficient):

- DC-10/30 = 326,000 roll overs
- 747-B = 214,000 roll overs
- US-SST = 59,000 roll overs

Using the U.S. Corps of Engineers' formula to calculate the relation between roll overs and number of stresses (coverages), we have:

$$C = D \times \frac{0.75\ NW}{12\ T}$$

Where:

C = Coverages
D = Cycles of Operations (one landing and one takeoff)
N = Number of wheels on one main landing gear
W = Width of contact area of one tire
T = Traffic width (width where 75% of the main gear paths fall)

The following results were reached:
For runways:

. DC-10/30 = 42,000 coverages
. 747-B = 30,000 coverages
. US-SST = 10,000 coverages

For taxiways and aprons:

. DC-10/30 = 140,000 coverages
. 747-B = 90,000 coverages
. US-SST = 33,000 coverages

From the above figures, the DC-10/30 resulted as the critical airplane for the above mentioned Brazilian airport.

Using the values obtained for this aircraft, traditional methods of calculation led to a 36cm normal concrete slab thickness, equivalent to a 2.04 safety coefficient.

By checking all other aircraft of the predicted fleet, safety coefficients higher than 2 were obtained, and the safety coefficient of 1.7 resulted for the future hypothetic airplane, that being the minimum value recommended by the Portland Cement Association.

3 - ANALYSIS OF CONCRETE PAVEMENT TYPES FOR APRONS AND RUNWAYS

In principle, there is no difference between types of concrete pavements because the determination of stresses due to external loading is essentially based on the Westergaard Theory of the infinite slab with load applied in the center.

The infinite slab hypothesis is valid for any type of rigid pavement, because in the normal concrete pavement there are load transfer devices between slabs that guarantee the continuity of pavement, and distances are reasonably large between continuous joints in reinforced or prestressed concrete thus making the infinite slab hypothesis perfectly admissible. Such hypothesis is also consistent with the fact that an aircraft seldom operates on the sides of the pavement.

At a first glance, it would appear that only economic considerations would guide the designer upon the choice of the pavement type, all the solutions beeing seemingly equivalent from the static design point of view. The costs of concrete and steel for reinforcement or prestressing, offered on national or foreign markets, could be the determinant factors for the selection of a pavement type. However, many factors should be considered aiming at determining not just the economy of the immediate investment, but also the maintenance and conservation costs of the pavement to keep it always in good operative conditions.

As already mentioned in relation to the flexible pavement, the repair work on runways and aprons may easily result in the shutdown of the airport, further causing economic burdens and losses to the airport authorities which go beyond the expenses of repair.

In a concrete pavement,the requirement of joints, whether of construction or expansion, creates stress points. In fact, the joints may cause several problems, either during the construction stage or during maintenance work on the pavement.

During construction, after placing dowel-bars, tie-bars, wood boards and concreting the slab, it is necessary to wait for the concrete to set before using the joint cutting machine. If the wait is too long, to ensure that the concrete will resist sawing without damage, retraction phenomena may occur before the cuts are made, with probable occurence of irregular cracks in places not previously established.

If cuts are done too soon, concrete disaggregation may occur during the cutting operation, creating the need for repairs of joint edges and extra expenses. Another problem, is the selection of a sealing material which must have the following characteristics:

a) It should be sufficiently flexible to follow the movement of the slabs;

b) It should have optimum adherence to the inner surfaces of concrete joints so as not to detach during maximum opening of the joint, thus ensuring continuity of sealing.

c) It must be placed in the right amount, in order to prevent sealing material from protruding above pavement level during maximum closure of the joint when, due to high temperatures, it may stick to airplane tires and be carried away, thus causing sealing problems.

d) It must be resistant to fuel chemical attack, so as to make its life span the longest possible.

The types of sealing materials offered on the market are the pitch-based elastic mastic types, treated either with polyvynil chloride polymers or with polysulphate sinthetic rubber and epoxy base. Theoretically, these materials have all been tested and proved to be of good quality, except for the epoxy which, in spite of the good results obtained to date, is still considered to be under test given the reduced number of years of its application. However, the major negative factor lies in its application and high cost. There are some materials whose costs cannot be disregarded when budgeting concrete pavement construction; those costs may be such as to make impracticable either their use or even the adoption of the type of pavement in question. Joints, besides representing very important expense items in pavement construction, require continuous and expensive maintenance. For this reason, concrete pavement design normally seeks to eliminate or reduce the need for expansion and contraction joints.

Another target in designing a rigid pavement,is the absence of fissures or cracks; these may let rain water infiltrate down to the grade and subgrade layers causing reduction of the subgrade's support capacity, leading to total pavement collapse. There are two main causes of cracks or fissures in a concrete pavement:

a) The mixture water loss phenomenon (hydration-evaporation) occurring on the first drying periods, producing the so called "hydraulic" retraction in the concrete, and forming inner tensile stresses in a situation where the cement concrete has not yet developed all of its mechanical capacity.

b) The deformations due to temperature changes (expansion and contraction) which

cause variations of length proportional to the slab overall length and to the magnitude of temperature change.

