Effect of Taxiway Configuration on the Design and Structural Life of Overlay over Runway Flexible Pavement

Swopnil Kalika
Department of Civil Engineering
Pulchowk Campus, Tribhuvan University
Lalitpur, Nepal
swopnilkalika@gmail.com

Guru Datta Adhikari
Realpath Engineering Consultancy Pvt. Ltd.
Lalitpur, Nepal
guru@realpath.com.np

***Abstract*—This paper aims to study the effect of centrally located exit taxiway vs. parallel taxiway configuration on the design and structural life evaluation of overlay over runway flexible pavement. We utilize the layered elastic design model with cumulative damage factor method implemented in the widely accepted FAARFIELD software for pavement design and evaluation. The aircraft fleet mix similar to that of Dhangadhi Airport has been adopted and aircrafts like ATR-72 and Xian MA-60 not present in the FAARFIELD library were added in the external library. Eighty one pavement samples with varying subgrade and layer properties were generated for design and evaluation for central vs. parallel taxiway configuration. It was found that the structural life of the runway pavement is 1.56 to 1.57 times greater in case of parallel taxiway than that of the central taxiway configuration for identical overlay design. Also, the required overlay thickness was found to be 5 to 18% lesser for parallel taxiway configuration than that of the central taxiway configuration. This result is expected to have significance in airside configuration planning and economic analysis of airport pavements.**

***Index Terms*—Airport Pavement, Structural life, Taxiway configuration, FAARFIELD, Aircraft Library.**

I. Introduction

A. Background

Most of the Nepalese airports have centrally located exit taxiway configuration (hereafter referred to as ”central taxiway”) and even among the few airports with parallel taxiway (e.g. Tribhuvan International Airport (TIA), Nepalgunj Airport and Biratnagar Airport) the taxiway is only partial, covering less than or about half the length of the runway. This is mainly due to unavailability of additional land and to avoid additional construction and maintenance cost of the parallel taxiway pavement. While this results in decreased runway capacity due to higher runway occupancy time, it does not cause appreciable loss for most of the domestic airports as they are rarely operating at peak capacity. However, full parallel taxiway could really prove to be beneficial for TIA which is operating at a high demand to capacity ratio with a single runway. While this aspect of the taxiway configuration is widely realized, its effect in runway pavement design and evaluation may remain unappreciated.

Firstly, it is important to understand how a single aircraft operation (arrival or departure) is regarded in runway pavement design. Federal Aviation Administration Rigid and Flexible Iterative Elastic Layered Design (FAARFIELD), the software used for airfield pavement design, only considers departures and ignores the arrival traffic when determining the number of aircraft passes. This is because in most cases aircrafts land at an airport at a significantly lower weight than at takeoff due to fuel consumption. Moreover, during touchdown, remaining lift on the wings and the landing gear shock absorber alleviates most of the dynamic vertical force that is transmitted to the pavement through the landing gears.

This means that for designing runway pavement, the user needs to input annual departures of all the aircrafts in the fleet mix in FAARFIELD. However, in case of central taxiway, an aircraft is required to taxi through a large part of the runway during the taxi movement itself (as shown in Fig. 2). In this condition, the aircraft must travel along the pavement more than once for a single departure operation. In other words, there are two passes of an aircraft with maximum load stress on the same area of the runway pavement for a single departure operation. In terms of runway pavement life, an operation counted as a single departure is actually equivalent to two departures for runway with central taxiway. It is evident that only about half of the runway is used during the taxi operations, but it is recommended to adopt a conservative stance in airfield pavement design by designing for the weakest section of the runway. Also, the structural pavement life is customarily evaluated for the weakest section. Therefore, for design and evaluation of runway pavement with central taxiway, the annual departures of all the aircrafts in the fleet mix must be multiplied by two before entering in FAARFIELD.

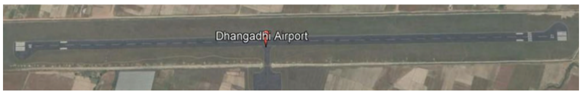

Fig. 1. Dhangadhi Airport with Central Taxiway Configuration.

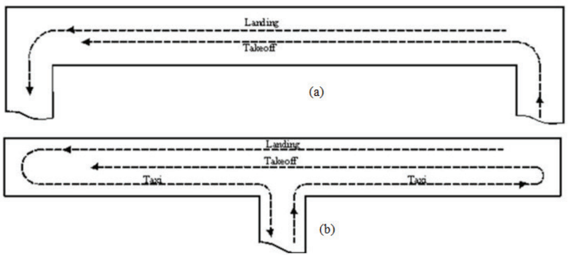

Fig. 2. (a) Parallel Taxiway Configuration vs. (b) Central Taxiway Configuration.

