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COMPARISON OF RIGID PAVEMENT DESIGNS FOR AIRPORT RUNWAYS UNDER STRONG AND WEAK GROUND CONDITIONS AT LOW AND HIGH TRAFFIC AIRPORTS

DÜŞÜK VE YÜKSEK TRAFİKLİ HAVAALANLARINDA GÜÇLÜ VE ZAYIF ZEMİN KOŞULLARI ALTINDA HAVAALANI PİSTLERİ İÇİN SERT KAPLAMA TASARIMLARININ KARŞILAŞTIRILMASI

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ABSTRACT

In this study, the FAARFIELD program was used to evaluate the construction of rigid pavements for the airport under different soil conditions, aircraft types, and annual traffic loads (number of take-offs). This is because take-off movements are important parameters for runway strength in design. In addition, gross weight values for each aircraft type were entered into the system and obtained from the system with annual tariff growth rates. For pavement life, 20-year periods were considered. The study includes 2 different traffic loads: low and high traffic. The high traffic study is an example of 1 year of flight operations (1 year of total departures for each aircraft type) at a hub airport with +50 million passengers per year. Low traffic is Air Traffic Management (ATM) traffic for 1 year of total departures at a small local/regional airport. The CBR (California Bearing Ratio) value was taken as 5 for low strength soil and CBR=15 for good soil. CDF (Cumulative Damage Factor) and P/C values were examined in the results of the data obtained from the analysis of rigid pavement designs for airport runways under strong and weak soil conditions for low and high traffic airports with the FAARFIELD program.

Keywords: cumulative damage factor, runway pavement, airport

ÖZET

Bu çalışmada, FAARFIELD programı, uçak tipi ve yıllık trafik yükleri (kalkış sayısı) altında farklı zemin koşulları altında havaalanı için rijit kaplamaların yapımını değerlendirmek için kullanılmıştır. Bunun nedeni, kalkış hareketlerinin tasarımda pist mukavemeti için önemli parametreler olmasıdır. Ayrıca, her bir uçak tipi için brüt ağırlık değerleri sisteme girilmiş ve yıllık tarife büyüme oranları ile sistemden elde edilmiştir. Kaplama ömrü için 20 yıllık periyotlar dikkate alınmıştır. Çalışma düşük ve yüksek trafik olmak üzere 2 farklı trafik yükünü içermektedir. Yüksek trafik çalışması, yılda +50 milyon yolcuya sahip bir merkez havalimanındaki 1 yıllık uçuş operasyonlarına (her uçak tipi için 1 yıllık toplam kalkışlar) bir örnektir. Düşük trafik, küçük bir yerel/bölgesel havalimanındaki 1 yıllık toplam kalkışlar için Hava Trafik Yönetimi (ATM) trafiğidir. CBR (Kaliforniya Taşıma Oranı) değeri düşük mukavemetli zemin için 5 ve iyi zemin için CBR=15 olarak alınmıştır. FAARFIELD programı ile düşük ve yüksek trafikli havalimanları için güçlü ve zayıf zemin koşulları altında havalimanı pistleri için rijit kaplama tasarımlarının analizinden elde edilen veriler sonucunda CDF (Kümülatif Hasar Faktörü) ve P/C değerleri incelenmiştir.

Anahtar Kelimeler: kümülatif hasar faktörü, pist kaplaması, havaalanı

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INTRODUCTION

In addition to being the most important sector that facilitates human life, the transportation sector is also the most important parameter in increasing the level of livability. Technological developments in the transportation sector have contributed greatly to the development of countries at the level of modern civilizations. Transportation is one of the leading sectors that contribute to economic growth, national income increase, social order, industry, and trade development for every country. Aviation is one of the transportation systems where parameters such as speed, comfort, safety, and technology come to the fore with technological developments in transportation systems. Although it is only a century old, air transportation is the locomotive of the system in terms of socio-economic globalization. Today, thanks to aviation, it takes no more than 5-10 hours to cross oceans and continents. From a systemic approach, aviation is also composed of subsystems. Among these systems, airports are the most fundamental system. Airports, which were obtained by modifying football stadiums in the early 1900s, today employ tens of thousands of people and have the appearance of a techno-city, which is the economic development parameter of the region where they are located (Bingöl, 2000).

One of the sub-sectors of the systems used for transportation purposes is air transportation, which has gained importance in the last century, and airports, which are an important infrastructure element of this system. Airports, which have a very important place in air transportation, have an important place for every country as a gateway to the world. From the point of view of airports, it is possible to mention many important contributions, including the promotion of the country among the purposes of use. In addition to this important function of the airport, airports are also known to contribute to the economic, social, and cultural development of the region in which they are located (Doganis, 2005).

The concept of quality, which is one of the main objectives of civil engineering, is important in airports as in every structure. Maintenance costs, which are seen as one of the main elements in the construction and operation costs of airports, are directly related to the quality of the structures and the extent to which they can meet scientific needs. The quality and selection criteria of the pavements, which are considered the basic structure of airports and the most important element of the service they provide, are also one of the important factors that will affect this service. The selection of the type of pavement to be used on the airport superstructure should be based on scientific facts and the appropriate type of pavement should be selected.

Air transport plays a vital role in inter-regional transportation. The past century has seen tremendous growth in air traffic. The failure or loss of serviceability of a pavement at an airport and the closure of a runway, especially a major runway, can affect the operations of the entire airport system. Therefore, the reliability of pavements on runways is critical for air transportation. There is a growing need for reliable pavement design at airports. It has long been recognized that pavements are integral to the smooth operation of airports. However, this is the exception rather than the rule for airport pavements, which by their original design complete their service life without extensive maintenance. One of the most common problems in the design of airport pavements has been the underestimation of air traffic growth rates and the consequent under-design of pavement characteristics. Considering the design characteristics of pavements, it can be said that they are one of the most difficult design problems faced by civil engineers during design. Superstructures are constructed with the use of low-cost materials depending on highly variable usage and design characteristics as well as environmental and loading conditions. Due to the modernization and globalization of the world, the increase in air traffic often exceeds expectations. Traffic loads are difficult to predict because of new aircraft entering airports as they are needed. It can be assessed on a probabilistic basis based on environmental conditions and historical trends; however, the specific environment at a given time can have a dramatic impact on the performance of the superstructure.

