Development of Climate Data Inputs Towards the Implementation of Mechanistic-Empirical Pavement Design in the UAE

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Abstract

The current state of practice in the UAE is to use AASHTO 1993 for pavement designs, yet this method is empirical and has several limitations. The local traffic characteristics, climate conditions, and materials properties must be incorporated in more explicit and mechanistic ways. This study is part of ongoing local research efforts to move towards the implementation of the Mechanistic-Empirical Pavement Design Guide, known as MEPDG, which depends on fundamental material properties, integrated climate conditions, and real traffic characteristics. The main objective of this study is to develop the historical climate data files and climate inputs for 20 different automatic and airports stations covering the entire UAE. These weather stations were divided into four geographical regions: desert area, urban area, coastal area, and mountainous area. In addition, the study investigates the impact of local climate conditions on the simulated asphalt pavement performance using the AASHTOWare Pavement ME Design. This study showed that, however, UAE is a small country yet there are some differences between the climate records of the different weather stations, which is expected to affect pavement design and performance depending on the project site location. For example, the warmest weather station has 36% higher temperature than the coldest weather station at Jabal Jais. This in turn displayed up to 40% and 23% differences in the asphalt concrete (AC) rutting and total rutting, respectively between these extreme weather stations. These findings and many other emphasize the crucial need to consider the climate data inputs at the project level bases, where a single climate data file cannot represent the entire UAE.

Keywords: AASHTOWare; MEPDG; Climate; Pavement Performance; Distress

1 Introduction

Road infrastructure is integral to any country’s economic and social development. Pavement design should consider the daily loads under the local climate conditions to ensure the level of serviceability that is required (Abu Dabous et al., 2021). The pavement performance is directly affected by the climate condition, especially temperature and moisture (Hemed et al., 2020). Low temperatures can cause asphalt to harden and crack in layers, and extremely low temperatures can cause it to crack due to thermal and fatigue stresses. In contrast, asphalt becomes softer and more viscous at high temperatures, causing more rutting (Kodippily et al., 2020). An empirical design method was developed by AASHTO for rigid and flexible pavements in 1972. It has been updated several times over the years, the last time in 1993, and has been implemented by many countries (El-Badawy et al., 2011). Due to its empirical nature, several limitations affect the reputation of thickness layers formed by the process. Additionally, the empirical drainage layer coefficients for expressing the influence of moisture on the unbound layers are a significant limitation. There is only one environmental consideration in this method, which is the seasonal variation of the roadbed resilient modulus and the coefficients of the drainage layer (Elshaeb et al., 2014).

As part of the Mechanistic-Empirical Pavement Design Guide (MEPDG), AASHTO published a temporary version in 2008. MEPDG criteria provide an advanced approach to pavement development (Li et al., 2011). In contrast to AASHTO (1993), the MEPDG predicts several performance metrics and considers material properties, structural design, climate conditions, traffic levels, and paving systems (El-shaib et al., 2017; Justo-Silva et al., 2022). It is an advanced tool used to design and analyze new and rehabilitated flexible and rigid pavement structures (Gkyrtis et al., 2022). Mulandi et al. (2006) compared between AASHTO 1993 and MEPDG, and they concluded that the AC section of the MEPDG produced better results than the AC sections derived from the 1993 AASHTO design guidelines because real traffic loads and different climate factors have been considered. Many research investigated the effect of using climate files to evaluate pavement distresses. (Elshaeb et al., 2014) developed a climate data to assist the implementation of pavement ME design in Egypt and to investigate its influence on flexible pavement performance. The research reported that the warm climate conditions result in higher predicted AC rutting and total rutting. Another study was conducted by (Qiao et al., 2013) to prepare a climate file including (temperature, precipitation, wind speed, sunshine, and groundwater level) to evaluate pavement performance in Virginia City, USA using MPDG. Furthermore, (Saha et al., 2014) used a mechanistic-empirical pavement design guide (MEPDG) to investigate the quality of the recently developed Canadian climatic database. According to the study, asphalt concrete, total pavement rutting, and the international roughness index are sensitive to the climate. (Ankit et al. (2011) investigated the impact of different environmental factors in India on flexible pavement performance modeling. Some models have been used to correlate different environmental variables and their structural characteristics. These models involved different environmental parameters, such as precipitation, wind speed, air temperature, relative humidity, and solar radiation.

