Evaluation of Runway Pavement Design Software and Application of Modified Asphalt Overlay on Airfields

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ABSTRACT: Different software has been offered by aviation administrations and investigation institutions to facilitate runway pavement designs. In this paper, four generic runway design software including LEDFAA 1.3, PCASE 2.09, FAARFIELD 1.305 and TKUAPAV were aimed. Hereon, communal layer structures with particular characteristics along with a sample airport containing wide-body commercial and military aircrafts were introduced to each software and the thickness of the pavement was obtained. Afterwards the output from software was compared with each other. Results imply that PCASE 2.09 take account of more precise details and analyses of material and condition behaviour of the pavement design and as a result it leads to an economical design. While, FAARFIELD because of analysing pavements based on three-dimensional finite element method, makes the prediction behavior of the aircrafts loading on the runway pavement more realistic. Additionally, this article presents an overlay design scheme for runway pavements using FAARFIELD 1.305 combined with a method of thickness reduction previously applied on highways and commercial airports. The application of this methodology lead to 40 millimeters reduction of asphalt overlay.

Keywords: Pavement Design, Runway Overlay Design, Pavement Design Software, Commercial and Military Aircrafts

INTRODUCTION

The advent of new generation of modern common aircrafts, rapid growth of air travel demand, consistent and exact traffic laws and regulations for different phases of flight operations have made the airport to be considered as a complex and dynamic system. Runway pavements, which are the passageways of different aircrafts, are flexible, rigid, and composite. Because pavement system is directly subjected to the aircraft loads, pavement behavior and condition have a significant effect on fleet performance; therefore having an adequate pavement system considering all the designing circumstances is necessary (Esfandani et al., 2013). Airport pavements are designed and constructed to provide sufficient support from the loads inflicted by aircrafts and to produce a stiff, abiding, plain, all weather surface free from debris or other particles that may be blown or picked up by propeller wash or jet blast. The pavement must be of such quality and thickness that it will not fail under the load imposed. Moreover, it must encompass adequate consistency to tolerate, without damage, the grating operation of traffic, detrimental weather conditions, and other deteriorating actions. To construct such pavements involves a concordance of many agents of design, construction, and detection to assure the best possible combination of available materials and a high standard of

workmanship (Advisory Circular, 2009). In this regard, engineers use various pavement design software released by different countries from relevant administrations. The evaluation presented in this paper can be cited such as FAARFIELD 1.305, LEDFAA 1.3, PCASE 2.09 and TKUAPAV. Afterwards, factors affecting airport pavement thickness, software capabilities and results are compared technically and economically. The next phase of this study is related to designing an asphalt overlay for a proposed runway pavement. With the increase of take-off and landing airplanes, especially military airports in critical conditions, aging and deterioration of pavements require some type of treatment to provide a safe and serviceable facility for the users. The types of treatment can range from simple maintenance to complete reconstruction, depending on the circumstances. For pavements exposed to moderate and heavy traffic, the most prevalent treatment is to place an overlay on the existing pavement. This article utilizes an overlay design procedure based on FAARFIELD 1.305 combined with a method of thickness reduction previously applied on highways and commercial airports.

MATERIAL AND METHODS

In this research, to assess the output presented by each software and compare their results, similar mixed

traffic assumption accompanied with pavement materials are introduced to each software and the thickness obtained are compared in tables and diagrams.

Traffic Assumptions of the Airport

Application of the latest version of the software is considered to design an airport adequate for military airport purposes. Initially a list of military and wide-body aircrafts which are common in the library of the software are chosen (Table 1). For this objective, each gear assembly group has been appointed the representative aircraft for that group. Traffic volume and pavement design life are substantial inputs to the pavement design

procedure. Minimum design life for military crops and commercial facilities is 20 years. Basically, aircraft departures are included as passes in pavement thickness design. Therefore, when site-specific traffic projections are not available such as this case, the traffic levels recommended from Unified Facilities Criteria (UFC) (Pavement Design for Airfields, 2008) are the minimum pass levels to be used in design. Moreover, for the rest of the aircrafts the default pass level of 1200 assumed by the software is considered. As a result, assuming with a 5% of flight annual growth, the complex traffic are described in Table 1.

