THE "SYSTEMS" APPROACH TO CONCRETE PAVEMENTS

Stephen W. Forster, Ph.D., P.G.
Federal Highway Administration, HRDI-12
6300 Georgetown Pike
McLean, Virginia 22101

ABSTRACT

The performance of concrete pavements is influenced by the series of processes that takes place during a project. This paper reviews the processes that have a major influence on the long-term performance of concrete pavements, and suggests a "systems" approach to help assure due consideration of the interaction among these critical processes. The three major processes are: materials selection and mixture design, pavement design and the construction process. Aspects of each process are considered as they can influence uncontrolled cracking, faulting and concrete durability. Decisions made during the three processes must be mutually compatible, as well as compatible with environmental conditions at the time of paving and over the long term. A "systems" approach to concrete pavements would assure that these areas and their interaction are adequately considered, and therefore that long-lasting, high-performance concrete pavements are the routine result. The framework of the HIPERPAV software developed by the Federal Highway Administration is a practical means to apply this systems approach to concrete pavements.

INTRODUCTION

Concrete pavements are considered to be a proven performer when long life and freedom from maintenance and repair for many years is a major concern. Most of the time, concrete pavements live up to this reputation in service. However, there are cases when concrete pavements have not been as distress-free, or lasted as long as we would have liked or expected. In these instances, one or more of the aspects of "engineering" the pavement was most likely not sufficiently considered and accounted for during the process of planning, designing and building the pavement. Premature problems with jointed plain concrete pavements (JPCP) usually fall into three major areas. These are: uncontrolled cracking; faulting across cracks and joints; and concrete deterioration. These problems may arise because of decisions made during materials selection and mixture design, pavement design and/or the construction process, and the interaction of these decisions with environmental conditions (both at the time of paving and over the long term) (1).

It is felt that greater coordination among the concrete materials engineer, the pavement design engineer and the construction engineer would help alleviate many of the performance problems encountered. Such coordination would increase the awareness of how each engineer's decision may impact or interact with the decisions of others. Consider that the people most familiar with the material selection, proportioning and performance of concrete as a material (that is, the concrete materials engineers). They often have little knowledge of, or involvement in, the process by which the pavements are designed which use their material, and in fact depend on the properties of their material for good performance. Similarly, pavement design engineers often lack a full appreciation of the properties and characteristics of the concrete on which the structural behavior of their pavement depends. Finally, the construction engineers have their own concerns and priorities, and may not fully realize how the needs and objectives of the other two groups impact their job and the end results. These three groups must be involved in a closer working relationship to fully and consistently achieve the potential performance of concrete pavements. As a result of such a relationship, each group would gain a better understanding of how their part of the puzzle interacts with the others and the environment to impact the final outcome in terms of pavement performance.

In the sections below, the problem areas will be described, then the four major areas (pavement design; materials selection and design; construction and environmental conditions) will be discussed as they may influence the onset of these problems, followed by a section on how the Federal Highway Administration (FHWA) is trying to make it easier for the groups involved to understand the role each plays and how the interaction of their work may impact the onset of these problems.

THE PROBLEMS

In this section, the three common areas of premature problems covered herein are briefly defined and their causes discussed. This section clarifies what is considered in the succeeding sections of the paper when these terms are used.

Uncontrolled Cracking

Concrete is strong in compression, and relatively weak in tension. Therefore, any uncontrolled full-depth cracking that occurs in concrete pavements is normally due to tensile stresses exceeding the tensile strength (flexural strength) of the concrete. This situation can occur when the concrete attempts to contract and is restrained; attempts to curl or warp (due to temperature or moisture gradients in the slab) and is restrained (due to the mass of the slab), or has inadequate support for an applied traffic load. As used here, this category of cracking is distinct from cracking due to lack of durability of the concrete as a material, which is included under the category of concrete deterioration, as described below.

