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PRESTRESSED CONCRETE PAVEMENTS FOR RUNWAYS AND CARRIAGEWAYS

by

G. Mittelmann

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CEMENT AND CONCRETE ASSOCIATION
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CONVERSION FACTORS

Length	1 cm	=	0·394 in.
	1 m	=	3·281 ft
Weight	1 kg	=	2·205 lb
	1 metric ton	=	0·984 long ton
Stress	1 kg/cm^2	=	14·22 lb/in^2
	1 kg/mm^2	=	0·635 ton/in^2
Bending moment	1 kg m	=	7·233 lb ft

PRESTRESSED CONCRETE PAVEMENTS FOR RUNWAYS AND CARRIAGEWAYS

Prestressed concrete runways and carriageways offer significant technical advantages over similar pavements constructed in reinforced or plain concrete. The spacing between joints can be made many times greater than is required in non-prestressed pavements, so that the number of joints is considerably reduced. Prestressed pavements have a higher load-carrying capacity and a longer service life; they permit the use of a lighter base and can be made substantially thinner.(24-30)

The firm of Philipp Holzmann A.G. has constructed a number of prestressed carriageways and runways; investigations have been carried out and significant information has been gained. This is described in the following.

GENERAL

Prestressed carriageway and runway pavements can be constructed by two different methods, which are often referred to as "external" and "internal" prestressing(1-7): "external" prestressing is produced by jacks thrusting against abutments, no prestressing steel being used; "internal" prestressing is produced by means of prestressing steel, as in prestressed concrete construction generally, pre-tensioning or post-tensioning being employed.

In post-tensioning, sheaths containing bundles of wires or individual bars are generally installed in the formwork before the concrete is placed. After the concrete has hardened, the tendons are tensioned by means of jacks or nuts. Disadvantages of post-tensioning are the loss of prestressing force due to friction between the tendon and its sheath and also the fact that the force is transmitted to the concrete by end anchorage only. These factors cause some uncertainty as to the actual magnitude of the prestress in the slab, which is particularly noticeable in slabs 100 m or 150 m in length. For example, the effect of sheath friction produces a loss of stress of approximately 15% in a slab 150 m in length. A further disadvantage is that the sheaths seriously weaken the concrete cross-section. Consequently, temperature and moisture effects (tensile stresses) are liable to cause cracking in the vicinity of the sheaths for the transverse prestress before the longitudinal prestress has been applied. To resist flexural stresses due to live load or temperature gradients it is necessary to install the tendon sheaths at mid-depth in the slab; otherwise the reduction in cross-section in the tensile zone will promote the formation of cracks. In addition, the local deformations caused by a load applied to a certain area of the pavement are not cancelled by the tendon forces introduced at the ends of the slab only, but rather tend to become stabilized. Besides these unfavourable effects of using sheaths* an additional operation is necessary, namely, grouting the ducts. Having regard to the German "Provisional directives for the grouting of prestressing ducts, July 1957", the grouting of 150 m long tendons can be satisfactorily performed only if the sheath is large enough, i.e., at least 35 - 40% of its cross-section must not be taken up by prestressing steel. If this requirement is not fulfilled, the water/cement ratio of the grout will have to be substantially increased, which entails serious disadvantages with regard to bond and protection against corrosion. The sheaths therefore have to be taken into consideration in choosing the thickness of the slab.

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*Although the author refers specifically to "sheaths", these considerations obviously apply to preformed ducts produced by any other means (extractable cores, etc.). (Translator's note.)

Pre-tensioning is used chiefly for precast members. The wires are first given the requisite amount of tension (on the prestressing bed) and the concrete is then placed. When it has hardened, the wires are released from their abutments, the tensile force in the wires being thus transmitted as a compressive force to the hardened concrete. One of the advantages of pre-tensioning is that the stresses are of known magnitude over the entire length of the wires; there are no losses due to sheath friction, so that - if sub-grade friction is neglected - a constant stress will be obtained all along the slab. Hence it follows that, to obtain stresses of equal magnitude at the centre of the slab by both methods of prestressing, the quantity of prestressing steel required for a pre-tensioned slab will be less than for a post-tensioned one.

Furthermore, there is continuous bond between the individual wires and the concrete, without any interposition of grout and sheath, and resistance to deformation by local loading is provided by wires in the immediate vicinity. If the transverse prestress can also be produced by the pre-tensioning method, then the reduction in cross-sectional area due to the ducts will also be eliminated. In addition to advantages of technical construction procedure, pre-tensioning provides the surest guarantee that, in the event of partial damage to the slab, the prestress will indeed only be destroyed locally in the damaged area.

With the pre-tensioning method it is always possible to dispense with eccentric arrangement of the tendons. With post-tensioning, on the other hand, it may be necessary to apply the prestress eccentrically if a symmetrical arrangement of the longitudinal and transverse tendons would call for disproportionately large slab dimensions. An eccentric prestress produces moments of varying sign only at the free edges of the slab. The effects of eccentricity are superimposed upon those of temperature differences between the top and bottom of the slab in an unfavourable manner, so that the likelihood of curving of the slab in the end region is greater. In addition, it should be borne in mind that the order of magnitude of the permissible eccentricities may be hardly greater than the constructional tolerances allowed.

The smallest slab thicknesses are obtained with pre-tensioning. This is a significant point, since all stresses arising from climatic influences are primarily bound up with the slab thickness and are liable, for large thicknesses, to produce stresses which are greater than those caused by live load.

In addition to prestressed pavement slabs manufactured by pre-tensioning, we have, for special purposes, also constructed post-tensioned carriageway pavements and pavements provided with external prestress (against abutments) in conjunction with post-tensioning.

After dealing with the system that has been developed on the basis of the knowledge gained, we shall consider these last-mentioned examples also.

THEORETICAL DESIGN CONSIDERATIONS

The significant difference in behaviour between a "normal" reinforced concrete structure and a prestressed concrete pavement slab is that, in the latter, relatively high stresses (e.g., due to temperature variations) occur from the very first hour after concreting, whereas in the case of bridges, for instance, this does not arise until the properties of the material (e.g., the modulus of elasticity and the strength) have approximately attained their final values.

In order to obviate the longitudinal tensile stresses, which occur in the first few days after concreting as a result of restraint of shortening when the temperature drops, it is essential to apply part of the prestress at the earliest possible moment. Furthermore, the slab should be provided with a protective membrane and be covered with straw matting to prevent drying-out and a fall in temperature during the final hardening of the concrete.

The stress analysis for a prestressed concrete pavement slab must therefore not confine itself to a consideration of individual loading conditions but should take account of and correctly assess the effect of time during the construction period and the consequent change in material properties.

Hence the stress calculations can suitably be based upon three "stages".

Stage 1: immediately after concreting

The stress conditions occurring in this stage are the uniform temperature change (temperature difference) and the non-uniform temperature effect (temperature gradient). With a uniform change in temperature, direct stresses occur as a result of the friction between the slab and the sub-grade and also, in the case of a pre-tensioned slab, as a result of extensional restraint of the slab "suspended" in the prestressing steel. The temperature gradient gives rise to flexural stresses at the top and bottom of the slab.