B. FAARFIELD

FAARFIELD, the airport pavement design software by Federal Aviation Administration (FAA), marks a remarkable difference in pavement design concept by introducing layered elastic design in place of the previous California Bearing Ratio (CBR) method and Cumulative Damage Factor (CDF) method instead of the previous Design Aircraft method. This software is widely used worldwide, recommended by International Civil Aviation Organization (ICAO) and is also the preferred procedure of airport pavement design in Nepal. FAARFIELD v1.42 is a mechanistic-empirical design software that evaluates pavement failure contribution due to each aircraft in the fleet mix in terms of a CDF using Miners rule. CDF is the amount of the structural fatigue life of a pavement that has been used up. It is expressed as the ratio of applied load repetitions to allowable load repetitions to failure.

- 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.

Here, 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 according to the definition of failure used in the design procedure, and within the constraints of uncertainties in material property assumptions. The thickness design is based on the assumption that failure occurs when CDF = 1. Multiple aircraft types are accounted for by using Miner's Rule:

$$CDF = CDF_1 + CDF_2 + ...CDF_n \tag{1}$$

Where, CDF_1, CDF_2 and so on represent the CDF for each aircraft type in the mix and n is the number of aircraft types in the mix. FAARFIELD computes a separate CDF for each failure mode included in the design procedure. In flexible pavement design, the thickness is adjusted to make the CDF for subgrade failure equal to 1. An additional computation is then made to find the CDF for asphalt fatigue cracking. If the asphalt CDF is found to be less than 1, the asphalt is predicted not to fail in cracking before the subgrade fails. But if the asphalt CDF is greater than 1, the asphalt is predicted to fail before the subgrade, and adjustments should be made to base and subbase layers so that asphalt CDF is less than 1 in the final design.

Various pavement layers as introduced in [1] and specified in [3] are included in the software. Some of which are given below with their relevant properties in the parenthesis.

- P-401: Hot Mix Asphalt surface course (layer thickness in mm and elastic modulus in MPa)
- P-209: Crushed aggregate base course (layer thickness in mm and elastic modulus in MPa)
- P-154: Aggregate base/ sub-base course (layer thickness in mm and elastic modulus in MPa)
- Subgrade (CBR in %, also represented in terms of elastic modulus in MPa)

The software includes a large library of aircrafts that could be added in the design fleet mix and its properties like gross weight, generally understood as its Maximum Take-off Weight (MTOW), number of annual departures and percent annual growth can be entered by the user. Annual Departures field is defined as the number of annual departures for the selected aircraft at the start of the pavements design life before any annual growth has been applied. Percent annual growth is defined as the percent change in annual departures per year over the design life of the pavement. Negative values represent a decrease in annual departures. Other properties like tire pressure, gear configuration and Pass-to-Coverage ratio are either taken from its internal library or calculated based on the user input. For aircrafts not present in the software library, they can be added in the file FAAaircraftLibrary.xml (in US units only) based on the manufacturers information and the users understanding of the following aircraft properties:

- GrossWt: Aircraft gross weight (lbs)
- MGpcnt: Percent of aircraft gross weight on main gear
- CP: Tire contact pressure, psi
- Gear: Gear designation letter code
- IGear: Gear identifier number
- TT, TS, TG, B: Gear geometric parameters
- NTires: Number of tires in 1 gear
- TX, TY: 1 pair of coordinates for each tire (1 through NTires), inches
- NEVPTS: Number of evaluation points for layered elastic strain or stress

- EVPTX, EVPTY: 1 pair of x,y coordinates for each evaluation point (1 through NEVPTS), inches

II. Methodology

For this study, aircraft fleet mix similar to that of Dhangadhi airport (DHI) has been selected. A range of subgrade and pavement layer properties have been selected to compose various pavement sections. It is worth noting that these sample pavement sections do not represent the actual pavement composition of DHI or any other airport. All possible combinations of the following four sets of pavement characteristics were generated to obtain various samples of pavement features. A total of 3ˆ4 = 81 combinations were obtained from among the following four sets of associated attributes:

- CBR = {3, 5, 6} (in %)
- P-154 = {230, 280, 300} (in mm)
- P-209 = {150, 180, 200} (in mm)
- P-401 = {50, 75, 100} (in mm)

The aircraft movement data of DHI for the recent years 2017 and 2018 was collected and total annual departures for all aircrafts in the fleet mix was calculated. Year 2018 data was used for design and evaluation purposes and the 2017 data was used to obtain the annual growth rate of departure movement of all the aircrafts. From among the adopted aircraft fleet mix, CRJ-700 and CRJ-200 are available in the internal library of FAARFIELD while the characteristics of ATR-72 and Xian MA-60 were added in the external XML library based on the aircraft flight manual and other sources [6]. The adopted aircraft departure data is presented in Table I.

TABLE I
Adopted Aircraft Departure Data

Aircrafts	Annual Departures		Annual Growth Rate
	for Parallel Taxiway case	for Central Taxiway case	
MA60	187	374	-10%
ATR72	608	1216	10%
CRJ200	337	674	10%
CRJ700	427	854	10%

Two designs with design period of 20 years for flexible pavement overlay over runway was conducted for each of the eighty one pavement samples. One design considered central taxiway configuration while the other assumed parallel taxiway configuration. Also, the structural life of the overlay thickness designed considering central taxiway was evaluated for configuration with parallel taxiway.