One of the most difficult aspects of pavement analysis is the determination of pavement damage. Excessive stresses in the pavement structure cause the material to crack. However, the development of cracking alone does not necessarily indicate a failure of the superstructure surface. Airplanes can fly over defective pavements. On the highway, field pavement failure is defined in terms of the functional properties of the pavement surface, primarily in relation to ride quality. There is no comparable definition of failure for airport pavements. On airport pavements, the cumulative effect of different types of distress is a major concern for the pavement engineer.

Due to the difficulty of the airport superstructure analysis process, design methods have been developed empirically. Although these methods have produced feasible designs, they have some shortcomings. Significant progress has been made in the fields of engineering mechanics and materials evaluation that can provide the basis for the development of improved airfield pavement design procedures. The purpose of this report is to summarize the state of the art in airport pavement analysis models. There is no clear limit to this task. There are models for superstructure design that have been used for many years. Some models have been applied only by engineers at the forefront of technology in the design of superstructure structures. Other models have been proposed by researchers but have not been widely used for airport pavement analysis. Finally, there are models developed in other engineering fields that can be applied to the analysis of airport pavements. This report attempts to cover all these levels of development (Zaniewski et al., 1991). The amount of reinforcing steel required to control volume changes in concrete and reinforced concrete structures, especially on surfaces subject to friction and heating, depends primarily on the slab thickness, the tensile strength of the concrete, and the yield strength of the steel. Other factors affecting the amount of steel are shrinkage due to temperature drop, shrinkage due to drying, and the modulus of elasticity of concrete and steel (Zaniewski et al., 1991). It is considered important to evaluate the studies on this subject or the studies on waste recycling in the literature (Akgül, Doğan and Etli, 2020; Akgül and Etli, 2023; Cemalgil and Etli, 2020; Cemalgil, Etli and Onat, 2018; Cemalgil et al., 2021; Etli, 2022a, 2022b, 2023a, 2023b; Etli, Cemalgil and Onat, 2018, 2021; Etli, Yılmaz and Hansu, 2024; Gesoglu et al., 2017; Hansu and Etli, 2022) with concrete or mortar content in pavement design for future studies in terms of both engineering and sustainable production.

The lack of a detailed baseline study on pavement-subgrade quality and traffic loading in the literature poses a significant challenge for designers in their initial studies during design. Therefore, the existence of such a study can guide the relevant researchers and designers. The service life of the runways where the main activities are carried out at airports is of great importance. The evaluation and design of runway pavements under the service loads to which they are exposed according to the aircraft operating on them is of great importance for the operation of airports. For this purpose, it is of great importance not only to evaluate the pavement properties but also to evaluate the ground capacity under service loads. The evaluation of this situation can be evaluated with software with current technological developments. The FAARFIELD program was used within the scope of the study. Annual traffic loads (number of take-offs) are evaluated by considering the aircraft type and airport operating capacity and characteristics in the program and the evaluation of the construction of rigid pavements for the airport under different ground conditions in the construction of runway pavements are carried out with this program. The reflection of runway pavement life on the design as load distribution of take-off movements is considered an important parameter in terms of runway pavement and embankment strength and its effects are evaluated in detail within the scope of the study. In addition, gross weight values for each aircraft type were entered into the system and obtained from the system with annual tariff growth rates. Within the scope of the study, 20-year periods were considered for runway pavement service life. In addition, two different traffic loads, defined as low and high traffic, were evaluated. The high traffic load study is an example of 1-year flight operations (1-year total departures for each aircraft type) at a hub airport with +50 million passengers per year. Low traffic load is considered as Air Traffic Management (ATM) traffic for 1-year total departures at a small local/regional airport. Another parameter, the soil bearing capacity, is considered with CBR (California Bearing Ratio). CBR value is taken as 5 for low strength soil sample and CBR=15 for good soil. As a result, 4 different case studies were conducted and the change in runway pavement properties within the airport traffic load and soil properties were evaluated with the FAARFIELD program. The 4 different case studies can be summarized as follows: Case-I with low traffic load and low soil capacity, Case-II with high traffic load and low soil capacity, Case-III with low traffic load and high soil capacity, and finally Case-IV for airport runways with high traffic load and high soil capacity. As a result of the data obtained, CDF (Cumulative Damage Factor) and P/C values were analyzed. Cumulative damage factor (CDF) is defined as a factor of the amount of life consumed from the structural fatigue life of a pavement. It is expressed as the ratio of the applied load repetitions to the load repetitions allowed until the pavement is damaged by the end of its lifetime, which is relevant for air traffic. The P/C (pass-to-coverage) ratio is the ratio of how many passes it takes for the aircraft wheels to cover a unit area in one full pass. One full coverage is the maximum response of the ground.

DETAIL OF CASES AND DESIGN METHODS

The design of rigid airport pavements under different soil conditions is the focus of this study. Such problems constitute an extremely complex engineering problem involving many interacting variables. The calculation of the design method for an airport pavement is very computationally intensive, Therefore, the FAA has designed a computer program called FAARFIELD (Federal Aviation Administration Rigid and Flexible Iterative Elastic Layered Design) to assist pavement engineers. The FAARFIELD is offered as a user-friendly and completely free software. As far as the design procedure is concerned, it provides a design method-based structural analysis based on layered elastic and three-dimensional finite element method developed for use in calculating design thicknesses for airfield pavements. Layered elastic and three-dimensional finite element-based design theories are adopted within the software to address the impact of new complex gear and wheel arrangements. Although the value selected for low soil strength is CBR value 5, the k coefficient used in the FAARFIELD program was calculated for this CBR value with the help of the formula given as Equation 1 and entered the FAARFIELD program. For high soil strength, the CBR value is 15, the k coefficient used in the FAARFIELD program was calculated for this CBR value with the help of the formula given as Equation 1 and entered the FAARFIELD program.

$$k = 28.6926 \times [CBR]^{0.7788} \times 0.271447138 \left(\frac{MPa}{m}\right) \tag{1}$$

Four different case studies can be summarized as follows: Case-I with low traffic load and low soil capacity, Case-II with high traffic load and low soil capacity, Case-III with low traffic load and high soil capacity, and finally Case-IV for airport runways with high traffic load and high soil capacity as given in Table 1. As a result of the data obtained, CDF (Cumulative Damage Factor) and P/C values were analyzed.

