Monitoring and Improving the Effectiveness of Quality Control and Quality Assurance in Road Construction at Al-Ain Municipality

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United Arab Emirates University
Faculty of Engineering
M.Sc. Program in Civil Engineering

Monitoring and Improving the Effectiveness of Quality
Control and Quality Assurance in Road Construction at
Al-Ain Municipality

BY
Mohammed Muftah Sultan Al Aryani

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ABSTRACT

A good roads network has an important bearing on the economic growth of the country. Construction of quality roads, which is considered a primary objective of any highway agencies and contractors, requires concerted efforts on many fronts. Over the past several years, agencies have been working with the construction industry to implement Quality Assurance/Quality Control activities (QA/QC) in an effort to improve the quality of highway construction. They are used as a mean to describe the materials, workmanship, and other general requirements for the project that the highway agencies expect from the contractors. Good specifications should be easy to understand by involved parties. Ambiguous specifications can mislead the contractor and result in increased cost to either or both client and contractor because of claims that may occur. Since the primary function of a QA/QC system is to describe the quality level of the product desired, it follows that an effective specification is one where the contractors correctly interpret the desired quality level and consistently provide that level. Therefore, once QA/QC system is developed and used in the field, they should be monitored to verify their effectiveness and to determine when improvement is necessary, thereby making continuous quality improvement possible. Very few highway agencies currently monitor how well their specifications work. In this research, QA/QC system of Internal Roads and Infrastructure Division at the Al-Ain Municipality (AAM) was selected as a case study for monitoring and improving the effectiveness of QA/QC system of road construction projects. To achieve these objectives, a good understanding of current QA/QC system being practiced by the AAM was felt necessary for which relevant evidence, information and sufficient data were collected. It was also considered that it would be foreseeing to know, analyze and compare the QA/QC system being followed by other authorities such as Road Department of Abu Dhabi Municipality (ADM), Roads and Transport Authority (RTA – previously known as Department of Roads, Dubai Municipality), and Dubai Central Laboratory (DCL), which is considered as an integral part of the RTA. Scheduled interviews were made with responsible persons of respective departments of the various organizations. References and data were obtained. Comparison and analysis were performed followed by recommendation for improvement of QA/QC system by developing short and long term measures.
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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The main function of the Roads, Bridges and Infrastructure Department of the Al Ain Municipality (AAM) is to plan and to develop road network throughout the city’s boundary. It also maintains existing roads network to transport people and goods in a good, safe, and economic manner. This study focuses on monitoring, enhancement and improvement of Quality Assurance and Quality Control (QA/QC) system of road construction projects perform by the Al Ain Municipality. However, design and surveying process is out of scope of this study. This piece of work exclusively deals with QA/QC of highway materials and how it affects the cost and time in completion of a project. The following paragraphs describe briefly concept of quality assurance and quality control.

"Quality" is a relative term. It is often used in a vague, blurred way. It may mean different things to different people. For example, a quality motor car may be one which has no defects and works exactly as we expect. There are groups who consider that less expensive products, with required features at reasonable cost and no (or few) defects are "quality" products. However, people in construction and manufacturing industry often promote quality as "conformance to specifications".

"Assurance" is referred to the act of giving confidence, the state of being certain or the act of making certain. The planned and systematic activities are implemented through a quality system so that quality requirements for a job or service will be fulfilled. Quality assurance is referred to those actions, procedures and methods employed at the management and senior technical levels to observe and ensure that prudent quality procedures are in place and are being carried out and that the desired result in a quality product is achieved. Those planned and systematic actions necessitate providing confidence that a product or department/facility will perform satisfactorily in service. Quality assurance addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, quality
assurance involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities.

Therefore, when the term "quality assurance system" is used, it means a formal management system that is used to strengthen organization. It is intended to raise standards of work and to make sure everything is done consistently. A quality assurance system sets out expectations that a quality organization should meet.

"Quality control" may be described as the observation and operational techniques and activities used to keep the quality of inputs or outputs to specifications; to fulfill and verify requirements of quality. Those quality assurance actions and considerations are necessary to assess production and construction processes so as to control the level of quality being produced in the end product. This concept of quality control includes sampling and testing to monitor the process.

Quality tools and methodologies help people work to improve quality at all levels. Efforts are made to create tools for multiple purposes. Many organizations develop their own bespoke quality systems, either from scratch or by adopting one of the established off-the-shelf systems. Typically, construction industries when implementing a quality system aim for the following tools and stages:

- Agree on Specifications/Standards
- Organization Chart of the Department/Project
- Selection of professional and identifying responsibilities
- Ensuring compliance with statutory requirements
- Project Management Control and Action Plan (What needs to be done, who will do it, how it will be done, and when)
- Inspection and Testing Plan
- Implement (do the work)
- Construction Supervision Plan
- Monitoring and evaluation
However, rising demands for quality always is leading to new developments in construction technology, which in turn demands organizations with special expertise to ensure optimum quality based realization of the projects. Result oriented objectives ensure economical cost and completion on time within the customized organizational structure for each individual project. Proper management and controls can assure project implementation, in terms of supervision and administration of contracts till finalization of the project.

### 1.2 HIGHWAY CONSTRUCTION SPECIFICATIONS

Specification is a legal concept adopted from Roman law. Some define specifications as an explicit set of requirements to be satisfied by a material, product, or service. Should a material, product or service fail to meet one or more of the applicable specifications, it may be referred to as being out of specifications. In construction industry, specifications are part of the contract documents consisting of written requirements for materials, equipment, construction systems, standards and workmanship, usually prepared in a standard format. Construction specifications normally consist of a series of instructions or prohibitions for specific operations.

Defining requirements to establish specifications is the first step in the development of an embedded system. However, in many situations, not enough care is taken in establishing correct requirements up front. This causes problems when ambiguities in requirements surface later in the life cycle, and more time and money are spent in fixing these ambiguities. Therefore, it is necessary that requirements are established in a systematic way to ensure their accuracy and completeness, but this is not always an easy task. This difficulty in establishing good requirements often makes it more of an art than a science. For example, specifications for percent voids in mix for asphaltic mixes used to be 3 – 5 both for the Al Ain and the Dubai Municipality. After experiencing problems of rutting, bleeding etc., the respective authorities amended the specifications and set the limit to 4 -8% according to Table 5-6.
Defects or failures in constructed pavement can result in very large costs. Even with minor defects, re-construction may be required and pavement functions impaired. Increased costs and delays are the result. In the worst case, failures may cause personal injuries or fatalities.

As with cost control, the most important decisions regarding the quality of a completed pavement are made during the design and planning stages rather than during construction. It is during these preliminary stages that component configurations, material specifications and functional performance are decided. Quality control during construction consists largely of insuring “conformance” to these original designs and planning decisions.

In recent years, “performance specifications” have been developed for many construction operations. Rather than specifying the required construction process, these specifications refer to the required performance or quality of the finished pavement. The exact method by which this performance is obtained is left to the construction contractor. For example, traditional specifications for asphalt pavement specified the composition of the asphalt material, the asphalt temperature during paving, and compacting procedures. In contrast, performance specifications for asphalt would detail the desired performance of the pavement with respect to ride-ability, strength, irregularities like bleeding, rutting etc. How the desired performance level was attained would be up to the paving contractor. In some cases, the payment for asphalt paving might increase with better quality of asphalt beyond some minimum level of performance.

About 35 years ago at its infant stage, in United Arab Emirates, all organizations dealing with building roads, bridges and infrastructures had no other choice than to borrow specifications from foreign countries to serve as “Recipe Specifications”. Various Specifications sourced from foreign countries and from elsewhere were being used for different activities. In the meantime local manufacturing industries for multiple products have been established. For overall benefit of the country, use of local products was being encouraged and performances of end products were monitored. Being satisfied, products data of these materials have
been incorporated in the specifications. In addition, "Performance Specifications" have been developed by many organizations to serve as a base line for the work and treated as "Standard Specifications". The standard specifications are incorporated into the written agreement (Contract), except where the contract indicates that Particular Specifications have been amended or replaced with a special provision to resolve project-specific issues. The decision to amend or replace any standard specification with a special provision is made during the design process and is based upon the sound engineering judgment of the project designer [Appendix D].

Specifications are to be used only as a guide line during the design process. Once they have been incorporated into the contract; however, they become legal and enforceable language of that contract. The standard specifications, the amendments to the standards and the Project Special Specification along with any other attachments in the Contract Documents define a contract and no longer seen as guidelines. Rather, they are considered as written agreement subject to revising only through the change of order process.

These Standard Specifications reflect years of refinement through projects that the Municipality delivers each year. In addition, the standards are the result of countless hours of development and review by both internal Department’s staff as well as industry partners. Finally, these standards reflect the contracting philosophy and balance of risk-sharing that the department adopts through the year. This balance of risk gives the lowest final cost solution to the transportation needs. For example, shifting risk to the contractor can provide more certainty on final cost, but may result in higher initial cost. On the other hand, accepting more risk by the owner can lower in lower initial cost, but less certainty on the final cost. Therefore, the Department is to reach the optimum point of balance for risk and is to consider this balance on all future specifications revisions. However, not enough done by the AAM to update the specifications tailored to the climatic conditions, available resources etc. On the other hand, Dubai has developed their specifications to suit Dubai climate and to incorporate available resources. Through research and development the Dubai Municipality has developed their own policy, procedures and method of testing of various materials and has successfully implemented in their Standard Specifications.
For example, the AAM for all embankment fill materials requires plasticity index maximum of 6. It is also specified depending on the depth of use with respect to Finished Road Level, the unit weight of material shall be 1.8 – 1.9 gm/cc and CBR shall be 15 – 30 %. (Refer to Table 5 -1)

However, it is very difficult to source the materials having above criteria from the borrow pits available in and around Al Ain region. The AAM has shifted the risk to the contractor. At tendering stage, the contractor is uncertain about the hauling distance and hence to minimize his risks, the item is priced high which results higher initial cost.

Roads and Transportation Authority (RTA) of Dubai Municipality amended their specifications to suit the availability of materials locally.

1.3 RESEARCH OBJECTIVES

There are four main objectives of this research

- Monitor, study, and analyze the current Quality Control system in road construction at the Al-Ain Municipality
- Compare Al-Ain Municipality Quality Control system with another Quality system in UAE.
- Identify shortcomings in the Quality Control system in road construction at the Al-Ain Municipality through a comprehensive discussion and analysis.
- Develop a framework to enhance the Quality Control system in road construction at the Al-Ain Municipality.

1.4 RESEARCH METHODOLOGY AND TASKS

In order to analyze and shed light on monitoring, enhancement and improvement, a good understanding of current QA/QC system being practiced by the
AAM is necessary for which relevant evidence, information and sufficient data were required. It was also considered that it would be foreseeing to know, analyze and compare the QA/QC system being followed by another authorities like Road Department of Abu Dhabi Municipality (ADM), Roads and Transport Authority (RTA – previously known as Department of Roads, Dubai Municipality), and Dubai Central Laboratory (DCL), which is considered as an integral part of the RTA. Major obstacle, which hindered the research, is “confidentiality” of data, except the AAM. However to overcome this problem, scheduled interviews were made with responsible persons of respective departments of the various organizations, as indicated above. Related physical data and evidence were obtained only from the AAM. Specifications for road works from the AAM, ADM and RTA were also made available.

Prior to proceeding with data collection procedures, interviews etc, mindset was made that the objective of QA/QC activities is to ensure the quality of construction of a project. The quality of the construction activities are interlinked to both the materials used in the construction and the way of performing the construction by systematic methods (i.e. quality procedure), schematic and efficient usage of right materials, manpower, plant and equipments. Often the terms “quality assurance” and “quality control” are used interchangeably to refer to ways of ensuring the quality of materials, workmanship and the final product(s). QA/QC activities are conducted throughout the course of the project.

The research methodology was divided into four phases:

**Phase (1): Literature Review**
- Perform a comprehensive literature review search to summarize the studies, guidelines, quality control tests (Inspection of Asphalt Binders, Aggregates and Hot-Mix Asphalt), pavement construction procedures, and evaluation techniques related to Quality Management System in road construction.

**Phase (2): Data Collection**
- Specifications, guidelines, manuals, flowcharts, quality control tests or other written information, which outlined methods or requirements of
QA/QC during road construction, were gathered, assessed, evaluated and reported for the following:

- **Client**: the Al-Ain Municipality:
  - Internal Roads and Infrastructure Division
  - Quality Control section
  - Quantity Surveying section
- **Consultant**: Engineering Associate Consultant
- **Contractor**: Saif Bin Darwish
- **Project Case Study**: Northern Ring Road Project (NRR)
- **Client**: the Dubai Municipality for the purpose of comparison with the Al-Ain Municipality
  - Dubai Central Laboratory
  - Roads and Transport Authority
- **Client**: The Abu Dhabi Municipality for the purpose of comparison with the Al-Ain Municipality

- **Knowledge Acquisition**: Number of interviews were carried out to collect information from references.

**Phase (3): Data Analysis & Identify Shortcoming**

- Tabulate and analyze all collected data using Excel Sheets.
- Compare using different criteria the QA/QC system of Al Ain with QA/QC system of Dubai as well as Abu Dhabi.
- Identify all shortcomings, if any, in the QA/QC specifications in road construction at the Al Ain Municipality though a comprehensive discussion and analysis.

**Phase (4): Development of a Framework for improvement of quality control system**

- Propose a short-term mitigation plan to improve QA/QC Specifications in road construction at Al-Ain Municipality.
- Propose a long-term plan to improve QA/QC Specifications in road construction at Al-Ain Municipality.
1.5 **THESIS ORGANIZATION**

This thesis consists of seven chapters and two Appendices. The following is a brief description of the thesis components.

**Chapter 1: Introduction.** This chapter describes the basic components of the research. It includes research motivations, objectives, and methodology.

**Chapter 2: Literature Review.** All previous studies that have been done in this area have been presented in this chapter.

**Chapter 3: Research Methodology.** It includes the steps that have been followed to achieve the objectives of this study.

**Chapter 4: Data Collection: Quality Assurance/Control system.** This chapter describes system being followed in the Al Ain Municipality, the Dubai municipality, Roads and transport Authority (RTA), Dubai Center laboratory (DCL) and finally the Abu Dhabi Municipality.

**Chapter 5: Comparison and Analysis.** It presents analytical approach used to define the systems in each organization showing advantages and disadvantages, weakness and strength; and discussions.

**Chapter 6: Recommendations for Improvement of Quality Control System at the AAM.**

The recommendation and conclusion of this research have been presented in this chapter.

Appendix A: Inspection of Asphalt Binders
Appendix B: Inspection of Aggregates
Appendix C: Inspection of Hot-Mix Asphalt
Appendix D: Interview Matrix
CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

A good road network has an important bearing on the economic growth of the country. Construction of quality roads requires concerted efforts on many fronts. Therefore, this chapter discusses creating a culture of quality that is necessary for any highway organization to achieve real quality. This culture embraces the concept that quality is not achieved after the fact by inspections and checks but rather by the systematic implementation of a quality program to assure that quality is built-in from the very start of a project, including its design, procurement, construction, operation, and maintenance. This Quality Assurance (QA) concept should be applied to any type of highway construction projects [AASHTO 1996, ASQ 2000].

“Whether it is required to provide or purchase a service, supply a part or component, provide materials (soil, aggregates, asphalt binders), or construct a facility (roads, bridges), the obligation to understand and satisfy the requirements of customers should be existed. The quality of what is delivered must be what was expected. If that target is missed, just as a referee that made one bad call in an entire game, product or service will forever be known for that one bad call. Should that occur, there will be a significant challenge to regain the confidence of customers, and both organization and customer’s business will be impacted” [Taguchi 1986].

Properly designed and implemented Quality Assurance Programs for both the supplier and customer define the level of quality expected and assure that level will be delivered. This chapter provides an understanding and appreciation of Quality Assurance as applied to design, engineering, procurement, construction, operations, and maintenance. It examines the technical components of a Quality Assurance Program which include all of those planned and systematic actions necessary to provide the level of confidence that a service, structure, system or component will perform as intended [ASQ 2000, Taguchi 1986]. The difference between quality assurance and Quality Control (QC) is also presented in this chapter. Furthermore, all quality control tests are presented in details.
2.2 QUALITY ASSURANCE AND QUALITY CONTROL

2.2.1 What is Quality?

Quality has become one of the most important consumer decision factors in the selection among competing products and services [Montgomery 1997]. This is true not only for individual consumers but also for large corporations, government organizations and the taxpaying public as a group. Thus, quality is a key factor in road construction. However; what is “quality”? In its broadest sense, quality is a degree of excellence: the extent to which something is fit for its purpose. In the narrow sense, product or service quality is defined as conformance with requirement, freedom from defects or contamination, or simply a degree of customer satisfaction. In quality management, quality is defined as the totality of characteristics of a product or service that bears on its ability to satisfy stated and implied needs [IQA 2001].

Quality may mean different things to different people. Some take it to represent customer satisfaction; others interpret it as compliance with requirements. Project Management Body of Knowledge (PMBOK) has defined the quality as it is the degree to which a set of inherent characteristics fulfill requirements [PMBOK 2004]. Many thoughts have considered that quality and grade of certain product have the same definition. Generally, quality and grade are not the same as grade means a category assigned to products and service in terms of functions. Therefore, it is considered that low quality is always a problem; however it is not for low grade. For instance, a software product can be of high quality which means has no defects. Alternatively, this software could be of low grade because of limited number of features. Consequently, low quality can be defined as poor organized user documentation together with many defects. On the other hand, high grade is referred to numerous features [Taguchi 1986].

Quality of engineering construction is difficult to define. This is because the product is usually not a repetitive unit but a unique piece of work with specific characteristics. In addition, there is a need to satisfy not only those of the client but
also the expectations of the community into which the completed building will integrate. The construction cost and time of delivery are also important characteristics of quality [Taguchi 1986, Chung 1999, PMBOK 2004].

2.2.2 Project Quality Management

Project quality management is involved in developing systems to ensure products or services are designed and produced to meet or exceed customer requirements. Elements of project quality management could vary depending on the objectives of a project. Project quality management can be formed into quality planning, quality assurance and quality control [PMBOK 2004].

An example of quality control can be referred to the activities that are carried out on a production line, such as production of ready-mixed concrete and fabrication of precast unit, to prevent or eliminate causes of unsatisfactory performance. Therefore, the major functions of quality control are to control of incoming materials, monitoring of production processes and testing of the finished product. However, elements of quality could vary depending on in which environment is being applied to. BMBOK has defined the meaning of the control elements in terms of project quality management as following [PMBOK 2004]:

1. **Quality Planning**: identifying which quality standards are relevant to the determine how to satisfy them.

2. **Perform Quality Assurance**: applying the plan and systematic quality activities to ensure that the project employs all processes needed to meet requirements.

3. **Perform Quality Control**: monitoring specific project results to determine whether they comply with relevant quality standards and identifying ways to eliminate causes of unsatisfactory performance.

Figure 2.1 shows all elements of project quality management, while a detailed description of each element is presented in the below sections.
Those processes of quality are considered to be the core of the business of quality. It also requires involved efforts by one or more person/group based on project needs whatever it is small or big project. On other hand, in order to apply those elements to any project, there is a need to understand the main objective of quality control. BMBOK has summarized the importance disciplines in quality management, which are shown below [Muench and Mahoney 2001, Chung 1999, PMBOK 2004]:

- **Customer Satisfactions**: Understanding, evaluating, defining and managing expectations so that customer requirements are met. This can be achieved by achieving fitness of use, which means the product or services must satisfy real needs.

- **Prevention over inspections**: the cost of preventing mistakes is generally much less than the cost of correcting them.
- **Management responsibility**: The success requires participating of all team members. Therefore, it is management responsibility to provide resources.

- **Continuous improvement**: Applying all new techniques such as Total Quality Management (TQM) and Six Sigma, Plan-do-check-act Cycle.

**2.2.3 Quality Assurance versus Quality Control**

Many people and organizations are confused about the difference between quality assurance (QA), quality control (QC), and testing. They are closely related, but they are different concepts. But all the following three are useful to manage risks of developing and managing product [Pavement 2010, ASQ 2000]:

- **Quality Assurance**: A set of activities designed to ensure that the development and/or maintenance process is adequate to ensure a system will meet its objectives. In other words, Quality assurance defined as all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. Quality assurance addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, quality assurance involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities.

- **Quality Control**: A set of activities designed to evaluate a developed work product. In other words, it is defined as monitoring specific project results to determine whether they comply with relevant quality standards and identifying ways to eliminate causes of unsatisfactory performance. Quality control is those quality assurance actions and considerations necessary to assess production and construction processes so as to control the level of quality being produced in the end
product. This concept of quality control includes sampling and testing to monitor the process but usually does not include acceptance sampling and testing.

The difference is that QA is process oriented and QC is product oriented. Testing therefore is product oriented and thus is in the QC domain. Testing for quality is not assuring quality, it is controlling it. In conclusion, Quality Assurance makes sure you are doing the right things, the right way. Quality Control makes sure the results of what you have done are what you expected [Taguchi 1986, ASQ 2000].

2.2.4 Quality Planning

As it was defined early, refer to Figure 2-1, quality planning means identifying the relevant quality standards and how to satisfy them. It is considered one of the key successful processes in quality system. Therefore, it should be performed on parallel with other elements of quality system. Moreover, quality planning is considered a part of project planning process. For example, change in product may necessitate adjustments in cost or schedules to meet identified quality standards [Taguchi 1986, ASQ 2000].

Quality planning can be achieved through three stages: considering input factors, applying tools and techniques and establishing outcomes. [PMBOK 2004]:

2.2.4.1 Input Factors of Quality Planning

For input stage, there are some factors need to be well considered. Some of these factors are drawn from PMBOK as shown below [PMBOK 2004, Chung 1999]:

1. **Enterprise Environmental Factors**: These factors need to be met to make a project successful, such as government agency regulations, rules and standards. For example, standards are considered as references for quality system. These references, which define the adequacy of a quality system, are called quality system standards that are being developed by many agencies. For instance, the International Organization for Standardization (ISO) which
develop a standard that would be internationally accepted. Therefore, may ISO standard called (ISO 9000 FAMILY OF STANDARDS) such as ISO 9001, ISO 9002 and ISO 9003 are for contractual, assessment or certification use. They serve as a benchmark for supplier assessment throughout the world.

2. Organizational process Assets: organization quality policy, procedure, guidelines, historical database and lessons learn.

3. Project scope statement: knowing the scope of the project will help to serve the defined requirements, which were derived from stakeholders and expectations.

2.2.4.2 Tools and Techniques of Quality Planning

There are three types of tools and techniques, which can be applied in order to achieve a better planning quality. Some of those tools and techniques are [PMBOK 2004]:

1. Cost-Benefit Analysis: The primary benefit of meeting quality requirements is by having higher productivity, lower costs and increased stakeholders and customer satisfaction. Therefore, cost-benefit tradeoffs must be considered.

2. Benchmarking: Compare between actual and planned project practices to generate ideas for improvement and to provide a guideline for performance measurement.

3. Design of Experiment (DOE): is being stated in PMBOK as a statistical method that helps identify which factors may influence specific variables of a product or process under development or in production line. It is very important techniques which play an important role in the optimization of product and process. It studies all the important factors. It also provides a statistical framework for systematically change all of important factors.
2.2.5 Quality Assurance

Quality assurance is the application of planned, systematic quality activities to ensure that the project will employ all the process needed to meet requirements. In the construction industry, quality assurance was first adopted in nuclear installation and offshore works mainly for safety and reliability reasons. Spread of the concepts to conventional types of construction has been gradual but slow. This is because the product of construction is in a sense always unique, unlike consumer goods which are repetitive in nature [PMBOK 2004, ASQ 2000].

In practice, the main objective of quality assurance is to continue process improvement by applying the outcomes of quality planning. Such as quality metrics and quality management plan [Taguchi 1986, ASQ 2000].

In order to perform quality assurance, many tools and technique can be used such as Quality Audit. PMBOK has described Quality Audits as a structure, independent review to determine whether project activities comply with organization and project policies, process and procedure. The main objective of a quality audit is to define the ineffective and inefficient policies, process and procedure in use of project and also confirm the implementation of approved changes requested, defect repairs and corrective and preventive actions. Quality audits can be conducted internally inside the organization by properly trained in-house auditors or by third part or external to the performing organization. The quality audits sometime are conducted according to scheduled or random basis [PMBOK 2004].

On the other hand, tools and techniques used in quality control are also applied to quality assurance. These tools will be described later in the quality control section. After auditing and applying the quality assurance, the outputs of those actions could be any of the following [Taguchi 1986, ASQ 2000, TRB 1999]:

- Requested change.
- Recommended corrective actions
In order to have a quality improvement, some actions needed to increase the effectiveness and the efficiency of policies, process and procedure of the performing organizations [Chung 1999, PMBOK 2004].

Quality assurance of highway construction requires proper answers to the following questions [McMahon and Halstead 1969]:

**What is required in Planning and Design stage?**
Answers to this question encompass research, development, engineering technology, and experience. When the proper materials are specified, the design is correct, good construction practices are followed, and gross deficiencies are eliminated from the beginning. The quality level of the finished project is judged by how well it serves society—physically, functionally, emotionally, environmentally, and economically.

**How the specifications are interpreted and programmed of works planned?**
The second question relates to how the details are spelled out in specifications. One factor that affects the attained quality is how well the requirements of the plan and specifications define the needed characteristics of the finished project.

**Is the target achieved through inspection, testing, and acceptance procedures?**
In order to answer this question, the inspection, testing, and acceptance procedures need to be done. The accuracy of the answer depends on both the skills of the engineer or inspector and on the results of a system of sampling and testing. How the samples are taken and how the results are interpreted depend on the type of specifications. Under the recipe approach, the highway agency’s inspector observes the procedures and makes necessary tests as construction proceeds. Thus, acceptance depends on the ability of the inspector to detect improper procedures or inferior materials. For the statistical quality assurance technique approach, a specific number of samples need to be taken on a random basis. The following are a number of problems regarding sampling and testing that affects the efficacy of quality assurance system:
1. The total of materials use in construction cannot be tested. The sample test results are only the characteristic estimation.
2. There is some testing variability. Different answers may be obtained even when the materials are the same.
3. It may take a long period of time to get the test results.
4. Often acceptance is based on indirect or empirical measurements to estimate the characteristic desired.

