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Evaluation of runways for Al-Habbaniya air base in Iraq

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Abstract

This study investigates both the concrete and asphalt runway sections to assess their mechanical and chemical deterioration. Defects and material degradation affected the asphalt and concrete layers, overall safety and performance of the airbase runway pavement structure evaluation. Al-Habbaniya Air Base is located in Al-Anbar Governorate, approximately 74 km west of Baghdad, near the Euphrates River and Habbaniya Lake. Several recent studies [1] highlighted the effect of sulfate attack and moisture susceptibility on airfield pavements under hot climates. Several layers of extensive field and laboratory tests, core sample testing, compressive strength checks, and Dynamic Cone Penetrometer (DCP) illustrated issues including blowups, cracking, moisture damage, and chemical-induced deterioration. The subgrade soil had high sulfate and gypsum content, further accelerating the deterioration, which poses a significant risk to the durability of the pavement. This study in Al-Habbaniya Air Base describes the primary defects presented, the effect of both chemical and mechanical properties on structural stability, and the measures needed to comply with ASTM standards. These findings emphasize the importance of prevention, better material selection, and redesign to secure the functionality of a runway in extremely hostile environmental and operating conditions. Core sampling revealed significant loss of strength in concrete (≈ 12–29 MPa) and noticeable moisture damage in asphalt layers.

1. Introduction

One key component of the airport infrastructure is the structural integrity of the runways, which is vital for safety and can be compromised over time by stress and environmental factors during service life. Several major causes of runway failure as identified in the literature include heavy and repetitive loads, high temperature, and aging related to deterioration. In this study, the evaluation focuses on identifying major distress types, understanding their causes, and proposing rehabilitation strategies specific to Al-Habbaniya Air Base. This study aims to evaluate the structural and material performance of Al-Habbaniya Air Base runways under harsh sulfate-rich and hot climatic conditions. The scope of the work includes field investigations, laboratory testing, and correlation of chemical composition with mechanical deterioration. The novelty of this research lies in integrating field DCP–CBR data with chemical analysis to understand sulfate-induced degradation mechanisms in Iraqi airbase pavements. Several international studies [1,2], [3] have examined runway evaluation and sulfate-induced deterioration in hot climates. However, limited research has focused on Iraqi airbases where high sulfate and gypsum contents coexist with extreme temperatures. This study fills this gap by integrating field and laboratory data to evaluate the combined effects of chemical and mechanical deterioration on runway performance and propose sustainable rehabilitation measures.

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1.1 Effects of Aircraft Loads on Runway Performance

While heavy aircraft can exert an amount of load on a runway pavement that exceeds its design capacity, the pavements are designed to resist controlled and predictable high value stresses, particularly during the aircraft takeoff and landing phases. These overloads lead to surface/dynamic cracking, reflective cracking, and might even fail in the subgrade layers [4]. Permanent deformation takes place under repeated application of loads in restricted locations such as touchdown zones, which weakens the pavement structure over time [5]. Moreover, the gradual pressures on the wheels characteristics of the landings introduce additional horizontal stresses that contribute to surface wear and compromise the structure [6].

1.2 Effects of Thermal on Runway Material

High temperature is also another important factor that impacts the runway performance. Thermal stress induced by thermal expansion, particularly in asphalt pavements, can result in serious tension that can cause cracking and shrinkage when this surface cools down [7]. Prolonged exposure to high temperatures softens asphalt and increases the risk of permanent deformations and ruts created by concentrated loads. Subgrade and base layers can lose strength due to high temperatures which can affect their contribution to load sharing and in some cases total runway durability.