Flexible pavement design in the UAE is currently based on the AASHTO 1993, which doesn’t take into account the local climate conditions in the UAE (Hassan et al.,2022 ; Ashour et al., 2022) Therefore, the primary goal of this research is to create the climatic data inputs necessary for structural pavement design in the UAE as a first step toward implementing the MEPDG, known as AASHTOWare ME Pavement Design in the UAE.

2 Study Area

United Arab Emirates, a federation comprising seven emirates along the Arabian Peninsula’s eastern coast. The largest emirate is Abu Dhabi, which accounts for more than three-fourths of the total land area of the federation. Followed by Dubai, which is situated at the base of the rocky Musandam Peninsula. The Peninsula is also occupied by the smaller emirates of Sharjah, Ajman, Umm Al-Quwain, and Ras al-Khaimah. Fujairah, the federation’s seventh member, confronts the Gulf of Oman. This study was conducted over the entire area of UAE, which is located at latitude 23.4 and longitude 53.8. Figure 1 shows the locations of the 20 weather stations considered in this study, including 14 automatic weather stations and 6 airports weather stations.

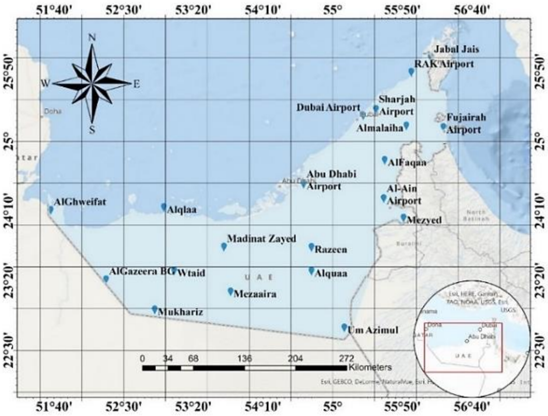


Fig. 1: Location of weather stations and airports

3 Methodology

To assess and compare the impact of climate across different climate zones in the UAE, a three-phase methodology was developed. These three phases are: data acquisition, data processing, and data analysis. The first phase includes data collection that involves historical climate data from 14 local and 6 International airports weather stations. The second step is the development of climate files and inputs needed for MEPDG considering five climate factors: Air Temperature, Precipitation, Wind Speed, Sunshine, and Relative Humidity. The third phase comprises investigating the impact of the climate files of different weather stations on simulated pavement performance using AASHTOware Pavement ME Design software in terms of five distresses (AC Rutting, Total Rutting, and Bottom-Up Fatigue Cracking, and International Roughness Index (IRI)).

3.1 Historical Weather Stations Data Acquisition

The AASHTOware Pavement ME Design software uses hourly records of air temperature, wind speed, sunshine, precipitation, and relative humidity to implement the analysis. Historical data for the main five climate factors were collected from the National Center of Meteorology. The duration of climatic data measurement is 15 minutes, which is appropriate for MEPDG implementation. The 14 weather station data involves 17 years (2004-2020) and 32 years for the airport weather station (1989-2020).

