A Cost-Effective Maintenance Treatment for Improving Airfield Pavement Friction

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ABSTRACT

Skid resistance is a key component affecting safety at an airport. Maintaining adequate skid resistance is a challenging task for a busy airport considering the intensive use of airport pavements in all weather conditions. Furthermore, the limited ability to restrict access to sections of the pavement to conduct maintenance adds further challenges in addressing pavement condition at airports around the globe.

This paper summarizes the non-destructive testing protocols used as well as the findings from a pavement investigation completed at a major North American airport hub. At the airport under study, there were documented incidents of aircraft skidding on a recently rehabilitated pavement surface. The skidding incidents occurred in close proximity to areas where standard operating procedures for gate deicing was being performed. The purpose of the pavement investigation was to examine the airport pavement's skid resistance properties within the airport's apron and gate areas where airplanes perform several low speed turning movements.

The non-destructive test protocols used in this project included a visual distress survey of the pavement surface and British Pendulum (BP) testing used to assess the skid resistance properties of the pavement in the affected area. Testing was performed in areas where skidding incidents were reported and other areas where no skidding incidents were reported. The BP testing was performed following ASTM E303 using water and a modified procedure using three different types of deicing agents commonly used in deicing operations at the airport during the winter season.

The objective was to determine if the skidding incidents were a result of the pavement surface or the deicing agent used at the airport. Statistical analysis was completed to objectively analyze the results of the BP testing. The results determined that the three glycol solutions used in the study contributed anywhere from 20% to 27% of the reduction in skid resistance, while the bituminous sealant used on the recently rehabilitated asphalt pavement was determined to contribute approximately 12% of the overall reduction in skid resistance. A shot blasting maintenance treatment was recommended to restore the pavement's surface friction. This maintenance technique was determined to be the cost-effective method to restore skid resistance. Significant savings were estimated by avoiding full pavement rehabilitation and temporary operation suspension in the work zone.

Introduction

Stantec Consulting Ltd. (Stantec) was retained to undertake an engineering study at a major US Airport to identify and recommend solutions to correct the cause of the asphalt condition that is driving aircraft tire slippage in the ramp alley at numerous gates. This paper summarizes the results of the field survey and rehabilitation recommendations that were developed to address the aircraft skidding during low speed turning movements.

Background

Skid resistance is a key component affecting the safety of airplane passengers as well as airport employees working on the airside pavements. Maintaining adequate skid resistance is a challenging task for any airport considering the intensive daily use of the facility's pavements in all weather conditions. Furthermore, the limited ability to shut down sections of the airport pavement to conduct maintenance adds further challenges in addressing pavement condition at airports around the globe.

The asphalt pavements around a terminal at a major North American hub airport were recently rehabilitated and resurfaced in 2010. After completing the asphalt resurfacing, the asphalt was sealed with an asphalt sealant. The type of sealant used by the contractor was not known at the time of writing this paper.

During the winter season, a glycol solution is used as part of the airport's standard operating procedures for gate deicing. As a result of this procedure, excess glycol is accumulated on the asphalt surface during the application of the solution to the aircraft. The airport authority received numerous reports that the glycol-covered asphalt has been compromising the maneuverability of aircrafts attempting to approach their destination gates to drop off its passengers. Aircraft tire slippage occurs even after the excess glycol is vacuumed off of the asphalt surface. It is important to note that the aircraft tire slippage was only reported on areas where the pavement was sealed with a bituminous sealant.

The initial thought of the pavement owner was that major rehabilitation would be required to remove the asphalt sealant and restore the pavement's frictional properties. Rehabilitation strategies such as a mill and overlay were being considered. However, these strategies would cause a major disruption to daily operations at the terminal and projected to cost in the order of several million dollars.

Pavement Data Collection

The engineering study and pavement inspection included a visual pavement distress survey, including photographs to document the existing pavement conditions observed on site. The second phase of the pavement assessment included measuring the asphalt surface frictional properties using a British Pendulum Tester following ASTM E303-08 "Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester".

The skid resistance tests were conducted on the recently sealed asphalt pavements as well as on asphalt pavements where tire slippage (or a sealant) had not been encountered in order to quantify the loss in frictional properties. Additionally, tests were performed on wetted surfaces using both water and three different glycol solutions currently used during deicing procedures to determine if the glycol solutions had any impact on aircraft tire slippage.

Pavement Distress Survey

The distress survey was completed using the ASTM Standard Test Method for Airport Pavement Condition Index and the Distress Identification Manual published by FHWA for the Long-Term Pavement Performance Program, dated June 2003.