In the design of the first type of rigid pavement (regular concrete), the concrete is forced to crack at pre-established places, forming transversal and longitudinal contraction joints generally distant from each other 3.5m to 7.5m, and transverse and longitudinal expansion joints distant 40 to 60m.

For the second type of pavement, (discontinuous and partially reinforced, with the steel area equal to 0.4% of the concrete cross section), the transversal joints cannot be eliminated. According to the magnitude of the loading, the distance between these joints could, theoretically, reach up to 100 meters; in practice, however, it generally does not exceed 20 meters at the most. The purpose of the light reinforcement is:

a) To absorb part of the tensile stresses;

b) To make possible a greater spacing between the transverse joints.

However, such reinforcement causes a considerable cost increase in relation to the normal concrete pavement, does not eliminate expenses for maintenance of joints, and shows no great advantages in relation to normal cement-concrete pavements. Therefore, this system is being gradually discontinued world-wide, especially in construction of highways, because the continuing existence of transversal joints executed by traditional methods does not justify the considerable cost increase with the reinforcement steel.

The AASHO Road Test does not show any differences in the behavior between non-reinforced and slightly reinforced slabs. However, this type of slightly reinforced cement-concrete pavement is universally recommended in the following cases:

a) When soil conditions, notwithstanding any substitutions or improvements, let foresee the possibility of differential settling.

b) In reconstructing roadway stretches (highways or airports), with common concrete overlay, when the observed wear no longer allows repairs and mendings and it is intended to construct a new pavement by utilizing the old one as subgrade. In such a case, the lightly reinforced concrete prevents the propagation of the fissures and cracks of the old pavement to the new one.

c) When the geometrical figure of the slab in plan view is irregular.

The type of continuous reinforced concrete pavement (cross section of steel equal to 1.00% of the concrete section) is based on the following principle: to let the concrete crack, and utilize the steel to control the fissures to reduce their openings to the minimum possible. The formation of a great number of cracks, is then to be expected, but they should be sufficiently thin (due to the presence of the reinforcement) and, consequently, making it more difficult for rain water to penetrate. Except for the construction joints, the cross joints are then eliminated, but the longitudinal ones must be maintained.

The cost of this pavement in relation to the types of items 1 and 2 increases considerably, the reinforcement having the specific function of controlling the openings of the fissures. Application of this type of pavement in airports is not known.

Prestressed Concrete Pavement

Prestressed concrete pavement deserves to be examined in greater detail since, due to its advantage of economy and safety in relation to other types, it may be considered as the pavement of the future for airport runways, taxiways and aprons. The system of prestressing to be utilized must answer the following requisites:

- Ensure design flexibility, allowing the construction of curved and gradually, sloped stretches of pavement connecting slabs located at different levels.

In order to meet this requisite the cables, either longitudinal or transversal, must be posttensioned, and they will not need additional anchoring structures. The absence of these structures, besides rendering the necessary flexibility to the project, represents a factor of considerable economy and simplicity of construction. As a matter of fact, the magnitude of these structures would be in function of the prestressing strength to be resisted (from 45t/m to 60t/m in the horizontal), and also of the nature of the soil and its resistance to friction.

- In relation to the formation of fissures and cracks during the concrete curing period, the system must have the possibility of accompanying the shortening of the slabs by means of prestressing applied gradually by stages which, by compressing the concrete by an adequate amount, eliminates the possibility of formation of fissures and cracks.

In order to comply with this requirement, the longitudinal cables must be prestressed and their anchoring system must not be made with wedges which, once having been fastened in a first stage of prestressing, cannot be realesed and fastened again on the next stage without damaging the cables and compromising their resistance.

When the possibility of prestressing by stages does not exist, during the concrete curing period and before the prestressing, there will be fissures and cracks due to retraction, notwithstanding the existence of chemical products.

It is true that during the transfer of the prestressing stresses to the concrete the fissures and the cracks close but, with the application of loads and vibrations transmitted by the aircraft, they open again and may even increase going through the whole depth of the slab. In such a case, besides allowing the rain water to penetrate down to the subgrade, the pavement will loose great part of its strength; the tensile stresses induced by bending will be resisted solely by the prestressing cables as the tensile strength of the concrete taken into account in static calculations will have been lost.

- Another essential requisite is that the cable anchoring pieces be directly embedded in the concrete of the pavement slabs.

The prestressing system that complies with the above requisites is the Dywidag, which substitutes cables by steel bars with a yield strength of 145kg/mm^2 and a breaking strength of 160kg/mm^2.

