

NEW DEVELOPMENTS IN THE CONSTRUCTION OF CONCRETE PAVEMENTS ON THE BRUSSELS-NATIONAL AIRPORT

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At the Brussels National Airport, important expansion works have been underway since 1989 in accordance with the masterplan "ZAVENTEM 2000". The goal of the development plan is to optimize and achieve as high profitability as possible for the total movements on the airfield.

In eight different phases, a surface area of 1,200,000 m² in both asphalt and concrete shall be placed for taxi-ways and platforms. For the new platforms, approximately 500,000 m² shall be predominantly paved with 35 cm thick high quality concrete pavements. As of end-1992, more than 300,000 m² of concrete paving have been completed. The procedure described in this paper, has been successfully executed by placing two concrete layers using two slipform paving machines "back-to-back" in widths of 10 metres.

Innovative execution methods, as well as, new construction practices by the contractors have been present throughout the construction.

During cold weather periods, special de-icing products are applied on the airfield in the areas of the concrete platforms. To protect the pavements, the top surface of concrete receives a special penetrating sealer treatment according to the latest concrete technology.

1. INTRODUCTION

Due to increased air-traffic, many airports are driven to expand their capacities. In Belgium and specifically the National Airport in Zaventem (*fig. 1*), an impressive expansion has been taking place since 1989 under the ZAVENTEM 2000 masterplan where expected yearly increase passenger loads could raise from 9,500,000 in 1992 to as much as 20,000,000 by the year 2005 (*fig. 2*).

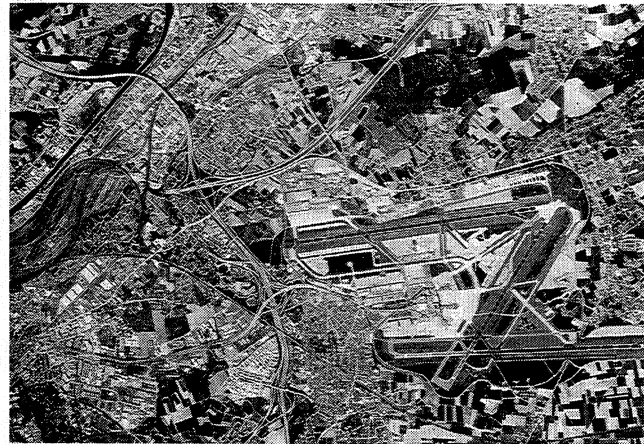


Figure 1. Brussels National Airport with three run-ways

New platforms and taxiways are necessary. No works are as yet planned for the runways; however, extensions of the run-ways could be foreseen in the future. The Airport Authority (RLW/RVA) working collectively with other investors such as Brussels Airport Terminal Company (BATC) has been given the task of planning and constructing the airside infrastructure works before mid 1994.

With reference to the "ZAVENTEM 2000", 0.5 million square metres of new concrete pavement are planned mainly for parking aprons.

Over the years large surfaces of concrete pavements have been constructed at Brussels National. The previous constructions were placed using a fixed form paving train. In 1977/78 a loading/unloading platform of 120,000 m² was placed using the first time a slipform paving machine at Brussels National. Sections were placed in 10 meter widths and 35 cm thick in one pass. The construction procedures were presented at Schiphol first "Workshop for Aircraft Pavements" in 1983 (1).

Because the construction method of laying the 35 cm thick pavement in one pass can lead to edge slump on the longitudinal construction joint, better procedures were sought and implemented for construction which began in 1990. The new procedure for Brussels National was based on placing the pavement in 2 layers. This principle was taken over from the works at the MUNICH M airport (2) what resulted in a better finishing of the longitudinal joints.

Besides the new conceptions for the placement of the slab during construction, the first exceptional requirement was to ensure that the concrete remained durable against applications of airport de-icing products. These products can be in contact with the pavement rather quickly after placement. Protection of the concrete consists of two means. One was to impregnate the young concrete and the other was the switch during the works to the use of air-entrainments sometimes commonly used in roadway construction.

The most important aspects of the design and construction for the pavements as discussed above are presented in this paper followed by methods in concrete technology for protection of pavements against de-icing products.

