Quality of Pavement Construction in Saudi Arabia

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Abstract: The road network in Saudi Arabia has experienced remarkable development both in length and standards to become one of the longest and most modern highway networks in the Middle East. Quality of performance of some roads, however, was below a satisfactory level. Various parameters directly and indirectly contribute to the pavement quality performance. The contributing factors are design, specifications, environment (traffic, temperature), and construction-related factors; the indirect factors are managerial-related factors. This paper reviews the factors that contribute to the quality of pavement performance in Saudi Arabia. This review was achieved via both a comprehensive literature review and a highway contractor's survey. The significant performance factors were arranged into three groups: (1) managerial-related factors that include qualification of owner's inspection team, contractor experience, and capability; (2) design and specifications-related factors that include consideration of regional conditions in design, aggregate quality, mix design and composition, and asphalt characteristics; and (3) construction-related factors that include aggregate characteristics, placement and compaction process, uniformity of materials, and mixing operation control. The consideration and improvement of these factors in future pavement construction could lead to better pavement performance, longer service life, and lower maintenance costs.

INTRODUCTION

The road network in Saudi Arabia has experienced remarkable development both in length and standards to become one of the longest and most modern highway networks in the Middle East. The total length of paved roads was 12,200 km in 1975, and currently the length is in excess of 40,000 km. The government has invested more than $30 billion in road construction.

Pavement engineers and contractors in Saudi Arabia are faced with the challenges of constructing pavement for desert sand dune areas, mountainous areas, and in the sabkha or salt flat areas. Each area has its own difficulties and requirements in terms of design, specifications, and construction practice. At the same time, the quality of materials varies according to their availability in each area. This may lead to varying pavement performance and varying service life for a highway that may cross more than one area.

Worldwide, there are numerous examples of successfully constructed asphalt pavements that were built to withstand heavy traffic in desert climates, or in airport runways where the aircraft loading is much more severe in gross loads and tire pressure than roadways. The construction of asphalt concrete, however, is a complex process involving many critical stages. The probability of deviating from the specified requirements during the construction process can be very high. Deviation from the specifications can impact the performance of the asphalt concrete pavement.

Some of the newly constructed highway pavements in Saudi Arabia have exhibited a marginal quality of performance. This has been manifested in a premature permanent deformation. There are multiple parameters that contribute to the pavement's performance quality. These parameters are grouped into three categories: (1) managerial-related factors; (2) design- and specifications-related factors; and (3) construction-related factors. To improve quality of pavement performance, top management (in contractor firms and highway organizations) should not address technical factors only, but rather both the technical and the managerial factors should be considered. The purpose of this paper is to make a global review of pavement quality performance. It identifies factors that contribute to pavement performance from the contractor's view; these include management, design and specifications, and construction-related factors. This was achieved via a literature review and a survey among highway contractors. The study is of benefit to both highway contractors and highway organizations. Identification of the factors that contribute to the problem will lead to a better understanding of pavement performance, and thus improved quality, longer service life, and lower maintenance costs.

SPECIAL DESIGN PRACTICE

Since about 50% of the land of Saudi Arabia is covered by sand dunes, several research studies have been carried locally about sand stabilization and sand control. The studies recommend using stabilized embankment, and the embankment slope should be as flat as possible. The slopes are chosen to allow most of the sand particles generated by the prevailing wind to travel the roadway (Fookes 1976, 1978; Oweis and Bowman 1981). In the case of the sabkha subgrade, highway designers in the past always attempted to keep the road alignment away from

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sabkha areas. Where this was not possible, it was necessary to overcome various problems. Sabkhas in general are made up of nonuniform, variable, and highly compressible materials. This leads to differential settlements in pavement structure constructed on their surfaces. Also, the high concentration of chlorides and sulfates in sabkha sediments makes it highly corrosive, which in turn renders concrete and steel structures susceptible to continuing deterioration. Additional problems associated with sabkhas include pavement cracking due to salt crystallization near the surface and volume change of gypsum in sabkhas due to hydration and dehydration. To overcome sabkha problems, initial road construction methods utilized a stone mattress. Through the many years of roadway construction the highway authority began to engineer solutions for specific sites. The most common method is to build the road over an embankment of at least 1 m in height. Other methods include the selection of a granular embankment material to minimize capillarity water rise, the use of geotextile as a stabilizer and a separator, and the stabilization of the sabkha with asphalt admixtures (''Highway'' 1988).