The steel bars are ribbed, thus offering better adherence to cement grouting in the sheaths. The most important use of these protuberances lies in the fact that they may be threaded, which makes possible the fixing of the cables by means of nuts.

This fact makes possible the execution of the prestressing by stages, as is in fact done, and the accompanying of the creep of the concrete during the first part of its curing.

After the installation of the longitudinal and transversal sheaths, and the insertion of the cables, the slab is concreted. Six or twelve hours after the concreting, the initial prestressing is applied, the intensity of which is established in accordance with the resistance attained by the concrete (determined by tests) and the climatic conditions, such as ambient temperature, relative air humidity and, most important, taking into consideration the judgement and experience of the operator. The operation is continued, increasing as time goes by the prestressing force until reaching 70% of the total strength established in design.

These successive prestressings guarantee that the retractions of the concrete during the beginning of the curing period may be accompanied by the partial prestressing, giving the slab the shortening compatible with ascertained retraction. This eliminates any possibility of cracking. The operation, obviously, is made possible by the cable anchoring system, that is, for each successive extension of the cable for a new adjustment it is just necessary to tighten a nut. Once the slabs are concreted on the total width of the strip (usually three slabs for taxiways with a width of 22.50m and six slabs for runways 45m wide) and the curing of the slab concrete is finished, the transversal cables are inserted and the completion of the longitudinal prestressing is carried out by applying, then, the total transversal prestressing. The last operation is the grouting of the sheaths with cement paste. There are no special structures for anchoring the cables for longitudinal and transversal post-prestressing; small anchoring pieces for the cables are simply embedded in the concrete of the pavement. This system has been thouroughly utilized by us in recent years, with very good results.

4 - DIMENSIONING OF A PAVEMENT IN PRESTRESSED CONCRETE

The static calculation for a pavement in prestressed concrete is based on the "equivalent single wheel" principle.

The moving concentrated load system of the landing gear must be transformed into a single wheel load which will produce, in the center of the slab, tensile stresses of the same magnitude that would be produced by the actual landing gear system. Tire pressure of the equivalent wheel is taken as being the same as that in the landing gear's tires. This equivalent single load makes it possible to apply the Westergaard theory to airport pavement design. By applying the Sidr formula, which is the extension of Westergaard's theory for a single load, the working stresses brought about by a moving load, are determined. The other part of the bending stress is due to the difference of temperature existing between the surface and the bottom of the slab, the gradient of which is established in relation to the worst climatic conditions for the location.

The resisting strength is represented by the prestressing force and by the tensile strength of concrete in bending, less the losses due to friction against the sheaths, to creep, and to contact friction between the concrete and the grade.
It is then possible to determine the safety factor against development of cracks, which depends on slab thickness and the number of prestressing stands per running meter of slab, in both directions. The safety factor should be greater than 1.25.

For construction purposes (size of the anchoring pieces), the thickness of a concrete slab cannot be less than 18cm and the cables are formed by 16mm dia. steel bars. Since, in accordance with theoretical calculations a concrete thickness of 14cm would be sufficient, the extra 4cm will impart to the prestressed concrete pavement a considerable "static reserve". This has been demonstrated by a test made in Germany, where a prestressed concrete slab (Dywidag System) 18cm thick calculated for a load of 40 tons (equivalent wheel load), and submitted to a progressively increased concentrated load, failed when the load reached 100t.

5 - TECHNICAL AND ECONOMICAL ASPECTS OF A PRESTRESSED CONCRETE PAVEMENT

According to experience acquired in Europe and North America in the last few years on the behaviour of pavements subjected to frequent stresses by heavy aircraft (747 and DC-10), it was ascertained that wear was much higher than foreseen and the useful life shorter than expected.

As a matter of fact, it is already being accepted that the minimum thickness of the common concrete pavement must not be less than 40 to 42cm when, until

recently, a depth of 36cm was commonly adopted. For prestressed concrete, however, it is still admitted that slab thickness must be between 18 and 20cm.

These new considerations are due to the fact that vibrations transmitted by the landing gear of wide-body aircraft, especially during takeoffs, are causing stresses that static calculations cannot foresee.

Therefore, it follows that the use of prestressed concrete can bring about a considerable reduction (about 50%) on concrete volume, as long as the same mix and the same tensile strength in bending as that of plain concrete are maintained.

Another important economy factor in the construction investment,is the fact that in prestressed concrete the expansion joints are located at every 100 to 120 meters, whatever the width of the paved strip, and contraction joints do not exist. Those joints are metallic and of easy installation and adjustment, not requiring highly skilled labor nor any sealing material for the finished surface.

Plain concrete paving is made with 7.50m wide by 7.50m long slabs, due to the need of contraction joints. The distance between expansion joints is about 40 to 60 meters.