Table 1. Definition of All Cases

Case No.	Traffic Load	Soil Capacity
I	low	low
II	high	low
III	low	high
IV	high	high

Aircraft weights and number of departures used in the coatings during the analysis are given in Table 2 and Table 3 for low and high traffic conditions, respectively. The tables also show the estimated annual growth rates of 10% for the annual departure values in Table 2 and Table 3.

Table 2. Airplane Information Used in Low Traffic Case

No.	Name	Gross Wt. (kg)	Annual Departures	(%) Annual Growth
1	A319-100 opt	68,400	56	10
2	A320-200 std	73,900	1,164	10
3	A321neo	97,400	783	10
4	A321neo	97,400	39	10
5	B737-400	68,266	5	10
6	B737-800	79,242	742	10
7	B737-700	70,307	1	10
8	B737 BBJ2	79,250	3,134	10
9	B737-900	79,242	593	10
10	B737-8/8-200/BBJ MAX 8	82,417	941	10
11	B737-9 MAX	88,541	42	10

For low soil capacity, modulus of elasticity values for PCC Surface, Lean Concrete, Crushed Aggregate, and Uncrushed Aggregate layers were defined as 27,579.04, 4,826.33, 300.18, and 101.50 MPa respectively. Poisson's ratio values of PCC Surface, Lean Concrete, Crushed Aggregate, and Uncrushed Aggregate layers were determined as 0.15, 0.2, 0.35, and 0.35 MPa respectively. Subgrade modulus of elasticity and Poisson's ratio values were defined as 61.94 and 0.4 respectively. On the other hand, for the high strength capacity of the soil, Crushed Aggregate and Uncrushed Aggregate layers were defined as 430.49 and 167.75 MPa respectively. Subgrade modulus of elasticity was defined as 155.17.

SOFTWARE PROPERTIES

The design of rigid airport pavements under different soil conditions is the focus of this study. Such problems constitute an extremely complex engineering problem involving many interacting variables. The calculation of the design method for an airport pavement is very computationally intensive, so the FAA has designed a computer program called FAARFIELD (Federal Aviation Administration Rigid and Flexible Iterative Elastic Layered Design) to assist pavement engineers. The FAARFIELD is offered as a user-friendly and completely free software.

Table 3. Airplane Information Used in High Traffic Case

No.	Name	Gross Wt. (kg)	Annual Departures	(%) Annual Growth
1	A319-100 opt	68,400	10,684	10
2	A320-200 opt	78,400	35,967	10
3	A321-200 opt	93,900	31,365	10
4	A300-600 Std Bogie	172,600	1,702	10
5	A310-200	142,900	1,926	10
6	A318-100 opt	68,400	626	10
7	A330-200 WV057	236,900	2,850	10
8	A330-300 WV022	233,900	1,066	10
9	A330-300 std	230,900	3,109	10
10	A340-300 opt	277,400	2,328	10
11	A340-300 opt Belly	277,400	2,328	10
12	B737-800	79,242	38,894	10
13	B737-300	63,503	1,525	10
14	B737-400	68,266	3,849	10
15	B737-500	60,781	1,095	10
16	B737-700	70,307	4,621	10
17	B757-200	116,100	1,693	10
18	B767-300 ER	175,994	1,072	10
19	B777-200 LR	348,358	880	10
20	B777-300 ER	352,441	997	10
21	B777F	348,722	1,720	10
22	B777-300 ER	352,441	686	10
23	A380-800 WV006	575,000	5,000	10
24	A380-800 WV006 Belly	575,000	5,000	10
25	MD-83	73,016	13,954	10

As far as the design procedure is concerned, it provides a design method based on structural analysis based on layered elastic and three-dimensional finite element method developed for use in calculating design thicknesses for airfield pavements. Layered elastic and three-dimensional finite element-based design theories are adopted within the software to address the impact of new complex gear and wheel arrangements. The FAARFIELD program also requires information on the fleet of aircraft that the airport will acquire in Figure 1 (Bhalla, Vankar and Zala, 2013).

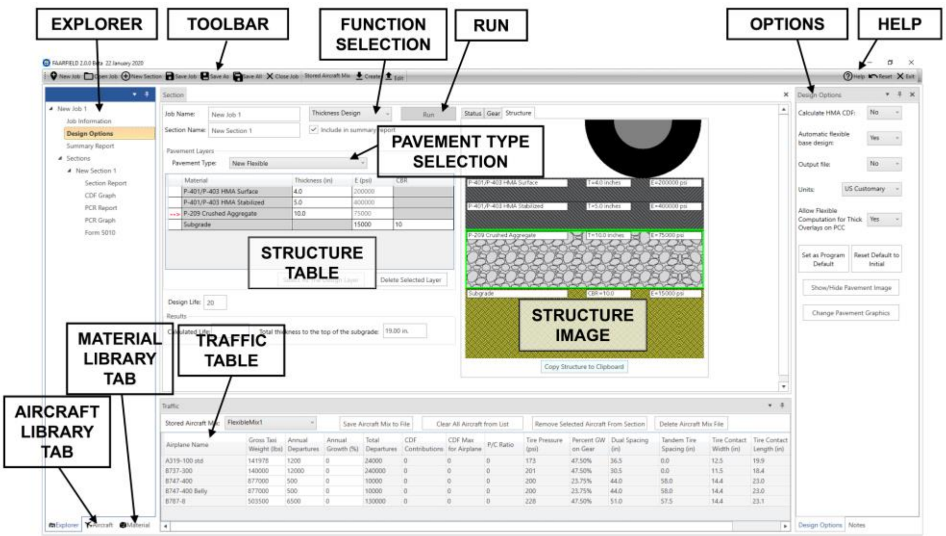


Figure 1. Example View of FAARFIELD Program (Bhalla et al., 2013)

The FAARFIELD program includes four functions (Figure 2) (Brill, 2021).

- Thickness Design: Compute required thickness per AC 150/5320-6 (Office of Airport Safety & Standards - Airport Engineering Division, 2021).
- Life: The structural life for a given structural system is calculated for the traffic it will be exposed to during its service life

- Compaction: Compute subgrade compaction requirements per AC 150/5320-6 (Office of Airport Safety & Standards - Airport Engineering Division, 2021). for a given structure and traffic mix. (Applies to completed designs.)
- PCR: Compute Pavement Classification Rating (PCR) for the structure and traffic mix.