Regarding the design standards, the first set of standards was introduced in 1964 by international consultants and were usually based on American and European highway practices. These standards were not always suitable for the specific conditions in Saudi Arabia. Over the many years of construction the highway authority developed experience and, aided by a team of specialists was able to establish its own standards. Now all designs are done inhouse based on the comprehensive design manual that was published in 1985. International consultants are also contributing to the research and development of pavement design and pavement rehabilitation.

PAVEMENT FAILURE MODES

Although there are several modes of pavement failures in Saudi Arabia (i.e., rutting, cracking, fatigue, etc.), the prominent failure mode is rutting, which is the permanent deformation in the form of longitudinal depressions that develop under traffic in the wheel paths. These ruts have a considerable length (6 m or more). Rutting reduces road serviceability, driving comfort, and presents a hazard to moving vehicles. The possible causes of rutting can be classified into five basic categories: traffic-related causes, climatic-related causes, construction-related causes, materials selection-related causes, and asphalt mix design-related cause. The increased occurrence of rutting, particularly in pavements that have performed satisfactorily for several years, is due to the larger truck traffic volumes, increased gross vehicular weights, and higher tire contact pressures. Changes in asphalt mix design, materials selection, and construction practices should be adopted to upgrade the pavement quality to the level required to meet with these increased loads.

RESEARCH METHOD

A survey was designed to identify construction-related factors that affected pavement quality of performance. The survey was forwarded to highway contractors in Saudi Arabia. Sixty-one contractors were sent questionnaires; 31 contractors responded to the survey.

A questionnaire form was developed based on a thorough review of the related literature and several interviews with highway contractors. The questionnaire consists of two parts. The first part includes general information questions about the respondent's firm. The second part lists 16 factors that impact pavement performance (six management-related factors, six design and specifications-related factors, and six construction-related factors). It is well understood that there are several other factors that can affect pavement performance; however, the factors under study are the ones suggested by the contractors in the preliminary interview. These factors were explained and ranked according to their impact index.

The respondents chose one out of four possible answers representing varying degrees of impact, on a scale of 0 to 3. A response of 0 meant the factor had no impact; 1, little impact; 2, moderate impact; and 3, high impact. The questionnaires were analyzed and the impact index was calculated for each factor using the following formula:

$$\text{Impact index} = \sum_{I=0}^{3} \frac{(Ai \cdot Xi)}{N} \cdot \frac{100}{3}$$

where Ai = weight for each response; i = 0, 1, 2, and 3; and Xi = frequency of the ith response.

FACTORS AFFECTING PAVEMENT PERFORMANCE

The result of the questionnaire is shown in Table 1. The factors that are believed to affect pavement performances are listed with their level of impact. The three groups of factors (management, design and specifications, and construction) are discussed in the following paragraphs.

TABLE 1. Factors Affecting Pavement Performance in Saudi Arabia

Factors	Impact index (%)
Managerial	
Qualifications of owner's inspection team	85
Contractor's experience	83
Contractor's workforce and equipment capability	83
Contractor's qualification	73
Delay in progress payment	72
Amount of work subcontracted	39
Design and specification	
Pavement not designed for regional conditions	94
Quality of aggregate	94
Mix design	89
Mix composition	87
Asphalt characteristics	84
Construction process	
Aggregate characteristics	94
Placement and compaction process	88
Uniformity of materials	85
Mixing operation control	80
Acceptance procedure	62

Managerial Factors

Although the quality of pavement performance is a direct function of material selection and mix design, it is influenced by the contract management. The most important elements in successful construction management are the people, their attitude, skill, and knowledge. The first factor in the managerial group is the qualifications of the owner's inspection team and the contractor's personnel. It has an impact index of 85%. The qualifications and experience of the inspection team are essential for quality work. The inspection team should ensure that the plan and the specifications are followed to verify that the finished pavement meets the project's requirements. They should understand the design of each element of the pavement and its practical functions. Otherwise, the finished pavement might not satisfy the minimum requirement resulting in a pavement with a reduced performance level (Gendell and Masuda 1988; Jackson 1990; Al-Hassan 1993).

Almost all construction workers in Saudi Arabia— skilled, semiskilled, and unskilled— are expatriates from all over the world. To cut operation costs, many contractors have employed young, inexperienced engineers to carry out their field supervision (Al-Jarallah and Mohan 1986). Since the quality of a pavement is generally the product of the materials utilized and the construction process followed, lack of an experienced staff can lead to inadequate process control resulting in low quality work. To ensure that contractor's engineers are suitably qualified, personnel prequalification for engineers has been adopted by the Saudi Ministry of Communication (MOC).