The above-mentioned effects occur within the first two or three days; some assumptions must therefore be made regarding the characteristics of the material. As the concrete is still very young and the temperature variations proceed at a relatively slow rate (if the slab is covered with straw matting), it is permissible (in connexion with temperature stresses) to adopt a considerably lower value than usual for the modulus of elasticity of concrete.

In this stage, lateral strain (Poisson's ratio) is neglected.

For the uniform temperature changes it should be considered that, owing to covering the concrete with straw mats during the period in question, the differences become very small. In the absence of such covering, temperature differences of 0·7°C/cm may occur(8) but these are greatly reduced if straw mats are used(9), a value of 0·3°C/cm being a safe assumption. The magnitudes of the absolute variations in temperature in the concrete are not decisive because for a certain temperature change the frictional forces acting between the slab and the sub-grade are fully overcome, i.e., the maximum possible stresses will occur - when the slab cools, these will be tensile stresses. It should furthermore be remembered that no dependable relations have yet been established with regard to the effect of the moisture content of the hardened concrete.(10) Since the effect (e.g., expansion of the slab) almost invariably is opposed to that of temperature (and therefore substantially reduces the temperature stress), the above assumption for the temperature change appears to be quite justified.

It should be noted that tensile stresses due to uniform and non-uniform temperature changes are complementary at the top of the slab only when the temperature falls.

In calculating the frictional stress, a coefficient of friction of between 0·35 and 0·40 should be assumed at ordinary temperatures, in conjunction with the type of sliding layer used by us.(11)

The deformation of the slab due to a change in temperature produces a change of stress in the prestressing wires in the prestressing bed(12): for instance, the tensile stress in these wires will increase when the temperature goes down. This in turn will affect the state of stress in the slab.

The additional tensile force arising in the prestressing steel on cooling is:

$$S_{max} = F_z (\sigma_s - \sigma^*)$$

where $\sigma_s = 14{\cdot}5\ t/cm^2$ is the yield point and σ^* is the initial stress of the steel.

In comparing the most unfavourable stresses with the permissible values it should be borne in mind that these stresses will not actually occur, since constructional precautions (straw mats, time at which concreting is carried out, etc.) will largely obviate them.

The conditions relating to stage 1 are applicable only to the first ten hours after concreting.

Stage 2: partial prestress

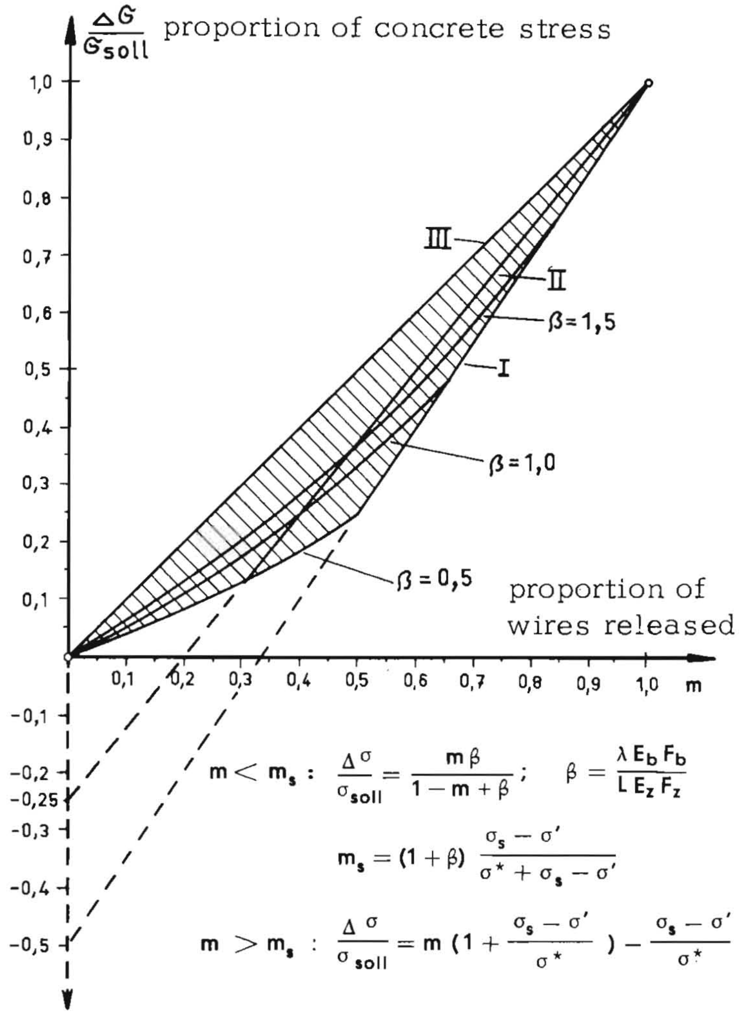
This stage is also characterized by the fact that the concrete has not yet attained its full strength.

It may sometimes occur that the straw mats are no longer present, so that a larger temperature change should be taken into account, namely, for a temperature gradient of 0·7°C/cm. If the temperature falls (in relation to the initial temperature) the yield point may be reached in the free (non-embedded) length of wire, causing plastic elongation; and if the temperature then rises, causing the slab to expand, a partial prestress will be produced in the slab. Similarly, an initial temperature rise will relax the prestressing steel, so that this too will produce a partial prestress.

When part of the prestress is actually applied by releasing wires on the prestressing bed, the restraining action of the prestressing wires when the temperature falls will be less pronounced. The proportion of the wires to be released can be so chosen that the yield point is reached in the remaining ones. As a result of this, no increase in tensile stress (in consequence of restraint on cooling) can occur in the concrete.

This possibility is not present if all the wires are instead partly released to produce a partial prestress. In that case, if the temperature subsequently goes down, the restraining action will again increase until the yield point is reached in the wires and additional tensile stresses will therefore be produced in the concrete.

The dependence of the partial prestress upon the number of wires released is represented in the following diagram. In all cases the state of stress immediately after concreting has been adopted as the basis.



$$m < m_s : \quad \frac{\Delta\sigma}{\sigma_{soll}} = \frac{m\beta}{1 - m + \beta} ; \qquad \beta = \frac{\lambda E_b F_b}{L E_z F_z}$$

$$m_s = (1 + \beta) \frac{\sigma_s - \sigma'}{\sigma^* + \sigma_s - \sigma'}$$

$$m > m_s : \quad \frac{\Delta\sigma}{\sigma_{soll}} = m \left(1 + \frac{\sigma_s - \sigma'}{\sigma^*}\right) - \frac{\sigma_s - \sigma'}{\sigma^*}$$

σ^* initial stress in the steel

soll = nominal (or desired) stress

$$\left.\begin{array}{r} \mathrm{I} : \sigma' = 0{,}6\,\sigma_s \\ \mathrm{II} : \sigma' = 0{,}8\,\sigma_s \\ \mathrm{III} : \sigma' = 1{,}0\,\sigma_s \end{array}\right\} \text{stress on releasing the wires}$$

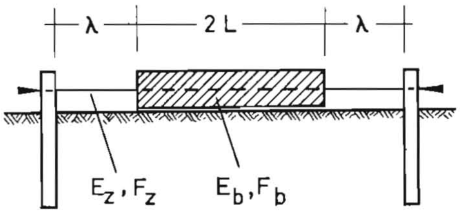


Figure 1: Relation between the stress in the concrete and the number of wires released in pre-tensioning

Stage 3: full prestress and live load

The concrete has attained its full strength, so that the appropriate value of the modulus of elasticity should now be adopted. Numerous measurements indicate a value of approximately 0·25 for Poisson's ratio.(13) As regards temperature changes, the same assumptions as for stage 2 are valid.

