Climatological Literature Pertaining to Performance of Highway Concrete

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Drawing from literature, the current state of knowledge regarding the effects of environmental factors on the serviceability of concrete pavements is explored. The basic parameters involved are those that comprise and define climatic domain. However, it is shown that wide variations of these parameters (e.g., temperature) can occur over relatively short distances within a given climatic domain because of topographic, geologic, hydrologic, and floral differences. Thus, while the problem is related to microclimate, the measurements and data currently available are, for the most part, representative of the macroscale. It is concluded that if the prediction of the occurrence of extremes in microenvironmental conditions that lead to localized deterioration of concrete pavement components is ever to be realized, it will first be necessary to determine the critical limits of the various environmental parameters, individually and in combination, and the development of the technology to predict accurately the occurrences of the critical conditions.

•THIS rather pertinent statement was made more than 40 years ago (1): "Any definite information, easily available to the engineer and contractor, about any climatic factor enables them to more surely build good roads." The occasion was a report of an HRB subcommittee charged with the task of preparing an outline of the information regarding the various phases of climate that affect the building, maintenance, and use of highways. This statement is certainly as applicable today as it was in 1929. Furthermore, it appears that, while our knowledge of the mechanisms by which environmental factors influence the performance of highway components has advanced significantly, our knowledge of the critical limits for these factors is still sorely lacking. Even more frustrating is our inability to predict, with any degree of certainty, where the environmental and material factors will combine to create a condition adversely affecting the serviceability of highway pavements.

MACROENVIRONMENT VERSUS MICROENVIRONMENT

One of the major reasons for this problem is the fact that climatological data are usually relied on to define the atmospheric part of the environment. Climatological data, of course, purport to represent conditions over relatively large areas. It can be shown, on the other hand, that environmental conditions can vary greatly over relatively short distances. For example, Geiger (2) reported that only one night with a temperature below freezing (29 F) was recorded during a particular month of May at the meteorological station in Munich, Germany. In the same month, 23 nights with below freezing temperatures as low as 6 F above zero were measured in the air layer near the ground only 12 miles outside the city. In addition to the relatively great distances between weather stations, the problem is further compounded by the fact that the weather instruments from which climatological data are compiled are located at a height of about 6 ft above the ground. Geiger presented additional data showing that

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the extremes of temperature and humidity are considerably more pronounced in the air layer at the ground surface than they are at the level of the meteorological instruments.

The major hurdle in the path of associating environmental factors with pavement performance now becomes eminently clear. It is one of scale—we are going to have to shift our attention from the macroenvironmental to the microenvironmental level.

In speaking of environment, micro or macro, as related to pavement structures, it must be recognized that we are dealing with two domains—the atmosphere and the earth. Furthermore, these two domains are not independent. For example, it can be shown that microclimate is strongly influenced by topography. It should be readily evident that the variations in environment associated with the earth will be great, perhaps greater than those associated with the atmosphere.

USE OF CLIMATOLOGICAL DATA

In view of the variability of microclimate over relatively small areas, it becomes clear that what we have here is a problem in sampling. This immediately implies the need for a statistical approach for both the gathering and the analysis of environmental data. Thom (3), for example, stated it this way: "For the large area of planning decisions for years, even many years in the future, the statistical analysis of historical data resulting in the climatological prediction is required." He goes on to state, "There is today a good body of valid climatological analysis available which can give unbiased climatological prediction for the development of engineering design data almost anywhere in the world." This statement appears to be overly optimistic in view of the high degree of variability in the microclimate within a given climatic domain, as illustrated earlier. The engineering design data and climatological data are related by a so-called "weather design value," which Thom defines as, "The magnitude of a meteorological variable which, when used in the design of an engineering system, nonmeteorological factors having been accounted for jointly or independently, will assure with a given probability that the system will adequately meet a set of prescribed design requirements."

