PAVEMENT DESIGN OF THE AIRPLANE PARKING AND TAXIWAY AREAS OF THE SALGADO FILHO INTERNATIONAL AIRPORT IN PORTO ALEGRE

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ABSTRACT: Due to the increase of Brazilian air traffic in the last years, as well as due to the preparations for the 2014 Football World Cup, there is an urgent need to improve the capacity of the airport facilities in the metropolitan area of Porto Alegre. This improvement is associated to the expansion of the Salgado Filho International Airport (SFIA) in Porto Alegre, as well as to the potential construction of another airport, whose feasibility is currently being studied. Regarding SFIA, the expansion includes the terminal building, the airplane parking and taxiway area as well as the rehabilitation or replacement of the runway. This paper addresses the pavement design procedures adopted for the parking and taxiway areas of the SFIA extension plan. Due to the poor capacity of the soil in the region, the geotechnical solution adopted for the infrastructure of the parking and taxiway areas is comprised of bored piles and foundation slabs. The pavement structure was designed above the foundation slabs, following FAA (Federal Aviation Administration) recommendations. The pavement of the new parking area will be composed by a concrete slab (320-mm thick) with embedded steel for crack control, placed above an EconoCrete layer (100-mm-thick). The taxiway pavement will consist of a 250-mm-thick asphalt layers (50-mm-thick SMA overlying 150 mm-thick layers of high modulus HMA and a bottom HMA layer 50-mm-thick). For both parking and taxiway pavements, graded crushed rock layers will be included, underneath the EconoCrete layer aiming to reduce the magnitude of the stresses in the bottom of the pavement structure, thus reducing the stresses on the top of the foundation slabs and piles, as required by the geotechnical solution. The minimum thickness of the crushed rock layer will be 215 mm in the parking pavement and 850 mm in the taxiway structure. The pavement design solution described in this paper has already been approved by the specific regulation authorities and is presently being constructed.

KEY WORDS: Airport, parking area, taxiway, soft clay, pavement design

1. INTRODUCTION

The Brazilian air traffic has grown significantly in the last years, caused mainly by the start-in-operation of low-cost airlines and by the continuous development of the Brazilian economy. The upcoming events related to the 2014 World Cup are also implying special attention to the air traffic infrastructure. Considering Brazil as a large country, and taking into account the lack of efficient ground transportation (coach and train services), it is expected that a large amount of World Cup viewers should reach the host cities by air.

These factors lead to an urgent need to improve the capacity of the major airports in Brazil, especially those of the World Cup host cities, which includes the Salgado Filho International Airport (SFIA) in Porto Alegre.
Porto Alegre is the capital of Rio Grande Sul State, located in the most southern area of Brazil, bordering Uruguay and Argentina. The capital itself has approximately 1.5 million inhabitants, whilst it may reach up to 4.5 million people taking into account the population of the neighbor cities. SFIA serves also the metropolitan area of Porto Alegre and is located in a strategic part of the city, very close to main roads that connect the capital to its countryside and metropolitan area.

SFIA was previously enlarged in 2001 when a second terminal building and a parking facility were constructed. This also included the lengthening of the taxiway and the construction of a second airplane parking area to attend the new terminal building. However, these facilities are already outdated due to the air traffic increase. Besides, considering the proximity with the Football World Cup, there is an urgent need to improve the conditions of the air traffic infrastructure in the metropolitan area of Porto Alegre.

The improvement on these conditions is associated to the expansion of SFIA, as well as to the potential construction of another airport in the metropolitan area of Porto Alegre, whose feasibility is currently being evaluated. Regarding SFIA, the expansion includes the terminal building, the airplane parking and taxiway areas as well as the rehabilitation or reconstruction of the runway. This paper presents a case study based on the pavement design procedures adopted for the parking and taxiway areas of the SFIA extension project, emphasizing the influence of the local soil bearing capacity.