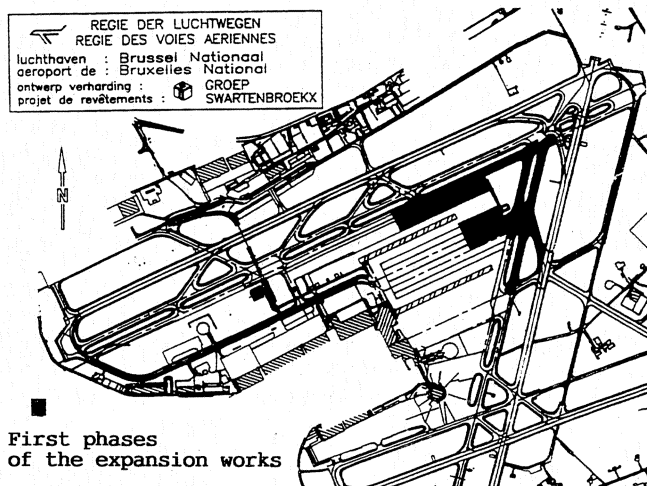


Figure 2. "Masterplan Zaventem 2000"

2. DESIGN AND CONSTRUCTION ASPECTS

2.1. Design Aspects

For dimensioning paving sections on airports, traditional accepted methods for public roadway systems cannot be used due to the extreme loading characteristics of aircraft. The design engineering office (Swartenbroeckx N.V.) in consultation with the airport authority (RLW/RVA) dimensioned the paving sections at Brussels National Airport based on the following principle : 1) wheel loading of 400 kN (40 tons) and 2) buggy load of 4 X 400 kN (1600 kN total) spread over a rectangular surface of 150 x 125 cm.

This results in a total load of 6400 kN spread over a surface area as given in the sketch (fig. 3). Use of computer programming based on three-dimensional theories were used in the design analysis and calculations.

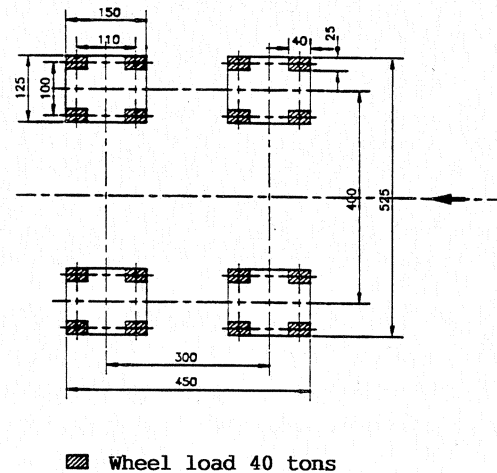


Figure 3. Typical Aircraft Loading

The aircraft industry's tendency to manufacture larger aircraft not only influences the construction of the pavements but as well the geometric requirements such as larger paving widths. This results in reduced cross and longitudinal slope allowances.

The new Jumbo-version of the B747-400 with a span of 65 m and a body length of 71 m was taken as the design standard for dimensioning the platforms.

Slope is especially critical for platforms where according to the latest ICAO requirements only 0,5 % is allowed in elevation with respect to the aircraft parking position. To prevent standing water, the concrete roughness is limited to 3 mm measured with a 3 m straightedge (for highways the accepted norm is 4 mm). The removal of rain water on the platforms and taxi-ways is mainly carried out with a slotted drain system (see figure 7).

Concrete sections for the platforms were not only chosen for obvious reasons such as load carrying capacity, durability and minimum maintenance - other following points played as well a role :

- bright colour of concrete (grey/white) provides a optically recognizable area such as remote and gate parking (platforms);
- high resistance of concrete to kerosine (Jet A-1) and other aggressive synthetic hydraulic fluids;
- high resistance to mechanical loadings from equipment around the aircraft (i.e. towing tractor, etc.).

The just mentioned respective loading and design requirements have resulted in the following well known designed section (fig. 4).

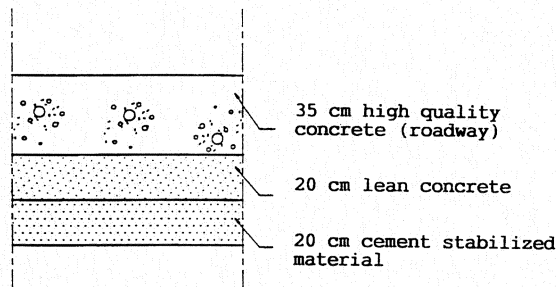


Figure 4. Platform Cross-Section

The 35 cm thickness, which may appear relatively thin for modern airports, is sufficient in Belgium due to its high flexural strength of min. 6.5 N/mm^2 at 90 days.

In addition, an exceptional subbase is prepared on Brussels National consisting of 40 cm cement stabilized material. The underlayer has a required minimum compressive strength of 4 N/mm^2 (average per 10 samples) at 28 days measured on field drilled core samples 100 cm^2 and 10 cm high.

An alternate paving section of 25 cm steel fibre concrete was more expensive than the 35 cm paving section in the initial phase of construction. With its economical advantage as well as successful execution, the Airport Authority choose to continue the following phases using only the two layer 35 cm paving section.

Since classical longitudinal joint details have sometimes lead to settlements or damage to the joints themselves, a new joint detail was taken as example from Munich M having a waved "sine curve" profile (fig. 5).