Various methods are available for calculating the flexural tensile stresses due to live load. The basis of all such calculations consists in establishing a so-called "equivalent" single-wheel load which is so defined that, when it acts with the same bearing pressure as the wheels of the wheel assembly, it produces stresses which are equivalent to those produced by the wheel assembly as a whole.

It does not matter a great deal with a rigid (i.e., thick) concrete slab whether the load acts upon the slab through one wheel or through a dual tandem wheel assembly but this is not the case with prestressed concrete slabs which are thinner. In the latter, the load-spreading action of a dual tandem wheel assembly can take effect, i.e., the equivalent single-wheel load will be substantially smaller than the original wheel assembly load. In the limiting case the equivalent single-wheel load will be no greater than the load of only one wheel of the dual tandem wheel assembly. The prestressed concrete slab is therefore extremely good in this respect; the four wheels have hardly any effect upon one another as far as the adverse tensile stresses on the underside of the slab are concerned.

For calculating the equivalent single-wheel load the ICAO, in their Draft Report of Sixth Session of the AGA Division, Montreal, 12 March - 15 April 1957, Chapter VII, outline a method which provides a rapid solution with the aid of diagrams.

The stresses due to live load may, for example, be calculated in accordance with the ICAO recommendations or according to Peltier(14) or Voellmy(15). Compared with the last-mentioned method, the standard methods based on the elastic theory (elastically supported slabs) give approximately 40% higher stresses on the underside of the slab and lower stresses at the top. This is also true of the improved Westergaard formula, taking account of the additions indicated by Teller and Sutherland(16, 17).

If all the influencing factors are taken into consideration, it is possible to analyse the individual states of stress of a prestressed concrete slab with sufficient accuracy. The following stresses occur:

stress due to friction between the slab and the sub-grade in consequence of uniform temperature change (temperature difference, shrinkage, creep and effect of moisture);

additional stress due to restraint of the slab by the pre-tensioned wire in the prestressing bed;

stress due to non-uniform temperature change (temperature gradient and moisture distribution);

stress due to prestress (or partial prestress);

stress due to live load.

The results for the individual states of stress are summarized in Table 1, from which the most unfavourable flexural tensile stresses are determined.

The concrete properties as a function of time are calculated with reference to a publication by Voellmy(18).

In the case of a prestressed slab no fracture of the slab as a whole will occur if the permissible flexural tensile stresses are exceeded: on the contrary, hair-cracking will result in a greater amount of co-operation of the sub-grade in resisting the load. On removal of the applied loading, the cracks close up completely, so that no permanent damage is caused. Thanks to this advantageous co-operation of slab and sub-grade, prestressed concrete pavements possess a high degree of flexibility and can carry heavy loads.

TABLE 1: Summary of states of stress.

Condition	Cause	Place	Loading	Index	
immediately after concreting	uniform temperature change	slab, sub-grade	frictional force	R	1
		slab, prestressing bed	extensional restraint	A	
	non-uniform temperature effect	top, bottom of slab	flexural stress	Δt	
partial prestress	uniform temperature change	slab, sub-grade	frictional force	R	2
		slab, prestressing bed	extensional restraint	A	
	non-uniform temperature effect	top, bottom of slab	flexural stress	Δt	
	longitudinal prestressing force	slab	longitudinal prestress	V	
full longitudinal and transverse prestress	uniform temperature change	slab, sub-grade	frictional force	R	3
	non-uniform temperature effect	top, bottom of slab	flexural stress	Δt	
	prestressing force	slab in longitudinal and transverse direction	longitudinal and transverse prestress	V	
	live loading	slab	equivalent single-wheel load	P	

CONSTRUCTION OF PRESTRESSED CONCRETE PAVEMENTS

The basic theoretical and structural features, the execution of the work and the knowledge gained in connexion with various jobs carried out, particularly by our Hanover branch, have been dealt with in several publications(19,20), which have been duly taken into account in the following.

The two anchorage abutments for the longitudinal prestress are spaced about 600 m apart and are constructed from sheet piling (e.g., Larssen III new). Two horizontal walings consisting of rolled-steel sections are provided with a gap of 2 cm between them. The longitudinal wires are passed through this gap and are anchored to the rear flanges of the walings. The abutments are retrieved for re-use on completion of the prestressing operations. The "give" of the sheet piles until the passive earth resistance is fully mobilized has no practical effect on the prestressing force since the tendon extension is at least 3·40 m, so that the prestressing operation is unaffected by minor inaccuracies.

The required good sliding surface is produced by stabilizing the top part of the frost blanket (granular sub-base) with cement - to an extent depending upon the nature of the material available - so that a perfectly level formation is obtained on which men can walk without damaging it. The sliding layer is specially prepared to minimize the negative effects due to friction.

Our officially authorized "KA" prestressing system* - a development of the "SH" system - is employed, in conjunction with obliquely-ribbed flat-rolled tendons of grade St 145/160 steel.

The permissible stress in pre-tensioned steel tendons on the prestressing bed or in post-tensioned tendons prior to grouting is $0{\cdot}8\ \sigma_S$ - i.e., 11,600 kg/cm^2 or 72% of the tensile strength.

The prestress coincides with the centroid of the slab in both directions. First the bottom longitudinal steel is installed. In general, the length in which the prestressing steel is commercially supplied is too short to extend between the pre-tensioning abutments. The wires are therefore spliced by means of a special coiling process, which can be applied to oval ribbed or twisted tendons (test report by Technological University of Darmstadt, Institute for Concrete and Masonry Construction, Prof. Dr.-Ing. Mehmel). The experimentally determined slip values for this splice connexion are about 2 mm maximum; since the wire extensions are around 3·50 m, the effect of such slip is of no significance. The prestress is produced by means of a special tensioning device whereby extensions of up to 4·50 m can be obtained in one operation. To avoid damaging the sliding layer, the prestressing steel is laid on rollers before tensioning is carried out. When the bottom prestressing steel has been installed, the sheaths for the transverse prestress are fixed in position and secured to the bottom layer of tendons. Then the top layer of longitudinal tendons is installed and tensioned. The stresses in the steel are checked by means of a strain gauge supplied by the German Federal Materials Testing Laboratory, Berlin-Dahlem(12).

For constructional and economic reasons pre-tensioning is not yet a practicable means of producing the transverse prestress. Efforts are, however, being made to find a solution in the not too distant future whereby pre-tensioning can also be employed for the transverse prestress.

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*"KA" prestressing system: Certificate of Approval issued by the Hessian Minister of the Interior, 20 July 1961 (AZ: Vb - 64 b . 08/27 - 10/61).

