# Subgrade Geotechnical Study for Riverbank Road Construction and Maintenance Management System Quality Control

Zahraa Amad Salem [1], Asma Thamir Ibraheem[2*]

**Authors affiliations:**
1) Civil Engineering Department, College of Engineering, Al-Nahrain University, Baghdad, Iraq.
amadzahraa5@gmail.com

2) Civil Engineering Department, College of Engineering, Al-Nahrain University, Baghdad, Iraq.
asma.th.ibraheem@nahrainuniv.edu.iq

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## Abstract

Quality control of riverbank roads is a vital part of the road construction and maintenance process and aims to ensure infrastructure quality, safety, and sustainability. This requires adherence to technical standards, constant auditing, and regular maintenance to maintain the condition of the roads and avoid potential problems. The first step in the quality control of roads is to test the efficiency of the subgrade soil. A geotechnical investigation of subgrade soil under river bank roads is carried out to evaluate the engineering properties of the soil and determine the soil's ability to bear the loads resulting from vehicle movement and road traffic. This investigation includes analyzing soil samples and laboratory tests to determine soil properties and determine any improvements the soil needs to bear the loads. Soil samples were collected from Al-Kadhimiya Corniche Street. It was dried and subjected to laboratory tests, the soil in this study is classified as poorly graded sand (SP), GS 2.589, the shear strength parameters an internal friction angle of 33 degrees and cohesion of 0.5 kN/m$^2$, and the results of the compaction test indicated that the optimal moisture content was 8.1%, with a maximum dry density was 18.24 kN/m$^3$, CBR 26.04%, and chemical tests ($SO_3$ 0.222, pH 8.55, T.SS 0.891, CL 0.085). Software FAARFIELD was used to check pavement design, the thickness design was executed utilising a subgrade CBR value of 26.04%. The subgrade pavement thickness was determined to be 304mm in total. The results agree with the actual design of Al-Kadhimiya Corniche Street, which was recently maintained during the field investigation in 2023.

**Keywords:** Geotechnical Investigation, Subgrade Soil, Riverbank Road, Laboratory Tests.

## دراسة جيوتقنية للطبقة التحتية لمراقبة جودة نظام إدارة إنشاء وصيانة طريق ضفة النهر

زهراء عماد سالم ، اسماء ثامر ابراهيم

**الخلاصة:**

تعد مراقبة جودة الطرق على ضفة النهر جزءًا حيويًا من عملية بناء الطرق وصيانتها وتهدف إلى ضمان جودة البنية التحتية وسلامتها واستدامتها. وهذا يتطلب الالتزام بالمعايير الفنية والتدقيق المستمر والصيانة الدورية للمحافظة على حالة الطرق وتجنب المشاكل المحتملة. الخطوة الأولى في مراقبة جودة الطرق هي اختبار كفاءة التربة التحتية. يتم إجراء الفحص الجيوتقني للتربة التحتية تحت طرق ضفة النهر لتقييم الخواص الهندسية للتربة وتحديد قدرة التربة على تحمل الأحمال الناتجة عن حركة المركبات وحركة المرور على الطرق. يتضمن هذا التحقيق تحليل عينة التربة وإجراء الاختبارات المعملية لتحديد خصائص التربة وتحديد أي تحسينات تحتاجها التربة لتتحمل الأحمال. تم جمع عينة التربة من شارع كورنيش الكاظمية. تم تجفيفها وإخضاعها للاختبارات المعملية، وقد تم تصنيف التربة في هذه الدراسة على أنها رملية رديئة التدرج ((SP، GS= 2.589، ومعايير مقاومة القص زاوية احتكاك داخلي = ٣٣ درجة وتماسك = ٠,٥ كيلو نيوتن/م٢، وكانت النتائج من اختبار الضغط أشار إلى أن محتوى الرطوبة الأمثل كان ٨,١٪، مع أقصى كثافة جافة كانت ١٨,٢٤ كيلو نيوتن/م٣، CBR= 26.04%، والاختبارات الكيميائية ($SO_3$ = 0.222، PH= 8.55، T.SS = 0.891، CL= 0.085). تم استخدام برنامج FAARFIELD لفحص تصميم الرصف، وتم تنفيذ تصميم السمك باستخدام قيمة CBR للطبقة التحتية البالغة ٢٦,٠٤٪. تم تحديد سمك الرصف الأساسي ليكون ٣٠٤ ملم في المجموع. وتعطي النتائج توافقاً جيداً مع التصميم الفعلي لشارع كورنيش الكاظمية والذي تم اجراء الصيانة له مؤخراً خلال التحقيق الميداني في عام ٢٠٢٣.