Table 1. Traffic Assumptions

Total Departures	Annual Growth %	Annual Departure	Tire Pressure (kPa)	Gross weight (tns)	Aircraft
300,000	5	10,000	2334	30.844	F-15C
100.000	5	3334	1310	64.41	P-3
50,000	5	1668	724	70.307	C-130
25,000	5	834	1310	156.489	C-141
25,000	5	834	731	348.13	C-5
36,000	5	1200	951	265.352	C-17A
36,000	5	1200	1600	334.751	B747-100SF
36,000	5	1200	1358	591.995	A380-800 F
36,000	5	1200	1524	352.441	B777-300 ER
36,000	5	1200	530	171	IL76T
36,000	5	1200	1220	264.444	KC-10
36,000	5	1200	1055	264.444	KC-10 Belly

Layer Structure and Material Assumption

After determining the traffic assumptions of the airport, it is necessary to specify material and structural information to design flexible or rigid runway pavement. Accordingly, these assumptions are as follow:

• According to Table 2, the flexible pavement system is consisted of four layers of Asphalt Concrete, Stabilized Flexible Base (existence of aircrafts weighing more than 45,500 kg according to AC-150/5320-6E), Crushed Aggregate Subbase and natural subgrade with CBR= 10%.

• Table 3 specifies the rigid pavement system comprised of Portland Cement Concrete, Cement Treated Base (existence of aircrafts weighing more than 45,500 kg), Crushed aggregate sub-base and natural subgrade with foundation modulus (k)= 38.38 MN/m3.

Table 2. Layer Structure and Material Assumptions for Flexible Pavement Design

Type of layer	Modulus (MPa)	Poisson's Ratio
Asphalt Concrete	1378.95	0.35
Stabilized Base	2757.90	0.35
Subbase Cr Ag	368.04	0.35
Natural Subgrade	103.42	0.35

Table 3. Layer Structure and Material Assumptions for Rigid Pavement Design

Type of layer	Modulus (MPa)	Poisson's Ratio
Portland Cement Concrete	27579.03	0.15
Stabilized Base	3447.38	0.20
Subbase Cr Ag	244.27	0.35
Natural Subgrade	103.42	0.40

It should be stated that, in software FAARFIELD and LEDFAA the modulus value of materials are generated automatically and cannot be modified. Furthermore, the calculation of subgrade modulus for flexible pavement design is calculated as equation 1 (US Army and Airforce, 1989):

$$E_{SG} = 1500 * CBR \qquad (1)$$

Where:

E_{SG} = Subgrade Modulus (Psi)

This method is based on flexible pavement design method and is required to determine the CBR value for the subgrade soil. In addition, in order to design rigid runway pavement whenever high reliability is required, equation 2 is used to calculate foundation modulus of the subgrade.

$$E_{SG} = 26k^{1.284}; \quad k = \left[\frac{1500 \times CBR}{26}\right]^{0.778} \qquad (2)$$

In this equation:

E_{SG} = Subgrade Modulus (psi)

k= Foundation Modulus of subgrade soil (Psi)

Conventional Software in Designing Runway Pavements

In this section, software that is chosen for runway pavement design is described and their bases of application are evaluated.

FAARFIELD 1.305 Software: Federal Aviation Administration Rigid and Flexible Iterative Layered Elastic Design is a computer program for airport pavement thickness design. It implements both layered elastic based and three-dimensional finite element-based design procedures developed by the Federal Aviation Administration (FAA) for new and overlay design of flexible and rigid pavements. The thickness design procedures implemented in the program are the FAA airport pavement thickness design standards referenced in Advisory Circular (AC) 150/5320-6E (FAARFIELD User's Manual, 2009).

LEDFAA 1.3 Software: Layered Elastic Design Federal Aviation Administration is a computer program for airport pavement thickness design. It implements layered elastic theory based design procedures developed under the sponsorship of the Federal Aviation Administration (FAA) for new and overlay design of flexible and rigid pavements. The layered elastic procedures, as implemented in the program, are the FAA airport pavement thickness design standards referenced in Chapter 7 of Advisory Circular AC 150/5320-6D. (LEDFAA User's Manual, 2005).

