APPLICATION OF FAA METHOD FOR EVALUATING THE IMPACT OF AIRFIELD PAVEMENT ROUGHNESS ON AIRCRAFT WHEEL DYNAMIC LOADING

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Abstract

The paper presents the researched content to apply BBI (Boeing Bump Index) method of ICAO, FAA to evaluate the influence of airfield pavement roughness on the dynamic load of aircraft wheel with measured data in Cam Ranh International Airport, thereby proposing to apply to the actual design and operation of the airports in Vietnam.

Keywords: *Roughness; dynamic load; airfield pavement; BBI.*

1. Introduction

Airfield pavement roughness is one of the most important criteria that significantly affects the quality of airport surface operations.

All over the world, there are many methods to evaluate the roughness of airport pavement such as: measuring method with 3 m (5 m) straight-edge [1-3], methods of spectral density estimation for airfield pavements, method of expert survey applied used in Russia and some Eastern European countries, BBI method of ICAO, FAA and Western European countries, method for IRI measurement used in Brazil, India...

In Vietnam, the roughness has been normally estimated by deviation between the bottom of 3 m (or 5 m) straight-edge and the pavement surface for checking and taking over the works. The method of spectral density estimation for airfield pavements was initially applied by some authors with actual measured data in Vietnam [4], but its application in practice required to perform big amount of geodetic measurements in the field.

With the integration trend, in Vietnam standard (TCVN 8753:2011) - Civil airports - General requirements for design and operation, the roughness evaluation criteria as recommended by ICAO [2] have been applied, however the application on actual requires modern equipments and studies according to Vietnamese conditions.

To evaluate the influence of the airport pavement roughness on the aircraft wheel load, the statistical dynamics method was applied when evaluating through the pavement elevation spectral density estimation method [4-7].

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In the content of this article, based on the measured datasets at Cam Ranh International Airport, the authors would analyze and evaluate the roughness through the BBI, also evaluate the impact of airfield pavement roughness on aircraft wheel dynamic loading by the specialized software of American Federal Aviation Administration (FAA).

2. The basis of the method for evaluating the airport pavement roughness of the of FAA

The airfield pavement surface can be considered collecting of countless longitudinal profiles. Each pavement surface longitudinal profile $P(t)$, which is a random process consisted of three different components: macroprofile $M(t)$, microprofile $q(t)$ and surface texture $\psi(t)$ [7]:

$$P(t) = M(t) + q(t) + \psi(t) \tag{1}$$

In three components above, according to studies in the Russian Federation, it has been shown that the microproflile $q(t)$ with a wavelength from 1 m to 80 m is the main kinematic disturbing factor when the aircraft is moving along the runway and the object of research for evaluating the influence of pavement surface roughness on the dynamic load of aircraft.

Surface texture $\psi(t)$ also does not affect the vertical vibrations of the aircraft while driving, it only affects the braking conditions and tire wear.

In the actual operation of the airport, there are many methods of measuring the longitudinal profiles to evaluate the airfield pavement roughness.

2.1. Methods of measuring the longitudinal section of the road airfield pavement surface

a) Measuring method by Surveying Equipment:

To be a popular and simple method to measure figure the airfield pavement surface through the elevation at measurement points on it. However, to collect measurement data for evaluation pavement roughness by surveying method that requires to perform a big amount of work, with a lot of time, which is normally only suitable in the process of measuring and taking over the pavement surface elevation, not appropriate for operation time in airports.

b) Measurement method by Walking Profilers device:

The ARRB Walking Profler (WP) G3 produces outputs from pavement profle, providing International Roughness Index (IRI), MPD texture (as an optional parameter) and distance. The WP unit utilises a tri-axial accelerometer mounted on a rolling platform, to enable measurement of longitudinal profle. This platform is separate to the carriage, which means it is less susceptible to operator input. Data can be collected at variable speeds up to 5 km/hr and is controlled by an Android tablet. Real-time results are displayed on the screen, allowing for on-site decision making [8].