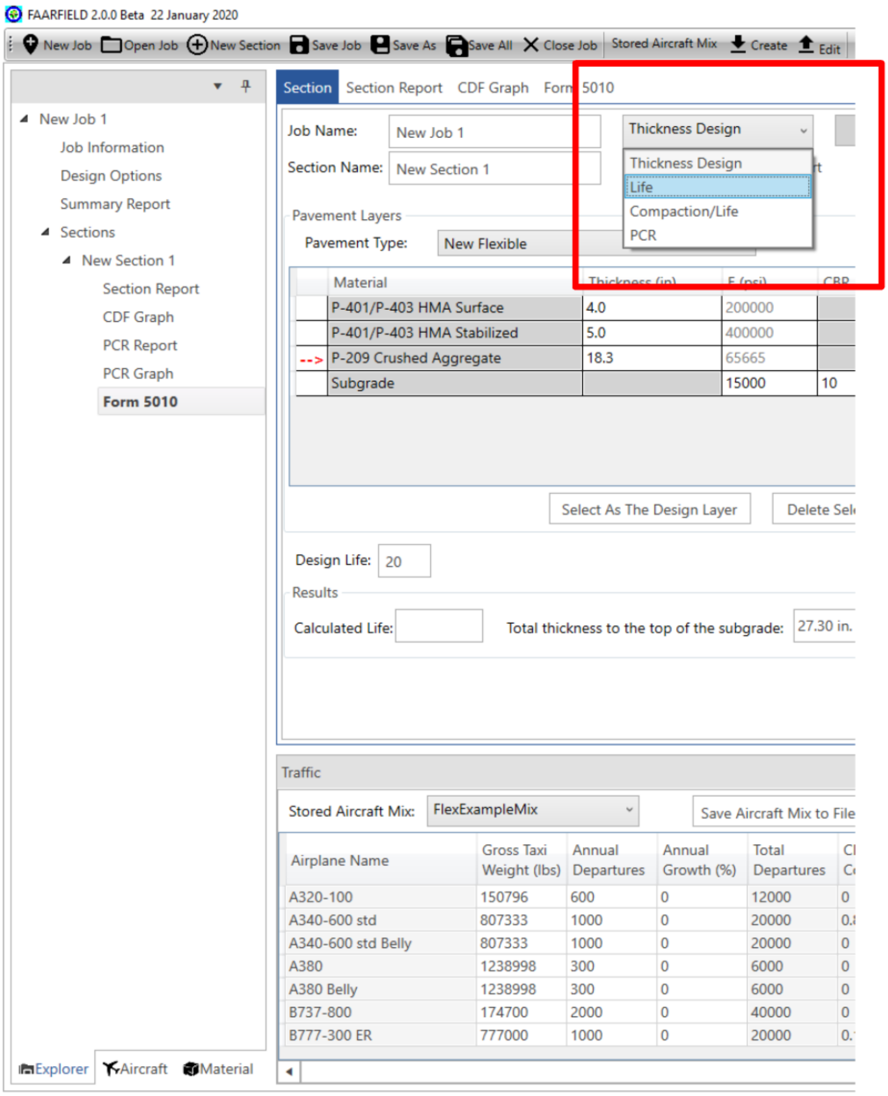
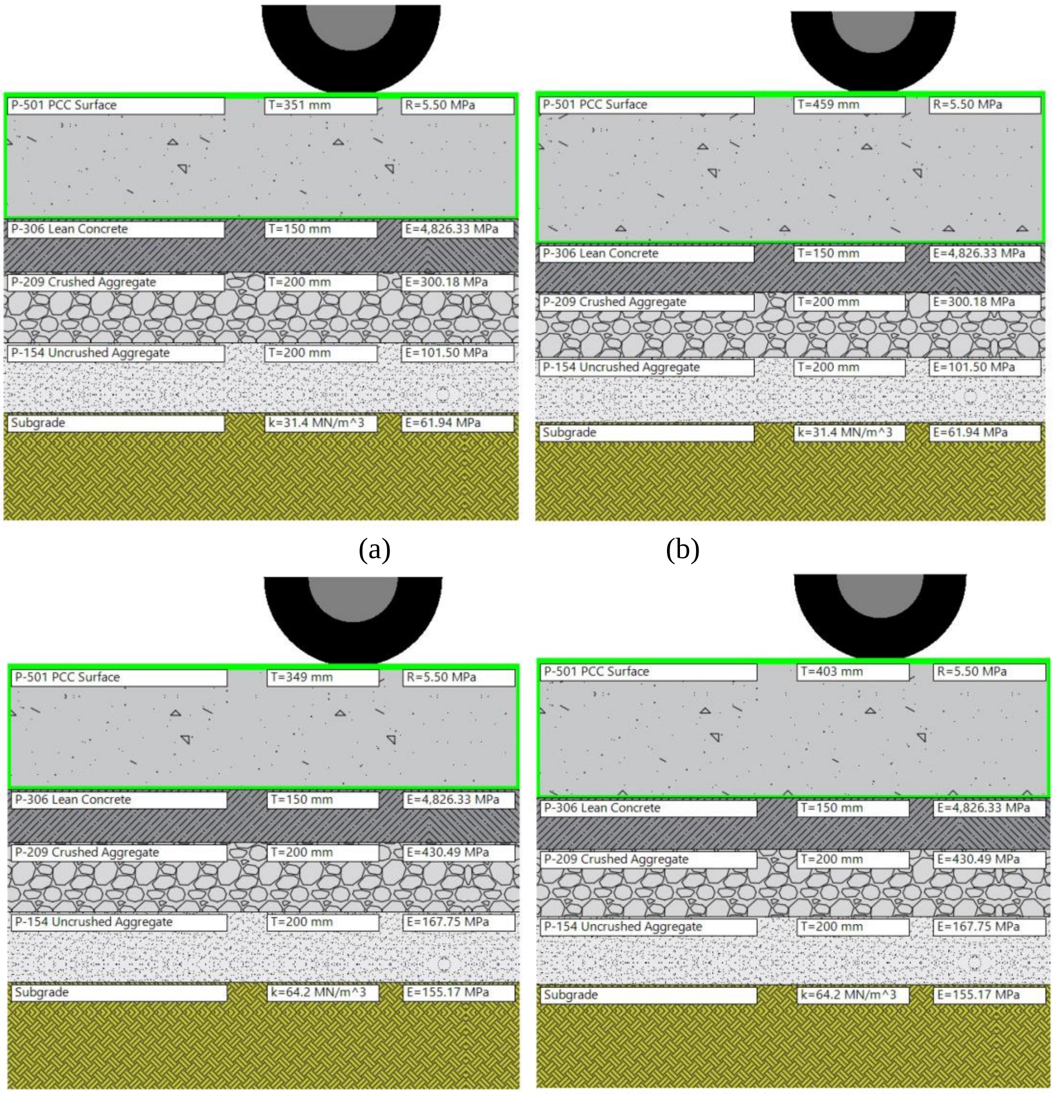