2.2.6 Quality Control

A training manual for Komatsu Ltd. in Japan defines quality control as follow [Walton 1986]: "The first step in quality control is to judge and act on the basis of facts. Facts are data such as length, time, fraction defective and sales amount. Views not backed by data are more likely to include personal opinions, exaggeration and mistaken impressions. Data volume has nothing to do with accuracy of judgment. Data without context or incorrect data are not only invalid but sometimes harmful as well. It is necessary to know the nature of that data and that proper data to be picked as well".

Performing quality control involves monitoring specific project results to determine whether they comply with relevant quality standards and identifying ways to eliminate causes of unsatisfactory performance. Generally, quality control requires testing, which is a process of executing a system with the intent of finding defects. QC can include actions to eliminate causes of unsatisfactory project performance. The project management team should have a working knowledge of statistical quality control especially sampling and probability. In order to understand the process of quality control, there are fundamental elements need to be addressed such as the feedback loop, the process, quality control plan and statistical quality control. [Chung 1999].

Figure 2-2 shows process techniques in quality control using PDCA cycle [HCl 2009]
Figure 2-2 Process Technique in Quality Control using PDCA Cycle [HCI 2009]

- **Plan** to improve your operations first by finding out what things are going wrong (that is to identify the problems faced), and come up with ideas for solving these problems.

- **Do** changes designed to solve the problems on a small or experimental scale first. This minimizes disruption to routine activity while testing whether the changes will work or not.

- **Check** whether the small scale or experimental changes are achieving the desired result or not. Also, continuously check nominated key activities, regardless of any experimentation going on, to ensure that you know what the quality of the output is at all times to identify any new problems when they crop up.

- **Act** to implement changes on a large scale if the experiment is successful. This means making the changes a routine part of your activity.
2.2.6.1 Planning for Quality Control

Planning for control is the activity, which provides system, concepts, methodologies, and tools through which company personnel can keep the operating processes stable and thereby produce the product features required to meet customer needs. Therefore, customers' needs are the main target for any company seeking quality control [Juran 1999].

Planning for quality control helps to bridge that gap by supplying a translation of what are customers' needs along with defining responsibility for meeting those needs. In this way, planning for quality control includes providing operating personnel with information on customer needs whether direct or translated, and definition of the related control responsibilities of the operating personnel. On the other hand, planning for quality control can be conducted by [Juran 1999]:

- Staff planners who also plan the operating processes
- Staff quality specialists
- Multifunctional teams of planners and operating personnel
- Departmental managers and supervisors

Furthermore, there is a need to define the following elements in order to build quality control plan [Juran 1999]:

**Quality Control Concept**: methodologies of quality control that are built around various concepts such as the feedback loop, process capability, self-control,

**The Flow Diagram**: the first step in planning for quality control is to map out the flow of the operating process.

**The Control Subject**: design control station, which is an area in which quality control takes place.

All these activities are mainly covered in quality planning as an ideal case, however some organizations work out as a one concept which adding of quality control.
2.2.6.2 Quality Control Tools and Techniques

Role of statistics is very important step in the quality control. It is an essential activity within the feedback in terms of collection and analysis of data. The methods and tools used are often called statistical methods. Many organizations use statistical methods to establish a mean of statistical process control to bring the organization to SixSigma levels of quality [PMBOK 2004, PIRUN 2009].

Statistical process control is an analytical decision making tool, which allows checking whether a process is working correctly or not. Therefore, most companies are using such tools as frequency distributions, Pareto principle, Ishikawa (fish bone) diagram, Shewhart control chart. Through the concept of the control charts, the useful information to the companies can be produced for instance, monitoring processes to show how the process is performing and how the process and capabilities are affected by changes to the process. This information is then used to make quality improvements. Control charts are also used to determine the capability of the process. They can help identify special or assignable causes for factors that impede peak performance. The preparatory phases of Statistical Process Control (SPC) involve several steps using a number of different tools. [PMBOK 2004, Anglade 1998]:

2.2.7 Summary

Quality, in general terms, is fitness for purpose but in building construction it is more appropriately interpreted as compliance with contractual requirements. A system of quality management complements the operational techniques of quality control in assuring quality [ASQ 2000]. Moreover, it is a framework for quality management. Its functions are to clarify responsibility and authority of staff and their interrelation, to rationalize the administrative and production processes, and to generate permanent records of verification of quality. Developing a quality system is the key success of the future organizations. A quality system standard constitutes a reference base against which the adequacy of a quality system can be judged. The most widely adopted quality system standards are the ISO 9000 family. In order to achieve a sustain quality system; it has to be built on the strong foundations of quality planning and quality controls. It is suggested that planners are the key success of the
quality system. It is believed that the greater the stability and uniformity of the process, the less the need for frequent measurement and maintenance. Those who establish for quality planning should have a thorough understanding of the concept of process capability and its application to both areas of planning the operating processes as well as planning the controls. On the other hand, the quality control is a universal managerial process for conducting operations, which is very important stage in quality system. It provides stability to prevent adverse change and to maintain the system. It also takes place by use of the feedback loop. Each feature of the product or process becomes a control subject a center around which the feedback loop is built [Anglade 1998, ASQ 2000]. Generally, the cost of implementing and maintaining a quality system is high. However, significant investment in terms of money and staff time is needed route to quality system, especially for staff training, monitoring, establishing quality planning and document preparation and finally applying either quality control or quality assurance. Some people see this as another item of overhead for the organizations. However, they should not lose sight of the savings that will accrue later with much reduced incidents of rework or reject. In addition, the overall quality related costs decrease rapidly as quality awareness among the organizations increases.

2.3 HIGHWAY CONSTRUCTION SPECIFICATIONS

Specifications are one of the most important tools to be concerned with in producing a good quality pavement. Specifications are used to describe the materials, workmanship, and other general requirements for the project that the highway agencies expect from the contractors. Good specifications should be easy to understand for both the contractors and the highway agencies in describing what quality is expected from the contractors. Unclear specifications often result in increased cost to the contractor, resulting in claims that have to be evaluated by the owner and that, in many cases, end up in court [Roberts et al., 1996]. According to a survey conducted by the American Society of Civil Engineers, the contractors estimated that owners could save about 7.8% on construction costs if specification quality were upgraded. Assuming the annual cost of new construction (excluding homebuilding) to be $100 billion, $7.8 billion could be saved [ASCE 2000].
2.3.1 History

Before the 1970s, recipe or method specifications were used in most highway projects to define the quality that the highway agencies expected from contractors. When using recipe specifications, the highway agency spells out in detail what is to be built and how it is to be done. As was mentioned in the AASHO Road Test, the use of recipe specifications does not insure that the pavement would perform and last as expected [TRB 1996; Rilett 1998]. Moreover, the acceptance procedure is based on engineering judgment. Engineering judgment is strongly based on past experience, and if variables unknown to the specification writer change under new conditions, the end result may not be satisfactory [Dobrowolski and Bressette 1998; Rilett 1998]. It is difficult to define quality in legal or contractual terms when engineering judgment is used. The degree of acceptable variation will differ from engineer to engineer and from job to job.

In more recent years, quality assurance specifications have been emphasized. The advantage of quality assurance specifications to state agencies is the actual placing of responsibility for materials and construction quality on the contractor or producer. The specifications place few restrictions on the materials and methods to be used in order to obtain a completed product. The contractors and producers can generally choose their own materials and equipment and design the most economical mixtures meeting the specified requirements. Quality assurance specifications rely on statistical acceptance plans based on random sampling both to define the product wanted and to determine its acceptability [McMahon and Halstead 1969; Miller-Warden Associates, 1965; TRB, 1996; Rilett, 1998].

Since the late 1980's, the evolution of transportation construction specifications has focused on the development of Performance-Related Specifications. At a May 2000 workshop conducted by the Florida DOT, FHWA, and the NQI, the following technical definition of Performance-Related Specifications emerged: Performance-Related Specifications = "Specifications that use quantified Quality Characteristics and Life Cycle Cost (LCC) relationships that are correlated to product performance." Performance-Related Specifications contain two types of models: Performance-prediction Models and Maintenance-cost Models. These models provide the basis for
rational acceptance and/or pay adjustment decisions. Pay adjustments are determined by determining two different LCCs: The "As-Designed LCC" and The "As-Constructed LCC [Rilett, 1998, ASCE 2000].

2.3.2 Purposes of Highway Specifications

Highway specifications are used as follows:

1. To provide contractor a definite basis for preparing bid.
2. To inform all buyer representatives as to what the contractor is obligated to do.
3. To describe procedures that are required by the highway agencies.
4. To state the basis for sampling and testing methods, including acceptance or rejection of the completed work [Miller-Warden Associates, 1965].

2.3.3 Function of the Specifications

Practical and realistic specifications are an important consideration in any quality system. A practical specification is designed to ensure the highest overall value of the resulting construction. A realistic specification acknowledges the cost associated with specification limits and the presence of variability in all products, processes, and construction. The quality level of any product should be associated with the degree of variability. Statistically developed specifications are both practical and realistic because they provide a rational means for achieving the highest overall quality of the material or construction, while recognizing and providing for the variability of the process and product [Willenbrock, 1976].
2.4 ROAD CONSTRUCTION PROCEDURES & QC TESTS

2.4.1 General

The materials used for roadway construction have progressed with time. Such materials have been accompanied with corresponding advancements in methods with which these materials are characterized and applied to pavement structural design. Currently, there are two primary types of pavement surfaces: Portland cement concrete (PCC), which is composed of mix between aggregates and cement, and Hot-Mix Asphalt concrete (HMA), which is composed of mix between aggregates and asphalt binder. Below this bound surface, there are unbound material layers that provide structural support for the pavement system. There are various methods by which the mix can be designed. For example, HMA can be designed using Marshall, Hveem, or Superpave mix design systems. PCC can be designed using the American Concrete Institute (ACI) or the Portland Cement Association (PCA) method. On the other hand, thickness of each layer can be calculated using empirical design or mechanistic-empirical design methods, which depend on traffic loading, material characteristics, and environmental factors [Pavement 2010].

HMA consists of two basic ingredients: aggregate and asphalt binder. HMA mix design is the process of determining what aggregate to use, what asphalt binder to use and what the optimum combination of these two ingredients ought to be [Pavement 2010]. The good performance of HMA measures to a mean of which resistance to the three primary HMA distresses: permanent deformation, fatigue cracking, and low-temperature cracking.

Permanent deformation refers to the plastic deformation of HMA under repeated loads. This permanent deformation can be in the form of rutting (lateral plastic flow in the wheel-paths) or consolidation (further compaction of the HMA after construction) [FWA 2006]. HMA mix design has evolved as a laboratory procedure that uses several critical tests to make key characterizations of each trial HMA blend. Although these characterizations are not comprehensive, they can give the mix designer a good understanding of how a particular mix will perform in the field during construction and under subsequent traffic loading [Pavement 2010].
This section provides a general description for all road construction procedures and the accompanied quality control tests. However, a detailed description of all quality control tests related to asphalt binders, aggregates, and HMA is presented in Appendices as follow:

- Appendix A: Inspection of Asphalt Binders
- Appendix B: Inspection of Aggregates
- Appendix C: Inspection of Hot-Mix Asphalt

### 2.4.2 Quality Control Tests on Materials before Incorporation in the Works

All materials before incorporation in the work shall be tested by the Contractor for the tests indicated under 'Tests to be carried out Prior to Construction'. The tests shall be carried out from each source identified by the Contractor. The test samples shall be representative of the material available from the source. Any change/variation in the quality of material with depth of strata shall be reported. Important tests like the Moisture-Density relationship (Proctor Compaction), Aggregate Impact Value, Plasticity Index, CBR and any other tests specified by the Engineer shall invariably be carried out in the presence of a representative of the Engineer, who will not be below the rank of Junior Engineer. The test results shall form the basis for approval of the source and the material for incorporation in the work and shall be approved by the Engineer.

### 2.4.3 Quality Control Tests during Construction

During execution of the work, quality control for workmanship and ensuring conformance to specifications shall be exercised on the basis of the tests indicated under 'Field Quality Control Tests During Construction'. The tests shall be carried out by the Contractor independently or in the presence of Employer’s representative, normally a Junior Engineer, when available at site or where association of the Employer’s representative in test is prescribed. The Junior Engineer shall record the results in his own handwriting. The Contractor shall be fully responsible for all the
tests carried out for the work. The Assistant Engineer/Executive Engineer during their site visits shall have a few tests carried out in their presence and sign the Quality Control Register.
CHAPTER 3 RESEARCH METHODOLOGY

3.1 RESEARCH OBJECTIVES

There are four main objectives of this research which are itemized as follows:

- Monitor, study, and analyze the current QA/QC system of road construction at the Al-Ain Municipality (AAM)
- Compare the AAM QA/QC System with that of other authorities of constructions regulating industry in UAE.
- Identify shortcomings in the QA/QC system in road construction at the AAM through a comprehensive discussion and analysis.
- Develop a framework to improve and enhance the QA/QC system of road construction at the AAM.

3.2 RESEARCH METHODOLOGY AND TASKS

In order to analyze and shed light on monitoring, enhancement and improvement, a good understanding of current QA/QC system being practiced by the AAM is necessary for which relevant evidence, information and sufficient data were required. It was also considered that it would be foreseeing to know, analyze and compare the QA/QC system being followed by another authorities like Road Department of Abu Dhabi Municipality (ADM), Roads and Transport Authority (RTA – previously known as Department of Roads, Dubai Municipality), and Dubai Central Laboratory (DCL), which is considered as an integral part of the RTA. Major obstacle, which hindered the research, is “confidentiality” of data, except the AAM. However to overcome this problem, scheduled interviews were made with responsible persons of respective departments of the various organizations, as indicated above. Related physical data and evidence were obtained only from the AAM. Specifications for road works from the AAM, ADM and RTA were also made available.
Prior to proceeding with data collection procedures, interviews etc, mindset was made that the objective of QA/QC activities is to ensure the quality of construction of a project. The quality of the construction activities are interlinked to both the materials used in the construction and the way of performing the construction by systematic methods (i.e. quality procedure), schematic and efficient usage of right materials, manpower, plant and equipments. Often the terms “quality assurance” and “quality control” are used interchangeably to refer to ways of ensuring the quality of materials, workmanship and the final product(s). QA/QC activities are conducted throughout the course of the project.

The research methodology was divided into four phases as shown in Figure 3-1 and as illustrated below:

**Phase (1): Literature Review**

- Perform a comprehensive literature review search to summarize the studies, guidelines, quality control tests (Inspection of Asphalt Binders, Aggregates and Hot-Mix Asphalt), pavement construction procedures, and evaluation techniques related to Quality Management System in road construction.

**Phase (2): Data Collection**

- Specifications, guidelines, manuals, flowcharts, quality control tests or other written information, which outlined methods or requirements of QC/QA during road construction, were gathered, assessed, evaluated and reported for the following:
  - Client: the Al-Ain Municipality:
    - Internal Roads and Infrastructure Division
    - Quality Control section
    - Quantity Surveying section
  - Consultant: Engineering Associate Consultant
  - Contractor: Saif Bin Darwish
Project Case Study: Northern Ring Road Project (NRR)

Client: the Dubai Municipality for the purpose of comparison with the Al-Ain Municipality
  - Dubai Central Laboratory
  - Roads and Transport Authority

Client: The Abu Dhabi Municipality for the purpose of comparison with the Al-Ain Municipality

Knowledge Acquisition: One to one interviews were carried out to collect information from professional engineers who are expert in respective fields. These specialists represent different organizations such as Al Ain Municipality, Abu Dhabi Municipality, Roads and Transport Authority (RTA, Dubai), Central Laboratory of Dubai Municipality (DCL), Road Consultants and Contractors.

Phase (3): Data Analysis & Identify Shortcoming

- Tabulate and analyze all collected data using Excel Sheets.
- Compare using different criteria the specifications of Al Ain Municipality with specifications of Dubai municipality & RTA as well as Abu Dhabi Municipality. Also construction manuals and QA/QC system of those agents were reviewed and studied.
- Identify all shortcomings, if there is any, in the QA/QC specifications in road construction at the Al Ain Municipality though a comprehensive discussion and analysis.

Phase (4): Development of a Framework for improvement of quality control system

- Propose a short-term mitigation plan to improve QA/QC system in road construction at the Al-Ain Municipality.
- Propose a long-term plan to improve QA/QC system in road construction at the Al-Ain Municipality.
Phase (1): Literature Review

- Perform a comprehensive literature review search to summarize the studies, guidelines, quality control tests (Inspection of Asphalt Binders, Aggregates and Hot-Mix Asphalt), pavement construction procedures, and evaluation techniques related to Quality Management System in road construction.

Phase (2): Data Collection

- Specifications, guidelines, manuals, flowcharts, quality control tests or other written information, Client: the Al-Ain Municipality, Consultant: Engineering Associate Consultant, Contractor: Saif Bin Darwish, Case Study: Northern Ring Road Project (NRR), Client: the Dubai Municipality The Abu Dhabi municipality
- Knowledge Acquisition: One to one interviews

Phase (3): Data Analysis & Identify Shortcoming

- Tabulate and analyze all collected data using Excel Sheets.
- Compare using different criteria the specifications of Al Ain Municipality, with specifications of Dubai municipality & RTA as well as Abu Dhabi Municipalities. Also, construction manuals and QA/QC system of those agencies were reviewed and studied.
- Identify all shortcomings in the QA/QC specifications in road construction at Al Ain Municipality though a comprehensive discussion and analysis.

Phase (4): Development of a Framework for Improvement of Quality Control System

- Propose a short-term and long term mitigation plan to improve QA/QC Specifications in road construction at Al-Ain Municipality.

Figure 3-1 Layout for Research Methodology and Tasks
CHAPTER 4 DATA COLLECTION FOR QUALITY ASSURANCE/CONTROL SYSTEM

4.1 GENERAL

This chapter focuses on data collection related to Quality Assurance and Quality Control system followed by the Al-Ain Municipality and other related highway organizations such as Roads and Transport Authority in Dubai and the Abu Dhabi Municipality. Data of other highway organizations were gathered to have comparison with that of the AAM. Specifications, guidelines, manuals, flowcharts, quality control tests or other written related information, which outlined methods or requirements of QA/QC during road construction, were gathered, assessed, evaluated and reported for the AAM and the related highway organizations. Moreover, due to the restriction of confidentiality, some information could not be available. However, responsible personnel of these organizations as well as some of the experienced consultants and contractors were kind enough to participate in face-to-face interview from where much of the relevant data were collected.

4.2 QA/QC SYSTEM OF THE AL-AIN MUNICIPALITY

4.2.1 Introduction

The City of Al Ain is an ancient crossroads. For at least 5,000 years, it has offered a pleasant, cool respite from the heat of the surrounding desert. Al Ain is located in the Eastern region of Abu Dhabi Emirate just south of Dubai and east of Abu Dhabi. The Eastern region covers an area of approximately 13,100 km² [Wikipedia 2010]. The development and urbanization process has gone through a well thought-out master plan. Physical characteristics of the city are dominated by major road and street network with roundabouts; horizontal expansion (building heights restricted to max. 4 stories); extensive vegetation and landscape; public gardens and distinctive existence of oasis within the urban fabrics [Al Ain times 2010].
The Al Ain Municipality constitutes one of several departments within the Municipal Affairs Authority. It is a government institution basically directed to serve Al Ain Area, which covers Al Ain City and the neighbouring outskirts. The Al Ain Municipality was established in 1967. An Emiri Decree was issued in 1974 AD to control and regulate the city's affairs. It was after that date that Al Ain Municipality started to function as a government department, which is, directed to provide wide range services to Al Ain City. The Al Ain Municipality stands as a leading institution of development in the area. This is due to the role it plays and the systems and services it renders for improving the quality of life to the highest possible standards. The Al Ain Municipality has also projected a clear strategy based on a vision entitled, "A Distinguished Municipality and an Enduring Development for the City of Oases". This strategy is expected to be implemented through "Providing such distinguished municipal services and advanced infrastructure to Al Ain City and the surrounding areas, by qualified staff and advanced systems, while taking into account the peculiarity and genuineness of the City", abiding in the same time by the values stemming from heritage, leadership, credibility, quality, innovation, participation and community service within the aims of this strategy [CMR 2010, Wikipedia 2010].

As a service authority, the Al Ain Municipality has been able to absorb the latest and most advanced scientific and professional standards of quality and excellence through development and upgrading work systems, taking benefit, in this respect, from the extensive development of the means of communications and information technology, as well as from the continuous development of its human resources with a view to render faster and more distinguished services for the population of Al Ain City. Such vision and practices followed in providing services by the Municipality have been met with satisfaction and appreciation by both citizens and residents of the Area [CMR 2010].

4.2.2 Strategic Objectives of the Al-Ain Municipality

The objectives of the Al Ain Municipality, as delineated in Law No (11) for the year 2007 AD, which governs and regulates the Municipality and the Municipal Council of Al Ain City at the Emirate of Abu Dhabi, can be summarized as follows:
• Coordination with the concerned authorities in matters relating to the Structural Development plans of the area,
• Enforcement of laws, systems, regulations and specifications relating to construction works, which are issued by the concerned authorities and are currently applied and implemented in the Emirate of Abu Dhabi for all the projects executed therein, as well as to issue building permits and control procedures for execution of projects as per the aforesaid laws and regulations,
• Devising regulations and layouts to control and upgrade the features of the area, as well as to keep it clean and elegant,
• Planning, designing, constructing, shaping and operating the infrastructure facilities, such as roads, gardens and green spaces within the jurisdiction of the Municipality, as well as to coordinate with the concerned authorities in this respect,
• Keeping the area clean and hygienic,
• Rendering real estate registration services as per the requirements of the Department of Municipal Affairs and in coordination with the other competent authorities,
• Planning, designing, constructing, maintaining and operating the public utilities in the Area [CMR 2010].

4.2.3 Organizational Structure

The Al Ain Municipality consists of several sectors, which are subsequently support by respective Divisions. Figure 4-1 shows the proposed organization structure for the AAM; while Figure 4-2 presents all divisions inside Municipal Infrastructure and Assets Sector. The Internal Roads and Infrastructure division is responsible for designing, execution, controlling and maintaining roads and infrastructure; therefore the required data were collected from this division.
4.2.4 Internal Roads and Infrastructure Division

Figure 4-3 shows all sections that located inside the internal roads and infrastructure division. The main responsibility of internal roads and infrastructure department, which is considered the main role of this agency, is to

- Manage, Plan, Design, Construct, and Control of Roads systems,
- Maintain Roads Network and related facilities in an optimum operational state,
- Manage the Planning, Servicing, Controlling of Traffic systems to build traffic culture and awareness,
- Provide vehicles, drivers and commercial licensing services.

In addition, the department reviews the following: [Al Dhaher 2006]
- Design drawings of roads, structures and other miscellaneous disciplines of project submitted by project’s Consultant.
- Tender documents of roads and other projects submitted by project’s consultant.
- Preparing contractors contract agreement for signing, upon approval by the Executive Council.

Figure 4-3 Sections inside Internal Roads and Infrastructure [CMR 2010]

4.2.5 Material Characterization Tests before incorporation in the works

The current system outlines that all materials before incorporation in the work shall be tested by the Contractor for the tests as indicated in its specifications under ‘Tests to
be carried out Prior to Construction' or "Material Characterization Tests". The tests shall be carried out from each source identified and proposed by the Contractor. The test samples shall be representative of the material available from the source. Any change/variation in the quality of material with depth of strata shall be reported. Tests like the sieve analysis, plasticity index, Moisture-Density relationship (MDD), California Bearing Ration (CBR), Los Angeles Abrasion (LAA), Aggregate Crushing Value and any other related tests to comply with project specifications shall be witnessed by the Employer's representative. The test results shall form the basis for approval of the source and the material for incorporation in the work and shall be approved by the AAM. Prior to the execution of the works, the contractor is obliged to submit method statement for each activity which shall be reviewed and approved by the supervising consultant.

4.2.6 Quality Control Tests during Construction

During execution of the work, quality control for workmanship and ensuring conformance to specifications shall be exercised on the basis of the tests indicated under 'Field Quality Control Tests During Construction'. The tests are carried out by the Contractor or independent laboratory in presence of the Employer's representative. These tests results certify that the end-product of each layer of the pavement is in conformity with the project specifications.

4.2.7 Quality Assurance Flow Chart

A typical flow chart for quality assurance checks during the construction of roads is given as an illustration in Figure 4-4.
Figure 4-4 General Flowchart for Quality Assurance at Road Construction [Al Dhaher 2006]
4.3 CASE STUDY: QA/QC SYSTEM FOR RUNNING PROJECT AT THE AAM

4.3.1 General

A running project titled “Upgrading Northern Ring Road in Al Ain City” was selected as a case study to understand the QA/QC system of the AAM while executing the project works. The contract value of the job is AED 610 million. Two international organizations namely Hill International and Engineering Associates are engaged by the AAM for project management and supervising the execution of the job, respectively. M/s Saif Bin Darwish (SBD), the winning bidder, is working as the contractor. Relevant data of the case study is presented in Table 4-1

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Upgrading &amp; Intersections Improvement of Northern Ring Road of Al-Ain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>Al Ain Municipality (AAM)</td>
</tr>
<tr>
<td>Project</td>
<td>Hill International</td>
</tr>
<tr>
<td>Management</td>
<td>Engineering Associates</td>
</tr>
<tr>
<td>Contractor</td>
<td>Saif Bin Darwish</td>
</tr>
<tr>
<td>Contract Amount</td>
<td>AED 610,034,205.70</td>
</tr>
<tr>
<td>Start Date</td>
<td>2 November 2008</td>
</tr>
<tr>
<td>Completion Date</td>
<td>1 November 2010</td>
</tr>
<tr>
<td>Project Duration</td>
<td>730 Days</td>
</tr>
</tbody>
</table>
4.3.2 Project Scope of works

The project scope of works can be summarized as follow [Ring Road 2008]:

- Construction of new dual carriageway (6.5 km approximately) having three-lane in each direction and upgrading of existing northern ring road (12.8 km approximately).
- Construction of a three-lane flyover bridge (Interchange-1) at the location of Al Ain – Dubai Road.
- Construction of a four-lane dual carriageway underpass (Interchange-2) at the location of the Bide Bint Saud Roundabout.
- Construction of a four-lane dual carriageway underpass (Interchange-3) at the location of the Al-Towayya Roundabout.
- Construction of Al Foah Underpass.
- Construction of two Wadi Bridges. One near Interchange-1 and another near Interchange-2.
- Construction of T-junction, landscaping, storm water drainage, street lighting and necessary road furniture.