Figure 1. ARRB Walking Profiler (WP) G3 measured device [8].

c) Inertial Profilers device:

Nowadays, the most complex roadway shaping devices are those that use inertial reference systems. These systems include:

- Accelerometer to measure the movement of the chassis;

- Non-contact sensor (conventional) to measure the relative displacement between the chassis and the road surface at fixed intervals along the road surface;

- Distance measuring device to record the distance along the measuring range on the runway. Combined together, these features create a simulation of the longitudinal section.

There are two types of inertial profilers:

- *High speed Inertial Profiler:* These devices are considered to be highly accurate, and have been used for measuring pavement roughness at the network level. The measurement equipment is mounted on the front or rear of the data collection vehicle and the measurements are collected at posted speeds. In addition to collecting pavement smoothness data, the modern data collection equipments in use today also collect other data such as right-of-way video, downward imagery of pavement surface (to enable pavement condition surveys), sign and signal inventory, highway grade, cross-slope, and so on [9].

- *Lightweight Inertial Profiler:* These types of profilers employ the same technologies used in high-speed systems, but in a smaller, lightweight vehicle, making them ideal for testing new pavement construction, and particularly newly constructed concrete pavements that have not yet achieved sufficient strength to support regular traffic loading. Most agencies that have inertial profiler-based smoothness specifications generally allow the use of lightweight profilers [9].

With the above measurement methods, the runway surface would be measured into the evaluation corresponding measuring ranges. Each measuring profile will be a collection of pavement elevation values with predefined steps required by ICAO, FAA (0.25 m and 0.5 m) [10, 11].

2.2. BBI determination method

In the documents of ICAO, FAA, the method of roughness evaluation of the airport pavement according to the BBI. The basis of the Boeing Bump method, which constructs a virtual straightedge between two points on the longitudinal elevation profile of a runway and measures the deviation from the straightedge to the pavement surface [10, 11]. On that basis, "bump height" would be determined as the maximum deviation (positive or negative) from straightedge to the pavement surface.

The bump length is the shortest distance from either end of the straightedge to the location where the bump event is measured (Figure 2).

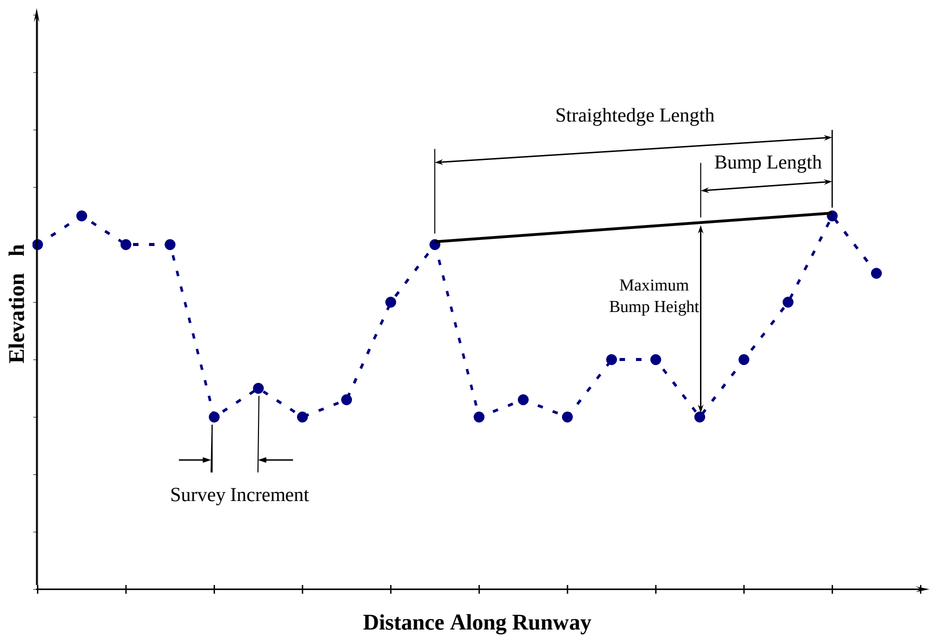

Figure 2. Roughness measurement diagram [10].