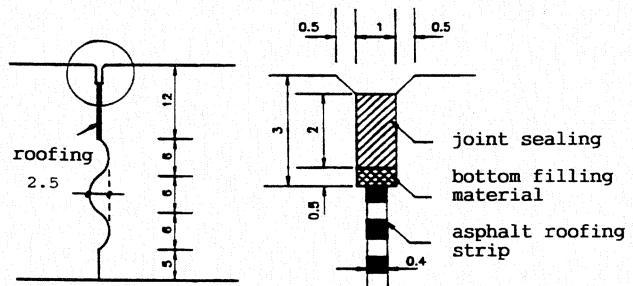


Figure 5. Cross-Section longitudinal joints

These longitudinal joints are constructed without reinforcement except at the perimeter panels where tie-bars of diam. 16 mm are placed at 75 cm centre to centre. These tie-bars are placed and fixed in drilled holes, which avoids damage on the longitudinal construction joints. Sawed control joints (12 cm deep) are present every 5 meters with diam. 25 mm dowel bars every 30 cm on centre (fig. 6).

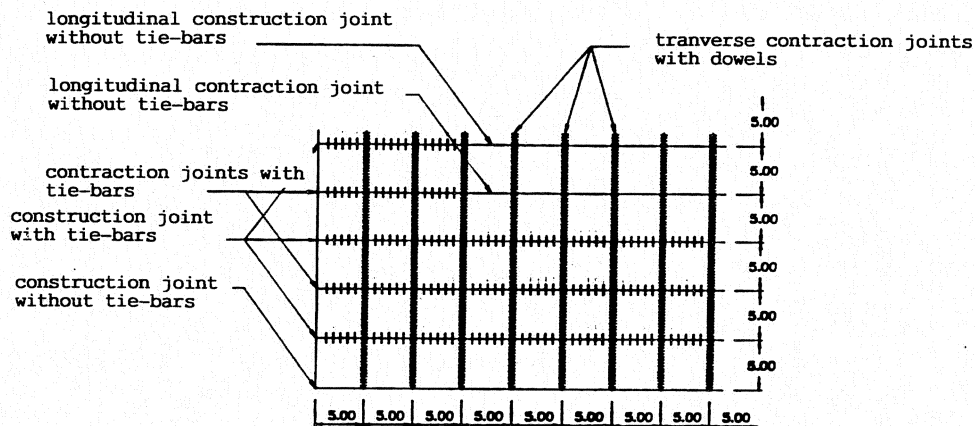


Figure 6. Concrete slab layout

In order to reduce uncontrolled cracking in the 35 cm paving section before sawing control joints, specification requirements call for super-imposing and cutting the joint pattern into the lean concrete subbase.

The lean concrete shall be protected against drying-out after placement by either a classical accepted procedure or by keeping the surface wet for a period of min. 3 days. The later method be preferred following successful results.

As observed on large platforms during the summer periods, high compressive forces can occur in the pavements due to expansion. Special precautions were taken at the longitudinal joints to reduce damage. The placement of an asphalt roofing strip in the upper section of each construction joint limited the compressive stresses by 'curling' action. At each slotted drain, a 25 mm expansion joint was constructed with a synthetic elastic profile filler material. As well, the concrete paving section at the drains is thickened thus allowing a path under the drain for the transmission and reduction of the compressive stresses (fig. 7 and fig. 8).

