The AASHTO Method for rigid pavement (RP) design considers the influence of the localized soil erosion under the rigid pavement by reducing the stiffness of subgrade under the pavement to a certain constant value over the whole area. A reduced modulus of subgrade reaction is generally obtained in this method of design by considering the Loss of Support (LS) which is included in the AASHTO design of concrete pavements to account for the potential loss of support arising from subbase erosion and/or differential vertical soil movements. However, the effect of soil erosion is localized beneath certain parts of the RP (generally beneath the edges of pavements). Therefore, damage generally occurs at these edges. In addition, the ultimate responses of the rigid pavement under the actual soil erosion scenarios may be affected by several other parameters such as percentages and location of soil erosion occurred, the value of subgrade stiffness, slab dimensions, and slab thickness which almost are neglected in the AASHTO design method. Therefore, in this research the ultimate RP responses obtained using the AASHTO design method are evaluated and compared with those obtained from a new proposed technique for modeling the soil erosion. In this technique the different parameters mentioned above are considered in evaluating the RP behavior and their significance in predicting the responses is examined. The proposed technique is conducted using a non-linear finite element procedure considering the Soil Structure Interaction (SSI) under different soil erosion scenarios. Finally, the importance of considering these parameters in the rigid pavement design procedures is highlighted.
The concrete pavement design procedures evaluate a candidate pavement design with respect to two potential failure modes: fatigue and erosion. Damage of the pavement is mostly caused by soil erosion beneath the pavement. Moisture trapped in the soil typically reduces subgrade strength and causes loss of slab support due to subbase and subgrade erosion and pumping, which results in pavement settling, faulting at joints and corner breaks. The main objective of this research is to investigate the influence of several parameters such as different scenarios and percentage numbers of soil erosion, slab dimension and slab thickness on the structural behavior of slab pavements. Furthermore, a comparison between the pavement responses resulted from the analysis in this study and the pavement responses resulted from the AASHTO design procedure was conducted. The analysis of the results showed that there is a significant effect of these parameters in the ultimate behavior of the rigid pavements under different soil erosion scenarios.

Mineral aggregate constitutes approximately 95% of hot-mix asphalt (HMA) by weight. The mineral aggregate is made predominantly of coarse aggregate. Characteristics of the coarse aggregate such as particle size, shape and texture influence the performance and serviceability of hot-mix asphalt pavement. Flat and elongated particles tend to break during mixing, compaction and under traffic. Therefore, aggregate properties are considered to be very important factors that should be included in the mix design of asphalt pavement to avoid premature pavement failure. The objectives of this research is to: (1) evaluate the influence of coarse aggregate properties selected from different sources in Egypt on the tensile strength of HMA mixes, and (2) evaluate the effect of natural aggregate on HMA properties. To achieve these goals three sources of aggregate were selected from different locations in Egypt to encompass as wide range as possible. The aggregate characteristics included in this study are percentages of flat and elongated particles, percentages of fractured faces and particle index. The strength of mixes was evaluated using the indirect tensile, stability and flow tests. The analysis of the results indicated that the properties of aggregate significantly affect the indirect tensile strength and stiffness of mixtures.
The Mechanistic-Empirical (M-E) design method for rigid pavement employs mechanistic models to calculate a huge number of pavement responses due to a spectrum of traffic loading. One major assumption frequently associated with the mechanistic models is the uniform tire-pavement contact stress distribution over a circular contact area with the contact stress simply equal to the tire inflation pressure. However, experimental measurements and recent studies have demonstrated that the actual tire pavement contact stress (loading condition) is non-uniform and depends on the tire construction, tire load and tire inflation pressure. In this study, calculated non-uniform tire-pavement contact stress data for different tire load and inflation pressure conditions were used to predict rigid pavement responses through a finite element (FE) procedure. The objective was to establish a procedure on how wheel load can be considered in currently mechanistic models to represent the non-uniformity of tire contact stress. Finally, a comparison was conducted between the two different contact stress distribution (uniform and non-uniform). The data generated from this study illustrated that there is a significant difference between the responses computed with uniform (conventional assumption) and
Recently, many highway agencies have moved toward the development of Performance-Related Specifications (PRS) to calculate the payment to the contractor. In this method of specifications, the pay factor is determined by comparing the anticipated performance of the as-constructed pavement to the corresponding as-designed pavement through an acceptance plan. The anticipated performance mainly influenced by the measurable quality characteristics such as resilient modulus of pavement layers, California Bearing Ration (CBR) of subgrade soil and layers thickness. These variables can be controlled by the contractor and can be also selected in a manner to satisfy the specifications. On the other hand, the environmental parameters affect on the variation of pavement materials properties. Consequently, these changes affect on the anticipated performance and the payment to the contractor. Therefore, the objective of this paper is to develop a procedure considering the environmental effects in establishing the PRS and payment schedule for flexible pavements. The key parameter that was selected to reflect the environmental effects is the layer elastic modulus, which changes with surrounding environment parameters, such as: temperature (for asphalt bound layers) and moisture (for unbound materials). The effect on the elastic modulus or modulus of resilience value of a pavement layer may be represented by a multiplying factor, called "Seasonal Adjustment Factor". Finally, a framework has been established for the PRS including the environmental effects.