## 1. Introduction

In the present day, there is a heightened focus on quality control in road construction due to its contribution to the attainment of well-constructed pavements that adhere to standard specifications. Quality control is an essential component throughout the entire process of constructing and maintaining pavements, beginning with the design phase and continuing through the construction project mix. Quality control in construction projects is a systematic process that examines particular project outcomes to ascertain their adherence to predetermined standards, while also identifying methods to overlook the underlying factors contributing to substandard results [1]. Relevant quality control tests should be carried out on construction materials. The plants and equipment must be of good quality and must be consistent with the type of job to be done. Effective supervision of construction or maintenance works as well as plants and equipment by qualified engineers is the key to the achievement of the overall objective of quality control. Engineers are to ensure that contractors comply with all the project specifications. Efficient quality control results in decreased expenditures on construction and maintenance, as well as on the operation, transportation, and maintenance of vehicles. It is highly recommended that proactive maintenance be given precedence over reactive repair for our roads, as the former results in extended road service life and significant cost savings. In road construction and maintenance, quality control pertains to the degree of uniformity and consistency in the manufacturing process. Additionally, it should facilitate the optimal use of materials and the implementation of systematic building techniques. Thus, effective quality control decreases operating, transportation, and maintenance expenses for vehicles, in addition to construction and maintenance costs [2]. It is estimated that quality control expenses account for 1.5 to 2% of the total building cost, with a direct and indirect economic return of 5 to 10% of the construction cost, and occasionally even higher [2,3].

Soil is a critical construction material due to its considerable abundance and pervasive presence. Unless established on granite, the majority of land-based engineering projects based on soil necessitate a robust foundation capable of sustaining the structure's weight. Before constructing any engineering structure, a thorough geophysical and geotechnical investigation must be conducted to guarantee post-construction stability. An area of soil's suitability for a specific purpose is determined by its reaction to that purpose. Thus, adequate knowledge of the properties and factors that influence the behaviour and performance of soils is necessary for their effective utilisation [4].

The stability of a structure is contingent upon its material composition. In the case of roads, the stability, performance, and longevity of the pavement infrastructure are regulated by the subgrade strength, degree of saturation, and expected behaviour under saturated conditions. It has been acknowledged that the subgrade strength is influenced by the geology of the site, which imparts protection against floods and wave erosion, traffic stress, surface and other environmental factors. [2,5]. It has been reported by [6] that subgrade strength and traffic volume are the most crucial considerations in the structural design of flexible or rigid pavements. Subgrades serve the primary function of distributing applied vehicle loads so as to prevent distress in the foundation layers or overlying layers during construction, where stresses will be applied by delivery vehicles, pavers, and other construction equipment. Subgrades provide the foundation for the pavement. Research findings indicate that the majority of untimely road failures in Nigeria, particularly in the coastal Niger Delta, can be ascribed to several factors. These include inadequate subgrades, which render the area prone to persistent flooding and pavement deterioration caused by an excess of surface and groundwater, subgrade compression, settlement, wetland conditions such as marshes, bogs, and swamps with low bearing capacity, and poor drainage characteristics.

## 2. The Aim of This Study

The aim of this study is to improve the quality of roads and ensure their safety for users, and identify and evaluate the characteristics of subgrade soil, understand its mechanical behavior and usability, and thus identify potential geotechnical risks and take the necessary precautions to avoid them.

## 3. Methodology

1. Definition of quality control and its types.
2. Subgrade soil efficiency testing.
3. Collection of soil sample from the site, and keep the soil sample in a closed bag and transport it to the laboratory.
4. Basic tests on sample to determine its properties.
5. Particle size determination by sieve analysis.
6. Specific gravity test.
7. Direct shear test.
8. Determination of the maximum dry density (MDD) and the corresponding optimum moisture content (OMC) of the soil by Proctor compaction test.

9. CBR test on plain soil sample for 2.5 mm and 5 mm penetration.
10. Chemical tests (SO3, CL, PH, TSS).
11. Checking of pavement design using FAARFIELD Software.
12. Results and discussion.

## 4. Quality Control in Construction Projects

Quality control in construction projects can be defined as a procedure that monitors specific project results to determine whether they meet specifications, and identifies ways to ignore the causes of poor results. The true reflection of the critical risks facing the implementation of infrastructure projects in developing countries is inadequate quality control. The rationale behind quality control is that it involves carrying out monitoring, but it is also concerned with finding and eliminating the causes of quality problems, so that customer needs are strictly met. From a construction project perspective, quality control involves observing or measuring remedial actions of actual performance to determine if there are deviations. Quality control carries with it a general framework of quality management and is essentially the procedures and systems in place to achieve and maintain the quality of a product or service. Quality controllers must be experts in the areas of project and statistical quality control, sampling and probability, and must be able to measure quality output. Mostly These monitoring processes include monitoring the actual project results to evaluate them, Commitment to quality standards and eliminating poor performance and developments and products [1].

### 4.1 Types of Quality Control

One of the most important tasks of the supervision during the execution of a road contract is technical quality control, i.e. control as to whether the materials and work supplied by the Contractor meet the technical requirements in the contract specifications [7]. There are two types of quality control which are described below [8]:

**1. Process Quality Control:** The designer makes the decisions regarding the type of equipment, Procedure of construction and the amount of work required to obtain the desired result.

**2. End Quality Control:** In the end result type of quality control the construction agency which may be a private contractor has a free hand in the selection of road construction methods and equipment to achieve the desired end product. In the end result type of specification, the field engineering personnel carry out tests on finished work at regular intervals to evaluate whether it meets the specification requirements or not whereas in the process type control the responsibility of field personnel is to make sure that the work is carried out as per laid down specifications.

### 4.2 Quality Control Techniques for Road Construction

Quality control and inspection are essential aspects of road construction, as they ensure the safety, durability, and functionality of the infrastructure. However not all quality control and inspection techniques are equally effective and some may be more suitable for certain types of projects than others, The most effective quality control techniques for roads construction are as following [9,2]:

**1. Geotechnical Investigation**

Effective quality control and inspection technique for road construction is geotechnical investigation, which involves studying the soil and rock conditions of the site and assessing their suitability and stability for the project. Geotechnical investigation can help you determine the bearing capacity, settlement, slope stability, erosion, and seismic hazards of the site, and design the appropriate foundations for the project.

**2. Materials Testing**

One of the most important quality control and inspection techniques for road construction is materials testing, which involves checking the properties and performance of the materials used in the project, such as concrete, asphalt, steel, and aggregates. Materials testing can help you verify the quality, strength, durability, and suitability of the materials for the intended use, and detect any defects or deviations from the specifications.

**3. Visual Inspection**

A simple but essential quality control and inspection technique for road construction is visual inspection, which involves observing and examining the physical condition and appearance of the project components, such as the pavement, Visual inspection can help you identify any cracks, spalls, deformations, displacements, corrosion, or other signs of damage or deterioration that may affect the performance or safety of the project.

**4. Non-Destructive Testing**

A more advanced quality control and inspection technique for road construction is non-destructive testing, which involves applying various methods and technologies to evaluate the internal structure and condition of the project components, without damaging or altering them. Nondestructive testing can help you detect any flaws, defects, or anomalies that may not be visible from the surface, such as voids, cracks. Non-destructive testing can be done by using ultrasound, infrared thermography, ground-penetrating radar, magnetic flux leakage.

**5. Quality Audit**

A comprehensive quality control and inspection technique for road construction is quality audit, which involves reviewing and verifying the compliance of the project with the quality standards, specifications, regulations, and best practices. Quality audit can help you evaluate the effectiveness of the quality management system, the performance of the contractors and subcontractors, the adequacy of the documentation and records, and the satisfaction of the clients and stakeholders. Quality audit can be done by using checklists, interviews, surveys, and reports.

## 5. Investigation of Subgrade Soil as the Case Study

As the case study area for this article, Al-Kadhimiya Corniche Street was utilized. Located in the sacrosanct Al-Kadhimiya district, Al-Kadhimiya Corniche Street spans the eastern bank of the Tigris

River and is regarded as one of the most significant recreational and tourist destinations in the Al-Kadhimiya vicinity. This road was constructed in the 1950s, coinciding with the inauguration of the Imams Bridge. It extends from Abdul Mohsen Al-Kazemi Square to the Imams Bridge, measuring 1400 meters in length and 10 meters in breadth. It is two-lanes two way. The paving material utilized is flexible tiling, which is distinguished by its capacity to acclimatize and endure fluctuations in temperature and ground expansion and contraction. It is extensively implemented on heavily travelled roads and offers drivers enhanced comfort while mitigating noise and vibrations caused by traffic. Figure 1 shows the location of the street on the map.


**Figure (1):** The position of Al-Kadhimiya corniche street.

## 6. Subgrade Soil

The performance of flexible road pavement is primarily determined by the functions of the component strata, particularly the subgrade. The subgrade, which comprises the stratum of natural soil upon which the pavement or subbase is constructed, is a component of the pavement system [10]. In order to sustain the remainder of the pavement system, subgrade soil is utilized. Road pavements ultimately rest upon the subgrade, which is the native soil. Therefore, the attributes of the subgrade have an impact on the efficacy of the pavement. Furthermore, a primary purpose of road pavements is to mitigate the stresses that are transmitted to the subgrade to an extent that the soil can withstand without undergoing substantial deformation [11]. In order to withstand the weight of the pavement and its concomitant traffic burden without experiencing excessive deformation or shear failure, the subgrade must have adequate strength and rigidity. Due to the transitory and short-lived nature of the stresses applied to pavements, as well as their comparatively low magnitude, it is not customary to consider the tensile strength of the soil as a crucial determinant when designing pavement thickness. The principal parameters required for the foundation are the elastic properties (E) of the subgrade. However, these are relatively complex properties to measure and bearing in mind the variability of soils. General desirable properties of a subgrade soil include: Stability good strength and stiffness under adverse loading and climatic moisture conditions, incompressibility, good drainage properties, ease of compaction, volume stability (no/minimum shrink / swell characteristics with change in moisture content), pavement performance is influenced by subgrade uniformity. However, the attainment of an ideal subgrade is challenging owing to the intrinsic unpredictability of the soil as well as the impact of water temperature fluctuations and construction operations. Emphasis should be placed on developing a subgrade CBR of at least 10. Previous studies have demonstrated that when the subgrade strength is below a CBR of 10, the subbase material experiences similar deflection to the subgrade when subjected to traffic loads; this deflection subsequently affects the pavement, initially affecting flexible pavements but eventually rigid pavements as well [12]. In fact, the subgrade is one of the most significant determinants of pavement performance. Achieving optimal subgrade compaction is a critical construction requirement that must be met in order to maximize the road's durability and minimize the thickness of the required pavement. In certain instances, subgrade compaction may not be of optimal quality, however, due to the diversity of soils utilized for subgrade and the difficulties associated with quantifying their properties. To achieve high quality subgrade, proper understanding of soil properties proper grading practices and quality control testing are required [6].

## 7. Laboratory Tests

The first step in quality control of roads is to test the efficiency of the subgrade soil. The laboratory test of the soil samples was performed on six tests. For each test the sample of the soil was taken from Al-Kadhimiya Corniche Street in Al-Kadhimiya area.

### 7.1 Sieve Analysis Test

The data from the grain size analysis test, which determines the proportion of each grain size in a soil sample, can be used to construct the grain size distribution curve [13]. The purpose of conducting sieve analysis in our study was to classify the soil. In this study, ten sieve sizes were used. The examination was performed in accordance with the ASTM D 422-63 standard. The initial procedure involved subjecting the soil sample to oven dehydrating. After that arrange the sieves in such a way that those with wider apertures are placed on top of those with smaller openings. Underneath the final sieve (#200), position a receptacle to collect the soil that passes through. It is essential to consistently include sieves #4 and #200 in the array. The soil sample was poured into the stack atop the sieve arrangement, and the stack was covered with the lid. By covering the tower of sieves with the lid, the soil can be poured from above. Ten to fifteen minutes after securing the clamps and inserting the stack into the sieve shaker, operate the shaker. The results from the test show that the soil of AL-Kadhimiya Corniche Street is sandy soil with a 91% percentage. When the shaker has stopped, the remained soil in the pan was weighted and the soil in all of the sieves. Table (1) Particle size distribution, table (2) sieve analysis results are shown below.

**Table (1):** Particle size distribution.

| Sieve | Opening size | Wt. Retained (gm) | Retaining % | Passing % |
|---|---|---|---|---|
| 2´´ | 50.8 | | 0.0 | 100 |
| 11/2 ´´ | 38.1 | | 0.0 | 100 |
| 1 ´´ | 25.4 | | 0.0 | 100 |
| 3/4 ´´ | 19.1 | 1.8 | 1.1 | 98.9 |
| 3/8 ´´ | 9.52 | 1.8 | 1.1 | 98.9 |
| No. 4 | 4.76 | 2.43 | 1.4 | 98.6 |
| No. 10 | 2 | 3.95 | 2.3 | 97.7 |
| No. 40 | 0.42 | 43.88 | 25.8 | 74.2 |
| No. 100 | 0.149 | 148.8 | 87.5 | 12.5 |
| No. 200 | 0.074 | 156.53 | 92.1 | 7.9 |

The results have been drawn as a relationship between the diameter of the sieve opening and the percentage finer as shown in Figure (2).

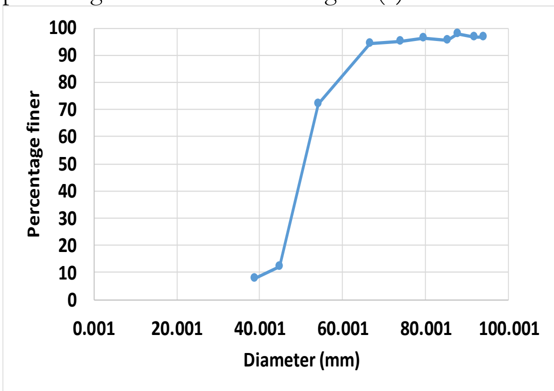


**Figure (2):** The relationship between diameter and percentage finer.

**Table (2):** sieve analysis results.

| clay | silt | sand | gravel | Pass #200 | $D_{10}$ | $D_{30}$ | $D_{60}$ | $C_u$ | $C_c$ |
|---|---|---|---|---|---|---|---|---|---|
| ---- | --- | 91% | 1% | 8% | 0.109 | 0.236 | 0.383 | 3.51 | 1.33 |

## 7.2 Specific Gravity Test

The specific gravity Gs of a soil is the ratio of the mass of a unit volume of a material at a stated temperature to the mass of the same volume of distilled water. Or the specific gravity of soil grains is unit weight of the solid particles to the unit weight of distilled water [14]. The test was performed according to ASTM D 854/02 specification. For accurate analysis, specifications require distilled or demineralized water and all water and material measurements must be performed at specified temperatures. During the process of determining the Gs, it is really important for the operator to ensure the air is removed out from the sample in order to get an accurate result [15]. The results from the test are shown in table (3) below.

**Table (3):** Specific Gravity test for soil.

| | |
|---|---|
| Pycnometer No | 5222 |
| Wt. of(Pycnometer+Water+Soil($W_1$) | 86.326 g |
| Wt. of (Pycnometer+Water($W_2$)) | 80.066 g |
| Wt. of soil ($W_s$) | 10 g |
| Specific gravity of liquid (GL) | 0.9683 |
| Specific gravity of soil (Gs) | 2.589037 |

## 7.3 Direct Shear Test

Direct shear test is a test used to measure the resistance of soil to deformation and sliding when loaded with direct shear force. This is done by loading a soil sample at an angle and applying a direct shear force to it using a special device [16]. Shear strength is the main engineering property of soil, which controls the stability of the soil mass under loads. Accurate determination of soil shear strength parameters (angle of internal friction and cohesion) is one of the main concerns in the design of various geotechnical structures [17]. This test was performed according to ASTM D 3080 – 11 specifications. The dimensions of the sample were (60*60*30) mm. The soil sample is placed in the shear box. A normal load is applied to the sample and the sample is sheared across the predetermined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement, and normal displacement are recorded. The test is repeated for two identical specimens under different loads. The shear box, also known as the shear ring, consists of two vertically stacked parts. The soil sample in the shear box is subjected to a predetermined vertical force (normal stress) by the direct shear machine. The shear machine holds the lower half of the shear box in place while applying a controllable horizontal force to move the upper half in one direction. The deformation and strength of the specimen are monitored and recorded until shear failure occurs. The weights used in this test for three samples are 1000 kg, 3000 kg, and 5000 kg. Figure 3 show Picture of a direct shear test device. And Figure 4 represents the relationship between the normal and the shear stress. The results Shear Strength parameters for Soil used in this test showed that angle of internal friction (ϕ) about 33 degrees and a cohesion (C) about 0.5 kN/m².


**Figure (3):** Direct shear test device.

**Table (4):** Direct shear test result.

| Sample No. | Normal stress (kN/m²) | Shear stress (kN/m²) |
|---|---|---|
| A | 27.24 | 13.10904 |
| B | 81.72 | 65.5452 |
| C | 136.19 | 82.50984 |

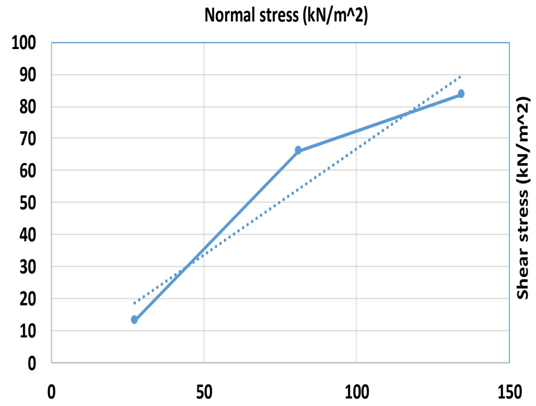


**Figure (4):** The relationship between normal stress and shear stress.

### 7.4 Compaction Test

Compaction is the process by which the soil's density is increased through the closer clustering of particles; in doing so, the air volume in the soil decreases but the water volume remains relatively constant. The aim of compaction is to expel air voids. The process of soil compaction involves the application of external forces by mechanical means of rolling, tamping or soil vibration. The extent of compaction is usually determined by finding the relationship between soil dry density and moisture content [18]. This is achieved by carrying a laboratory test on soil sample (Proctor Test), in which the varying volumes of water are added to the dried and sieved soil. The mixture is then compacted in a proctor mold. The soil is then trimmed at the top of the mould and weighed. The moisture content is determined by oven-drying while dry density is calculated from the bulk density and the moisture content. The test is repeated for several moisture contents and dry density is plotted against moisture content to obtain a curve in which the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) are obtained. According to the results obtained it was found that the optimum moisture content was 8.1% while the maximum dry density was 18.24 KN/m³, when the water content of the soil increases, the spaces between the soil particles decrease, which ultimately leads to a decrease in density. Determination of moisture content and dry density is shown in the tables (5, 6, 7) below; figure (5) the relationship between the dry density and the moisture content.

**Table (5):** Compaction test determination.

| | | | | | |
|---|---|---|---|---|---|
| Weight of mold and wet sample (g) | A | 5530.7 | 5599.3 | 5616 | 5592.5 |
| Weight of mold (g) | B | 3608.4 | 3608.4 | 3608.4 | 3608.4 |

**Table (6):** Moisture content determination.

| | | | | | |
|---|---|---|---|---|---|
| Weight of container and wet sample g | C | 206.1 | 200.1 | 208.9 | 200.4 |
| Weight of container and dry sample g | D | 200.1 | 192.6 | 198.8 | 189.5 |
| Weight of container g | E | 100 | 100 | 100 | 100 |
| Moisture content % w= 100((C-D) (D-E)) | W | 6.0 | 8.1 | 10.2 | 12.2 |

**Table (7):** Density determination.

| | | | | |
|---|---|---|---|---|
| Wet density g/cm³ $\gamma_w$ = (A-B) + 989.6 | 1.94 | 2.01 | 2.03 | 2.00 |
| Dry density g/cm³ $\gamma_d$ =γ | 1.83 | 1.86 | 1.84 | 1.78 |
| Dry density kN/m³ | 17.95 | 18.24 | 18.04 | 17.46 |

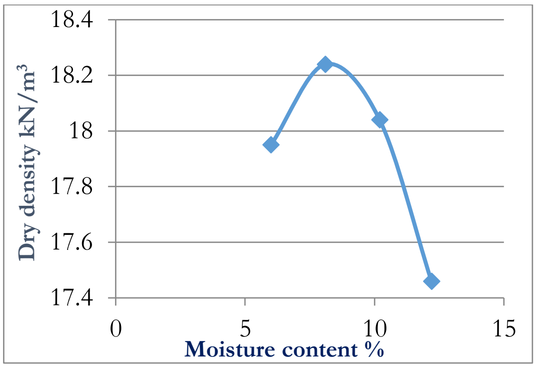


**Figure (5):** The relationship between the dry density and the moisture content.

### 7.5 California Bearing Ratio (CBR)

One of the most frequently used strength tests to assess the subgrade quality and suitability of soils for subbase and base courses in pavements is the California bearing ratio (CBR) test [19]. A laboratory experiment is to measure the pressure necessary to insert a needle of a certain diameter and a certain loading speed into a soil sample at specific values of water content and density and compare it with the results of a standard soil test [20]. The compacted specimens are immersed in water for four days before the penetration test. The soaking process is to simulate the worst moisture condition of the soil that may occur in the field. During this period, the sample is loaded with a surcharge load that simulates the estimated weight of pavement layers over the material tested according to ASTM D 1883 the sample was placed in five layers in the mold, and each layer was compacted 56 strokes. The load is applied by cylindrical metal plunger and readings of the applied load are taken at appropriate intervals of penetration. The California bearing ratio is calculated from the experiment curve by reading the stress value corresponding to penetration amounts equal to (2.5–5) mm, respectively, from the experiment curve, then calculating the percentage between the unit of the experiment loads and the loads necessary for the same penetration amounts in the standard sample. Table 8 relationship between CBR values and quality of subgrade soils, table (9) California bearing ratio test result are shown below.

**Table (8):** Relationship between CBR values and Quality of subgrade soils [21].

| CBR Values | Quality of subgrade soils |
|---|---|
| 0-3 | Very poor |
| 3-7 | Poor to fair |
| 7-20 | Fair |
| 20-50 | Good |
| >50 | Excellent |

The CBR ratio is calculated at penetration values of 2.5mm and 5mm using equation (1), Figure (5) the relationship between the penetration and the stress.

$$CBR=\frac{Test\ unit\ stress}{Standard\ unit\ stress}\times 100 \qquad \ldots(1)$$

**Table (9):** California bearing ratio test result.

| P.Ring factor | Area of plunger | Penetration (mm) | Stress (kPa) | Standard unit stress (kPa) | CBR% |
|---|---|---|---|---|---|
| 1.05 kg/Div | 19.4 cm² | 2.5 | 1797 | 6900 | **26.04** |
| | | 5 | 2483 | 10300 | **24.11** |

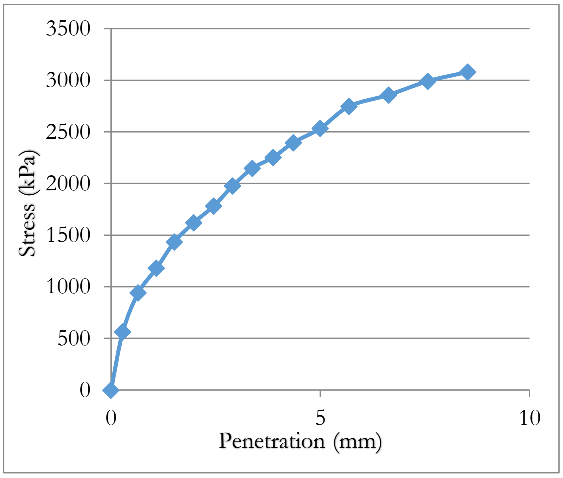


**Figure (5):** The relationship between the penetration and the stress.

### 7.6 Chemical Tests

Conducting chemical tests on subgrade soil constituted the last stage of the soil experimental work. The objective of these tests was to ascertain the characteristics of the soil, including its chemical constituents and any alterations that might impact the road's quality. The extent to which chemical tests ascertain the soil's susceptibility to erosion aids in determining the preventative measures required to ensure the road's longevity and avoidance of expensive repairs in the future. The chemical outcomes of soil analyses are detailed in table 10.

**Table (10):** The chemical results of the soil.

| Test | subgrade soil |
|---|---|
| $SO_3$ | 0.222 |
| pH | 8.55 |
| T.SS | 0.891 |
| CL | 0.085 |

## 8. Checking of Pavement Design

In this paper the software FAARFIELD is considered for checking the pavement design. FAARFIELD, an airport pavement specific software, is applied to the design of rigid and flexible pavements. Nevertheless, its methodologies and guiding principles are applicable to pavement in additional transportation sectors as well. By providing the requisite thicknesses for each pavement stratum, FAARFIELD empowers engineers to refine the design of pavements with the intention of enhancing durability and performance. It assists in determining which asphalt mixtures, materials, layer thicknesses, and elastic properties are optimal [22]. The process of pavement structural design entails the calculation of the component elements thickness. There are numerous determinants that impact the minimum pavement thickness required to guarantee satisfactory service. The aforementioned elements comprise the volume and pattern of traffic, the concentration of traffic in particular areas, the strength of the subgrade soil, the qualities of materials employed in the fabrication of the pavement structure, and the characteristics and magnitude of the stresses that necessitate support. In order to determine the required pavement thickness, a subgrade performance relationship that has been calibrated against the CBR method beforehand is utilized. The type of car was used for the design is Semi-Trailer Truck, (176,370 Kg). The result of the FAARFILED software gives a total thickness to the top of the subgrade (304mm). Figure (6) pavement layer design result by FAARFILED software (Flexible pavement), table (11) design inputs, table (12) pavement structure information by layer are shown below.

**Table (11):** Design Inputs.

| Design Inputs | | |
|---|---|---|
| ESALs Applications Over Design Period | W18 = | $4*10^6$ |
| California Bearing Ratio | CBR = | 26.04% |
| Subgrade Resilient Modulus | MR = | 39,000 psi |
| Design Life (Years) | DL = | 20 |

**Table (12):** Pavement Structure Information by Layer.

| No. | Type | Thickness (mm) | Modulus (MPa) | Poisson's Ratio |
|---|---|---|---|---|
| 1 | p-401/p-403 HMA Surface | 102 | 1,378.95 | 0.35 |
| 2 | p-401/p-403 HMA Stabilized | 127 | 2,757.90 | 0.35 |
| 3 | p-209 Crushed Aggregate | 75 | 438.56 | 0.35 |
| 4 | Subgrade CBR (26.04%) | | 269.31 | 0.35 |

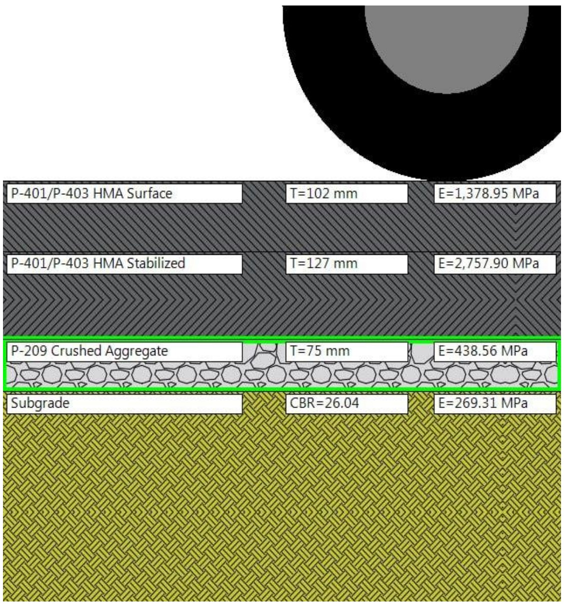


**Figure (6):** Pavement layer design result by FAARFILED software (Flexible pavement).

## 9. Results and discussion

Quality control of riverbank roads is a vital part of the road construction and maintenance process and aims to ensure infrastructure quality, safety and sustainability. Quality control begins from the planning stage. A comprehensive plan must be developed that specifies the standards and specifications that must be available in the final method. This includes specifying the components of the methods used, implementation methods, schedule, and required resources. From this research, the following results were reached:

**1.** The sieve analysis test results indicate that the soil in AL-Kadhimiya Corniche Street is 91% sandy soil., with a coefficient of uniformity (Cu) of 3.51 and a coefficient of curvature (Cc) of 1.33. The soil in this study is classified as poorly graded sand (SP).

**2.** The soil has a specific gravity of 2.589.

**3.** The results of the direct shear test indicated that the normal stress was approximately (27.24, 81.72, and 136.19) $kN/m^2$ and the shear stress was approximately (13.10904, 65.5452, and 82.50984) $kN/m^2$. The shear strength parameters for the three samples examined in this investigation revealed an angle of internal friction ($\phi$) of approximately 33 degrees and a cohesion (C) of approximately 0.5 $kN/m^2$ for the soil. Due to the extremely low cohesion of the soil, it is necessary to manage it by either compacting it or adding water in order to increase cohesion, or by employing materials that enhance cohesion.

**4.** The results of the compaction test indicated that the ideal moisture content was 8.1%, with a maximal dry density of 18.24 $kN/m^3$.

**5.** California Bearing Ratio (CBR) was 26.04%, it indicates good quality of soil as a subgrade.

**6.** The chemical tests showed that the soil sample contained a 0.085% chloride (CL) with PH value about 8.55 it indicates that the soil is generally alkaline and the percentage of TSS was 0.891% and the percentage of $SO_3$ was 0.222%. The results of these tests will help ensure the long-term stability, durability and safety of the riverbank road infrastructure.

**7.** The thickness design was carried out using subgrade CBR values of (26.04%) using FAARFIELD software, this program helps optimize pavement design to improve performance and durability. The total pavement thickness for subgrade was computed to be (304mm). The pavement structure consists of (102mm) of P-401/P-403 (Hot Mix Asphalt) HMA Surface, (127mm) of P-401/P-403 HMA Stabilized, and (75mm) P-209 Crushed Aggregate base course layer. The results give a good agreement with the actual design of Al-Kadhimiya Corniche Street, which was recently maintained during the field investigation in 2023.

**8.** Deterioration of roads and major repair costs can be avoided in the future through quality control and preventive maintenance of roads. This leads to cost savings in the long term. High quality roads and smooth surfaces contribute to improved traffic flow and reduced congestion. This saves time for passengers, increases productivity, and reduces fuel consumption and emissions.

## 10. Recommendations

Based on the results in the present work, the following recommendations were put forward:

**1.** It is recommended to conduct periodic inspections on river bank roads and updating maintenance plans to improve and renew the infrastructure.

**2.** It is recommended to adherence to specifications and standards in design and construction, providing continuous training for workers to improve quality standards and ensure their correct application.

**3.** It is recommended to laboratory tests must be performed by accredited laboratories and field testing must be performed by specialized supervisory staff.

**4.** It is recommended to enhance communication and cooperation between all parties concerned with roads, including supervising engineers, contractors, observers, and users, to ensure the continuous implementation of quality improvement plans.

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