Research cited by Boeing has been demonstrated that bump lengths in excess of 120 meters (394 feet) do not contribute to dynamic airplane response or negatively impact the airplane [11]. Similar to the spectral density estimation method, the Boeing Bump method has been determined the minimum length of the line segment depending on the step interval or measurement interval of the pavement profile measurement data. The minimum length to consider is 2 times the survey interval, so a minimum of 3 profile data points is needed to determine the roughness relative to the imaginary line (Figure 3).

The FAA standard for sampling distance is 0.25 m (0.82 feet) for Boeing Bump evaluation. Therefore, the minimum straightedge length is 0.5 m (1.64 feet).

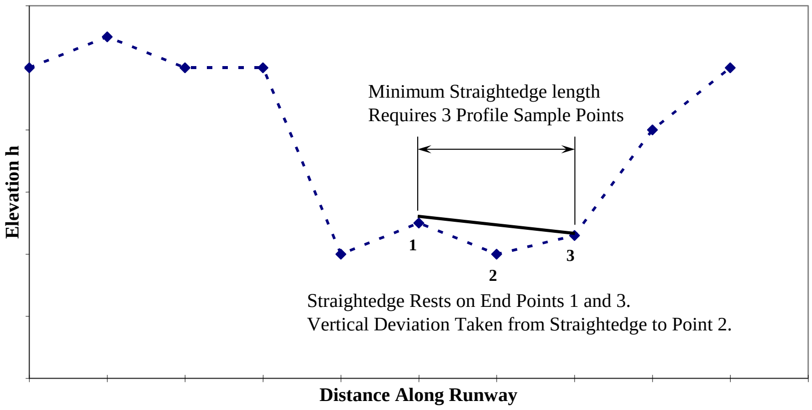

Figure 3. Determine the minimum straight line [10].

Airfiled pavement roughness will be evaluated by zones: acceptable, excessive and unacceptable [10, 11] according to the following chart:

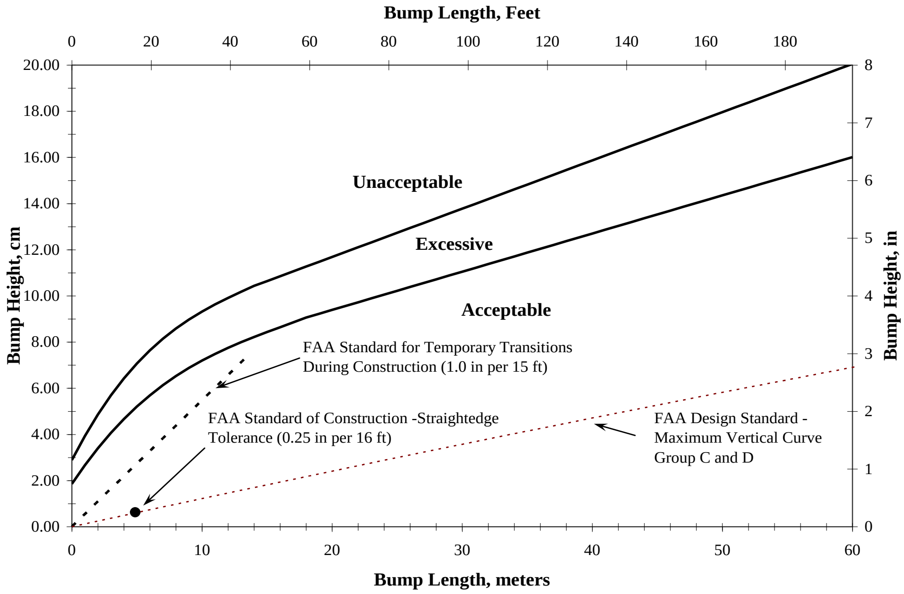

Figure 4. Roughness evaluation criteria for a single bumpy section [10].

To summarize the bump criteria and compare computed bump criteria with other measures of roughness, the FAA created an additional parameter for the Boeing Bump procedure. This new index, called the "Boeing Bump Index" (BBI), is determined by the ratio of the measured bump height to the accptable bump height for the bump length.