1.3 Aging and Long-Term Material Degradation

Environmental factors, such as ultraviolet (UV) radiation, and moisture ingress, cause the natural deterioration of runways materials over time. These conditions aggravate asphalt brittleness and concrete pavement surface erosion [9]. Over time, the accumulated fatigue stress caused by cyclical loading results in the formation and expansion of microcracks, compromising the structural integrity of the pavement [8]. This problem is further exacerbated due to poor maintenance, as minor defects once ignored or overlooked can lead to high prevalence of structural and functional failures, causing the functional life of the runway to greatly reduce [11]. Airbase runways are important infrastructures that can withstand heavy loads over time, extreme weather, and high traffic. However, with aging, environmental factors, and operational stress, these pavements suffer significant wear and tear over time. The study concentrates on the structural evaluation of runway pavements, where critical defects in asphalt and concrete layers were highlighted and the potential factors contributing to them were investigated. It was found that the concrete pavements had severe distresses including blowups, punchouts, and corner breaks, generally caused by thermal expansion (especially from the top), overloading, and lack of support condition [11]. These tests on core samples (Concrete and asphalt layers thickness varies from 0.28 to 0.3 m according to Table 4) showed that compressive strength of the concrete had failed throughout the structure, indicating material degradation and mix design issues. Likewise, asphalt pavements were observed for surface irregularities, aging, oxidation, and moisture damage as well as functional and structural conditions leading to premature distress and/or early failure [9].

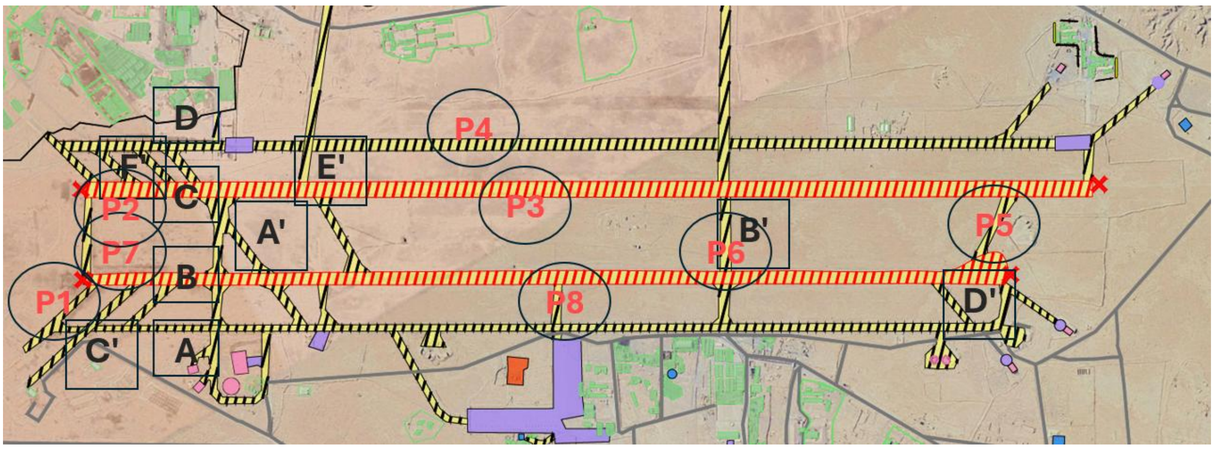

Fig. 1. Site plan of Habbaniya air base

This study intended to clearly document these defects and assess their effect on runway performance, as well as to provide remediation strategies to meet the industry standard and prolong the service life of the pavements. Al-Habbanyia Air is located in Al-Anbar Province, approximately 74 km west of Baghdad, near the Euphrates River and Habbaniyah Lake, which has two runways (North runway is 4 km length composite of concrete and asphalt, south runway one is 3.7 km length composite of concrete and asphalt), see Figure 1. Also, the main aims of this study are to document these defects exhaustively, evaluate their influence on the performance of the affected runways, and recommend remedial methods and techniques to maintain the pavements within the industry-engineering and serviceability standards, and extend their service life.

2. Methodology

2.1 Pavement Evaluation

Although the main experimental procedures were described, additional details were included to improve transparency and reproducibility. Sampling points were selected based on observed surface distresses along both runways and taxiways. Each test type (CBR, DCP, compressive strength, and moisture susceptibility) was performed in triplicate, and the average values with standard deviations were reported. All tests followed ASTM and FAA standards, including ASTM D1883 for CBR, ASTM D4867 for moisture damage, ASTM C42 for concrete cores, and ASTM D6951 for DCP testing.