PCASE 2.09 Software: Pavement-Transportation Computer Assisted Structural Engineering software is produced by the U.S. Army Corps of Engineers association and the 2009 version of this software is the latest one which has become available for public use since 2005 (Wells Walker and Adolf Mary, 2010) PCASE software has the ability to design and evaluate flexible and rigid road and airport pavement based on empirical methods of K, CBR, and analytical method of LED. This software has collected all evaluation and design criteria and benchmarks of road and airport in a collection.

TKUAPAV Software: Tamkang University Airfield Pavement is the software to design airport rigid pavements thickness. TKUAPAV was developed at Tamkang University in Taiwan by Shao-Tang Yen under the supervision of professor York Ying-Haur. This software is used to design airport rigid pavement based on the theory of Westergaard page and in choosing the airplanes, based on the list of available airplanes in LEDFAA program. This program was manufactured in 2002.

Design Process of the Software

The design procedure in most software is mainly similar. First of all, the mixed traffic along with their pass levels are selected, afterwards the pavement materials are specified and design process is accomplished based on the cumulative damage factor of each airplane to the extent that cumulative value of this factor is equal to one. This ratio represents the pavement failure rate and is dependent on many factors such as aircraft weight, wheel placement, the percentage of aircraft weight on the main wheels, axles distance, and pavement type. Cumulative damage factor refers to the amount of the structural fatigue life of a pavement which has been utilized. It is expressed as the ratio of applied load repetitions to allowable load repetitions to failure, or, for one airplane and constant annual departures (FAARFIELD User's Manual, 2009):

$$CDF = \frac{Number\ of\ applied\ load\ reperirions}{number\ of\ allowable\ repetitions\ to\ failure}$$
$$= \frac{(annual\ departures)\times(life\ in\ years)}{(pass/coverage\ ratio)\ \times(coverages\ to\ failure)} = \frac{applied\ coverages}{coverages\ to\ failure}$$

Coverage: The number of times the aircraft passes unit area of flight path, one wheel of a plane main wheels that passes through it.

Pass: The distance a plane passes to the loading location until it flies or the distance from where the aircraft touches the ground to the discharge site.

The CDF value ranges from zero to one and it splits among the planes in the mix traffic list in a cumulative manner and each aircraft contributes to this amount. This factor indicates the amount of damage caused by complex traffic on the pavement.

When CDF = 1,

the pavement will have used up all of its fatigue life.

When CDF < 1, the pavement will have some life remaining, and the value of CDF will give the fraction of the life used.

When CDF > 1, all of the fatigue life will have been used up and the pavement will have failed.

In these definitions, failure means failure in a particular structural failure mode according to the assumptions and definitions on which the design procedures are based. A value of CDF greater than one does not necessarily mean that the pavement will no longer support traffic, but that it will have failed based on the signification of failure in the design procedure, and within the constraints of uncertainties in material property assumptions, etc. Nevertheless, according to the thickness design assumption failure occurs when CDF = 1.

Multiple airplane types are calculated for by using Miner's Rule instead of the "Design Airplane" concept as in the current procedures, or:

CDF= CDF1 + CDF2 + CDF3 + … + CDFN   (3)

Where CDFI is the CDF for each airplane type in the mix and N is the number of airplane types in the mix.

CONCLUSION AND DISCUSSION

Based on the traffic and material assumptions mentioned in Section 2, the airport runway design for both flexible and rigid pavement system is undertaken by each software and the results and thickness of each layer are provided in the following tables.

Tables 4 and 5 represent layer thicknesses obtained from FAARFIELD. Total pavement thicknesses obtained for flexible and rigid pavement are 706.7 mm and 750.6 mm respectively.