The following sections describe in details the construction and quality control procedures for Earthwork, Granular Subbases/Bases, Asphalt works, and Concrete Work. The Al Ain Municipality has deeply covered the required specifications for each construction step through tender documents. The contractor is required to construct a site laboratory for testing of materials under supervision of the consultant.

4.3.3 Earthworks

Earthworks stage contains construction of embankment and subgrade layers. To carry out the earthworks of the project, the contractor shall obtain approval from the AAM for the location of borrow area. After getting approval for the borrow area, which is located next to Al-Foah Underpass KM 07 of the project under study, the contractor prepared stockpiles of the borrow materials by excavating, watering and mixing with help of earth moving machines as shown in Figure 4-5 and Figure 4-6. Sampling and testing procedures were started for each stock pile by the consultants and contractor.
The selected samples were tested in a site laboratory, which is located near to Nahil road, and/or in an approved independent laboratory. [Ring Road 2008]

Figure 4-5 Mixing of borrow material in progress

Figure 4-6 Hauling and transporting of borrow material in progress
4.3.3.1 Material Characterization Tests Prior to Construction

To evaluate the quality of the material and to ascertain compliance with the specifications, the following tests are carried out prior to seeking approval for the source to be used in the permanent works.

1. Modified Proctor Compaction Test (Figure 4-7)
2. California Bearing Ratio-CBR Test (Figure 4-8)
3. Sieve analysis (Figure 4-9)
4. Plasticity Index (Figure 4-10)

The site laboratory is equipped to carry out the above tests. The following tests are performed in one of the approved (by the AAM) independent laboratory:

1. Water soluble salt (%)
2. Linear shrinkage
3. Organic matter

Specification criteria for different type of materials to be used in earthworks (embankment and subgrade) are tabulated in Table 4-2. Material type A and material type B are used for embankment, while material type C is being used for Sub-grade construction and are tested for specified properties every 1500 Cubic M.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Material Type A</th>
<th>Material Type B</th>
<th>Material Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDD mg/cc</td>
<td>-</td>
<td>1.8 mg/cc min</td>
<td>1.9 mg/cc min</td>
</tr>
<tr>
<td>CBR %</td>
<td>15 min</td>
<td>20 min</td>
<td>30 min</td>
</tr>
<tr>
<td>Liquid Limit %</td>
<td>40 max</td>
<td>35 max</td>
<td>35 max</td>
</tr>
<tr>
<td>Plasticity Index %</td>
<td>11 max</td>
<td>06 max</td>
<td>06 max</td>
</tr>
</tbody>
</table>

*MDD: Maximum Dry Density*

The contractor compiles all the test results, draw the compliance check list, fill up the designated form and seek for the approval of the material. The supervising consultant reviews the submittal and being satisfied on approval pass the same to the AAM for
endorsement. It is stated that the entire process takes about a month. Contractor is permitted to work only when the material is approved.

Figure 4-7 Site Lab: Modified Proctor Test in progress

Figure 4-8 Site Lab: CBR moulds in 96 hrs soaking phase
4.3.3.2 Quality Control Tests during Construction

Adherence to the approved method statement (actual method/steps to be followed in executing the job) and testing of in-situ material to verify the conformity of the approval are the integral part of quality control during construction.

Material is excavated from the approved borrow area, hauled to the site, dumped on the road bed, spread in layers to attain each layer 150mm thick after
compaction, watered, mixed thoroughly (maintain ±2% of moisture determined by MDD) and compact to the required density (min. 95% of MDD). Motor grader, vibratory steel roller, pneumatic tire roller, water tanker, wheel loader and tipper truck are the common equipment used in the process.

In-situ density measurements should then be carried out to check degree of compaction using sand cone method, as shown in Figure 4-11. One test is to be carried out to check the thickness of subgrade layer per 750m² of fill.

Figure 4-11 Site Lab: Field density test in progress

4.3.4 Granular Sub-base and Aggregate Road Base Courses

4.3.4.1 Material Characterization Tests prior to Construction

Based on project specifications and designed cross section, the subbase course should be placed over the approved subgrade layer with thickness of 150mm and compacted to 98% of the MDD followed by 150mm layer of compacted Aggregate Road Base. To meet the physical requirements of the material as outlined in the specifications, the contractor identified Siji Query in Al Fujaira as the source of supply. Samples of both the above type of materials were obtained jointly by the consultant and the contractor
as shown in Figure 4-12. Following tests were performed on the materials as per designated standards as per specification:

1. Gradation
2. Dry Density-Moisture Content Relationship
3. Plasticity Index
4. California Bearing Ratio (Figure 4-13)
5. Los Angeles Abrasion (LAA)
6. Soundness
7. Sand Equivalent
8. Sulphate and chloride content
9. Flakiness Index (Figure 4-14)

All the above tests were carried out at the site laboratory except LAA, soundness, sulphate and chloride content, which were performed at the independent laboratory. Specification limits and frequency of different tests are outlined in Table 5-2 and Table 5-3 in Chapter 5 for subbase and aggregate road base, respectively.

Approval process of subbase and aggregate road base is more or less identical to that of earthworks material.

4.3.4.2 Quality Control Tests during Construction

Principle of quality control during construction of Aggregate Road Base and Subbase is somehow similar to that of earthworks except water mixing is performed outside the road bed and is paved by the finisher. However, sub base material may be mixed on the road bed and is permitted to spread by the motor grader. Layer thickness is 150mm maximum. Water mixed material (maintain ±2% of moisture determined by MDD) and compact to the required density (min. 98% of MDD). Other equipments involved are vibratory steel roller, pneumatic tire roller, water tanker, wheel loader and tipper trucks etc. Figure 4-15 shows field density test in progress.
Figure 4-12 Sampling of Subbase and Aggregate Road Base Material in progress at Siji Source

Figure 4-13 CBR Test for Granular Materials
Figure 4-14 Flakiness & Elongation test in progress

Figure 4-15 Field Density Test in progress
4.3.5 Bituminous Paving Courses

The project is designed to have total 170mm thick of asphaltic concrete in three layers having three different bituminous mixes namely,

- Bituminous Base Course 60mm thick.
- Bituminous Binder Course 60mm thick.
- Bituminous Wearing Course 50mm thick.

4.3.5.1 Material Characterization Tests prior to Construction

There are three steps that are involved in approval process of Hot Mix Asphalt (HMA) as follow:

1. Approval of the aggregate – source (crusher)
2. Approval of bitumen – source – refinery
3. Approval of mix design (Marshall Mix Design)

Based on petro-graphic analysis and some mechanical/chemical test results, initial approval of the crusher is given. Consultant and contractor jointly sampled the aggregates from the crusher, run the required tests (refer to Table 5-4, the AAM) and on conformity with the specifications consultant recommend for final approval which AAM endorsed. Siji crusher located in Fujairah has also been approved for aggregates being used for asphaltic concrete.

Similarly when the contractor proposes the source of bitumen, joint sampling is carried out by the consultant and the contractor. The 60-70 penetration grade of bitumen from Bahrain Petroleum has been endorsed for this project after having satisfactory results for the following criteria (Test procedures of which are briefed in appendix A)

1. Penetration: Determined by test method ASTM D 5.
2. Flash Point: Determined by test method ASTM D 92.
4. Solubility in Trichloroethylene: Determined by test method ASTM.
5. Thin Film Oven Test: Determined by test method ASTM D2872.

Job mix formula for each type of asphaltic mixes was established by the contractor following Asphalt Institutes Manual MS-2. Marshall Criteria were cross checked by the consultant and based on project specifications, refer to Table 5-6-AAM in Chapter 5, which has been endorsed by the AAM.

Korean made asphalt plant, SPECO having 250 ton/hr capacity, has been in operation since August 2009 for producing bituminous mixes as shown in Figure 4-16.

Figure 4-16 Project Asphalt Batching Plant
4.3.5.2 Quality Control Tests during Construction

During asphalt paving, HMA samples are obtained jointly (consultant & contractor) from the road bed as shown in Figure 4-17. Bitumen extraction is performed to check gradation and the percent of binder content in the HMA. Theoretical Maximum Density (Rice Method) is also carried out on daily basis. Marshall Specimens are made and on the following day reading for specific gravity (Marshall Specimen), stability and flow are recorded. Voids calculation is performed through volumetric calculations of HMA, which is considered the foundation of any good mix design. All these test results are compared with the approved Job Mix Formula. As soon as the pavement is cured, cores are drilled to check in-situ compaction. On conformity with the specifications limits (refer Table 5-6, AAM in Chapter 5), the pavement layer is then approved for payment.

Figure 4-17 Sampling of HMA
4.4 **QA/QC SYSTEM OF THE DUBAI MUNICIPALITY**

4.4.1 **Organizational Structure**

One of the most important tools of an organizational structure is to construct out an organizational chart. An organizational chart shows how departments, divisions and various levels of an organization interact with one another. This chart provides a picture of various departments, who make decisions, and shows the sequences of work flow. Organizational structure is design based on department’s/project’s goals and needs. It reflects how the work gets done starting with the beginning step all the way to the end result.

Quality Management System (QMS) enables an organization to achieve goals and objectives set out in its policy and strategy. It provides consistency and satisfaction in terms of methods, materials, equipments, etc., and interacts with all activities of the organization. Quality management can be considered to have three main components: quality control, quality assurance and quality improvement. Elements associated with these are responsibilities (job description), procedures (method), resources etc. Figure 4-18 shows the organization structure of the Dubai Municipality, while Figure 4-19 presents the sub-structure of the above representing details of Technical Service Directorate. Dubai Accreditation Centre (DAC) and Dubai Central Laboratory (DCL) both operate under the umbrella of the Dubai Municipality and Road and Transport Authority (RTA), which its organizational chart is shown in Figure 4-20.

DAC formulate, develop and implement policies and procedures related to accreditation. It also monitors implementation of DAC quality management system, develop internal audit plan and schedule the management review in coordination with related involved parties.
Figure 4-18 Organization Chart at the Dubai Municipality – Part A [DM 2010]
Figure 4-19 Organizational Chart at the Dubai Municipality – Part B [DCL Interview]
Figure 4-20 Organizational Chart at Roads and Transport Authority [RTA 2010]
4.4.2 Role of Roads and Transport Authority

Since Dubai is one of the fastest growing cities in today's world, making the provision of high quality infrastructure facilities absolutely imperative, and since providing an advanced transport network for the people of Dubai has been high on the government’s agenda, which is evident from its initiatives to enhance the public transport facilities and improve roads across the emirate to make travel safer and smoother, the Roads and Transport Authority was formed by the decree number 17 for the year 2005. RTA is responsible for planning and providing the requirements of transport, roads & traffic in the Emirate of Dubai, and between Dubai and other Emirates of the UAE, neighboring countries in order to provide an effective & an integrated transport system capable of achieving Dubai’s vision & serving the vital interests of the Emirate. RTA responsibilities also include Buses, Taxis, Inter-City, Transport Roads, Engineering Registration & Licensing, Marine Transport, Commercial Ads on the Right of Way, Public Buses, Roads Beautification, Roads & Parking Rail Project, Traffic Safety [RTA 2010]. Roads and Transport Authority consists of many agencies. Dubai Traffic & Roads Agency is one of them. The main role of this agency is managing the Planning, Designing, Construction, and Controlling of Roads systems, Maintaining Road Networks and related facilities in an optimum operational state, Managing the Planning, Servicing, Controlling of Traffic systems to build traffic culture and awareness, Providing vehicles, drivers and commercial licensing services [RTA 2010].

As it was stated early that managing the Planning, Designing, Construction, and Controlling of Roads systems is part of Dubai Traffic & Roads Agency, therefore all roads and infrastructure projects in Dubai city are being the responsibility of such agency. There are many projects have been constructed in Dubai to meet the demand of city expansion as well as dramatic increase of population in the city and also to meet the vision of the department which is smooth roads.

The quality assurance and quality control carried out in investigating the quality of road construction materials in Dubai is based on British Standards or the British Standards adopted by the European Union (i.e. BS EN) are the mostly used for
the specifications of soil and aggregate testing. ASTM standards come in the second order and mainly preferred for the asphalt material and asphalt concrete mixes. Other standards such as AASHTO come as the last option. Therefore, specification which controls the quality range is the same.

In terms of methods statement, which represents how the contractor will carry out any activity in the site such as constructing of subgrade layers, subbase or asphaltic layers, follow the normal practice which is worldly known

4.4.3 Role of Dubai Central Laboratory

Dubai Central Laboratory or DCL was established in 1997 with aim centralizing all the labs within the Dubai Municipality under one department. The DCL comply with ISO/IEC 17025:2005, the international standard against which the competence of testing and calibration laboratories is assessed. The accreditation of the DCL testing and calibration services are through the Dubai Accreditation Department DAD, even though at the start of accreditation was through the United Kingdom Accreditation Services UKAS for three years (2006-2009). The DCL is also certified to International Standard ISO 9001:2008 “Quality Management System Requirements” since 2000; and certified to OHSAS 18001:200, since 2008. Currently the DCL is armored with 125 people. All managers, engineers, inspectors and technicians are well equipped with their wealth of experience, skill and ability. The definite tasks for each one of them are outlined in respective job descriptions [DCL 2010].

From Figure 4-19, it is understood that in addition to other services, the DCL provides factory assessment, inspection, certification, materials testing, calibration and equipment testing services. Certification services are accredited to ISO/IEC Guide 65:1996.

In Emirate of Dubai, many products cannot be sold or used without independent confirmation that they meet certain regulatory requirements. The Dubai Municipality issues local regulations in order to protect consumers from substandard
and unsafe products. These regulations specify that the identified products must be certified before they can be used or sold in Dubai. The DCL is the recognized body that can provide the required certification services for these products.

The DCL Mark is an instant indication to buyers and users that the product meets recognized performance requirements as given in local, national and international standard specifications. Compliance with recognized national and international standard specifications means wider acceptance of the product in the local and international market.

The DCL Mark factory assessment scheme is an ISO 9001 quality-based program that involves continuous monitoring of the product performance and the consistency and effectiveness of the production processes involved; leading to improved production efficiency and overall performance improvement. [DCL 2010]

Upon payment of set fees, a supplier may apply for certification of his product against recognized international, national, or local specifications. The DCL carries out various tests of the product against the relevant standard as per specification requirements by selecting random samples. Certification auditors carry out assessment of the factory, quality management system against the requirements of ISO 9001 standard. On satisfactory test results and factory assessment, the supplier is granted a license to affix the DCL-MARK on his product for specific. The Mark is an indication that the product has been certified as having complied with the relevant standard specifications. Certification is followed by surveillance testing of the product in the market as well as from factory. [DCL 2010]

Applicants for certification through factory assessment may submit their application using specific form as shown in Table 4-3. The general testing rules, procedures and requirements for this scheme are shown in Figure 4-21: the DCL receiving system for testing process. While Figure 4-22 shows the entire flow chart for the DCL system.
Table 4-3 Test Request Form and Sampling for the DCL [DCL2010]

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<tr>
<th>PROJECT DETAILS</th>
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<tr>
<td>PROJ. NAME</td>
<td></td>
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<tr>
<td>CONSULTANT</td>
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<td>CONTRACTOR</td>
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<tr>
<th>SPECIFIC DETAILS</th>
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<tbody>
<tr>
<td>SOIL</td>
<td>MDO (Mg/m³)</td>
</tr>
<tr>
<td></td>
<td>OM (%)</td>
</tr>
<tr>
<td></td>
<td>DATE</td>
</tr>
</tbody>
</table>
| ASPHALT          | Ref. Grade/Gle.
|                  | Slump Type |
|                  | Laying/Production Date |
|                  | Calibration Factor |
| STEEL            | Manufacturer’s Cert. No. |
|                  | Grade of Steel |
|                  | Cement Content (%) |
| CONCRETE         | Grade of Concrete |
|                  | SU |
| LUBE OIL         | Service Category |
|                  | Viscosity Grade |
| OTHERS           | No. of Sample |
|                  | No. of Tests Per Sample |

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<tr>
<th>SAMPLING DATE</th>
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<th>AMB TEMP.</th>
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</thead>
<tbody>
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<td>SAMPLE SOURCE</td>
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<tr>
<td>CONDITION OF SAMPLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POINT OF TAKING SAMPLE</td>
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<tr>
<td>NUMBER OF INCREMENT</td>
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<tr>
<td>TRUCK / D.O. No.</td>
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</tr>
<tr>
<td>NOMINAL SIZE</td>
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<tr>
<td>SIZE OF SAMPLE</td>
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<tr>
<td>SAMPLING METHOD</td>
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<td>UNIT SIZE</td>
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<tr>
<td>SOURCE OF MINERAL AGG. (for Plant Mixes Only)</td>
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<td></td>
<td>SENDER No.</td>
<td></td>
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<td></td>
<td>Loc. No.</td>
<td>ID No. / PLOT No.</td>
</tr>
<tr>
<td></td>
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<table>
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<tr>
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<tr>
<td>NAME</td>
</tr>
<tr>
<td>SIGNATURE</td>
</tr>
<tr>
<td>CONTACT No.</td>
</tr>
</tbody>
</table>

NOTE:
1. ADDITIONAL INFORMATION REQUIRED SHALL BE PROVIDED.
2. SAMPLING & TESTING CAN BE WITNESSED BY AN AUTHORIZED PERSON.
3. PLEASE REFER TO THE LABORATORY FOR MINIMUM MATERIAL REQUIREMENT.
Figure 4-21 The DCL Receiving System for Testing Process [DCL 2010]
Figure 4-22 Flow Chart for the DCL System [DCL Interview]
The specific requirements for each particular product are given in the "Specific rules" for that particular product. All block factories, ready mix concrete plant, reinforced steel, cement and cementitious product factories, pipe and pipe products manufacturing units are assessed, certified and regulated by the DCL. Every supplier/manufacturer ensure that this product, for which DCL-MARK has been issued, conforms at all times to the requirements of the General Rule and Specific Rules and shall maintain to the satisfaction of the DCL, a system of quality control including inspection and testing. The DCL certification body carries out surveillance at least once in every three months to the factories, yards, construction sites and ensures continuing compliance with the requirements of certification scheme. During this visit, the certification body shall confirm that the factory QMS continues to be implemented effectively. Certification body examines the results of the internal product quality assurance plan to verify consistence compliance of the product with the Standard specifications. The inspectors (certification personnel) may obtain samples for testing in the DCL and/or by an accredited laboratory. Results of independent testing are evaluated to confirm that the product continues to comply with the Standard Specifications. Any non-compliance is addressed by General rules (RD-IC-02-01), which calls for penalty/warning followed by withdrawal of certification, total restriction on using the product until the time corrective and preventive actions are in place and new certificate is issued [DCL 2010]. Dubai Central Laboratory Department Sections consist of Food & Environment Laboratory Section established in 1975, Engineering Materials Laboratory Section established in 1979 as shown in Figure 4-23, Inspection & Certification Section established in 1991, Research and Standardization Management Office 1997, Consumer Product Laboratory Section established in 1998 and Metrology Section established in 2002.
4.4.3.1 Soil Tests

In current practices, the DCL plays the main role in conducting the tests for the soil material. In some roads projects, the geotechnical tests for the subgrade soil are undertaken by independent laboratory accredited by the DCL. The Dubai Accreditation Centre follows an accreditation process before granting a license to an independent laboratory. The accreditation requirements of construction material testing laboratories–DAC-REQ-4 includes more than 120 tests for soil, aggregates, asphalt, concrete, steel, and road marking materials. According to the DCL requirements, all accredited laboratories shall participate in parallel and re-check programs according to the DAC annual plan. There are more than 20 tests for the soils undertaken for the purpose of roads construction [R901-Phase 2].

According to the specification, there are some rules that should be applied in terms of testing materials into an independent laboratory. For example, any testing,
which is required under the contract and as detailed in DM Administrative Decision No (160) for year 2000, needs to be carried out on the independent laboratory such as earthworks. Also independent laboratories that operate in Dubai Emirate shall meet all the requirements of Dubai Municipality rules and regulations including Dubai Center Laboratory accreditation requirements. For independent laboratories operate outside the city of Dubai, they shall have accredited to one of the National Accreditation Systems for laboratories such as UKAS, NATA, etc. The Contractor shall forward a copy of the accreditation certificate to DCL for approval prior to approaching such laboratories for testing services [R901-Phase 2].

4.4.3.2 Aggregate tests, Asphalt Tests and Cement Concrete Tests

Dubai Central Laboratory plays the main role in conducting the required tests for the aggregate material used in roads subbase, base and HMA as well as other construction works. The aggregate are usually used in both asphalt mixtures and concrete mixes. There are more than 32 tests related to aggregates and used for the purpose of roads and bridges constructions [R901-Phase 2]

For asphalt binder and HMA used in roads construction throughout all stages of roads projects, all tests for the asphalt mixtures are undertaken by the DCL laboratory. There are more than 34 tests related to asphalt, used for the purpose of roads and bridges constructions.

In addition, the DCL plays very crucial role in conducting tests for the concrete and cement material. These materials can be used in building, bridges and other roadwork. There are more than 70 tests related to concrete and cement material used for the purpose of roads and bridges constructions [R901-Phase 2]

4.4.4 Quality Control Procedures in the RTA

According to the specification, contractors working with the RTA need to put into consideration that every single test should be approve by the DCL and independent laboratory. Such test, as it was stated early, depends on the nature and type of project. For instance, embankment work should be tested at independent
laboratory where all the pavement structure layers should go to the DCL. Therefore contractor should always study the time and the cost required to carry out any test. Specifications have clearly stated that "the contractor shall give the Engineer details of the source of materials to be incorporated into the works; reasonable notice must be given to the contractor to allow the engineer to carry out such tests and enquiries as many as appropriate before giving approval". Moreover, the contractor should comply with rules made by the RTA; some of these rules are listed below [DCL 2010]:

1.1 All transportation of personnel and materials on site and to/from the DCL shall be borne by the contractor. Suitable approved transport with driver shall be maintained for this specific use by the Contractor.

1.2 The contractor shall pay for all the tests carried out by the DCL.

1.3 Any testing which is required under the contract which cannot be carried out by the DCL shall be carried out at Contractor’s expense at an Independent Laboratory in accordance with Appendix “A2”. Copy of such sampling and testing reports shall be forwarded to the DCL and to the DM Department concerned for information not later than a week from the date of the issuance of the reports.

1.4 The testing of the works by the DCL shall in no way absolves the contractor from his responsibilities to carry out his own job control testing of the quality of his work and the materials used.

1.5 Representatives of the Consultant and the Contractor shall be permitted to witness the testing carried out by DCL.

1.6 DCL will not be held liable for interpreting test data, since this will be the responsibility of the Consultant.

1.7 All sampling for such tests shall be earned out by the Consultant’s Representative and labeled as per relevant standard sampling requirements and submitted by the Consultant to DCL along with the sampling reports.
1.8 The Contractor shall submit to DCL Monthly Laboratory Testing Programmes. The programme shall detail the specific test requirements for the coming month which includes the type, number and approximate date that testing will be required.

1.9 Minimum twenty-four (24) hours’ notice shall be given to DCL before any tests are scheduled to be carried out.

1.10 The Consultant shall inform DCL and DM Department concerned of all failed test results along with his course of action in addition to submission of compliance materials testing reports. [RTA Specification 2009]

**TESTING AT AN INDEPENDENT LABORATORY** [RTA Specification 2009]

1 Any testing which is required under the contract and as detailed in DM Administrative Decision No. (160) for year 2000 may be carried out at the Contractor’s expense at an approved Independent Laboratory, provided this laboratory meets the following requirements.

1.1 Independent laboratories that operate in Dubai Emirate shall meet all the requirements of DM rules and regulations including DCL accreditation requirements.

1.2 Independent laboratories that operate outside Dubai Emirate shall be accredited to one of the National Accreditation Systems for laboratories such as UKAS, NATA, etc. The Contractor shall forward a copy of the accreditation certificate to DCL for approval prior to approaching such laboratories for testing services.

2 AU sampling for such tests shall be carried out by the Consultant’s Representative and labeled as per relevant standard sampling requirements and submitted by the Consultant to the independent laboratory along with sampling reports.
3 Representatives of the Consultant and the Contractor shall be permitted to witness the testing carried out by the independent laboratory.

4 The testing of the works by the independent laboratory shall in no way absolves the Contractor from his responsibilities to carry out his own job control testing of the quality of his work and the materials used according to the contract specifications.

5 The Consultant shall inform D.C.L and DM Department concerned of all failed test results along with his course of action in addition to submission of compliance materials testing reports [RTA Specification 2009].

4.4.5 A Request for Material Testing Process

4.4.5.1 Stage (1)

The Contractor shall submit to the DCL a Monthly Laboratory Testing Program. The program shall detail the specific test requirements for the coming month, which includes the type, number and approximate date that testing will be required. Samples were collected from proposed source, which should be approved by the engineer, of the material for confirmation of its Physical, mechanical & Chemical Properties. Some contractors avoid taking risk as well as in order to save time and cost, they tend to carry out the required tests using their own lab to verify the compliance with specifications before submission samples to the DCL. Consultant should witness every single test.

4.4.5.2 Stage (2)

Once the contractor is satisfied with regards to the compliance of his test results, as mentioned above, 24 hours' notice is served to the DCL through the consultant in order to submit all the samples (materials), which are required be tested
4.4.5.3 Stage (3)

If the results were positive, the DCL will give approval to proceed with site trial then production phase. Consequent to approval of material source, the Contractor should submit a method statement for execution of required layer of the project. After approval of method statement, a trial section was prepared at site to demonstrate execution of an activity with the proposed resources.

4.4.5.4 Stage (4)

Following successful site trial, the contractor should carry out the construction of approved material. For example, if the approved material is Road Base, the contractor shall construct stock piles of material, having a volume of about 1000 Cumm, which is also sampled and tested jointly by supervision consultant and contractor staff for Gradation, Moisture Density relationship, CBR, Sand Equivalent, and Plasticity Index, before it is being sent to the DCL for testing. After approval, stockpiles can be used. The Aggregate Road Base material is laid by paver and be compacted using PTR and Steel Drum Vibratory rollers etc. as described in the method statement. The compacted layer is checked for compaction every 50 LM by sand cone method and making correction for coarser particles in accordance with AASHTO T 224. The tests again need to be sent regularly to the DCL for approval.