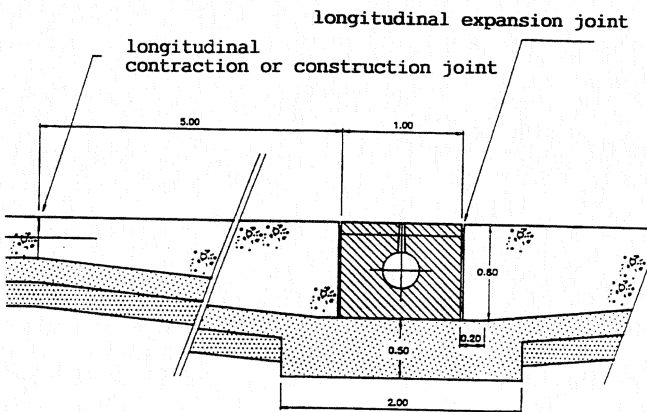


Figure 7. Slotted drain cross-section

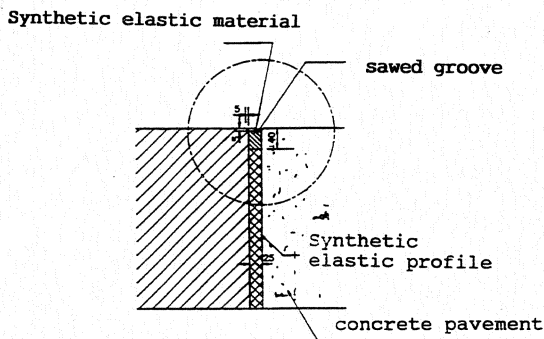


Figure 8. Detail longitudinal expansion joint

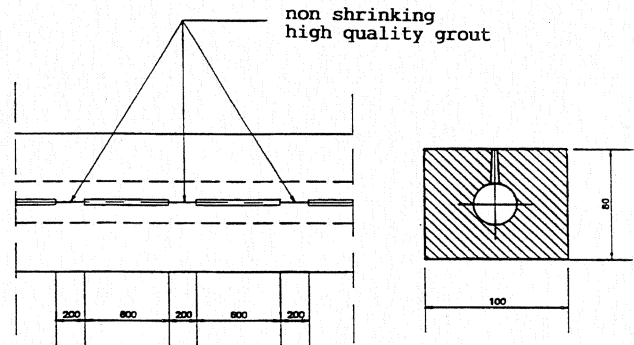


Figure 9. Slotted drain - plan and side view

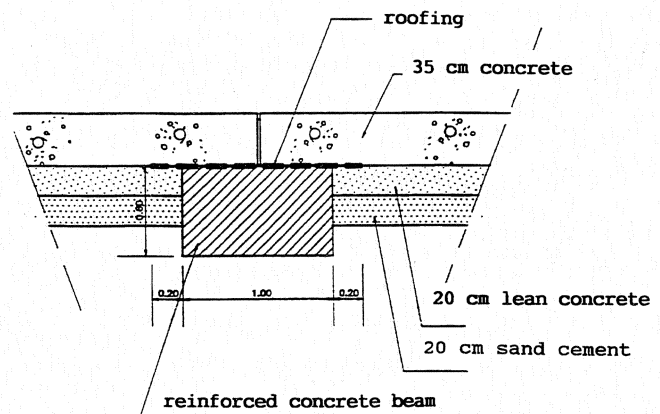


Figure 10. Grade beam detail

To further strengthen the section, the structure creating the open slots on the topside of the drain are filled with non-shrinking grout (fig. 9).

To prevent settlements during paving expansions at new platform phases, a grade beam is poured around the perimeter of each new phase.

These 'end' grade beams have a width of 1 meter and depth of 60 cm reinforced by steel fibres and longitudinal reinforcement (fig. 10).

2.2. Construction Aspects

Concrete Pavements

The construction Company **Van Broekhoven** was the first contractor to use two slip-form pavers machines to place the 10 metres - 35 cm thick pavement during Phase I of the RLW/RVA works and was followed by the Joint Venture of **Aswebo-Betonac-Wegebo** with the same procedure in the next phase. From hence forth, the RLW/RVA required the remaining contract phases to be executed in the same manner.

The first machine lays a layer (bottom course) of approximately 20 cm concrete composed of limestone aggregate. The side-forms of the first slipform paver are about 7 cm indented compared to the side-forms of the second slipform paver. This is necessary for a good finish of the longitudinal joint with sine wave by the second machine. The second machine passes within 15 minutes to realize the second layer (top course) of approximately 15 cm thickness (fig. 11).



Figure 11. Construction of a 35 cm thick concrete pavement using two slipform pavers

Aggregate from the top course consists of porphyritic rock that has a high freeze/thaw durability and a high resistance to polishing as specified in Belgium's TB 150 (General Specifications for Highways). The concrete mixtures are set up with 3 fractions of aggregates - 20/32, 7/20 and 4/7 - and the fraction 20/32 is limited to maximum 450 kg/m³ to ensure a workable mix. (3).

The aggregate particle size is determined by using wire mesh sieves with square openings.

To ensure a continuous progress of the spreading, compaction and finishing of the concrete, several plants (concrete batch plants) were foreseen to provide 200 m³/hour capacity.

The dowel bars, instead of being placed on chairs, are set by hand in deep longitudinal grooves created by the first slip-form paver (fig.12).

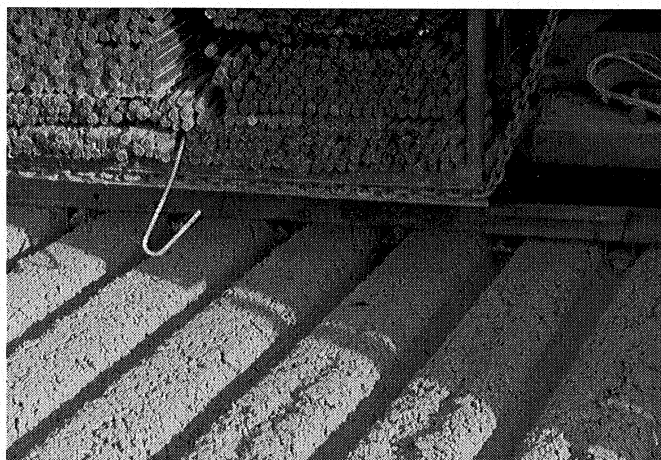


Figure 12. Deep grooves in bottom layer for setting dowels

The grooves were formed by angle plates 7 x 7 cm, fixed under the slip-form paver.