Table 4. Results of the Flexible Design Using FAARFIELD Software

Layer Type	AC	Stabilized Base	Subbase Cr Ag	Total Thickness
Thickness (mm)	127	280.7	299	706.7

Table 5. Results of the Rigid Design Using FAARFIELD Software

Layer Type	PCC	CTB Base	Subbase Cr Ag	Total Thickness
Thickness (mm)	445.8	152.4	152.4	750.6

Likewise, the total thickness of flexible pavement system and the total thickness of rigid pavement system are 742.5 mm and 717.2 mm, respectively from LEDFAA software.

Table 6. Results of the Flexible Design Using LEDFAA Software

Layer Type	AC	Stabilized Base	Subbase Cr Ag	Total Thickness
Thickness (mm)	127	203.2	412.3	742.5

Table 7. Results of the Rigid Design Using LEDFAA Software

Layer Type	PCC	CTB Base	Subbase Cr Ag	Total Thickness
Thickness (mm)	412.4	152.4	152.4	717.2

In Figure 1, layer structures and material of flexible pavement design of runway using PCASE 2.09 software is illustrated. As noted, surface concrete asphalt layer thickness is selected 127 mm by default. After design processes, the underneath layer thicknesses of base and subbase are 229 mm and 257 mm. In runway pavement design using LED method, thickness of surface is selected by default and the design is done based on the underneath layers by the software. The final thickness of flexible pavement is 613 mm by PCASE software.

Similarly in Figure 2, characteristics and layer materials in rigid pavement design are shown by PCASE software.

As pictured in Figure 2, the dense basis layer thickness is equal to 152 mm and the subbase layer thickness is equal to 152 mm which are selected by default. After design phases, surface concrete thickness is obtained as 399 mm. The runway rigid pavement design based on LED method and base and subbase layers thicknesses are selected by default and the design is performed based on surface concrete slab thickness by the software. The final thickness of runway rigid pavement is obtained 703 mm by PCASE software.

In addition, runway rigid pavement design is performed by TKUAPAV software. In the software there is no possibility to create base or subbase layers and the software has only considered the natural properties, modulus of elasticity, and flexural strength of concrete in the assumptions section. Based on these data and the given traffic data, the thickness of the surface concrete slab is calculated by the software. This has been done for the sample airport with the mentioned assumptions and the results are shown in Figure 3.

As displayed in Figure 3, the coefficient of modulus of subgrade reaction resilience for rigid pavement is assumed as 38.38 KPa/mm and according to this value; the concrete slab thickness is obtained as 516 mm.

**Figure 1.** Layer Structure and Materials in Flexible Pavement Design by PCASE Software

Figure 2. Layer Structure and Materials in Rigid Pavement Design by PCASE Software
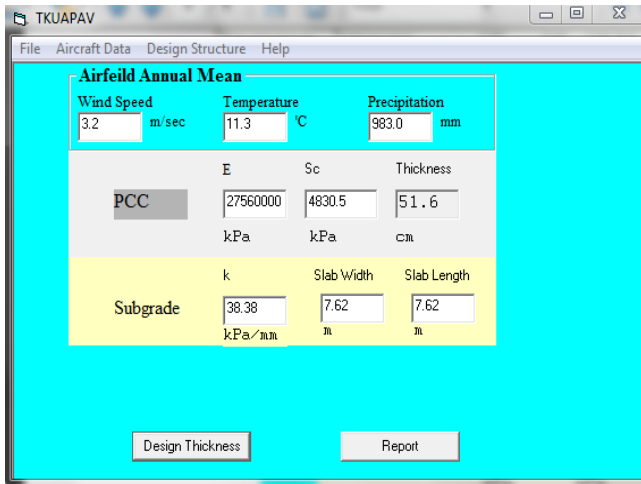
Figure 3. Runway Rigid Pavement Design by TKUAPAV Software