2. LOCAL GEOTECHNICAL CONDITION

SFIA is located in a region where the soil is extremely soft and compressible. Considering the paramount importance of geotechnical conditions in pavements design, a short description of geotechnical constraints is presented. A geotechnical investigation was carried out to determine the subgrade profile of the local soil. Figure 1 shows two surfaces, one representing the top of the terrain (in red) and other representing the top of the sand layer (in light blue); the difference between both surfaces is the thickness of the soft clay layer. These surfaces are based on SPT data from the geotechnical report written by consultants of Ecoplan Engenharia [1].

Figure 1. Surfaces of the terrain and the top of the sand layer, representing the thickness of the soft clay layer
Five relevant geotechnical materials were found in the site where the new airplane parking and taxiway will be constructed:
   a) Fills over the subgrade in areas previously constructed. Even if composed of many different materials, those fills are considered as a unique layer;
   b) Clay crust: Superficial layer found close to non constructed areas, with different visual characteristics than the deeper layers. The thickness is usually close to 1.5 m;
   c) Overconsolidated clay: gray soft clay layer presenting overconsolidation characteristics. It is defined by laboratory and CPT testing results. The depth of the layer is within 1.5 and 3.0 meters;
   d) Normally consolidated clay: gray soft clay found below the overconsolidated clay layer, also defined by laboratory and CPT testing results. The thickness of this layer is nearly 3.0 m;
   e) Sand layer: underlying the clay package. Being stiffer than the soft clay layer, it plays an important role in the design of deep foundations.

In a general analysis of the geotechnical report [1], two design scenarios were defined:
   a) The expansion of the existing airplane parking area will imply the occupation of an area with normally consolidated clay, without any influence of existing loads or constructions. An embankment 0.80-m high is necessary to reach the present pavement level.
   b) The extension of taxiway will imply the occupation of an area with normally consolidated clay, without any influence of existing loads or constructions. The sol profile is variable especially due to the existence of drainage ditches. Therefore, soil cuts and embankments will be necessary to reach the required pavement level.

Due to the soil characteristics and the short time available for the construction of both taxiway and airplane parking pavements, the geotechnical designers decided that both structures should be constructed over an infrastructure system composed of bored piles and foundation slabs. The reinforced concrete slabs 40 cm-thick will be placed over 60 cm-diameter bored piles spaced at every 4 m. The foundation system also comprises chapters 2 m x 2 m x 0.3 m overlying the piles.

3. PAVEMENT DESIGN PROCEDURES

The design criterion for both rigid and flexible pavements followed the recommendations of the Federal Aviation Administration (FAA), shown in Circular 150/5320-6E [2].

3.1 Air Traffic Mix

The design methodology proposed by the FAA is based on the maximum horizontal stress at the bottom of the concrete slab as an indicative of the pavement service life. The concrete slab thickness is calculated based on the airplane traffic mix. The overall design is based on the FAARFIELD 1.305 software [3].

The airplane traffic mix of SFIA, shown in Table 1, was described in the CF 9120/GTPA document [4], which considers as 90,100 the average annual airplane passes in 2010, with an annual growth rate of 6.15%.

<table>
<thead>
<tr>
<th>Airplane traffic mix</th>
<th>Group 1</th>
<th>12,0%</th>
<th>BEC 58P</th>
<th>9,0%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 2</td>
<td>1,5%</td>
<td>EMB-120</td>
<td>1,5%</td>
</tr>
<tr>
<td></td>
<td>Group 3</td>
<td>2,5%</td>
<td>EMB-145</td>
<td>2,5%</td>
</tr>
<tr>
<td></td>
<td>Group 4</td>
<td>10,0%</td>
<td>A-319</td>
<td>10,0%</td>
</tr>
<tr>
<td></td>
<td>Group 5</td>
<td>46,0%</td>
<td>A-320</td>
<td>36,8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B-737/800</td>
<td>9,2%</td>
</tr>
<tr>
<td></td>
<td>Group 6</td>
<td>22,0%</td>
<td>B-767/300</td>
<td>11,0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A-321</td>
<td>11,0%</td>
</tr>
<tr>
<td></td>
<td>Group 7</td>
<td>6,0%</td>
<td>B-777/300</td>
<td>6,0%</td>
</tr>
</tbody>
</table>
3.2 FAARFIELD Recommendations

FAA recommendations, included in FAARFIELD software, consider the cumulative damage factor (CDF) concept in the design procedures, in which the contribution of each airplane in a given traffic mix to total damage is separately analyzed. The CDF is expressed as the ratio of applied load repetitions to allowable repetitions to failure. The computation takes into account the use of finite element method in a 3-D scale.