4.5 QA/QC SYSTEM OF ABU DHABI MUNICIPALITY

4.5.1 Introduction

The Municipality of Abu Dhabi City was established in 1962 as the "Department of Abu Dhabi Municipality and Town Planning". In 1969, a royal decree was issued to appoint the first municipal board for the city of Abu Dhabi, with the task of providing comprehensive services to the public and ensure proper planning of the developing city, with regularized road networks, maintenance services, sewerage, lighting works, launching the Agriculture Development Plan in the Emirate and establishing public markets in various areas [AD 2010].

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With the ongoing growth of the Emirate, it was decided, in 2005, to merge the Municipality of Abu Dhabi City, Al Ain Municipality, Works Department, Agriculture and Animal Production Department of Al Ain into the Department of Municipalities and Agriculture, to create a streamlined administration and to provide a higher standard of service to the customer [AD 2010].

In May 2007, His Highness Sheikh Khalifa bin Zayed Al Nahyan, President of the UAE and the Ruler of Abu Dhabi, issued a law establishing the Department of Municipal Affairs as an umbrella body overseeing the three administratively independent municipalities, the Municipality of Abu Dhabi City, Al Ain Municipality and Western Region Municipality [AD 2010].

The Municipality of Abu Dhabi City, has since its inception, developed a number of key objectives, notably the implementation of projects aimed at establishing modern infrastructure for the city including bridges, drainage systems, road networks, modern means of transportation, consolidation of comprehensive development projects. It has also simultaneously been moving towards attaining the goals set out by the development plans [AD 2010].

In line with the policies of the government which aim at making Abu Dhabi a modern capital city, it is Municipality of Abu Dhabi City's priority to create an ideal living environment for city residents, with unmatched quality of life and modern amenities. The Municipality of Abu Dhabi City is a founding member of the General Secretariat of UAE Municipalities, a member of the Arab Towns Organization, and the Organization of Islamic Cities [AD 2010].

4.5.2 Organizational Structure

The Department of Municipal Affairs (DMA) was established in May 2007, and replaced the Department of Municipalities and Agriculture to act as the main focal point of all municipal planning and to oversee public works projects in the Emirate of Abu Dhabi. The DMA aims to produce efficiencies and higher customer
satisfaction in accordance with the national Policy Agenda which will represent a new era in municipal services to the general public [ADM 2010].

As a regulatory body, the DMA supervises the three regional municipal councils and municipal administrations; Abu Dhabi Municipality, Al Ain Municipality and Western Region Municipality. Therefore the organization chart for Al Ain Municipality and Abu Dhabi Municipality is more or less the same, however there are some slightly changes. Figure 4-24 shows Municipal Infrastructure and Asset Sector at Abu Dhabi Municipality.

![Municipal Infrastructure & Assets Sector](image)

**Figure 4-24 Municipal Infrastructure and Asset Sector at Abu Dhabi Municipality (ADM) [ADM 2010]**

The following points are to ensure preparation of plans to contribute towards the development of the City of Abu Dhabi into one of the top five capitals in the world by providing quality services of the highest standard:

- Maintain service levels and operation of road networks and maintain safety levels to make sure that at least 85% of the road network of the emirate meets the international standards set for scale service roads.
- Strike a balance between greenery and infrastructure so as to cope with an increasing population density by enhancing the rate of green area per capita.
- Preparation of programs and controls to identify and develop operations and maintenance management projects.
- Development and training of national staff in the field of design, implementation, operation and maintenance.
• Using latest scientific techniques in agriculture and irrigation to reduce operating and maintenance costs, as well as optimize water use so as to impose less pressure on the environment.

• Establish a road asset management database in order to predict the need for future services and requirements of maintenance, leading to reduced public expenditure.

4.5.3 QA/QC Procedures in the ADM

As it was mentioned early, the Abu Dhabi Municipality and the Al Ain Municipality are established under one umbrella which indelicate that regulation and policies are more or less the same; however, in terms of highway construction every organization has their own specifications and process.

Generally, both parties have the same process on carrying the quality control on highway construction material. Nevertheless the Abu Dhabi Municipality over the past years has stated on their contracts that every contractor should establish a site laboratory and provide fully equipments and machines. At the completion of the project, all the equipments should be transferred to the Abu Dhabi Municipality store and become Asset to the organization. With many projects executed, the Abu Dhabi Municipality has owned a large number of machines and equipments that can be used for material testing. Thus, independent laboratory was established based on these assets where a group of more than 20 material engineers and material inspectors have been hired. Abu Dhabi Laboratory was only established to carry out a regular check on the construction materials. It is not linked to any program of work. In addition, there are no fees to be paid by the contractor and no obligations stated on the contract regarding this process. Contractor awarding a project still needs to establish his own site laboratory. The Abu Dhabi Municipality laboratory only visits construction site and take samples parallel to the daily sampling activities, which are done by the consultant. A results report by the Abu Dhabi Municipality laboratory will be then forwarded to execution section while a comparison is made to the consultant’s report to verify if there is any discrepancy.
CHAPTER 5: DISCUSSION AND ANALYSIS

5.1 CONSTRUCTION SPECIFICATIONS

Specifications are to be used as a guideline during the design and construction process. Once they have been incorporated into the contract; however, they become legal and enforceable language of that contract. The standard specifications, the amendments to the standards and the Project Special Specification along with any other attachments in the Contract Documents define a contract and no longer seen as guidelines. Rather, they are considered as written agreement subject to revising only through the change of order process.

These Standard Specifications reflect years of refinement through delivered projects by municipalities each year. In addition, the standards are the result of countless hours of development and review by both internal Department’s staff as well as industry partners. Finally, these standards reflect the contracting philosophy and balance of risk-sharing that the department adopts through the year. This balance of risk gives the lowest final cost solution to the transportation needs. For example, shifting risk to the contractor can provide more certainty on final cost, but may result in higher initial cost. On the other hand, accepting more risk by the owner can lower in lower initial cost, but less certainty on the final cost. Therefore, the Department is to reach the optimum point of balance for risk and is to consider this balance on all future specifications revisions. However, not enough done by the AAM to update the specifications tailored to the climatic conditions, available resources etc. On the other hand, Dubai has developed their specifications to suit Dubai climate and to incorporate available resources. Through research and development the Dubai Municipality has developed their own policy, procedures and method of testing of various materials and has successfully implemented in their Standard Specifications.

The comparative specifications data dealing with different materials by the AAM, the ADM and the RTA/DCL is summarized in the following tables:

- Table 5-1: Comparative data showing test method, frequency of tests and specifications limits of earthworks materials
Table 5-2: Comparative data showing test method, frequency of tests and specifications limits of subbase materials

Table 5-3: Comparative data showing test method, frequency of tests and specifications limits of aggregate road base, and wet mix macadam

Table 5-4: Comparative data showing test method, frequency of tests and specifications limits of aggregate for asphaltic base, binder and wearing course including compaction of bituminous courses

Table 5-5: Comparative data of combined aggregates of asphaltic base, binder and wearing course

Table 5-6: Comparative data of properties (Marshall) of asphaltic base, binder and wearing course

Table 5-1 clearly indicates that there is wide margin of thought between the specialists while specifying the acceptable limits to measure the quality of earthworks materials for their respective organizations. Granular materials having Liquid Limit (LL) and Plasticity Index (PI) maximum of 40 and 10 respectively are rated as “excellent to good” in soil classification of American Association of State Highway and Transportation Officials (AASHTO M-145) which is universally accepted. In the same classification a mixture of silty or clayey gravel and sand having LL and PI value as minimum of 41 and 11 is also rated as “excellent to good” materials. Essentially the ADM and the RTA specified these criteria accordingly. However, the AAM classified the earthworks materials into three different categories, namely as type A, B and C based on value of PI, CBR and unit weight of mixtures, which are to be used at different depth of embankment and/or subgrade. The AAM stipulated limits for earthworks materials as shown in Table 5-7.
<table>
<thead>
<tr>
<th>Description</th>
<th>Test Method</th>
<th>Frequency of Test</th>
<th>Specifications Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Liquid Limit</strong></td>
<td>AASHTO T 89</td>
<td>BS1377</td>
<td>40% Max for Type A</td>
</tr>
<tr>
<td></td>
<td>ASTM D 4318</td>
<td>P2</td>
<td>35% max for Type B &amp; C</td>
</tr>
<tr>
<td></td>
<td>BS 1377</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plasticity Index</strong></td>
<td>AASHTO T 90</td>
<td>BS1377</td>
<td>11 Max for Type A</td>
</tr>
<tr>
<td></td>
<td>ASTM D 4318</td>
<td>P2 AMD</td>
<td>6 max for Type B &amp; C</td>
</tr>
<tr>
<td></td>
<td>BS 1377</td>
<td>P1 x % passing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.425μ Max</td>
<td></td>
</tr>
<tr>
<td><strong>Linear Shrinkage</strong></td>
<td>BS 1377 Part 2</td>
<td>Min one test per 1500 M³ fill</td>
<td>2% max for Type B &amp; C</td>
</tr>
<tr>
<td></td>
<td>Not a criteria</td>
<td>BS 1377 Part 2</td>
<td>0.25% max for Type B &amp; C</td>
</tr>
<tr>
<td><strong>Organic Matter</strong></td>
<td>BS 1377 Part 3</td>
<td>Not a criteria</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 3</td>
<td>BS 1377 Part 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MDD</strong></td>
<td>AASHTO T 180</td>
<td>BS1377</td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>ASTM D 1557</td>
<td>P4</td>
<td>1.8 gm/cc for Type B</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 4</td>
<td>P4</td>
<td>1.9 gm/cc for Type C</td>
</tr>
<tr>
<td><strong>CBR</strong></td>
<td>ASTM D 1883</td>
<td>BS1377</td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 193</td>
<td>P4 AMD</td>
<td>15% for Type A within 1500mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8259-95</td>
<td>20% for Type B within 300 mm to 1500mm &amp; 30% for Type C within 300 mm of top elevation of subgrade</td>
</tr>
<tr>
<td><strong>Water Soluble Salts</strong></td>
<td>Sample boil for 15 minutes, cool, filter and determine salt content</td>
<td>BS 1377 Part 3</td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>Not a criteria</td>
<td>BS 1377 Part 3</td>
<td>5% Max \ By weight of dry material</td>
</tr>
<tr>
<td><strong>In-situ compaction</strong></td>
<td>AASHTO T 191</td>
<td>BS1377</td>
<td>Min</td>
</tr>
<tr>
<td></td>
<td>ASTM D 1556</td>
<td>P4</td>
<td>Min one test per 750 M³ fill</td>
</tr>
<tr>
<td></td>
<td>BS 1377</td>
<td>P4</td>
<td>Min one test per 500 M³ fill</td>
</tr>
</tbody>
</table>

*Remarks: Where PI exceed 6 PI x % passing 0.425μ = Max 400*
<table>
<thead>
<tr>
<th>Test Method</th>
<th>Frequency of Test</th>
<th>Specifications Limits</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO T 2</td>
<td>AASHTO T 2</td>
<td>AAM: 35% Max, ADM: 35% Max, RTA: 35% Max</td>
<td></td>
</tr>
<tr>
<td>Liquid Limit</td>
<td></td>
<td>AASHTO T 89: 6% Max, BS 1377 Part 2: 6% Max</td>
<td></td>
</tr>
<tr>
<td>Plasticity Index</td>
<td></td>
<td>AASHTO T 90: 3% Max, BS 1377 Part 2: 3% Max, In-Index</td>
<td></td>
</tr>
<tr>
<td>Linear Shrinkage</td>
<td></td>
<td>BS 1377 Part 2 Method 6.5: 6% Max, Not a criteria</td>
<td></td>
</tr>
<tr>
<td>MDD With correction for oversized material</td>
<td></td>
<td>AASHTO T180 Method D: 6.5, BS 1377 Part 4: 65% Max</td>
<td></td>
</tr>
<tr>
<td>Sand Equivalent</td>
<td></td>
<td>AASHTO T 176: 25% Min, AASHTO T 176: 25% Min</td>
<td></td>
</tr>
<tr>
<td>LA Abrasion</td>
<td></td>
<td>AASHTO T 96: 40% Max, BS 812 Part 118: 0.5% Max</td>
<td></td>
</tr>
<tr>
<td>Soundness Magnesium Sulphate</td>
<td></td>
<td>ASTM C 88: 15% Max, AASHTO T104: 15% Max</td>
<td></td>
</tr>
<tr>
<td>Acid Soluble Sulphate</td>
<td></td>
<td>BS 812 Part 118: 1%, BS 812 Part 118: 1%</td>
<td></td>
</tr>
<tr>
<td>Acid Soluble Chloride</td>
<td></td>
<td>BS 812 Part 117: 1%, BS 812 Part 117: 1%</td>
<td></td>
</tr>
<tr>
<td>CBR @ 98% of MDD</td>
<td></td>
<td>ASTM D 1883: 65% Min, AASHTO T193: 65% Min</td>
<td></td>
</tr>
<tr>
<td>In-situ compaction</td>
<td></td>
<td>AASHTO T191: 98% of MDD, BS 1377 Part 4: 98% of MDD</td>
<td></td>
</tr>
</tbody>
</table>

Table 5-2 Comparative data showing Test Method, Frequency of Tests and Specifications limits of Subbase Materials

## Table 5-3 Comparative data showing Test Method, Frequency of Tests and Specifications limits of Aggregate Road Base (ARB) and Wet Mix Macadam (WM)

<table>
<thead>
<tr>
<th>Description</th>
<th>Test Method</th>
<th>Frequency of Test</th>
<th>Specification Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sampling</strong></td>
<td>AASHTO T 2</td>
<td>Min one test per 1000 M³</td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 2</td>
<td></td>
<td>Not specified</td>
</tr>
<tr>
<td></td>
<td>ASTM D75</td>
<td></td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td><strong>Linear Shrinkage</strong></td>
<td>BS 1377 Part 2</td>
<td>Min one test per 1000 M³</td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>Not specified</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td><strong>Flakiness Index</strong></td>
<td>BS 812 Part 105.1</td>
<td></td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td></td>
<td>Not applicable</td>
<td></td>
<td>Not specified</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td><strong>Elongation Index</strong></td>
<td>BS 812 Part 105.2</td>
<td></td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td></td>
<td>Not applicable</td>
<td></td>
<td>Not specified</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>3% Max ARB, WM</td>
</tr>
<tr>
<td><strong>Liquid Limit</strong></td>
<td>AASHTO T 89</td>
<td>Min one test per 1000 M³</td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>Not applicable</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>Plasticity Index</strong></td>
<td>AASHTO T 90</td>
<td>Min one test per 1000 M³</td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>Not applicable</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>Aggregate Crushing Value</strong></td>
<td>BS 812 Part 110</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>BSEN 1907</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>MDD With correction for oversized material</strong></td>
<td>AASHTO T 110 Method</td>
<td>Min one test per 1000 M³</td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 180</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>Sand Equivalent</strong></td>
<td>AASHTO T 176</td>
<td>Min one test per 1000 M³</td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 176</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>LA Abrasion</strong></td>
<td>AASHTO T 96</td>
<td>Min one test per 1000 M³</td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 96</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>Soundness Magnesium Sulphate</strong></td>
<td>AASHTO T 104</td>
<td>Min one test per 1000 M³</td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 88</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>Organic Impurities</strong></td>
<td>BS 812 Part 117</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td></td>
<td>Not a criteria</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>Acid Soluble Chloride</strong></td>
<td>BSEN 1744-1</td>
<td>Min one test per 1000 M³</td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>CBR @ 98% of MDD</strong></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>25% Max</td>
</tr>
<tr>
<td><strong>In-situ compaction</strong></td>
<td>AASHTO T 191</td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 191</td>
<td></td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 4</td>
<td></td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
</tr>
<tr>
<td><strong>Chloride</strong></td>
<td>BSEN 1744-1</td>
<td></td>
<td>1% Max</td>
</tr>
<tr>
<td><strong>CBR @ 98% of MDD</strong></td>
<td>BS 1377 Part 2</td>
<td></td>
<td>1% Max</td>
</tr>
<tr>
<td><strong>In-situ compaction</strong></td>
<td>AASHTO T 191</td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
</tr>
<tr>
<td></td>
<td>AASHTO T 191</td>
<td></td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
</tr>
<tr>
<td></td>
<td>BS 1377 Part 4</td>
<td></td>
<td>Min one test per 300 M³ laid for ARB &amp; 250M³ for WM</td>
</tr>
</tbody>
</table>

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Table 5-4 Comparative data showing Test Method, Frequency of Tests and Specifications limits of Aggregates for asphaltic concrete Base, Binder (BC) and Wearing Course (WC)

<table>
<thead>
<tr>
<th>Description</th>
<th>Test Method</th>
<th>Frequency of Test</th>
<th>Specifications Limits</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AAM</td>
<td>ADM</td>
<td>DCL</td>
<td>AAM</td>
</tr>
<tr>
<td><strong>Sampling</strong></td>
<td>AASHTO T2</td>
<td>AASHTO T2</td>
<td>ASTM D75</td>
<td></td>
</tr>
<tr>
<td><strong>Flakiness Index</strong></td>
<td>BS 812 Part 105.1</td>
<td>BS 812 Part 105.1</td>
<td>BS 812 Part 105.1</td>
<td>Max 30% BC 25% WC</td>
</tr>
<tr>
<td><strong>Elongation Index</strong></td>
<td>BS 812 Part 105.2</td>
<td>Not applicable</td>
<td>BS 812 Part 105.2</td>
<td>Max 30% BC 25% WC</td>
</tr>
<tr>
<td><strong>Plasticity Index Combined Aggregate</strong></td>
<td>AASHTO T 90</td>
<td>Not applicable</td>
<td>BS 1377 Part 2</td>
<td>NP</td>
</tr>
<tr>
<td><strong>Aggregate Crushing Value</strong></td>
<td>BS 812 Part 110</td>
<td>Not applicable</td>
<td>BS 812 Part 110</td>
<td>Min 65%</td>
</tr>
<tr>
<td><strong>Sand Equivalent Combined Aggregate</strong></td>
<td>AASHTO T 176</td>
<td>AASHTO T 176</td>
<td>ASTM D2419</td>
<td></td>
</tr>
<tr>
<td><strong>LA Abrasion</strong></td>
<td>AASHTO T 96</td>
<td>AASHTO T 96</td>
<td>ASTM C 131</td>
<td>Max 30% BC 25% WC</td>
</tr>
<tr>
<td><strong>Soundness Magnesium Sulphate</strong></td>
<td>ASTM C 88</td>
<td>AASHTO T 104</td>
<td>ASTM C 88</td>
<td>10% Max both for Coarse &amp; Fine Aggr</td>
</tr>
<tr>
<td><strong>Organic Impurities</strong></td>
<td>BS 812 Part 117</td>
<td>Not a criteria</td>
<td>BS 1377 Part 3</td>
<td></td>
</tr>
<tr>
<td><strong>Acid Soluble Chloride</strong></td>
<td>BSEN 1744-1</td>
<td>Not applicable</td>
<td>BS 1377 Part 117</td>
<td>Max 0.1%</td>
</tr>
<tr>
<td><strong>Acid Soluble Sulphate</strong></td>
<td>Not applicable</td>
<td>BSEN 1744</td>
<td>BS 812</td>
<td>Max 0.5%</td>
</tr>
<tr>
<td><strong>Water Absorption</strong></td>
<td>BS 812</td>
<td>Not applicable</td>
<td>BS 812</td>
<td>Max 2%</td>
</tr>
</tbody>
</table>
Table 5-5 Comparative data of Combined Mineral Aggregates of Asphaltic concrete Base, Binder and Wearing Course

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Bit. Base Course</th>
<th>Bit. Binder Course</th>
<th>Bit Wearing course</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AAM</td>
<td>ADM</td>
<td>RTA</td>
<td>AAM</td>
</tr>
<tr>
<td>37.5</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>25</td>
<td>80 - 100</td>
<td>72 - 100</td>
<td>80 - 100</td>
<td>100</td>
</tr>
<tr>
<td>19</td>
<td>62 - 92</td>
<td>60 - 89</td>
<td>62 - 92</td>
<td>80 - 100</td>
</tr>
<tr>
<td>12.5</td>
<td>-</td>
<td>46 - 76</td>
<td>-</td>
<td>63 - 85</td>
</tr>
<tr>
<td>9.5</td>
<td>45 - 75</td>
<td>40 - 60</td>
<td>45 - 75</td>
<td>57 - 77</td>
</tr>
<tr>
<td>4.75</td>
<td>30 - 55</td>
<td>30 - 54</td>
<td>30 - 55</td>
<td>40 - 60</td>
</tr>
<tr>
<td>0.18</td>
<td>6 - 15</td>
<td>*4 - 14</td>
<td>6 - 15</td>
<td>6 - 15</td>
</tr>
<tr>
<td>0.075</td>
<td>2 - 8</td>
<td>2 - 8</td>
<td>2 - 8</td>
<td>2 - 8</td>
</tr>
</tbody>
</table>

COMPACTATION OF BITUMINOUS COURSES

<table>
<thead>
<tr>
<th>Specifications Limit</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Method for Specific Gravity of compacted asphalt ASTM D2726 / AASHTO T 230</td>
<td>98% Min 101.8% Max</td>
</tr>
<tr>
<td>Individual result of daily density shall not vary from the mean of six standard specimens by more than 0.015 gm/cc</td>
<td></td>
</tr>
<tr>
<td>Daily Marshall Density shall not vary by more than ±0.75% of Job Mix Density</td>
<td></td>
</tr>
<tr>
<td>If does, higher density (Marshall Density or Job Mix Density) shall be applied</td>
<td></td>
</tr>
<tr>
<td>In-situ VIM shall be Min 4.5% Max 8.5%</td>
<td></td>
</tr>
<tr>
<td>Density of compacted mix related to Daily Marshall Density</td>
<td></td>
</tr>
</tbody>
</table>

Temperature of Mix °C

<table>
<thead>
<tr>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>135 - 163 to be introduced in the paver</td>
</tr>
<tr>
<td>120 - 160 shall be delivered to the paver</td>
</tr>
<tr>
<td>135 - 163 to be introduced in the paver</td>
</tr>
</tbody>
</table>
Table 5-6 Comparative data of Properties of Asphaltic concrete Base, Binder and Wearing Course Mixes

<table>
<thead>
<tr>
<th>Marshall Properties</th>
<th>Specifications Limits</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bit. Base Course</td>
<td>Bit. Binder Course</td>
</tr>
<tr>
<td></td>
<td>AAM</td>
<td>ADM</td>
</tr>
<tr>
<td>Number of blows each side</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Stability (Kg) Min</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Flow (mm)</td>
<td>2 - 4</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Stiffness Min</td>
<td>500</td>
<td>490</td>
</tr>
<tr>
<td>VIM %</td>
<td>4 - 8</td>
<td>3 - 5</td>
</tr>
<tr>
<td>VMA %</td>
<td>13</td>
<td>10 - 13</td>
</tr>
<tr>
<td>VFB %</td>
<td>50 - 65</td>
<td>65 - 75</td>
</tr>
<tr>
<td>Loss of Stability Max</td>
<td>25%</td>
<td>30%</td>
</tr>
<tr>
<td>Filler Bitumen Ratio</td>
<td>0.6</td>
<td>To 0.8</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Range of Bitumen Content</td>
<td>3.4 to 4.4</td>
<td>3.0 - 4.0</td>
</tr>
<tr>
<td>Refusal (400, 500 &amp; 600 blows) voids in the mix</td>
<td>shall not be less than 2%</td>
<td>No requirement</td>
</tr>
</tbody>
</table>

Note: AAM follow Asphalt Institute – MS-2 with the exception of in-situ compaction determination
DCL determine VIM, VMA & VFB in accordance with DMS 9:2001 (DCL Standards)
DCL also determine crushed face of aggregates as per their test method DMS 7:2001
DCL permits 20% recycled aggregates in the mix, alternative method of Gyratory compaction with AASHTO T312 is followed
ADM determine in-situ compaction as per AASHTO T-230
Table 5-7 Limits for Earthworks Materials

<table>
<thead>
<tr>
<th>Type</th>
<th>PI (Max)</th>
<th>CBR % (Min)</th>
<th>Unit Weight (gm/cc Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>20</td>
<td>1.8</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>30</td>
<td>1.9</td>
</tr>
</tbody>
</table>

It is noteworthy that unit weight is not considered as a qualifying factor for evaluation of embankment and/or subgrade materials for road construction. When different materials are compacted with the same force, higher unit weight represents heavier particles of particular material. However, this does not indicate that the same material will have higher bearing capacity.

It will not be out of place to mention that Al Ain had been blessed with high quality granular materials and it used to be in abundance. Years ago when the AAM compiled its specifications, the above limits were rightfully outlined. However, those exceptionally high quality materials are almost exhausted. Quality material is now in short supply and/or unavailable. It is learnt that most of the on-going projects of the AAM is facing the scarcity of suitable materials, which may comply with the current specifications. The AAM clearly shifted its risk to the contractor. In addition to other factors, it is evident from the record that the scarcity of specified materials is aiding in higher initial cost and longer period in completion of works.

It is learnt that few years ago the RTA had the same requirement for PI (6 maximum). Demand and supply in conjunction with non availability of specified materials forced the RTA engineers to relax specifications limits without scarifying quality. They have introduced a new method of measurement for PI value, called Weighted Plasticity Index (WPI) to control the influence of PI on material performance as follow:

\[ WPI = PI \times \% \text{passing } 0.425\text{mm sieve} \]

Through this method of measurement, the RTA very much satisfy the limits of “excellent to good” rating stipulated in AASHTO soil classification for soil and soil-aggregate mixtures [AASHTO Designation: M 145].

The ADM specifications are silent about measuring the amount of organic matter present in soil. The RTA specifications allow maximum of 2.0% of organic matter; whereas the AAM restricted this value to be 0.25%. It may be mentioned here that both Abu Dhabi and Dubai is rich in natural “Subkha” materials. These two emirates have got plenty of dredged materials as well.