At the present time the transverse tendons are either placed in the sheaths prior to concreting or are subsequently threaded through the preformed ducts. These tendons are tensioned from alternate ends. To keep weakening of the concrete section to a minimum, sheaths of the smallest possible diameter are employed. Since subsequent threading of the tendons requires a somewhat larger sheath diameter, it is preferable to install the tendons in their sheaths before the concrete is placed; the side forms on which the finishing machine travels have to be appropriately designed to allow of this.

The tendon spacing in the longitudinal and transverse directions is determined by the requisite compressive stresses in the concrete, having regard to the effects of live load, temperature, moisture and friction. The slab is concreted in strips of 7·50 m width and approximately 150 m length. The longitudinal prestressing wires are tensioned a short time before the relevant strips are concreted. As a safeguard against the excessively early onset of shrinkage and to prevent the concrete's drying out too quickly, the slabs are protected with Antisol or by other appropriate means. In order to minimize the temperature variations in the concrete directly after concreting, the slab is covered with straw matting until a certain proportion of the prestress has been applied and the concrete has acquired some degree of tensile strength.

The joints are constructed with particular care, as the calculations show that they are liable to open very widely; the provision of a cover plate therefore appears appropriate. The tendons are connected directly to the end faces of the steel joints so that no part of the slab is without prestress in both directions.

The early transfer of part of the longitudinal prestress to the concrete is effected by releasing about half the total number of prestressing wires at the abutments and in the joints between the slabs, this being done at the earliest possible time (after 12 hours at the latest). This is possible with ribbed prestressing steel because, in contrast to plain round wires, good shear-resisting bond is achieved after only a few hours. The transmission of the prestressing forces to the ends of the slabs is effectively assisted by connecting the tendons to the steel joints.*

In general the wires are cut by means of a flame-cutter. In this operation the slow but steady heating of the steel causes it to yield, so that transfer of the force to the concrete with a sudden jerk is completely ruled out. As soon as the concrete has attained the required strength, the full prestress is transferred by releasing all the wires.

SOME EXAMPLES OF PAVEMENTS CONSTRUCTED

1. Volkswagen motor-car testing track at Wolfsburg

In 1956 our Hanover branch undertook the construction of a running-in track for the Volkswagen motor works. This track, approximately 1800 m long and 9·0 m wide on plan, has a roughly oval shape and comprises four sections with the following lengths(21):

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*The reference to "steel" joints presumably means that the faces of the joints are encased in steel or are formed by steel plates or joists. (Translator's note.)

east curve	649 m
west curve	591 m
north straight	230 m
south straight	230 m

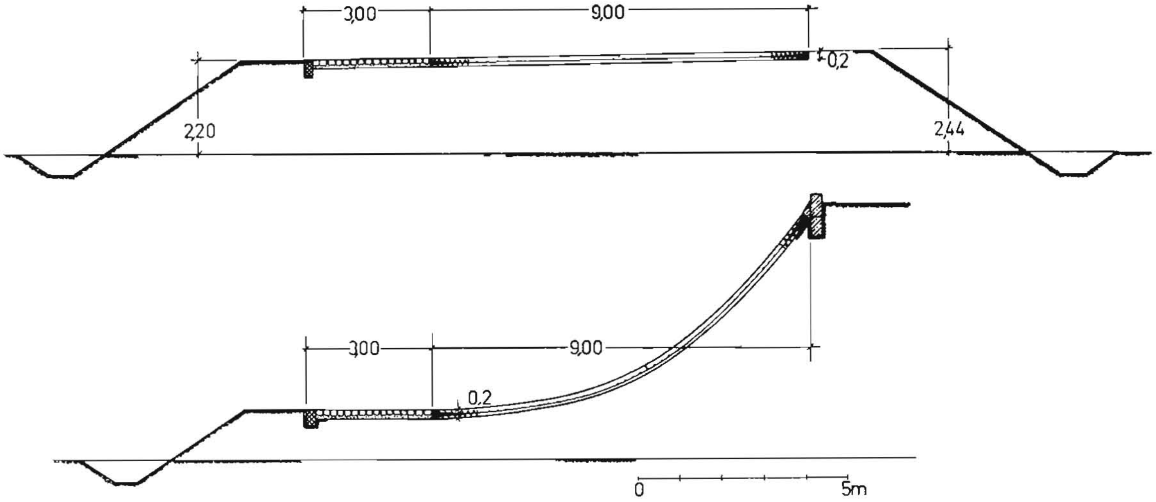

Figure 2: Volkswagen car testing track at Wolfsburg. Cross-sections through the straight and curved stretches.

The carriageway slab (18,000 m^2) is prestressed in both directions.

The transverse prestress of the concrete prior to creep and shrinkage was 15 kg/cm^2 and was produced by approximately 1200 "HG" type tendons* spaced 1·50 m apart(22,23).

The magnitude of the longitudinal prestress is, in the main, determined by the conditions of friction between the slab and its base. The effect of live load is negligible (total weight of Volkswagen vehicle is 1,650 kg).

To obtain the most favourable friction conditions, a concrete base of 13 - 15 cm average thickness and containing 130 - 140 kg of cement per m^3 was constructed with the aid of a finishing machine. A waterproof underlay of bitumen paper was stuck to the concrete base and was sprayed with a warm solution of a sliding paste. This sliding layer, consisting of Roxtone 34 (spindle oil distillate) and Petrolatum G 2 (paraffin residue), has the consistence of axle grease at normal temperature. It was covered with a layer of grade 500 talcum-treated bitumen felt. By this means it was possible to obtain coefficients of friction of less than 0·4 (as determined in site tests)(11).

Since in theory the greatest variations in stress occur at the centres of the lengths of slab (assuming the ends to be able to move freely), the prestress has been correspondingly graduated, so that there is less stress at the ends than at the centre. At the lowest anticipated temperature there is

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*"HG" prestressing system ("HG" tendons): Certificate of Approval issued by the Hessian Minister of the Interior, 15 May 1961 (AZ: Vb - 64 b . 08/27 - 11/61).

largely a uniformly distributed compressive stress in the concrete (which stress, for example, cancels the flexural tensile stresses due to live load). Thus, the longitudinal prestress ranges from the force produced by 28 tendons (type HG 10) at the centres of the curves to that produced by 12 tendons at the ends of the curved portions. The corresponding numbers of tendons in the straight portions of slab are 15 and 11 respectively.

To keep the slab thickness as small as possible, sheaths of oval, almost rectangular, cross-section were employed. Some of the tendons extend the entire length of the slab portions, so that in the final condition the pavement contains tendons up to 649 m in length. To avoid excessive losses of stress due to friction of the tendons in the sheaths, intermediate tensioning points at intervals of 30 and 75 m were provided. These joints were subsequently filled with concrete, so that the four portions of slab forming the track are each without joints.

