Performance and Applications of Pervious Concrete Pavement Material as an Overlay on Existent Concrete Slabs

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Abstract. Portland Cement Pervious Concrete (PCPC) is a quite innovative type of concrete that has woken up the interest of the academy and construction field due to its economic, social and environmental advantages. PCPC is composed by coarse aggregate, little or no fine aggregate, a reduced water/cement ratio and additives. In consequence to its lack of fine aggregate, PCPC has high porosity and lower strength in comparison with traditional concrete, thus its main applications are in low traffic areas such as parking lots, sidewalks, residential streets, path in natural areas. Within its benefits stand out the simplification of drain system, the management of storm water runoff and the reduction of pavement infrastructure costs. Pervious concrete pavement is worldwide recognized for its environmental benefits; the use of pervious concrete for urban pavements produce a reduction of traffic noise, as well as the water and soil pollution, it allows the natural recharge of the groundwater and helps in limiting the heat island effect, due to its clear surface and permitting the soil transpiration. In the very few years a new application of this material has been implemented: pervious concrete layer as an overlay over existing concrete slab. The resulting pavement structure may be used for high traffic volume roads, thanks to the support of the stiff concrete slab, with the addition of the benefits of the optimal pervious concrete surface characteristics. In the present investigation work, design methodologies, construction techniques, laboratory measurements and long term evaluations of this innovative material are presented. Pervious concrete has proven to have a broad scope and a promising future for the research of eco-friendly materials for the construction of pavements throughout the world. In conclusion, the case of study of the application of a pervious concrete overlay in an airport infrastructure is proposed. In particular, the pavement structural behaviour was studied and verified for determining the suitability for solving drainage problems in an aircraft parking lot.

1. Introduction
The growth of the population and, therefore, the urbanization of cities with typical impervious structures, such as concrete pavements or asphalt pavements, have generated imbalances in the environment [1]. Among them flash floods, high levels of pollution, urban heat island effect, CO2 emissions. Other problems are associated with traffic safety and comfort of the vehicle users and pedestrians due to splashes close to road surface during raining events, which could cause hydroplaning or splash & spray [2].

For this reason, several studies have been conducted on new strategies to protect and restore natural ecosystems around the world. An interesting case is pervious concrete or pervious concrete; it is an eco-friendly type of concrete with high porosity that let water to infiltrate through its porous structure
Portland Cement Pervious Concrete (PCPC) is recognized as an effective storm water management device to control surface runoff, to allow groundwater recharge and to protect water and soil qualities [4]. Besides, it absorbs the noise of vehicles creating a quiet and comfortable environment for drivers and pedestrians [2,4].

Pervious concrete consists of Portland Cement, coarse aggregate, little or no fine aggregate, additives, and water. It is characterized by its low w/c ratios between 0.27 and 0.30, although they have been used satisfactorily up to 0.42. The matrix of interconnected pores typically ranges from 15% to 35% on volume of concrete [3,4]. When porosity increases, the permeability usually grows accordingly but the strength of the hardened concrete tends to decrease. The optimum balance between mechanical and functional properties must be achieved to ensure durable and resistant road structures [4,5].

Pervious concrete is considered as the best solution from the environmental, operational to the economic approach. Although the material may be new for some countries of the world, for others, like Japan and the United States, is now a common practice since researches and projects were developed since 1980 [2,3]. Due to its multiple benefits, its popularity has increased in the last 15 years becoming a valuable solution for paving parking lots, sidewalks, residential streets, path in natural areas, other low traffic areas [2,3]. However, in the last few years alternative and innovative applications have been proposed, expanding its scope as a pavement material.

On the one hand, on September 2008, a pervious concrete overlay was constructed on Cell 39 of MnROAD’s Low-Volume Road (LVR), over concrete which was originally constructed during July 1993. The cell has been monitored over the years and has shown that effective PCPC overlays can be designed [6]. On the other hand, in 2013 a pervious concrete roadway was constructed at Paine Field/Snohomish County Airport. The pavement design was studied for light to medium traffic load. PCPC is showing a good response to traffic during this years, even it has to be underlines that it is mainly a straight section of the road with few turning movements [7].

The previous demonstrates the great versatility of the material. Therefore, the application of a pervious concrete overlay in an airport infrastructure is proposed. The resulting pavement structure may be used for high traffic-volume roads, thanks to the support offered by the stiff concrete slab, with the addition of the benefits of the optimal pervious concrete surface characteristics. Currently, airport regulations for the use of PCPC pavements are very limited, and to now, few applications exist. The project, for a full scale application in an airport parking lot, is form this reason particularly innovative and several future developments can derive from this initial analysis.