Figure 2. Example View of FAARFIELD Program Menu (Brill, 2021)

PAVEMENT DESIGNS

In Case-I, the total thickness value up to the top of the subgrade is defined as 901 mm in total. The layers that make up this value are PCC (Portland cement concrete) Surface, Lean Concrete, Crushed Aggregate, Uncrushed Aggregate, and Subgrade. PCC Surface, Lean Concrete, Crushed Aggregate, and Uncrushed Aggregate layer thicknesses are 351, 150, 200, and 200 mm respectively as defined in Figure 3(a). In Case-II, the total thickness value up to the top of the subgrade is defined as 1009 mm in total. PCC Surface, Lean Concrete, Crushed Aggregate, and Uncrushed Aggregate layer thicknesses are 459, 150, 200, and 200 mm respectively as defined in Figure 3(b). In Case-III, the total thickness value up to the top of the subgrade is defined as 899 mm in total. PCC Surface, Lean Concrete, Crushed Aggregate, and Uncrushed Aggregate layer thicknesses are 349, 150, 200, and 200 mm respectively as defined in Figure 3(c). The total thickness value up to the top of the subgrade is defined as 953 mm in total. PCC Surface, Lean Concrete, Crushed Aggregate, and Uncrushed Aggregate layer thicknesses are 403, 150, 200, and 200 mm respectively as defined in Figure 3(d).



(c) (d)

Figure 3. Pavement Structure Information by Layer View of FAARFIELD Program a) Case-I, b) Case-II, c) Case-III, and d) Case-IV

RESULTS

Case-I

P/C ratios for each aircraft type were obtained through analysis and calculated by the software. The A321neo with the highest weight of 97.4 t is considered in the analysis. The CDF contribution value for this aircraft was calculated as 0.86 and 0.04 for 783 and 39 annual departures, respectively (Table 2 and Table 4). On the other hand, the same values were obtained for CDF max for this aircraft. The P/C ratio values are 3.36 for both number of departures for this aircraft. A320-200std and B737-BBJ2 aircraft with the highest departure values were included in the calculations as 73.9 and 79.25 t, respectively. CDF contribution values are calculated as 0 and 0.04 for A320-200std and B737-BBJ2 aircraft, respectively. Moreover, CDF max contribution values are calculated as 0 and 0.07 for A320-200std and B737-BBJ2 aircraft, respectively. P/C ratio values are calculated as 3.7 and 3.53 for A320-200std and B737-BBJ2 aircraft, respectively (Table 2 and Table 4). Details of the subgrade compaction requirements for noncohesive soil are presented in Table 5. Table 5 shows the compaction values and depths of the superstructure and subgrade layers for noncohesive soil. For Case-I, the critical aircraft mobility was observed for the A321neo aircraft. For this aircraft, compaction depths of 0-358, 358-494, 494-1277, and 1277-2552 mm should be achieved for maximum dry density values of 100, 95, 90, and 85 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 90 and 85 percent should be achieved at 0-375 and 375-1651 mm respectively (Table 5). For Case-I, critical aircraft mobility was observed for the A321neo aircraft for cohesive soil. For this aircraft, compaction depths of 0-349, 349-442, 442-616, and 616-1229 mm should be achieved for maximum dry density values of 95, 90, 85, and 80 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 80 percent should be achieved at 0-327 mm respectively (Table 6). The CDF plot for Case-I is presented in the study as in Figure 4. From this graph, the fatigue effects of the aircraft on the runway pavement can be easily evaluated. When this situation is evaluated for Case-I, the highest fatigue effect will be observed with the A321neo aircraft, while the lowest fatigue effect will occur with the landing and take-off effect of the B737-400 aircraft (Figure 4).

Table 4. Airplane Departure CDF and P/C Ratio Results in Case-I

No.	Name	CDF Contribution	CDF Max for Airplane	P/C Ratio
1	A319-100 opt	0.00	0.00	3.66
2	A320-200 std	0.00	0.00	3.7
3	A321neo	0.86	0.86	3.36
4	A321neo	0.04	0.04	3.36
5	B737-400	0.00	0.00	3.52
6	B737-800	0.01	0.02	3.53
7	B737-700	0.00	0.00	3.68
8	B737 BBJ2	0.04	0.07	3.53
9	B737-900	0.01	0.01	3.53
10	B737-8/8-200/BBJ MAX 8	0.03	0.05	3.47
11	B737-9 MAX	0.01	0.01	3.39

Table 0. Subgrade Compaction Requirements for Noncohesive Soil Used in Case-I

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction
100	0 - 358	--	A321neo
95	358 - 494	--	A321neo
90	494 - 1277	0 - 375	A321neo
85	1277 - 2552	375 - 1651	A321neo

Table 6. Subgrade Compaction Requirements for Cohesive Soil Used in Case-I

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction
95	0 - 349	--	A321neo
90	349 - 442	--	A321neo
85	442 - 616	--	A321neo
80	616 - 1229	0 - 327	A321neo

