Investigating the Impact of Domestic Sewage on Asphalt Concrete Pavement Strength

Afzal Ahmed
Department of Urban and Infrastructure Engineering, NED University of Engineering and Technology, Pakistan
afzalahmed@neduet.edu.pk

Sajjad Ali
Department of Civil Engineering, NED University of Engineering and Technology, Pakistan
sajjad.ali@cloud.neduet.edu.pk

Ashar Ahmed
Department of Urban and Infrastructure Engineering, NED University of Engineering and Technology, Pakistan
aahmed@cloud.neduet.edu.pk (corresponding author)

Farah Khan
Department of Urban and Infrastructure Engineering, NED University of Engineering and Technology, Pakistan
farah.iftikhark@gmail.com

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ABSTRACT

This study evaluates the impact of exposing asphalt pavement to sewage and fresh water. In total, 87 samples were prepared, where half of them were immersed in sewage and the others were immersed in freshwater. The Marshall mix design method was adopted for the preparation of samples. Three immersed samples were tested for stability and flow every 24 hours in both fresh water and sewage, comparing the results with a control sample. The samples immersed in fresh water lost their stability and flow after 11 days, while the ones immersed in sewage water lost their stability and flow after 9 days. Furthermore, the loss in stability for samples immersed in fresh water and sewage after 14 days was found to be 38.8 and 55.6%, respectively. The results revealed that sewage water affects asphalt concrete pavement more severely than freshwater. Finally, it was concluded that proper drainage and adequate supplemental sewerage systems are necessary to maintain the desired strength of the pavement throughout its design life.

Keywords-pavement deterioration; Marshall mix design; sewerage overflows; potholes; drainage system

I. INTRODUCTION

Pavements are engineered structures constructed to facilitate the movement of vehicles. With time, pavements deteriorate due to various reasons, including traffic loading, weather, and other external factors. In addition to these factors, one of the primary causes of distress in Hot Mix Asphalt (HMA) is moisture susceptibility and water ponding [1-2]. The accumulation of water on pavements for more than 24 hours results in pavement deterioration, making the road less efficient by decreasing speed and increasing traffic congestion and accidents [3-4]. A cross slope of about 1.5 to 2.0% is used to reduce the chance of possible water accumulation on the pavement and to facilitate water flow through drainage systems [5-6]. A proper and well-maintained drainage system can increase pavement life by approximately 50% [7-8].

Underdeveloped and developing countries are mainly affected by water pond issues due to improper drainage systems and sewage overflows. Drainage is often blocked due to poor maintenance, leading to water accumulation on the road surface [4, 9]. Poor drainage systems also contribute to rainwater ponding, especially during the monsoon season [10-11]. Water pounding has harmful effects on road pavements, whereas the intensity of the damage depends on the type of rainfall. Heavy pouring for a continuous period results in pavement disintegration and pothole creation [12]. In addition to rainwater, pavements are also prone to sewage water that contains some amount of soaps, shampoos, toilet cleaning detergents, etc., and can cause emulsification, while a high acid content can cause pH instability [13-14]. Furthermore, toxic chemicals from industrial zones can infiltrate sewage water and flow through roads in the event of an overflow of the sewer system [15-16].

Moisture damage leads to loss of stiffness and strength due to inundation by water on pavements. The presence of moisture severely affects asphaltic pavements by making the asphalt mastic lose its cohesion, thus damaging the bond between the aggregate and the asphalt and disintegrating the aggregates [17-19]. Moisture creates various problems on the pavement, such as fatigue, potholes, rutting, and reduction in compressive strength [20-21]. Aggregate gradation plays an important role in the formation of adhesive bonds between mineral aggregates and the asphalt binder. The loss of adhesion results in more serious damage to the pavement, such as stripping of asphalt [22-23].