Faulting

Faulting is a relative vertical displacement that occurs across joints or cracks in the concrete slab because of inadequate load transfer across that joint or crack, and/or inadequate support of the slab at that location. Often the loss of support is due to the presence of water and pumpable materials beneath the slab.

Concrete Deterioration

Concrete deterioration as used here is a material durability (rather than a structural) problem, a failure of the concrete to withstand the chemical and physical environment in which it is placed. Familiar causes of this deterioration are freeze-thaw cycling, alkali-aggregate reactivity, sulfate attack or combinations thereof.

THE RIGID PAVEMENT DESIGN PROCESS

For the purposes of this discussion, we will consider the design of a jointed plain (un-reinforced) concrete pavement (JPCP). Many of the same concerns discussed here also apply to jointed reinforced concrete pavement (JRCP) and continuously reinforced concrete pavement (CRCP). There are a number of pavement design aspects that have an impact on the occurrence of the problems of uncontrolled cracking, faulting, and concrete deterioration. These aspects will be discussed below under each problem area, along with the guidance provided by the frequently-used AASHTO design procedure.

Uncontrolled Cracking

The distance selected for transverse contraction joint spacing (slab length) will have an impact on the potential for uncontrolled cracking in the pavement, since the greater the slab length, the higher the tensile stress build up in the slab because of restraint to slab contraction. This stress can be due to overall temperature and/or moisture changes in the concrete. The AASHTO design guide (2) and the later supplement to the guide (3) recommend local service records as the best source of guidance on joint spacing. A rough guideline provided is that the joint spacing (in feet) should not exceed twice the pavement thickness (in inches). The slab thickness plays a role not only in its relationship to joint spacing, but also as it influences the mass of concrete present to resist slab curling and warping and the resultant stress build up. The base under the slab provides restraint to contraction because of the friction developed at the slab to base interface. Since friction varies according to base type, the type of base selected will also influence the possibility for uncontrolled cracking. The base also influences the tensile stress developed in the slab through its elastic modulus and thickness. Design input values for concrete flexural strength and elastic modulus will influence the occurrence of uncontrolled cracking by influencing the levels of tensile stress necessary to bring about the onset of cracking. It should be noted that the AASHTO guide allows either the direct measurement of the concrete elastic modulus (E_c) via testing such as with ASTM C469, or estimation of E_c from an assumed relationship with compressive strength (f'_c):

$$E_c = 4770 (f'_c)^{0.5} \text{ [units are MPA]}$$

Using this equation can lead to significant errors in estimating the elastic modulus. For input of flexural strength, the required value is that determined at 28 days of age (S'_c) using the third-point loading procedure (ASTM C78, AASHTO T97).

Table 1 lists pavement design factors that influence uncontrolled cracking.

Faulting

As noted above, faulting may be due to loss of support and/or loss of load transfer across joints or cracks. In JPCP, load transfer at transverse joints is accomplished either by aggregate interlock (for short joint spacing) or load transfer devices (usually dowel bars). Successful load transfer by aggregate interlock is dependent on the joint spacing used, as well as (to a lesser extent) the design slab thickness. As the joint (or crack) opening becomes greater, the efficiency of the load transfer by aggregate interlock becomes less, and any differential vertical movement at the joint tends to abrade the opposing surfaces resulting in a degradation of load transfer with time. The AASHTO faulting model for doweled joints includes concrete bearing stress, joint spacing, freezing index, precipitation, base type and use of widened lanes. In addition, the undoweled faulting model includes days with temperatures over 90^o F (32.2^o C) and slab thickness.

Table 2 lists pavement design factors that influence faulting.

Concrete Deterioration

Environmental conditions, as they may affect the durability of the concrete, are not considered in the current version of the design procedure. Thus there is currently no way to include the effects of freezing and thawing, alkali-aggregate reactivity and sulfate attack on the concrete durability.