The objective of this paper is to investigate the impact of changing the environmental parameters on performance of flexible pavements. There are many input parameters to the Mechanistic-Empirical (M-E) design procedure such as traffic loading, structural capacity, and variation of pavement material properties due to seasonal environmental changes, especially the temperature for asphalt materials and moisture variations for unbound materials. The variation of the unbound material properties due to environmental effects is incorporated in the M-E design procedure via a series of Seasonal Adjustment Factors (SAF) that adjust the unbound layer moduli from one season to another. Error in estimating SAFs of unbound layers leads to variability in the designed asphalt thickness and consequently in the pavement performance. To achieve the objective of this paper, a sensitivity analysis has been performed on a selected pavement cross section located in the northern of Egypt. The analysis was conducted using M-E overlay design program based on Egyptian climatic zones named OLFLEX. In this analysis the errors in estimating SAFs were changed from ±10% to ±50% creating 121 runs or design cases. For each run, the designed thickness and corresponding pavement responses, number of repetitions to failure (due to fatigue cracking and rutting distress), and year of failure have been calculated. The results indicated that changing the environmental parameters, represented by SAFs for unbound layers, has a significant effect on pavement performance.
The Mechanistic-Empirical (M-E) overlay design procedure incorporates many design factors. These factors include the expected future traffic, the structural capacity of the existing pavements, and the variation of pavement material properties due to seasonal environmental changes, especially the temperature of asphalt materials and moisture variations in unbound materials. Miscalculation of these factors produces over or under design cases. The effect of these blunders on the pavement Life-Cycle Cost (LCC) has major concern to pavement designers and decision makers. Therefore, this study addresses the effect of over/under design due to underestimation/overestimation of Seasonal Moduli Adjustment Factors (SAF) of unbound materials on the pavement LCC. Sensitivity analysis has been conducted on a pavement cross section located north of Egypt. The analysis was performed using M-E overlay design program based on Egyptian climatic zones, named OLFLEX. Analysis of the results indicated that variability of SAF of the base layer has more sound effect than of the subgrade layer on the designed overlay thickness and pavement LCC. For over design cases, every 1% increase in overlay thickness produces an average of 1.16% reduction in LCC due to underestimating the SAFs. For the under design cases, every 1% decrease in overlay thickness creates an average of 0.17% increase in LCC due to overestimating the SAFs. The outputs of this study are considered beneficial and vigorous in designing and/or rehabilitating the flexible pavements.
Sameh A. Galal, "Influence of Coarse Aggregate Particle Shape and Texture on Characteristics of Hot-Mix Asphalt", Proc. of 3rd Regional Conference on Civil Engineering Technology and 5th International Symposium on Environmental Hydrology, ASCE, Egypt-Section, Cairo, Egypt, 3-5 September, 2007.
Particle shape, angularity and surface texture are critical properties in assessing aggregate usage for asphalt concrete mixtures. Fractured and flat and/or elongated particles are used in most specifications to assure quality. The particle index and the percentages of flat and elongated particles indirectly measure particle shape, angularity and surface texture and offer alternative options. The objectives of this study are: (1) to characterize and quantify the coarse aggregate particle shape and texture that are used in hot mix asphalt (HMA) mixtures and selected from different aggregate sources in Libya and (2) to evaluate the influence of flat and/or elongated particle and fractured particles percentages on the particle index of the coarse aggregate produced from these sources. The aggregate shape and texture are evaluated in this research using percentages of fractured particles, particle index, flat or elongated particles and flat and elongated particles.