Another important criterion is the CBR value. Both the ADM and the RTA specified minimum CBR value of 10% at 0.5m below Finished Road Level (FRL). The AAM requires minimum CBR value of 15% at 1500mm below top elevation of subgrade, 20% within 300mm to 1500mm below top elevation of subgrade and 30% within 300mm below top elevation of subgrade.

As shown in Table 5-2, the RTA specified only CBR value of 30% for subbase materials. The AAM requires minimum CBR value of 60% under roads and shoulder; while CBR value of 45% under the footpath. It should be kept in mind that CBR value is directly related to the structure number of the pavement layers that influences the thickness design of the pavement.

Based on earlier discussion and analysis, Dubai as well as Abu Dhabi, to some extent, chalked out their specifications focusing on sustainable construction through conservation of readily available natural resources, re-use and minimizing waste that deliver quality and durable end products without compromising the quality. However, this may affect the thickness design of the pavement.

Table 5-1, Table 5-2, Table 5-3, and Table 5-4 indicate that the RTA/DCL follows British standards for all type of testing for soil and aggregates except tests for Sand Equivalent, Los Angeles Abrasion and Soundness, which refer to American Society for Testing and Materials (ASTM). The ADM, in general, for all types of
testing refers to AASHTO standards. It is interesting to note that the AAM follows all of the international standards in testing to suit their requirements.

From all previous tables, it is evident that there is wide range in frequency of testing among the AAM, the ADM and the RTA/DCL. The number of tests to be carried out for each property is left to the Engineer’s (supervising consultant at the site) discretion by the ADM. The AAM for each type of physical properties specified minimum one number of test for each 1000 m$^3$ of different types of material except 1500 m$^3$ for earthworks (fill) materials. On the contrary, the RTA/DCL specified minimum a test per [AAM Specification Civil Works, Standard Specifications, Abu Dhabi Municipality, Standard Specifications For Construction of Roads and Bridges in Dubai Emirate DES-09]:

- 5,000 m$^3$ fill (all tests for earthworks, except CBR)
- 10,000 m$^3$ materials for CBR (earthworks, subbase, aggregate road base and wet mix macadam)
- 20,000 m$^3$ for abrasion, soundness and sand equivalent.

Each type of test requires specific amount of time to conduct and to report, as dictated by the relevant standards. Time, equipment type and number of people involved are directly related to the cost of each type of tests. For example, minimum 11-day is required to report the results of soundness test of aggregates. For each 20,000 m$^3$ of material, the DCL/RTA requires only one test and the ADM has left it based on the discretion of the supervising engineer. On the other hand, AAM’s specifications require total of 20 tests for the same 20,000 m$^3$ of materials. Cost of testing and the time required to conduct has got direct effect on “quality control cost” of any typical road project.

Table 5-5 and Table 5-6 indicate that requirements of combined mineral aggregates for asphaltic base, binder (except for the ADM) and wearing course are almost identical for the AAM, the ADM and the RTA. However, they differ in method of testing. For Job Mix Formula (JMF) and Marshall Properties, the AAM follows Asphalt Institute’s manual MS-2 with the exception of in-situ compaction determination. The DCL/RTA specified DMS (DUBAI Municipality Standards
9:2001) to measure Voids in Mix (VIM), Voids in Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB). They also specified Gyratory Method of tests when recycled aggregates and polymer bitumen is used. The ADM specified AASHTO for method of testing. Specified limits for Marshall Properties are identical both for the AAM and the DCL/RTA except for stability. For base, binder and wearing course, the AAM requires minimum stability 1200, 1400 and 1500 kg, respectively, while requirements for that of the RTA are 980, 980 and 1176 kg.

Requirement of minimum stability (kg) is calculated by pavement designer, which is based on equivalent single axle load (ESAL). There is no physical statistical data in hand to compare ESAL, for example, of a typical secondary road of Abu Dhabi, Dubai and Al Ain. However, it is understood that this ESAL value for Al Ain area will no way be higher than that of Abu Dhabi and Dubai, if not less.

In Table 5-5, stunning variations is observed in measuring the density of the compacted asphalt. The ADM follows ASHTO T 230 test method and apply daily Marshall Density to check degree of compaction. Both the AAM and the RTA specified that individual result of daily density shall not vary (from the mean of six and four Marshall Specimen, respectively) of daily Marshall Specimens by more than 0.015 gm/cc. the RTA also mentioned that daily Marshall density shall not vary by more than ±1% of Job Mix Density and daily Marshall Density is applied to check degree of compaction [RTA General Specification Clause 3/27.12]. In contrast, the AAM requires that daily Marshall Density shall not vary by more than ±0.75% of Job Mix Density and if it does, higher density (Marshall density or Job Mix Density) shall be applied [AAM Specification civil Works Clause 4.14.12].

The consequences of the above may be explained for a particular bituminous mix, assume the following:

- Job Mix Density
  - Density of compacted mix (core)
  - Daily Marshall Density
  - As per RTA daily density shall be within

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job Mix Density</td>
<td>2.50 gm/cc</td>
</tr>
<tr>
<td>Density of compacted mix (core)</td>
<td>2.419 gm/cc</td>
</tr>
<tr>
<td>Daily Marshall Density</td>
<td>2.475 gm/cc</td>
</tr>
<tr>
<td>As per RTA daily density</td>
<td>2.525 gm/cc max</td>
</tr>
</tbody>
</table>
As per the AAM daily density shall be within 2.475 gm/cc min. 2.519 gm/cc max 2.481 gm/cc min.

Therefore, compaction as per the RTA = \( \frac{2.419}{2.475} \times 100 = 97.7\% \) (98\% required)

As per the AAM, daily density is out of limit and hence higher density, i.e. Job Mix Density, 2.50 gm/cc shall be applied in measuring the compaction of the pavement.

Therefore, compaction as per the AAM = \( \frac{2.419}{2.50} \times 100 = 96.8\% \) (98\% required)

The RTA specification also states, if the achieved density is 0.5\% below the specified density, the asphaltic material would be accepted in the works subject to a 20\% reduction to the billed rates [RTA General Specification Clause 3/38.1].

According to the AAM specification, if the achieved density is 0.5\% below the specified density, the asphaltic material would be accepted in the works subject to a 20\% reduction to the billed rates. If the density is between 0.5\% and 1\% below the specified density, the asphaltic material shall be accepted with a 30\% deduction from billed rate. Any section of the pavement compacted to less than 1\% of the specified density, shall be removed and replaced with new approved material at contractor’s cost.

Based on the above discussion and analysis, it appears that when a section of road, in a given day, is carpeted with a mix having job mix Density 2.50 gm/cc and compacted to yield in-situ density of 2.419 gm/cc, the pavement would be accepted by the RTA having 20\% reduction.

On the other hand, due its own rigorous policy of in-situ density calculation, the pavement is not acceptable to the AAM and the contractor shall have to remove and to replace the pavement at his own cost and consequently there will be delay in completion of the job.
Conformance is the measure of quality during the construction process. Therefore, specification of quality requirements in the design and contract documentation becomes extremely important. Quality requirements should be clear and verifiable, so that all parties in the project can understand the requirements for conformance.

Specification limits for quality characteristic measurements are established to differentiate between adequate material and inadequate (or defective) material. For instance, a lower specification limit for 28-day compressive strength of concrete might be 20.7 MPa (3,000 psi). Therefore, a measurement of 20.7 MPa (3,000 psi) or higher represents adequate strength while a measurement below 20.7 MPa (3,000 psi) represents inadequate strength.

Specification limits must be based on sound engineering judgment and sound statistical analysis. Specifically, engineering judgment is used to establish a target value for each quality characteristic and statistical analysis is used to establish an acceptable range around the target value. This range is used to account for the various sources of variability inherent in producing and testing asphaltic concrete mixes as an example. It will not be out of place to mention that there are several types of variability to consider:

1. The material’s inherent variability is the true random variation of the material and is a function of material characteristics alone. A contractor’s manufacturing and construction process cannot control this variability.

2. Sampling variability is the variation in sample characteristics from sample-to-sample that is attributable to variations in sampling technique. A contractor’s manufacturing and construction process cannot control this variability.

3. Testing variability is the lack of repeatability of test results. Operators, equipment condition, calibration, and test procedure all contribute to testing variability. A contractor’s manufacturing and construction process cannot control this variability.
Manufacturing and construction variability is the variation in material caused by the manufacturing and construction process. These variations can be extremely localized within a lot and therefore difficult to detect by random sampling (like density differentials and pavement thickness variations) or they can be more global (e.g., between lots or days) and therefore more easily detected by random sampling (like changes in water-cement ratio, asphalt content or aggregate gradation between lots). Contractor quality control can minimize these types of variability. The total variability is then the sum of the material, sampling, testing and manufacturing/construction variability.

5.2 QUALITY MANAGEMENT SYSTEM

5.2.1 Inspection and Testing Plan

5.2.1.1 Dubai: RTA and DCL

The RTA and the DCL are two independent entities. However, both are interconnected in terms of their authority. The RTA is responsible for the design and execution of the projects. In reality, the DCL has got the upper hand in terms of QA/QC of RTA’s construction projects. Specifications are written, reviewed, edited and confirmed by the DCL, while the RTA is required to follow these specifications. Unless the material is certified and/or tested by the DCL, no material is used in RTA projects.

The DCL usually update their list of certified materials, suppliers, manufacturers on regular and recurrent basis. Accordingly, contractors propose those materials for approval through the consultants and then RTA engineers approve the same material without any hesitations. As a result, it is understood that the quality of all listed materials to be used in RTA projects are essentially pre-assured by the DCL. This significantly reduces the time of “Material Approval Process”.

For RTA projects, materials like soil, aggregates and asphaltic mixes are proposed by the contractor through the supervising consultants, which are cross
checked by the DCL. At this stage, the DCL serves as an independent laboratory and provides the test results only. The RTA basically relies on DCL test results and on conformity (specification) it approves the submittals. Table 5-8 shows, for all RTA running projects, tests for all materials above subgrade including in-situ compaction tests that are carried out by the DCL at contractors cost. Embankment materials and that of compaction test at the site are performed by other accredited laboratory.

The DCL is well equipped with high class modern equipment and skilled technicians who are well versed with modern technology. Equipments are regularly calibrated, while in-service staff trainings are conducted when required. These processes assure the reliability of test results.

However, for in-situ density test, the DCL requires significantly longer period of time (more than 48 hours) to provide official test results. Years ago, initially this hindered the progress of works at the site. The DCL did not change the system. Contractor had to adjust his schedule of works. Soon after the test, bulk density and the volume are measured in the DCL laboratory in presence of contractor and consultant’s representative. Dry density is calculated only after measuring the moisture. Compaction test result is furnished after 48 hours. This does not stop the contractor to proceed for the next layer due to the fact that experienced contractor is smart enough to ascertain the degree of compaction from the wet density, which is generally in their hand within few hours. Therefore, it is evident that overall Quality Management System, Inspection and Testing Plan of the RTA and the DCL, results in quality job.

5.2.1.2 Abu Dhabi Municipality

For all ADM projects, there is site laboratory as well. These laboratories are maintained by the respective contractors and supervised by the consultants. In addition, the ADM has a central laboratory of its own. ADM Materials Inspectors collect samples and cross check in their own laboratory on regular recurrent basis. Table 5-8 shows inspection and testing plan for all materials.
## Table 5-8 Inspection and Testing Plan of AAM, ADM and RTA

<table>
<thead>
<tr>
<th>Description</th>
<th>AAM</th>
<th>ADM</th>
<th>RTA</th>
</tr>
</thead>
</table>
| Soil (Embankment, Subgrade, Subbase, Aggregate Road Base and Wt Mix materials) including in-situ compaction | Carry out at the site laboratory and supervised by the consultant.  
Specific tests for which the site laboratory is not equipped are performed by pre-approved (by AAM) laboratory  
AAM Materials Inspectors are on regular tour and randomly witness the tests | Carry out at the site laboratory and supervised by the consultant  
In addition to the above ADM Materials  
Inspectors collect samples and cross check at their own laboratory on regular recurrent basis | Materials above subgrade carry out by DCL at contractor’s cost  
Materials below subgrade carry out by preapproved (by RTA) laboratory at contractor’s cost |
| Aggregate Testing                                                            | ditto                                                                 | ditto                                                                 | Carry out by DCL at contractor’s cost                                                                                                                                                           |
| Concrete and concrete related materials                                       | ditto                                                                 | ditto                                                                 | Cubes are made at the site.  
All tests related to concrete, bitumen and bituminous mixes including in-situ compaction are carried by DCL who acts as Independent laboratory for RTA. Cost charged to the contractor. |
| Bitumen, Asphalt aggregates and Bituminous Mixes                              | ditto                                                                 | ditto                                                                 | Carry out by DCL at contractor’s cost                                                                                                                                                           |
| Materials related to Ancillary Works (e.g. Thermoplastic paint, pipes, manhole covers etc) | Carry out by accredited laboratory at contractor’s cost  
Inspection committee members visit the local manufacturing units/yard. Evaluate, make assessment and certify for accreditation.  
However, AAM neither do specify validity period nor do follow up check  
Delivered (site) materials are rechecked at the site laboratory. Some specific tests are rechecked by the consultant at the in-house laboratory of the manufacturer | Carry out by accredited laboratory at contractor’s cost  
Carry out by independent laboratory at contractor’s cost | Carry out by DCL at contractor’s cost  
Dubai Municipality has got specific structural unit for accreditation of various local manufacturing units. After satisfactory evaluation and assessment, certificates are issued.  
Materials obtained from these sources are accepted at the project site without further testing unless irregularities are spotted.  
However, even after accreditation all the facilities remain under constant surveillance. On detection of error/s penalty is imposed and warning is issued for the first time. On second time occurrence accreditation is withdrawn.  
For accreditation process DCL charge specific fees for specific types of manufacturing units. |
| Paving blocks, tiles etc                                                      |                                                                      |                                                                      |                                                                                                                                                                                                 |

Note: Samples are delivered to DCL by respective project’s contractor and consultant’s representative. Contractor/consultant may elect to choose the testing. DCL has got posted and definite rate for each and every test. Frequency of test is specified in the relevant sections of the specifications. Contractors are well aware of the system of RTA and incorporate the cost of inspection and testing in the unit rates of related items while bidding. For providing equipped laboratory and maintenance of the same with man power, transportation and consumables at the site, there is BOQ item both AAM and ADM. Research (documents and interviews) indicates that average cost for inspection and testing is 2.74% of final contract value for AAM and that of RTA is 5%. Cost for ADM is unknown.
5.2.1.3 Al Ain Municipality

Organization structure of the Al Ain Municipality can be seen in Figure 4-1 and Figure 4-2. Under Internal Roads and Infrastructure Division (to some extent relate to the RTA) there are four different sections namely projects design, projects execution, quality, road traffic and road maintenance. Only activities of “quality” and partial activities of “projects execution” are related to this study. Quality section is comprised of three different units: QA/QC, QMS, and HSE (Health, Safety and Environment).

The AAM does not have an operational laboratory on its own. For each running project, there is a site laboratory maintained by the contractor and supervised by the consultant. Table 5-8 shows that all materials to be used in project works are carried out at the site laboratory for the AAM. Specific tests for which the site laboratory is not equipped are performed by pre-approved laboratory at contractor’s cost. However, AAM Materials Inspectors are on regular tour to witness all tests.

5.2.2 Cost Analysis of QA/QC

5.2.2.1 Inspection, Testing and Construction Cost

The DCL has got definite posted rate for each performed test. Frequency of tests is stipulated in the specifications. Accordingly, cost of inspection and testing is built up in the related pay items by the contractor. Interviews with responsible personnel of the DCL, the RTA and with few contractors’ representatives indicated that inspection and testing cost for RTA projects are in the range of 5% of total project value. Cost for supervision shall be added to this 5% to calculate the total cost of QC/QA for RTA projects. On confidential ground figures for cost of supervision could not be obtained. However, experience indicates that it might be in the range of 0.5% of total project value. Therefore, total cost of QA/QC for RTA projects is calculated as 5.5%.

Table 5-9 Table 5-10 and show cost of pavement materials (including construction) for the AAM, the ADM, and the RTA. ADM projects are significantly
higher than that of AAM projects. Assuming identical width and depth of pavement layers, as per 2008 – 2009 market prices (tendered during 2007 – 2008), cost of 1.0 km road for the RTA is 2.50 million, for the ADM is 2.36 million and for the AAM is 2.04 million. In other words, compared to the AAM, the cost of the pavement for the ADM is higher by 16% and that of the RTA as high as 22%. This does not mean that there is no competition in Dubai or in Abu Dhabi Market. In fact, in emirate of Dubai, there are quite good numbers of international and prestigious local contractors. Strict measures (QA/QC and QMS) of the DCL and the RTA have not stopped the reputed contractors and consultants for bidding and executing the new jobs day-in and day-out. They are especially attracted to the established policy of mode of payment. Usually on the first week of the month, for works done in the previous month, bill is prepared and submitted by the contractor. Supervising consultant checks and certifies the payment and the RTA approves the same. Payment is made by the appropriate authority immediately. The entire process does not take more than two weeks and this is a big boost for the contractor’s cash flow. Generally speaking, no contractor is to knock the door of the lender (bank) to ease the progress of work on financial aspect. Another attraction for Dubai and Abu Dhabi projects is the Contracts amount with respect to time of completion. The contracts amount for these projects is significantly higher than that of the AAM and the completion period is less than that of the AAM.

Any or all of the following factors could be the reasons for high unit rates:

1. Increased cost due to systematic and well organized QMS and QA/QC procedures – risk factor is considered by the contractors
2. Scarcity of material and its haulage cost which is influenced by distance
3. Traffic restrictions in the city both in terms of time and locations especially for RTA projects
4. Strict implementation of penalty clause in case of delay
5. Factor of “demand and supply” during pre-recession period
6. Status and class of contractors
Table 5-9 Comparison of Unit Rates of Pavement Materials (including construction)

<table>
<thead>
<tr>
<th>Item</th>
<th>2008 – 2009 Unit Rate (AED)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AAM</td>
<td>ADM</td>
</tr>
<tr>
<td>Fill Material (Borrow) M³</td>
<td>38</td>
<td>42</td>
</tr>
<tr>
<td>Subgrade Material M³</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>Subbase M³</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Aggregate Road Base M³</td>
<td>150</td>
<td>197</td>
</tr>
<tr>
<td>Asphaltic Concrete Base Course 80 mm thick M²</td>
<td>55</td>
<td>57</td>
</tr>
<tr>
<td>Asphaltic Concrete Wearing Course 50 mm thick M²</td>
<td>42</td>
<td>48</td>
</tr>
<tr>
<td>Tack Coat M²</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Prime Coat M²</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

Note: Unit rates reflect average tendered figures (year 2008 – 2009)

Table 5-10 Cost of 1 Km Road (assuming identical width and depth of pavement layers)

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>AAM</th>
<th>ADM</th>
<th>RTA</th>
<th>ADM Compared to AAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill Material (300 mm) M³</td>
<td>4500</td>
<td>171,000</td>
<td>189,000</td>
<td>189,000</td>
<td>ADM 21% high, RTA 31% high, RTA is higher than ADM by 7.8%</td>
</tr>
<tr>
<td>Subgrade (300 mm) M³</td>
<td>4200</td>
<td>210,000</td>
<td>189,000</td>
<td>189,000</td>
<td>Asphalt Works only, ADM 12% high, RTA 16.7% high, RTA is higher than ADM by 4.1%</td>
</tr>
<tr>
<td>Subbase (150 mm) M³</td>
<td>1950</td>
<td>195,000</td>
<td>292,500</td>
<td>372,450</td>
<td></td>
</tr>
<tr>
<td>Aggregate Road Base (150 mm) M³</td>
<td>1800</td>
<td>270,000</td>
<td>354,600</td>
<td>354,600</td>
<td></td>
</tr>
<tr>
<td>Sub total (except asphalt) - A</td>
<td>-</td>
<td>846,000</td>
<td>1,025,100</td>
<td>1,105,050</td>
<td></td>
</tr>
<tr>
<td>Asphaltic Concrete Base Course 80 mm thick M²</td>
<td>11300 M²</td>
<td>621,500</td>
<td>644,100</td>
<td>655,400</td>
<td></td>
</tr>
<tr>
<td>Asphaltic Concrete Wearing Course 50 mm thick M²</td>
<td>10950 M²</td>
<td>459,900</td>
<td>525,600</td>
<td>580,350</td>
<td></td>
</tr>
<tr>
<td>Tack Coat M²</td>
<td>10950 M²</td>
<td>54,750</td>
<td>87,600</td>
<td>76,650</td>
<td></td>
</tr>
<tr>
<td>Prime Coat M²</td>
<td>11300 M²</td>
<td>56,500</td>
<td>79,100</td>
<td>79,100</td>
<td></td>
</tr>
<tr>
<td>Sub total (Asphaltic Layers only) - B</td>
<td></td>
<td>1,192,650</td>
<td>1,336,400</td>
<td>1,391,500</td>
<td></td>
</tr>
<tr>
<td>GRAND TOTAL (A + B)</td>
<td></td>
<td>2,038,650</td>
<td>2,361,500</td>
<td>2,496,550</td>
<td></td>
</tr>
</tbody>
</table>

Note: Unit rates reflect average tendered figures (year 2008 – 2009)
The unit rates in Table 5-9 are extracted from Bill of Quantities (BOQ) of various projects of respective establishments. These are the tendered figures during the ‘construction boom period’ in the country and hence these prices appears to be little on the higher side when compared to the current market price (tendered during and or post-recession period).

Most of the contractors operating in Dubai and Abu Dhabi are well established, well-resourced and well experienced. It appears that they are skillfully able to identify the scope of work, possible obstacles and risk, if any. Rightfully allocate required number of manpower, plant and machinery, come up with sound “Programme of Works” and follow them in strict manner and generally complete the job on time. Sound operating system has got high establishment cost and it reflects in unit price while bidding for the job.

5.2.2.2 Detailed Cost Analysis for AAM Projects

Table 5-11 deals with the QA/QC cost of individual projects of the AAM. Ten different projects were selected randomly for study. Duration of these projects run through the year 2007 to 2011. Some are completed, where few are on-going. QA/QC cost of the AAM is estimated under two heads as follow:

1. Cost of the laboratory
   a. Setup: 1.23 Million (0.34% of final contract value)
   b. Operation cost: 3.73 Million (1.05% of final contract value)
   c. Subtotal (lab): 4.96 Million (1.39% of final contract value)

2. Supervision fee:
   a. Consultants QA/QC: 1.04 Million (0.29% of final contract value)
   b. Total QA/QC Cost: 6.0 Million (1.68% of final contract value)

Cost of QA/QC for AAM projects is one third when compared with the QA/QC cost of RTA projects.
## Table 5-11 QA/QC Cost of the AAM

<table>
<thead>
<tr>
<th>Projects</th>
<th>Duration (Months)</th>
<th>Contract Value (Million)</th>
<th>Contractor’s Lab cost (Million)</th>
<th>Consultant’s Supervision Fee (Million)</th>
<th>Total Cost (Million) to Project A + B</th>
<th>Total Cost % of Project Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original</td>
<td>Extension</td>
<td>Total</td>
<td>Original</td>
<td>Final</td>
<td>Set up</td>
</tr>
<tr>
<td>1</td>
<td>23</td>
<td>14</td>
<td>37</td>
<td>78.9</td>
<td>112</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>12</td>
<td>35</td>
<td>167.9</td>
<td>396.04</td>
<td>0.76</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>12</td>
<td>40</td>
<td>779.00</td>
<td>794</td>
<td>0.65</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>0</td>
<td>24</td>
<td>500.00</td>
<td>500</td>
<td>4.24</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>8</td>
<td>32</td>
<td>610.00</td>
<td>664</td>
<td>1.23</td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>6</td>
<td>24</td>
<td>314.00</td>
<td>314</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>7</td>
<td>31</td>
<td>96.80</td>
<td>119.8</td>
<td>0.18</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>4</td>
<td>28</td>
<td>34.00</td>
<td>34</td>
<td>0.27</td>
</tr>
<tr>
<td>9</td>
<td>17</td>
<td>12</td>
<td>29</td>
<td>326.30</td>
<td>326.30</td>
<td>0.15</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>14</td>
<td>30</td>
<td>312.00</td>
<td>312.00</td>
<td>2.00</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>22</td>
<td>9</td>
<td>31</td>
<td>321.89</td>
<td>357.21</td>
<td>1.23</td>
</tr>
</tbody>
</table>
5.2.2.3 Central Materials Testing Laboratory at the AAM

A Central Materials Testing Laboratory (CMTL) housed with latest modern high class equipment along with trained, well experienced engineers and technicians is believed to be a big boost in enhancement and improvement of QA/QC system for Road Construction Projects of Al Ain Municipality. CMTL shall have the facility for physical and mechanical testing of soil, aggregates, bitumen, bituminous mixes, cement, concrete, masonry components and other general materials of construction. Table 5-12 presents the estimated yearly running cost of proposed CMTL.