Influence of Other Aspects of Pavement Design

Several other aspects of the pavement design process may have an indirect effect on the potential for the subject problems because of their impact on pavement thickness or other design characteristics. These aspects are mentioned here.

Time considerations in the design process include the performance period, i.e. the time period for which the pavement is expected to perform acceptably without rehabilitation (typically around 20 years), and the analysis period, the period used for life-cycle costing of the pavement. The analysis period may include one or more stages of rehabilitation, and will hence be longer than the performance period, e.g. 20 - 50 years. As the time considerations increase, the output in terms of pavement thickness will also increase.

Like most procedures, the AASHTO design procedure defines traffic based on the expected cumulative 80. kN (18-kip) equivalent single axle loads to which the pavement will be subjected. As estimated traffic levels increase, the design structure of the pavement must also increase, through either increased slab thickness or increased strength of the concrete.

Reliability addresses the degree of certainty that the design selected will meet expectations. As the reliability factor goes up, so also does the structure of the pavement, and therefore either the thickness or materials properties (including PCC strength).

Serviceability is the ability of a pavement to serve the traffic using the facility, and is measured in term of the Present Serviceability Index (PSI). PSI ranges from 0 (impassible condition) to 5 (perfect condition). The acceptable loss of PSI during the design period could indirectly affect thickness and/or materials requirements (including concrete strength).

MATERIALS AND MIXTURE DESIGN

Although still extensively used, the "recipe approach" to concrete mixture specifications is often not a good, systematic means to optimize concrete in order to achieve long lasting rigid pavements. Matching all the properties of the concrete (not just strength) to the requirements of the project needs added emphasis in order to provide the performance desired. The materials and mix design selected can significantly contribute to, or help prevent, the problems considered here.

Uncontrolled Cracking

Several aspects of the materials and mix design affect the concrete shrinkage/volume change and therefore the concrete cracking potential due to tensile stresses. The coefficient of thermal expansion (CTE) of the aggregate varies according to the aggregate lithologic type. In general, siliceous rocks have higher CTEs than carbonate rocks. This means that for a given temperature drop, a concrete with limestone aggregate will contract less than an equivalent concrete with siliceous aggregate. Since cement paste has a higher CTE than any rock type, as the percentage of aggregate in a given concrete increases, the CTE will decrease (4).

The water-cementitious materials (w/cm) ratio of the concrete will impact the amount of drying shrinkage of the concrete. As w/cm decreases, so too does the drying shrinkage. Also, since the aggregate is usually much more volume stable with moisture change than the cement paste, as the volume percentage of aggregate in the concrete increases, the drying shrinkage will decrease. .

The cementitious materials and their percentages used will control the heat of hydration of the concrete. This in turn will affect the maximum temperature achieved by the concrete during curing, and therefore the potential temperature drop and thermal gradient which the slab may undergo. Drying shrinkage, CTE, and strength of the concrete should all be considered as they affect the volume stability of the concrete, and therefore the uncontrolled cracking of the concrete pavement. At early ages all these concrete properties, as well as creep and elastic modulus, will be changing as the concrete hydrates. Their values and relative values at any given time will affect the potential for early-age cracking in the concrete.

Table 1 lists materials and mix design factors that influence uncontrolled cracking.

Faulting

As noted under pavement design, faulting depends on the amount of joint (or crack) opening, load transfer efficiency, and support provided by the pavement layers under the slab. Concrete materials and mix design influence the first two characteristics. Those factors that influence concrete volume change noted under uncontrolled cracking will also affect the amount of joint or crack opening (which contributes to faulting). In addition, the maximum size of the coarse aggregate, and its volume percentage in the concrete will help prevent faulting in those pavements that depend on aggregate interlock for load transfer, by providing rougher, tougher joint faces that are better able to resist faulting movement. Also, as the strength of the concrete increases, it will be better able to resist faulting.

Table 2 includes materials and mix design features that influence faulting.