The discussion of the structural damage of a flexible pavement due to the combined influence of traffic loading and environmental considerations has been the thought that this knowledge, measured in terms of stress, strain and deflection, could be applied in some way to the pavement analysis, performance prediction, and design. Such application can not be realized, however without the ability to determine the state of stress that occurs within the pavement due to the effect of loading and environmental factors. In addition, mechanistic-empirical pavement design methods for flexible pavement are based on the assumption that the pavement performance and life are inversely proportional to the magnitude of the traffic-induced pavement strains. These strain vary with the stiffness of the asphalt layer, which in turn, varies with temperature. Because these relationships are nonlinear, the additional pavement life consumed at higher-than-average temperature is not offset by savings at lower-than-average conditions. As a result, whenever average pavement temperatures are used to determine the asphalt stiffness, pavement life is overestimated. There are two major failure mode of thermal cracking: low-temperature cracking and thermal fatigue cracking. Low-temperature cracking is caused by accumulated thermal stresses in the pavement layer during cold winters. Thermal fatigue cracking is caused by daily cyclic thermal loading. This paper presents a review of the effect of temperature on asphalt mixture stiffness and pavement performance and life.
Many agencies use End-result specifications to calculate pay factor. This specification considers the variability of materials and construction (M&C) factors, but does not recognize the long-term performance. For this reason, the highway agencies have developed the performance-related specification (PRS), which depends mainly on the anticipated long-term pavement performance. In this specifications, the life cycle cost (LCC) of the as-constructed pavement is calculated and compared with the LCC of the as-designed pavement to determine the pay factor. The previous studies of the PRS have used limited models when calculating the pavement response. These models are based on linear elastic theory or linear viscoelastic theory and are not representative to the exact behavior of the pavement materials. Finite element method can deal with the nonlinearity and orthotropy of the materials. The aim of this study is to develop a framework for flexible pavement PRS using a suitable finite element model comprises material properties models more representative to the actual behavior of pavement layers to determine the pavement response. To demonstrate this framework, a computer program is developed to relate the M&C factors to the expected pavement performance and in turn to calculate the contractor pay factor using the finite element procedure.
A finite element model is used to calculate the pavement response through a framework of a performance-related specification (PRS). In this framework, the quality characteristics of the pavement is related to the mixture response, the pavement response, the anticipated pavement performance and, at the end of the chain, the contractor pay factor using different mathematical models. A sensitivity analysis is an important tool for evaluating the behavior of the models that included in the framework of the PRS. A wide range of conditions (levels of independent variables) that cover the region of interest may be used in the sensitivity analysis. Such an analysis will indicate whether the models respond realistically to the independent variables. A sensitivity analysis can also be used to identify the variables that require careful definition. The main objective of this study is to evaluate the effect of the finite element meshing parameters and materials properties models (independent variables) on the pavement response and contractor pay factor (dependent variables). This involves the selecting of two or three levels of values for each independent variable and determining the response value for all combinations of all independent variables. The results of this analysis are calculated from a computer program that developed for the framework of the PRS to determine the pay factor. This program uses the finite element procedure in determining the pavement response.
Statistically-based end-result specifications (ERS) have been adopted by many highway agencies. These specifications shift the burden of process control from the agency to the contractor by allowing the contractor to choose the methods and procedures to accomplish the work. The agency then accepts or rejects the work based on the results of the acceptance test. ERS specify minimum or maximum test results (or percent defective limitations) required for work to be acceptable. The test results or limitations are based on unbiased statistically quality assurance procedures. The main deficiency of ERS is the dependence of payment schedules on the contractor’s present performance task ignoring what might be the long-term performance of the pavement. This deficiency is what has given rise to the development of performance-related specification (PRS). In the PRS the anticipated performance of the as-constructed pavement is predicted using many mathematical algorithms and then compared with the performance of the as-designed pavement to calculate the contractor pay factor. In this paper a comparison between the procedure of statistically-based ERS and PRS is presented. A case study using data collected from the highways network in Egypt is examined and presented in this study.
