Response Factors and Quantitative Characterization for Moisture Equilibria of Subgrade

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Abstract: Water of subgrade soils root in atmospheric precipitation, underground water and wet migration. It is clear that the moisture of subgrade have been inclined to reach equilibrium conditions with surrounding environment after many years for highway operation through investigation for variation law of moisture with seasons alternation. The environmental factors of subgrade moisture can be divided into climate condition and groundwater table based on summary for influence factors of moisture equilibria comprehensively. Prediction method of subgrade moisture consist of conventional estimation, regional classification estimation and enhanced integrated climatic model chiefly. Regional classification estimation has been recommend to forecast moisture equilibria due to quantification for impact of environmental factors on subgrade moisture.

1. Introduction
The most significant factor affecting the structural characteristics of the subgrade is humidity. The research results show that the subgrade soil is usually in an unsaturated state after the completion of the construction compaction, and the moisture content is generally the optimum moisture content OMC±2%. The absorption of plants, the evaporation of surface water, the seepage of slopes, the rise and fall of groundwater levels, and the infiltration of rainwater have made the moisture content of roadbeds constantly changing. After 3 to 5 years of general road operation, the water content of the roadbed tends to be stable and is in equilibrium with the surrounding environment. At this time, the water content of the roadbed is called the equilibrium moisture content (EMC) [1]. For a long time, many scholars at home and abroad have carried out a lot of research on the influence factors of subgrade humidity, and based on these research, various humidity estimation methods have been proposed.

2. Change source and variation law of subgrade humidity

2.1. Subgrade humidity change source
Changes in the humidity of the subgrade can be understood as changes in the Earth's water circulation system. The water cycle of subgrade soil usually means that the water in the air returns to the surface by means of rainfall and condensation, and the rainwater flows into the river and finally flows into the sea. Due to the influence of gravity, part of the surface runoff will seep into the soil during the flow, and will be stored in the soil or form underground runoff.

Subgrade humidity changes are mainly caused by atmospheric precipitation, groundwater, and water migration caused by temperature[2], as follows.
(1) Atmospheric precipitation: Slopes and shoulders that relatively easy-to-water permeable are soaked by atmospheric precipitation. Water seepage will continue to spread to the roadbed by means of voids; at the same time, precipitation will also penetrate the road surface, infiltrate and wet the roadbed; in addition, evaporation will make moisture follows the same path and escapes back from within the subgrade.

(2) Groundwater: When the groundwater level is high, the groundwater rises to the upper part of the subgrade by capillary action; on the contrary, when the surrounding terrain is low and the drainage is poor, the water accumulated in the trench or in the higher position of the soil will pass through into the subgrade by wet or seepage.

(3) Temperature: When a large temperature gradient occurs with the depth of the subgrade, the moisture migrates from the hot ground in a gaseous or liquid form under the action of the temperature difference and accumulates continuously.

Depending on the environment in which the subgrade is located, the extent to which the above factors affect the humidity of the foundation varies with time and geography. For example, in a seasonally frozen area, when a negative temperature gradient occurs in the subgrade, the humidity accumulation caused by the temperature difference is more serious; in non—frozen areas, the temperature is not the main factor affecting the humidity of the subgrade, because the temperature gradient in the subgrade is not clear.

2.2. Subgrade humidity variation law

Due to the volatility and periodicity of environmental factors, the change of water content shows seasonal fluctuations and annual cycle characteristics before the roadbed reaches a steady state. In order to study the effects of seasonal changes in environmental factors such as humidity, temperature, and freezing and thawing on material parameters of various layers of the road, a Seasonal Monitoring Program (SMP) was set up in the US LTPP test road [3]. The study found that the water content of the subgrade soil changes with the seasons, but the change is not large. The change in water content also causes a corresponding change in the submarine elastic modulus.

Marks [4] measured on a test section in Oklahoma. The difference in humidity at different depths was large, but with seasonal fluctuations, the general fluctuation range was only about 2%. Guinnee [5] researched the seasonal variation of the moisture content of the roadbed in Missouri. The study found that the change of subgrade humidity is not affected by seasonality, but the roadbed humidity is increasing with the road operation longer.