This system as developed by **Van Broekhoven's** appears to function as designed with practically all shrinkage control joints "working" normally with no apparent cracking next to sawed joints.

Grooves, which are made in the lower course, considerably improve the bonding of the top and bottom layer. Finishing of the top surface occurs according to a **Van Broekhoven's** proposal and includes in addition to the super-smoother a heavy tube pulled over the surface in order to approach a "super-smooth" finishing (fig. 13 and fig. 14).

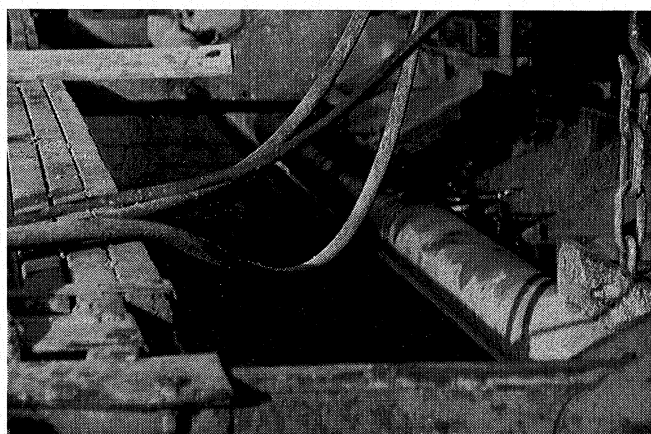


Figure 13. Hanged heavy tube float pulled over the concrete

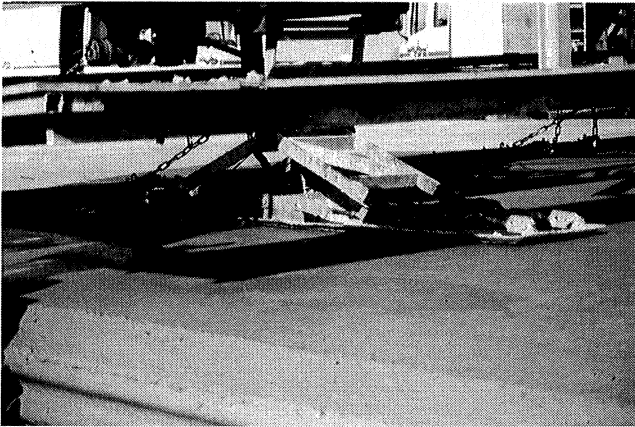


Figure 14. Final finishing with "super-smoother"

After the tube and super-smoother, a PVC brush is pulled in longitudinal direction over the entire width at a regulated pressure to form finishing grooves of approximately 1 mm deep. Simultaneously, the fresh concrete is sprayed with a curing compound with a rate of 150 g/m² to prevent drying of the surface (fig. 15).



Figure 15. Brushed longitudinal grooves and perfect longitudinal construction joint

A constant mix, consistency and thickness for both bottom and top layers, is important to ensure smoothness of the concrete finishing, as given in the detailed specifications. For the bottom layer a relatively stiff mix is used (slump max. 2 cm), which is helpful for a good finish of the top layer. In these prescriptions unevennesses are limited to less than 3 mm measured with a 3 m straightedge.

Slotted drain

The drain systems are constructed in place using a slip form paving machine with an internal circular form - cardboard, PVC, or rubber (figures 16 and 17).



Figure 16. General view of the slotted drain construction

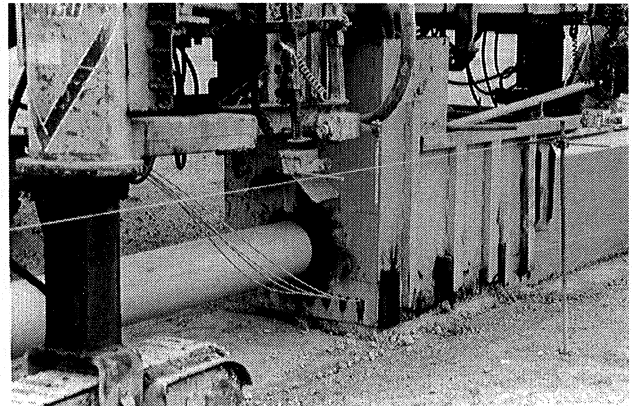


Figure 17. Special mold for the slotted drain construction with steel cable strains

These drains, having a width of 100 cm and a height of 80 cm in the platforms, are constructed using steelfiber concrete (min. 30 kg/m³) and are also provided with steel cable strands to restrict the opening of the shrinkage cracks at the control joints. Every 50 metres the slotted drain is connected by man-hole to a storm drain collection system (fig. 18).