To evaluate the BBI of the pavement depending on the roughness length, the FAA has been set up a map (Figure 5) based on the roughness evaluation areas mentioned in the ICAO and FAA standards. In which, if the computed index value is less than 1.0 roughness falls in the acceptable zone; if it is greater than 1.0, it falls in the excessive or unacceptable zone (BBI > 1.24).

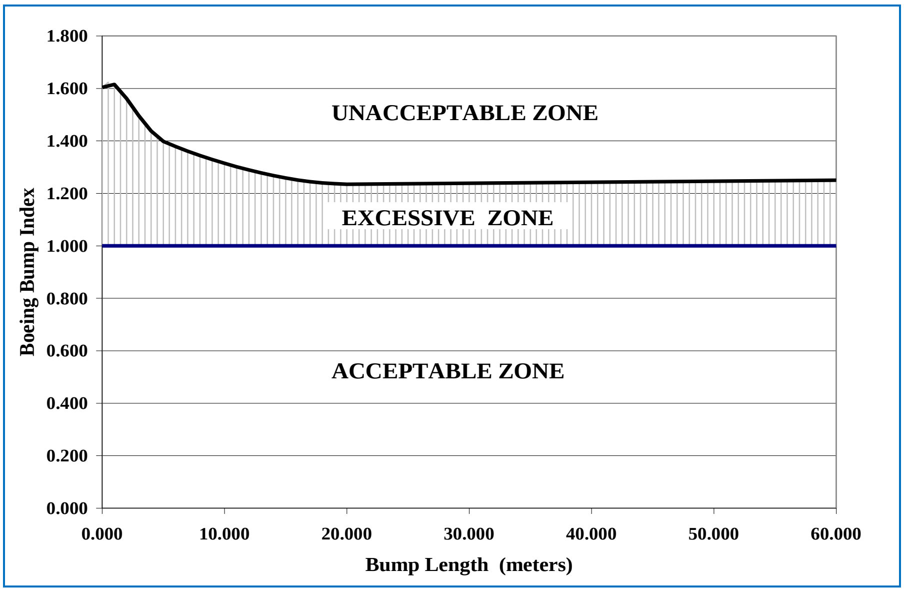

Figure 5. Evaluation of roughness through the Boeing Bump Index [10].

To help calculating of the BBI, the FAA developed ProFAA software with the data part being formatted as a .pro file. With this data, the specified sample spacing could be 0.984 inches (25 mm), the airport pavement elevation has been used in inches. In order for the FAA's ProFAA software to accept input data from a variety of formats, it should be necessary to convert the input data to the preferred .pro format and calculate the BBI and other pavement parameters.

To use a variety of measurement data from different devices such as *.erd, *.ASTM by IRI devices, *.txt by surveying equipment, the FAA also developed software called "Convert Profile Format", wich can convert between different types of measurement data [10].

Through ProFAA software, the values that can be calculated include: determination of longitudinal profile, BBI, straightedge length, determination of acceleration, vertical force when sample aircraft (B727, B747, DC-9, DC-10) moving on the runway or main taxiway with different velocity values.

3. Evaluation of the pavement roughness and dynamic load by FAA method at Cam Ranh International airport

The runway (02R/20L) elevation data of Cam Ranh International Airport at the runway longitudinal profile are used to evaluate the roughness and dynamic load of the aircraft wheels. The taken measurement step is 0.5 m by geodesic method when taking over the concrete pavement of the runway during the 2016-2018 period. Measurements are save as .txt files.

To use the software "Convert Profile Format" to convert the input txt file data to file.pro format (Figure 6) in the default format for using ProFAA software.