According to the procedure described above, this running-in track was post-tensioned. Wedges were installed in the gaps between the four slab portions to form "abutments". As distinct from the method whereby the prestress is produced by thrusting against abutments ("external" prestressing), the abutments in the present case are neither of the rigid or the flexible type, but come into action only when the slabs undergo elongation. When the slabs contract, the wedges pull in, so that the gaps are always closed. When the temperature rises, the wedges remain in position, and considerable compressive stresses may then occur which in turn cause a larger amount of creep, with the result that the compressive stresses are partially cancelled. Hence it follows that, as the creep capacity of the concrete diminishes as the years go by, the compressive stresses in this system are liable to become too high. For this reason the wedges were released, during the past year, leaving a gap of a few millimetres between the slab ends and the wedges. When the track had shown itself to behave satisfactorily in this condition too, the wedges were removed and replaced by a finger type structure* of rolled steel plates, which has so far proved very satisfactory. Even when a measuring wheel as used for speed and acceleration measurements in the motor-car industry crosses such a joint, no perceptible jolt occurs.

Because of the lack of long-term experience in the construction of prestressed concrete roads in general, and in the absence of special knowledge regarding the conditions pertaining to this particular case, our technical department performed preliminary tests for determining some of the important characteristic values, such as friction, and carried out measurements of concrete stress during prestressing and check measurements on the concrete over fairly long periods(11). Among others, the following values were determined: concrete stresses due to longitudinal and transverse prestress, friction between slab and concrete base course, friction between prestressing steel and sheath, and temperature movements of the slab ends. In addition, long-term measurements were carried out. These showed, for example, that the relative atmospheric humidity (and therefore also the moisture content of the hardened concrete: shrinkage and swelling) has a not inconsiderable effect upon the stresses in the concrete.

By the riding quality standards of the Volkswagen works the condition of the track continues to be excellent.

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*Presumably some kind of interlocking device. (Translator's note.)

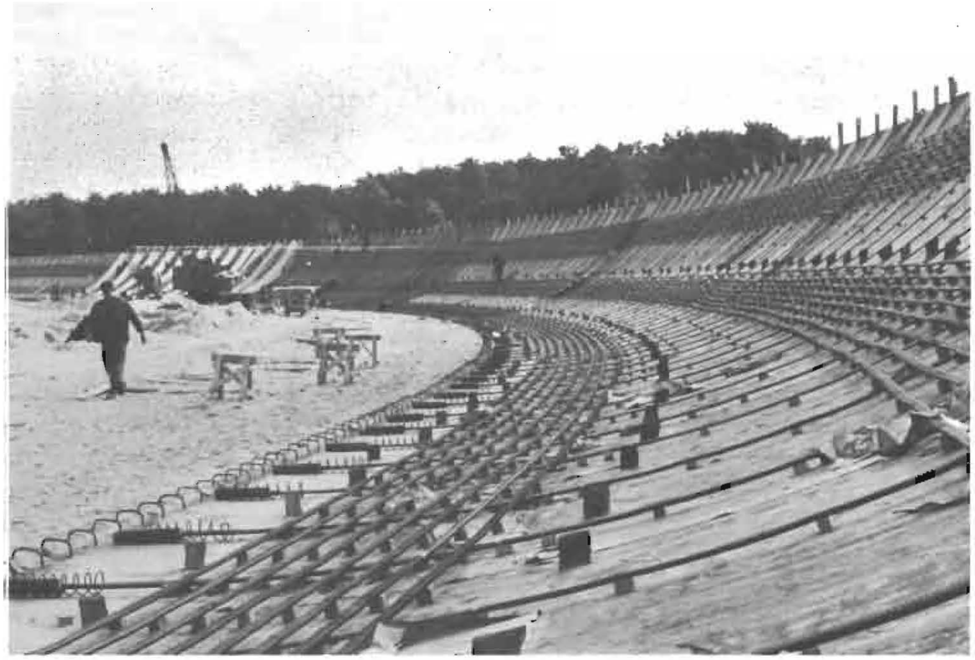

Figure 3: Longitudinal and transverse tendons on a curve.

Figure 4: Volkswagen car testing track Wolfsburg.

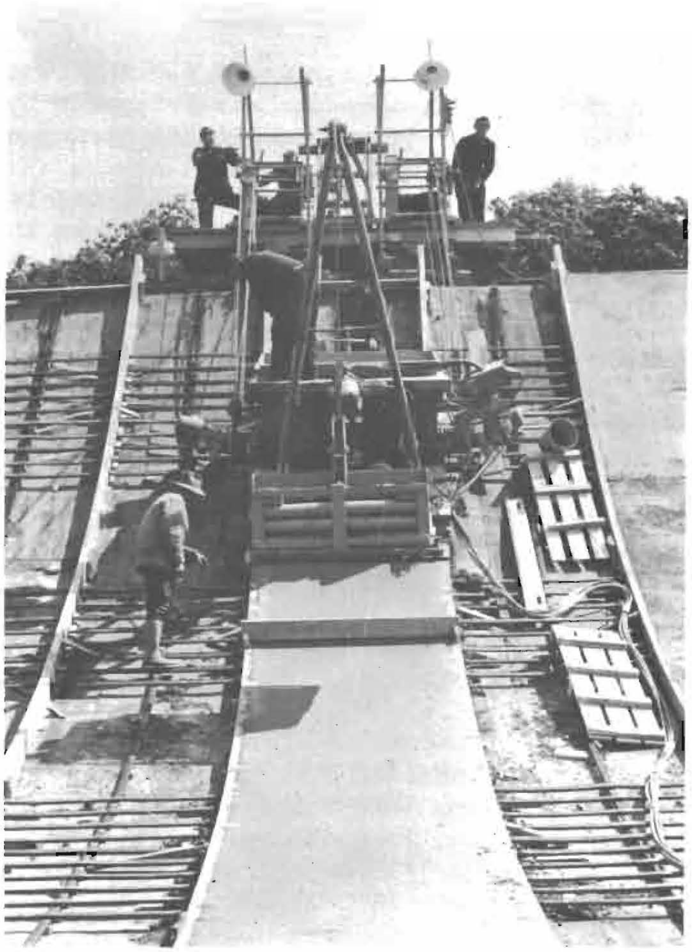

Figure 5: Concrete finishing machine operating on a curve.

Figure 6: Test for determining the coefficients of friction between slab and base for various types of sliding layer.

2. Roller-skating rinks at Detmold, Wolfsburg and Cassel

At the beginning of 1958 we were asked to investigate the possibilities of repairing a roller-skating rink which had become unserviceable because proper account had not been taken of the subsoil conditions during construction (jointed reinforced concrete slab damaged by cracking). At the suggestion of our Hanover branch a post-tensioned prestressed concrete slab was constructed ("HG" prestressing system). In the case of roller-skating rinks the live loading is negligible and the stresses are caused mainly by friction between slab and sub-grade and by the temperature gradient. The surface of the old rink was very irregular, so in order to obtain a base having the required level surface and presenting the least possible friction, a levelling course of hydraulic lime mortar with added cement was constructed in such a thickness as to provide at least 5 mm cover over the largest irregularities (which were of 2 cm absolute height). This levelling course, which was laid by hand with the aid of screeds, was overlaid with two layers of a special "sliding" paper which exhibited favourable friction coefficients. The prestressing tendons were then installed and the concrete was placed by hand. The slab was finished by means of a finishing machine (with an operating width of 4 m): a curing compound ("Curing WS") was employed.