Three severity levels were used for each distress type; Low, Moderate, and High. The pavements surrounding the area of investigation were observed to be in good condition. The only distresses observed within the area of investigation were low severity linear and fatigue cracking.

Linear Cracking

Linear cracking is defined as independent cracks not intersecting other cracks.

The distress severity is based on the crack width and condition as follows:

- **Low:** Crack widths < 1/4 inch with light or no spalling and little or no Foreign Object Debris (FOD) potential;
- **Moderate:** Cracks widths 1/4 – 3/4 inch, or with slight to moderate spalling, some FOD potential.
- **High:** Cracks widths > 3/4 inch, with moderate to severe spalling at edge, definite FOD potential.

Fatigue Cracking

Fatigue cracking is defined as a series of interconnecting cracks caused by fatigue failure of the asphalt concrete (AC) surface under repeated traffic loading.

The distress severity is based on the crack condition as follows:

- **Low:** Fine, longitudinal hairline cracks running parallel to one another with none or only a few interconnecting cracks, and little or no FOD potential;
- **Moderate:** Further development of light fatigue cracking into a pattern or network of cracks that may be lightly spalled, some FOD potential.
- **High:** Network or pattern cracking has progressed so that the pieces are well defined and spalled at the edges; some of the pieces rock under traffic and may cause FOD potential.

Observed Pavement Distresses

Low severity linear cracking was observed on the asphalt surfaced pavements at seven terminal gates. Low severity fatigue cracking was observed on the asphalt surfaced pavements at only two terminal gates. Photos of the observed characteristic low severity linear and fatigue cracking are presented below in Figures 1 to 4.

Figure 1: Low Severity Linear Crack and Asphalt Sealant

Figure 2: Low Severity Linear Crack

Figure 3: Low Severity Fatigue Cracking

Figure 4: Low Severity Linear Crack

Pavement Microtexture and Macrotexture

The skid resistance of a pavement depends on the pavement surface's microtexture and macrotexture. Microtexture is related to the degree of roughness of individual aggregate particles within the asphalt mix; while macrotexture is a function of mix properties, compaction method and aggregate gradation. At low speeds, microtexture is responsible for pavement friction. At higher speeds, macrotexture produces most of the available pavement friction [Abd El Halim 2010].

A figure illustrating the difference between microtexture and macrotexture is presented in Figure 5.

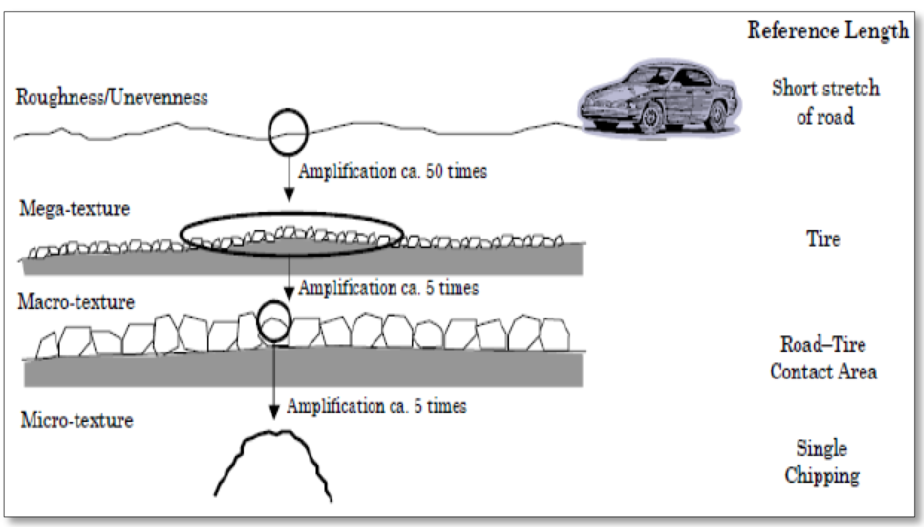

Figure 5: Microtexture and Macrotexture of a Pavement Surface [NCHRP 2009]

During the field investigation, it was noted that there was a visible difference between the micro- and macrotextures of the sealed and unsealed asphalt pavements in the recently rehabilitated area. The roughness of the aggregates and pavement surface in general was observed to be "less rough" in the areas where the sealant had been applied. The visual difference is evident and is illustrated below in Figures 6 and 7.