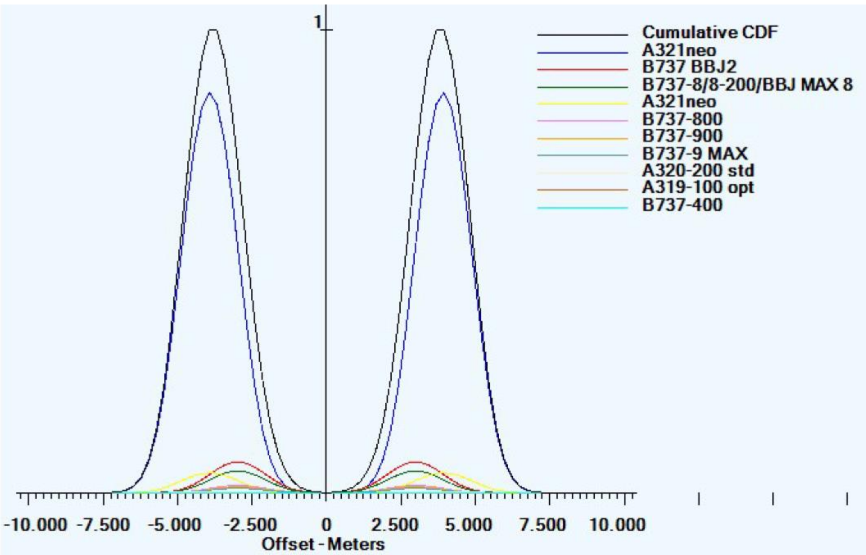


Figure 4. CDF Values in Case-I

Case-II

P/C ratios for each aircraft type were obtained through analysis and calculated by the software. The A380-800 WV006 and A380-800 WV006 Belly are the highest weight of 575 t is considered in the analysis. The CDF contribution value for these aircraft was calculated as 0 for 5000 annual departures of both airplanes, respectively (Table 3). On the other hand, the CDF max values were obtained as 0 and 0.03 for CDF max for this aircraft. The P/C ratio values are 3.78 and 4.2 for both A380-800 WV006 and A380-800 WV006 Belly airplanes and a number of 5000 departures. A320-200opt and B737-800 aircraft with the highest departure with values 35967 and 38894 were included in the calculations as 78.4 and 79.242 t, respectively. CDF contribution values are calculated as 0 for A320-200opt and B737-800 aircraft, respectively. Moreover, CDF max contribution values are calculated as 0 for A320-200opt and B737-800 aircraft, respectively. P/C ratio values are calculated as 3.67 and 3.53 for A320-200opt and B737-800 aircraft, respectively (Table 7). Details of the subgrade compaction requirements for noncohesive soil defined in Case-II are presented in Table 8. Table 8 shows the compaction values and depths of the superstructure and subgrade layers for noncohesive soil. For Case-II, critical aircraft mobility was observed for the B777-300ER aircraft under the condition of noncohesive soil. For this aircraft, compaction depths of 0-417, 417-1109, 1109-3517, and 3517-5882 mm should be achieved for maximum dry density values of 100, 95, 90, and 85 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 95, 90, and 85 percent should be achieved at 0-99, 99-2527and 2527-4872 mm respectively (Table 8). Details of the subgrade compaction requirements for cohesive soil are presented in Table 9. Table 9 shows the compaction values and depths of the superstructure and subgrade layers for cohesive soil. For Case-II, the critical aircraft mobility was observed for the B777-300ER aircraft for cohesive soil. For this aircraft, compaction depths of 0-407, 407-577, 577-1943, and 1943-3447 mm should be achieved for maximum dry density values of 95, 90, 85, and 80 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 85 and 80 percent should be achieved at 0-934 and 934-2348 mm respectively (Table 9).

Table 1. Airplane Departure CDF and P/C Ratio Results in Case-II

No.	Name	CDF Contribution	CDF Max for Airplane	P/C Ratio
1	A319-100 opt	0.00	0.00	3.66
2	A320-200 opt	0.00	0.00	3.67
3	A321-200 opt	0.00	0.00	3.42
4	A300-600 Std Bogie	0.00	0.00	3.38
5	A310-200	0.00	0.00	3.69
6	A318-100 opt	0.00	0.00	3.65
7	A330-200 WV057	0.00	0.00	1.86
8	A330-300 WV022	0.00	0.00	1.87
9	A330-300 std	0.00	0.00	1.88
10	A340-300 opt	0.00	0.00	1.81
11	A340-300 opt Belly	0.00	0.00	3.78
12	B737-800	0.00	0.00	3.53
13	B737-300	0.00	0.00	3.8
14	B737-400	0.00	0.00	3.52
15	B737-500	0.00	0.00	3.82
16	B737-700	0.00	0.00	3.68
17	B757-200	0.00	0.00	3.92
18	B767-300 ER	0.00	0.00	3.63
19	B777-200 LR	0.09	0.09	3.86
20	B777-300 ER	0.13	0.13	3.84
21	B777F	0.70	0.70	3.86
22	B777-300 ER	0.09	0.09	3.84
23	A380-800 WV006	0.00	0.00	3.78
24	A380-800 WV006 Belly	0.00	0.03	4.2
25	MD-83	0.00	0.00	3.42

The CDF plot for Case-II is presented in the study as in Figure 5. From this graph, the fatigue effects of the aircraft on the runway pavement can be easily evaluated. When this situation is evaluated for Case-II, the highest fatigue effect will be observed with the B737F aircraft, while the lowest fatigue effect will occur with the landing and take-off effect of the A330-300std aircraft (Figure 5).

Table 2. Subgrade Compaction Requirements for Noncohesive Soil Used in Case-II

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction
100	0 - 417	--	B777-300 ER
95	417 - 1109	0 - 99	B777-300 ER
90	1109 - 3537	99 - 2527	B777-300 ER
85	3537 - 5882	2527 - 4872	B777-300 ER

Table 3. Subgrade Compaction Requirements for Cohesive Soil Used in Case-II

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction
95	0 - 407	--	B777-300 ER
90	407 - 577	--	B777-300 ER
85	577 - 1943	0 - 934	B777-300 ER
80	1943 - 3447	934 - 2438	B777-300 ER