The "axial" prestress, which obviates any curvature at the edges of this relatively small slab, was produced by three layers of tendons. For 2·5 cm concrete cover to the sheaths the slab had to be 12 cm thick. The prestressing force in each tendon was approximately 18·6 tons. Tendons were 1·02 m apart for the longitudinal direction (prestress 18·2 tons/m) and 1·16 m for the transverse direction (16·0 tons/m). The longitudinal prestress in the concrete is therefore 15·1 kg/cm^2 (F_{Z1} = 1·26 kg/m^2) and the transverse prestress is 13·3 kg/cm^2 (F_{Z1} = 1·10 kg/m^2).* Stressing was commenced five days after concreting.

In order to obtain a surface that would be skid-proof even in rainy weather, the prestressed concrete slab was provided with a 5 mm surfacing consisting of a mortar made with cement, 0·2 mm quartz sand and Asoplast (a plastic supplied by Schomburg & Co. KG, Dortmund).

The rink (20 by 40 m) constructed in this way is very suitable for roller skating, since the surface is sufficiently smooth in dry weather and not too slippery in wet weather. Surface finishes made with plastics do, however, require more maintenance. For this reason, in the case of a roller-skating rink at Wolfsburg constructed in 1961 according to the same principle, the requisite riding quality was obtained by grinding the surface.

Yet another rink of this type was built at Cassel-Wolfsanger in 1962.

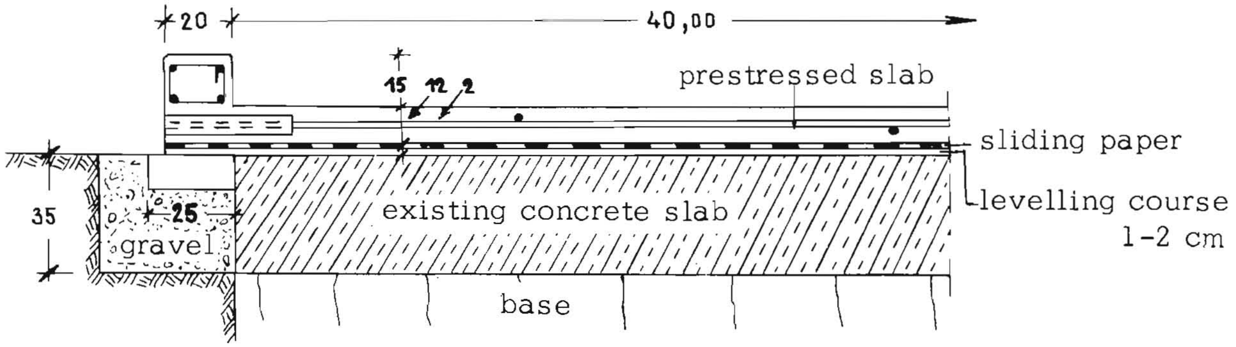

Figure 7: Roller-skating rink at Detmold. Section through slab, showing edge construction.

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*F_{Z1} possibly indicates the weight of prestressing steel per square metre of slab. (Translator's note.)

Figure 8: Concreting a strip of slab.

3. Runway in Lower Saxony

In 1958 our Hanover branch installed the prestressing steel and carried out the tensioning operations, together with all the ancillary work, for the construction of two sections of an airfield runway at Lüneburger Heide. This was the first time that pre-tensioning was used in runway construction in Germany.

The east section (head of the runway) was 7,260 m^2 in area. The base consisted of a 20 cm thick concrete slab with joints spaced at 3·75 m in one direction and 7·50 m in the other. The west section, with a total area of 21,600 m^2, was an extension to the runway. The sub-grade consisted of gravelly and sandy heath soil. A 40 cm thick frost blanket was installed under the slab, and for both sections of runway the transverse prestress was produced by post-tensioning (in sheaths).

The pre-tensioning abutments were installed 720 m apart, the tendon extension being about 4·15 m.

The two abutments for the west section of runway were constructed of 5 m long sheet piles surmounted by a reinforced concrete capping beam (in future applications of this system, rolled steel joists will be used instead).

The sliding layer was formed by two layers of a special "sliding" paper on a 3 - 5 cm thick stabilized course (the frost blanket consisted of very fine-grained uniform sandy soil), so that the paraffin layers lie one upon the other.ⱶ With these "sliding" papers the coefficient of "static" friction is probably greater than of sliding friction. Partly as a result of unfavourable weather conditions, some cracks occurred before the partial prestress was applied, but these subsequently closed up, thanks to the favourable friction conditions and the adequate prestress.

ⱶThe "paraffin layers" presumably denote layers of paraffin-impregnated paper. (Translator's note.)

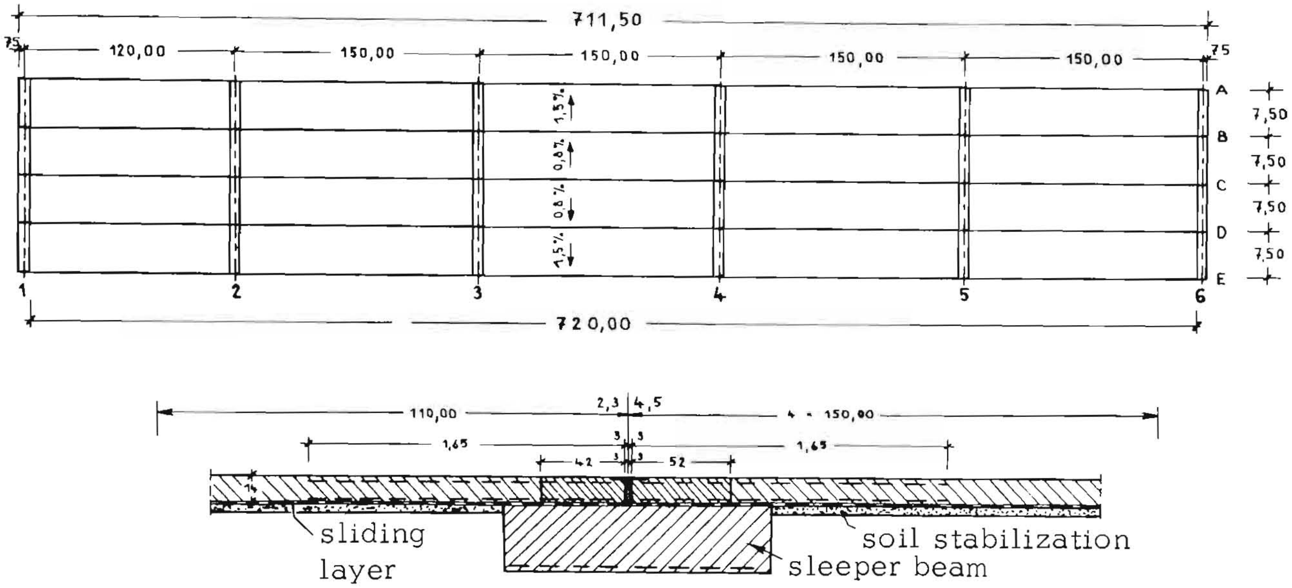

Figure 9: Runway in Lower Saxony. Plan and longitudinal section.