A series of tests were conducted to assess the condition of the asphalt and concrete layers:

- Material Sampling: Extraction and laboratory analysis of core samples.
- Dynamic Cone Penetrometer (DCP) Tests: Evaluated the subgrade's strength.
- Moisture Damage Analysis: Assessed the impact of water infiltration according to Table (2).

2.2 Runway Distresses

During the evaluation of the runway, several defects and signs of distress were identified in the asphalt and concrete layer. These findings are critical in understanding the extent of the damage [11].

2.3 Asphalt Pavements Distresses

The evaluation revealed significant distress in the asphalt layers, including alligator or fatigue cracking, characterized by interconnected cracks resembling alligator skin caused by repeated traffic loading. These cracks, originating from the bottom layer and extending to the surface, often require reconstruction in severe cases [11]. Block cracking, another common defect, is primarily caused by asphalt shrinkage and temperature fluctuations, resulting in rectangular patterns unrelated to traffic loads but varying in severity. Corrugation, or wash boarding, was identified as closely spaced ridges and valleys perpendicular to traffic direction, caused by unstable pavement or subbase layers. Reconstruction is necessary to meet ASTM standards, Figure 2.

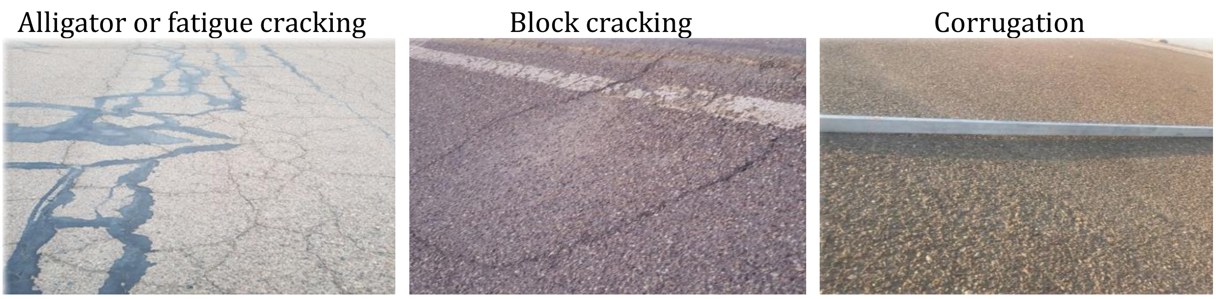

Fig. 2. Asphalt pavements distresses

Longitudinal and transverse cracks, indicative of sub-structural concerns, were noted. Potential longitudinal cracks are appearing along the direction of the pavements which are connected to bad quality in construction or material deterioration, while transverse cracks where emerged induced by temperature stress. Other repairs, like patching and utility cut patching, are all noted as defects, since they generally show roughness and will deteriorate much faster than the original pavement, which has an impact on ride quality. Traffic wear results in polished aggregate, creating a smooth surface that decreases skid resistance and decreases vehicle traction, Figure 3.

Fig. 3. Problems of asphalt runways

Swelling, identified by upward bulges in the pavement, is caused by swelling soil, leading to surface deformation and cracking. Lastly, raveling and weathering were prevalent, with surface degradation attributed to asphalt aging, poor-quality mixtures, or environmental factors like oil spills, resulting in the loss of aggregate particles and compromised pavement performance, Figure 4.

Fig. 4. Soil and weather problems

2.4 Concrete Pavement Distresses

The evaluation of concrete pavements at the runway revealed several significant defects [12]. Instances of blowup or buckling were observed, particularly during hot weather, caused by insufficient expansion space due to incompressible materials infiltrating joints. This results in upward slab movement and deformation, requiring immediate intervention. Divided slabs were another common defect, where slabs fractured into multiple pieces due to overloading or inadequate support. Repairs ranged from sealing cracks to full slab replacement. Faulting was identified across several joints, characterized by elevation differences between slabs, caused by foundation settlement or erosion. Slabs with significant elevation differences require recasting, Figure 5.

Fig. 5. Concrete pavement distresses

- Linear cracking in the form of longitudinal, transverse, and diagonal cracks was observed, often caused by repeated loads, thermal gradients, and moisture. Low-severity cracks posed minimal risks, but medium-to-high severity cracks were structurally significant.