Aggregates are mechanically interlocked when asphalt enters the pores and the irregularities present on the aggregate surface. As a concequence, the aggregates are coated and mechanical forces are formed after the mix cools [24]. This mechanical bonding is highly affected by the physical properties of the aggregate in use, that is, an aggregate with a rough texture as well as more pores and angularity can bring about stronger bonding [25]. In [26], the effects of aggregate gradation on moisture damage on pavements were evaluated. Tests were carried out on three different grades of crushed limestone aggregate that were used to prepare the specimens. Stability and tensile strength tests were conducted on the pavement to assess moisture susceptibility, according to the AASHTO T-283. The outcomes showed that the gradation significantly affected the performance of the pavement against moisture. The chemical composition of the water to which the pavement is exposed also influences the damage. In [27], pavement damage due to exposure to seawater was evaluated. Asphalt Cement (AC) of grade 60/70 and crushed limestone were utilized along with hydrated lime as a filler to stiffen the asphalt binder. Marshall specimens were prepared and immersed into seawater, according to AASHTO T-283. The results of the Marshall stability test revealed that the specimens submerged in seawater had lower stability. In [28], the role of the chemical properties of water, such as pH and salt concentration, in the damage to asphalt pavements was investigated. The specimens were prepared employing grade 60/70 asphalt and then immersed into four different types of water solution, including acidic, alkaline, distilled, and saline water. The testing method involved immersing 6 grams of asphalt binder into different volumes and pH of water solutions for 7 days. A visual observation of the immersed samples disclosed that the surfaces became rough and micropits were observed over time. The study concluded that asphalt damage was highest for the alkaline solution, followed by the acidic solution, and then the saline solution. However, this study did not explore the effects of exposure to moisture on the mechanical and physical properties of the asphalt.

Moisture-damaged pavements deteriorate with time, as they withstand traffic and other loads while pounded by water [29]. In [30], the premature failure of asphalt pavements in South China during the humid and rainy seasons was examined. Field investigations observed the mechanism that occurs on pavements in service by traffic and axial loading in the presence of moisture. Nine highways and expressways were studied, detaching cores for laboratory tests. The results showed that water infiltrates the pavement from the push it receives from the traffic load and, in return, causes the asphalt film to strip. The stripped asphalt then moves upwards due to dynamic hydraulic flow and gathers on the road surface as spots. While the asphalt immigrates upward, the aggregates disintegrate as an outcomre of loss of adhesion to the asphalt binder. Also, owing to poor interior drainage conditions, a pumping action occurs, causing the base cement to become a slurry and after that make its way to the surface through the voids in the permeable surface layer. Cracks are generated as a concequence of settlement due to pumping, and deformation arises to a considerable degree.

In Karachi, the most populous city in Pakistan, the sewer system is often blocked with garbage due to poor infrastructure and lack of municipal services, inducing sewage overflows. This problem is combined with the lack of a stormwater drainage system, causing water ponds on the roads for prolonged periods after rains [31-32]. It has been observed that road segments with sewage ponding are damaged earlier than road segments without. Only 7% of the roads are in good condition compared to the 26% of roads in bad condition [33]. This study aimed to evaluate the hypothesis that sewage creates greater damage to asphalt pavements and significantly reduces their serviceability.

II. RESEARCH GAP AND CONTRIBUTION

This study aimed to investigate the damage caused to the asphalt concrete mix due to prolonged exposure of pavements to rain and sewage. There is no study in the existing literature that quantifies the impact of sewage on pavements. In [27], the impact of freshwater and seawater on pavements was investigated by immersing samples for 14 days, carrying out Marshall stability and flow tests only on selected days (1, 3, 7, and 14). In [28], the influence of acidic, alkaline, distilled, and saline water was explored by immersing samples for 7 days. However, this study did not perform any mechanical tests and the deterioration was only visually observed. All in all, this study examines the impact on pavement due to prolonged exposure to sewage using Marshall stability and flow measurements.

III. EXPERIMENTAL FRAMEWORK

Figure 1 describes the research framework of this study.

A. *Material Testing and Selection*

Physical and mechanical tests were performed for the selected aggregates and asphalt. Aggregates and asphalt were tested according to ASTM/BS/AASHTO standards, while the Marshal mix design method was used to examine the behavior of HMA.

1) *Testing of Aggregates*

Crushed limestone was selected as the aggregate for this experimental program. The aggregates were sieved in the required proportions according to the specifications defined by the National Highway Authority (NHA) in Pakistan [34]. Table I displays the physical properties of aggregates with relevant standards and limits. All physical properties of the aggregates were under the limitations specified by NHA. The sieving of aggregates was performed using the NHA specification, as illustrated in Table II. The aggregates were thoroughly washed, oven-dried, and left at ambient temperature overnight before use. All samples followed this gradation, and the average values were taken for the sieves with the specified ranges.