Table 5-12 Estimated Yearly Running Cost of Proposed CMTL

<table>
<thead>
<tr>
<th>Item</th>
<th>Capital Cost (AED)</th>
<th>Yearly cost (AED)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Land &amp; Building</td>
<td>10,000,000</td>
<td>400,000.00</td>
<td>Amortized over 25 yrs</td>
</tr>
<tr>
<td>Maintenance</td>
<td>50,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-total A</td>
<td>450,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment &amp; furniture</td>
<td>5,000,000.00</td>
<td>1,250,000.00</td>
<td>Amortized over 4 yrs.</td>
</tr>
<tr>
<td>Consumable items (chemicals solvent filter paper etc.)</td>
<td></td>
<td>50,000.00</td>
<td></td>
</tr>
<tr>
<td>Equipment Maintenance</td>
<td></td>
<td>150,000.00</td>
<td>3% of capital cost</td>
</tr>
<tr>
<td>(Replacement/Calibration/spares)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation 4WD double cabin pickup  6 numbers</td>
<td>720,000.00</td>
<td>180,000.00</td>
<td>Amortized over 4 yrs.</td>
</tr>
<tr>
<td>Transport Maintenance &amp; (fuel, oil, tyre etc)</td>
<td>108,000.00</td>
<td>@1500.00 per month per vehicle</td>
<td></td>
</tr>
<tr>
<td>Utility cost (electricity, water + cleaning etc)</td>
<td>120,000.00</td>
<td>@10,000.00 per month</td>
<td></td>
</tr>
<tr>
<td>Sub-total B (equipment, transport 7 utility)</td>
<td>1,858,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Management &amp; Staff cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head of Laboratory</td>
<td>900,000.00</td>
<td>@75,000.00/month</td>
<td></td>
</tr>
<tr>
<td>4 Sections (soil &amp; aggregate, concrete, asphalt, chemicals)</td>
<td>1,680,000.00</td>
<td>@35,000.00/month</td>
<td></td>
</tr>
<tr>
<td>12 Technicians/Inspectors</td>
<td>1,728,000.00</td>
<td>@12,000.00/month</td>
<td></td>
</tr>
<tr>
<td>8 Assist. Technicians</td>
<td>768,000.00</td>
<td>@8,000.00/month</td>
<td></td>
</tr>
<tr>
<td>26 Assistants + Drivers</td>
<td>1,092,000.00</td>
<td>@3500.00/month</td>
<td></td>
</tr>
<tr>
<td>5 others (watchman, cleaners, office boy etc)</td>
<td>180,000.00</td>
<td>@3000.00/month</td>
<td></td>
</tr>
<tr>
<td>Sub-total C (Manpower)</td>
<td>6,348,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAND TOTAL</td>
<td>8,656,000.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2.3 Factory Assessment and Material Approval Process

Under QMS unit, there is a committee in the AAM for assessing manufacturing facilities. These facilities produce different materials to be used in road projects viz., paving blocks, footpath tiles, ready mix concrete etc. Through the supervising consultant of the respective project, request is initiated by the contractor who intends to use the products of a specific manufacturer/supplier. The committee members inspect and assess the facility. On conformity to AAM specifications requirements and to ISO: 9000, a general approval is given for that particular project where there is no specific time limit for this approval. There is no surveillance, i.e. no follow up of the above assessment/approval. Even if the project extends to another 12 months, the approval remains valid. Upon delivery at the site and prior to use in the permanent works, materials are sampled and tested to assess the conformity once again. During day-to-day job, for some specific items viz., ready mix concrete daily samples are taken and tested.

However, the above approval does not mean that the same approved products can be used in another project of the AAM even if the project is running concurrently. For each project fresh assessments/approvals are required by the AAM. It appears that this policy results in significant time loss of QA/QC personnel including the delay in material approval process of the project in question.

The AAM has got two standard forms for initiating the request for material approval. Form “P” is used for previously approved materials by the AAM and form “N” is applicable to materials, which were never approved earlier by the AAM [Clause 1.12.2 of sub-section C27 of General specification]. However, essentially material approval process is the same in both the two cases. Contractor initiates the request along with required documents as stipulated in the specifications and shall include among others recent test results (independent lab), compliance check list, letter of guarantee, copy of ISO certification and product certification. Supervising consultant review the submittals, sometimes obtain samples and run few tests to verify the submitted test results and on conformity recommend the same to QA/QC.
section of the AAM for endorsement. The AAM scrutinizes the entire submittals, if necessary, seldom re-check/verify the test results at the site laboratory and/or at the independent laboratory. Typically, the entire process takes about a month, which may be considered long time, refer to Table 5-13. There are certain materials (even if they are produced within the country) which no contractor is able to make them available at the site immediately. Only after securing the approval of the AAM, the contractor can issue Letter of Purchase (LPO) to the supplier/manufacturer. Manufacturer may not keep all types of materials in stock all the times. They produce only when the LPO is in hand.

Material approval process at the ADM is quite simple. Contractor proposes along with requisite documents with the evidence of conformity to the specifications. Supervising consultant reviews, if required, cross check some of the test results. If satisfied, approve the submittal and the respective ADM engineer attached to the project endorse the same.

For RTA projects, materials like soil, aggregates and asphaltic mixes are proposed by the contractor through the supervising consultants, which are cross checked by the DCL and the entire approval process does not take more than one week.
Table 5-13 Material Approval Process in the AAM [NBR-1]

<table>
<thead>
<tr>
<th>MS#</th>
<th>Material Submittals</th>
<th>Submittal by RBO</th>
<th>EA Forwarded to AAM</th>
<th>Hill to AAM</th>
<th>AAM App.</th>
<th>Remarks</th>
<th>Duration (Month)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rev. 1</td>
<td>Rev. 2</td>
<td>Rev. 3</td>
<td>Rev. 4</td>
<td>Rev. 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3/3/2009</td>
<td>Forwarded to AAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3/8/2009</td>
<td>Forwarded to AAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3/8/2009</td>
<td>Forwarded to AAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>29/9/2009</td>
<td>Revise the plant &amp; Site trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>29/9/2009</td>
<td>Revise the plant &amp; Site trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD 57</td>
<td>Asphalt Binder Course (Mix Design)</td>
<td>23/9/2009</td>
<td>07/2/2009</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>40219</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23/9/2009</td>
<td>Forwarded to AAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>23/9/2009</td>
<td>Forwarded to AAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD 72</td>
<td>Asphalt Wearing Course (Mix Design)</td>
<td>20/5/2010</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20/5/2010</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17/11/2009</td>
<td>Provide test results copies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>17/11/2009</td>
<td>Cross reference chart</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>17/11/2009</td>
<td>Cross reference chart</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MD 65</td>
<td>Expansion Joints (TransfoCou)</td>
<td>05/12/2009</td>
<td>27/12/2009</td>
<td>09/2/2010</td>
<td>14/3/2010</td>
<td>-</td>
<td>40253</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27/12/2009</td>
<td>Readmitt after specifying the gap</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>27/12/2009</td>
<td>Readmitt after specifying the gap</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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5.2.4 Delay in Completion of Job for AAM projects

Table 5-11 also indicates the following:

1. Average duration of the project:
   a. Original 22 Months
   b. Extension given 9 Months (41% extra)
   c. Total duration 31 months

2. Average Contract value:
   a. Original 322 Million
   b. Final 357 Million (11% variation)

The above figures are worrisome. For 322 million projects, completion time was estimated to be 22 months. Variation Order (VO) was issued worth of 11% of the original contract value. Completion period always cannot be estimated in terms of money (contract value) due to the nature/scope of works involved. However, if viewed in proportionate way, maximum of 3 months may be awarded to the contractor as extension of time instead of 9 months, i.e. 6 months extra time have had been taken by the contractor in completion of the job. Even if it is not proportionate, extra 6 months appears to be out of line. Clearly there have had been “delay” and it is true for all the projects listed in Table 5-11 except Shiab Al Ashkar, which will be running through the year 2011.

According to the RTA, most of projects invariably complete in time (source of information – interview with RTA, DCL, contractor and consultant of Dubai). On the other hand, it appears that the “delay” in completion of job is a common feature for AAM projects. However, when extension of time is awarded, the word “delay” is not appropriate. There could be legitimate reason(s) on the part of the contractor to claim for extension of time but may not be always. Records indicate that AAM projects run behind mainly because of the following factors:

1. Conservative estimation of time during tender stage
2. Floating the tender while the design is incomplete
3. Change of design during execution and the amount of time to get the revised drawing approved.

4. Design and approval of traffic diversion followed by traffic control and traffic management during execution period

5. Define and approval of land for site office

6. Define and approval of borrow pit

7. Slow process in obtaining N.O.C.’s from relevant service authorities for utility works

8. Lengthy process of material approval

9. Significant amount of time to get supervision staff approved

10. Absence of Construction Manual, QC/QA Manual (both for consultant and contractor)

11. Incompetent contractors

It appears that seldom AAM invite tender for projects to be executed in hurried manner. Occasionally without ascertaining the total scope of works tender documents are prepared. During the execution period, original design is reviewed and revised which affects the program of works severely. Generally speaking, the job is awarded to the lowest bidder even if the contractor is not well equipped with required resources and expertise. Often several number of projects are awarded to one contractor (contractor is rightfully lowest bidder) without scrutinizing available resources to be dedicated for each individual job. Most of the time, the contractor lacks in plant, machinery and man power and tends to flip-flop with his resources within the awarded projects and the contractor fails to comply with the original schedule.

As per contract documents, each contractor is to obtain No Objection Certificate (NOC) from relevant service authorities. Evidence indicates that AAM contractors have real difficulty in coordinating with the relevant statutory authorities in organizing, planning and executing the job especially related to utility works.

The department of Town Planning, Municipal Affairs Al Ain Municipality is the legal authority to approve the land for site office (project to be executed). It is not
uncommon that the job is awarded to the contractor who is ready to move at the site but unfortunately unable to mobilize because permission to set up the site office is not granted. Obviously, mobilization is delayed which may qualify the contractor for extension of time and this is before starting the actual job at the site. Often similar thing happens in getting the borrow pit approved.

For traffic control and traffic management the contractor is obliged to obtain all necessary approvals from the appropriate local agencies which involve design and approval of police traffic diversion. Seldom significant amount of time is killed to cope with the process of securing the approval and to cope with the increasing traffic flow and the original Program of Works.

Process of material approval is discussed earlier. Construction Manual represents a current compilation of collective experiences and good practices that have accumulated during the years of managing the construction. The manual provides department construction engineering personnel instruction for fulfilling the objectives, procedures, and methods for construction administration of projects. The Construction Manual is intended as a reference book. The manual provides guidance in several key areas. Guidance is provided on effective means of managing field construction operations. Equally important, the Manual addresses record keeping and field administrative procedures that are essential in achieving cost effective projects with clear audit trials. All involved in executing the construction program, including planners, designers, construction managers and inspectors, safety, quality assurance, quality control, must perform jobs as outlined in respective job descriptions with professionalism, integrity and excellence.

Similarly supervising consultant and contractor, the executors of the project shall have respective QA/QC Manual which must contain job descriptions of designated key people. This manual is to ensure that construction activities comply with the design criteria, engineering plans and specifications, and good engineering practice. QA/QC manual provides system and procedures for inspections, sampling, testing, survey controls, and records required to demonstrate that the contractor has met the requirements as stipulated in contract documents.
Diligent application of Manual’s guidance ensures attainment of the high quality, cost effective and timely construction. The ADM is equipped with Construction Manual. However, neither the AAM nor the RTA has developed any construction Manual of their own.

A general comment can be made that except a few, the roads and infrastructure contractors operating in Al Ain are believed to be ill managed and ill resourced and are not able to meet the target as per programme of works. Seldom one quarter of a dozen of road projects are awarded to only one contractor as because he becomes the lowest bidder although he is poorly organized and the total resources are not adequate at all compared to the magnitude of works are awarded to him. The same contractor formed sister companies in different names and sub-contract significant portion of the original jobs even though the total resource for the main contractor and the sub-contracts remain the same. Both the main contractor and sub-contractors flip-flop the plant, equipment and manpower within the projects in hand which affects the program of works negatively for all the running jobs. There are other less known contractors who are not up to the mark.
CHAPTER 6 RECOMMENDATIONS FOR IMPROVEMENT OF QUALITY CONTROL SYSTEM AT THE AAM

The website of the AAM states that its vision and mission is to create an attractive, livable and sustainable managed urban environment where all necessary services and infrastructure are provided in a timely manner by competent workforce considering its values without compromising the sustainability and efficiency. This is to be achieved through the following:

- Comply with all contractual and legal requirement (statutory and regulatory)
- Confirm highest technical international standards and quality management
- Ensure continual improvement in quality management system
- Provide quality and excellence
- Adopt best practices and proven approaches.

The above strategy is expected to be implemented by talented and qualified staff by adopting the latest and most advanced scientific and professional standards of quality and excellence through development and upgrading work systems but at optimum cost.

Obstacles, which hinder the progress of on-going projects, are identified and described above. Keeping in mind these negative factors and the vision and mission of the AAM, recommendations for “Enhancement and Improvement of Quality Control and Quality Assurance System of Road Construction Projects at Al Ain Municipality” may be grouped under two categories namely “Short Term Measures” and “Long Term Measures”. 

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6.1 SHORT TERM MEASURES

A. Prior and during tender stage

1. A new clause for QA/QC Manual both for design and construction supervision may be introduced in TOR of "Engagement of Consultant".

2. Consultant is to gather necessary old plans, utility information and other useful background information related to the project, review all scoping documents, review all cost estimates, review time of completion.

3. Incorporate QA/QC thinking into the design process.

4. Provide a correct, accurate and workable design and establish standard process.

5. Perform quality check and ensure that the design is complete and buildable. Never float the tender when the design is incomplete.

6. Design consultant is to coordinate with the respective statutory authority to obtain the permit for the land to be used for site office. Same is applicable for borrow (earthworks material) area. Consultant is to investigate and indicate in the tender documents about the quality and approximate quantities of material to be expected from the said borrow area.

7. Consultant is to analyze and to comment on all qualifying tenders, especially for least three renderers. Contractors’ ability in terms of plant, equipment, manpower, experience, expertise with respect to the tendered job shall be scrutinized and accordingly recommendations shall be made.

8. It is considered to be prudent that the design consultant liaise with the Department of Traffic Police for traffic diversion. They shall study, propose and get approved sufficient diversions keeping in mind the sequence of construction activities.

B. During Execution Stage

1. Both supervising consultant shall submit QA/QC Manual to the AAM for approval. This manual shall explicity indicate the responsibilities
of each individual to be engaged for the supervision of works. Consultants will adhere to the approved QA/QC procedures for inspections, sampling, testing, survey controls, and records required to demonstrate that the contractor has met the requirements as stipulated in contract documents.

2. Similarly, the contractor will also get its QA/QC Manual approved by the supervising consultant/AAM. This manual shall confirm that the contractor through quality management practice producing quality job. Contractor’s manual shall ensure that construction activities comply with the applicable standards, approved design criteria, specifications, and good engineering practice.

3. The AAM (pre-execution stage), supervising consultant and the contractor – all shall engage Planning Engineer having wealth of practical experience that will be responsible for sound construction planning (Program of Works). Construction planning is a fundamental and challenging activity in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks. A good construction plan is the basis for developing the budget and the schedule for work. Developing the construction plan is a critical task in the management of construction, even if the plan is not written or otherwise formally recorded. In addition to these technical aspects of construction planning, it may also be necessary to make organizational decisions about the relationships between project participants and even which organizations to include in a project. For example, the extent to which sub-contractors will be used on a project is often determined during construction planning.

If there is any priority for any specific task to be carried out early, Program of Works shall be drawn accordingly.

In developing a construction plan, it is common to adopt a primary emphasis on either cost control or on schedule control. Some projects are primarily divided into expense categories with associated costs. In
these cases, construction planning is cost or expense oriented. Within
the categories of expenditure, a distinction is made between costs
incurred directly in the performance of an activity and indirectly for
the accomplishment of the project. For example, borrowing expenses
for project financing and overhead items are commonly treated as
indirect costs. For other projects, scheduling of work activities over
time is critical and is emphasized in the planning process. In this case,
the planner insures that the proper precedence among activities is
maintained and that efficient scheduling of the available resources
prevails. Traditional scheduling procedures emphasize the maintenance
of task precedence (resulting in critical path scheduling procedures) or
efficient use of resources over time (resulting in job shop scheduling
procedures). Finally, most complex projects require consideration of
cost and scheduling over time, so that planning, monitoring and record
keeping must consider both dimensions.

4. Shop drawings, diagrams, schedules and other data specially prepared
for the work by the contractor or sub-contractor to illustrate some
portion of the works shall be checked and evaluated by the supervising
consultant promptly. Shop drawing is to show the details to make sure
that the item to be built meets the intent and function of the design.

5. Choice of materials having aesthetic value e.g., decorative tiles,
decorative lanterns, poles shall be concluded at the initial stage
(preferably within two months) of the project.

6. A list of all materials (Materials Log) to be used in the project shall be
prepared by the contractor within the first month of commencement.
Consultant shall review and confirm the same.

7. The contractor priority wise and having link with Program of Works
shall initiate the approval process of material immediately. Material
submittals must not be pending. All materials approval shall be
accomplished within the first quarter of the scheduled completion
period.
8. It is suggested that the current procedures of material approval process is reviewed and an alternative policy and procedure is established to have speedy approval without compromising quality.

Contractor shall submit the “Material Approval Request” (MAR) along with all the required documents as stipulated in the specifications. Consultant shall review and if required cross-check (test results) the submittal and on conformity may recommend to AAM for endorsement.

If on the other hand, the submittal is found not in line shall be returned back to the contractor by the consultant with definite and precise comments. Contractor will re-submit the MAR which shall strictly adhere to consultant’s comments.

In the event of failing more than twice for the same MAR, a system to penalize the contractor may be introduced and may be incorporated in the QA/QC section of the specifications.

The above process shall not take more than 48 hours.

On conformity consultant shall forward the MAR with his recommendation to AAM. Concerned engineer of AAM may not hold the submittal more than another 48 hours.

If due his ignorance and or otherwise, the consultant forward (to AAM) the MAR that is not in line with the specifications requirement, the respective consultant’s personnel shall be warned and shall be penalized on repetition.

9. The AAM shall have the list of products which are produced by the AAM assessed and approved manufacturers/suppliers.

10. Practice of assessing the same manufacturer for the same product number of times for different projects may be stopped.

Once it is approved there shall be valid expiry date and shall be listed in the vendor list. Any project that may need the product shall be permitted to use the same without going through rigorous and time killing process once again.
11. Supervision staff (consultant) shall be at the site in appropriate time to ensure smooth progress of works. Right people shall be engaged at the right time and at the right place.

Detailed responsibilities (job description) for all of the supervisory staff shall be outlined in Consultant's manual. Accordingly consultant shall filter the applicants and after being satisfied only he shall propose to the AAM.

Current system of two steps interview (written and oral) by the AAM is considered to be fine. However, the existing procedure appears to be too long. Electronic software may be used for this purpose. Different sets of questions for each position may be loaded. Software will be equipped with the correct answers which will be unknown to the applicant. However, as soon as the candidate finishes his task computer will be prompt to display the score. The AAM may set minimum number to score to qualify for oral test. There shall be at least three AAM engineers in the selection committee who will conduct the oral test. This committee may be formed having different engineers who have the relevant expertise of the position for which the interview is conducted. It is also suggested that the respective Project Engineer (AAM) to be a member of the committee. The entire process shall be over within 48 hours.

In the event of failing to provide the right candidate there is a penalty clause in consultant's TOR and appears to be dormant. It is recommended to implement this clause strictly as and when the situation arises.

6.2 LONG TERM MEASURES

6.2.1.1 Standardization of Specification

There shall be one and only one Standard General Specifications for all roads, bridges and infrastructure projects of Al Ain Municipality. Keeping in mind the vision and mission of AAM, Specifications may focus on sustainable and
performance based construction maintaining safe environment, health and safety. This may be accomplished following below mentioned stages:

- Identify and select the copy of the best specification currently used by the Roads Consultants of AAM and initially may be treated as draft specifications.
- Designate the engineers for different sections/items (of specifications) to review/modify/comment within specified time.
- Engage a responsible person to distribute different sections/parts of the draft specifications to the respective designated engineers for their review and comments.
- All designated engineers are to return their respective sections/parts to this person within stipulated time. All sections/parts shall be compiled in one binder.
- The above responsible person is to ensure that all sections/items required for Road Section have been covered/entered in the proposed specifications. This compiled copy will be treated as Preliminary Specifications (General)
- Preliminary copy may be distributed to all the ongoing appointed consultants for their comments and recommendations within specified timetable.
- There shall be a review committee. If desired by the committee consultant's comments/recommendations will be incorporated
- Once approved by the committee this specification shall be regarded as standard one for all roads, bridges and infrastructure projects of AAM and shall be password protected.
- There may be Particular Specifications tailored to each project depending on specific requirements, which will be drafted by the respective consultants and require to be approved by AAM prior to tender. Project Particular Specification may focus on sustainable and environment friendly construction through conservation of energy, water and natural resources by re-use, recycling and minimizing waste, pollution, noise and traffic that deliver quality and durable end products without compromising the needs of future generations. Emphasis shall be on creating infrastructure and adopting construction methods that are environmentally friendly, conserve virgin materials and do not rely heavily on rapidly diminishing resources. Specifications may be tailored to minimize waste, pollution, traffic movement and to provide safer working environment
for all involved in construction, maintenance and use. The focus for material selection is to identify products with a relatively high sustainability at no significant increase in capital cost over a traditional material option.

- In future, if there is need of editing and or adding new clauses, proposal shall be initiated. Specification Committee will scrutinize the same and if recommended shall be incorporated in Standard Specification.

6.2.2 Set up AAM Central Laboratory

A Central Materials Testing Laboratory (CMTL) housed with latest modern high class equipment along with trained, well experienced engineers and technicians is believed to be a big boost in enhancement and improvement of QA/QC system for Road Construction Projects of Al Ain Municipality. CMTL shall have the facility for physical and mechanical testing of soil, aggregates, bitumen, bituminous mixes, cement, concrete, masonry components and other general materials of construction. CMTL shall function as:

- Quality Control testing laboratory which will perform independent assurance or verification tests of field-tested materials in coordination with the QC testing laboratories.
- Random representative samples may be collected to additionally evaluate quality of field produced products.
- Perform tests not within the capabilities of site laboratory
- Serve as an independent laboratory
- Provide an independent reliability of acceptance (verification) data obtained at the site laboratory
- May act as “referee” laboratory for resolution of disputes between consultant and contractor’s QC test results unless a potential for conflict of interest exists. The sampling and testing results determined by the “referee” laboratory shall be final and binding on both parties and subject to dispute.
- Preliminarily qualities of asphalt mixtures, concrete mixture shall be reviewed, examined.
- MAR for all mix designs for concrete, bituminous mixes shall be cross-checked by CMTL.
• All projects’ materials approval may be handled by CMTL.
• Asphalt Plant, Concrete Batching Plant, Kerbstone, Tiles, Interlocking Blocks Manufacturing Plant, Paint, and Road Marking Material manufacturing Plant etc. may be inspected, assessed and certified by CMTL for definite period of time.
• The facilities shall be under constant surveillance of CMTL. In the event of irregularities, warning followed by penalty shall be imposed.
• Electronic system may be developed so that CMTL always remain in picture with projects’ daily Request for Inspection (RFI) which will ease the process of “surprise” inspection by CMTL staff.
• CMTL may play a vital role in analyzing and recommendations for corrective and preventive maintenance of existing networks.

For any enhancement and improvement task, there is a price tag. Table 5-12 indicates that the proposed Central Materials Testing Laboratory will cost about 0.43% of the project value. Current cost of QA/QC for Al Ain Municipality, refer to Table 5-11, is 1.68% of project value. Including cost of CMTL, total cost of QA/QC will be 2.11% of project value, which is less than half of the figure of RTA/DCL.

6.2.3 Introduce Road Management Technology Centre

Al Ain road network is getting extensive and needs to be kept in top condition because of progressively increased traffic volume and larger freight vehicles. Moreover, scarcity of right aggregates, borrow material road disaster prevention management, to cope with natural calamities such as occasional strong and heavy rain, is also a crucial issue.

In order to respond appropriately to these situations, there is a need for information about road management to be systematically collected and stored, and research using this information should be promoted. At the same time, qualified specialists in both the public and private sectors need to be quickly trained in this field.
The objective is to develop comprehensive road management technology, including disaster prevention and environmental conservation. Road Management Technology Center may be established in order to make contributions in the area of road management through coping with various problems relating to roads.

It is the work to provide investigation, research and development of road management technology, development and maintenance of various road management systems, fostering of technical experts of road management, and so on. CMTL could act as partner and will be big help in achieving this goal.

Council for Construction Technology Review and Certification may be formed which shall carry out technology review and certification relating road constructions, maintenance, contributing to the spread of superior new technologies.

This system is intended to promote research and development of new technologies in the private sector, and their appropriate and rapid adoption in construction projects, thereby contributing to the improvement of road construction and maintenance technology.

The program will cover technology for methods, machines, equipment, tools, materials and products which can assist in assuring quality, safety, raising durability and usability, and improving the environment, relating to sustainable construction and maintenance of pavement, slopes, bridges, underpasses, and other parts of the road structure, vegetation and road information management installations, and guardrail and other items of street furniture.

Instead of the conventional system of competition on price alone, to achieve procurement of high quality at a good price, a comprehensive evaluation is suggested for both price and other factors other than price, in determining the winning bid.

Carry out various research projects on road asset management to enable efficient road management to provide the maximum benefit for the minimum cost.
Perform research and development activities regarding ITS (Intelligent Transportation Systems) and GIS (Geographic Information Systems), technologies designed to improve the efficiency of road support management businesses, enable oversize/overweight vehicle management, and provide information to users of roads.

6.3 PROPOSED FUTURE RESEARCH: LOOKING AHEAD TO PERFORMANCE-RELATED SPECIFICATIONS

Performance-Related Specifications means "Specifications that use quantified Quality Characteristics and Life Cycle Cost (LCC) relationships that are correlated to product performance." From a management standpoint, Performance-Related Specifications (PRS) are seen as "the bridge between construction quality and long-term product performance". The major distinguishing features of Performance-Related Specifications include:

- Acceptance based on key Quality Characteristics that have been found to correlate with fundamental engineering properties that predict performance.
- Mathematical models used to quantify the relationship between key materials and construction Quality Characteristics and product performance.
- Price adjustments related to the expected Life-Cycle Cost (LCC) of the constructed transportation facility.

Performance-Related Specifications attempt to relate the material attributes (Quality Characteristics) being measured to the likely performance of the in-place product. Like Quality Assurance Specifications, however, they specify only the product Quality Characteristics measured at the time of construction, and do not specify the desired long-term product performance.

The tests used to determine Acceptance with Performance-Related Specifications are selected because the Quality Characteristics being measured relate in some way to the performance of the product. Some examples of Quality Characteristics that relate to the long-term performance of transportation facilities include:
- The total in-place Air Voids or Ride Smoothness of Hot Mix Asphalt pavements.
- The Permeability or the Strength of Portland Cement Concrete.

These Quality Characteristics lend themselves to Acceptance sampling and testing at the time of construction.

True Performance-Related Specifications not only describe the desired levels of these Quality Characteristics, but also employ the quantified relationships (i.e., mathematical models) containing the characteristics to predict subsequent product performance. The use of quantifiable models is a feature that distinguishes Performance-Related Specifications from other transportation construction specifications. The models are based on data and present a much clearer picture of what influences a constructed product's performance than can be visualized through engineering judgment and intuition alone. With recent research that has been conducted under the Strategic Highway Research Program (SHRP), and by the FHWA and the National Cooperative Highway Research Program (NCHRP), it is now possible to relate the specifications to the predicted performance of the product.