- Large patches and utility cut repairs exceeding 5 square feet were found, often deteriorating faster than original pavement. Severe cases require recasting to meet ASTM standards.
- Punchouts, or localized slab fragmentations were common near cracks and joints, often resulting from repeated heavy loads and insufficient slab thickness. These necessitate recasting, Figure 6.

Linear cracking | Large patches | Punchouts

Fig. 6. Types of cracks and patches in runway slab

Corner spalling was identified as deterioration near slab corners due to stress and material degradation. Partial-depth patching was recommended for minor cases. Similarly, joint spalling, occurring along slab edges, was caused by traffic stresses, material infiltration, with repairs ranging from patching to joint reconstruction. Lastly, vegetation growth in cracks indicated possible water infiltration and soil salinity issues, suggesting inadequate drainage and potential structural instability. Comprehensive repairs and preventive measures are recommended to mitigate these distresses, Figure 7.

Corner spalling | Joint spalling | Vegetation growth

Fig.7. Stress and material

3. Extraction and Laboratory Analysis of Core Samples

3.1 Asphalt Core Sampling

These tests are essential for evaluating the structural integrity and quality of the pavement [13]. The data provides insights into the core samples' condition, helping us assess whether the pavement meets the required standards, in regarding the asphalt, 18 cores were extracted from the main runways, taxiways, and branch runways as shown in Figure 8.

Core sampling | Asphalt test | Compressive

Fig. 8. Sampling and tests

Table 1. Number, types and the stability of layers for the asphalt pavement

Location		No. of layers	Type of each layer	Thickness of each layer (cm)	Stability (kN)
Taxiway 1 (A)	A1	1	Surface	5.5	6.72*
		2	Binder	9.2	6.43*
		3	Base	14.8	5.22
	A2	1	Surface	6.1	8.43
		2	Binder	6.2	6.10*
		3	Base	13.5	5.29
	A4	1	Surface	10	7.90*
		2	Base	8.5	5.23
	A5	1	Surface	7	6.88*
		2	Base	7.6	4.56*
	A6	1	Surface	8	8.14
		2	Base	7	3.22*
	A7	1	Surface	7.2	8.45
		2	Base	7.9	4.33*
	A8	1	Surface	8.8	8.34
		2	Base	7.4	5.41*
Runway 1 (B)	B3	1	Surface	6.7	3.22*
		2	Binder	7.6	3.98*
		3	Base	11.5	2.87*
	B4	1	Surface	5.5	4.45*
		2	Binder	8	5.76*
		3	Base	6.7	4.84*
	B5	1	Surface	14.1	5.37*
		2	Base	15.4	3.67*
	B6	1	Surface	10.8	6.90*
		2	Base	10.4	5.42
	B7	1	Surface	11.1	8.12
		2	Binder	4.5	7.11
		3	Base	3.8	4.17*
	B8	1	Surface	7	6.43*
		2	Binder	10	7.56
		3	Base	15.3	5.64
Runway 2 (C)	C5	1	Surface	4.5	7.09*
		2	Binder	7.6	7.15
		3	Base	9.3	5.45
	C6	1	Surface	11.5	5.65*
		2	Binder	9.5	5.28*
		3	Base	8.2	2.43*
Intersections (Branch Runways)	Ć	1	Surface	10.2	8.11
		2	Binder	10	6.21
		3	Base	10.7	5.32
	É	1	Surface	7.1	7.25*
		2	Binder	7.8	7.98
		3	Base	14.1	5.80
	F́	1	Surface	5	6.56*
		2	Base	11.5	4.43*

The core samples taken from the runway were subjected to compressive strength tests, and the results indicated significant failures as shown in Table 1. Most of the cores did not meet the required standards for compressive strength, with additional failures observed in stability and moisture content. These issues highlight critical concerns regarding the material quality and overall structural integrity of the runway. The results of analysis of pavement layers, Figure 9 and the effect of moisture damage in asphalt pavement is given in Table 2.