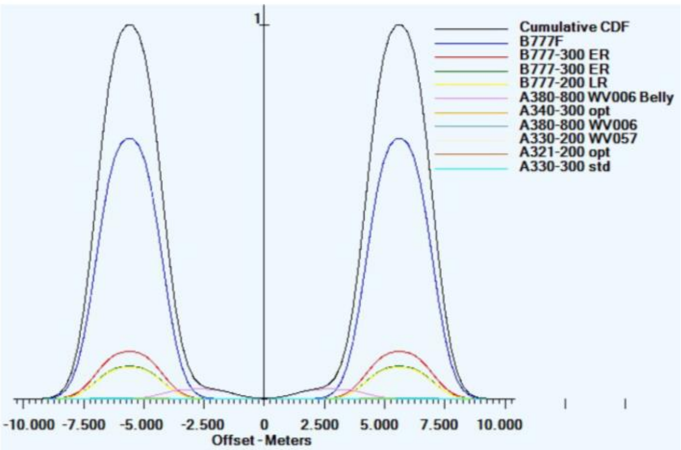


Figure 5. CDF Values in Case-II

Case-III

Aircraft weights, annual growth rates, and number of departures used in the coatings during the analysis are given in Table 2 as in Case-I. Furthermore, maximum contribution ratios and CDF values for each aircraft are presented (Table 10). On the other hand, P/C ratios for each aircraft type were obtained through analysis and calculated by the software. The A321neo with the highest weight of 97.4 t is considered in the analysis. The CDF contribution value for this aircraft was calculated as 0.91 and 0.05 for 783 and 39 annual departures, respectively (Table 10). On the other hand, the same values were obtained for CDF max for this aircraft. The P/C ratio values are 3.36 for both number of departures. A320-200std and B737-BBJ2 aircraft with the highest departure values were included in the calculations as 73.9 and 79.25 t, respectively. CDF contribution values are calculated as 0 and 0.02 for A320-200std and B737-BBJ2 aircraft, respectively. Moreover, CDF max contribution values are calculated as 0 and 0.02 for A320-200std and B737-BBJ2 aircraft, respectively. P/C ratio values are calculated as 3.7 and 3.53 for A320-200std and B737-BBJ2 aircraft, respectively (Table 10). Details of the subgrade compaction requirements for noncohesive soil are presented in Table 11. Table 11 shows the compaction values and depths of the superstructure and subgrade layers for noncohesive soil. For Case-III, the critical aircraft mobility was observed for the A321neo aircraft under the condition of noncohesive soil. For this aircraft, compaction depths of 0-406, 406-928, 928-2041, and 2041-3250 mm should be achieved for maximum dry density values of 100, 95, 90, and 85 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 95, 90, and 85 percent should be achieved at 0-29, 29-1142, and 1142-2352 mm respectively (Table 11). Details of the subgrade compaction requirements for cohesive soil are presented in Table 12. Table 12 shows the compaction values and depths of the superstructure and subgrade layers for cohesive soil. For Case-III, the critical aircraft mobility was observed for the A321neo aircraft for cohesive soil. For this aircraft, compaction depths of 0-393, 393-577, 577-1273, and 1273-1996 mm should be achieved for maximum dry density values of 95, 90, 85, and 80 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 85 and 80 percent should be achieved at 0-374 and 374-1097 mm respectively (Table 12). The CDF plot for Case-III is presented in the study as in Figure 6. From this graph, the fatigue effects of the aircraft on the runway pavement can be easily evaluated. When this situation is evaluated for Case-III, the highest fatigue effect will be observed with the A321neo aircraft, while the lowest fatigue effect will occur with the landing and take-off effect of the B737-400 aircraft (Figure 6).

Table 4. Airplane Departure CDF and P/C Ratio Results in Case-III

No.	Name	CDF Contribution	CDF Max for Airplane	P/C Ratio
1	A319-100 opt	0.00	0.00	3.66
2	A320-200 std	0.00	0.00	3.7
3	A321neo	0.91	0.91	3.36
4	A321neo	0.05	0.05	3.36
5	B737-400	0.00	0.00	3.52
6	B737-800	0.00	0.01	3.53
7	B737-700	0.00	0.00	3.68
8	B737 BBJ2	0.02	0.03	3.53
9	B737-900	0.00	0.01	3.53
10	B737-8/8-200/BBJ MAX 8	0.02	0.03	3.47
11	B737-9 MAX	0.00	0.01	3.39

Table 5. Subgrade Compaction Requirements for Noncohesive Soil Used in Case-III

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction
100	0 - 406	--	A321neo
95	406 - 928	0 - 29	A321neo
90	928 - 2041	29 - 1142	A321neo
85	2041 - 3250	1142 - 2352	A321neo

Table 6. Subgrade Compaction Requirements for Cohesive Soil Used in Case-III

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction
95	0 - 393	--	A321neo
90	393 - 577	--	A321neo
85	577 - 1273	0 - 374	A321neo
80	1273 - 1996	374 - 1097	A321neo