Performance-Related Specifications contain two types of models:
- Performance-prediction Models
- Maintenance-cost Models

Performance-prediction Models predict when and to what extent a construction product (such as a pavement) will exhibit a given type of distress, such as fatigue cracking or joint spalling. Maintenance-cost Models estimate the post-construction Life-Cycle Cost (LCC), which is the cost of maintenance and rehabilitation necessary throughout the projected life of the product. Inputs for these models include design variables (such as traffic loading, climatic factors, drainage, soil factors) and Quality Characteristics (such as Asphalt Binder Content & Air Voids, Concrete Permeability & Strength, and Ride Smoothness).
These models provide the basis for rational acceptance and/or pay adjustment decisions. Pay adjustments are determined by determining two different LCCs:

- The "As-Designed LCC"
- The "As-Constructed LCC"

The As-Designed LCC is determined by using the target values of the specified Quality Characteristics as inputs to the Models. The As-Constructed LCC is determined by using the actual measured values of a construction project's Quality Characteristics as input. The difference between the As-Designed LCC and the As-Constructed LCC is the basis for any pay adjustment.
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A.1 Background, Definition and Types of Binder

A.1.1 Background

Bituminous materials such as asphalts cement are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost [NPTEL 2008]. Asphalt cement is a dark brown- or black-colored bituminous material, sticky, semisolid cementitious material, and highly viscous material used in HMA paving. It occurs naturally in geologic strata and was used in the late 19th century for paving roads. The Trinidad Lake deposit, Figure A-1, is a well-known source of naturally occurring asphalt. Asphalt cement can also be derived synthetically from the petroleum refining process. Since asphalt cement consists primarily of the highest boiling fraction of petroleum, it is captured as the residue from the vacuum tower. Tar is a distinctly different product that is often mistaken for asphalt cement. It was also used in late 19th century paving. However, it is a product derived from the destructive distillation of bituminous coal. Due to environmental and health concerns as well as inherent undesirable physical characteristics, tar is seldom used for Paving purposes today [WSDOT 2010, FWA 2008].

For production of oil, bitumen is the residue or by-product when the crude petroleum is refined. A wide variety of refinery processes, such as the straight distillation process, solvent extraction process etc. may be used to produce bitumen of different consistency and other desirable properties. Depending on the sources and characteristics of the crude oils and on the properties of bitumen required, more than one processing method may be employed [NPTEL 2008].
A.1.2 Refinery Operation

In the vacuum-steam distillation process the crude oil is heated, as shown in Figure A-2, and is introduced into a large cylindrical still. Steam is introduced into the still to aid in the vapourisation of the more volatile constituents of the petroleum and to minimise decomposition of the distillates and residues. The volatile constituents are collected, condensed, and the various fractions stored for further refining, if needed. The residues from this distillation are then fed into a vacuum distillation unit, where residue pressure and steam will further separate out heavier gas oils. The bottom fraction from this unit is the vacuum-steam-refined asphalt cement. The consistency of asphalt cement from this process can be controlled by the amount of heavy gas oil removed. Normally, asphalt produced by this process is softer. As the asphalt cools down to room temperature, it becomes a semi solid viscous material [NPTEL 2008].
A.1.3 Asphalt Types

The residuum or “resid” from the distillation process is used to make various asphalt cement products: Asphalt Cement, Cutbacks, and Emulsions.

- Asphalt cements
  - Generally refinery produced material
  - Air blown asphalt cements
- Cutbacks
  - Asphalt cements “cut” with petroleum solvents
- Emulsions
  - Mixture of asphalt cement, water, and emulsifying agent

A.1.3.1 Cutbacks

Cutbacks are liquid at room temperature and are manufactured by adding or “cutting” asphalt cements with petroleum solvents. The volatility of the solvent dictates the rate at which the solvent evaporates. How fast the solvent escapes into the atmosphere regulates how fast a mixture of cutback and aggregate will set. Environmental regulations are increasingly limiting the use of these products [WSDOT 2010].
A.1.3.2 Emulsions

Emulsions are produced by blending asphalt cements, water and an emulsifier (e.g. soap) in a high shear colloid mill. The resulting asphalt droplet suspended in the water has a charge which reflects the chemistry of the emulsifier. The charge of the emulsion is usually selected so that it is opposite that of the aggregate to promote adhesion of the asphalt to the aggregate surface. Emulsions are an asphalt-based product which is also liquid at room temperature [WSDOT 2010].

A.2 How Asphalt Behaves

Asphalt is a viscoelastic material. This term means that asphalt has the properties of both a viscous material, such as motor oil, or more realistically, water, and an elastic material, such as a rubber. However, the property that asphalt exhibits, whether viscous, elastic, or most often, a combination of both, depends on temperature and time of loading. The flow behavior of asphalt could be the same for one hour at 60°C or 10 hours at 25°C [FWA 2008, Pavement 2010].

In other words, the effects of time and temperature are related; the behavior at high temperatures over short time periods is equivalent to what occurs at lower temperatures and longer times. This is often referred to as the time-temperature shift or superposition concept of asphalt cement. This concept is illustrated in Figure A-3 [FWA 2008, Pavement 2010].

![Figure A-3 Behavior of Asphalt](WSDOT 2010)
A.3 Desirable Properties of Asphalt

For engineering and construction purposes, three main properties of asphalt are important [FWA 2008, Pavement 2010]:

1. Consistency (also often called fluidity, plasticity or viscosity),
2. Purity, and

**Consistency** is the term used to describe the degree of fluidity or plasticity of asphalt at any particular temperature. The consistency of asphalt cements varies with temperature; therefore, it is necessary to use a standard temperature when comparing the consistency of one-asphalt cement with another. Asphalt cements are graded, based on ranges of consistency, at a standard temperature. Consistency of paving asphalts is commonly specified and measured by a penetration test or a viscosity test. For air-blown asphalts, a softening point test is used [FWA 2008].

**Purity:** refined asphalts are almost pure bitumen and are usually more than 99.5 percent soluble in carbon disulfide. Impurities, if they are present, are inert. Normally, asphalt cement is free of water or moisture as it leaves the refinery. However, transport-loading asphalt may have some moisture present in their tanks. This may cause the asphalt to foam when it is heated above 100°C (212°F) [FWA 2008].

**Safety:** Asphalt foaming can be a safety hazard and specifications usually require that asphalt does not foam at temperatures up to 175°C (347°F). Also asphalt cement will flash in the presence of a spark or open flame, if heated to a high enough temperature. This flash temperature is well above the temperature normally used in paving operations. However, to be sure that there is an adequate margin of safety, the flash point of the asphalt should be known [FWA 2008].

A.4 Physical Property Tests for Asphalt

Asphalt binders are most commonly characterized by their physical properties. An asphalt binder's physical properties directly describe how it will perform as a constituent in HMA pavement. The challenge in physical property
characterization is to develop physical tests that can satisfactorily characterize key asphalt binder parameters and how these parameters change throughout the life of an HMA pavement. The earliest physical tests were empirically derived tests. Some of these tests (such as the penetration test) have been used for the better part of the 20th century with good results. Later tests (such as the viscosity tests) were first attempts at using fundamental engineering parameters to describe asphalt binder physical properties [FWA 2008, Pavement 2010].

Durability is a measure of how asphalt binder physical properties change with age (sometimes called age hardening). In general, as an asphalt binder ages, its viscosity increases and it becomes more stiff and brittle. There is no direct measure for asphalt binder aging. Rather, aging effects are accounted for by subjecting asphalt binder samples to simulated aging then conducting other standard physical tests. Simulating the effects of aging is important because an asphalt binder that possesses a certain set of properties in its as-supplied state may possess a different set of properties after aging. Asphalt binder aging is usually split up into two categories [FWA 2008, Pavement 2010]: Typical aging simulation tests are: Thin-film oven (TFO) test

- **Short-term aging.** This occurs when asphalt binder is mixed with hot aggregates in an HMA mixing facility.
- **Long-term aging.** This occurs after HMA pavement construction and is generally due to environmental exposure and loading.

### A.4.1 Penetration Testing

Penetration is the number of units of 0.1 mm penetration depth achieved during the penetration test. It is an empirical measure of the asphalt cement's hardness. This property is determined using AASHTO T49 (ASTM D5) "Standard Method of Test for Penetration of Bituminous Mixtures" [AASHTO 2003]. The penetration test started out using a No. 2 sewing machine needle mounted on a shaft for a total mass of 100 g. This needle was allowed to sink into (penetrate) a container of asphalt cement at room temperature (25°C) for 5 seconds as shown in Figure A-4. The consistency (stiffness) of given asphalt was reported as the depth in tenths of a millimeter (mm) that the needle penetrated the asphalt [FWA 2008, Pavement 2010].
Harder asphalt cement will have a lower penetration; while a softer asphalt cement will have a higher penetration.

A.4.2 Viscosity Testing

Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, it resists the compactive effort and thereby resulting mix is heterogeneous, hence low stability values. At low viscosity instead of providing a uniform film over aggregates, it will lubricate the aggregate particles [NPTEL 2008].

Two viscosity measurements are tested: Absolute viscosity (60°C) and kinematic viscosity (135°C). Both use the principle of the rate of flow through a known area to measure viscosity. Because asphalt is still very thick (stiff) at 60°C, a vacuum is needed to move the asphalt through the tube in a reasonable time. At 135°C, gravity and a falling head pressure is sufficient to get the asphalt to flow. Figure A-5 shows different tubes used in viscosity tests [Pavement 2008].
Absolute Viscosity: At the 60°C test temperature, the tube is charged at 135°C and then placed in the test temperature bath. The tube temperature is allowed to equalize with the bath temperature, a vacuum line is attached to the top of the small diameter tube, and the flow is started. The time it takes the asphalt to flow past the timing marks times the tube calibration constant gives the viscosity of the asphalt in Poise [Pavement 2010].

Figure A-6 shows the apparatus used to determine Absolute viscosity. The procedures described earlier to determine Absolute viscosity can be summarized as follow [Pavement 2010]:

- U-shaped tube with timing marks & filled with asphalt
- Placed in 60°C bath
- Vacuum used to pull asphalt through tube
- Time to pass marks
- Visc. in Pa s (Poise)

The standard absolute viscosity test is AASHTO T 202 and ASTM D 2171: Viscosity of Asphalts by Vacuum Capillary Viscometer.
**Kinematic Viscosity**: The tube is charged in the 135°C bath and left for about 20 minutes. A vacuum line is touched briefly to the top of the small diameter tube until the asphalt moves over the upper hump in the tube. The time it takes the asphalt to flow past the timing marks times the tube calibration constant gives the viscosity of the asphalt in centistokes. Centistokes is converted to centipoise by multiplying Centistokes by the specific gravity of the asphalt.

The procedures described earlier to determine Kinematic viscosity can be summarized as follow [Pavement 2010]:

- Cross arm tube with timing marks & filled with asphalt
- Placed in 135°C bath
- Once started gravity moves asphalt through tube
- Time to pass marks
- Visc. in mm² / s (centistoke)

The standard kinematic viscosity test is AASHTO T 201 and ASTM D 2170: Kinematic Viscosity of Asphalts (Bitumens).
A.4.3 Flash Point Testing

If an asphalt cement is heated to a high enough temperature, it gives off sufficient vapors to flash (ignite) in the presence of a spark or open flame. The Cleveland Open Cup test determines the temperature at which this flash occurs [AASHTO 2003].

In this test as shown in Figure A-7, a small sample of asphalt is poured into the brass cup which is placed over an electric heater. A thermometer is submerged to a prescribed depth into the asphalt and used to monitor the temperature rise. When the temperature gets close to the suspected flash point, the gas line is turned on and a small flame lit at the end of the wand. The flash point is the temperature at which a small blue flicker around the inside of the cup is seen as the wand is passed horizontally over the surface of the cup [AASHTO 2003].

![Flash Point Test Apparatus](image)

**Figure A-7 Flash Point Test Apparatus | Pavement 2010**

A.4.4 Ductility Testing

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking [NPTEL 2008].

This test evaluates the ability of an asphalt sample to stretch at a rate of 5 cm/min at 25°C, as shown in Figure A-8. The distance the samples can be pulled is

- 129 -
measured directly from the centimeter scale mounted to the top of the tank. The significance of the ductility test to indicate performance-related properties has been debated for a number of years due to its empirical nature and poor reproducibility of test results. In general, asphalts with lower ductility have a greater tendency to produce pavements which have excessive cracking [Fwa 2008].

![Figure A-8 Ductility Test Apparatus](Pavement 2010)

The standard ductility test is AASHTO T 51 and ASTM D 113: Ductility of Bituminous Materials

### A.4.5 Solubility (Purity) Testing

Solubility is the percentage of an asphalt cement sample that will dissolve in trichloroethylene. This property is determined using AASHTO T44 (ASTM D2042) "Standard Method of Test for Solubility of Bituminous Materials" [AASHTO, 2003]. In this procedure, an asphalt cement sample is dissolved in trichloroethylene and then filtered through a glass-fiber pad where the weight of the insoluble material is measured, as shown in Figure A-9. The solubility is calculated by dividing the weight of the dissolved portion by the total weight of the asphalt cement sample. This test is used to check for contamination in asphalt cement [AASHTO 2003].

### A.4.6 Softening Point (Ring & Ball – R&B) Testing

The softening point is defined as the temperature at which a bitumen sample can no longer support the weight of a 3.5-g steel ball. Although it is commonly used in Europe, it is mostly used for roofing asphalts in the U.S. Basically, two horizontal disks of bitumen, cast in shouldered brass rings, as shown in Figure A-10, are heated
at a controlled rate in a liquid bath while each supports a steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough to allow each ball, enveloped in bitumen, to fall a distance of 25 mm (1.0 inch) [AASHTO 1995, NPTEL 2008].

**Figure A-9 Solubility Test Equipments [WSDOT 2010]**

The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 50°C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below. Generally, higher softening point indicates lower temperature susceptibility and is preferred in hot climates [NPTEL 2008]. The standard softening point test is AASHTO T 53 and ASTM D 36: Softening Point of Bitumen (Ring-and-Ball Apparatus)
A.4.7 Thin Film Oven Aging

Thin film oven aging is a laboratory procedure for simulating the change in asphalt cement properties (effect of short-term aging) which occur during tank storage, mixing and construction processes. This test is conducted using AASHTO T179 (ASTM D1754) "Standard Method of Test for Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)". This test can also be used to measure the loss of volatiles in the asphalt cement by determining the percent difference in the mass before and after aging [AASHTO 2003].

A 50 g sample of asphalt is poured into each of three flat-bottomed pans. This results in a layer of asphalt of about 3.2 mm deep. Three pans are placed on a rotating shelf in a 163°C oven for 5 hours, as shown in Figure A-11. The aged samples are then combined into one container, mixed, and used to determine the aged asphalt cement properties [FWA 2008].
A.5 Asphalt Binder Specifications

In order to purchase a product, the desirable characteristics and important material properties must be known. When these parameters are presented in written form, they are called specifications.

A.5.1 History of Specifications

The first approach to characterizing the stiffness of asphalt cement was to chew on it. An engineer would take a small sample of asphalt, roll it into a ball, and place it between his teeth. The pressure required to deform the ball was considered an indication of the stiffness of the asphalt. However, this method was very subjective and could not be used to routinely specify the particular requirements of an asphalt cement for a given construction project. These drawbacks eventually led to the development of the penetration test [NPTEL 2008].

A.5.2 Penetration Grading Specifications

Grading of bitumen by penetration test at 25°C was adopted by the American Society for Testing and Materials (ASTM) Committee D04 on Road and Paving Materials in 1903, more than 100 years ago. Error! Reference source not found. shows the schematic of the penetration test, in which a needle loaded with 100-grams is allowed to penetrate the bitumen maintained at 25°C temperature in a water bath, for 5 seconds. The resulting penetration is measured in mm; 1 penetration unit = 0.1
mm. The greater the penetration, the softer is the bitumen. ASTM Standard D946 specified five penetration grades for bitumen:

- 40-50 (hardest bitumen grade)
- 60-70
- 85-100
- 120-150
- 200-300 (softest bitumen grade)

Other tests have been added to address safety issues (the flash point test), the ability of the asphalt to deform without breaking (ductility test), and the influence of heat hardening on asphalt cement properties (thin film oven test).

- Uses penetration results to specify
- Adds
  - Flash point test
  - Ductility
  - Solubility
  - Thin film oven aging
  - Penetration
  - Ductility

Table A-1 presents typical penetration specifications

<table>
<thead>
<tr>
<th>Penetration Grade</th>
<th>40-50</th>
<th>60-70</th>
<th>85-100</th>
<th>120-150</th>
<th>200-300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration @ 77°F (25°C) 100g, 5s</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Flash Point, °F (Cleveland open cup)</td>
<td>450</td>
<td>--</td>
<td>450</td>
<td>--</td>
<td>450</td>
</tr>
<tr>
<td>Ductility at 77°F (25°C) 5cm/min, cm</td>
<td>100</td>
<td>--</td>
<td>100</td>
<td>--</td>
<td>100</td>
</tr>
<tr>
<td>Solubility in trichloroethylene, %</td>
<td>99</td>
<td>--</td>
<td>99</td>
<td>--</td>
<td>99</td>
</tr>
<tr>
<td>Retained penetration after thin-film oven test, %</td>
<td>55+</td>
<td>--</td>
<td>52+</td>
<td>--</td>
<td>47+</td>
</tr>
<tr>
<td>Ductility at 77°F (25°C) 5cm/min, cm after thin-film oven test</td>
<td>--</td>
<td>--</td>
<td>50</td>
<td>--</td>
<td>75</td>
</tr>
</tbody>
</table>

A If ductility at 77°F (25°C) is less than 100 cm, material will be accepted if ductility at 60°F (15.5°C) is 100 cm minimum at the pull rate of 5 cm/min.

Table A-1 Penetration Specifications
Advantages

Several advantages are responsible for the penetration specifications being widely used throughout the 20th century. For instance, as late as 1995 the Minnesota Department of Transportation was still using this specification to purchase asphalt cements. These advantages include an estimate of material properties at the average in-service temperature (i.e., the average between summer highs and winter lows), low cost of the equipment, simplicity, and short testing times needed to obtain results. The advantages can be summarized as follow [NPTEL 2008]:

- Grades asphalt near average in-service temp.
- Fast
- Can be used in field labs
- Low capital costs
- Precision well established
- Temp. susceptibility can be determined

Disadvantages

However, there are several disadvantages associated with penetration specifications. These include allowing a wide range of material properties at high and low temperatures for a given penetration grade, variable shear rates (i.e., the needle will penetrate the asphalt faster for softer as compared to harder asphalts), lack of fundamental measurements needed for mechanistic pavement performance prediction models (i.e., no stress or strain measurements), their inability to evaluate shear rate dependent materials (e.g., polymer modified asphalts), and lack of information for selecting appropriate mixing and compaction temperatures (necessary information for preparing mixtures in the laboratory and plant). The disadvantages can be summarized as follow [NPTEL 2008]:

- Empirical test
- Shear rate
  - High
  - Variable
- Mixing and compaction temp. information not available
- Similar penetrations at 25°C (77°F) do not reflect wide differences in asphalts
A.5.3 Viscosity Graded Specifications

The disadvantages of penetration grading specifications led to the development of the viscosity grading system in the 1970's, which is detailed in ASTM D3381. This one ASTM standard actually contains three separate specifications designated as: Table 1, Table 2, and Table 3. The first two specifications are based on the original properties of the asphalt while the last table is based on the properties of the asphalt after rolling thin film oven aging. Each of these tables and differences between them will be discussed in the following slides [NPTEL 2008].

All three of the viscosity graded asphalt specifications are listed in ASTM D3381. The first two specifications are based on the viscosity of the original asphalt at 60°C. The third specification is based on the viscosity of the rolling thin film oven aged residue at 60°C [NPTEL 2008].

Table 1 & 2 Tests and Grades

Requirements on both the absolute and kinematic viscosities are set in these specifications. The grading system is based on the absolute viscosity (60°C). A minimum viscosity at 135°C is included to help define the maximum rate of change of material properties with temperature. A minimum penetration value is also included in these specifications as a means limiting temperature susceptibility. The penetration values decreases with increasing viscosity. In other words, the stiffer the asphalt, the less distance the needle will penetrate into the asphalt [NPTEL 2008].

As with the penetration specifications, requirements for safety and limits on aging of the binder during construction are included. The flash point temperature requirements increase with increasing viscosity (less volatiles with increasing viscosity). Maximum limits on viscosity after thin film oven aging limit the amount of acceptable aging during mixing and construction. Six asphalt cement (AC) viscosity grades were established as follows [NPTEL 2008]:

<table>
<thead>
<tr>
<th>GRADE</th>
<th>VISCOSITY at 60°C, poises</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-2.5</td>
<td>250 +/- 50</td>
</tr>
<tr>
<td>AC-5</td>
<td>500 +/- 100</td>
</tr>
</tbody>
</table>

- 136 -
Low viscosity grades such as AC-2.5 and AC-5 were used in cold climate of Canada. AC-10 was used in the northern tier states of the US, AC-20 was used in most of the US, and high viscosity AC-30 was used in southern states such as Florida, Georgia, and Alabama with hot climate and rainfall [NPTEL 2008].

Table A-2 shows Table 1 specifications that contains AC 2.5, AC 5, AC 10, AC 20, AC 40 [NPTEL 2008].

Table A-2 REQUIREMENTS FOR ASPHALT CEMENT, VISCOSITY GRADED AT 140°F (60°C), ASTM D3381

<table>
<thead>
<tr>
<th>VISCOSITY GRADE</th>
<th>AC-2.5</th>
<th>AC-5</th>
<th>AC-10</th>
<th>AC-20</th>
<th>AC-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, 140°F (60°C), P</td>
<td>250 ± 50</td>
<td>50 ± 100</td>
<td>1000 ± 200</td>
<td>2000 ± 400</td>
<td>4000 ± 800</td>
</tr>
<tr>
<td>Viscosity, 275°F (135°C), min, cSt</td>
<td>80</td>
<td>110</td>
<td>150</td>
<td>210</td>
<td>300</td>
</tr>
<tr>
<td>Penetration, 77°F (25°C), 100g, 5s, min</td>
<td>200</td>
<td>120</td>
<td>70</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Flash point, Cleveland open cup, min, °F (°C)</td>
<td>325 (163)</td>
<td>350 (177)</td>
<td>425 (219)</td>
<td>450 (232)</td>
<td>450 (232)</td>
</tr>
<tr>
<td>Solubility in trichloroethylene, min, %</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>Tests on residue from thin-film oven test:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity, 140°F (60°C), max, P</td>
<td>1250</td>
<td>2500</td>
<td>5000</td>
<td>10,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Ductility, 77°F (25°C), 5 cm/min, min, cm</td>
<td>100%</td>
<td>100%</td>
<td>50%</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

*If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a pull rate of 5 cm/min

Table 2 viscosity specifications are very similar to Table 1 specifications with two exceptions: Table 2 specifications allow for an AC 30 grade, and Table 2 asphalts are required to be less temperature susceptible.

*Table 3*

Table 3 viscosity specifications are based on rolling thin film oven (RTFO) aging. This method of aging was developed by the California Department of Transportation to simulate both the oxidation and heat aging of asphalts which occurs...
during mixing and construction and uses an AR (asphalt residue) designation. As with the AC designations, the numbers are directly related to the viscosity at 60°C. For example, the RTFO aged viscosity of an AR 4000 is 4,000 Poise. Both penetration and ductility of the residue are also included. Two tests are conducted on the original asphalt: penetration (to get percent of original penetration value) and the flash point (safety) test [NPTEL 2008].

- **AR Grades**
  - AR 1000, AR 2000, AR 4000, AR 8000, AR 16000
- **Tests on RTFO aged residue**
  - Viscosities at 60 and 135oC
  - Penetrations at 25oC
  - % of Original Penetration
  - Ductility
  - Properties of unaged asphalt
    - Flash point and solubility

**Advantages for (Original AC Visc. Grade)**

Advantages to using viscosity specifications include measurements with engineering units, limits on maximum temperature susceptibility and changes in properties due to aging, and information can be obtained on appropriate mixing and compaction temperatures [NPTEL 2008].

- Fundamental property
- Wide range of temperatures
- Based on max. pavement surface temp.
- Wide range of instruments
- Test method precision established
- Temperature susceptibility is controlled
- Limits aging
- Information on mixing & compaction temps.
Disadvantages for (Original AC Visc. Grade)

Disadvantages include the higher cost of the more sophisticated equipment and glassware required for viscosity tests, longer testing times, increased training needed for technicians, the lack of lower limits for temperature susceptibility, and the inability of these viscosity measurements for assessing non-Newtonian (shear rate dependent) properties [NPTEL 2008].

- More expensive
- Longer testing time
- More technician skill needed
- Not applicable for Non-Newtonian materials
- Wide range of properties for same grade

Advantages (AR Visc. Grade)

The main advantage to this specification is that it is based on the properties of the asphalt behind the paver. That is, it is based on the in-place asphalt properties at the time the roadway is opened to traffic. Other advantages are similar to those for the first two viscosity specifications [NPTEL 2008].

- Represents asphalt properties after mixing
- Fundamental properties
- Covers wide range of temperatures
- Limits aging

Disadvantages (AR Visc. Grade)

Disadvantages include a problem with a lack of wide-spread experience in determining desirable properties, longer times before results can be reported because the material has to be aged prior to testing, and other disadvantages as seen in the previous viscosity grading specifications [NPTEL 2008].

- Highly regional
- Requires different testing equipment
- Longer testing time
- No consistency test on original AC
- Not applicable for Non-Newtonian materials
- Wide range of properties for same grade
Figure A-12 provides a general comparison of the various traditional specifications. While there is no direct relationship between the specifications, there is a general relationship between stiffness and viscosity. Higher penetration numbers correspond with lower viscosities [NPTEL 2008].

![Penetration Grades Diagram]

**Figure A-12 Comparison of the Various Traditional Specifications [NPTEL 2008].**

### A.5.4 Introduction to Superpave Specifications

The viscosity grading system gave excellent performance results in the US for over 20 years. However, the viscosity grading system, although it is more rational than the penetration grading system, was still based on experience. A 50-million dollar, 5-year Strategic Highway Research Program (SHRP) was undertaken from 1987 to 1992 to develop a performance based grading system for bitumen, which was based on engineering principles to address common asphalt pavement distress problems. The so-called Superpave performance grading system includes new bitumen tests and specifications with the following salient features [SHRP 1990].