The second and third factors are the contractor's experience, and the contractor's workforce and equipment capability. Both have an impact index of 83%. Proper construction experience and equipment often determine the overall quality of performance. They enable the contractor to develop better and more economical ways to accomplish the work. They play a major role in highway construction projects. They are of special importance to Saudi Arabia since it encompasses varying suitable subgrades, i.e., sand dune areas, mountainous areas, and sabkha ''salt flat'' areas that require special experience and capability to provide the design, specifications, and construction challenges for the specific subgrades.

The qualification of the contractor has an impact index of 73%. The success with which a project is executed is largely dependent on the capability of the contractor. It is very important to obtain a qualified and competent contractor to construct the project. If an owner awards the contract without seeking proper verification of the contractor's capabilities or when the prequalification process is not effectively implemented, it may result in having an incompetent contractor executing the project. This can lead to additional cost and/or poor quality (Koehn and Regmi 1990; Russell 1990).

Delay in progress payments has an impact index of 72%. Delay in payment or a slow payment procedure by the owner to the contractor will impose serious problems on managing contractor cash flow operations, keeping working capital at an adequate level, and on other financial obligations. When the contractor feels that payment is being unreasonably delayed, an adverse relationship may develop that may jeopardize project quality (Halsted and Hughes 1981).

The amount of work subcontracted has the lowest impact index of 39%. General conditions of highway contracts in Saudi Arabia require the prime contractor to execute not less than 50% of the original contract amount with his own organization. The prime contractor should submit the subcontractor's list for approval by the MOC. This includes providing information regarding the subcontractor's experience, qualifications, equipment, type of activities performed, and capability.

Design and Specifications Factors

Management of personnel during the scope of pavement construction is important; however, management of the process itself is the key to continuous process improvement. The adverse affect of inaccurate design and specifications on project quality is severe. They will cause confusion, poor quality, and problems in contract administration. Pavement that is not structurally designed for the regional conditions has the highest impact index of 94%. The pavement design process consists of finding an appropriate combination of materials and layer thickness that mitigates various forms of distress induced in the pavement from traffic and environmentally related factors. Such a process requires relatively accurate traffic, climate and soil-type data, and reliable design procedures in order to select material characteristics and thickness to provide an adequate pavement performance for the required design life. Within Saudi Arabia, there are special traffic and environmental (temperature and soil type) conditions that do not allow the use of design criteria and standards based on other countries' experiences. An example is the use of the full-depth asphalt concrete pavement method. Owing to the increase in the traffic volume and the type of vehicles using the road network in the 1970s, full-depth asphalt concrete layers up to 25 cm thick were used for primary roads. The limitations of the full-depth asphalt pavement became evident when the roads were subjected to high axle loads coupled with extreme temperature conditions. Some of these roads developed early rutting. The rutting problem may not be directly attributable to the implementation of full depth design. The use of full depth design, however, did not improve the pavement performance. The new design procedure limits asphalt concrete layer thickness to 15 cm. The remaining required thickness is made up of crushed aggregate coarse or angular subbase materials.

The quality of aggregate also has an impact index of 94%. Pavement performance can be greatly influenced by the quality and uniformity of the aggregate used. The angularity, durability, and chemical nature of the aggregate have a significant effect on the properties of the mix in resisting permanent deformation. The previous specifications requirement for fine aggregate in Saudi Arabia allows contractors to use aggregate that has undergone insufficient crushing or that contains natural sand (dune sand) in the asphalt concrete mix production. Since dune sand has a significant amount of well-rounded and subrounded particles, and because this material has very low internal friction compared to crushed sand, the use of this material in mix production would tend to produce mixes with lower mechanical strength. Permanent deformation can develop under heavy traffic loading when the mix has low mechanical strength.

Mix design that does not take into account local conditions (i.e., traffic and climate) has an impact index of 89%. In Saudi Arabia, there are special traffic and climate conditions that can be considered unique. Such conditions are far more severe than those encountered in most western countries, and so make the transfer of mix design technology and experience from developed countries an intricate and often risky practice.

Asphalt concrete mixes in Saudi Arabia have always been prepared using the Marshall mix design method. This method does not indicate the shear strength of the mix design and therefore does not eliminate the mixes that may be prone to rutting. The MOC recently started using the Hveem stability test along with the Marshall requirements to eliminate the mixes that may be prone to rutting. Mahboub (1990) stated that current methods of mix design are being used for purposes beyond what they were developed to do. Current mix design procedures are based on specific conditions that no longer completely apply today. For example, gross axle weight and tire pressure are frequently much higher today than they were just a few years ago.