The first stage of the design procedures was based on the inclusion of the airplane traffic mix in the software. Afterwards, the layers below the surface pavement were defined. These layers depended on the type of pavement (rigid or flexible) and on the geotechnical solution adopted for the pavement infrastructure.

As previously reported, due to the poor soil condition, the geotechnical solution was based on bored piles and reinforced concrete foundation slabs. However, due to the high load originated by the critical airplane (B-777), and aiming at making feasible the geotechnical solution, the vertical stresses on top of the foundation slabs was limited in 60 kPa (considering both the airplane loading and geostatic stresses). That allowable compressive stress was previously defined based on a sensitivity analysis, where several pavement structures were considered in order to determine the effect of pavement thickness on the vertical stress acting on top foundation slab. Though reducing pavement thickness might not cause the pavement slab failure, it would result in thicker foundation slab and even closer piles (that is greater number of piles and higher costs).

For that reason, the pavement included a graded crushed rock layer under the wearing course of both pavements (rigid and flexible). As explained above, the thicknesses of those layers were computed to reduce the magnitude of the vertical stresses in the bottom of the pavement structures, thus reducing the stresses on top of the foundation slabs and piles.

Regarding the rigid pavement, an EconoCrete layer was also used below the concrete slab and above the crushed rock layer to help reducing the tensile stress in the bottom of the slab and also providing the slab with a uniform and stable subbase.

However, it is important to note that FAARFIELD software considers that the pavement structure is constructed over a subgrade and not over a rigid infrastructure (as for this case study). Hence, following a conservative criterion, a subgrade reaction modulus of 20 MPa/m was adopted, considering the pavement structure placed on a soft subgrade. Although the reaction modulus of soft clay subgrade would be as low as 5 MPa/m, it was taken into account that the pavement will not lie over a soil subgrade, but on a foundation system composed by the slab, chapiters, piles and soft clay.

The pavements were designed considering a service life of 20 years, according to FAA [2] specifications. Design results for both rigid and flexible pavements are presented in the following sections.

4. RIGID PAVEMENT FOR PARKING AREA

According to FAA, there are three types of rigid pavements that can be used in airplane parking areas:

a) Plain concrete slabs: the joint spacing is limited to 6.1 m due to shrinkage stresses.

b) Concrete pavement containing embedded steel for crack control: the transverse joint spacing between plates can reach up to 23 m since a steel mesh is used to control shrinkage cracks.

c) Continuously reinforced concrete pavement: the transverse joint spacing is limited by the production capacity of concrete. Longitudinal steel is used to avoid transverse joints in the pavements.

For the purpose of this case study, the concrete pavement containing embedded steel for crack control was chosen due to the substantial reduction of contraction joints compared to the plain concrete (joints are costly to construct and require periodic resealing and are a source of maintenance problems). Moreover, the continuously reinforced concrete pavement would require a much higher amount of steel, which would increase the cost.

The design of the concrete pavement slab was carried considering the following material properties:
• Flexural strength of concrete slab – 5.0 MPa (adopted as design parameter)
• Modulus of elasticity of EconoCrete layer – 4,800 MPa (FAARFIELD default parameter)
• Modulus of elasticity of graded crushed rock layer – 100 MPa (FAARFIELD default parameter)

A trial rigid pavement, composed of Portland concrete slab, EconoCrete subbase, graded crushed rock layer and foundation slab, was entered in the software. The EconoCrete layer was fixed in 100 mm (minimum thickness default value) and the graded crushed rock was set to 215 mm (minimum thickness that allows the vertical stress on top of the foundation slabs to be less than 60 kPa).