In a comparison of prestressed concrete slabs (120 meters long and 7.50 meters wide) with a common concrete strip of the same dimensions, one or two expansion joints and 14 contraction joints would be needed for the latter. Special care must be taken in the execution of these joints, especially during the placing of the steel bars, which must be installed in a perfectly horizontal position in order to guarantee the free movement of the slabs during expansions and contractions due to temperature variations. This operation evidently requires skilled labor and, therefore, its cost is considerable.

As regards construction duration, the time necessary for the construction of a prestressed concrete pavement can be estimated as about 70% of the time necessary for the construction of the same area in plain concrete.

The preparation of joints for plain concrete pavement is the most time consuming of all operations prior to concrete placing, and is undoubtedly much more lenghty than sheath installation and cable insertion for a prestressed concrete slab. Since the thickness of prestressed concrete is half the thickness of plain concrete, the time for placing concrete in a prestressed pavement shall evidently be shorter.

Where the prestressed concrete has a large advantage in comparison with plain concrete is on the finishing, maintenance,and duration of the pavement. Contraction and expansion joints in plain concrete create stress points in the pavement. Notwithstanding the dowel bars that distribute the loads and resist the edge stresses, joints represent a solution of continuity and originate sharp edges which are subject to failure when the pavement is under use. All these factors bring about the need for repairs,which may even signify the demolition and reconstruction of entire slabs. Maintenance, as time goes by, shall be constant, expensive and, furthermore, shall require repairs on slab edges, possibly bringing about the replacement of whole stretches of pavement finish. In prestressed concrete pavements, the absence of joints eliminates the above mentioned problems. The absence of joints, besides bestowing to the prestressed concrete pavement a pleasant aspect, allows a continuous finished surface, without grooves on the joint cuts, where, in order to make possible the movement of the slab, the filling with waterproof material is left below the pavement level.

From a static point of view, prestressed concrete pavements, notwithstanding being included in the type of rigid pavements, have elastic characteristics that permit the absorption of stresses due to possible differential settlings, without originating depressions from one slab to another, as usually occurs in

plain concrete pavements.

6 - CONCLUSIONS

Let us now analyse the types of pavements examined above, with the purpose of their application in the construction of runways, taxiways and aprons of a large airport.

At the very beginning we can eliminate the flexible (asphaltic concrete) type of pavement which does not offer the necessary requisites for the obtention of a satisfactory life span without continuous and costly maintenance, because of the previously mentioned causes of deterioration and wear, which can not be foreseen by any hypothesis of analysis.

Of the rigid pavements, the plain concrete, due to the existence of a great number of contraction and expansion joints of very difficult execution, presents high costs for skilled labor during the construction period, and continuous maintenance during the operational stage.

As regards partially-reinforced concrete, it was ascertained that it did not present advantages of behaviour in relation to plain concrete. Besides, it has the disadvantage of higher costs due to the reinforcing steel. It has never been utilized in construction of new strips, but only as overlaying of old plain concrete strips which, due to their stage of disaggregation, did not warrant any further maintenance services. Therefore, we can conclude that these two types of pavements do not possess sufficient requisites of safety and economy for application on a larger scale on the construction of airports.

Of the two last types of rigid pavements, continuous reinforced concrete and prestressed concrete, a comparative analysis shall be made, seeing that they both present the same characteristics of absence of joints and problems related thereof. Nevertheless, there do exist substancial differences between the two pavements and they are the following:

- In a prestressed concrete pavement design, it is admitted that cracks will not occur, neither during the curing period (hypothesis guaranteed by prestressing by stages) nor due to expansion and contraction caused by temperature variations (metallic joints every 100-120 meters and prestressing in both orthogonal directions).

- In a continuous reinforced concrete design, the occurence of cracks is admissible during the curing stage, the reinforcement having the function of controlling their width and limiting, but not completely hindering, the penetration of water through the pavement. It must also be observed that accidental stresses or those foreseen in static calculations (touch-down zone of runways, and vibrations) shall cause, undoubtedly, widening of these cracks. This fact, neither guarantees the perfect damp-proofing of this type of pavement, nor the continuity of the total capacity of support of its lower layers. Consequently, the useful life of the pavement can have a duration shorter than foreseen, creating, as well, a discontinuity in the pavement structure.

The establishment of an economic comparison between the two types of pavements shall be based upon static calculations for the continuous reinforced concrete pavement.

Taking the same thickness of concrete slab as for prestressed concrete, that is, 18cm, the necessary longitudinal reinforcement for the control of the fissures is given by:

$$W_o = \frac{A}{B} = \frac{\sigma_r}{0.75\sigma_e - m\sigma_r} \times 100\%$$

Where:

A = steel section (cm^2) per meter of slab width

$0.75\sigma_e$ = 75% of the yield limit in kg/cm^2, which for high grade ribbed bars is $5,000 kg/cm^2$.