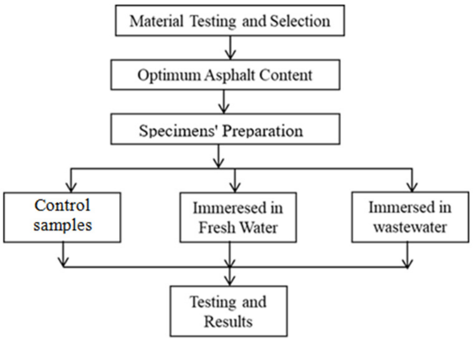

Fig. 1. Research method to evaluate the effect of water ponding.

TABLE I. SUMMARY OF AGGREGATES TESTING

Properties (unit)	Standard	Test result	NHA Specification
Specific Gravity	ASTM C127-07 [35]	2.50	≤ 2.60
Absorption (%)	ASTMC127- 07 [35]	0.68	≤ 2.0
LA Abrasion (%)	ASTM C131-06 [36]	2.32	≤ 40
Impact Value (AIV) (%)	BS 812-112 [37]	15.82	-
Crushing Value (ACV) (%)	BS 812-110 [38]	20.52	-

TABLE II. SIEVE SIZES AND PERCENTAGE PASSING AS RECOMMENDED BY NHA

Sieve Size	Passing (%)
1"	100
3/4"	90-100
3/8"	51-75
#4	33-54
#8	23-35
#16	5-12
#200	2-8
Pan	0.0

2) *Testing of Asphalt Binder*

Conventional asphalt was used as the binder. Table III depicts the properties of the binder with their standards and specifications, which were within the limits defined by NHA.

TABLE III. SUMMARY OF ASPHALT TESTING

Properties (unit)	Standard	Observed	NHA Spec.
Penetration Grade	ASTM: D 5-86 [39]	60-70	60 - 70
Softening point (°C)	ASTM: D 36-8 [40]	43.75	-
Flashpoint (°C)	ASTM: D 92-78 [41]	180	-
Fire point (°C)	ASTM: D 92-78 [41]	300	> 232
Ductility (°C)	ASTM: D 113-86 [42]	105	> 100
Specific Gravity (-)	ASTM: D 70-97 [43]	0.99	-

B. *Specimen Preparation*

The Marshall mix design procedure was applied to determine the Optimum Asphalt Content (OAC). In total, 36 samples were prepared, 18 compacted and 18 uncompacted. The percentage of asphalt content ranged from 3.5 to 6.0% as per the weight of the specimens. The compacted samples were utilized to determine the volumetric properties of the mix, while the uncompacted samples were used to determine the maximum theoretical specific gravity (GMM) and then the air voids percentage (Va). OAC was determined at 4.0 to 7.0% of the air voids as per NHA specifications. Figure 2 shows the behavior of air voids in HMA with increasing asphalt. The optimum asphalt content percentage was 5.25% at 4.0% air voids.

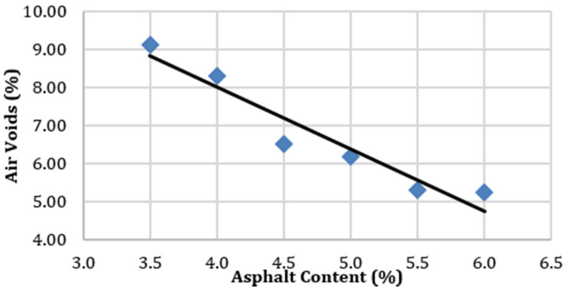

Fig. 2. Variation in air voids vs asphalt contents of mix samples.

Each specimen was prepared with 1200 g of washed and dried aggregates, which were obtained by passing through the sieves as portrayed in Table II. The samples were prepared following the standard procedure described in [44]. About 5.25% of asphalt by weight was added for the preparation of the asphalt mix. The final specimen had an approximate height of 64 mm and a diameter of 102 mm, as noticed in Figure 3.

Fig. 3. Preparation of specimens.