Most scholars have pointed out through research that the water content of the clay soil roadbed will gradually increase after it is put into operation, and will reach equilibrium with the surrounding environment after a few years. At this time, the water content of the roadbed is called the equilibrium water content, and its size can reach the soil. The plastic limit is 1.2~1.5 times. In addition, this equilibrium state is closely related to road surface conditions, vegetation, groundwater level, soil type and surface and slope rainwater infiltration path[6~8].

3. Influence factors of roadbed balance humidity

The subgrade humidity state is affected by both external environmental factors and internal factors. Environmental factors such as sunshine hours, groundwater level, precipitation, and temperature are external factors that affect the humidity of the roadbed; the soil properties of the roadbed, drainage system are internal factors.

3.1. Climatic conditions

The climatic conditions mainly include rainfall, evaporation, temperature and seasonal changes.

(1) Rainfall

Subgrade humidity is greatly affected by rainfall. However, in many studies in the past, the empirical relationship between subgrade humidity change and rainfall has not been established. The reason is that there is hysteresis and complexity between them. Marks [4] and Bandyopadhyay [9]
research shows that rainwater gradually infiltrates into the subgrade from the road surface and takes about 4 to 6 weeks to produce a corresponding change in humidity. In addition, Cumberledge [10] found that during the rainfall concentration period, the amount of subgrade humidity growth is uncertain, and the maximum subgrade humidity may be reached earlier than expected.

2) Evaporation

Barbour [11] study found that evaporation has a greater impact on the humidity at the edge of the subgrade than at the center of the subgrade, and that the evaporation has a more pronounced effect on the humidity when the object is in a dry or semi—dry area.

3) Temperature and seasonal changes

Field observations by Marks [4] and Cumberledge [10] show that the maximum horizontal arrival time of subgrade humidity is usually in early spring or late winter season, because a large amount of rain makes the roadbed saturated. Mitchell [12] studied the subgrade in the freezing period and found that the water in the subgrade gradually moved from the groundwater level to the surrounding area because of the energy level, because the energy level in the non—freezing zone is relatively high, while the energy level in the freezing zone is lower. Groundwater will naturally flow from a high energy level to a low energy level. Yao [13] found that during freezing, the amount of water accumulated in the frozen area of the roadbed, the thickness and spacing of the ice are mainly related to the freezing rate, the type of subgrade soil, the particle size, and the particle distribution. Vaswani [14] studied the effect of temperature on the humidity of the roadbed during freezing. It is found that the temperature has a certain influence on the humidity change of the roadbed below the road surface, and the humidity of the roadbed changes by 1% ~ 5% due to temperature changes.

3.2. Groundwater level

Another important factor is the groundwater level. Groundwater levels fluctuate due to temperature and seasonal variations. Usually the groundwater level rises in the spring and falls in the fall. Russam [15] found when the groundwater level is shallow, it has a more pronounced effect on the humidity of the subgrade than the climatic factors, but when the groundwater level is deep, the groundwater cannot be concentrated on the top of the subgrade due to evaporation.

3.3. Soil type

Soil conditions have an impact on the ability of the roadbed to absorb and saturate. Cumberledge [10] observed that in March and April, the silt or clay humidity increased less than sand, the general clay increased by 1%, the silt increased by 2%~3%, and the sand subgrade humidity increased by 3 %~ 4%. Marks [4] also found that humidity changes due to the type of subgrade soil.

3.4. Road conditions

The extent of precipitation, evaporation and groundwater impact on the humidity of the roadbed is related to road conditions. Road conditions such as drainage systems, play an important role in the change of roadbed humidity.

1) Drainage system

A reasonable drainage design reduces the amount of water that penetrates the roadbed. If there is no water infiltration in the roadbed, the service life of the road can be greatly improved. In order to quickly and thoroughly eliminate runoff water, a reasonable drainage system is necessary.

2) Road conditions

Different road conditions, the water seepage conditions are also inconsistent, resulting in a large difference in the humidity of the roadbed. For new pavements, Marks [4] found that humidity changes very little because the subgrade is better protected by the surface. Russam [15] found that in the case of pavement sealing, the subgrade humidity tends to be relatively stable except for the area near the edge of the subgrade, which is not obvious with the seasons. The subgrade humidity under poor road conditions is significantly affected by seasonal changes and atmospheric precipitation. The initial
amount of rainwater infiltration has a significant effect on the change in the humidity of the subgrade and its frequency.