B = concrete section in cm^2 per meter of slab = 18cm x 100cm

σ_r = concrete crushing strength in tension by bending (considered as an average of $55 kg/cm^2$).

m = relation between steel and concrete elasticity moduli, which is generally equal to 6.

We obtain:

$$W_o = \frac{A}{18 \times 100} = \frac{55}{0.75 \times 5000 - 6 \times 55} = 0,016$$

$$A = W_o B = 0.016 \times 18 \times 100 = 28.80 cm^2$$

which corresponds to reinforcement by one 1" dia. bar at each 17cm, i.e. 23.41kg of steel per square meter.

A transversal distribution reinforcement for the control of fissures, estimated at one 1/2" dia. bar at each 50cm, and with a weight of $2.54 kg/m^2$, would also be needed. The total weight would thus be:

$2.54 + 23.41 = 25.95$kg of high grade steel, per square meter of pavement.

This reinforcement, laid 7cm from the upper face of the pavement, is satisfactory from the static point of view, resisting the load transmitted by aircraft traffic. This type of pavement is statically and theoretically equivalent to prestressed concrete pavements built in Brazil.

For a simplified cost comparison, it was considered that the thickness of the concrete would be the same for both types of pavements and identical the preparation methods for mixing, transport and placing of concrete. Therefore, the only difference would be represented by the cost of reinforcement in the case of continuous reinforced concrete pavement, and with that of prestressing steel for a prestressed concrete pavement.

The prestressed concrete pavement offers a reduction in slab thickness of 45% and 30%, when compared to the plain and continuous reinforced types, respectively. Using a 40cm depth for the plain concrete slab, we would thus obtain 23cm for the reinforced and only 18cm for prestressed concrete slabs. For concrete prestressed by utilizing the Dywidag process, an equivalent wheel load of 40t requires, in accordance with static calculations, $5.37 kg/m^2$ of ST.145/160 steel.

Significant economy can thus be obtained by the use of prestressed concrete instead of continuous reinforced concrete in runways and aprons comparing only the costs of reinforcing steel.

A practical example shows that a saving of 39% was obtained at one of Brazil's international airports which, translated into dollars, amounted to no less than US$ 640,000 for $635,000 m^2$ of pavement built.

REFERENCES

1) Albouy, J. C., "L'Infrastructure de L'Airport de Roissy - en - France", Travaux, No. 416, pp. 580-582, November 1969.

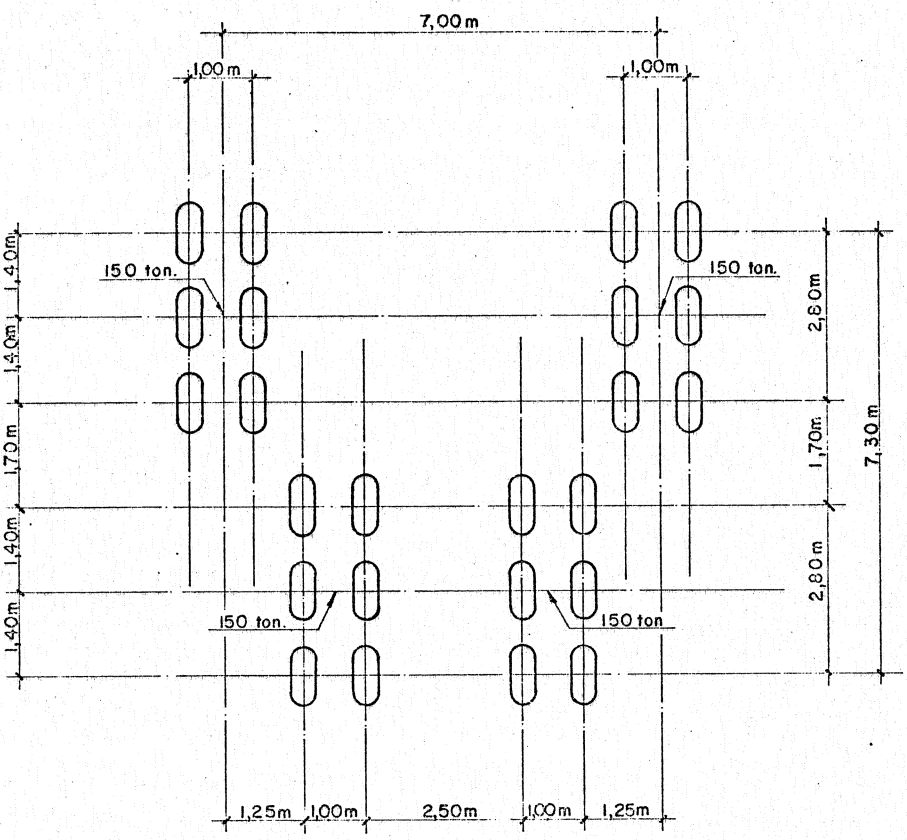
2) Waddell, Joseph J., et.al., Concrete Construction Handbook, New York, Mc Graw-Hill Book Company, 1968.