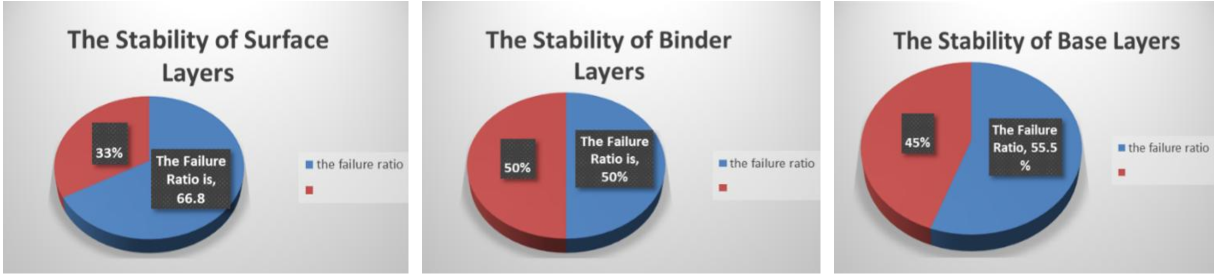

Fig. 9. Charts explain the types of layers failure ratio

Table 2. The effect of moisture damage in asphalt pavement according to ASTM D4867/D4867M

Location	Moisture damage, %	Specification limits
Taxiway 1 (A)		
A1	80	MIN. (80%)
A2	68*	
A4	76*	
A5	82	
A6	81	
A7	54*	
A8	61*	
Runway 1 (B)		
B3	66*	
B4	54*	
B5	80	
B6	81	
B7	63*	
B8	64*	
Runway 2 (C)		
C5	81	
B4	70*	
Intersections		
Ć	81	
É	80	
F́	74*	

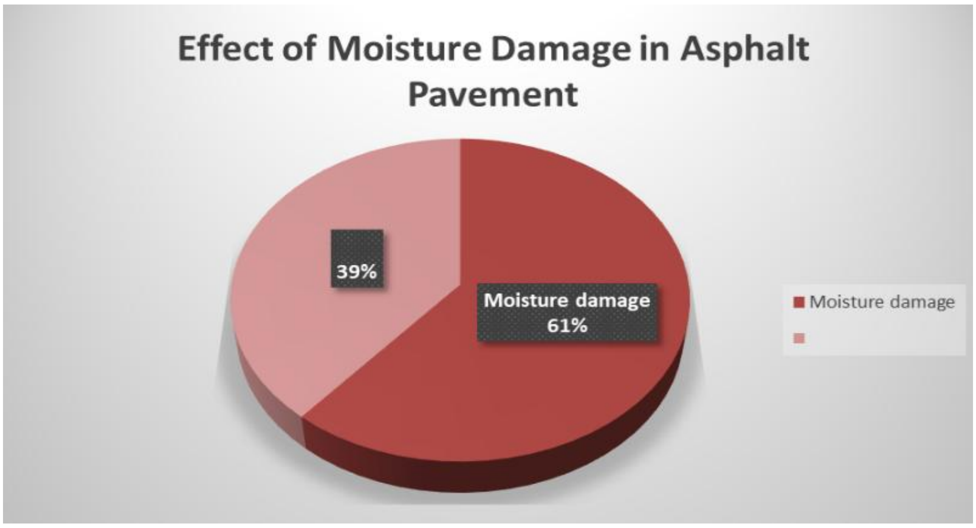

Fig. 10. The effect of moisture damage in asphalt pavement

3.2 Concrete Core Sampling

In regarding the concrete, 12 cores were extracted from the main runways, taxiways, and branch runways. Concrete core sampling test was conducted as well, it involved extracting cylindrical samples to analyze the material composition and condition and for further laboratory analysis to assess material quality and perform the necessary physical and chemical laboratory test, Figure 11 [14]. The compressive strength results shown in Table (3), which range from 11.95 MPa to 29.01 MPa, indicate that most of the samples do not meet the required standards for concrete used in runway construction. The majority of the values fall below the acceptable threshold, suggesting that the concrete is generally weak.