Since the software limits to three the number of layers above the subgrade, the reinforced concrete foundation slab and the graded crushed rock layers were combined in one layer with an equivalent modulus of elasticity, following Odermark Method, adapted by Ullidtz [5], shown in Equation 1. The calculated modulus of elasticity of the equivalent layer was then computed as 6,825 MPa.

\[ E_1 h_1^3 = E_2 h_2^3 \]  

Eq. 1

Where: \( E_1 \) and \( E_2 \) are the modulus of elasticity of layers 1 and 2, with thicknesses \( h_1 \) and \( h_2 \), respectively.

FAARFIELD was then used to design the thickness of the concrete slab for SFIA airplane parking area. Figure 2 shows the software screen with the design outputs for the rigid pavement and Figure 3 shows the rigid pavement adopted for the parking area of SFIA. The undefined material shown in Figure 2 is the equivalent layer obtained from the combination of both graded crushed rock layer and foundation slab. The polyethylene layers shown in Figure 3 are used over and under the EconoCrete layer to avoid friction between layers, thus reducing the possibility of stress concentration.

Figure 2. FAARFIELD screen output showing the concrete slab thickness design
The pavement structure shown in Figure 3 represents the concrete slab thickness regardless for any type of rigid pavement. The amount of steel for crack control was computed according to FAA [2] procedures, resulting in a longitudinal steel area of 3.79 cm²/m, whilst the transversal steel area was set to 1.6 cm²/m (minimum steel area). The distribution of concrete slabs in the airplane parking area is shown in Figure 4, with 201 concrete slabs measuring 5.0 x 21.1 m and three 3.05 x 21.1 m concrete slabs (highlighted on the right of the figure).

Dowels were used in the joints to allow load transfer between adjacent concrete slabs, in both longitudinal and transversal edges of the plates, for both construction and contraction joints. The ties geometry was designed following FAA [2] procedures: 520 mm in length, 32 mm in diameter and 30 cm spacing.

The transitions between rigid and flexible pavements and between the concrete slab and the foundation of passenger fingers were reinforced according to FAA recommendations: 16 mm steel bars spaced at 15 cm.

5. DESIGN OF THE TAXIWAY FLEXIBLE PAVEMENT

As previously stated, the low bearing capacity \( N_{SPT} \leq 1 \) and the high compressibility of the thick soft clay layer underlying a thin crust along the taxiway turn mandatory the construction of the taxiway pavement over a foundation system composed by bored piles and foundations slabs.

Considering the role of each asphalt layer, it was defined that:

a) The wearing course aimed to bear high vertical stresses will be made of stone mastic asphalt (SMA), a special kind of asphalt mixture used to reduce the risk of permanent deformation, and that also provides tire-pavement friction satisfactory for taxiways. The resilient modulus of this layer was set to 4,500 MPa. Although the tire-pavement friction of SMA layer could be reduced after years of service, planes on taxiway traffic at very low speeds; therefore tire-pavement friction is not an issue.

b) The intermediate layer will be made with High Modulus Asphalt Mixture (HMAM), a special kind of mixture originated in France, recommended for minimizing permanent deformation in pavements receiving high axle loads and remarkably reducing the stresses transferred to lower layers. With that purpose, the resilient modulus of this layer was set to 9,000 MPa. This kind of mixture is composed by high consistency asphalt binders and coarse cubic aggregates providing high cohesion and internal friction angle, respectively. Due to low tire-pavement friction such a mixture is not suitable for airways and highways wearing courses.
c) The lower asphalt mixture (on top of the crushed rock layer) will be made of aggregates and conventional penetration binder with characteristics improved by the addition of 2% of calcitic lime and will be designed to present a resilient modulus of 3,000 MPa. The addition of calcitic lime is needed in order to reduce the risk of asphalt stripping caused by the high water level and possible use of granitic aggregates.

d) The crushed rock layer will provide a stable and uniform subbase for and compacting smooth asphalt mixtures, besides reducing the vertical stresses acting on top of the foundation slabs. Its resilient modulus depends on the stress state.

The design of the asphalt pavement was also carried out using FAARFIELD. As this software does not compute stresses or strains, verification was complementary done using EVERSTRESS 5.0 of Washington State Department of Transportation.