3.2 Development of Climate Files and Inputs for MEPDG

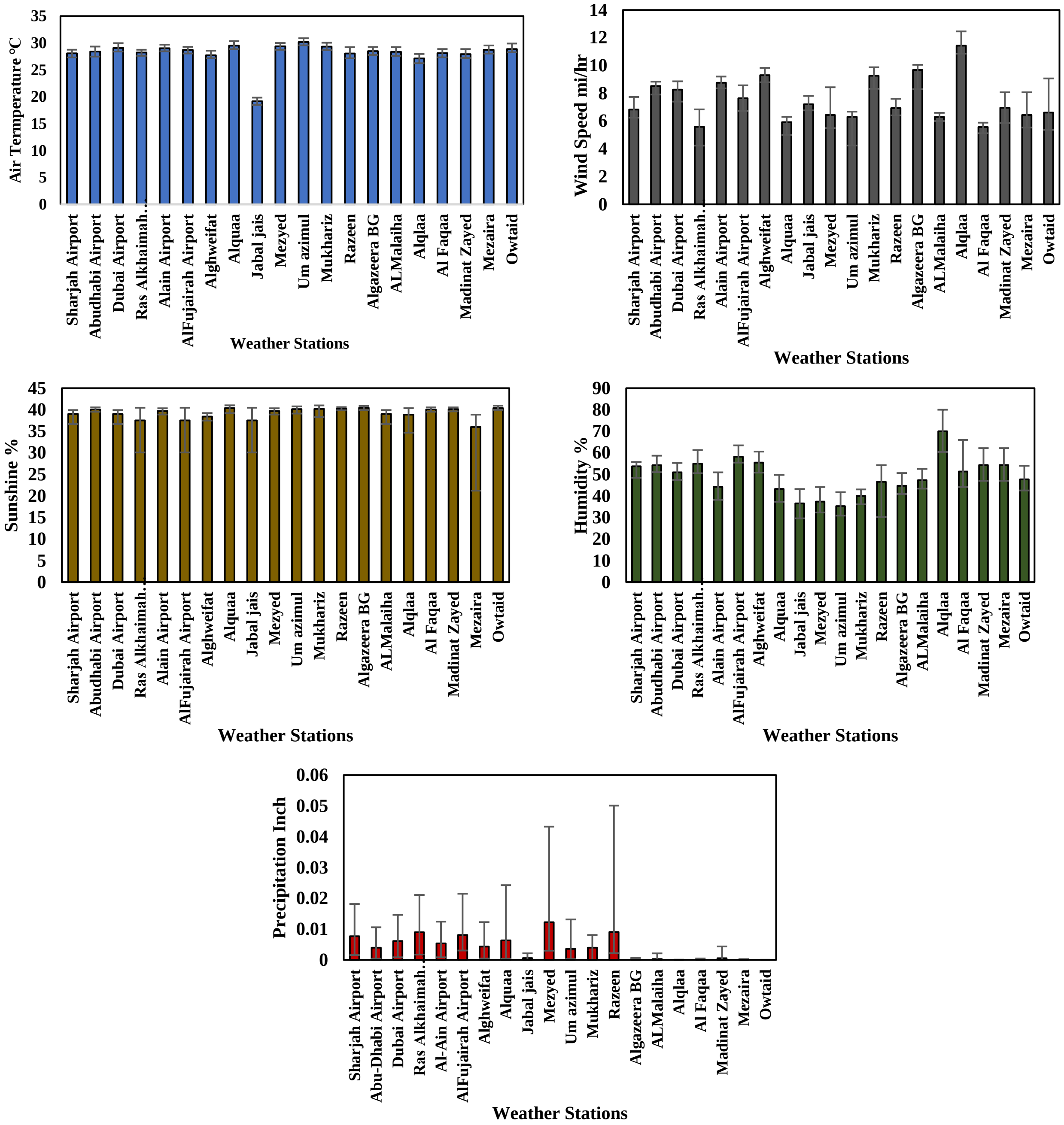
The MEPDG aims to define the physical causes and calibration of the restrictions on the design of the roadways with the performance of the pavement. In order to use the EICM model, climate information includes hourly air temperature, precipitation, wind speed, sunshine, and relative humidity. The climate data files should be prepared in the format acquired by the software. The modification of the climate data files to the required software format was conducted using initially Excel spreadsheets. In the Excel spreadsheets, climate data obtained initially have been translated into CSV files (Comma Delimited). The CSV files were first opened as text files, then saved as a text file in which the *. hcd extension for each text file was manually added. Each climatic file contains the following information in order: date (YYYY/mm/dd/hr), air temperature (ºF), wind speed (mile/h), sunshine (percentage), precipitation (in), and relative humidity (percentage).

3.3 Impact of Climate Files and Inputs on Simulated Pavement Performance

The primary research tool to evaluate the climate impacts on pavement performance considering different weather stations in the UAE was the AASHTOWare Pavement ME Design software. MEPDG is an iterative method for pavement design according to paving distresses and smoothness. Several site circumstances should be taken into consideration such as traffic, climate, subgrade, and current pavement requirements for rehabilitation. The sufficiency against user input, performance criteria, and reliability values would then be assessed through the output for both predicting distress and smoothness. If the specification does not fulfil the reliability performance requirements, it will be reviewed, and the assessment process will be replicated as required. This ME approach allows for the optimization of the design and ensures that some kinds of distress are reduced to values less than the failure criterion in the paving structure's design life.