Concrete Deterioration

It is during the materials selection and mix design phase that the primary defense against premature concrete deterioration must be established. Depending on exposure conditions, aggregate must be selected which is resistant to freeze-thaw cycling distress, and the paste must be adequately air entrained so that it is also resistant to distress from freeze-thaw cycling. If the aggregate is susceptible to deleterious reaction with the alkalis in the concrete (or more rarely, from external sources) the concrete mixture must be designed so as to prevent such reactions. This may require the use of a low-alkali cement, or the use of suitable admixtures in the concrete. A good overview of this topic is provided in a recent state-of-the-art report (5). Sulfate resistance of paving concrete is not usually a problem, unless it is already deteriorating due to other causes. In extreme cases, sulfate-resistant cement may be used in the concrete.

Table 3 lists materials and mix design factors that influence concrete deterioration.

THE CONSTRUCTION PROCESS

A number of aspects of the construction process interact with the concrete properties and pavement design to influence the acceptability of the concrete in-place, and in turn the performance of the concrete pavement. Mixing time and transportation of the concrete must be in concert with the characteristics of the concrete. The concrete must be adequately mixed to assure homogeneous distribution of the components, but not over-mixed so that aggregate degradation and other potential problems may arise. Transport time for the concrete must be such that adequate time remains for placement, consolidation and finishing prior to set. Problems with mixing and transport time, and stop-gap measures to compensate, will often lead to problems in all the performance areas under consideration. These logistical issues must be considered during the laboratory mix design process to avoid problems during actual paving.

Other aspects of construction directly relate to one or more of the performance problems. These will be addressed below under each performance problem.

Uncontrolled Cracking

For the construction of slip-formed concrete pavements, the concrete must be stiff enough to hold its edge once the paving train has passed. On the other hand, the concrete must have good workability so that it can be placed, consolidated and finished easily. Workability of the concrete depends not only the slump (yield stress) of the concrete, but also on its plastic viscosity. As workability of the concrete improves, due to changes in materials and/or mix design, the placement and consolidation of the concrete becomes easier. If placement and consolidation of the concrete is too difficult, the tendency of the construction crew is to over-vibrate the concrete, or add water in order to get it in place. This can result in segregation of the aggregates in the concrete, and also a reduction in strength. Segregation will cause greater shrinkage potential in those areas with lower aggregate content, increasing the susceptibility to uncontrolled cracking. Also, reduced strength means that lower levels of tensile stress can cause unanticipated cracking of the concrete. The temperature of the concrete at the time of placement, as well as the timing and type of curing used will also influence the potential for uncontrolled cracking. If excessive moisture or heat loss is allowed to occur from the concrete at an early age, critical tensile stresses can easily build up at the surface. Cracking can be the result. Finally, the joint sawing operation must be timely and consider the concrete temperature development and ambient conditions. This will be discussed further under the section on environmental conditions. Inadequate or non-uniform support from the base and subgrade can also lead to uncontrolled cracking.

Table 1 lists construction process factors that influence uncontrolled cracking.

Faulting

Consolidation is critical for jointed pavements using dowel baskets at the transverse joints, since the concrete must be well packed around the dowels in order for the dowels to effectively provide load transfer. This must be able to be accomplished easily, or other problems due to over-vibration and/or water addition will occur, as noted above. Consolidation is just as important for pavements that depend on aggregate interlock for load transfer across joints. The concrete must be well consolidated, without segregation, so that good aggregate interlock is present to provide load transfer and prevent faulting.

If the base and subgrade materials are non-uniform, or inadequately consolidated, the designed support will not be realized as a result of construction. Early failure due to faulting will often result. If the base or subgrade is easily erodable, pumping, loss of support and faulting are more likely to occur.

Table 2 lists construction process factors that influence faulting.