Fig. 11. Cores are being tested

Table 3. Data collected of the concrete core samples

Specimen No.	Area of Sample (mm^2)	L/D	Correction Factor	Compressive strength (MPa)	Modified comp. strength for L/D ratio	Equivalent modified comp. strength of cube	Corrected factor for bars	Final compression strength (MPa)
1	7850	1.25	0.9328	21.15	19.73	29.01	1	29.01
2	7850	1.25	0.9328	10.74	10.02	14.73	1.13	16.65
3	7850	2	1	14.61	14.61	21.49	1.13	24.28
4	7850	1.4	0.9511	9.90	9.41	13.84	1	13.84
5	7850	1.2	0.9269	19.11	17.71	26.05	1	26.05
6	7850	2	1	18.06	18.06	26.56	1	26.56
7	7850	2	1	14.60	14.60	21.47	1	21.47
8	7850	2	1	13.15	13.15	19.33	1	19.33
9	7850	2	1	16.31	16.31	23.98	1	23.98
10	7850	1.42	0.9522	8.54	8.13	11.95	1	11.95
11	7850	1.5	0.9615	13.80	13.27	19.51	1	19.51
12	7850	2	1	19.40	19.40	28.53	1	28.53

3.3 Dynamic Cone Penetration Report (DCP) and Sawed Concrete Cores Results

The Dynamic Cone Penetrometer (DCP) (shown as schematics in Figure 12) consists of two 16-mm (5/8-inch) diameter shafts coupled near midpoint. The lower shaft contains an anvil and a pointed tip which is driven into the soil by dropping a sliding hammer contained on the upper shaft onto the anvil. The underlying soil strength is determined by measuring the penetration of the lower shaft into the soil after each hammer drop. The layers of investigated site are shown in Table 4 and the coordinates of 8 points locations are given in Table 5.

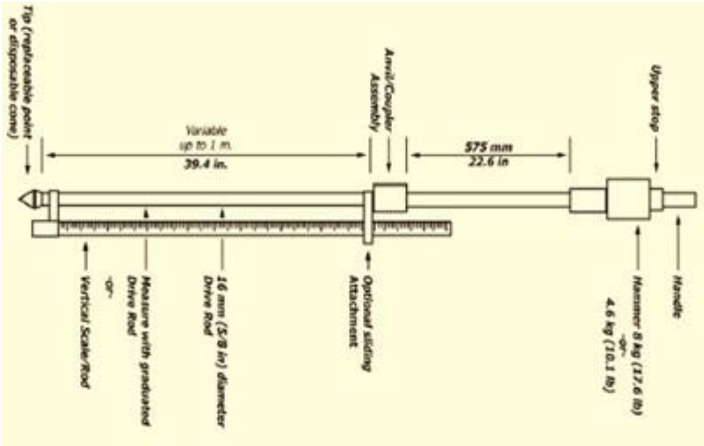

Fig. 12. Dynamic cone penetration

Table 4. Pavement explored profile specified by field works inspection and testing

Pavement	Level (m)	Symbol
Concrete or asphaltic layer	0.28~0.3	
Sub-base	~0.4	
Light brown to yellowish medium clayey silt soil filling layer	~0.85	

Table 5. Locations and title for each point (8 points) with date of field work

No.	Location	Coordination	Date of testing
1	P1	33°19'55.70"N 43°37'4.20"E	10/8/2024
2	P2	33°19'52.20"N 43°36'54.90"E	10/8/2024
3	P3	33°20'7.90"N 43°35'55.60"E	10/8/2024
4	P4	33°20'0.00"N 43°35'58.20"E	10/8/2024
5	P5	33°20'44.00"N 43°34'53.10"E	10/8/2024
6	P6	33°20'28.10"N 43°35'28.20"E	10/8/2024
7	P7	33°19'56.00"N 43°36'55.30"E	10/8/2024
8	P8	33°20'27.30"N 43°35'57.90"E	10/8/2024

4. Equations and Results Computation

Natural soil below subbase layer with respect to lab tests was coarse sand with gravely and fine soil with (9~10%) sulphate content (SO3) and (20-19%) gypseous content as shown in Table 6. From the most collected data water table not recognized through (0.85 m) but from CBR values were noted according to the soil consistency at the site figures below summarized field and laboratory tests result.