4 Visualization of Historical Climate Factors Data in the UAE

Adaptation and climate impact evaluations have been grown in number, consistency, and importance over the last few decades. Asphalt pavement performance is significantly affected by air temperature. Temperature, precipitation, wind speed, sunshine, and relative humidity are the climate factors taken from the different 20 weather stations as shown in 1Fig. 2. Although the weather stations are close to each other, there are remarkable differences between different climate factors measured at different locations of the weather stations. These differences are expected to induce differences in simulated pavement distresses including, bottom-up fatigue cracking, and total and AC rutting.



1Fig. 2: Historical Annual Average **(a)** Air Temperature, **(b)** Wind Speed, **(c)** Sunshine, **(d)** Relative Humidity and **(e)** Precipitation for Weather Stations.

5 Influence of Climate Data on Pavement Performance

The main aim of this section is to determine the impact of changes in climate conditions measured at different locations on the simulated pavement performance and corresponding pavement service life. If the simulated pavement performance at different locations varies remarkably across the UAE, this will indicate that using the project site climate conditions is a must as part of pavement design and performance. The AASHTOWare Pavement ME Design calculates the cumulative values of various distresses as a function of pavement age till the end of the pavement design life. Fig. **3** (a) illustrates the AC rutting value for the 20 weather stations that cover the entire UAE. The highest AC rutting recorded was 0.60 inches, whereas the lowest AC rutting was 0.36 inches. Fig. **3** (b) demonstrates the total rutting value, where the highest total rutting was recorded at 1.06 inches and the lowest total rutting was recorded at 0.83 inches. The southern region showed more AC and total rutting compared to the northern region due to elevated temperatures at the southern region. Fig. **3** (c) shows the IRI values across the entire UAE. IRI is an indicator to assess the smoothness of a road surface. The lower the IRI value, the smoother the road surface. It is commonly used to evaluate the condition of a pavement and to identify areas that may require maintenance or rehabilitation. As rutting and cracking develop, it can increase the roughness of the pavement surface, which will be reflected in a higher IRI value. Many transportation agencies around the world have developed IRI criteria for different maintenance and rehabilitation activities (Guidelines IRI, 2018; Baladi et al., 2017). The highest IRI value was 175 inches/mile, whereas the lowest IRI value was 161 inches/mile. The IRI differences between the different weather stations varied between 0% to 9.1%. The IRI result showed the same trend of AC rutting results across the UAE which indicate the relation between them. The bottom-up fatigue cracking values are shown in Fig. **3** (d). The highest bottom-up fatigue cracking value was 2.5% and the lowest bottom-up fatigue cracking was 2.2%. The bottom-up fatigue cracking values were so low as expected in warm climate regions with a percent difference between weather stations up to 15%.