Comparison of Software Results

After running the runway pavement design of the sample airport with the same traffic and layer material assumptions, the acquired results from each software for flexible and rigid pavement are compared and the results of total pavement thickness design is illustrated in Figure 4.
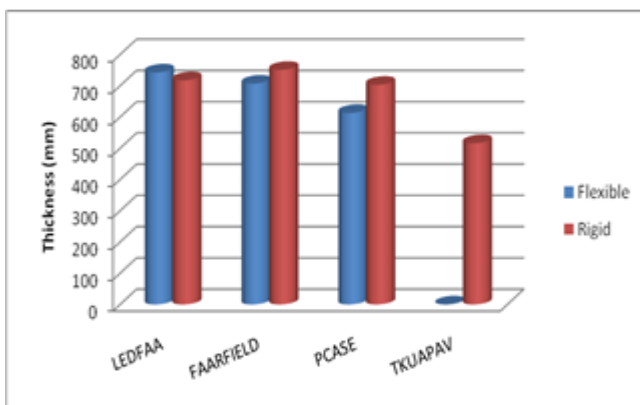
Figure 4. Comparison of Runway Pavement Design Results

As shown in Figure 4, the total thickness attained by PCASE 2.09 is notably lower than the other pieces of software. The results obtained from FAARFIELD 1.305 and LEDFAA 1.3 are approximately equal to each other but a shade of difference exists between the flexible and rigid thickness. Moreover, the result from TKUAPAV software shows much less thickness of the rigid pavement system. This software, however only calculates the concrete slab thickness and the base and subbase layers are not considered in the design process. In case of assuming equal under layer thickness, the overall thickness attained from this software is significantly higher than that from the other software. In regards to FAARFIELD and LEDFAA software, it should be noted that the overall thickness obtained in flexible pavement design have 35.8 mm difference, meaning that the overall

thickness obtained by FAARFIELD is less than LEDFAA software. On the other hand, the overall thickness obtained in rigid pavement design by FAARFIELD is 33.4 mm more than LEDFAA software. This is while both software are programmed in compliance with the Advisory Circular regulations and definitions of traffic loads and materials are similar in the database of the software. Therefore, the main reason for this difference could be attributed to the method of pavement layer analyses of software. As previously mentioned, the design process of both software is based on elastic layer theory thus, the core of the FAARFIELD program is a structural response module consisting of two programs, LEAF and NIKE3D. LEAF is a layered elastic computational program and NIKE3D is a three-dimensional finite element (3D-FE) analysis program and linked to the main program through a dynamic-link library. Therefore, FAARFIELD software because of having finite element analysis for flexible pavements shows more precise pavement modeled behavior (Gomez-Ramirez and Thompson, 2002).

Additionally, TKUAPAV software is programmed based on Westergaard's plate theory. In the 1970's this method of rigid pavement analysis approach showed its limitations, for instance:

- F-15E fighter had 2300 kPa tire pressure and this was causing damage to some pavements

- The effect of complex 3 leg main gear on the commercial DC-10 and the military variant, the KC-10 air refueling tanker, was of concern.

- The Westergaard models could not handle stabilized layers.

Eventually, the overall thickness obtained from TKUAPAV software is 516 mm for the concrete slab of the sample airport which by comparison to the other software is significantly higher.

However, it is tried to consider design parameters such as design period, type of traffic, number of flights per year, annual growth in flights and characteristics of pavement layers constant in every software, there are some differences. The causes of the difference can be related to differences in a series of assumptions available in the software such as the weight of aircrafts and initial definitions of base and underneath layers.

Application of Software for Rehabilitation and Overlay Design of Runway Pavement

Some conventional runway design software are able to evaluate the pavement but do not have the ability to design runway pavements and some not only have the ability to evaluate but also, have the capability to design pavement systems and overlays for instance FAARFIELD and LEDFAA. Depending on the types of overlay and existing pavement, four possible overlay designs may serve: HMA overlays on asphalt pavements, HMA

overlays on PCC pavements, PCC overlays on asphalt pavements, and PCC overlays on PCC pavements. In this research, a conventional HMA overlay and modified HMA overlay design on PCC pavement will be assessed and compared in a case example.