Laboratory results showed high sulfate (≈2%) and gypsum (≈18–20%) contents in subgrade soils. These cause sulfate-induced expansion in concrete and salt-related degradation in asphalt. DCP and CBR values decreased sharply after wetting, confirming that apparent strength was governed by soluble salts.

$$CBR = 292/DCP^{1.12} \quad (1)$$

$$CBR = 1/(0.017019 \times DCP)^2 \quad (2)$$

$$CBR = 1/(0.002871 \times DCP) \quad (3)$$

$$\log CBR = 2.628 - 1.273 \log (DCP) \quad (4)$$

$$q_u\ (kPa) = 65 \times (CBR - 1.5) \quad (5)$$

$$q_u\ (kPa) = 113 \times (CBR - 12.5) \quad (6)$$

$$q_u\ (kPa) = 172.6 \times (CBR) - 601 \quad (7)$$

$$k_s\ (kPa/m) = 40 \times q_u\ (kPa) \quad (8)$$

Table 6. Soil type content results

Soil type	Water-Soluble Sulfate SO_4^{2-} (% by mass)	Gypsum,%
Subbase (P2)	2.35	19.995
Subbase (P5)	2.47	19.82
Clayey Soil with Sand	2.33	18.748

4.1 Detailed DCP Results

There were many notes and observations can be drawn after reviewing all collected data come from field shown in Table 7.

- Unsaturated primarily granular soils in which a loose state is maintained by apparent cohesion, cohesion due to clays at the intergranular contacts or cohesion associated with the accumulation of soluble salts as a binder therefore CBR records with high CBR values were due to high soluble salt levels which are indicative of cementing agents in the subgrade layer. However, when the subgrade layer is moistened by water, the CBR values will be reduced to (20-18%).
- Based on the previous airbase evaluation, the Water-Soluble Sulfate (SO_4^{2-}) concentration for all soil samples exceeded 2% by mass. According to ASTM C1580-15 [18] guidelines, this indicates a high sulfate content in the soil, which is associated with very severe sulfate exposure. Such high levels of sulfate in the soil pose significant risks for concrete structures, as they increase the likelihood of sulfate attack, leading to potential deterioration, expansion, and cracking in the concrete.
- The recoded data for top subbase layer based on Ks values gave that soil medium to dense granular soils this classification for the samples within natural moisture content, during the excavation works and site observations for sulphate content the water was added then the Ks decreased dramatically.
- The CBR values also altering with wide range and it value like Ks reduced after adding water which indicated that apparent strength was caused by water soluble salts

4.2 High Levels of Sulfate and Gypsum Detected in Soil Samples

The laboratory analysis detected elevated levels of sulfate, classified as S3 grade according to ASTM C1580-15 [19]. This classification indicates very severe sulfate exposure, with levels exceeding acceptable limits. High concentrations of sulfate and gypsum can significantly compromise the durability and stability of both concrete and asphalt pavements. Sulfates can induce expansive reactions in concrete, leading to substantial deterioration and serious structural issues. The presence of gypsum may exacerbate these reactions, potentially causing severe damage to the pavement system.

Table 7.CBR results

Point / Type	Asphalt/Concrete layer thickness (m)	Clayey sand with gravel (m)	Test depth (cm)	CBR-1	Ks (kPa/m)	Results in MPa	Results in Psi
1/Asphalt	0.3	0.5	51.2	85.3114	145273.1	145.2	21070.08
2/Concrete	0.35	0.61	60.9	44.1674	73956.83	73.9	10726.53
3/Concrete	0.34	0.61	61.3	87.3224	146227.2	146.2	21208.46
4/Concrete	26.7	0.59	59.6	69.55431	117960.8	117.9	17108.76
5/Concrete	22.5	0.57	57.1	65.46742	110876.9	110.8	16081.33
6/Concrete	0.28	0.46	46	92.16496	157152.6	157.1	22793.05
7/Concrete	33.7	0.82	82	48.14337	104541.5	104.5	15162.46
8/Concrete	35.7	0.65	65	90.14436	153442.6	153.4	22254.96