2. Pervious Concrete: Case Study and Properties.

Pervious concrete has between 15% to 35% of porosity and surface permeability ranges from 0.2 to 1.5 cm/s [8]. Compressive strength (28-day) ranges from 3 to 28 MPa [9]. The reported values of pervious concrete flexural strength range from 1 to 4.1 MPa [9,10]. With low void content and additives in the mixture, higher compressive strength values can be achieved. The properties of material depend on various factors related to the selection of the mix-components, the mixing proportions, as well as construction and maintenance issues [3,11].

In literature, PCPC pavements are proposed as an alternative to impervious surfaces. As expected, few have direct applications on airports [12]. However, pervious concrete has already been used in airport applications, showing a good performance and increasing the interest in new possible uses [7]. This fact provides a lot of information and gives feasibility to the development of our proposal to use a PCPC overlay in airports.

Considering the pavement structure, where pervious concrete is just an overlay over an existing concrete slab, the greatest structural support will be given by the existing concrete slab while the PCPC overlay will provide functional drainage characteristics. Although, pervious concrete overlay must satisfy certain structural requirements. Therefore, the proposed structure only applies to airport cases in which the existing pavement does not present major structural damage.
Then, details of the proposal and a brief summary of the factors that must be taken into account to guarantee properties and performance of the structure.

2.1. Case Study: Structural Analysis of PCPC Overlay in Airport
Pervious concrete design has to consider hydrological and structural requirements [9,13]. In most cases, for road applications, hydrological requirements are the most limiting ones, so a pavement thickness that allows to respect the hydrological needs, will generally comply with the mechanical ones [12]. This happens because the structural requirements are based on vehicle loads from low traffic areas. However, aircraft weights are significantly higher than those of vehicles, so structural design will play a more important role in the required layer thicknesses [12].

Although, the greatest structural support will be given by the existing concrete slab, PCPC overlay must satisfy certain structural requirements. The FAA’s design procedure (Federal Aviation Administration of the United States Department of Transportation) include concrete overlays. If the mechanical properties of pervious concrete are guaranteed, a way of applying these design methods can be considered. The software FAARFIELD was firstly studied for the suitability for the structural evaluation of this type of pavement. FAARFIELD uses three-dimensional finite element-based design procedures for overlay designs of rigid pavement [14].

FAARFIELD provides a range of 3.45 to 6.21 MPa for flexural strength of concrete, only allows concrete with flexural strengths as low as 3.45 MPa [12,14]. According to the ACI report, pervious concrete can reach this value and it allows overlay modelling in the software. However, the elastic modulus in FAARFIELD is fixed at 27,000 MPa, and pervious concrete can be expected to have a lower modulus [12]. Another alternative is to use FAARFIELD’s rigid overlay model with user-defined layer. Therefore, the results of the program must be processed with care. Thicknesses design for PCPC pavements may be different but it is a good starting point.

The aim of this proposal was to project a real scale structure for airport application. This study aimed to pave 200 m² of a parking lot at an Italian airport, in a lot dedicated to airplanes Class C. The lot had a transversal slope of 1% connected to the drainages. With the purpose of reducing water puddles, that limited the visibility of the horizontal signals, an overlay over the existing slabs was suggested. The demolition of 10 cm of the existent slabs, maintaining 1% slope, on the base of the slab, and the construction of a new pervious concrete layer on it. The drainage level is supposed to be moved till the top surface of the concrete slab. The hydrological behaviour will provide that water vertically percolate the pervious concrete layer, reaching the impervious surface of the subjacent concrete slab. Afterwards, water will move horizontally until the drain caption. In this model the water is not filtering directly to the ground soil, both for structural and environmental reasons.

2.2. Mix Design and Materials
Over the years, mix proportions of pervious concrete had to be modified to ensure good performance under specific both environmental and loading conditions [6]. As can be seen in table 1, several studies have proposed different mix proportions with various size and shape of aggregate, cementitious materials, W/C ratios, A/C ratios and even additives aiming to obtain the optimal mix design for adequate strength and durability during pavement construction and service life [12,15].