In the field of aviation, and more specifically that of airport pavements, the design methods of the Federal Aviation Administration are deeply specified. The Advisory Circular offers the latest version of the design for new pavements and the rehabilitation of existing ones. Unfortunately, it does not clearly consider bituminous mixes with asphalt rubber in the special techniques for prevention of reflection cracking. Thus, it is not easy to apply thickness reductions to airport overlays as there is no existing methodology specifically designed for runway pavements that focuses on the resistance to reflection cracking offered by asphalt rubber mixes (Gallego et al., 2012). However, it has been clearly demonstrated that the resistance to aging and cracking are greater in asphalt rubber mixes, including in airport pavements (Saboundjian et al., 2004). This paper proposes that a method normally employed for the rehabilitation of highway pavements and commercial airports be applied to military airport pavements. Eventually, using related models provided in this field and the overlay thickness attained from FAARDIELD software, will lead to an overlay thickness reduction.

As previously mentioned, in addition to layer structure information, mixed traffic assumptions must be defined. Basically, designing an overlay on an existing flexible or rigid pavement system is very similar to designing a new pavement. The existing flexible or rigid pavement is defined by allocated the appropriate thicknesses and modulus of the existing layers.

Example: Conventional Asphalt Overlay Design for Runway Pavement Rehabilitation

Assume that a rigid pavement system requires rehabilitation after 20 years of service and has a homogenous profile. The following section is specified as follow:

- 40 cm of PCC slab, with flexural strength equal to 4.83 Mpa
- 15cm of crushed aggregate base with a modulus of 324 Mpa
- 15 cm of uncrushed aggregate subbase with a modulus of 157 Mpa
- Modulus of subgrade reaction equal to 38.4 MN/m^3

Stabilized layers were excluded so that the results could be explicitly compared. An undefined layer will be chosen as the overlay with an elasticity modulus of 2800 Mpa at 20° C (Saboundjian et al, 2004). As this is not a standard FAA material, the FAARFIELD results displayed a "non-standard structure" warning. As for the

structural state of the sample airport, the CDFU was established at 100, as the airport opened to traffic 20 years ago. This is a conservative hypothesis as it supposes that the pavement has consumed 100% of the structural life for which it was designed.

It is also assumed that a high percentage of the slabs, around 50%, exhibited structural cracks, although the state of the pavement is acceptable and its main problem is surface regularity. From this data, its SCI is estimated to be around 80.

With the application of the mixed traffic from the previous sections and assuming a 20 year design life for the asphalt overlay, the results show an overlay thickness of 148.7 mm as figure 5.
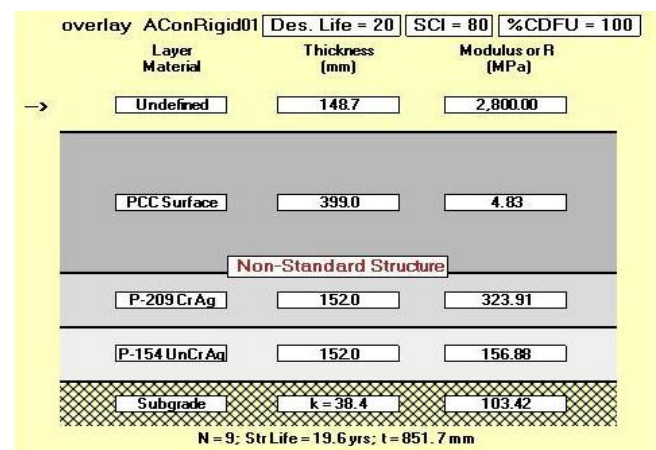

Figure 5. Existing Pavement and the Overlay Thickness Calculation

The Advisory Circular notes that reflection cracking is often a problem in hot mix asphalt overlays, particularly in rigid pavement overlays. The thickness generated by FAARFIELD, however, does not address reflection cracking. The AC suggests several techniques that have been tested in an attempt to address this problem, to varying degrees of success: coarse aggregate binders, rubblization of the existing PCC pavement, engineering fabrics, asphalt reinforcement with high tensile strength and low strain capacity, etc. (Advisory Circular, 2009). Therefore, this paper recommends the application of a highway-based method to reduce the thickness of the asphalt mix overlay in order to properly control the problem of reflective cracking.