The individual 7·50 m wide runway strips were concreted - in the sequence I, II, III, IV - in a continuous operation from one pre-tensioning abutment to the other; a gap approximately 1·10 m wide was left at each of the joints of the five successive slabs (generally 150 m in length) constituting each strip. Curing was carried out with the aid of Betosit E sprayed from a working platform on to the concrete as soon as it was surface-dry. Experience showed that it is necessary to cover the entire area of slab between two abutments with straw matting and also that it is advantageous to relate the concreting procedure to the diurnal temperature variation. Initially, it had been decided to dispense with the preliminary partial prestress (because in some cases quite complicated arrangements for this purpose had been adopted in works producing precast pre-tensioned members), and this was one of the causes of the above-mentioned cracks. Site tests showed, however, that with the prestressing steel employed, which was provided with a pattern of transverse ribs, adequate bond was obtained even when the concrete was only a few hours old. On completely releasing a wire the amount of slip was less than 1 mm. Thus, by releasing a certain number of wires at the joints between the slabs and between the slab ends and the abutments, it was possible to transfer any desired proportion of the prestress to the concrete. This immediately had a favourable effect on cracking.

A sliding cover-plate arrangement, without a rubber insert, was adopted for the joints. For draining, a semicircular channel was provided in the concrete of the sleeper beam. The joints function satisfactorily; the variations in length between summer and winter in the case of a 150 m long slab can be taken to be about 3 - 6 cm.

As the 9 cm thick slab of the east section was laid on an old runway of which only the major irregularities had been smoothed away, large coefficients of friction occurred here. For reasons of safety the 240 m long slab, originally constructed in one piece, was subdivided into three parts. The joints were subsequently each covered with a sliding cover plate arrangement, which merely involved cutting an approximately 3 cm wide joint in the slab. This job can be regarded as a standard example for dealing with possible damage to a prestressed concrete slab.

This runway - which, according to information received, is much favoured by fighter pilots - has proved entirely satisfactory in actual use.

Here again extensive measurements were made during construction - temperatures, stresses in the concrete and steel, movements of the slab ends - under various conditions (e.g., without prestress, with partial prestress, with full prestress, with and without covering with straw mats). From the results obtained it can definitely be inferred that satisfactory construction without initial cracking can be achieved with certainty, provided the following requirements are fulfilled:

(1) the provision of an absolutely level sliding layer, firm enough for men to walk on it;

(2) taking account of the diurnal temperature variations in connexion with concreting;

(3) the prevention of a fall in temperature in the interior and at the top of the concrete by suitable precautions during the first few hours after concreting;

(4) the transfer of a sufficiently large "partial prestress" to the concrete at an early age.

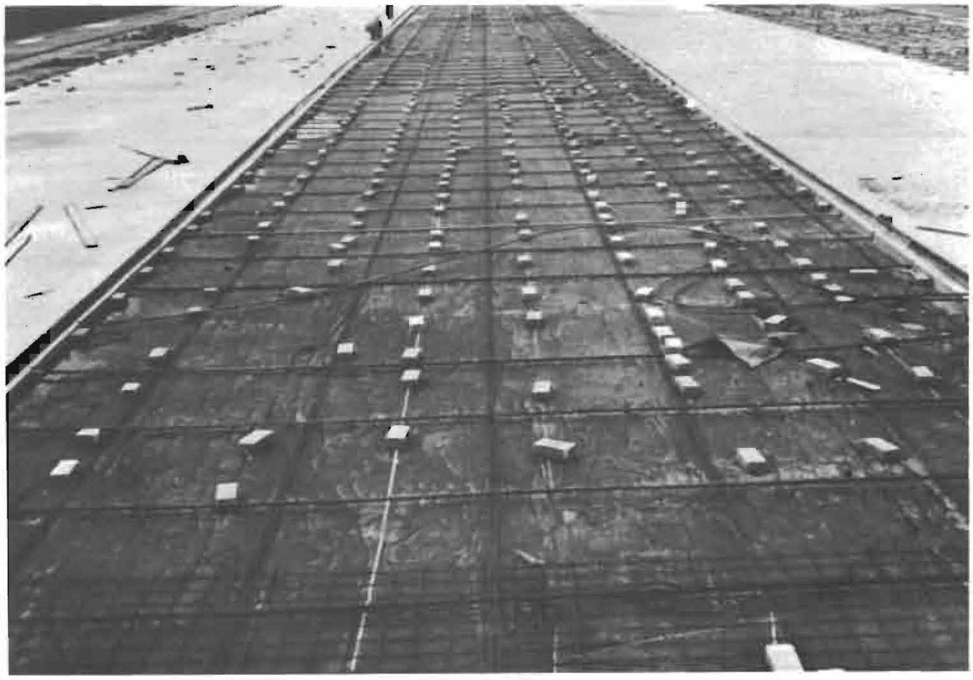

Figure 10: Runway in Lower Saxony. Installing the transverse tendons in strip II.

Figure 11: Jack for producing tendon extensions up to 4·50 m.

4. Floor in television studio of Hessian Broadcasting System, Frankfort

In a television studio the floor must be absolutely free from joints so that the carriage on which the cameras, microphones, etc. are mounted can travel to and fro without vibration. Since such studios are becoming increasingly large in consequence of the ever greater demands made upon them, it seems obvious to construct the floor as a prestressed concrete slab: the live loading is small; in this particular case the design was based on the assumption of an individual wheel load of 3 tons.

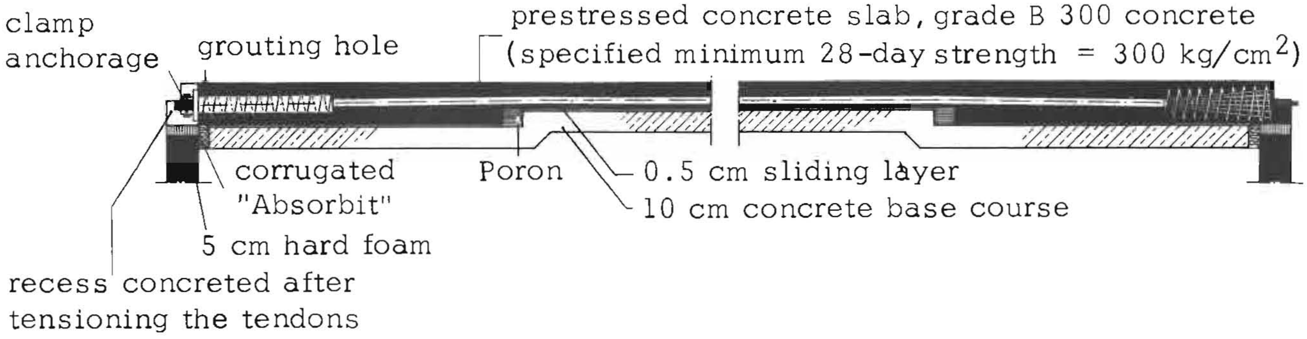

Figure 12: Television studio at Frankfort-on-Main. Section through the floor.

The slab is 13 cm thick and is prestressed in both directions ("KA" prestressing system). The tendons are spaced 1·90 m apart, and are provided with "broom" type dead-end anchorages at alternate ends. The tendon sheaths have an outside diameter of 4 cm and have a concrete cover of 2·5 cm.

The prestressed slab is separated from the 10 cm thick concrete base course by a sliding layer similar to that used on the running-in track at Wolfsburg.