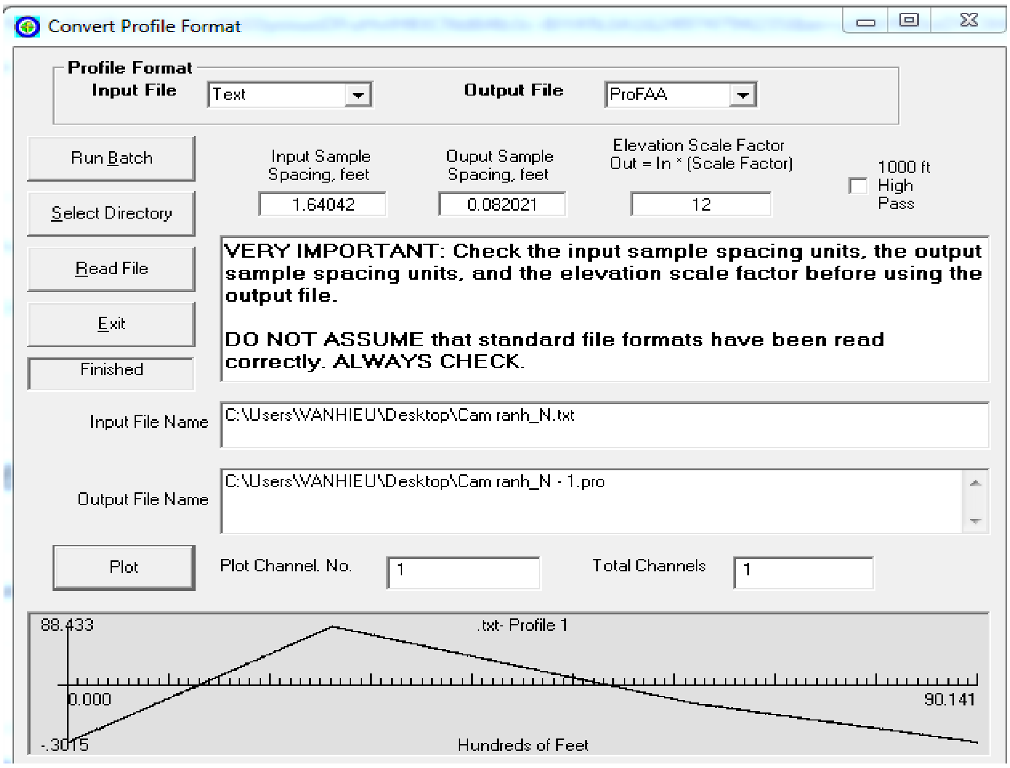

Figure 6. Data file conversion results from .txt format to .pro format.

With the converted data, the roughness evaluation of the measuring range at the runway center at Cam Ranh Intenational Airport, which could be obtained the following results: longitudinal profile at the center, calculated wave length and BBI along the runway (Figure 7).