5. Discussion

These existing preliminary evaluations and tests of Al-Habbaniya Air Base runway pavements show critical conditions of these pavements that may affect their structural integrity, durability, and function of this infrastructure [20,21]. A Few Key Findings from Field and Laboratory Tests. The results clearly show that high sulfate (≈2%) and gypsum (≈18–20%) contents in the subgrade accelerate pavement degradation. These salts cause expansion and loss of cohesion in the subbase, leading to cracking and reduced bearing capacity. The decrease in CBR values and compressive strength corresponds directly with increased sulfate concentration, confirming a cause-and-effect relationship between chemical attack and mechanical weakening. Figures 9–11 illustrate this correlation, highlighting that chemical deterioration significantly governs the structural performance of both asphalt and concrete layers.

5.1 Subgrade Soil Composition and Its Impacts

- Sulfate attack: Below the runways, high sulfate content soil was experienced, reaching over 2 masses %, classified as a very severe sulfate exposure, as indicated in ASTM C1580-15 [19]. This significantly increases the probability of sulfate-induced expansive reactions that can cause cracking, strength loss, and degradation of asphalt and concrete layers.
- High levels of gypsum: Elevated gypsum concentrations (18 to 20%) increase structural instability risk. In dry conditions these salts work as cementing agents, but when dissolved due to moisture, they lower soil cohesion and reduce subgrade strength.
- Moisture deficiency: Dynamic Cone Penetrometer (DCP) and California Bearing Ratio (CBR) tests show lower apparent strength when saturated. Initially, there were high CBR values due to soluble salts, which reduced drastically with the persistence of water.

5.2 Asphalt Pavement Deficiencies

- Crack types: Structural and environmental distress can be inferred from fatigue cracking, block cracking, and longitudinal/transverse cracks These include defects due to fatigue loading, material wear, thermal cycles, among others.
- Moisture: The moisture susceptibility tests show severe damage in most places, further, some locations are less than the acceptable limit (≥ 80%).
- Surface deterioration: Raveling, weathering, and polished aggregates are common, adversely affecting skid resistance and surface durability.

5.3 Concrete Pavement Deficiencies

- Sulfate attack: Concrete core samples reveal compressive strengths ranging from 11.95 MPa to 29.01 MPa, with most values falling below the threshold for adequate runway performance. The high sulfate environment is a significant factor in reducing durability and causing spalling and cracking.
- Structural failures: Punchouts, corner spalling, and joint faulting reflect foundational weaknesses and material incompatibilities under load.

5.4 Drainage and Environmental Factors

To mitigate these environmental and chemical hazards, the use of resilient materials, efficient drainage systems, and proper construction techniques is essential. The wide variation in compressive strength (≈12–29 MPa) is mainly attributed to sulfate-induced expansion and microcracking, which weaken the cement matrix and reduce cohesion between aggregates. Similar degradation patterns were reported by Wang [1] for sulfate-rich soils in hot climates. These results highlight that pavement design in such environments must incorporate sulfate-resistant materials, proper drainage, and stabilized subbase layers to minimize expansion and strength loss under wet–dry cycles.

- Inadequate drainage: Water infiltration into the subgrade layers is a major concern. Poor drainage exacerbates sulfate-related damage and accelerates the weakening of the pavement structure.
- Thermal stresses: Temperature fluctuations and extreme heat cause expansion and contraction in the pavement layers, contributing to blowups in concrete and cracking in asphalt.

6. Conclusion

In order to address the issues appeared in the evaluation requires, a multifaceted approach involving soil stabilization, material upgrades, structural improvements, and enhanced drainage systems., Al-Habbaniya Air Base runways can be achieving improved durability, according with engineering standards, and extended service life, ensuring safe and reliable operations under Iraq's challenging environmental conditions. The researcher recommends reconstructing the runways according to the test results. The objectives outlined in the introduction have been achieved through a combined evaluation of field and laboratory results. The study confirmed that sulfate and gypsum concentrations exceeding 2% and 18–20%, respectively, are key factors causing loss of strength and durability in both asphalt and concrete layers. These findings highlight the need for sulfate-resistant materials and improved drainage systems for future runway rehabilitation.

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