The concreting of the slab and the tensioning and grouting of the tendons call for no special comment.

The prestressed concrete slab was given a special surface finish.

When completed, this television studio with its jointless prestressed concrete floor will be one of the largest in Europe.

5. Skidding track for Volkswagen motor works at Wolfsburg

A short description will be given of a skidding track built for the Volkswagen motor works in 1959 to designs prepared by our Hanover branch.

In contrast with the usual arrangement adopted in prestressed concrete road construction, in which the tendons run at right angles to one another, circular prestressing by a "concentrated" tendon at the perimeter of the circle was proposed in this case. In this way the rectangular recesses required for the anchorage of tendons arranged in an orthogonal mesh are obviated.

The stabilized base and the sliding layer consisting of two layers of paraffin-impregnated paper were generally similar to those employed in the prestressed concrete pavements already described.

Our mechanical engineering department developed spacers and tensioning devices for putting the idea of the annular tendon into practice.

First of all, 120 individual rings of wire were laid round the track. The precise theoretical circumference was marked on the wire, which was then installed in the spacers. After each layer of eight wires an intermediate plate was inserted, its purpose being to prevent movement of the wires in the vicinity of the coiled splice* during tensioning and also to permit satisfactory embedment of the prestressing steel in cement mortar (as a protection against corrosion). To form a splice in the prestressing wires, the wire was tensioned up to the mark with the aid of a wire stretcher and then connected by coiling (Vogt system). To obtain better guidance and to prevent possible upward displacement of the tendon as a whole, guide forks were concreted into the slab to the left and right of the spacers provided with tensioning bars. The screw spindles (HGL tensioning bars M 30) are arranged in a tensioning tube for HG prestressing tendons. The force developed by the tensioning nut is first transmitted to a guide bush which at the same time provides a safeguard against buckling. Behind the tube a thick load-distributing plate exerts a pressure of not more than 150 kg/cm^2 on the concrete. The tensile forces tending to split the concrete are resisted by mild steel reinforcement. The stress thus transmitted to the concrete is approximately 14 kg/cm^2, the slab thickness being 12 cm.

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*Splicing of wires by a "special coiling process" (or possibly a wrapping process) has already been referred to on page 8. (Translator's note.)

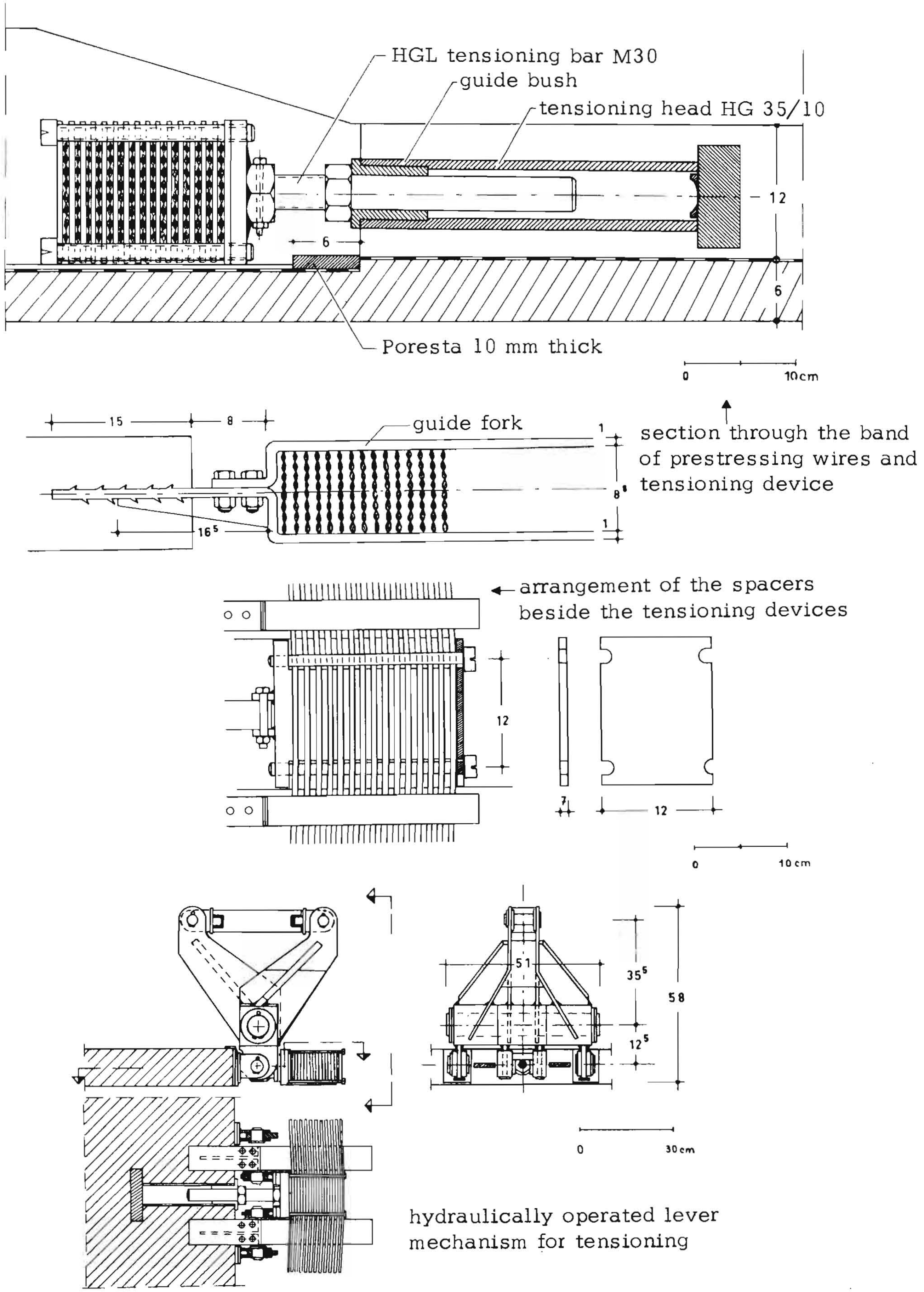
The tensioning points are spaced at 1·50 m intervals, the force applied at each of these points being 25 tons (for a steel stress of 10·5 tons/cm^2). The stress was not given a higher value, as the buckling strength of the screw spindles rapidly decreases with increasing extension.

About half the required tendon extension (increase in tendon diameter) was produced by means of spanners at a torque of around 60 kg m. The rest of the extension was obtained by a lever mechanism (transmission ratio 3:1) equipped with a 10-ton hydraulic jack. The total extension was 154 mm.

The track was concreted in 3·50 m wide strips and calls for no special comment. For practical reasons concreting could be done only at night. A light mesh reinforcement was installed in the top of the slab. On completion of the tensioning of the prestressing steel, it was embedded in neat cement paste, and the edge strip of the slab was then concreted.

The track has proved entirely satisfactory.

Figure 13: Skidding track of Volkswagen motor works at Wolfsburg



section through the band of prestressing wires and tensioning device

arrangement of the spacers beside the tensioning devices

hydraulically operated lever mechanism for tensioning

Figure 14: Skidding track of Volkswagen motor works at Wolfsburg - details of prestressing method

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