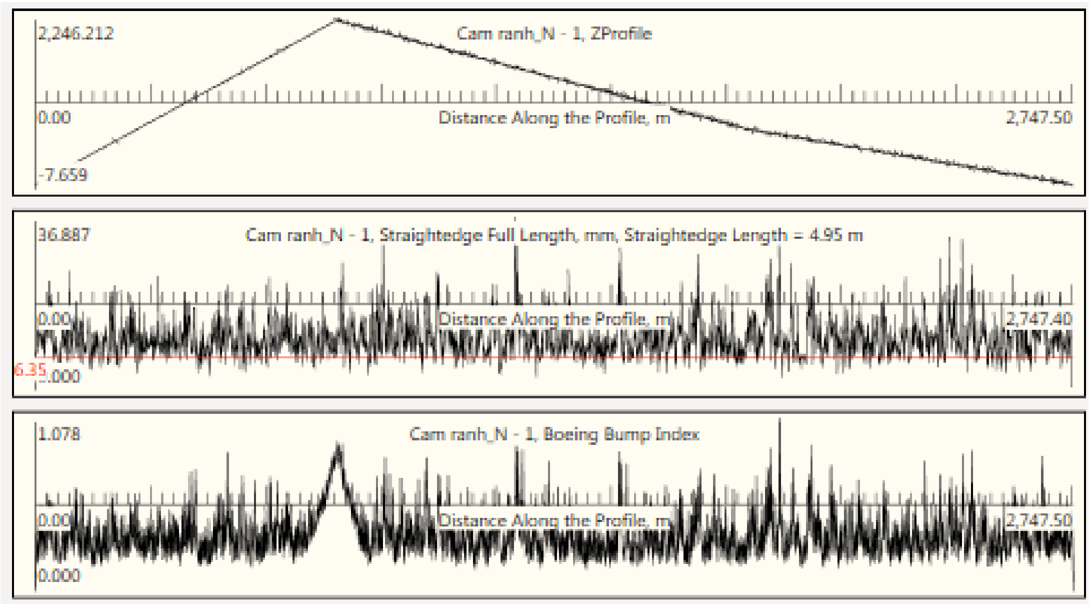

Figure 7. Results of determining the BBI of the runway center of Cam Ranh International Airport.

Using the study segment enlargement feature of ProFAA software, to enlarge the segment with the largest BBI with the value BBI is 1.078.

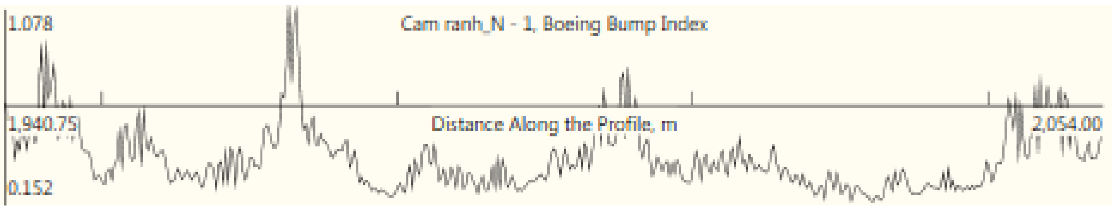

Figure 8. Detail of the paragraph with the largest BBI.

From the results shown, the segments at coordinate position from 1940.75 m to 2054.0 m (Figure 8) contain segments with BBI > 1, located in the recommended area to pay attention to the roughness [10, 11], in which at the 1970.0 m process, BBI max is 1.078. However, this level of roughness allows to ensure normal airport operation.

The results of the roughness evaluation of Cam Ranh International Airport have been consistent with the evaluation by the method of estimating the spectral density of the road surface with the level of spectral density at the center of the runway C is $8.1656 \cdot 10^{-6}$ in the published range from C is $1.5 \cdot 10^{-6}$ to C is $17 \cdot 10^{-6}$ $m \cdot rad$ [4] of survey airports in Russia and Vietnam.

To use the feature of the aircraft wheel load evaluation acting on the road surface at the calculated speeds, the researchers have been obtained the calculated force results at the nose and main gear of the sample aircraft in the software such as B727, B747, DC-9, DC-10.

Figure 9 shows the results of the calculated load at the main and nose gear (B727) corresponding to the aircraft speed of 100 knots (185.2 km/h).

With a high speed of movement, when the aircraft moves through the slope, the aircraft wheel load has a great change. At the 826.5 m location, the nose gear force of aircraft B727 has been reached the maximum value equal 6801.993 kG, the maximum force value at the one of main gears amount to 36456.176 kG.