We might ask ourselves at this point, to what extent have environmental data been correlated with design of pavement structures to date? Examples of compilation and use of climatological data are worth mentioning. Eno's 1929 report (1) contains a wealth of information gleaned from publications of the U.S. Weather Bureau. It includes annual variation of temperature at various locations in the United States, lowest temperatures ever observed (through 1922) throughout the United States, lowest monthly mean temperatures throughout the United States for the months of April and November, average lowest temperatures throughout the United States, number of times in a 20-year period that the lowest temperature was 9 F or more below the average lowest temperature throughout the United States, average date when the mean daily temperature falls below 35 F throughout the United States, average dates of last killing frost in the spring throughout the United States, average dates of first killing frost in the fall throughout the United States, average percentage of sunshine in summer throughout the United States, annual average wind velocity throughout the United States, average minimum relative humidity (October) throughout the United States, evaporation rates during warm season throughout the United States, percentage of annual rainfall that occurs each month for various regions of the United States, average annual precipitation throughout the United States, total number of periods of 20 consecutive days or more without 0.25 in. of precipitation in 24 hours throughout the United States, average annual snowfall throughout the United States, average annual number of days with snow cover throughout the United States, and average annual number of clear days throughout the United States. This long list is mentioned to illustrate the varied types of climatological data that were available from the Weather Bureau in 1929 and, presumably, are still being gathered by that agency.

Siple (4) in 1952 presented climatic and geographic data to depict the distribution of frost heave elements and to predict the severity of frost heave.

In 1956, Jumikis (5) analyzed 55 years of U.S. Weather Bureau data in New Jersey and found a strong periodicity of occurrence of severe winters. He also noted that the first damage to roads occurs when the freezing index value of 285 degree-days is reached in any given winter.

Russam and Coleman (6) in 1961 examined the climatic factors related to subgrade moisture conditions.

Larson and co-workers (7) in 1968 presented climatological information compiled from U.S. Weather Bureau data related to bridge deck durability in Pennsylvania. This included average number of freeze-thaw cycles, average annual precipitation, and ASTM weathering index.

The design manual (8) of the U.S. Army Corps of Engineers provides one of the best sources of information with regard to severity of winters at various locations. The manual provides plots of the "design freezing index" covering the areas of the globe where freezing conditions may be encountered.

The examples of sources, compilation, and use of climatological data, just discussed, point up the large number of climatological parameters that have to be taken into account. This brings up another problem: How can the various parameters be combined to provide a unique descriptive factor that can be related to engineering design factors? The Corps of Engineers "design freezing index" and ASTM's "weathering index" are limited attempts to arrive at such a factor. Thornthwaite (9) in 1948 devised a system for rational classification of climate based on precipitation, evapotranspiration, and temperature that might prove to be of use to the highway engineer.

MICROENVIRONMENTAL STUDIES

So far we have dealt only with the gathering and use of climatological data. However, as mentioned earlier, the microclimate within any given climatic domain is so variable as to greatly impair the usefulness of climatological data. In recognition of this fact, numerous studies have been undertaken to evaluate the microenvironment under various specified conditions. Examples of several such studies will be cited briefly for illustrative purposes.

Crabb and Smith (10) in 1953 described a series of extensive experiments in which seasonal soil temperature variations were related to various types of ground cover.

In 1958, Guinnee (11) reported on field studies of subgrade moisture content carried out by the Missouri Department of Highways over a 5-year period. This study entailed considerably detailed measurement of temperature and moisture distributions in pavement subgrades as related to various design parameters.

In a 1968 study for the Pennsylvania Department of Highways, Fang (12) examined the influence of temperature and other climatic factors on the performance of soil pavement systems using data from specific test locations at the AASHO Road Test. Groundwater level fluctuations, frost penetration, and soil temperature distributions and variations were examined in terms of the air temperatures, season, ground cover, pavement type, and amount of traffic for the specific test locations.

Emerson (13) in 1968 reported on an extensive study on bridge temperatures relative to air temperatures.

In 1969, Straub and co-workers (14) described a test installation in which the temperature and moisture distributions were examined beneath pavement and shoulders as a function of the color of shoulders.

In one of two known very recent studies, Larson and co-workers (15) carried out limited tests for the Pennsylvania Department of Highways to evaluate the moisture distribution in a concrete pavement as a function of precipitation, season, topography, and geology of the test area. This group is currently carrying out similar studies on two concrete bridge decks. Moisture distribution studies in concrete slabs on grade were also recently carried out by Stark (16).

CONCLUSIONS

Although the examples just related indicate that work is progressing in an effort to relate microenvironmental factors to those conditions known to be detrimental to pavement structures, it is evident that much remains to be done. The current state of the art in environmental effects on highway components, then, can be summarized as follows: Considerable data are available on the climatic parameters and the mechanisms by which environmental factors adversely affect highway components. However, there are distinct shortcomings in our ability to predict the occurrence of extremes in microenvironmental conditions that lead to localized problems. The determination of the critical limits of the various environmental parameters, individually and in combination with each other, and the development of the technology to predict accurately the occurrences of critical conditions must be our primary concern in the future.

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