III. Results and Discussion

From among the eighty one pavement compositions, only fifty nine with overlay design having CDF= 1 were selected for discussion. The rest of the pavement compositions were found to be designed at CDF value lower than 1 for the minimum required overlay thickness of 50.8 mm (2 inches) and hence, were not relevant from the pavement life comparison perspective. Results for six of the fifty nine samples used are presented in the Fig. 4. It was also found that only CRJ-200 and CRJ-700 i.e. the regional jet aircrafts had significant influence in the pavement design as the CDF values for the ATR-72 and MA-60 i.e. the turboprop aircrafts were mostly found to be around zero, as illustrated in Fig. 5.

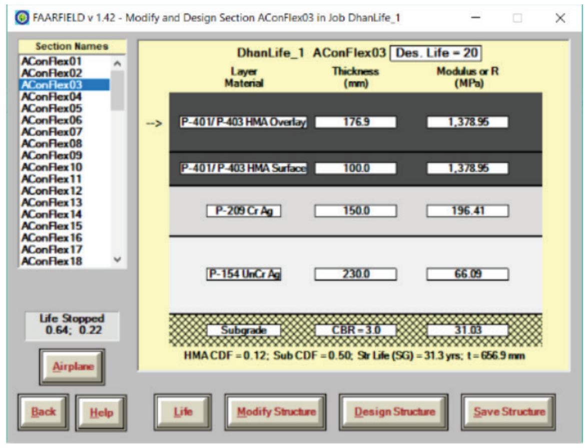

Fig. 3. FAARFIELD window showing design for one of the samples.

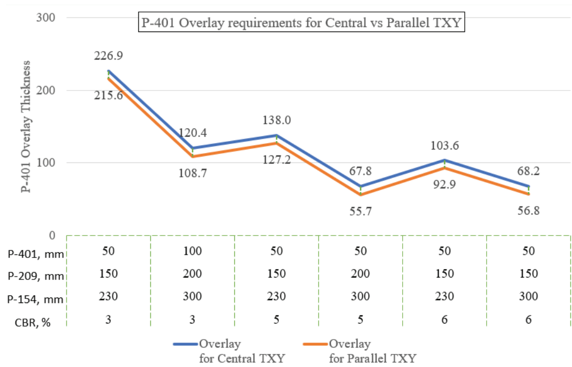

Fig. 4. Graph showing variation in overlay thickness for six representative samples from among the fifty nine samples.

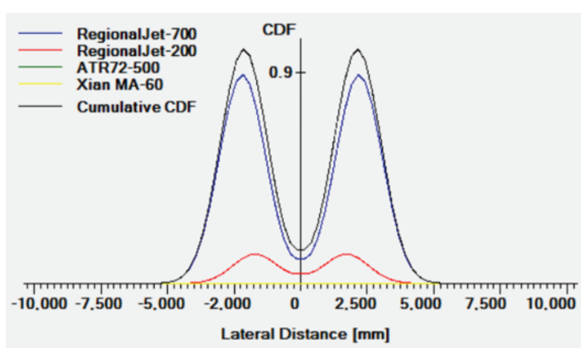

Fig. 5. CDF graph obtained after design of one of the samples.

The difference in the structural life of the same overlay pavement from central vs. parallel taxiway consideration has been represented as life factor in this study. Similarly, the variation in overlay thickness as per design for both configurations has been presented as thickness factor. The thickness factor ranged from 0.82 to 0.95 and the life factor was about 1.56 to 1.57 across all the samples. The mean, standard deviation and coefficient of variation of the results are shown in Table II.

TABLE II
SUMMARY OF RESULTS

	Thickness Factor	**Life Factor**
Mean	0.9	1.56
Standard Deviation	0.038	0.005
Coefficient of Variation	4.24%	0.32%

Where,

- the Thickness Factor is the ratio of overlay P-401 thickness as per design for parallel taxiway case to that for central taxiway case, *ceteris paribus*
- the Life Factor is the ratio of structural pavement life of runway for parallel taxiway case to that for central taxiway case for identical pavement

IV. CONCLUSION

The result discussed above has significance in airside configuration planning and associated economic analysis of runway-taxiway system. Beside the known benefit of parallel taxiway for runway capacity as it allows significantly lesser runway occupancy time as compared to central taxiway for each aircraft movement, this study discusses additional benefit in terms of greater pavement life and/or economical overlay design. However, this could be offset by the additional land acquisition cost, and construction and maintenance cost of greater area of parallel taxiway in comparison to that of the central taxiway. Therefore, airport-specific cost-benefit analysis should be conducted before any airside features planning by considering all known costs and benefits.

Moreover, two aircrafts operational in Nepalese domestic air transport but not included in FAARFIELD library, namely ATR 72-500 and Xian MA-60, have been added in the course of this study. The aircraft characteristics can be added to the external XML library of FAARFIELD as required for any design or evaluation works.

Also, this study was limited to a single fleet mix (similar to the kind commonly encountered in Nepalese domestic air transport) and hence, may not fully cover all the possible variations in pavement design and evaluation. Therefore, a more comprehensive study with various probable fleet mixes including that of international airliners should be conducted for a complete understanding of this subject.

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