Example: Asphalt Rubber Modified Overlay Design for Runway Rehabilitation

In order to utilize the suggested model, additional information is required. Assuming that the sample airport is located at Imam Khomeini International Airport (IKIA), Tehran, IRAN in terms of similar weather, the necessary details are as follows:

- Cracking at the end of life: 5%
- Maximum air temperature: 44.4° C (Meteorolgical Organization of IRAN, 2013)

- Mean monthly air temperature: -8° C
- PCC moduli: 27500 Mpa
- Slab thickness: 40 cm
- Granular layer elastic modulus: 324 Mpa
- Granular layer thickness: 30 cm
- Subgrade elastic modulus: 103.4 Mpa

Figure 6 demonstrates the results obtained by this method. It can be observed that the approximate thickness of 149 mm of conventional mixes, generated by the FAARFIELD program, is equivalent to 108 mm of mixes with asphalt rubber.
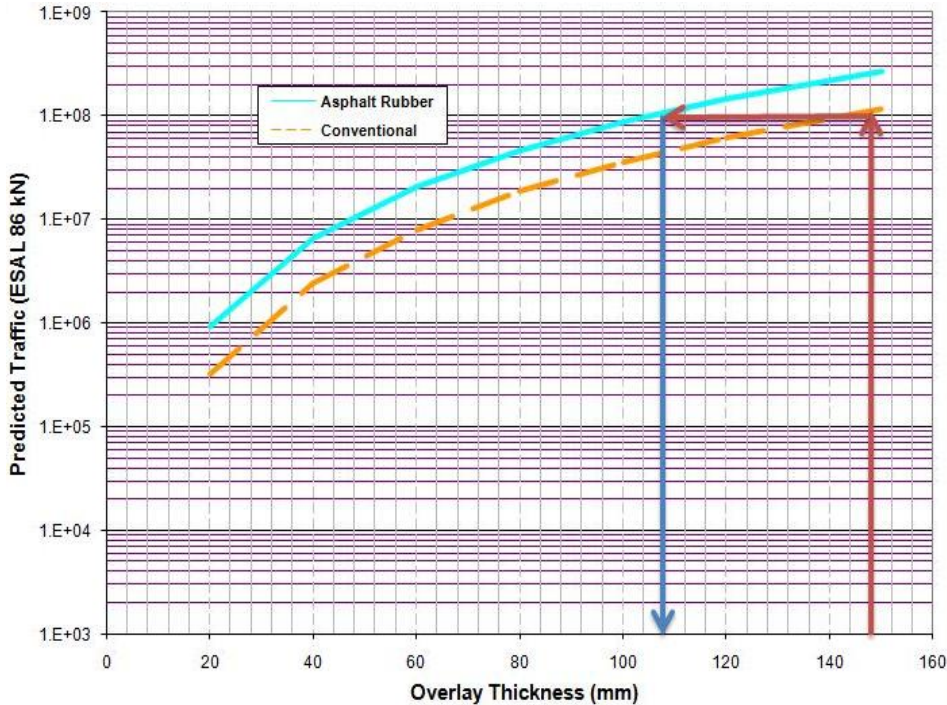
Figure 6. Thickness equivalent of overlay with conventional and asphalt rubber mixes

With regards to controlling reflection cracking, a 149 mm overlay of conventional bituminous mixes would offer the same protection to the pavement as 108 mm of gap-graded asphalt rubber mixes. Nonetheless, this method has limitations such as:

- It is a highway-based method, calibrated on the basis of highway observations
- Vehicles have an equivalent single axle load (ESAL) of 86 kN. It is obvious that the loads transmitted to pavements by aircraft are much higher, especially in the case of wide-body aircrafts.

CONCLUSION

As stated earlier, the PCASE 2.09 flexible and rigid pavement designs were significantly thinner than the other software. In addition, this software has the ability of defining precise details of material characteristics. Therefore, it leads to a more economical design. However, it has the ability to evaluate and design the pavement system and cannot analyse it; whereas, FAARFIELD and LEDFAA software in addition to pavement evaluation and design, have the ability to analyse the pavement system.