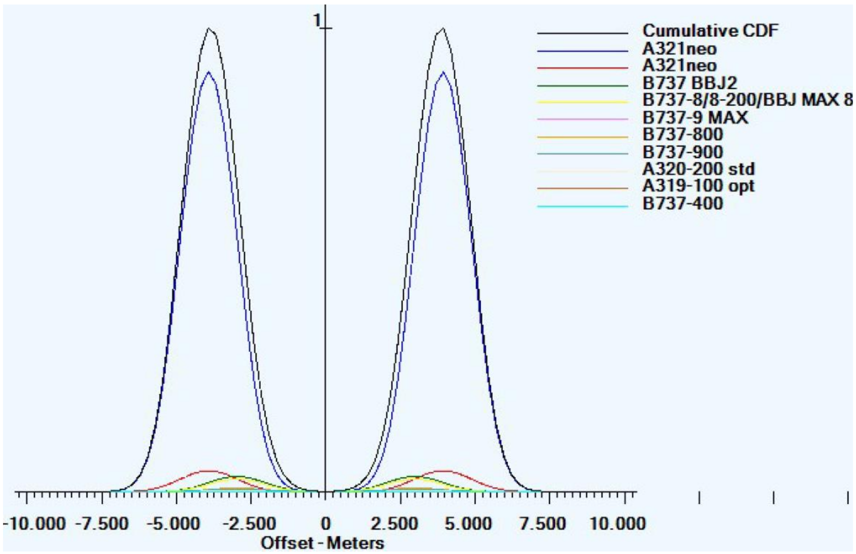


Figure 6. CDF Values in Case-III

Case-IV

Aircraft weights, annual growth rates, and number of departures used in the coatings during the analysis are given in Table 3 as in Case-II. Furthermore, maximum contribution ratios and CDF values for each aircraft are presented (Table 13). On the other hand, P/C ratios for each aircraft type were obtained through analysis and calculated by the software. The A380-800 WV006 and A380-800 WV006 Belly are the highest weight of 575 t is considered in the analysis. The CDF contribution value for these aircraft was calculated as 0 for 5000 annual departures for both airplanes, respectively (Table 13). On the other hand, the same values were obtained for CDF max for this aircraft. The P/C ratio values are 3.36 for both number of departures. A320-200std and B737-800 aircraft with the highest departure values were included in the calculations as 78.4 and 79.242 t, respectively. CDF contribution values are calculated as 0 and 0.02 for A320-200std and B737-800 aircraft, respectively. Moreover, CDF max values are calculated as 0 for A320-200std and B737-800 aircraft, respectively. P/C ratio values are calculated as 3.67 and 3.53 for A320-200std and B737-800 aircraft, respectively (Table 13). Details of the subgrade compaction requirements for noncohesive soil are presented in Table 14. Table 14 shows the compaction values and depths of the superstructure and subgrade layers for noncohesive soil. For Case-IV, the critical aircraft mobility was observed for the B777-300ER aircraft under the condition of noncohesive soil. For this aircraft, compaction depths of 0-486, 486-2618, and 2618-4597 mm should be achieved for maximum dry density values of 100, 95, and 90 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 95 and 90 percent should be achieved at 0-1664, and 1664-3644 mm respectively (Table 14). Details of the subgrade compaction requirements for cohesive soil are presented in Table 15. Table 15 shows the compaction values and depths of the superstructure and subgrade layers for cohesive soil. For Case-IV, critical aircraft mobility was observed for the B777-300ER aircraft for cohesive soil. For this aircraft, compaction depths of 0-467, 467-1795, 1795-3220, and 3220-4517 mm should be achieved for maximum dry density values of 95, 90, 85, and 80 percent from the pavement surface. For compaction depth from the top of the subgrade, maximum dry density values of 85 and 80 percent should be achieved at 0-842, 842-2267, and 2267-3653 mm respectively (Table 15).

Table 13. Airplane Departure CDF and P/C Ratio Results in Case-IV

No.	Name	CDF Contribution	CDF Max for Airplane	P/C Ratio
1	A319-100 opt	0.00	0.00	3.66
2	A320-200 opt	0.00	0.00	3.67
3	A321-200 opt	0.03	0.11	3.42
4	A300-600 Std Bogie	0.00	0.00	3.38
5	A310-200	0.00	0.00	3.69
6	A318-100 opt	0.00	0.00	3.65
7	A330-200 WV057	0.00	0.00	1.86
8	A330-300 WV022	0.00	0.00	1.87
9	A330-300 std	0.00	0.00	1.88
10	A340-300 opt	0.01	0.01	1.81
11	A340-300 opt Belly	0.00	0.00	3.78
12	B737-800	0.00	0.00	3.53
13	B737-300	0.00	0.00	3.8
14	B737-400	0.00	0.00	3.52
15	B737-500	0.00	0.00	3.82
16	B737-700	0.00	0.00	3.68
17	B757-200	0.00	0.00	3.92
18	B767-300 ER	0.00	0.00	3.63
19	B777-200 LR	0.11	0.11	3.86
20	B777-300 ER	0.17	0.17	3.84
21	B777F	0.55	0.55	3.86
22	B777-300 ER	0.12	0.12	3.84
23	A380-800 WV006	0.00	0.01	3.78
24	A380-800 WV006 Belly	0.00	0.02	4.2
25	MD-83	0.00	0.00	3.42

Table 7 Subgrade Compaction Requirements for Noncohesive Soil Used in Case-IV

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction
100	0 - 486	--	B777-300 ER
95	486 - 2618	0 - 1664	B777-300 ER
90	2618 - 4597	1664 - 3644	B777-300 ER

Table 8 Subgrade Compaction Requirements for Cohesive Soil Used in Case-IV

Percent Maximum Dry Density(%)	Depth of compaction from pavement surface (mm)	Depth of compaction from top of subgrade (mm)	Critical Airplane for Compaction

95	0 - 467	--	B777-300 ER
90	467 - 1795	0 - 842	B777-300 ER
85	1795 - 3220	842 - 2267	B777-300 ER
80	3220 - 4517	2267 - 3563	B777-300 ER

The CDF plot for Case-IV is presented in Figure 7. From this graph, the fatigue effects of the aircraft on the runway pavement can be easily evaluated. When this situation is evaluated for Case-IV, the highest fatigue effect will be observed with the B777F. In contrast, the lowest fatigue effect will occur with the landing and take-off effect of the A330-300std aircraft (Figure 7).

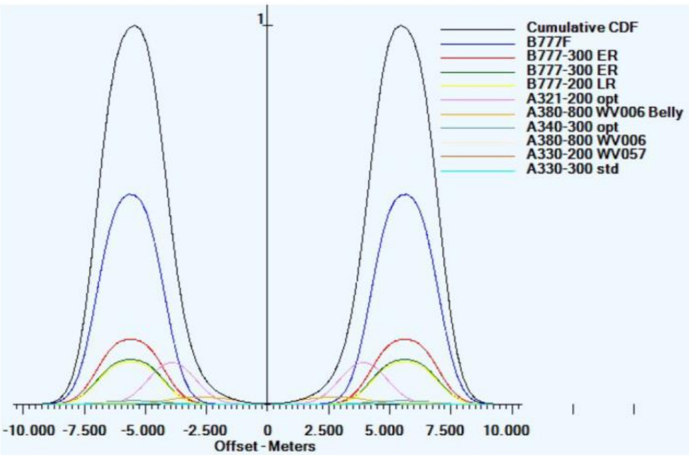


Figure 7. CDF Values in Case-IV

CONCLUSIONS

A summary of the results of the data obtained from the analysis of rigid pavement designs for airport runways under strong and weak soil conditions for low and high traffic airports with the FAARFIELD program is given below.

- For the low and high air traffic runway operating conditions examined in the study, the rigid pavement thickness for low traffic-low ground capacity is 351 mm, while the pavement thicknesses for high traffic-low ground capacity, low traffic-high ground capacity, and high traffic-high ground capacity are 459, 349 and 403 mm, respectively.
- Under low air traffic runway operating conditions, the CDF values obtained for the highest number of departures were calculated as 0.07 for the low soil strength condition.
- Under high density air traffic runway operating conditions, the CDF values obtained for the highest number of take-offs were calculated as 0 for the low soil strength condition.
- Under low air traffic runway operating conditions, the CDF values obtained for the highest number of take-offs were calculated as 0.03 for the high ground strength condition.
- Under runway operating conditions characterized by high air traffic, the CDF values obtained for the highest number of take-offs were calculated as 0 for the high soil strength condition.
- For low soil strength, the highest CDF values were 0.86 and 0.70 for runways operated with low and high air traffic, respectively.
- For high soil strength, the highest CDF values were 0.91 and 0.55 for runways operated with low and high air traffic, respectively.

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