Because of pavement durability problems during the 1960s, the highway general specifications were revised in 1972. Densely graded wearing and a base coarse mixture were specified along with the use of natural sand. The minimum requirement for crushed sand in fine aggregate was set at 25%. In other words, natural sand can be used up to 75% by weight of fine aggregate. For asphalt content, the policy of adding as much asphalt as possible was promoted to improve the durability of highway pavements. The tremendous increase in the volume and type of traffic using the highway network has resulted in early rutting in some of the newly constructed asphalt concrete pavements. With densely graded mix and a large quantity of natural sand, voids in the mineral aggregate (VMA) are usually low. Asphalt concrete mixes become more prone to rutting as their VMA decreases. Low VMA values generally indicate that a mix will be deficient in either asphalt content or air-void content. Low VMA can cause a further reduction in the air-void content in the asphalt concrete layer owing to traffic compaction. This will cause flushing, loss of stability, and severe rutting with a collapse of the bearing capacity of the asphalt concrete layer. Recently, new specifications for primary roads have been introduced. Both asphalt concrete base and wearing course are now composed of a more open and coarse aggregate gradation with minimum VMA to achieve higher air-voids content.

Mix composition (aggregate gradation and asphalt content) has an impact index of 87%. Mix composition plays a great role in providing the necessary properties, i.e., stability, durability, and so forth. The proper aggregate gradation allows sufficient voids to accommodate the proper asphalt film thickness on each particle. Severe rutting, with a collapse of the bearing capacity, occurs for any asphalt concrete layer if the air-void content is not sufficient. Therefore, it is necessary to avoid producing a low air-void content under the highest degree of compaction from traffic. The use of relatively coarse aggregate gradation will ensure enough free air voids during the pavement's service life.

The proper asphalt content is critical in obtaining the desired void content in the compacted mix, and affects durability, flexibility, fatigue resistance, stability, and susceptibility to moisture damage (Hay and Kopack 1986). The optimum asphalt content of a mix is highly dependent on aggregate gradation and absorptiveness. The finer the mix gradation, the larger the total surface area of the aggregate and the greater the amount of asphalt required to uniformly coat all particles. In hot climate conditions, as is the case of Saudi Arabia, a densely graded mix with high asphalt content may produce mixtures that are susceptible to deformation. With coarse gradation, the quantity of asphalt can be reduced since coarse gradation has less total aggregate surface area, which demands less asphalt.

Asphalt characteristics have an impact index of 84%. The physical properties of the asphalt cement used are important and have significant effects on the properties of the mixture. Asphalt cement grade 60–70 is the bitumen used in Saudi Arabia. Considering Saudi Arabia's hot climate, this is a soft bitumen for primary roads and thus as a major factor in the problem of pavement rutting. A soft-grade asphalt in hot climatic conditions results in tender mixes prone to permanent deformation and bleeding when subjected to heavy traffic loading. Grade 60–70 bitumen has a softening point between 49 and 54°C. This is far below possible pavement surface temperatures in Saudi Arabia, which can reach 70°C. Because the filler content increases the softening point of the bitumen-filler mortar, special requirements for the filler-to-asphalt ratio have recently been adopted by MOC for primary roads in Saudi Arabia. A filler-to-asphalt ratio of 1.5 is targeted at the optimum asphalt content to achieve a softening point exceeding 75°C. Fatani et al. (1992) suggested the use of either a harder asphalt grade or polymer-modified asphalt to mitigate the problems associated with performance of grade 60–70 asphalt.

Construction Process Factors

During the construction phase, there are many factors that can affect the quality performance of pavement—

from the source of material—to mixing, placing, and testing. Control of aggregate gradation, amount of asphalt content, mixing temperature, and paving and compaction processes are all critical factors in pavement performance.

Aggregate characteristics (gradation, shape, type) have an impact index of 94%. In Saudi Arabia there are three distinct regions as far as the quality of aggregate for road construction is concerned. The western and northern regions have good quality aggregate with some areas of marginal aggregate. The central region has an average quality aggregate, but the aggregate quality in the eastern region is marginal to average. Since these regions encompass different traffic, climate, and subgrade conditions, variation in aggregate quality can result in the difference in pavement performance within these regions, especially when standard aggregate specifications are used in the asphalt concrete pavement construction projects throughout the country. In addition, lack of good quality aggregate in some areas can result in higher construction costs, either owing to the transportation of good aggregate quality from other regions or because of the rejection and consequent rework of the construction work.

The placement and compaction process has an impact index of 88%. Compaction is the most important factor in ensuring satisfactory pavement performance. Lack of adequate compaction during construction will result in low pavement density. Subsequently, traffic will consolidate the pavement. This consolidation occurs principally in the wheel path and appears as a channel in the pavement surface forming rutting. During the compaction process, several factors can affect the final pavement density. These include mixture temperature, rolling equipment type and conditions, compaction pattern, driver experience, and weather conditions.