(3) Shoulder and edge
The type of shoulder directly affects the amount of water infiltrated, and thus has a greater impact on the change of roadbed humidity. On the one hand, the edge of the pavement structure is a weak zone where water can quickly enter the roadbed; on the other hand, the edge portion of the pavement has more moisture that may penetrate the subgrade than the central zone. The results of Benkelman [16] showed that dirt shoulders penetrate more water than hard shoulders; The wider the shoulder, the less water enters the subgrade.

4. Subgrade equilibrium humidity state estimation method
Based on the analysis of the influencing factors of the roadbed humidity condition, domestic and foreign scholars have proposed various humidity estimation methods. In summary, they can be roughly divided into the conventional prediction method, the regional classification prediction method, and EICM method.

4.1. Normal method
The conventional prediction method refers to the fact that the roadbed humidity condition is directly expressed by the empirical relationship using a certain humidity evaluation index, such as the US Navy law [17], the Arkansas Highway Traffic Department (AHTD) [18], and the seasonal monitoring plan (SMP), the volumetric water content prediction equation method [19] and so on. Conventional methods are empirical prediction methods. These methods have certain applicability to a specific area, terrain, pavement structure, soil type, etc., but beyond this range, applications will be greatly limited.

4.2. Regional classification estimation method
The regional classification estimation method uses natural and climatic factors (such as rainfall, evaporation, temperature, etc.) as variables, and uses multiple indicators to quantify the impact of the environment on the humidity of the roadbed, and divides the classification by the area. Estimates, in short, are based on the classification of areas with similar environmental factors into the same category in order to understand their impact on the humidity of the roadbed. At present, the commonly used zoning includes China's highway natural zoning [20], the US TMI climatic zoning [21] and the FHWA climatic zoning [22~23] and so on.

Rainfall, evaporation, relative humidity of the air, sunshine time, etc. are the main climatic factors affecting the humidity of the roadbed, and the location of the roadbed is related to climatic factors, such as the wet and rainy areas in the south of China, and the drought and rain in the northwest. Therefore, in order to be able to characterize both the impact of climate and the impact of geographic location, an estimate is needed. China's current "Road Natural Regionalization Standards" (JTJ 003—86) uses the moisture coefficient K in the secondary division standard, but the moisture coefficient K only reflects the effect of evaporation and rainfall; similar humidity index TMI (Thornthwaite Moisture Index) is used to classify the current climate region of the United States. The effects of typical soil parameters, temperature, rainfall days, and rainfall, latitude, and evaporation are included in the humidity index TMI, which is not only climatic impact, and also the impact of geographic location.

TMI is an annual indicator, which is obtained by the following three main steps: (1) calculation of potential evapotranspiration, (2) calculation of humidity balance, and (3) calculation annual values. The detailed calculation process and description of TMI can be found in the literature [24].

The main representative of FHWA climate zoning method is that Darter [22~23] studied the freezing index and rainfall and evaporation data of various regions in the United States, and divided the whole country into four climate zones, namely: (1) wet frozen zone, (2) Dry non—frozen area, (3) wet non—freeze areas, (4) dry frozen areas.
4.3. Climate model
The most common model for calculating roadbeds affected by climatic factors is EICM. It was evolved from the Joint Climate Model (ICM) in the late 1980s, and was revised twice in the late 1990s and early 2000s to analyze the subgrade and pavement structure as a whole, including “Four sub—models: climate—material—structural model, “precipitation model”, “frozen and sinking model”, “infiltration and drainage model”.

ICM and EICM obtain the humidity condition by estimating the matrix suction of the roadbed under the equilibrium humidity state by means of the soil—water characteristic curve. However, the influence factors in the model estimation are single, and the obtained prediction results have large errors. Especially when the groundwater level is deep, the model needs to be improved.

5. Conclusion
(1) The climatic conditions and groundwater level are external environmental factors that affect the humidity state of the roadbed. The soil properties of the roadbed, the drainage system, and the road surface conditions are internal factors.

(2) Relatively speaking, the regional classification forecasting method can quantify the influence of environmental factors on the roadbed humidity to a certain extent. However, the FHWA climate zoning uses only two variables, with fewer considerations and wider division; and TMI climate zoning The TMI indicators used are more comprehensive and the climate division is more reasonable.

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