Materials selection and mix design bias the performance of PCPC overlay surface in terms of clogging, ravelling and freeze-thaw durability [2,6,12,21]. Pervious concrete overlay application in airport may be affected by these issues, then PCPC mixture must possess at least the following properties:

- High workability that facilitates its placement and compaction [6,12].
- Uniform porosity along the structure to achieve environmental benefits like noise reduction [6,12].
- Adequate bond with underlying concrete slabs to enhance strength and durability while aircraft displacement [6,12].
• Sufficient resistance to reduce wearing, reduce production of foreign object debris caused by ravelling or abrasion and increase freeze-thaw durability [6,12].

Table 1. Mix proportions used by various researchers

| Year | Coarse Agg (kg/m³) | Fine Agg (kg/m³) | Water (kg/m³) | Cement (kg/m³) | w/c ratio | Ad I | Ad II | Ad III | Author |
|------|------------------|------------------|---------------|----------------|------------|------|-------|--------|--------|
| 2001 | -                | 20 (%)           | -             | -              | 0.22       | sf a 6(%) | sp b 0.8(%) | hw c 1160 (ml) | [2]    |
| 2011 | 1440             | 109              | 100           | 390            | 0.3        | la e 39 (kg/m³) | -         | -           | [16]   |
| 2011 | 1525             | 80               | 94            | 345            | 0.27       | hw e 2.75(ml/kg) | ae f 2.8 (ml/kg) | -           | [17]   |
| 2011 | 1420             | 140              | 110           | 370            | 0.29       | cs g 0.9(kg/m³) | hs h 8 (ml/kg) | la e 8 (kg/m³) | [18]   |
| 2012 | 1390             | -                | 138           | 395            | 0.35       | hw e 4.35 (kg/m³) | -         | -           | [19]   |
| 2013 | 1620             | -                | 85            | 283            | 0.3        | rp i 14 (kg/m³) | -         | -           | [20]   |

*a: silica fume; b: superplasticizer; c: latex; d: viscosity modifying admixture; e: high water reducing agent; f: air entraining admixture; g: cellulose microfibers; h: hydration stabilizer; i: cohesive agent; j: redispersible polymer powder.

Various admixtures are available to enhance its overall performance. Water reducers and hydration stabilizers increase workability [9,12,16,17,19]. The freeze–thaw durability of PCPC can be improved using a slightly higher w/c ratio, adding polypropylene fibers, replacing some Portland cement with fly ash or silica fume, introducing entrained air, using a latex admixture, increasing paste volume, and using a small amount of fine aggregate [2,3,12,16,22]. Also, abrasion resistance can be improved using a small amount of Nano-silica or styrene butadiene rubber polymer latex [11,12].

A strong, permeable, highly workable and durable pervious concrete mix design that will withstand high-medium loading and wet, hard freeze environments is possible. In addition to the above, PCPC overlay materials should comply specific requirements.

2.2.1. Aggregates. Coarse aggregate should comply with ASTM C33 “Standard Specification for Concrete Aggregates”. Aggregate contents between 1300 to 1800 kg/m³ [9,23]. The recommended aggregate size number used for pervious concrete include No. 67 (19.0 to 4.75 mm), No. 8 (9.5 to 2.36 mm), and No. 89 (9.5 to 1.18 mm) [9,12]. Angular and crushed aggregates must be used to improve strengths [3]. Little or no fine aggregate is used in the mix [1-4,11]. The addition of a small amount of sand (around 6-8% of the total aggregate weight) improve compressive strength, freeze-thaw-durability, flexural strength and density [3,6,24]. Although it can reduce porosity and permeability.

2.2.2. Water. Water should comply with ASTM C1602 “Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete”. Potable water can be used to produce pervious concrete [5,24]. Typically, the water-cement (w/c) ratios range from 0.27 to 0.30. Although they have been used satisfactorily up to 0.42[1-4,9]. While low w/c ratios can result in very low workability, high w/c ratios may lead to a mixture with excessive paste segregated and can reduce permeability and porosity [3,9,12].

2.2.3. Cement. Cement should comply with ASTM C150 “Standard Specification for Portland Cement”. Ordinary Portland Cement can be used to produce pervious concrete [3,9,18]. In most cases, the aggregate-cement(A/C) ratio is more important than the w/c ratio, due to the typical pervious concrete failure occurs in the binder layer since the strength of the cement paste-aggregate interface is very weak [2,4,25]. A/C ratio ranges of 4 to 4.5 by mass [9].
2.2.4. Admixtures. Additives should comply with ASTM C494 “Standard Specification for Chemical Admixtures for Concrete”, ASTM C1240 “Standard Specification for Silica Fume Used in Cementitious Mixtures”, ASTM C618 “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete”. Various additives are available to enhance strength, durability and workability of pervious concrete. Among them, water reducer, latex, air entrainment, polymer, hydration stabilizer, polypropylene fibres, viscosity modifier, cohesive agent, silica fume and fly ash [2,3,9,11,12,16-22].