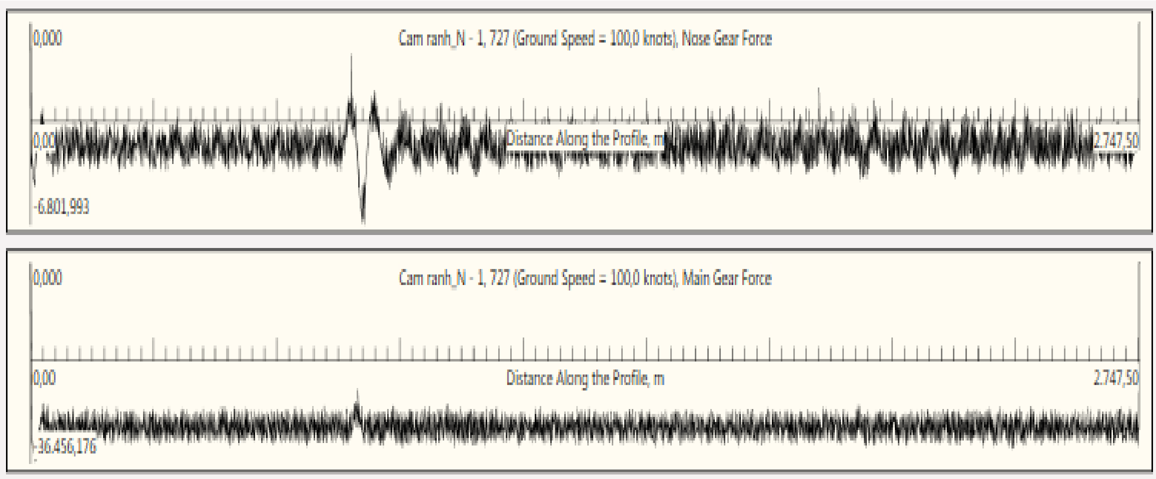

Figure 9. Result of aircraft wheel load evaluation by roughness.

ProFAA software allows evaluating average load on each measuring section. Figures 10 and 11 show the average force of the nose gear and main gear calculated over 9 sections along the runway length, each section length is 305 m (1000 feet).

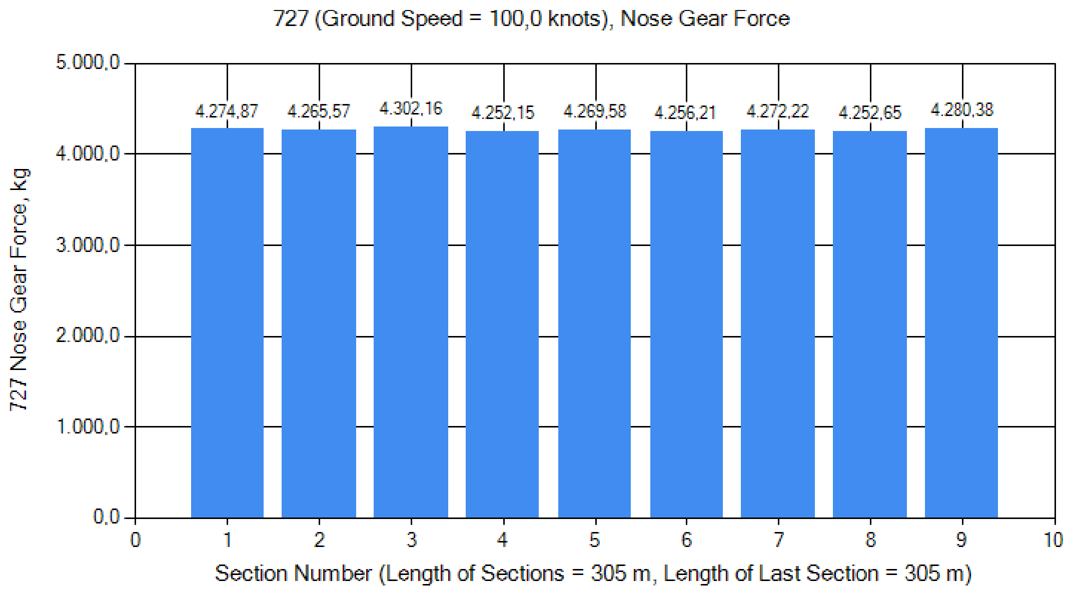

Figure 10. Average force of nose gear for each runway segment.