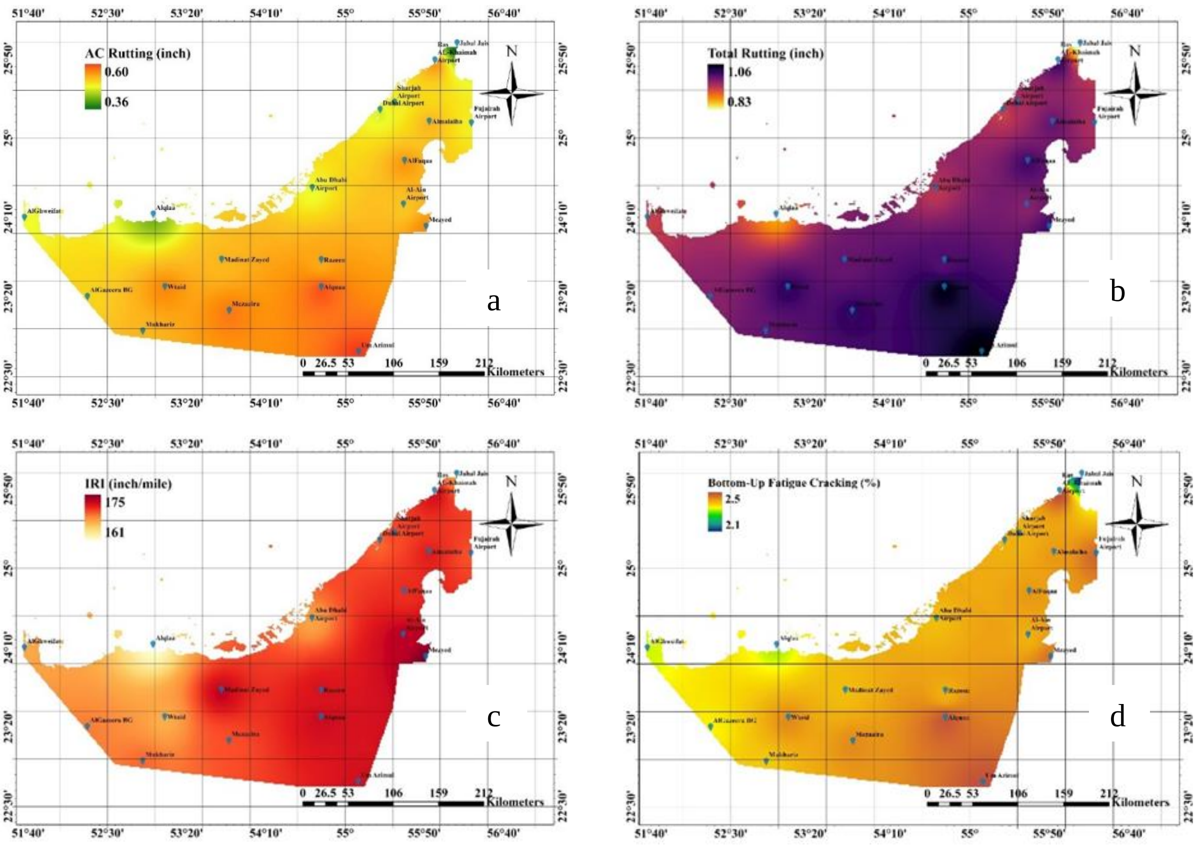


Fig. 3: Simulated **(a)** AC Rutting; **(b)** Total Rutting; **(c)** Terminal IRI; and Bottom-Up Fatigue Cracking Maps

Figure 4 shows the performance results and corresponding pavement service life of both AC and total rutting since rutting was the most significant distress leading to pavement failures. The percentage changes in AC Rutting between different weather stations varied between 0% to 42.9%. For the pavement age calculated corresponding to AC rutting of 0.25 inches, the difference in AC rutting age was found to range from 0-11 years. These differences in AC rutting and corresponding pavement life were due to the significant variation in temperatures between the northern and southern regions. Similarly, the total rutting values varied between different weather stations with up to 22.6%, causing differences in corresponding pavement lives 13 years. Since the simulated pavement performance and corresponding pavement service life reviled different results, which are expected to remarkably affect the construction and maintenance costs, it is therefore critical to consider the local climate conditions at a project level as part of the pavement design and rehabilitation. This surely will not be attained using the 1993 AASHTO design method, yet it could be achieved by implementing more updated and accurate pavement design methods such as the MEPDG.