C. *Testing Scheme*

Based on the estimated OAC, the selected materials were employed to prepare the samples for the described testing scheme. In total, 87 samples were prepared for Marshall testing. Three samples were taken as control (dry) samples and were tested after 24 hours of preparation. All the other samples were divided into two groups of 42, which were kept in dry conditions for 24 hours before immersion in water. One set of samples was immersed into freshwater, while the other one was immersed into sewage. From each set, three random samples were drawn every day until the 14th day to perform the Marshall stability test. Figure 4 (a) and (b) exhibit the samples immersed into fresh water and sewage, respectively.

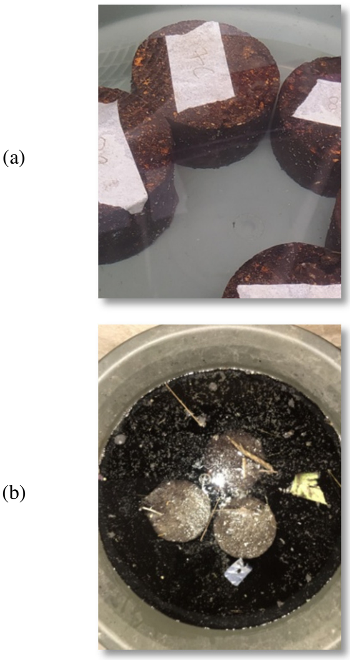

Fig. 4. Specimens immersed into (a) freshwater (a) and (b) sewage.

D. Water Ponding

Two different immersion conditions were created for this experiment. Half of the samples were immersed into fresh water, while the remaining samples were immersed into sewage, taken from one of the main sewer lines in Karachi. These conditions were created because the study area is a city where the cross-slope and longitudinal slope are almost nonexistent. As a result, fresh water and sewage remain on the roads for several days, generating a situation in which the pavement remains completely immersed. The pH of freshwater and sewage water was examined, being 6.8 and 8.1, accordingly.

E. Marshall Testing

The Marshall testing apparatus was put into service to estimate the strength parameters of all specimens, including stability (lb) and flow (in). Based on the observed values of stability and flow, the Marshall quotient, defined as stability per unit of flow, was also determined, which helps in understanding the loss of strength due to prolonged exposure to water. Figure 5 displays the Marshall testing apparatus implemented in this experiment, where the standard procedure for Marshall testing was followed [45]. For the Marshall stability and flow test, the compacted samples were immersed into water for 30 minutes at 60°C. After this, the samples were placed one by one on the breaking head of the Marshall tester.

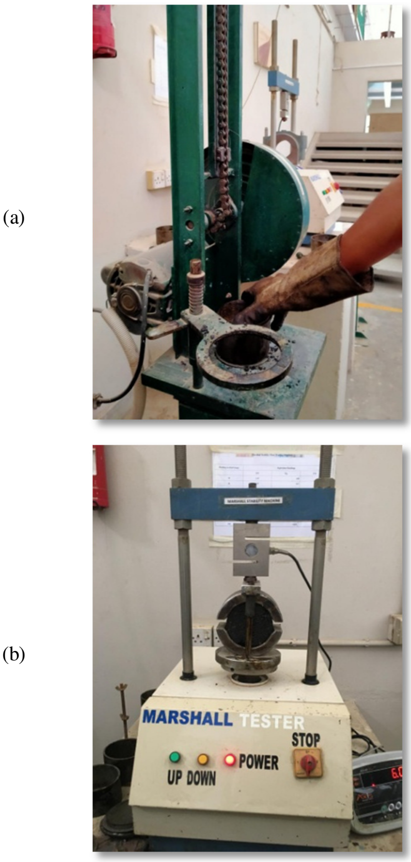

Fig. 5. Marshar (a) compacter and (b) tester.

IV. RESULTS AND DISCUSSION

The stability and flow of the immersed samples were tested every day for 14 days. All samples were kept in dry conditions for 24 hours before Marshall testing. On Day-0, after 24 hours in dry conditions, three samples were tested as control samples while all the others were immersed into water. Three samples were drawn every 24 hours in freshwater and sewage water for Marshall testing. Table IV presents the mean values for stability and flow of the three samples tested each day.