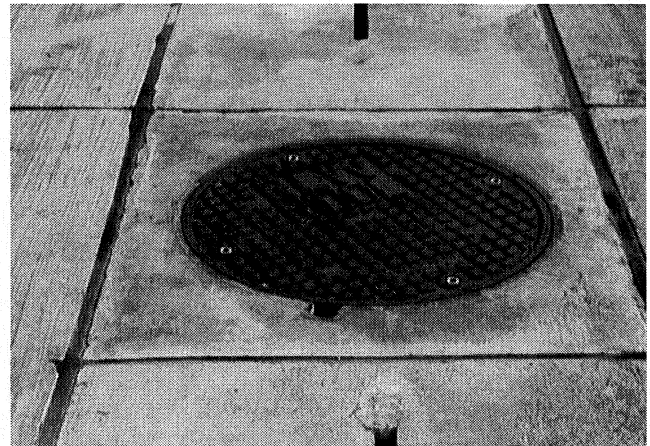


Figure 18. Manhole in slotted drain

3. CONCRETE TECHNOLOGY ASPECTS

3.1. Requirements and Characteristics

Underlayers and subbases

- Underlayers consist of cement stabilized material generally being sand-cement with a minimum 28 day strength of 4 N/mm² on field coring samples. When alternate materials are proposed, additional specification requirements are necessary (i.e. resistance against moisture etc.). To ensure a homogeneous mixture, the RLW has required the mixing of the materials be at a batch mixing plant. In practice, the 28 day strengths are generally around 4 to 6 MPa on specimens of 100 cm² and 10 cm high.
- Requirements for lean concrete subbases have changed little since the 1970's with no significant points to note. Cement content is held to 6 % and water content to 8 % to reduce shrinkage cracks as much as possible. For economic reasons, the use of broken concrete from the demolition of old platforms is maximized for recycling. All classical specifications are respected during construction.
- Compressive strength of a lean concrete, as taken on bored core samples 100 cm² and 10 cm high, shall have a 90 day strength of 6 MPa plus twice the standard deviation (per 10 field samples); that means approximately 11 to 12 MPa. The mixture is batched using 4 to 5 % cement (Blast furnace cement - class 30) and approximately 50 % broken concrete (0/20 - 20/40) as replacement material for natural aggregate. This mixture meeting all requirements of specification demands. Placement of the concrete is executed using bulldozers and motor grades equipped with laser systems.

Concrete pavements

- For placement of concrete pavement, the basis for execution are according to TB 150. (Belgium's specifications for heavy highway constructions). In this specification, air entrainment is still not foreseen for roadway surfaces but is added for secondary structures such as curbs, gutters and shoulders.
- Use of de-icing products are often used on the airfield and under certain circumstances on young concrete pavements. By placement of platforms in the fall of 1991, test areas were established to determine the effects with and without air entraining agents.
- When specifying air-entrained concrete, it is necessary to revise the strength requirements of the concrete. From experience and after recent tests performed at Brussels National Airport, entrained air of 3.5 % to 6 % reduce the compressive strength by 10 to 20 %. With respect to the same concrete without air entrainment. The loss in compressive strength due to entrainment air can be notable especially for high-strength concrete.

- Existing requirement for no air entrained concrete of 55 MPa + 2 x the standard deviation (of ten field samples (s is mostly 6-8 MPa) is in fact too low to achieve a pavement that has a hard and durable surface, a resistance to scaling, and which can resist de-icing materials used on airports. For concrete without air-entrainment, it is hence more desired to change the characteristic compressive strength from 55 MPa to 60 MPa. This correspondence with an average strength of 70 MPa after 90 days for a test of minimum 10 samples. By increasing cement content to minimum 375 kg (Blast furnace cement - class 40), these results are obtainable. When it is useful to include air-entrainment, the strength requirement should be modified to 50 MPa + 1.64 x the standard deviation of ten field samples measured at 90 days on 100 cm² 10 cm cores long. Compressive strengths with air-entrainment greater than 60 MPa are defiant but become more achievable when air content is held around 4 %.

Supplemental investigations, including Belgian material and equipment practices are desirable for proper preparation of specification requirements when using air-entrainment on heavy loaded pavement at airfields. As well, the control of the air-entrainment during execution should be more detailed for a tighter control.