1. Tests and specifications are intended for bitumen “binders”, which include both modified and unmodified bitumen.
2. The physical properties measured by Superpave bitumen tests are directly related to field performance by engineering principles rather than just the experience.
3. A long-term bitumen aging test, which simulates aging of bitumen during 5-10 years in service, was developed and included for the first time.

4. Tests and specifications are designed to eliminate or minimize three specific types of asphalt pavement distresses: rutting, fatigue cracking, and thermal cracking. Rutting typically occurs at high temperatures, fatigue cracking at intermediate temperatures, and thermal cracking at low temperatures.

5. As shown in Figure A-13, the entire range of pavement temperatures experienced at the project site is considered. New testing equipments were developed / adopted for testing bitumen for this purpose. A rotational viscometer is used to measure the bitumen viscosity at 135 C. A dynamic shear rheometer is used to measure the viscoelastic properties of the bitumen at two temperatures: high temperature corresponding to the maximum 7-day pavement temperature during summer at the project site, and intermediate temperature corresponding to the average annual temperature of the pavement at the project site. A bending beam rheometer and a direct tension tester are used to measure the rheological properties of the bitumen at the lowest pavement temperature during winter at the project site [SHRP 1990].
The Superpave performance grade (PG) bitumen is based on climate. For example, PG 64-22 bitumen is suitable for a project location, where the average 7-day maximum pavement temperature is as much as 64°C, and the minimum pavement temperature is −22°C.
APPENDIX B: INSPECTION OF AGGREGATES

B.1 Background

"Aggregate" is a collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium (such as water, bitumen, portland cement, lime, etc.) to form compound materials (such as asphalt concrete and Portland cement concrete). By volume, aggregate generally accounts for 92 to 96 percent of HMA and about 70 to 80 percent of Portland cement concrete. Aggregate is also used for base and subbase courses for both flexible and rigid pavements.

Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry), in the form of sands and gravel or crushed rocks, Figure B-1. Usually the rock is blasted or dug from the quarry walls then reduced in size using a series of screens and crushers, Figure B-2. Some quarries are also capable of washing the finished aggregate. Gravel and sand are examples of natural aggregates. Gravel is normally defined as aggregates passing the 3 in. (75 mm) sieve and retained on the No. 4 (4.75 mm) sieve. Sand is usually defined as aggregate passing the No. 4 sieve with the silt and clay fraction passing the No. 200 (0.075 mm) sieve. These aggregates in their natural form tend to be smooth and round. Manufactured rock typically consists of industrial byproducts such as slag (blast furnace slag: byproduct of the metallurgical processing – typically produced from processing steel, tin and copper) [Pavement 2010, FWA 2008].
B.2 Aggregates Desirable Properties

The aggregate desirable properties are strength, hardness, toughness, shape of aggregate, adhesion with bitumen, durability and freedom from deleterious particles. Table B-1 summarizes the desirable properties of aggregates [NPTEL 2008].
### Table B-1 Aggregates Desirable Properties [NPTEL 2008]

<table>
<thead>
<tr>
<th>Properties</th>
<th>Definition or use for</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strength</strong></td>
<td>Aggregates at top layers are subjected to high stresses due to traffic wheel loading, wear and tear, and crushing. For a high quality pavement, aggregates should have high resistance to crushing and to withstand the stresses due to traffic wheel loading.</td>
</tr>
<tr>
<td><strong>Hardness/Toughness</strong></td>
<td>Aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. Aggregates should be hard enough to resist abrasive action caused by the movements of traffic.</td>
</tr>
<tr>
<td><strong>Shape of aggregates</strong></td>
<td>Aggregates, which happen to fall in a particular size range, may have round, cubical, angular, flaky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible.</td>
</tr>
<tr>
<td><strong>Adhesion with bitumen</strong></td>
<td>The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials, otherwise the bituminous coating on the aggregate will be stripped.</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td>The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.</td>
</tr>
<tr>
<td><strong>Freedom from deleterious particles</strong></td>
<td>Specifications for aggregates used in bituminous mixes usually require the aggregates to be clean, tough and durable in nature and free from excess amount of elongated pieces, dust, clay balls and other objectionable material. Similarly aggregates used in Portland cement concrete mixes must be clean and free from deleterious substances such as clay lumps, silt and other organic impurities.</td>
</tr>
</tbody>
</table>
B.3 Aggregates Tests and Specifications

Traditional aggregate specifications for HMA include many standards such as the American Association of State Highway and Transportation Officials (AASHTO), M29 (ASTM D1073) "Standard Method of Test for Fine Aggregate for Bituminous Paving Mixtures", ASTM D692 "Standard Specification for Coarse Aggregate for Bituminous Paving Mixtures," and ASTM D242 "[FWA 2008]. There are critical properties required to develop a desirable HMA such as Consensus Properties and Source Properties [FWA 2008].

**Consensus Properties**

It was the consensus of the pavement researchers that certain aggregate characteristics were critical and needed to be achieved in all cases to arrive at well performing HMA. These characteristics were called “consensus properties” because there was wide agreement in their use and specified values. Those properties are:

- coarse aggregate angularity (Particle Shape),
- fine aggregate angularity,
- flat, elongated particles, and
- clay content.

**Source Properties**

Selecting aggregate material for use in an asphalt pavement depends upon the availability, cost, and quality of the material, as well as the type of construction that is intended. The suitability of aggregates for use in asphalt construction is determined by evaluating the material in terms of:

- Cleanliness
- Toughness
- Soundness
- Surface Texture
- Absorption
- Affinity for Asphalt
B.3.1 Coarse Aggregate Angularity

This property ensures a high degree of aggregate internal friction and rutting resistance. It is defined as the percent by weight of aggregates larger than 4.75 mm with one or more fractured faces. The test procedure for measuring coarse aggregate angularity is ASTM D 5821, Standard Test Method for Determining the Percentage of Fractures Particles in Coarse Aggregate. The procedure involves manually counting particles to determine fractured faces. A fractured face is defined as any fractured surface that occupies more than 25 percent of the area of the outline of the aggregate particle visible in that orientation [AASHTO 2003, FWA 2008].

The appropriate percentages of each aggregate stockpile are combined and then split on the 4.75 mm screen. The material retained on the 4.75 mm screen is used to determine the percent crushed faces, Figure B-3. This is a measurement of coarse aggregate angularity. The amount of crushing (angularity) is important because it determines the level of internal shear resistance which can be developed in the aggregate structure. Round, uncrushed aggregates tend to “roll” out from under traffic loads and therefore have a low rutting resistance [AASHTO 2003].

The required minimum values for coarse aggregate angularity are a function of traffic level and position within the pavement. These requirements apply to the final aggregate blend, although estimates can be made on the individual aggregate stockpiles, as shown in Table B-2 [AASHTO 2003].
Table B-2 Coarse Aggregate Angularity Requirements [AASHTO 2003]

<table>
<thead>
<tr>
<th>Superpave Coarse Aggregate Angularity Requirements</th>
<th>Percent, Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic, million ESALs</td>
<td>Depth from Surface</td>
</tr>
<tr>
<td>&lt; 0.3</td>
<td>&lt; 100 mm</td>
</tr>
<tr>
<td>0.3 to &lt; 3</td>
<td>100 mm</td>
</tr>
<tr>
<td>3 to &lt; 10</td>
<td>&gt; 100 mm</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td></td>
</tr>
<tr>
<td>≥ 30</td>
<td></td>
</tr>
<tr>
<td>85/80</td>
<td>50/-</td>
</tr>
<tr>
<td>95/90</td>
<td>60/-</td>
</tr>
<tr>
<td>100/100</td>
<td>80/75</td>
</tr>
</tbody>
</table>

Note: "85/80" means that 85 % of the coarse aggregate has one fractured face and 80 % has two fractured faces.

B.3.2 Fine Aggregate Angularity

This property ensures a high degree of fine aggregate internal friction and rutting resistance. It is defined as the percent air voids present in loosely compacted aggregates smaller than 2.36 mm. Higher void contents mean more fractured faces. The test procedure used to measure this property is AASHTO T 304 "Uncompacted Void Content - Method A." In the test, a sample of fine aggregate is poured into a small calibrated cylinder by flowing through a standard funnel, as shown in Figure B-4. By determining the weight of fine aggregate (W) in the filled cylinder of known volume (V), void content can be calculated as the difference between the cylinder
volume and fine aggregate volume collected in the cylinder. The fine aggregate bulk specific gravity (Gsb) is used to compute fine aggregate volume [AASHTO 2003, Pavement 2010].

![Diagram of fine aggregate test](image)

Figure B-4 Fine Aggregate Angularity [AASHTO 2003]

- Fine aggregate at a specified gradation is allowed to flow freely into a 100 cm³ cylinder.
- Knowing the specific gravity of the aggregate, the voids between aggregate particles can be determined.
- The more angular the aggregate, the higher the void content.

The required minimum values for fine aggregate angularity are a function of traffic level and position within pavement. These requirements apply to the final aggregate blend, although estimates can be made on the individual aggregate stockpiles, as shown in Table B-3 [AASHTO 2003].
Table B-3 Fine Aggregate Angularity Requirement [AASHTO 2003]

<table>
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<tr>
<th>Traffic, million ESALs</th>
<th>Percent, Minimum</th>
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<tr>
<td>&lt; 0.3</td>
<td>&lt; 100 mm</td>
</tr>
<tr>
<td>0.3 to &lt; 3</td>
<td>40</td>
</tr>
<tr>
<td>3 to &lt; 10</td>
<td>45</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>45</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>45</td>
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</tbody>
</table>

Note: Criteria are presented as percent air voids in loosely compacted fine aggregate.

B.3.3 Flat, Elongated Particles

Flat and elongated particles are undesirable since they have a tendency to break during construction and under traffic. If they do not break, they tend to produce mixtures with directionally-oriented material properties [AASHO 2003].

Flat or elongated particles are defined as aggregate having a ratio of width to thickness or length to width greater than a specified value. This property is determined using ASTM D4791 "Standard Practice for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate" [ASTM 2003]. This test is conducted on aggregates retained on the No. 4 (4.75 mm) sieve. In this procedure, a proportional caliper is used to measure the dimensional ratio of a representative sample of coarse Aggregates. Aggregates used in HMA mixes should be cubic rather than disproportionate in their dimensions [AASHTO 2003]. Aggregates particles that are significantly longer in one dimension than in the other one or two dimensions have a propensity to break during the construction process or under traffic loading [Fwa 2008].

The procedure uses a proportional caliper device to measure the dimensional ratio of a representative sample of aggregate particles. The aggregate particle is first placed with its largest dimension between the swinging arm and fixed post at position "A", as shown in Figure B-5. The swinging arm then remains stationary while the aggregate is placed between the swinging arm and fixed post at position "B", Figure B-5.
If the aggregate passes through this gap, then it is counted as a flat or elongated particle, Figure B-6. The total flat, elongated, or flat and elongated particles are measured.

The required maximum values for flat, elongated particles in coarse aggregate are a function of traffic level. These requirements apply to the final aggregate blend, although estimates can be made on the individual aggregate stockpiles, Table B-4.
Table B-4 Flat, Elongated Particle Requirements [AASHTO 2003]

<table>
<thead>
<tr>
<th>Superpave Flat, Elongated Particle Requirements</th>
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<tr>
<td>Traffic, million ESALs</td>
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<tr>
<td>------------------------</td>
</tr>
<tr>
<td>&lt; 0.3</td>
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<td>0.3 to &lt; 3</td>
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<td>3 to &lt; 10</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
</tr>
<tr>
<td>&gt; 30</td>
</tr>
</tbody>
</table>

Note: Criteria are presented as maximum percent by weight of flat and elongated particles.

B.3.4 Clay Content

Clay content is the percentage of clay material contained in the aggregate fraction that is finer than a 4.75 mm sieve. It is measured by AASHTO T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test.

In this test, a sample of fine aggregate is placed in a graduated cylinder with a flocculating solution and agitated to loosen clayey fines present in and coating the aggregate. The flocculating solution forces the clayey material into suspension above the granular aggregate. After a period that allows sedimentation, the cylinder height of suspended clay and sedimented sand is measured, as shown in Figure B-7 [AASHTO 2003, FWA 2008]. The sand equivalent value is computed as a ratio of the sand to clay height readings expressed as a percentage.

The required clay content values for fine aggregate are expressed as a minimum sand equivalent and are a function of traffic level. Table B-5 shows the clay content requirements as a function of traffic level. These requirements apply to the final aggregate blend, although estimates can be made on the individual aggregate stockpiles.
Some aggregates contain certain foreign or deleterious substances that make them undesirable for asphalt paving mixtures unless the amount of foreign matter is reduced. Typical of objectionable materials are vegetation, shale, soft particles, clay lumps, and clay coating on coarse-aggregate particles.

The percentage of deleterious materials in blended aggregate is determined using AASHTO T112 (ASTM C142) “Standard Method of Test for Clay Lumps and Friable Particles in Aggregate” [AASHTO 2003]. In this procedure, aggregates are individually subjected to finger pressure (while soaking) to determine materials that are friable or clay lumps. The percent of clay lumps and friable particles is determined by taking the difference between the original and final mass retained on a No. 200
(0.075 mm) sieve, after wet sieving, expressed as a percentage of the original mass. The percent of deleterious materials can range from 0.2 to 10% [FWA 2008].

**B.3.6 Toughness**

Aggregates undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities including manufacturing, stockpiling, production, placing, compaction (in the case of HMA) and consolidation (in the case of PCC). Furthermore, they must be able to adequately transmit loads from the pavement surface to the underlying layers (and eventually the subgrade). Aggregates not adequately resistant to abrasion and polishing will cause premature structural failure and/or a loss of skid resistance [WSDOT 2010]. Toughness is the percent loss of material from an aggregate blend during the Los Angeles Abrasion test. This property is determined using AASHTO T96 (ASTM C131) "Standard Method of Test for resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine [AASHTO 2003]. This test covers a procedure for testing aggregates up to 1.5 in. (37.5 mm) in size. A STM C535 should be used for aggregates with a larger maximum size up to 3 in. (75 mm) [Fwa 2008]. The L.A. abrasion test measures the degradation of a coarse aggregate sample that is placed in a rotating drum with steel spheres, as shown in Figure B-8. As the drum rotates the aggregate degrades by abrasion and impact with other aggregate particles and the steel spheres (called the "charge"). Once the test is complete, the calculated mass of aggregate that has broken apart to smaller sizes is expressed as a percentage of the total mass of aggregate. Therefore, lower L.A. abrasion loss values indicate aggregate that is tougher and more resistant to abrasion [PAVEMENT 2010].

Relatively high resistance to wear, as indicated by a low percent of abrasion loss, is a desirable characteristic of aggregates to be used in asphalt pavement surface layers. Aggregates having higher abrasion losses, within limits, may generally be used in lower pavement layers where they will not be subject to the high stresses caused by traffic.
B.3.7 Soundness

Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles [NPTEL 2008]. Aggregates must be resistant to breakdown and disintegration from weathering (wetting/drying and freezing/thawing) or they may break apart and cause premature pavement distress. Durability and soundness are terms typically given to an aggregate’s weathering resistance characteristic [WSDOT 2010]. Soundness is the percent loss of material from an aggregate blend during the sodium or magnesium sulfate soundness test. This property is determined using AASHTO T104 "Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate" [AASHTO 2003]. The soundness test repeatedly submerges an aggregate sample in a sodium sulfate or magnesium sulfate solution. This process causes salt crystals to form in the aggregate's water permeable pores. The formation of these crystals creates internal forces that apply pressure on aggregate pores and tend to break the aggregate after a specified number of submerging and drying repetitions, the aggregate is sieved to determine the percent loss of material [WSDOT 2010], as shown in Figure B-9.
B.3.8 Surface Texture

Like particle shape, the surface texture also influences the workability and strength of asphalt paving mixtures. Surface texture has often been considered more important than the shape of the aggregate particles. A rough, sandpaper-like surface texture as opposed to a smooth surface tends to increase the strength of the paving mix and requires additional asphalt to overcome the loss of workability [Pavement 2010, Fwa 2008].

Natural gravels, such as river gravels, often have a smooth texture as well as round-shaped particles. Crushing, however, often produces a rough surface texture and changes the particle shape. Smooth-surface aggregates may be easy to coat with an asphalt film but the smooth surface, compared with a rough surface, does not grip the film coating and help hold it in place [Pavement 2010, Fwa 2008].
B.3.9 Absorption

The porosity of an aggregate is generally indicated by the amount of water it absorbs when soaked in water. A certain degree of porosity is desirable, as it permits aggregate to absorb asphalt, which then forms a mechanical linkage between the asphalt film and the stone particle. Highly porous aggregates are not normally used [Pavement 2010].

B.3.10 Affinity for Asphalt

Stripping — separation of the asphalt film from the aggregate through the action of water — may make an aggregate material unsuitable for asphalt paving mixes. Such material is referred to as hydrophilic (water loving). Siliceous aggregates such as quartzite and some granite are examples of aggregates, which may require attention from the stripping viewpoint [Pavement 2010, Fwa 2008].

Aggregates that exhibit a high degree of resistance to film stripping in the presence of water are usually most suitable in asphalt paving mixes. Such aggregates are referred to as hydrophobic (water hating) aggregates. Limestone, dolomite, and trap rock are usually highly resistance to asphalt film stripping. There are various tests that evaluate a mixture's propensity for stripping: AASHTO T283, ASTM D3625, and AASHTO T165 (ASTM D1075). Unfortunately, none of these tests could accurately predict the stripping potential of HMA mixes in different environments [Fwa 2008, pavement 2010].
APPENDIX C: INSPECTION OF HOT-MIX ASPHALT

C.1 Design of Hot-Mix Asphalt Concrete

The bituminous mix design aims at determining the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical [NPTEL 2008]. From a performance standpoint, the HMA should be durable and be able to resist pavement distresses (such as permanent deformation, fatigue cracking, low temperature cracking, and moisture induced damage). From a construction standpoint, the mix should be workable enough to place and compact with reasonable effort. Additionally, surface courses should provide sufficient skid resistance for safety considerations. There are many design methods for HMA such as Marshall, Hveem and Superpave mix design. Although the Superpave mix design is the recent method, prior to the development of the Superpave mix design procedure, the Marshall Mix design was the most commonly used mix design procedure in the United States. Even now, it is still the most commonly used procedure in many parts of the world. Therefore, this section focuses only on Marshall Mix design.

C.2 Marshall Mixture Design Method

Extensive research was conducted by Bruce Marshall, while serving as Bituminous Engineer with the Mississippi State Highway Department to put together the concepts behind the Marshall mix design procedure. The U.S. Corps of Engineers becomes the first to introduce Marshall's concepts and eventually established the mix design method named after Marshall [Fwa 2008], AASHTO adopted this mix design procedure as AASHTO R-12 "Standard. Recommended Practice for Bituminous Mixture Design Using the Marshall and Hveem Procedures" [AASHTO, 2003]. This procedure can be broken into seven major steps as follow:

*Step 1: Aggregate Evaluation*
The aggregates proposed for use in the mix design should be evaluated against the aggregate requirements set forth by the specifying agency. Descriptions of the commonly used aggregate tests are described early. No matter the specific method; the overall mix design procedure begins with evaluation and selection of aggregate and asphalt binder sources. Different authorities specify different methods of aggregate acceptance. Typically, a battery of aggregate physical tests is run periodically on each particular aggregate source. Then, for each mix design, gradation and size requirements are checked.

**Step 2: Asphalt Binder Evaluation**

The asphalt binder used in the mix design should be suitable for the geographical location where the mix will be placed. Run the required tests to ensure that the asphalt cement meets all the agency specifications.

**Step 3: Preparation of Marshall Specimens**

Approximately 1200gm of aggregates and filler is heated to a temperature of 175 to 190°C. Bitumen is heated to a temperature of 121 to 125°C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 154 to 160°C. The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of 138°C to 149°C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/−3 mm. Vary the bitumen content in the next trial by +0.5% and repeat the above procedure. This procedure is to be conducted based on requirements set in AASHTO R-12. Three replicate specimens are compacted at five asphalt contents. The asphalt contents should be selected at 0.5% asphalt increments with two asphalt contents falling above and below the "optimum" asphalt content. These specimens are compacted using the Marshall compactor. Three loose specimens should also be prepared for determining the maximum theoretical specific gravity near the "optimum" asphalt content.

Determine the bulk specific gravity of the compacted specimens and maximum theoretical specific gravity of the loose mix using AASHTO T166 (ASTM

**Step 4: Marshall Stability and Flow**

Marshall Stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (5 cm per minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm is called the Marshall Flow value of the specimen. Generally, to determine the Marshall stability and flow the mean of ASTM D1559 is introduced. The primary use of the Marshall stability is to evaluate the effect of asphalt cement in the Marshall Mix design procedure. It is not specifically correlated to the stability of mixes in the field. Increasing the Marshall stability in the laboratory does not automatically translate to increased stability of mixes in the field. Flow is the vertical deformation of the sample at failure. High flow values typically indicate a plastic mix that could be susceptible to permanent deformation. Low flow values may indicate low air voids that may lead to premature cracking.

**Step 5: Density and Void Analysis**

Using the bulk specific gravity and maximum theoretical specific gravity test results, the volumetric properties of the mix can be determined. This information is used in Step 6.

**Step 6: Tabulating and Plotting Test Results.**
With the completion of Steps 4 and 5, the average (from three replicates) results can be tabulated and plotted. The following plots can then be made to evaluate the mix:

- Density (or Unit Weight) vs. Asphalt Content
- Marshall Stability vs. Asphalt Content
- Flow vs. Asphalt Content
- Air Voids vs. Asphalt Content
- VMA vs. Asphalt Content
- VFA vs. Asphalt Content

The density plot typically shows a trend of increasing density until the peak is reached. After this peak, the density begins to decrease. The Marshall stability has a similar trend but its peak is typically at lower asphalt content than density. Some recycled mixes may show a decreasing stability with increasing asphalt content with no peak. Flow typically increases with increasing asphalt content. The percent air voids should decrease and the Void Field with Asphalt (VFA) increases with increasing asphalt content. Voids in Mineral Aggregates (VMA) is another property that increases with asphalt content until it reaches its peak and then decreases with additional increase in asphalt content.

**Step 7: Optimum Asphalt Content Determination**

The criteria used to select the optimum asphalt content can vary considerably between agencies. Figure C-1 shows the Marashal graphical pots that can be used to determine the optimum asphalt content [Asphalt Institute 1997, NPTEL 2008].
Figure C-1 Marshall Graphical Plots [NPTEL 2008]
## APPENDIX D: INTERVIEW MATRIX

<table>
<thead>
<tr>
<th>No</th>
<th>Names</th>
<th>Designation</th>
<th>Organization</th>
<th>Specification</th>
<th>Material Approval</th>
<th>Material Testing</th>
<th>Use of Independent Lab</th>
<th>Actual Work Progress with respect to Program of work</th>
<th>Management</th>
<th>Experience</th>
<th>WorkEthics</th>
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<td>Ali Al-Aidha</td>
<td>Head of Engineering Materials Laboratory Section</td>
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رصد وتطوير فعالية مراقبة وضمان الجودة
لأعمال إنشاء الطرق في بلدية مدينة العين

تؤثر كفاءة شبكة الطرق على النمو الاقتصادي للدولة، وعلى هذا فإن إنشاء الطرق الجيدة والتي تُعتبر الهدف الأساسي لهيئات الطرق المختلفة والمقاولين تتطلب تضاعف الجهود على سنتين عديدة للوصول إلى الهدف المطلوب. وعلى مدى السنوات العديدة الماضية، شجعت هذه هيئات الطرق المختلفة مع المقاولين والهيئات العامة في إنشاء الطرق لتقديم أنشطة ضمان/مراقبة الجودة في محاولة لتحسين نوعية وجودة إنشاء الطرق. ويستخدم نظام ضمان/مراقبة الجودة كوسيلة لوصف المواد المستخدمة في الإنشاء وغيرها من المتطلبات العامة للمشروع التي تتوافق هيا تطبيقات الطرق المختلفة من المقاولين. وينبغي أن تكون مواصفات الإنشاء المعول بها في إنشاء الطرق متماثلة وواضحة ليكمل من السهل فهمها من قبل الأطراف المعنية، وعلى النحو الآخر فإن المواصفات الغامضة والغير جيدة تضاعف القولون عنها زيادة التكلفة لقطاع الطرق أو المقاول على حد سواء بسبب المطالبات التي قد تحدث. ورغم أن الوظيفة الأساسية لضمان/مراقبة الجودة هي وصف مستوى المنتج المطلوب، فإن تطوير وإنشاء مواصفات عامة وخاصة للمشروع خطوة هامة نحو تحقيق الهدف. لذلك فلقد تم في هذا البحث، فقد تم اختيار نظام ضمان/مراقبة الجودة وتطبيقه في المشاريع المختلفة، فإنه يجب رصدها للتحقق من فعاليتها وتحديد مدى تقدر إجراء تحسينات وتطوير عليها، مما يجعل تحسين الجودة ممكن، ويوجد هيا تطبيقات الطرق لتسهيل هذا الهدف. وتحقيق هذا الهدف، فإن الفهم الجيد للممارسات التي تتم لنظام ضمان/مراقبة الجودة من قبل بلدية مدينة العين أمر ضروري ينبعه تجميع معلومات وبيانات كافية. كما أن المرموقة معرفة وتحليل ومقارنة أنظمة ضمان ومخاطر الجودة التي يجري إتباعها من قبل هيا تطبيقات الطرق أخرى مثل إدارة الطرق في بلدية أبو ظبي، هيئة الطرق والمواصلات- المعروفة سابقاً باسم إدارة الطرق، بلدية دبي، ومختبر دبي المركزي، وقد أجريت مقابلات مع الأشخاص المسؤولين عن الإدارة المعنية من مختلف المنظمات للحصول على بيانات ومعلومات، وقد أجريت المقارنة والتحليل لتحسين نظام ضمان/مراقبة الجودة وقد تم تطوير خطط تدريب على المدى القصير والطويل لتحسين نظام ضمان/مراقبة الجودة في بلدية مدينة العين.
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