TABLE IV. RESULTS OF MARSHALL TEST OF SPECIMENS

Days	**Freshwater**		**Sewage**	
	Flow (0.01 in.)	**Stability (lbs)**	**Flow (0.01 in.)**	**Stability (lbs)**
Day-01	11.74	2221.9	11.91	2206.0
Day-02	12.01	2198.0	12.72	2146.8
Day-03	12.64	2163.4	13.41	1937.8
Day-04	13.18	2051.7	13.62	1930.7
Day-05	13.21	2043.4	13.56	1848.6
Day-06	13.30	1996.2	14.3	1718.5
Day-07	13.36	1984.7	14.38	1700.8
Day-08	13.49	1862.9	14.49	1695.7
Day-09	14.26	1706.4	15.61	1540.2
Day-10	14.74	1684.2	16.42	1403.2
Day-11	15.01	1601.0	17.99	1324.0
Day-12	16.11	1489.4	19.04	1212.0
Day-13	16.24	1411.0	20.04	1198.6
Day-14	16.82	1386.0	22.12	1004.2

A. Loss of Stability

The stability and flow of the control sample, which was not exposed to any kind of immersion, were 2265 lbs and 11.1 in. Figure 6 showcases the loss of stability over time for samples immersed into fresh water and sewage. The stability of these samples was compared with that of the control sample. The Marshall testing results disclosed a decrease in stability for samples immersed into fresh water and sewage. The loss of stability for samples immersed into sewage was significantly greater than that of samples immersed into freshwater. The samples were prepared for heavy traffic with 75 blows on each side. The Asphalt Institute recommends a minimum acceptable stability of 1500 lbs for pavements designed for heavy traffic, implying that a lower value would be subject to failure [46]. The control sample had significantly higher stability, demonstrating the compatibility of the samples with heavy traffic. Therefore, it can be implied that when the sample strength is reduced below 1500 lb, the pavement will not support the traffic load. The samples immersed into freshwater failed after Day-11, as they lost 34.24% of their strength during this period. Samples immersed into sewage failed after Day-09, as they lost 38.04% of their stability. After 14 days, the samples immersed into freshwater lost their stability by 38.81% while those exposed to sewage lost their stability by 55.66%. Therefore, samples exposed to sewage water had a 28% reduced stability on the 14th day than samples exposed to fresh water. Comparison of stability loss with time also revealed that the loss stability rate for samples immersed in sewage was higher than the other set of samples.

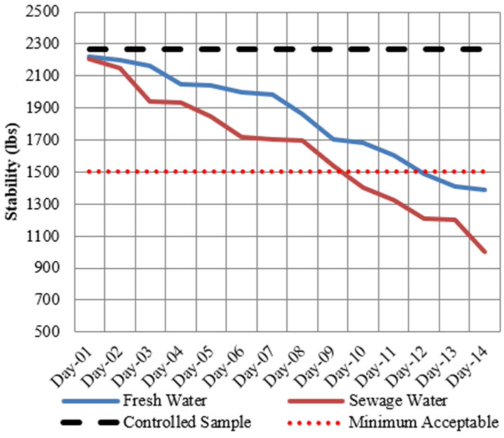

Fig. 6. Loss in stability of samples with time.

The findings exhibit a similar trend to other studies. In [27], the use of seawater displayed a lower value in the Marshall stability test, concluding that lower pH and salt concentration in water pose a high disintegration risk for asphaltic pavements. In [28], the alkaline solution affected the asphaltic pavement samples more severely compared to acidic and saline solutions. Therefore, it can be deduced that sewage has a pH in the alkaline range and thus has a more detrimental effect on the pavement compared to rainwater.

B. Loss in Flow

Flow is the measure of the maximum deformation in the asphalt mix when subjected to the maximum load. The flow values were also observed during the Marshall test. Figure 7 portrays the observed flow values for the samples. The Asphalt Institute recommends a range of 8-16 (0.01 in.) as an acceptable value for flow on pavements subjected to heavy traffic [46]. The failure in terms of flow follows a similar pattern to that of stability. Samples immersed into freshwater crossed the acceptable maximum value of flow after Day-11, whereas samples exposed to sewage crossed this limit after the 9th day. The flow of the specimens exposed to fresh water increased by 51.5% after 14 days, while the flow of samples immersed into sewage rose by almost 100%. The change in flow for samples exposed to sewage is significantly higher than for those immersed into freshwater. The comparison of the change in flow and stability during the observation period indicates that the change in flow was more than the change in stability. The samples lost their stability by 38.81%, whereas flow change was 51.5% for the same period. Similarly, the samples placed in sewage lost their stability by 55.66% and increased their flow by 100%.