- In the Belgium specifications for Highways and as well for airports, requirements are given for water absorption limits. Generally accepted limits for highways and airports are less than 6 % absorption. These requirements are obtainable with no significant problems without air-entrainment. With the addition of air-entrained agents, the water absorption appears to be somewhat lower than when no entrainment is foreseen.
- In the Belgium's General Specifications (TB), no requirements are given concerning penetrating sealers for use on a higher void content pavement to protect against penetrating moisture.

However, these materials are being used more and more on concrete roadways and concrete barriers which have begun to show scaling in order to provide protection against further damage. At Brussels National Airport, a special measure of precaution was taken for pavement which was placed just before the winter period of 1990/1991. This pavement was treated with a known and accepted penetrating sealer due to the fact that the young pavement was being put into service during the winter period.

3.2. Review of Resistance with de-icing Products

Measurement of pavement resistance against de-icing products which are used on the airport by the use of Belgium's freeze-thaw test specifications have little value. The Rilem-Method CDC2 conducted using de-icing products, also known by the ISO Norm DIS4846.2, (4) is better applied. This exceptionally strict testing procedure is more recently used in Belgium because it most closely models the effects of de-icing products on pavements therefore providing a more practical prediction of the pavements characteristics.

To determine the resistance against de-icing products, the specimens were measured for weight (mass) loss after 5, 10, 15, 20, 30 or more freeze thaw cycles.

By experience, it is noted that the percent loss by weight over the area of application is generally lower than 10 to 15 g/dm², which corresponds with a scaling of less than 1 mm. For important roadways, as well as airport pavements, it is recently expected that weight loss after 25 cycles be less than 5 g/dm².

3.3. Preventive Treatment with Penetrating Sealers

When the described Rilem Test indicates that a high absorption might exist creating a certain degree of scaling, it is often advisable in highway constructions to apply preventive products. This philosophy is particularly valid for pavements which are placed just before the winter period and shall be subjected to de-icing products in an early stage.

The method of application consists of treating the concrete surface with fluidized solutions (i.e. linseed oil, plastics on basis of epoxy or polyurethane, acrylics, silicones, etc...

Supported by a positive experience with modified silicon agents (siloxane) as protective sealers against scaling on some roadways showing a little sign of scaling, pavements placed at Zaventem during months of September/October were treated with this application method.

3.4. Effects of Preventive Treatment with Penetrating Sealers at the Brussels National Airport

Concrete paving laid on October 23, 1990 was investigated for resistance to de-icing products after treatment with the modified penetrating agent "siloxane" (fig. 19).

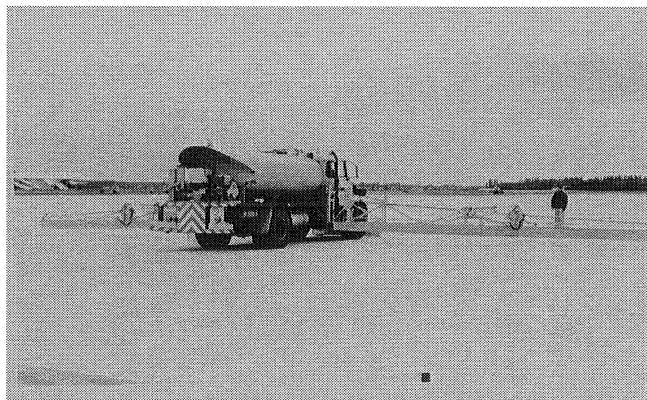


Figure 19. Treatment with a modified siloxane sealer

The outstanding characteristics strength of the investigated concrete are as follows:

- average compressive strength top course (porphyry aggregate type) : 76.8 N/mm² (without air entrained agents)
- average compressive strength bottom layer (limestone aggregate) : 79.3 N/mm² (without air entrained agents)
- waterabsorption top layer : 5.39 %

The Rilem Test was performed with a 3 % CaCl₂ solution and as well a 7 % Altantol solution which is used on the airport as a de-icing agent.

In the table below, a summary is given of the investigation. The study clearly shows the effects of de-icing products and the positive results of the applied penetrating sealer. For an optimum protection, it is desirable to handle the pavement in two applications (i.e. 2 X 200 g/m²) as done in the test case given in this report. Total weight (mass) loss as given in Table 1 is less than 1 g/dm² (5). This investigation was realized by the Belgian Cement Industry Collective Research Centre.