3) Anonymous, "Dywidag Licensed Posttensioned Concrete Structures", Dywidag Report, Dyckerhoff and Widmann AG, Munich, 1974.

4) Anonymous, Design of Concrete Airport Pavement, Portland Cement Association, Skokie, Ill., 1973.

5) Anonymous, "Airfield Flexible Pavements - Air Force", Department of The Air Force Manual AFM 88-6, Chapter 2, 1969.

6) Anonymous, "Airport Paving", Advisory Circular 150/5320-6B, Federal Aviation Administration, 1974.



TYPICAL LANDING GEAR SCHEME

FIG. 1

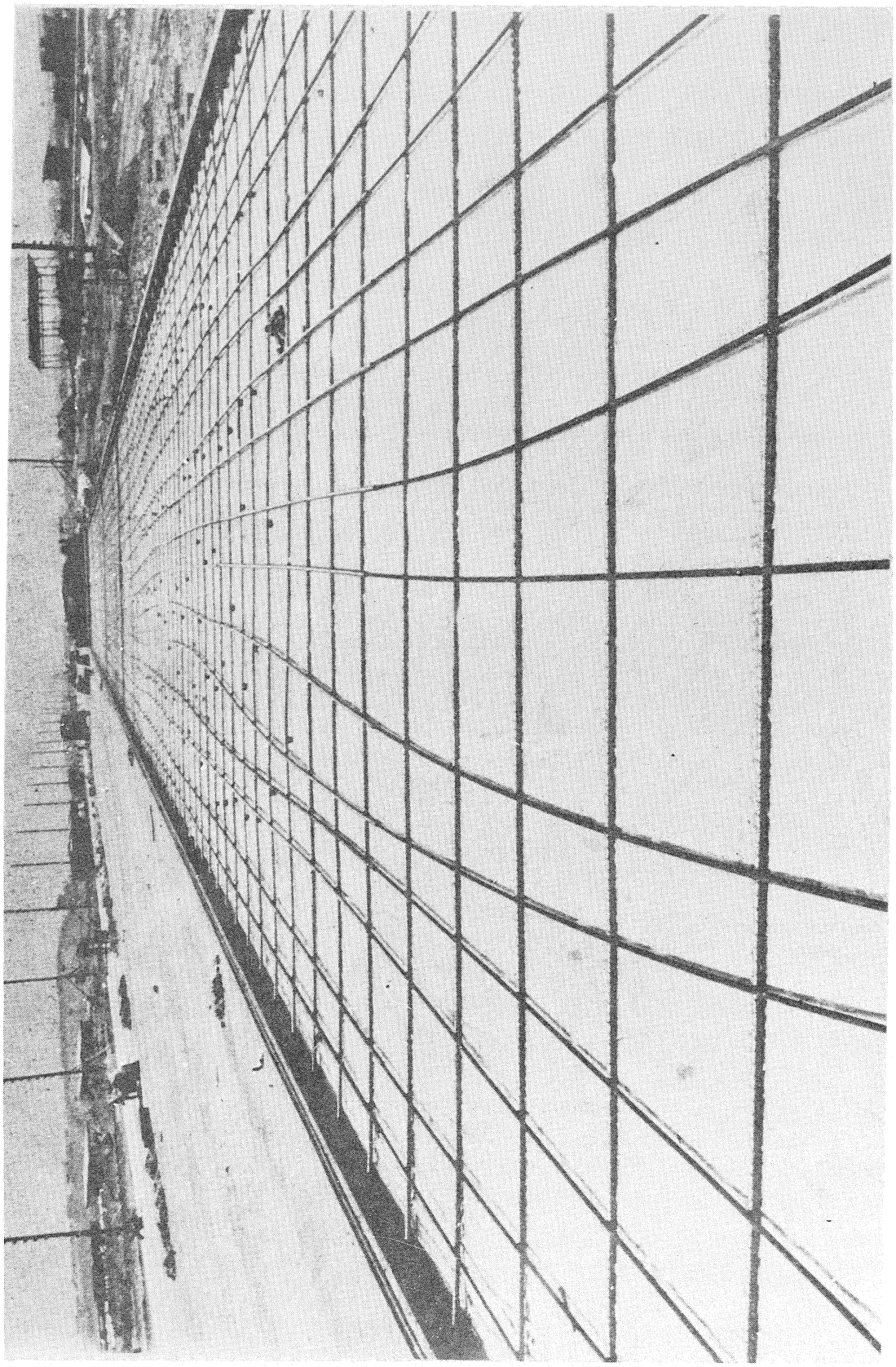


FIGURE 2 - POSI TIONING OF TRANSVERSAL AND LONGITUDINAL SHEATHS

