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Analysis of Runway Pavement Overlay Design using FAARFIELD 2.1

Analisis Desain Overlay Perkerasan Landasan Pacu Berbasis FAARFIELD 2.1

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ABSTRACT

This study utilizes FAARFIELD software to calculate the necessary overlay thickness for the runway pavement at Hang Nadim International Airport. The evaluation relies on primary data, including field assessments such as Pavement Condition Index (PCI) analysis and Dynamic Cone Penetration (DCP) testing, to estimate subgrade bearing capacity. Secondary data is sourced from the Airport Pavement Management System (APMS), which provides historical pavement conditions, maintenance records, and aircraft traffic statistics. The results show that for the runway section from STA 0+000 to 4+025, with a subgrade CBR of 8%, the required overlay thickness is 55 mm (5.5 cm) of Hot Mix Asphalt (HMA). These findings incorporate projections of aircraft traffic growth over 20 years, ensuring the pavement's structural integrity despite increasing loads. The study also emphasizes the need for future research to refine methodologies for determining subgrade bearing capacity. While historical CBR data is available, updating field data will offer a more accurate reflection of current subgrade conditions. Moreover, DCP testing on the runway side may not accurately reflect conditions at the runway center, suggesting the use of core drilling to verify subgrade conditions at critical points. Core drilling can provide more precise depth measurements for reconstruction based on observed damage.

1. Introduction

Airport pavements play a crucial role in the transportation infrastructure network by facilitating the movement of people and goods daily, supporting regional economic growth, and increasing tourist traffic [1]. The operational performance of Hang Nadim Airport has continued to increase in recent years, particularly due to growing passenger movements and expanding transportation activities around the airport area [2]. As mobility intensifies, the supporting airside infrastructure including runway pavements requires reliable structural capacity to ensure safe and efficient airport operations. Airport pavement construction is vital and must be designed with high-quality structures to minimize accident risks [3]. Runway pavements are subjected to continuous loads from aircraft movements, environmental pressures, and material aging, requiring regular maintenance and rehabilitation to ensure safety and performance. The integrity of runway pavements throughout their service life is a primary concern for all airport authorities [4].

Thorough planning and continuous maintenance, such as runway resurfacing, are crucial to ensure the safety, reliability, and efficiency of the overall air transportation system [5]. The application of overlay design is essential to restore structural integrity, effectively extend the pavement's lifespan, and reduce high maintenance costs associated with more severe structural damage. By implementing the right maintenance strategies, airports can ensure smooth operations and minimize disruptions to flight schedules. The primary approach to extending pavement life is through surface maintenance using resurfacing methods, which have proven to be an effective and reliable solution [6].

The structural capacity of pavement refers to its ability to withstand loads without experiencing damage [7]. The number and type of aircraft operating at an airport are crucial factors in determining the pavement's structural capacity. Aircraft characteristics, such as weight, directly impact the calculation of overlay thickness [8]. Accurate assessment of these parameters ensures that the overlay design meets operational standards and performance criteria established for the airport. The use of FAARFIELD 2.1 software enables the calculation of optimal overlay thickness based on the aircraft load conditions.

The development of airport pavement maintenance management, pavement testing and performance technology, and other technological advancements underscores the need for further research. This study aims to evaluate the required thickness for runway pavement design using the FAARFIELD software for pavement performance analysis. This assessment is conducted to address challenges related to pavement damage, increased air traffic volume, and ongoing maintenance of runway pavements. The results of this study are expected to contribute to the development of more efficient and environmentally friendly pavement design and management strategies, as well as to guide the implementation of a circular economy in airport pavements.

2. Literature Review

2.1 Maintenance and Rehabilitation Strategies in Airport Pavement Management System

The goal of M&R is to improve pavement performance while minimizing maintenance costs [9]. According to [10], maintenance and rehabilitation (M&R) activities for airport pavements, including runways, taxiways, and aprons, require significant funding. The growth of air traffic over time is a key factor in increasing pavement loading, ultimately impacting pavement structures that are approaching or exceeding their technical service life. According to [11], planning maintenance programs for pavements showing signs of structural fatigue degradation becomes increasingly complex as uncertainties in the material response of ageing pavements increase.

The issue of suboptimal runway maintenance should be approached holistically through three main dimensions: social, economic, and environmental, to ensure operational sustainability and minimize long-term negative impacts [12]. According to [13], the primary objective of the airport pavement maintenance decision-making system is to maintain or restore pavement conditions within budgetary constraints efficiently. This strategy not only ensures user safety but also extends the pavement's service life, thereby delivering long-term economic benefits.