2.3. Engineering Properties of PCPC

Engineering properties of PCPC can be divided into two categories: tests in fresh PCPC and test in hardened PCPC [4,20]. Currently, there is very little standardization that regulates the way to perform tests on pervious concrete. In most cases, standards for conventional concrete are used [5]. According to previous studies, there are differences in the results of tests on cylinders compared with those of cores. This shows the great variability associated with laboratory and field conditions [4,26]. It has been proven that specimens prepared in two layers with ten blows of a 2.5 kg Proctor Hammer per layer result in the closest properties to the field pervious concrete [4,9,26].

2.3.1. Fresh Pervious Concrete. The testing for freshly pervious concrete include:
- According to ASTM C1611 “Standard Test Method for Slump Flow of Self-Consolidating Concrete”, workability of the material can be measured with slump flow test. Typically, slump is less than 20 mm, although porous concrete with it up to 50 mm can be found [9].
- ASTM C 1688” Standard Test Method for Density and Void Content of Freshly Mixed Pervious Concrete” This test method covers determining the density (range 1750 to 2000 kg/m³) of freshly mixed pervious concrete and gives formulas for calculating its void content [27].

2.3.2. Hardened Pervious Concrete. The testing for hardened pervious concrete include:
- Compressive strength (ASTM C390” Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens”) Pervious concrete can develop compressive strengths upwards of 28 MPa, with typical values around 17 MPa [9,21].
- Flexural strength (ASTM C78 “Standard Test Method for Flexural Strength of Concrete”). Flexural strength in pervious concretes ranges between about 1 MPa and 3.8 MPa [9,21].
- Tensile splitting (ASTM C496 “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens”) [5,9,12,24]
- Density and porosity (ASTM C1754 “Standard Test Method for Density and Void Content of Hardened Pervious Concrete”) In-place densities on the order of 1602 kg/m3 to 2002 kg/m3 are common [9,21].
- Abrasion resistance (ASTM 1747” Standard Test Method for Determining Potential Resistance to Degradation of Pervious Concrete by Impact and Abrasion”) [9,12].
- Permeability (ASTM C1701” Standard Test Method for Infiltration Rate of in Place Pervious Concrete”). The last one, to determine field water infiltration rate. It can also be measured in the laboratory with a variable or constant head permeameter. Infiltration rates for water through permeable concrete are 0.2 cm/s to 0.54 cm/s, with rates up to 1.2 cm/s and higher (10 cm/s) have been measured in the laboratory [9,21].

Table 2 shows recent studies carried out by different authors. This corroborates the possibility of achieving high engineering (mechanical) properties in PCPC and increases the opportunity to use the material at the airport. In addition, it guarantees durability, performance and safety of the structure.
Table 2. Pervious concrete properties of various mixes

| Year | Void Ratio (%) | Permeability (mm/s) | Compressive Strength (Mpa) | Flexural Strength (Mpa) | Author |
|------|---------------|---------------------|---------------------------|------------------------|--------|
| 2011 | -             | 2.9                 | 35.5                      | -                      | [2]    |
| 2011 | 10            | 1.4                 | 31                        | 2.3                    | [16]   |
| 2011 | 20.7          | 2                   | 24.4                      | 2.85                   | [17]   |
| 2011 | 23            | 2.1                 | 23.2                      | 2.8                    | [18]   |
| 2011 | 18            | 2.5                 | 25                        | 4                      | [19]   |
| 2013 | 22            | 26                  | 16                        | 4                      | [20]   |

2.4. Construction
Proper construction of pervious concrete overlay is essential to long-term performance. It includes several stages.

2.4.1. Plans, Specifications and Estimates. First phase related to management and quality control. The plans depict location, details and limits of the project. The specifications give the governing procedures and requirements for the materials, the quality of workmanship expected and the consequences by deficient levels of them. The estimates reflect the expected quantities of material and the rates of application [12].