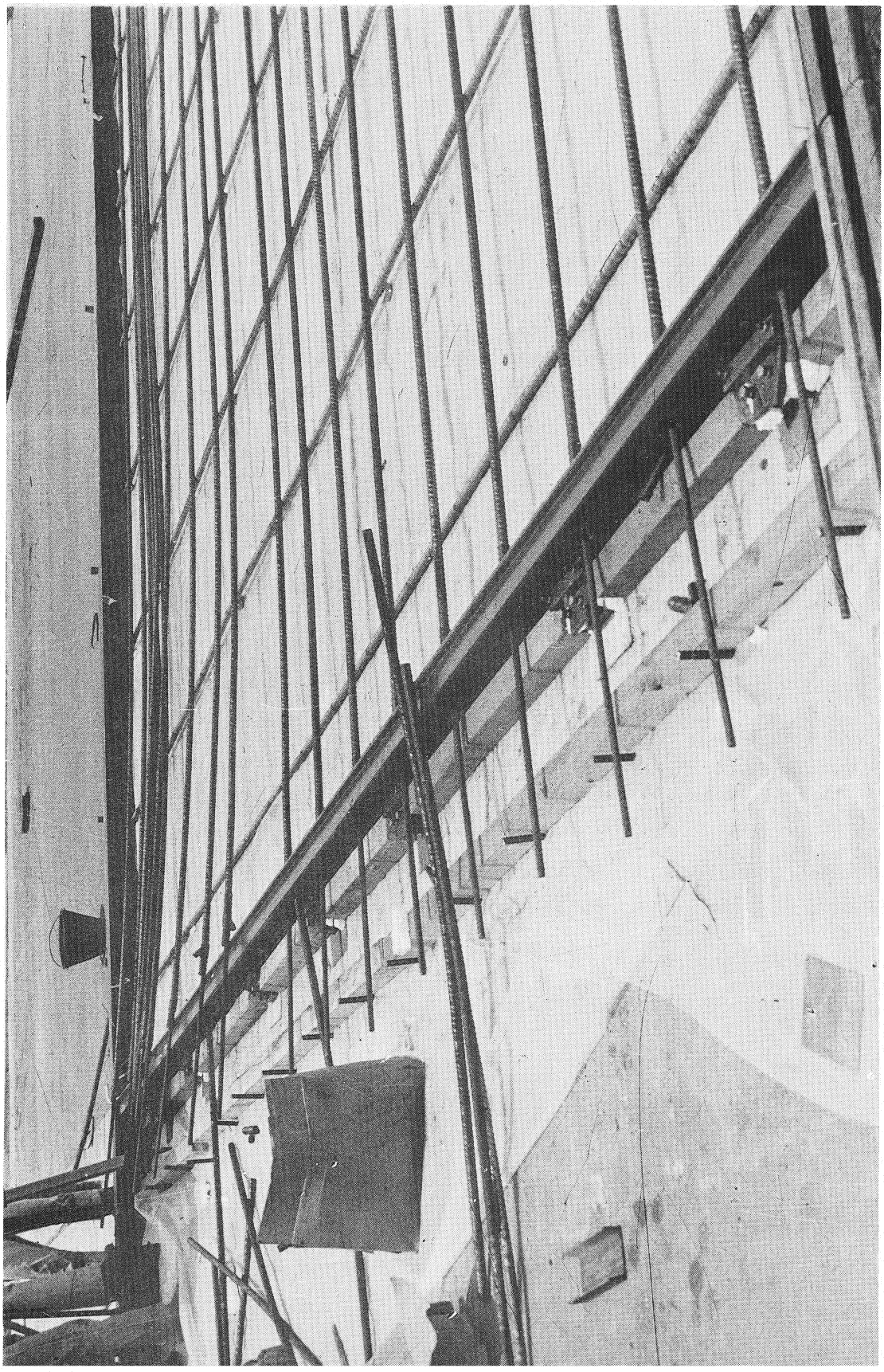


FIGURE 3 - INSERTION OF LONGITUDINAL CABLES

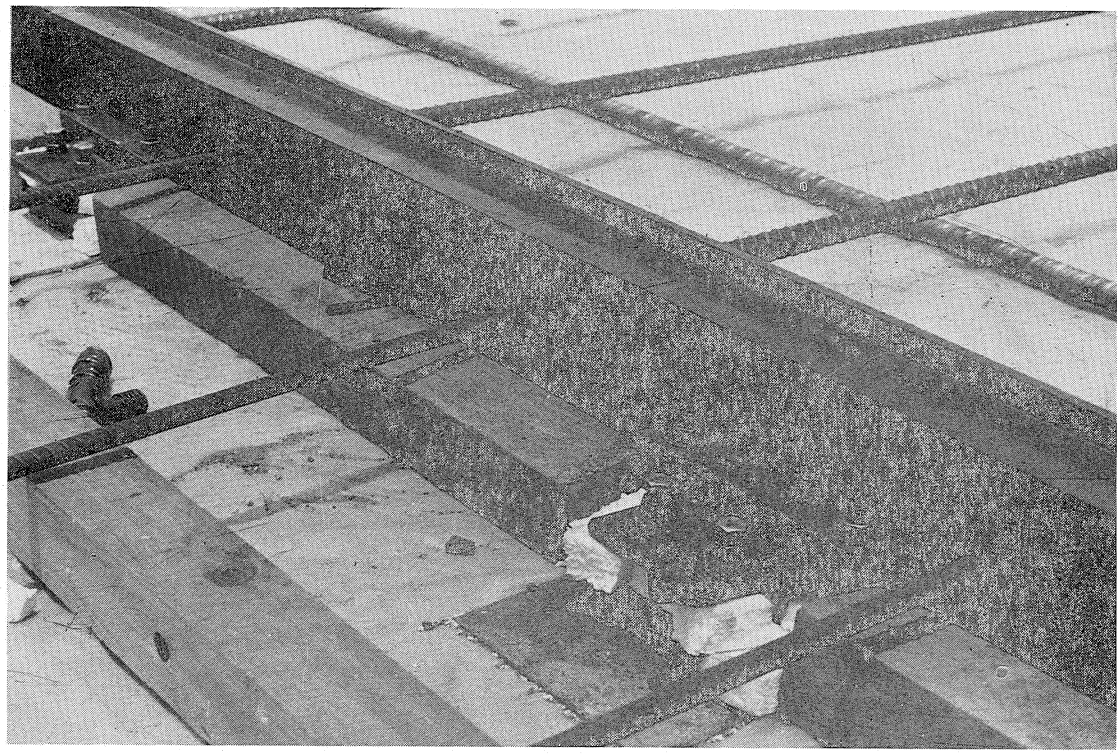


FIGURE 4 - SLAB READY TO BE CONCRETED, SHOWING DETAIL OF EXPANSION JOINT

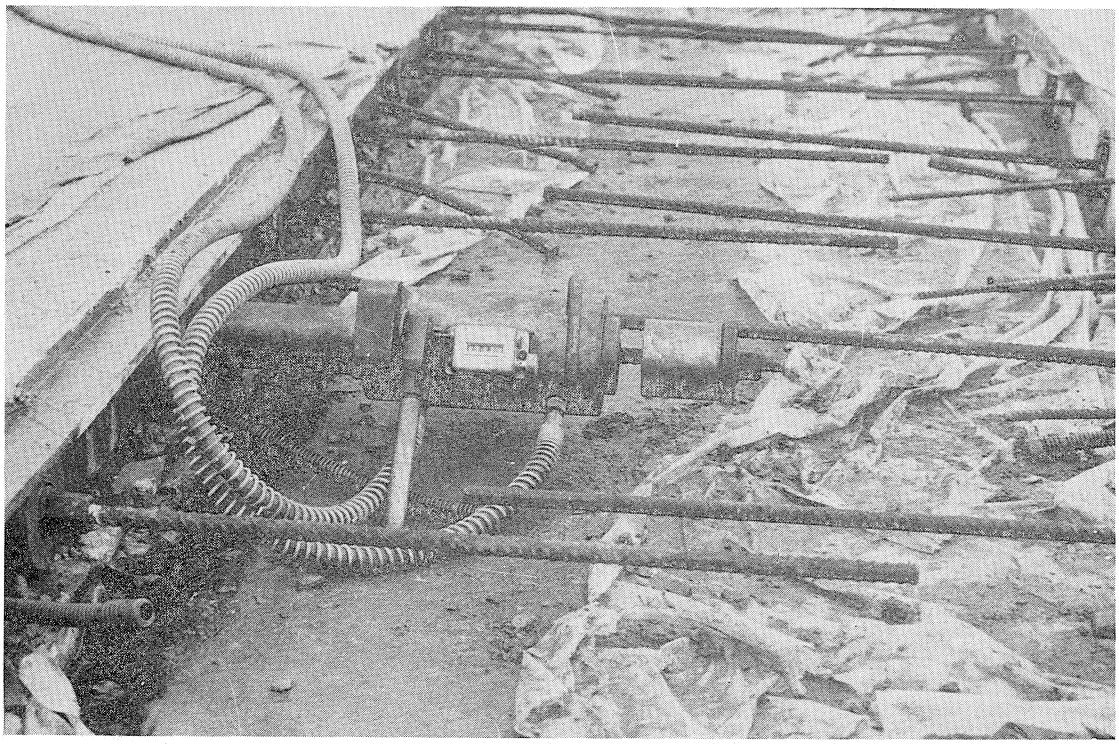


FIGURE 5 - POSTTENSIONING OF LONGITUDINAL CABLES