Once again, the mix shown in Figure 1 was entered as input in FAARFIELD. Since the software does not allow considering a concrete slab as pavement foundation, it was assumed that the pavement (asphalt layers and crushed rock) was placed on a subgrade with elasticity modulus of 340 MPa (the maximum allowable subgrade modulus in FAARFIELD).

Based on analysis performed with EVERSTRESS 5.0, it was concluded that in order to limit the vertical compressive stress on top of the concrete slab foundation to a maximum value of 60 kPa, the pavement total thickness (asphalt layers + crushed rock) should be at least 1.1 m. It was also concluded that to prevent pavement failure due to excessive tensile stress acting in the bottom of the lower HMA layer, the asphalt layers total thickness should be no less than 25.0 cm.

Therefore, the flexible pavement designed for the new taxiway will present the layers shown in Table 2.

Table 2. Layers materials and thickness as designed for the new taxiway

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mastic Asphalt (SMA)</td>
<td>50</td>
</tr>
<tr>
<td>High Modulus Asphalt Mix (HMAM)</td>
<td>150</td>
</tr>
<tr>
<td>Conventional Hot Mix Asphalt (HMA)</td>
<td>50</td>
</tr>
<tr>
<td>Crushed Rock</td>
<td>≥ 850</td>
</tr>
</tbody>
</table>

Following FAA Circular AC 150_5320-6e, the flexible pavement for the taxiway shoulders was designed considering only one aircraft depart per year and a design period of 10 years.

Once again, using Odermark Method it was computed an equivalent modulus of 369 MPa for the combined layer of crushed rock and foundation slab. An average modulus of 3,500 MPa was adopted for the asphalt layers with total thickness of 10.0 cm and the foundation system was considered to have a CBR value of 20%. These data were entered as input in FAARFIELD, resulting in a crushed rock layer 15.4 cm thick. However, due to the necessity of reducing the compressive vertical stress on top of the slab foundation, the minimum thickness of the crushed rock layer was set to 1.0 m. Table 3 resumes the pavement for taxiway shoulders.

Table 3. Layers materials and thickness as designed for the new taxiway shoulders

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mastic Asphalt (SMA)</td>
<td>50</td>
</tr>
<tr>
<td>High Modulus Asphalt Mix (HMAM)</td>
<td>50</td>
</tr>
<tr>
<td>Crushed Rock</td>
<td>≥ 1000</td>
</tr>
</tbody>
</table>
6. FINAL CONSIDERATIONS

The following considerations can be deduced from the case study presented in this paper:

a) The pavement design of both taxiway and airplane parking areas was ruled by the geotechnical features of the local area, which was characterized by a thick layer of a very soft and compressible clay;

b) The geotechnical solution led to the use of a rigid pavement infrastructure composed of bored piles and reinforced concrete foundation slabs. The pavement structure design, for both taxiway and airplane parking area, was carried out considering that the maximum vertical stress arriving at the top of the foundation slabs is 60 kPa. Hence, a graded crushed rock layer was used below the roller pavement to dissipate the stresses originated by the critical design airplane;

c) For the rigid pavement used in the airplane parking area, the minimum thickness of the crushed rock was 215 mm. An EconoCrete layer of 100 mm thickness was also added to the pavement structure to help minimizing the vertical stresses at the foundation system and also to create a leveled surface to receive the concrete pavement plates;

d) The airplane parking area was designed considering the use of concrete pavement with embedded steel for crack control. This solution was chosen in order to reduce the amount of contraction joints (which are usually a maintenance issue in concrete pavements) compared to plain concrete and to reduce the density of steel compared to continuously reinforced concrete pavements;

e) In the design of flexible pavements of the taxiway and its shoulders three different types of asphalt mixtures were considered in order to provide resistance to permanent deformation and to fatigue and also an acceptable level of tire-pavement friction. Thick (850 to 1,000 mm) crushed rock layers were designed to reduce the compressive vertical stress on top of the foundation system.

It is important to note that the designed pavements of this case study have already been approved by the specific regulation authorities. The information presented in this paper was mainly based on a report developed by Ecoplan Engenharia [6].

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REFERENCES: