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Subgrade Soil Properties and Their Impact on Asphalt Road Performance

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ABSTRACT

The road system is an important part of any country's social and economic growth since, it is vital that towns, areas, and neighborhoods should properly linked. The Pavement Condition Index (PCI), as established by ASTM D6433, will be used to evaluate the pavement condition of Qurna-Chibayish road in Basra Governorate, Iraq, and its connection to natural subgrade soil qualities.

The research includes visual (PCI) surveys as well as laboratory tests to evaluate subgrade soil characteristics, including grain size distribution, specific gravity, Atterberg limits, compaction, and California bearing ratio. The classification results of subgrade soil samples taken from (21) road sections reveal fine grained silty and / or clayey deposits with varied sand contents, according to the unified system, with AASHTO classes from (A-4) to (A-7). The soaked values of California Bearing Ratios (CBR) divided the soil sections into three, nearly equal groups: poor (CBR ≤ 5%); moderate (5 < CBR ≤ 10) and good strength (CBR > 10) conditions. The road evaluation process generally indicated satisfactory to good pavement conditions across most of the study area, where (53%) of the (PCI)-values fall within the range of (70 to 85) and (35%) within (85 to 100). Only (12%) received a fair rating with (PCI) lie between (55) and (70). It is evident from this study that, the Californian bearing ratio of the subgrade has a negligible effect on the pavement performance, as it is evaluated utilizing the pavement condition index. This is attributed to the addition of a fill layer that functions as a capping layer where the subgrade is greatly improved. Therefore, well designed and constructed pavement section would reduce the adverse effects of week subgrade soil and enhance high (PCI)-values.

1. Introduction

Road infrastructure is a basic point of any country’s economic and social progress, namely a vital connection between cities, regions, and communities. Roads are the mode of transport for both people and goods in countries (like Iraq) where other forms of transportation, such as planes, railways, and waterways, are either scarce or undeveloped. In this regard, good road quality is critical in ensuring proper traffic safety, minimizing the cost of operating vehicles, and supporting connectivity in the regions.

Roads play an undeniable role in Iraqi development; however, the current situation in the road network is excessive degradation. As reported, over 70% of the current roadway system is deteriorated, resulting from poor implementation of the Pavement Maintenance Management System (PMMS), insufficient funds, and a maintenance process that relies not on data but on subjective decisions. (Sarsam et al., 2009 and Khaleefah, 2019) [1], [2].

Successful prediction of pavement performance is important to the efficient management of surface transformation

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infrastructure. Usability of the pavement at the network level is an essential function for successful activity scheduling, project prioritization, and budget assignments. Remedial measures that have to be adopted at the project level, including maintenance & rehabilitation, have to be carefully identified (Prozzi et al., 2002) [3].

These challenges underscore the urgent need for systematic evaluation tools and predictive maintenance strategies. Among the most recognized tools for assessing pavement performance is the Pavement Condition Index (PCI) (Uglova et al., 2016 and Tighe et al., 2004) [4], [5], which quantifies the surface condition of pavements based on observable distresses.

The PCI method enables engineers to determine the appropriate maintenance or rehabilitation actions by analyzing the type, severity, and extent of surface distresses. This data was utilized to record current pavement condition, analyses historical performance, and forecast future pavement performance (Shahin, 1994) [6]. The PCI methodology was established by Engineers of the U.S. Army Corps in 1997 (ASTM, 2016) [7]. The PCI gives an objective determination as to maintenance and repair necessities and priorities. The rate of pavement deterioration is determined by continuous monitoring of the PCI that allows for early detection of significant restoration requirements as show in Table (1). The PCI offers a fair assessment and presentation of the pavement's overall state. (Shahin et al., 1990) [8]. PCI is an inexpensive way to compare overall pavement condition and rehabilitation needs. The pavement condition tends to deteriorate, as described by Figures (1). The new pavement has a long period where it maintains a good condition, but once it starts to fail, its condition drops rapidly (Weil, 2009) [9].

Table 1: Typical maintenance strategies based upon PCI-value [8].

PCI	Rating	Strategy
100-85	Good	Routine Maintenance
85-70	Satisfactory	Preventive Maintenance
70-55	Fair	Minor Rehabilitation
55-40	Poor	Minor Rehabilitation
40-25	Very Poor	Major Rehabilitation
25-10	Serious	Reconstruction
10-0	Failed	Reconstruction

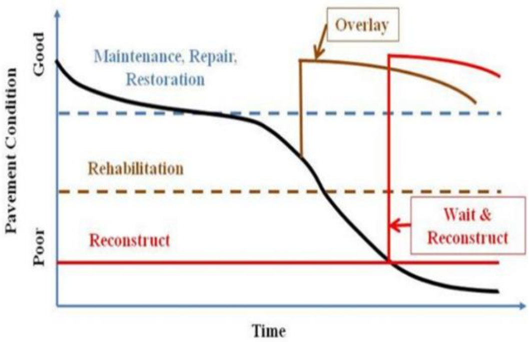

Figure 1: Relationship between pavement condition and time [10].

The functions pursued that were related to the evaluation of in-service pavement have one of their most important functions in pavement engineering. It is necessary to understand the state of pavement from the perspective of setting criteria for design and planning maintenance and priority (Yoder et al., 1975) [11]. It fulfilled several functions, including proving the necessity of including design criteria for operations and identifying specific situations that affected the overlay design. (Finn et al., 1984) [12].

Elkins (2013) [10] pointed out that pavement and highway agencies were worried about how the various data garnered from manual or visual reviews largely differ to the extent of influencing the way such agencies allocate public resources depending on arguable evaluation outputs. He diagnosed the problem of the variation of manual methods of data collection.

Timm et al., (2004) [13], disclosed the importance of pavement condition evaluation for the administration of road networks and brought to light its crucial role for anticipating future performance, estimating maintenance and rehabilitation (M & R) needs, determining maintenance and rehabilitation priorities, and enabling budget distribution.

Vishwanath et al. (2013) [14] employed the pavement condition index as a measure to delineate pavement repair options following a distress survey. A method was provided to construct the (PCI) distribution for selected arterial road segments to implement cost-effective maintenance strategies. A conclusion was drawn that, early detection of significant repairs required may serve as a warning system via PCI. The effects of distress kind, density, and degree on (PCI) were also determined.

Zubaidi et al. (2023) [15] studied and presented a comprehensive evaluation of pavement distress and its implications on traffic sustainability within Al-Diwaniyah city, Iraq, using the pavement condition index. The study focused on five districts with high accident rates: Al-Askari (PCI = 52.1, Poor), Al-Wahda (PCI = 57.6, Fair), Al-Jamhouri (PCI = 67.2, Fair), Al-Urouba (PCI = 70.7, Fair), and Al-Jazaer (PCI = 73.7, Satisfactory). It was found that poor pavement conditions and high accident rates are directly correlated. The highest number of crashes was reported in Al-Askari district, which had the lowest PCI-value. The significance of pavement condition for traffic safety was highlighted by the fact that crash frequencies were lower in even districts with marginally higher-PCI values.

The impact of subgrade non-uniformity on the reaction of PCC pavement and on the long-term performance of old roads was studied by White et al. (2005) [16]. They realized that, non-uniform subgrade soils amplify local deflections and stresses in PCC pavements, hence aggravated the tendency towards fatigue cracking, pumping, rutting, faulting, and other problems. The study proposed an inverse relation between pavement performance and non-uniformity of subgrade. It was also concluded that, the subgrade uniformity is considered a significant aspect for enhancing pavement long term performance.

Ahmed et al. (2008) [17] conducted a comprehensive field and laboratory investigation to evaluate the impact of water content of subgrade soil and other geotechnical characteristics on pavement performance. Pavement distresses were surveyed, and the (PCI) was determined for a large number of agricultural road segments, followed by collection of subgrade soil samples to analyze their influence on pavement behavior during service. The results indicated that increased water content of subgrade soils, particularly from external sources, significantly affected pavement conditions and that differential settlements due to elevated water content were major contributors to pavement cracking and eventual structural failure.

Hassanin (2019) [18] discussed the impact of subgrade soil non-uniformity on pavement performance. The field and laboratory experiments were supported by a data collected from the early investigations of the dualization project for the Qena-Luxor West desert route in Egypt. This route opened access to a wide range of soil types within the depth of the subgrade soils. There was an enormous effect of variance in subgrade carrying capacity on pavement performance. Associating the subgrade bearing capacity, as expressed by CBR), and pavement performance, as measured by the (PCI), was not practicable since, an unacceptable value of (R^2 = 0.6281) was predicted for this relationship. This was attributed to the numerous other factors that influenced pavement performance.

2. Methodology

Basrah governorate is selected as the research area, as it represents the economical capital of Iraq. It is located in the Southern part of the country. The geographical location of this governorate lies between longitudes (48.8o to 74.5°) and latitudes (29.3° to 30.7°). The chosen route for research is situated inside one of the most significant thorough-fares in the Northern region of Basrah, encompassing both urban and rural zones characterized by various pavement kinds and diverse forms of distress.

Al-Qurna-Chibayish road is considered as one of the important roads connecting the Northern districts of Basra with Thi-Qar Governorate. It is more than (45 km) long and (8 m) wide. In (2015), the road was officially opened following the completion of its construction, which involved elevating the roadway through a two-layer backfilling process, with each layer having a thickness of (30 cm). The lower layer consisted of Type (C) mixed gravel with sand, placed and compacted in two stages. The upper layer was made of Type (B) mixed gravel with sand also constructed in two stages (Iraqi Standard Specifications for Roads and Bridges, 1983) [19]. Subsequently, a base layer composed of crushed stone with a total thickness of (30 cm) was laid in two layers. The pavement structure was then completed with a (6 cm) asphalt binder course, followed by a (5 cm) asphalt surface course.

The study was conducted on about (10.5 km), from the left of the Al-Ezz river to the Madinah bridge. This distance was divided into sections; each section is (500 m) long. A soil sample was taken from every section, and the PCI value was also predicted.

2.2 The Pavement Condition Index

Pavement condition index measurement is often a good instrument for pavement evaluation. The (PCI) is a number indicating pavement surface quality, and a functional performance only would indicate the structural stability of the pavement surface. (PCI) values vary from (100) for a pavement devoid of defects to (0) for a pavement that has reached the end of its useful lifespan. The measure is useful in the characterization of suffering and easy comparison of pavements. (PCI) surveys are included in ASTM- D6433.

Site investigations were conducted in Al-Madinah on the Al-Qurna-Chibayish Road to gather essential data on pavement distress. The road was divided into 21 sections based on consistent features observed along its entire length. The pavement condition was evaluated through visual inspection and field measurements. All data, measurements, and estimated Pavement Condition Index (PCI) values were summarized in data sheet (figure 2) that served as inspection records for the road. It is worth noting that four sections were excluded from the distress survey due to ongoing maintenance activities.

Asphalt surfaced roads and Parking lots
Condition survey data sheet for sample unit

Branch ——— Section ——— Sample unit ———
Surveyed by ——— Date ——— Sample area ———

1. Alligator cracking	6. Depression	11. Patching &Utility patch	16. Shoving
2. Bleeding	7. Edge cracking	12. Polished Aggregate	17. Slippage Cracking
3. Block cracking	8. Jt Reflection cracking	13. Potholes	18. Swell
4. Bumps and sags	9. Lane/ shoulder drop off	14. Railroad crossing	19. Weathering / Raveling
5. corrugation	10. Long & Trans cracking	15. Rutting	

Distress severity	Quantity										Total	Density %	Deduct Value

Figure 2. Data Sheet for Flexible Pavement Condition Survey [7].

2.3 Grain size analysis

1-Sieve Analysis

Sieve analysis is a method of separating soil particles by shaking it over a set of sieves having progressively smaller openings (Table 2)

Table 2: Sieves openings.

Sieve No.	4	10	40	100	200
Aperture Size(mm)	4.75	2	0.425	0.15	0.075

Sieve analysis was performed on all the collected soil samples, revealing that the majority were classified as fine soils, with a few exceptions that exhibited sandy characteristics and, in addition, oyster shells.

2-Hydrometer

Hydrometer analysis is the process of sedimentation in which particles are permitted to settle under the influence of gravity. The principle is founded on the observation that larger particles in a water suspension settle at a faster rate compared to smaller particles, provided that all particles share comparable densities and shapes as reported by Stokes (1891) and cited by ASTM (2021) [20]. Specific measurements taken at established time intervals can evaluate the particle size distribution. The hydrometer test is applied to find out the distribution of grain size of fine-grained soils having particle sizes less than (0.075 mm). especially when over (10%) of the soil passes through the (# 200) sieve.

2.4 Atterberg limits

The liquid limit (LL) is the percentage of water applied in a standard cup, and a groove of a precise diameter so that a pat of soil in the cup and in the groove will start flowing together at the groove's base, at a distance of (13 mm = 1/2 in.) after the cup is plumped down (25) times at a rate of two shucks per sec in a standard liquid limit instrument. The plastic limit (PL) is the percentage water content at which a soil will no longer deform to (3.2 mm = 1/8 in.) diameter threads without fragmenting. The tests are conducted according to (ASTM-D 4318).

2.5 Specific gravity

Specific gravity is the mass ratio of a soil unit volume at a particular temperature to the mass of an equivalent volume of gas-free distilled water at the same temperature. Soil samples are tested according to (ASTM-D 854).

2.6 Water-density relation (compaction) test

In order to find the correlation between dry density and water content in soil at a specific level of compaction effort, the modified Proctor test, method (A) is conducted under a compaction effort of (2,700 kN-m/m3), according to (ASTM-D 1557).

2.7 California bearing ratio (CBR)

It is the percentage of force to unit area needed for a plunger of cylindrical of (50 mm) diameter to penetrate into a soil sample a distance of (1.25 mm), to its counterpart achieving the same penetration into the crush stone. The tests are carried out on natural and soaked samples according to (ASTM-D 1883).

3. Results and discussion

3.1 Soil Classification

Soil classification requires conducting sieve and hydrometer analyses, and predicting the consistency (Atterberg) limits. Table (3) presents the values of specific gravity (Gs), liquid limit (LL), plastic limit (PL), plasticity index (PI), the results of grain size distribution and soil classification.

According to the USCS, the majority of the samples are classified as fine-grained, particularly consisting of silts (ML) and lean clays (CL), with varying amounts of sand, while some exhibit transitional classifications, such as CL-ML (silty clay) and SC-SM (silty, clayey sand).

The AASHTO classification supports these findings, indicating that numerous soils are classified within the A-4 and A-6 groups, which imply fair to poor subgrade materials.

Table 3: Results of Classified Tests.

No.	Gs	L.L.	P.L.	P.I.	Particle Size Analysis % Sand	silt	Clay	USCS Symbol	Description	AASHTO (GI)
1	2.63	24	17	7	45.4	54.6	0	CL-ML	sandy silty clay	A-4(1)
2	2.78	26	19	7	21.9	78.1	0	CL-ML	silty clay with sand	A-4(4)
3	2.78	25	21	4	15.6	61.4	23	CL-ML	silty clay with sand	A-4(2)
4	2.7	24	20	4	54.5	45.5	0	SC	clayey sand	A-4(0)
5	2.7	41	26	15	3.3	96.7	0	ML	Silt	A-7-5(17)
6	2.78	39	21	18	10.94	89.06	0	CL	lean clay	A-6(16)
7	2.78	37	26	11	10.28	89.72	0	ML	Silt	A-6(11)
8	2.7	40	20	20	3.06	88.94	8	CL	lean clay	A-6(21)
9	2.7	32	19	13	33.6	46.4	20	CL	sandy lean clay	A-6(7)
10	2.78	40	20	20	9.44	90.56	0	CL	lean clay	A-6(19)
11	2.78	22	16	6	2.06	92.94	5	CL-ML	silty clay	A-4(4)
13	2.78	31	25	6	25.16	74.84	0	ML	silt with sand	A-4(4)
14	2.78	27	20	7	39.16	51.84	9	CL-ML	sandy silty clay	A-A(2)
15	2.78	46	23	23	1.82	80.18	18	CL	lean clay	A-7-5(25)
16	2.7	-	-	-	62.16	37.84	0	SM	silty sand	A-4(0)
17	2.7	-	-	-	42.24	57.76	0	ML	sandy silt	A-4(0)
18	2.63	-	-	-	51.18	48.82	0	SM	silty sand	A-4(0)
19	2.63	34	29	5	16.1	83.9	0	ML	silt with sand	A-4(5)
20	2.7	42	24	18	1.32	78.68	20	CL	lean clay	A-7-6(20)
21	2.63	47	29	18	10.94	89.06	0	ML	silt	A-7-6(19)

3.2 California Bearing Ratio

The results of compaction and CBR tests are listed in (Table 4). The optimum water contents for soils with a significant sand content are lower than their counterparts for silty clay soils. Specifically, the optimum water content for sandy soils ranged between (8.5%) and (11.5%), while for silty clay soils, it ranged between (11% and 16%). Regarding the soaked (CBR) values, the soil samples were classified into three groups with: low value (CBR ≤ 5%); moderate value (5% < CBR ≤ 10%); and high value (CBR > 10%).

Table 4: Results of compaction and CBR tests.

No.	O.W.C %	ρ_{dry} (g/cm^3)	Un-soaked CBR (%)	Soaked CBR (%)	No.	O.W.C %	ρ_{dry} (g/cm^3)	Un-soaked CBR (%)	Soaked CBR (%)
1	8.5	1.92	44.3	13.3	11	15.2	1.84	34.6	10.4
2	11	2	31.4	9.4	13	13.4	1.9	38.4	11.5
3	11	1.93	9.3	2.8	14	11.4	1.87	29.2	8.8
4	11.5	1.87	29.5	8.8	15	13.9	1.87	14.8	4.4
5	14.3	1.82	16.0	4.8	16	8.7	1.93	33.9	10.2
6	11	1.93	42.1	12.6	17	11.5	1.85	34.0	10.2
7	15	1.79	26.6	8.0	18	11.4	1.92	15.7	4.7
8	14	1.87	8.9	2.7	19	16	1.71	32.8	9.8
9	12.9	1.91	36.6	11.0	20	15.5	1.81	21.9	6.6
10	15.5	1.87	16.2	4.9	21	16	1.8	12.4	3.7

3.3 PCI calculation results

The results of the PCI analysis, based on both field surveys and collected data, indicate that the pavement condition ratings ranged from fair to good. Specifically, two sections were rated as fair, nine sections were rated as satisfactory, and five sections was rated as good.

Table 5: PCI values and the corresponding rankings for each section.

No.	PCI	Rating	No.	PCI	Rating
1	91.5	Good	10	82	Satisfactory
2	74	Satisfactory	11	76	Satisfactory
3	84	Satisfactory	16	89	Good
4	84	Satisfactory	17	75	Satisfactory
5	84	Satisfactory	18	90	Good
6	82	Satisfactory	19	90	Good
7	66	Fair	20	94	Good
8	63	Fair	21	92	Good
9	74	Satisfactory			

3.1 Correlating PCI to CBR

The resulting pavement condition indices and subgrade soaked Californian bearing ratios are statically analyzed utilizing (SPSS) software. A Pearson correlation of (0.039) showed a weak relationship between CBR and PCI. The significance level is (0.882), much is over the (0.05) limit. There is no significant association between the variables. The simple linear regression results supported this finding, where the coefficient of determination (R^2) is just (0.0015), meaning that (CBR) explains only (0.15%) of the variation in (PCI), (Figure 3). Also, the analysis of variance (ANOVA) test for the regression model gave a p-value of (0.882), indicating that the model lacked statistical validity.

The correlative relation obtained from regression analysis is:

$$PCI=80.966+0.105\times CBR \quad (1)$$

However, the slope of the equation (0.105) was not statistically significant. This confirms that (CBR) has no meaningful effect on PCI in this case.

Theoretically, the (PCI) values should be proportional to the subgrade (CBR), meaning that stronger soil would create better and longer-lasting pavement, leading to higher (PCI) scores. However, the current findings are not compatible to such an expected behavior. This is similar to the conclusion drawn by Hassanin (2019) [18]. This discrepancy could be attributed to the added fill layers used to increase the road level since they work as a capping layer. In addition to that, the good design and construction of pavement structure attenuate the stresses (due to traffic loads) reaching the natural subgrade soil.

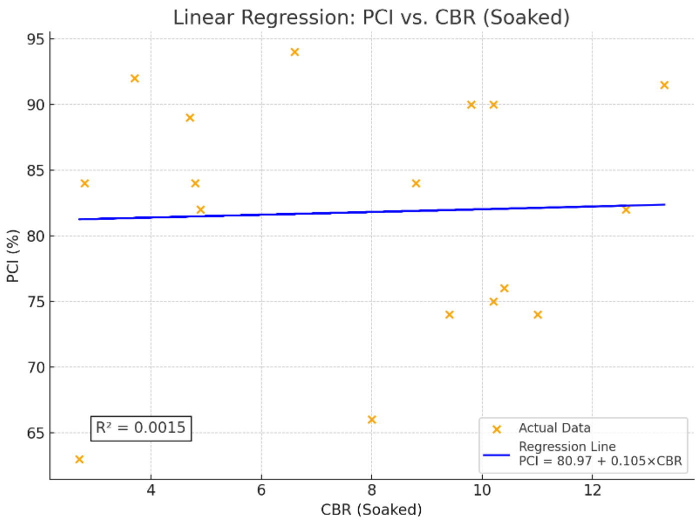

Figure 3: Linear regression: PCI vs. CBR.

4. Conclusions

1. Most of the natural subgrade soils are fine grained silty or clayey soils with varying amounts of sand. The (AASHTO) system classified most of soil samples between (A-4) and (A-6).

2. The results of (CBR) tests on soaked samples divided them into three equal classes of low (CBR ≤ 5%), moderate (5% < CBR ≤ 10%) and high values (CBR > 10%).

3. The pavement condition index for most sections ranged from (74) to (94), indicating satisfactory to good rating.

4. Visual surveys indicate that bleeding, depression, lane / shoulder drop-off, patching & utility cut patching, potholes and rutting, are the most prevalent pavement distresses in

the research area. The results of a sensitivity study indicate that pot-holes have the most significant impact on the (PCI) value.

5. The total visual survey results indicate that, the severity of pavement distresses across the study area is generally moderate, with the exception of bleeding in two sections.

6. The results indicate that, the soaked (CBR) value is not a reliable indicator for estimating the pavement condition index within the dataset of this study. This is due to the effects of adding a capping layer and good design and construction of flexible pavement structure.

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