In the Airport Pavement Management System (APMS), the primary focus is on decision-making. This process enables the formulation of optimal strategies to maintain airside infrastructure in a serviceable condition over a defined period, while also accounting for operational conditions [14]. The system encompasses a set of procedures, including planning and scheduling targeted maintenance and rehabilitation activities, optimizing costs to improve execution efficiency, and evaluating previous maintenance costs. According to [15] the APMS ensures that the airport pavements remain in optimal condition while minimizing operational costs and extending the service life of the pavements.

According to [16], APMS is effectively used to predict future conditions, which can be useful for estimating the relative rehabilitation costs at various points throughout the pavement's service life. Maintenance and rehabilitation (M&R) play a crucial role in keeping the pavement in good condition and ensuring optimal performance throughout the infrastructure’s service life [17]. As stated by [18], APMS not only evaluates the current service level of the pavement but also aims to predict future conditions by utilizing.

2.2 Overlay Design for Airfield Pavement

Airport pavements deteriorate gradually over time, making regular maintenance, repairs, and rehabilitation crucial to achieving the intended service life. The most widely used rehabilitation method for airfields is pavement restoration by adding a new layer over the existing pavement structure [19]. Research by [20] shows that increasing the asphalt layer thickness from 13 cm to 21 cm effectively improves stress conditions at critical points. This additional layer results in reductions of 8.82% and 8.92% in tensile and maximum shear stress, respectively. Furthermore, another study at Juba Airport in South Sudan demonstrated that increasing overlay thickness can improve stress distribution between layers and reduce the maximum shear stress, thereby enhancing the pavement's structural performance and service life [21].

Overlay on airfield pavements is an efficient and cost-effective rehabilitation method, often becoming the primary choice in airport pavement design. The use of a mechanistic-empirical overlay design approach, as implemented in the FAARFIELD software, offers a planning strategy that emphasizes structural performance while also considering cost efficiency and infrastructure sustainability [22]. Additionally, research on rigid pavements has shown that the Ultra-thin Concrete Overlay (UTO) technology, with enhanced interlayer bonding, improves resistance to tensile and shear failure, making it a reliable functional solution for dynamic load conditions such as aircraft landings and movements [23].

According to [23], reflective cracking remains a major issue for asphalt overlays applied over concrete pavements. One approach to reduce the rate of crack development is to increase the linear shrinkage coefficient of the overlay material and the asphalt layer thickness, which has proven effective in enhancing crack resistance on airport runways. Additionally, research by [24] shows that using FAARFIELD with a conservative local concrete strength standard lead to overly thick rigid pavement designs. This results in wasteful costs and a significant increase in carbon emissions. Therefore, designers must adjust design inputs to align with local material characteristics to avoid unnecessary overdesign.

Research by [25] shows that interlayer bonding conditions significantly affect shear stress and tensile strain in asphalt overlays. Simulations of two pavement models indicate that a higher frequency of overlays increases interlayer stress and accelerates surface damage. Moreover, maximum stress still occurs at the bottom of the top layer, indicating that adding overlays does not always improve the structural stress conditions. Therefore, overlay design must consider the cumulative effects of traffic loads and the quality of interlayer bonding to avoid accelerating surface pavement damage.

2.3 Pavement Structural Aspects of Airport Pavement Systems

Structural damage to airport asphalt pavements often results from the interaction between repeated aircraft loads and environmental temperature fluctuations, requiring appropriate structural evaluation methods to ensure pavement durability and service life [26]. Additionally, dynamic factors such as tyre pressure and descent speed during landing significantly increase stress and strain on the surface layer. As stated by [27], higher tyre pressure and descent speed can worsen the structural response, including effective stress, strain, and vertical displacement. Therefore, the design of airport pavement structures must consider bending stresses in the lower layers and pressure responses in the subgrade. Through continuous evaluation of PCN in the Airport Pavement Management System (APMS), the pavement's load-carrying capacity can be determined cyclically, thereby supporting more accurate decision-making in pavement maintenance and rehabilitation (M&R) [28]. As demonstrated by [29], asphalt pavement distress can also be evaluated cyclically by identifying the stages of distress evolution and either reducing or halting the progression to extend the pavement's lifespan. By integrating maintenance data with distress evolution models, maintenance decision-making can be more targeted, ensuring the airport pavement remains operationally optimal throughout its life cycle.

Composite pavement is the most used pavement structure for airport runways worldwide. To enhance the effectiveness of preventive maintenance (PM) on composite pavements, a new set of indices has been developed to more clearly differentiate distress types and to establish thresholds based on field data and neural network models, ultimately optimizing PM decision-making quantitatively [30]. Composite pavements provide an efficient solution to improve the performance of airport pavements, but irregularities in concrete slabs can trigger reflective cracking. As shown in the study by [31], increasing the thickness of the asphalt overlay, using stress-absorbing interlayers, and improving load transfer efficiency (LTE) can reduce the potential for damage by up to 35% at the early crack stage, with the application of interlayers being more cost-effective and offering better elevation control. These mitigation techniques can be integrated into pavement maintenance management systems to improve efficiency and extend pavement service life.