Recently many agencies have developed quality control or quality assurance techniques with the desire to improve the quality of construction and provide an incentive for the contractors to use new construction methods or materials. Materials and construction variability is one of the measures to assess quality and it is thought that reduced variability is an indication of improved quality of construction. The objective of this research is to analyze the effect of variability in materials and construction variables (quality characteristics) in Egypt on pavement performance and contractor pay factor. The study reviewed the variability in pavement construction in Egypt and used these results in developing the variability in pavement performance and pay factor using two approaches: Monte Carlo approach and Partial Derivative method. A sensitivity analysis was performed to examine the effect of deviation from the target for different variability of materials and construction variables on pavement performance and contractor pay factor. From this study, it can be concluded that the variability in pavement construction significantly affects the pavement performance and contractor pay factor.
A highway construction acceptance procedure must be designed to encourage the control of materials and construction (M&C) variables that reflect long-term performance. Therefore, many highway agencies moved away from the traditional specification methods (Method-type and End-result specifications) to Performance-related Specifications (PRS).

Performance-related specifications take into account the long-term performance and Life Cycle Cost (LCC) of the pavement and relate them to the M&C variables. Reward or punishment applied on the contractor is based on comparing the LCC of the as-constructed to the as-designed pavements. To best meet these objectives, the procedure of pavement evaluation follows many statistical algorithms related to pavement performance and economy. These algorithms are executed in a general framework, which contains many steps to calculate the percentage of the payment to the bid price (pay factor). The first step in the framework of this study is input data used in estimating the response of both the asphalt mixture (resilient modulus) and the pavement (tensile and compressive strains). Failure of the pavement is indicated by the number of repetitions to failure due to rutting, roughness or fatigue cracking which are considered in this study as pavement performance indicators. The next step is the acceptance plan, which includes cost analysis and pavement economy to determine the contractor payment. Finally, the pay factor is calculated by relating the payment to the bid price.

Due to the importance of PRS and the concern of most highway engineers with this type, many previous computer programs were developed to sustain this type of specification. Unfortunately, these programs were developed under a rather rigid framework limited to specific conditions. The main objective of this study is to develop a new program to provide a much more flexible framework that suits various pavement conditions. Several user-friendly models are utilized in each step to calculate the pay factor. The most important variables that influence the pay factor are deduced from the sensitivity analysis performed on M&C variables.
The primary difference between performance-related specifications (PRS) and other specifications is the payment schedule. The PRS include a payment schedule that is related to the anticipated performance of the pavement. But, in order for performance-related specifications to be adopted and successfully implemented, the models that predict pavement performance must be well understood and must provide reasonable results. An excellent methodology for measuring and evaluating the effects of independent parameters upon their associated response variables is a sensitivity analysis. The objective of this study is to evaluate the effects of materials and construction parameters (independent variables) upon pavement performance as well as payment schedule (dependent variables). This process involved selecting ranges of values for independent variables, then using the models to determine the values of the dependent (response) variables. The results of this sensitivity analysis, are carried out from a computer program that was developed specially for this reason and was designed to obtain the payment schedule of performance-related specifications. This program has the flexibility to choose between different models to predict pavement performance or uses a user-defined option to utilize the users values. Another sensitivity analysis was made in this study to evaluate the effect of using different models that used in predicting fundamental mixture response variable (FMRV) on the pavement performance and payment schedules results.
The quality of highway construction has always been a major concern to highway engineers and contractors. The AASHTO Quality Assurance Guide Specification uses the variability of the materials and construction processes as one of the measures to assess quality. It is sometimes thought that a more uniform product, one with less variability, is an indication of better quality. In this study the variability in highway pavement construction in Egypt is investigated and the standard deviation was used as the most typical variability measure. The study reported typical variabilities found in materials and construction processes in selected highways in Egypt. From data gathered in this study, variability has a relatively wide range of values for each test procedure and materials and construction property. Factors that may influence this variability include the period of time, distance, area, and quality of material over which the variability is measured. The major objective of this study is to report the variability found in materials and construction processes for highways in Egypt, and to compare those values with the typical variability found in the previous international studies. Another objective is to discuss the use of these typical variability in establishing specifications limits.