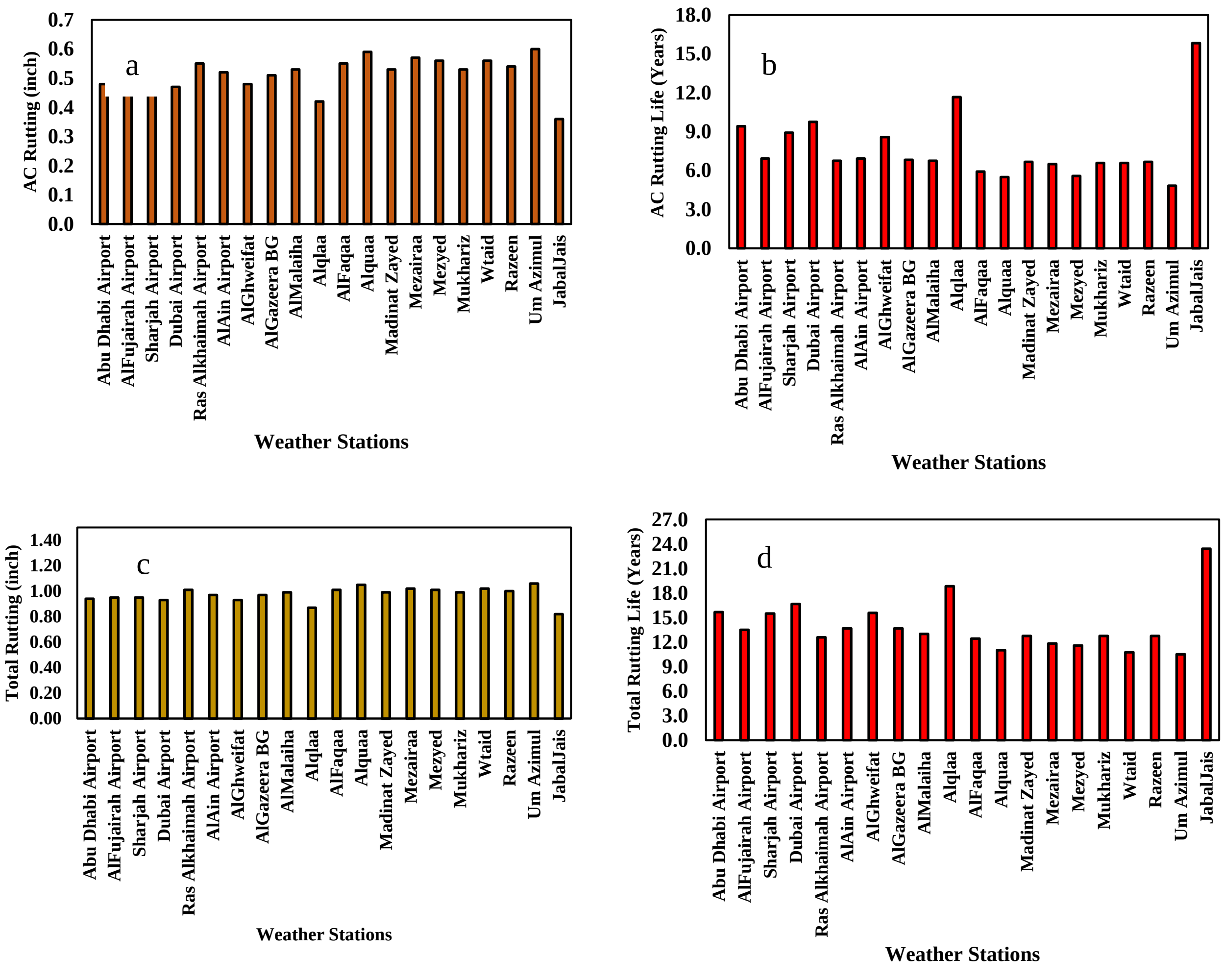


Fig. 4: Simulated **(a)** AC Rutting; **(b)** AC Rutting Life; **(c)** Total Rutting; and **(d)** Total Rutting Life for Different Weather Stations

6 Conclusion

MEPDG is the latest and state-of-the-art design methodology that offers an integrated platform to consider local climate conditions more preciously. In UAE, the MEPDG has not been yet implemented for structural pavement design, where the current pavement design practice is based on AASHTO 1993 design method. The main objective of this study is to develop the climate data files and inputs for the UAE as an initial step towards the implementation of the MEPDG in the UAE. The predicted pavement performance using 20 climate files representing different locations in the UAE was analysed to assess the impact of climate factors on simulated pavement performance. The following conclusions were drawn from this research effort.

- 20 different climate data files were successfully developed for the implementation of MEPDG in UAE using historical hourly data records collected from different weather stations across the country.
- The climate data files were incorporated and described successfully in the AASHTOWare pavement ME design software without any detected errors.
- AC rutting was significantly affected by the climatic zone ranging between 0% to 42.9%.
- The highest AC rutting recorded was 0.60 inches at Um Azimul weather station, whereas the lowest AC rutting was 0.36 inches in Jabal Jais.
- AC rutting life was decreased consequently with the increase in AC rutting values and the difference in AC rutting life between different stations was up to 11 years.
- Total rutting recorded 1.06 inches as the higher value and 0.83 inches as the lower value.
- There was a variation of up to 22.6% in the total rutting values among different weather stations.
- This results in pavement life differences of up to 13 years between weather stations.
- A maximum value of 2.5% was observed for bottom-up fatigue cracking, while the lowest value was 2.2%.
- In warm climate regions, fatigue cracking values are so low, with a percent difference of up to 15% between weather stations.
- In terms of IRI values, 175 inches/mile was the highest and 161 inches/mile was the lowest. It was found that the IRI differences between the various weather stations ranged as high as 9.1%.
- In this study, the impact of climate conditions at different locations across the UAE on pavement on pavement design and performance was investigated using the MEPDG. Impacts of materials selection and local traffic characteristics should be also investigated in future research work.

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