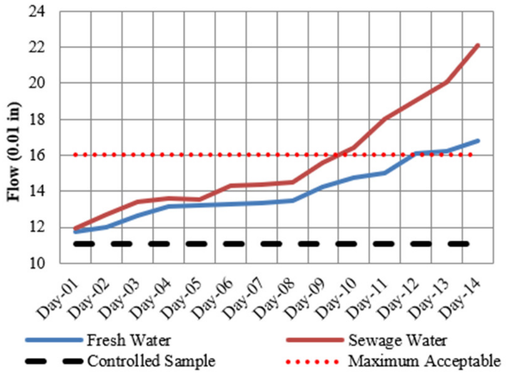

Fig. 7. Flow comparison for samples immersed into fresh and sewage water.

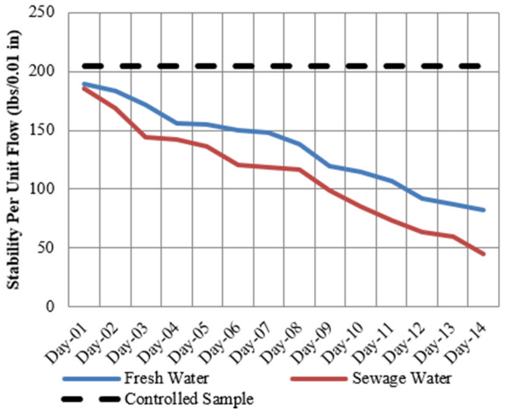

Fig. 8. Comparison of stability per unit flow for the samples immersed into fresh water and sewage.

C. Stability per Unit Flow

Stability per unit flow represents the overall capacity of load handling by the asphalt pavement, combining the effect of loss in stability and increase in flow. Figure 8 depicts the change in stability per unit flow over the observation period. Compared with stability per unit flow measured for the control sample, the samples exposed to freshwater and sewage experienced a reduction of 59.61 and 77.75%, respectively.

V. CONCLUSIONS AND RECOMMENDATIONS

This study highlighted one of the major problems faced by the transport network and commuters in Pakistan and other developing countries. The condition of the pavement of the road network in Karachi and other parts of the developing world is generally deteriorated. One of the contributing factors to the condition of pavements is exposure to water. The impact of water-exposed pavements was evaluated by immersing Marshall specimens under controlled conditions. The Marshall methodology has been widely used in previous studies for measuring flow and loss of stability in pavements [47-50]. The specimens were immersed into fresh water and sewage for 14 days. Three samples were used after each day to perform Marshall stability and flow tests. The test results showed that the stability of the samples fell below the minimum required value, implying that continuous exposure of pavement to ponded water would lead to rapid damage.

Poor rainwater drainage systems and improper sewerage cause excessive rainwater and sewage ponding, especially on local streets and collector roads. Severe damage to the pavement produces potholes that cause traffic congestion, delays, and road accidents. This study evaluated the impact of exposure to water on pavement conditions. The main contribution of this study is the quantification of the influence of sewage on the loss of strength of asphalt mix, in addition to quantifying the effect of extended exposure to water, such as water ponding and runoff. The samples immersed into freshwater had less stability than the minimum required after 11 days of immersion, while the samples immersed into sewage were found to have less stability than the minimum required after 9 days of immersion. The results reveal that sewage causes more damage to the pavement compared to fresh water. This study demonstrated that prolonged exposure of pavements to water can severely damage roads. Therefore, the importance of having a proper rainwater drainage system and efficient sewerage is further highlighted to ensure a road network with pavements that provide good riding quality. By reducing damage to pavements due to water, the cost of frequent road repairs could be decreased along with eliminating excessive delays and road accidents.

This study was limited to measuring the deterioration of the asphalt mix due to reduced stability and increased flow. The testing of such samples can be extended to include more detailed analysis using rutting susceptibility tests and fatigue analysis. Furthermore, the testing scheme should investigate extracted cores from road segments ponded with fresh water and sewage and test real-life conditions.

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