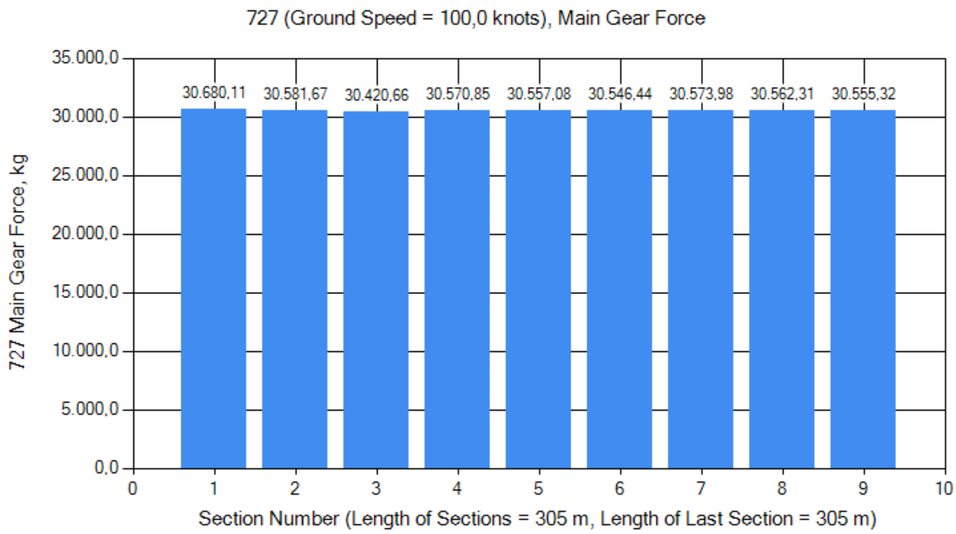

Figure 11. Average force of one main gears for each runway segment.

Figure 10 clearly shows section 3 (section from 710 m to 915 m) with the largest nose wheel force, corresponding to the large change in figure 9 when the aircraft wheels roll over the slope on the runway.

With the supportive of the program, we get a table of calculated data, which lists the force responses and acceleration values of the aircraft in each section. The impact coefficient is determined by the ratio of the dynamic and static force responses of aircraft landing gear system when moving on runway (Pt = 599.1065 kN) (Table 1).

Table 1. Results of acceleration and dynamic responses of aircraft on each section

Section	Length (m)	Cg (m/s^2)	Cp (m/s^2)	Nose dynamic response (kN)	Main dynamic response (kN)	Kf
1	305	0.0222	0.0301	92.4540	663.5295	1.108
2	305	0.0219	0.0253	92.2530	661.4005	1.104
3	305	0.0237	0.0310	93.0444	657.9181	1.098
4	305	0.0242	0.0291	91.9627	661.1665	1.104
5	305	0.0206	0.0293	92.3396	660.8685	1.103
6	305	0.0211	0.0289	92.0505	660.6385	1.103
7	305	0.0217	0.0289	92.3967	661.2340	1.104
8	305	0.0229	0.0326	91.9735	660.9817	1.103
9	305	0.0223	0.0289	92.5767	660.8185	1.103
Total	**2745**	**0.0223**	**0.0294**	**92.3396**	**660.9520**	**1.103**

4. Conclusions

The application of ICAO and FAA methods to evaluate the roughness of airport pavements in Vietnam through the BBI is feasible, especially whereas equipped with modern equipment, which would allow shortening time the evaluated time to be suitable to the actual conditions of airport operation with a short "free" time frame.

Runway 02R/20L of Cam Ranh International Airport have a good level of surface roughness, this result is consistent with the results when evaluate runway roughess by spectral density estimation method [4, 5].

The dynamic coefficient of aircraft landing gear system when moving on runway is about 1.1. This result is consistent with the result of dynamic coefficient published in [10] according to the method "Statistical dynamics" [12].

Through the use of ProFAA 20 software, it has been possible to evaluate the effective load of the aircraft wheels at the nose and main gear through the evaluation of the BBI, but the aircraft model only applies to four types of B727, B747, DC-9, DC-10 should still be limited, because only a few of these aircraft have been operated in Vietnam.

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Nguyễn Văn Hiếu, Đỗ Văn Thùy

Tóm tắt: *Bài báo trình bày nội dung nghiên cứu nhằm ứng dụng phương pháp BBI (Boeing Bump Index) của ICAO, FAA vào đánh giá ảnh hưởng của độ bằng phẳng mặt đường sân bay tới tải trọng động bánh máy bay với các số liệu đo tại sân bay Cam Ranh, qua đó đề xuất ứng dụng vào thực tiễn thiết kế, khai thác sân bay tại Việt Nam.*

Từ khóa: Độ bằng phẳng; tải trọng động; mặt đường sân bay; BBI.

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