Table 1 - Summary of Test according to ISO DIS 4846.2

specimen treatment	used de-icing product	Weight loss per Cycle (g/dm ²)					
		5	10	15	20	25	30
not treated	CaCl ₂	10,4	12,4	13,7	14,2	14,8	15,5
treated 1 x	CaCl ₂	0,4	0,7	2,3	5,0	7,9	11,4
treated 1 x	Altantol	0,2	0,7	1,7	3,7	5,5	7,2
treated 2 x	Altantol	0,2	0,3	0,4	0,4	0,6	0,7

3.5 Effect of Air-entrained Agents

As commented earlier, no general use of air-entrained agents is made in Belgium for highway pavement. It is assumed and proposed that when a minimum of 375 kg cement (Class 40) per m³ is used no problems exist with de-icing salts. With the use of slip form paving machines, the percent sand in the concrete mixture is often increase to provide for a more workable material. This combined with higher cement ratios creates a surface subject to increased scaling by use of salts for de-icing. In order to address this problem, the use of air entrainment becomes of increased interest.

Considering the large surfaces to be paved during the expansion works, directors of the RLW/RVA requested an investigation to determine the best possible concrete mixtures. This investigation resulted in the checking of different cement ratios, addition or exclusion of fly ash, as well as the use of exclusion of air entrainment. Compressive strength was not considered as a direct factor during the concrete mix investigation as opposed to the importance of resistance to de-icing products.

In order to achieve as realistic results as possible, different concrete mixtures were subject to de-icing products during the freeze-thaw test according to the Rilem Method. During which time the chosen melting product was a 10 % "cicasol solution" which is often used on the Brussels Airport.

From a series of tests, a mix design with minimum 375 kg/m³ cement and entrained air of 3 to 4.5 % indicated a material loss of less than 0,5 g/dm² after 25 freeze-thaw cycles. By a mixture of 350 kg/m³ cement plus 20 kg fly ash and 2.5 % to 3 % air entrainment, a material loss after 25 cycles was just below 5 g/dm². A mixture with 330 kg/m³ cement plus 40 kg/m³ fly ash and no air entrainment recorded a material loss after 25 cycles greater than 25 g/dm².

The use of fly ash seems to decrease air content and will generally retard the strength development, especially at low temperatures.

Therefore and based on the investigation results, it was apparent the use of less than 350 kg cement per m³ and addition of fly ash was not advisable for the top layer. A mixture of minimum 375 kg/m³ cement without fly ash and an air entrainment of approximately 4 % provided the best results and became the chosen concrete mix for the top layer during the constructions.

During the works, it was observed that the use of air-entrainment resulted not in an excessive loss of compressive strength when the "air-bubbles" remained small and uniform through the mix. The workability of the mix and especially the finishing of a smooth surface was greatly improved by the use of air entrained agents.

Design mixes used during RLW Phase I works are given in table 2 included batches with and without air-entraining agents (6).

As admixtures were used products of Master Builders:

- plasticizer: pozzolith 200 N
- air-entraining agent: micro-air.

Table 2 : Examples of used mixtures

Concrete Mix	Phase IB Without air-entraining agents	Phase IC With air-entraining agents
<u>1st Machine (bottom course)</u>		
limestone 20/32	427 kg	427 kg
limestone 7/20	522 kg	522 kg
limestone 4/7	367 kg	367 kg
sand 0/5	562 kg	562 kg
cement HK40-Blast furnace	350 kg	350 kg
fly ash	40 kg	40 kg
water	162 l	162 l
plasticizer	760 cc	760 cc
Vol./Mass (unit weight)	2430 kg/m ³	2430 kg/m ³
<u>2nd Machine (top course)</u>		
porphyry 20/32	445 kg	316 kg
porphyry 7/20	484 kg	561 kg
porphyry 4/7	523 kg	316 kg
sand 0/5	484 kg	561 kg
cement HK40-Blast furnace	375 kg	375 kg
water	166 l	161 l
Plasticizer	660 cc	750 cc
air-entraining agent	/	750 cc
Vol./Mass (unit weight)	2.477 kg/m ³	2.290 kg/m ³
Freeze/thaw test using de-icing Products - mass loss ISO DIS 4846.2	10,18 g/dm ² after 25 cycles	0,35/0,45 g/dm ² after 25 cycles

4. CONCLUSIONS

With the help of slip-form pavers, an economical 35 cm thick concrete pavement can be placed which answers to the demands of Airport Pavements.

Execution in two layers by use of slip-form pavers closely following each other provides not only an extra-economical benefit but as well provides an improved finishing. Particularly, the construction procedures for the longitudinal joints are noticeably better.

Indeed, by using two slip-form pavers it was possible to place the bottom layer with a relatively stiff mix, which permitted a better finish of the top layer and resulted in a lower edge slump.

To ensure a durable concrete surface, it is essential to have sufficient cement in the mix design, preferably a minimum of 375 kg/m³ and as well the addition of air-entraining agents.

As extra protection against de-icing products, especially when the pavement is placed during the fall period, the surface should be treated with a penetrating sealer, preferably minimum 400 g/m² in two applications on young and dry concrete.

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