Concrete Deterioration

It is during the materials selection and mix design phase that the primary defense against premature concrete deterioration must be established. Proper construction activities can only achieve the durability designed into the mix, not enhance it. Some construction actions can worsen the concrete durability, such as over-vibration resulting in a less effective air void system. Adding water to the concrete at the job site can lead to weaker concrete which may also be susceptible to freeze-thaw scaling at the surface. Over finishing can weaken the near-surface concrete and drive the entrained air out of the surface zone. This will make the surface susceptible to freeze-thaw damage and scaling. Proper curing is needed to develop proper strength of the concrete at and near the surface, in order that it is resistant to damage due to freeze-thaw cycling.

Table 3 lists construction process factors that influence concrete deterioration.

ENVIRONMENTAL CONDITIONS

There are two aspects of the environmental conditions in which a concrete pavement is placed that will impact performance: the short-term conditions during the paving process; and the long-term conditions over the service life of the pavement.

Uncontrolled Cracking

Short-term (considered here to be the first 72 hours after concrete placement) environmental conditions interact with the pavement design, properties of the concrete and the paving process to determine the degree of success in preventing uncontrolled cracking in the pavement during construction. Ambient temperature and moisture conditions, solar radiation, and wind speed in this period will determine whether precautions will have to be taken in terms of:

- Time of day of paving;
- Special curing procedures;
- Timing of joint sawing; or
- Changes in pavement and/or concrete mixture designs.

There are two aspects to the development of tensile stresses in the slab over the short term:

1. An overall temperature drop of the concrete that will cause the slab as a whole to try to

contract. This contraction will be opposed by the restraint imposed by the friction between the slab and the base.

2. A temperature gradient established in the slab that causes the slab to try and curl, with resulting tensile stresses either at the top or bottom of the slab depending on curl direction. The curl will be opposed by the mass of the slab as it tries to lift off the base.

Since changes in the pavement design or mixture design can't reasonably be made at the time of paving, this scenario emphasizes the need to consider short-term environmental conditions during the design phase.

Long-term environmental conditions to which the pavement will be exposed must be addressed during concrete mixture design and pavement design in order to avoid uncontrolled cracking. As noted above, the pavement responds to changes in temperature and moisture, which can occur on daily and seasonal cycles. The maximum seasonal range of temperatures must be considered during the design phase. Knowing these values, the thermal coefficient of expansion of the concrete, base to slab friction, and the planned joint spacing, the tensile stress versus tensile strength developed in the concrete can be estimated. During the design phase adjustment can be made if the potential for cracking appears too great.

Temperature and moisture gradients through the pavement will also develop stresses in the concrete. The resulting deformation of the slab (curling and warping) can actually lift the slab off the supporting layer for some distance from joints and free edges. This leaves the pavement susceptible to cracking when loads (traffic) are applied. Pavement and mix designs should fully consider the long-term exposure conditions that will exist at the project site, as they may induce curling and warping in the pavement.

Table 1 includes environmental condition features that influence uncontrolled cracking.

<u>Faulting</u>

Long-term environmental conditions are of concern as far as faulting at joints and cracks in the pavement are concerned. For joints without dowels, load transfer by aggregate interlock will rapidly decrease in efficiency as the joint opens. The average opening of the joints during the winter can be calculated. Based on this calculation, adjustments in the mix design and/or pavement design can be made during the design phase if the projected openings will be too great.

The curling and warping of the slab noted above can also make joints and cracks susceptible to faulting when the slab is lifted off the supporting layer. This susceptibility is enhanced when loads (traffic) are applied. Again, pavement and mix designs should fully consider the long-term exposure conditions that will exist at the project site, as they may induce curling and warping and possible faulting in the pavement.

Table 2 includes environmental condition features that influence faulting.

<u>Concrete Deterioration</u>

Freeze-thaw cycling is a common environmental condition that will impact long-term performance, through cracking of the paste and eventual concrete disintegration. This is a condition tied to long-term environmental conditions, both in terms of temperature and moisture. Air entrainment of the concrete is a common and effective means of dealing with this exposure condition by preventing the stresses that cause the distress. It should be verified that the aggregate to be used is not subject to freeze-thaw damage, since such aggregates can also lead to cracking and disintegration of the concrete, over time.