Periodic evaluation of airport pavement conditions is crucial for determining appropriate maintenance and rehabilitation (M&R) needs. By integrating field data and analytical software, the APMS provides more in-depth information and supports more accurate decision-making regarding airport pavement maintenance and rehabilitation [7]. According to [32], with advancements in pavement thickness analysis methods, the implementation of ACR–PCR provides many improvements, including a more accurate alignment between pavement thickness design and strength assessment, as well as the use of more representative data concerning aircraft traffic loads and pavement structure.

3. Methodology

This study used primary and secondary data collection methods to establish the input parameters for the FAARFIELD software. The primary data includes field observations used to evaluate the surface distress condition of the runway pavement and the bearing capacity of the existing subgrade. Meanwhile, the secondary data consists of documents from the Airport Pavement Management System (APMS) of Hang Nadim International Airport (IATA Code: BTH), which include specifications of the runway pavement structure, maintenance and rehabilitation (M&R) data, types of aircraft operating, and flight traffic data up to the year 2023. Additionally, recent literature from relevant journals and research is presented to support the schematic methodology used in this study.

4. Results and Discussion

4.1 Runway Specifications

To understand the historical layering of the pavement structure at Hang Nadim International Airport, the length of the runway from STA 0+000 to STA 4+025, with a width of 45 meters, is shown in Figure

1. Figure 2 illustrates the cross-section of the runway pavement, indicating that the entire runway uses a consistent layering system. With this consistent layering system, the overlay thickness resulting from FAARFIELD can be calculated for the whole length of the runway. This layering system is used as the dominant input parameter for the critical aircraft wheel path at the specified width.

4.2 Analysis Pavement Condition Index

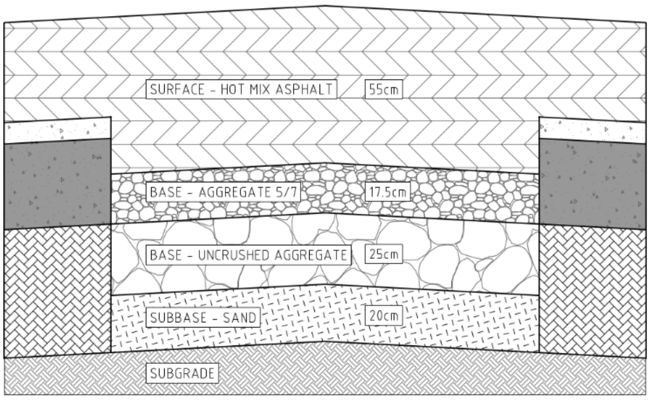
PCI is a method for assessing road conditions using a rating system that describes pavement conditions based on accurate, objective data. The PCI value is expressed on a scale from 0 to 100. According to data from the APMS document in 2023, a PCI survey conducted in 2021 showed a PCI value of 83.5, higher than the PCI recorded in 2020. It is assumed that minor repairs were carried out between 2020 and 2021, followed by a reassessment of the surface condition in 2021. The PCI value of the runway pavement is updated annually based on the M&R maintenance activities carried out. Pavement condition trends generally follow a non-linear pattern, with a sharper decline after reaching a certain PCI threshold. However, a PCI survey conducted again in 2023 indicated a drastic decline in the PCI value to 22.1, indicating a critical condition. Based on M&R maintenance records, the pavement must be reconstructed before designing the overlay. This sharp decline can be explained by understanding that with each M&R maintenance, the overall PCI value decreases and does not return to its original condition. The deterioration of pavement quality beyond the critical PCI range will accelerate and become more pronounced. For design purposes, it is assumed that reconstruction will be carried out to eliminate all surface damage completely.