2.4.2. Preparation: Milling, Clean and Drains. Preparation for placement of the overlay is relatively minor [6]. Track elevations should comply at airport; a given thickness (from PCPC overlay structural design) of the existing concrete slab must be milled. Next, cleaning the milled concrete surface with a broom or vacuum cleaner [6,12,15]. Finally, locate perforated PVC pipes 4 to 6 in. in diameter for conveyance/overflow purposes [6,9,12,15,22] or relocate existing drainage system to guarantee hydrological benefits of the overlay.

2.4.3. Pavement Transitions. Pavement transitions are a common design detail for overlays. They provide a smooth, ideally unnoticeable transition from the existing concrete slab to the overlay [28]. In this case it is recommended to use prime and tack coats to provide bond between layers [6,12].

2.4.4. Installation. Once PCPC arrives at field, workability must be measured (ASTM C1611) [6]. Due to its stiff consistency, it cannot be pumped [9]. Then, pervious concrete is direct discharged onto the surface. PCPC overlay is placed in a single layer, of given thickness [6,12]. The entire placement, spreading and strike off of PCPC should be continuous and rapid, within 60 min for conventional mixtures and 90 min in for modified (extended set control admixture) ones [9,12,30].

2.4.5. Consolidation and Finishing. The final compaction is carried out with a static drum roller (10 psi vertical force). Because of rapid hardening and high evaporation rates, it is recommended that consolidation must be completed within 15 minutes after the placement [6,9,12,21,29,30].

2.4.6. Joint Placement. Control joints are optional for pervious concrete. If done, it should be cut with ONE pass of a "pizza cutter" (see figure 1). The spacing and depths (1/4 of the overlay thickness) should be the same to the existing slab, to avoid reflective cracking. Joint installation should be soon after consolidation. Saw cutting joints also is possible, but is not recommended because created slurry may clog porous structure, and excessive ravelling of the joints often results [6,9,12,30].
2.4.7. Curing. Curing is essential for durability and performance of pervious concrete [21]. Within maximum of 20 minutes after placement, fog misting followed by plastic (6 mm) sheeting has to be placed. It should remain in place for at least 7 days (conventional PCPC) or 10 days (modified PCPC) [6,9,12,29,30]. Note: Edges can be secured with sandbags over plastic to ensure curing of the entire surface.

2.4.8. Testing and Opening to Traffic. In place infiltration rate should be measured (ASTM C1701), minimum values of 1.4 mm/s are expected [9,15,22,29,30]. For vehicle and aircraft traffic, it is recommended that the pavements not be opened for 7 days and 14 days (until reach full strength), respectively. Continuous curing is recommended until these deadlines are finished [9,12,30]. Once it happens, cores can be taken to measure thickness and density (ASTM C1754) [9].

2.5. Operations and Maintenance
Operations include routine inspection to rule out sediments or debris on surface that may clog porous matrix, inspection after rains to verify adequate drainage, permeability testing (ASTM C1701, twice per year), power washing and vacuum sweeping to restore permeability, and snow removal [6,9,12,15,22,30]. For the last one, it is essential to use plough with non-metal blades to avoid abrasion and ravelling of the surface, occasional application of sand as long as it is not fine, avoid anti-icing pre-treatments, and never use de-icers that contain magnesium chloride, calcium magnesium acetate, potassium acetate, ammonium sulphate or ammonium nitrate [12]. Over time of service, the PCPC overlay will need maintenance strategies [29,30]. Currently, these are not very clear or developed.

3. Conclusions
This research, review different studies and findings of pervious concrete around the world. In order to propose a novel application as an overlay for aircraft parking lot that can be sustained by previous cases. Thickness design of PCPC overlay has been proposed with the FAA’s design methodology and FAARFIELD software. Although it is based on conventional pavement performance models, it can be a good starting point for future application in real scale. A brief summary of mix design, construction techniques, engineering properties measurements and as well as operations and maintenance affairs was developed. In terms of engineering properties, the variability associated with different mixing proportions was detailed, which gives viability to development of the proposal.

Besides, it was showed requirements and specifications that PCPC must achieve to enhance strength, durability and long-term performance. It can be concluded, as long as the above issues are adequately carried out, the project in real scale of PCPC overlay in airport conditions is feasible. The documented information can provide an idea of the techniques available for different projects. However, it is necessary that future research be directed to the experimental development of the proposal in the laboratory and complement it with the pilot project in airport site to obtain information on long-term performance and design validation. Finally, this document was able to identify and expose the need to develop FAA specifications for pervious concrete pavements at airport.
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