FAARFIELD analyses the pavement system with 3D finite element method which shows more precise pavement modelled behavior. Based on the results of the issued field experiments and reports, behavior of the pavement designed by this software is more realistic (Gomez-Ramirez and Thompson, 2002).

Moreover, in FAARFIELD and LEDFAA software the load of the KC-10 aircraft is mentioned twice in the mixed traffic assumptions due to the type of gear assembly (KC-10 and KC-10 Belly); so that this matter will increase the number of pass levels of the fleet and eventually increases the cumulative damage factor and subsequently generates a thicker design. FAARFIELD uses all wheels of the aircraft to calculate the maximum subgrade strain, whereas, some software use single wheel group loadings because there is not yet any evidence that interaction between groups of wheels increases or decreases pavement life (Wardle and Roadway, 2010).

All mentioned software has the ability of pavement design with elastic layer method, while TKUAPAV is software programmed based in Westergaard's plate theory. This software has the ability to design a rigid concrete slab of pavement with natural conditions such as wind speed, temperature and precipitation. The thickness design obtained from this software is significantly thicker than the rigid pavement design of the other software. In the 1970's Westergaard's method of rigid pavement analyses showed its limitations and was substituted by layer elastic

method. Among other capabilities of FAA software is to design an overlay on an existing pavement based on elastic layer method, whereas PCASE 2.09 overlay design is based on empirical CBR method. A method was proposed, based on the FAARFIELD program and on a method used for highway pavements, for the estimation of reduced thickness overlays in airport pavements with asphalt rubber and for controlling the phenomenon of reflection cracking. The use of asphalt rubber mixed lead to a 40 mm reduction of overlay thickness for a proposed airport.

It is worth mentioning that the results presented in this paper are based on a case study and to generalize the results more samples and implementation of various structural and traffic conditions are necessary. In conclusion FAARFIELD 1.305 and LEDFAA 1.3 provide conservative designs compared to PCASE 2.09 software and results obtained from FAARFIELD are more realistic.

In the long run, this paper represented the importance of research on using rubber modified asphalt for overlay designs especially on airfields. It is clearly critical to continue this research in order to calibrate the procedure for thickness reduction of asphalt rubber overlays for application to military airport pavements.

REFERENCES

Advisory Circular AC-150/5320-6E (2009). Airport Pavement Design and Evaluation, Federal Aviation Administration, U.S. Department of Transportation.

Esfandani, M.T, Mansourian, A. and Babai A. (2013). Investigation of Runway Pavement Design Software and Determination of Optimization Softwar,. Journal of Basic and Applied Scientific Research, TextRoad Publication 3(4)143-150.

FAARFIELD User's Manual (2009). Federal Aviation Administration.

Gallego J, Sierra J and Perez I (2012). Design of asphalt rubber overlays for pcc pavements in airport runways, The case of the airport of Vitoria, Spain, Asphalt Rubber Conference. Munich, Germany.

Gomez-Ramirez FM and Thompson MR (2002). Characterizing Aircraft Multi Wheel Load Interaction for Airport Flexible Pavement Design, Civil Engineering Studies, COE Report, University of Illinois at Urbana-Champaign.

LEDFAA User's Manual (2005). Federal Aviation Administration.

Meteorolgical Organization of IRAN (2013). Available: http://www.tehranmet.ir/. [Accessed 5 February 2015].

Pavement Design for Airfields (2008). UFC (Unified Facilities Criteria), 3-260-02.

Saboundjian S, Knopke T and Raad L (2004). Field Aging Effects of Asphalt Rubber Mixes and Conventional Mixes for Runway Surface Applications, FAA Worldwide Airport Technology Transfer Conference, Atlantic City, New Jersey.

US Army and Airforce (1989). Flexible Pavement Design for Airfields, (Elastic Layer Method), Technical Manual, TM 5-825-2-1/AFM88.

Wardle L, and Roadway B (2010). Advanced Design of Flexible Aircraft Pavements, 24th ARRB Conference – Building on 50 years of road and transport research, Melbourne, Australia.

Wells Walker RS and Adolf Mary J (2010). PCASE User Manual, Transportation Systems Center and Engineering Research and Development Center.