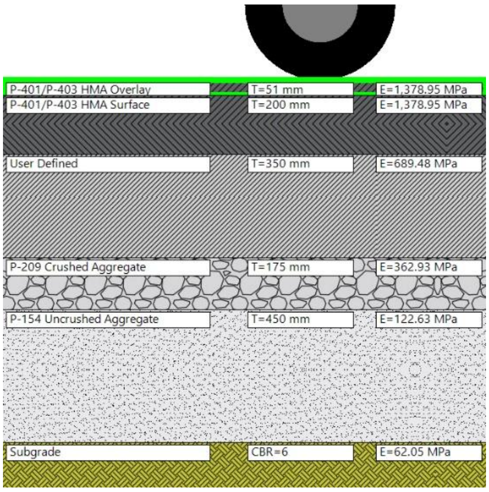
4.3 Subgrade Bearing Capacity Evaluation in Airport Pavement

The bearing capacity of the subgrade used for the FAARFIELD input parameter is the California Bearing Ratio (CBR). CBR testing is typically performed after the subgrade construction is completed. Based on the available data, the CBR for the subgrade of the runway pavement at Hang Nadim International Airport is 8%. The average CBR value calculated from DCP testing on the runway side from STA 0+000 to 4+025 is 5.20%, rounded to 5%, while for STA 2+025 to 4+025, the value is 9.75%, rounded to 10%, both of which represent more conservative input parameters. These results show a significant difference from the CBR value reported in the APMS document. The methodology used to obtain this CBR value is considered inadequate because the DCP testing was conducted on the runway side and does not fully represent the actual subgrade conditions. Variations in results due to differences in field measurement methods may occur, where inconsistencies in technical approaches particularly in elevation calculation can produce significant deviations between analytical outcomes and actual field conditions [33]. However, this does not imply that the overlay design disregards the bearing capacity analyzed using this method. Based on historical data, the runway pavement from STA 2+025 to 4+025 represents an extension that can reflect different subgrade conditions. Therefore, the overlay design for the runway pavement from STA 0+000 to 4+025 will use a CBR value of 8%

4.4 Subgrade Bearing Capacity Evaluation in Airport Pavement

All input parameters and their adjustments are applied in the FAARFIELD program to calculate the minimum overlay thickness required for the runway at Hang Nadim International Airport, as shown in the figure.





P-401/P-403 HMA Overlay T=51 mm E=1,378.95 MPa
P-401/P-403 HMA Surface T=200 mm E=1,378.95 MPa
User Defined T=350 mm E=689.48 MPa
P-209 Crushed Aggregate T=175 mm E=362.93 MPa
P-154 Uncrushed Aggregate T=450 mm E=122.63 MPa
Subgrade CBR=6 E=62.05 MPa

The pavement modeling in FAARFIELD follows the existing pavement conditions as previously described. The lowest pavement layer, or subgrade, uses a CBR value of 8%, based on the obtained data. The uncrushed aggregate in the FAARFIELD program consists of subbase (sand) and base, with a combined depth of 45 cm and an initial design modulus of 285.00 MPa. The crushed aggregate base has a design depth of 20 cm and an initial design modulus of 550.00 MPa. The "User Defined" layer refers to the existing HMA layer, which is not affected by the assumed reconstruction; therefore, justification is needed to reduce its modulus by 45% due to aging and temperature fluctuations. The HMA surface is a reconstructed HMA mix, assumed necessary to eliminate severe surface conditions following the PCI survey conducted in 2023. The designed top layer thickness is a 55 mm (5.5 cm) HMA mix. It can also be concluded that the proposed pavement design life of 20 years affects both the crushed and uncrushed base layers, resulting in performance decreases of 48% and 72%, respectively.

5. Conclusion

This study uses the FAARFIELD software to analyze and determine the required thickness for the runway pavement structure at Hang Nadim International Airport. FAARFIELD, developed by the FAA, adopts a layered elastic analysis methodology and finite element method to evaluate pavement performance and ensure compliance with overlay specifications. This process involves collecting primary and secondary data to obtain the required input parameters. Primary data consists of field evaluations, including Pavement Condition Index (PCI) analysis and Dynamic Cone Penetration (DCP) testing to estimate subgrade bearing capacity. Secondary data is obtained from the Airport Pavement Management System (APMS), which records historical pavement conditions, maintenance records, and aircraft traffic statistics. Projections for increased aircraft traffic use regional economic data to estimate future load demands. The results obtained from FAARFIELD indicate the required layer thickness for two pavement segments. For STA 0+000 to 4+025, with a subgrade CBR value of 8%, the required overlay thickness is 55 mm (5.5 cm) of Hot Mix Asphalt (HMA). These results account for projected growth in aircraft traffic over the 20-year design period, with the goal of maintaining structural integrity and performance despite increasing loads. For future studies using FAARFIELD, it is important to introduce more suitable methodologies for determining the bearing capacity of the subgrade layers. Although historical CBR data is available, collecting updated field data can provide a more accurate depiction of the subgrade conditions. DCP testing conducted on the runway side may not always reflect the subgrade conditions at the center of the runway. Therefore, it is recommended to use core drilling for pavement to verify subgrade conditions at critical locations. Using core drilling, the reconstruction depth can be more accurately determined based on the depth of the damage.

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