Uniformity of materials (asphalt and aggregate) at the source has an impact index of 85%. The asphalt cement in Saudi Arabia is produced by three refineries. The variation in asphalt quality among the three refineries is common; however, they all comply with the specifications. At the mixing plants, on the other hand, there might not be compliance with the requirement, either because of storage at high temperatures or accidental contamination in the delivery trucks or plant storage tanks.

Mixing operation control (aggregate composition, asphalt content, mixing temperature, and mixing time) has an impact index of 80%. The mixing operation can have a dramatic effect on the consistency of the asphalt binder and behavior of the finished mix during the laydown process. The amount of asphalt added to the aggregate and the temperature at the time of mixing are all very critical in producing quality mix. The control of mixing time and temperature is an attempt to avoid the harmful possibility of creating too much fine (i.e., aggregate degradation) and reducing the aging of the asphalt (oxidation) so that a uniformly coated and homogenous mixture is produced. It is necessary to control the asphalt content within a very close tolerance since the proper asphalt content is critical in obtaining the desired void content in the compacted mixture, and it affects durability, flexibility, stability, and susceptibility to moisture damage. Variation in asphalt content can result in either a dry mix that might lead to premature raveling and cracking, or in rich mixes that might lead to permanent deformation.

Acceptance procedures have an impact index of 62%. The clarity of the acceptance procedures (i.e., sampling procedure, test method, data analysis) and the effectiveness of their execution are extremely important in determining the pavement quality and its degree of compliance with the specifications. An inaccurate estimation of the quality may result if the specifications do not clearly define the acceptance procedure or are not properly carried out. This can lead to wrong acceptance decisions.

SUMMARY AND CONCLUSION

Pavement engineers and contractors in Saudi Arabia are faced with the challenges of constructing pavement for desert or sand dune, mountainous, and sabkha areas. The construction of asphalt concrete is a complex process involving many critical stages during which factors that affect the quality of performance of the asphalt concrete pavement might be overlooked. The newly constructed highway pavements in Saudi Arabia have exhibited a low quality of performance. There are various parameters that contributed to the quality of performance. Highway contractors were surveyed regarding the factors that control pavement performance. Factors that affect the pavement quality of performance were identified and ranked on a scale according to their impact. These include six managerial factors: the qualifications of the owner's inspection team and the contractor's personnel, the contractor's experience, the contractor's workforce and equipment capability, the contractor's qualifications, delay in progress payment, and amount of work subcontracted; five design- and specifications-related factors, namely structural design, aggregate quality, asphalt mix design, mix composition, and asphalt characteristics; and five construction practice-related factors, namely aggregate characteristics, placement and compaction process, uniformity of materials, mixing operation control, and acceptable procedure.

APPENDIX. SAMPLE QUESTIONNAIRE

Company Name: ____________________________

Location of Main Office:______________________

No. of Branches: ____________________________

Position of the Respondent: __________________

No. of years in the Position: ____________________

I. Information about the Respondent's Firm:

1. Company grading (classification) based on the grades specified by the Ministry of Housing and Public works.
   (a). 5 (b) 4 (c) 3 (d) 2 (e) 1

2. Number of years in the pavement construction industry in Saudi Arabia.
   (a) Less than 5 years (c) 15-20 years
   (b) 5-10 years
   (c) 10-15 years (d) more than 20 years

3. Number of employees.
   (a) Less than 100 (d) 500-1000
   (b) 100-300 (e) More than 1000
   (c) 300-500

4. Average job size (million of Saudi Riyals)
   (a) Less than one (d) 20-50
   (b) 1-5 (e) More than 50
   (c) 10-20

5. Average job duration (years)
   (a) Less than ½ (d) 2-3
   (b) 1 ½- (e) More than 3
   (c) 1-2

APPENDIX. (*Continued*)

What effect do the following factors have on the quality of asphalt concrete pavement?

M.E= Major effect E= Effect S.E = Some Effect N.E = No effect *= Does this factor occur in Saudi Arabia	M.E	E	S.E	N.E		*
Managerial Factors						
the qualifications of owner's inspection team						
contractor's experience						
contractor's work force and equipment capability						
contractor's qualification						
Delay in progress payment						
The amount of work subcontracted						
Design and Specification Factors						
Pavement that is not designed for the regional conditions						
Quality of aggregate						
Mix design						
Mix composition						
Asphalt characteristics						
Construction Process Factors						
Aggregate characteristics						
Placement and compaction process						
Uniformity of materials						
Mixing operation control						
Acceptance procedure						

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