Long-term conditions can accelerate alkali-aggregate reactivity (AAR). Moisture in the pavement is a necessity, and warmer temperatures accelerate the reaction. Preventative steps need to be taken during the mixture design process if this is a concern. If the pavement will be subject to deicer salt applications, this should also be considered, since the deicer appears to accelerate AAR.

Certain sites can be high in sulfate, which will lead to damage to the concrete due to sulfate attack. This can be prevented during the mix design phase by proper selection of the cementitious components.

Table 3 includes environmental condition features that influence concrete deterioration.

FHWA's SYSTEMS APPROACH

The previous sections of this paper have reviewed the many aspects of the three major processes of a paving project, and interactions that must be considered in order to attain the desired JPCP performance. Several years ago the FHWA began a study to develop guidelines to systematically look at these factors for the single issue of predicting and preventing early-age (the first 72 hours after placement) uncontrolled cracking in JPCP. As the work progressed, it became obvious that because of the complexity of the models involved, it would be impossible to develop a set of written guidelines that would be useable by the practicing engineer. Out of this dilemma was born HIPERPAV, a user-friendly software package which incorporated all the complex models, but was formatted for easy use (6, 7, 8, 9). HIPERPAV incorporates four input screens that address the four areas of concern addressed in the preceding sections of this paper:

1. The pavement design;
2. Concrete materials and mix design;
3. The construction process; and
4. Short-term environmental conditions.

For each of these areas, the influencing factors discussed above are considered; either as direct input values or through model prediction based on other input values. Predictive models within the software use the input data to predict the concrete and pavement characteristics and behavior over the 72-hour period. For estimating the potential for uncontrolled cracking, the software predicts and compares tensile stress and tensile strength within the pavement over the analysis period. Output is a simple graph with both stress and strength plotted versus time. From this graph, it is easy to see when the stress line exceeds the strength line, and therefore when cracking is likely. Additional runs of the program may be made in a few seconds, adjusting input data to correct the potential problem. The program not only provides one or more solutions to the problem, but also shows the user how the various inputs interact to impact the results. This is the important point as far as educating the user community to the need for coordination of decision-making during a project. By multiple runs, the user can see how changes in materials, design features or construction tasks can interact to provide a successful or unworkable solution.

Is HIPERPAV the ultimate answer to preventing premature distress? Certainly it is not. First, it only addresses early-age uncontrolled cracking in JPCP. Also, many of the models need additional refinement. However, it is a major step in the right direction. Interest in HIPERPAV is high, and many requests have been received to expand its range of applications and time period of prediction. A follow-up study is currently underway to address the longer-term behavior of JPCP, as discussed herein, and also the early age behavior of CRCP. Faulting and deterioration will be considered as a part of the JPCP behavior. The systems approach is here to stay, to the betterment of concrete pavement performance.

SUMMARY AND CONCLUSIONS

The major problem areas leading to premature deterioration of JPCPs are considered to be uncontrolled cracking, faulting, and concrete deterioration. In order to avoid these problems, and assure the performance of JPCPs, the interaction of pavement design, materials selection and mixture design, the construction process and environmental conditions must be adequately considered. This indicates that the pavement design engineer, mix design engineer, and construction engineer must work together to optimize the pavement.

Based on the discussion herein, it is concluded that:

1. Current pavement design procedures do not adequately consider the impact of concrete properties on all aspects of rigid pavement performance. Usually the concrete strength, in terms of elastic modulus, and/or the modulus of rupture, are the only concrete properties directly considered by the pavement design procedure, and then only as input to the structural design. The AASHTO 2002 Guide, currently under development, will certainly do a better job of considering concrete properties and characteristics.
2. Pavement design factors that influence performance and interact with the other areas in the process include: joint spacing; slab/base friction; slab thickness; concrete properties; base properties; the mechanism of load transfer and concrete bearing stress (with dowels).
3. Materials and mixture design factors that influence performance and interact with the other areas include aggregate type, grading, angularity, maximum size and volume percent; concrete w/cm; cementitious materials types and amounts; aggregate reactivity; and aggregate durability.
4. Construction process factors that influence performance and interact with the other areas include: concrete temperature at the time of placement; vibration and concrete consolidation; curing materials and procedures; as-constructed properties of the base and subgrade; and timing of joint sawing.
5. Environmental factors that influence the performance problems and interact with the other areas include: temperature and moisture levels and variation over the short term; and temperature variation, moisture variation and freeze-thaw cycling over the long term.

Sulfate and chloride exposure are also potential factors.

6. The FHWA has developed the software package HIPERPAV as a tool for systematically addressing the four areas of: pavement design, materials and mix design, the construction process and environmental conditions, when carrying out a rigid paving project. Use of the program educates the user as to the interaction and interdependence of the areas. The current version of HIPERPAV addresses only early-age uncontrolled cracking of JPCP, but additional capabilities will be added as model development and data allow.

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Table 1 - Factors Influencing Uncontrolled Cracking in JPCP

PAVEMENT DESIGN FACTORS	MATERIALS & MIX DESIGN FACTORS	CONSTRUCTION FACTORS	ENVIRONMENTAL CONDITION FACTORS
Joint Spacing	Aggregate Type	Vibration and Consolidation	Ambient Temp. & Moisture Conditions
Base/Slab Interface Friction	Aggregate Volume Percent	Added Water	Changes in Ambient Temp & Moisture during Construction
PCC E-modulus Input Value	w/cm	Curing Materials & Procedures	Daily & Seasonal Changes in Ambient Temp. & Moisture
Flexural Strength Input Value	Cementitious Material Type(s)	Timing of Joint Sawing	Solar Radiation at Time of Construction
Elastic Modulus and Thickness of the Base	Amount of Cementitious Materials	Concrete Temp. at Time of Placing	Wind Speed at Time of Construction
Thickness		As-constructed Properties of the Base and Subgrade	Traffic Loading

Table 2 Factors Influencing Faulting

PAVEMENT DESIGN FACTORS	MATERIALS & MIX DESIGN FACTORS	CONSTRUCTION FACTORS	ENVIRONMENT'L CONDITION FACTORS
Joint Spacing	Cementitious Materials Type(s)	Vibration, Consolidation	Daily/Seasonal Temp. & Moisture Changes
Concrete Bearing Stress (Dowels)	Aggregate Type	Adequacy & Uniformity of Base Density	Daily/ Seasonal Temp. & Moisture Levels
Freezing Index	Aggregate Volume Percent	Adequacy & Uniformity of Subgrade Density	
Pavement Thickness	W/cm	Erodability of Base and Subgrade	
Precipitation	Aggregate Max. Size		
Widened Lanes (Y/N)	Amount of Cementitious Materials		
Days w. T > 90^{o} F			
Base Type			

Table 3. Factors Influencing Concrete Deterioration

PAVEMENT DESIGN FACTORS	MATERIALS & MIX DESIGN FACTORS	CONSTRUCTION FACTORS	ENVIRONMENT'L CONDITION FACTORS
	Aggregate Durability	Over-Vibration	Freeze/Thaw Cycling
	Aggregate Reactivity	Addition of Water	Change in Ambient Temp. & Moisture During Construction
	Air Entrainment	Inadequate Curing	Seasonal and Annual Temp. & Moisture Levels
	Alkali content in Cement & Concrete	Over-Finishing	Sulfate Soils
	Admixtures to Prevent ASR	.	Use of Deicer Salts
	Sulfate Resistant Cement		