Figure 6: Unsealed Asphalt Pavement

Figure 7: Sealed Asphalt Pavement

British Pendulum Skid Resistance Testing (ASTM E303-08)

The British Pendulum Tester (BPT) is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface. The BPT was chosen to quantify the frictional properties of the asphalt pavement surrounding the ramp alley area due to its portability and relatively quick testing time. These attributes made it an effective method of testing skid resistance in a high traffic area.

The BPT uses a pendulum equipped with a standard rubber pad to determine the frictional properties of a test surface. The frictional properties are measured in units of British Pendulum Number (BPN). At each test location, the BPT is leveled and calibrated to the pavement surface by adjusting several leveling screws and an adapter nut to ensure accurate readings. The test surface is cleaned from debris using a small brush and wetted using water prior to testing. The pendulum is then raised to a locked position and then released allowing the slider to make contact with the test surface. A drag pointer on a scale indicates the BPN. A larger BPN measurement is the result of a more retarded swing, therefore greater friction between the rubber pad and the pavement surface. The lower the BPN number, the lower the amount of friction between the rubber pad and the pavement surface. Five tests were performed at each specific test location and an average was taken as being a representative BPN test result. A photo of the BPT equipment is presented below in Figure 8.

Figure 8: BPT Equipment on Sealed Asphalt Pavement

In order to identify the potential causes of aircraft tire slippage, the BPT tests were conducted on both the sealed and unsealed pavements. Furthermore, the tests were performed on wetted surfaces using both water and three different glycol solutions currently used during deicing procedures in order to quantify and pinpoint the driving force behind the loss in frictional properties.

At each test location, four different solutions were applied to the pavement surface prior to measuring the BPN. However, the BPT equipment was setup on a clean surface prior to each application of solution so as not to introduce cross-contamination between the various solutions.

The types of solutions used are as follows:

1. Water
    - Used as part of the standard ASTM procedure for the British Pendulum Test
2. Glycol Type I
    - Product name is Octaflo EF Concentrate manufactured by Clariant
    - Is a propylene glycol based de-icing fluid
    - This solution is diluted with water to form a 50/50 glycol to water concentration prior to being used for de-icing purposes and is pink in color
3. Glycol Type IV
    - Product name is Max Flight 04 manufactured by Clariant
    - Is a propylene glycol based de-icing fluid
    - This solution is **not** diluted with water and is used as 100% glycol for de-icing purposes and is green in color
4. Combination of Glycol Type I and Glycol Type IV
    - The glycol products listed above in #2 and #3 are mixed to a 50/50 solution

British Pendulum Test Results

British Pendulum testing was completed on both sealed and unsealed asphalt pavements surrounding the airport terminal at numerous gates. Each test location was tested using four different solutions to wet the surface prior to BPN measurements.

BPT measurements on the sealed asphalt pavements were associated with locations where aircraft tire slippage or skidding was reported. BPT measurements on the unsealed asphalt pavements were associated with locations that had no reports of aircraft tire slippage or skidding.

The BPT measurements taken at each of the gates on both the sealed and unsealed asphalt pavements are summarized below in Tables 1 and 2 and include the minimum, maximum, average and standard deviation of the measurements.

Table 1: BPN Measurement Summary – Unsealed Pavements (No Skidding)

Solution	Min	Max	Average	Std. Dev.	% Reduction in BPN
Water	18.9	33.1	27.2	3.9	-
Glycol Type I	8.3	32.3	21.7	5.9	20%
Glycol Type IV	5.3	29.3	19.9	6.8	27%
Glycol Type I and IV	7.2	27.9	20.2	5.3	26%

Table 2: BPN Measurement Summary – Sealed Pavements (Skidding)

Solution	Min	Max	Average	Std. Dev.	% Reduction in BPN
Water	21.6	34.5	26.3	3.6	-
Glycol Type I	8.3	25	18.5	4.6	32%
Glycol Type IV	8	21.1	16.8	4.2	38%
Glycol Type I and IV	5.6	25.5	16.9	5.6	38%

As shown in the tables above, the test results show there is a difference in BPN between the glycol solutions and water. However, there was not a significant difference between the BPN on the sealed and unsealed asphalt pavements using water as the wetting solution. The BPN measurements taken at each test location are illustrated below in Figures 9 and 10 for unsealed and sealed asphalt pavements, respectively.

Also shown in the tables above, are the percent reduction in BPN, thus skid resistance in general, categorized by the type of wetting solution used. It is evident that there was a higher loss in skid resistance when performing the BPT measurements on the sealed asphalt pavements. There is an approximately 11% to 12% reduction in BPN when using the glycol solutions on the sealed asphalt pavements. This relationship is illustrated below in Figures 11 and 12 and categorized by both pavement and glycol type respectively.

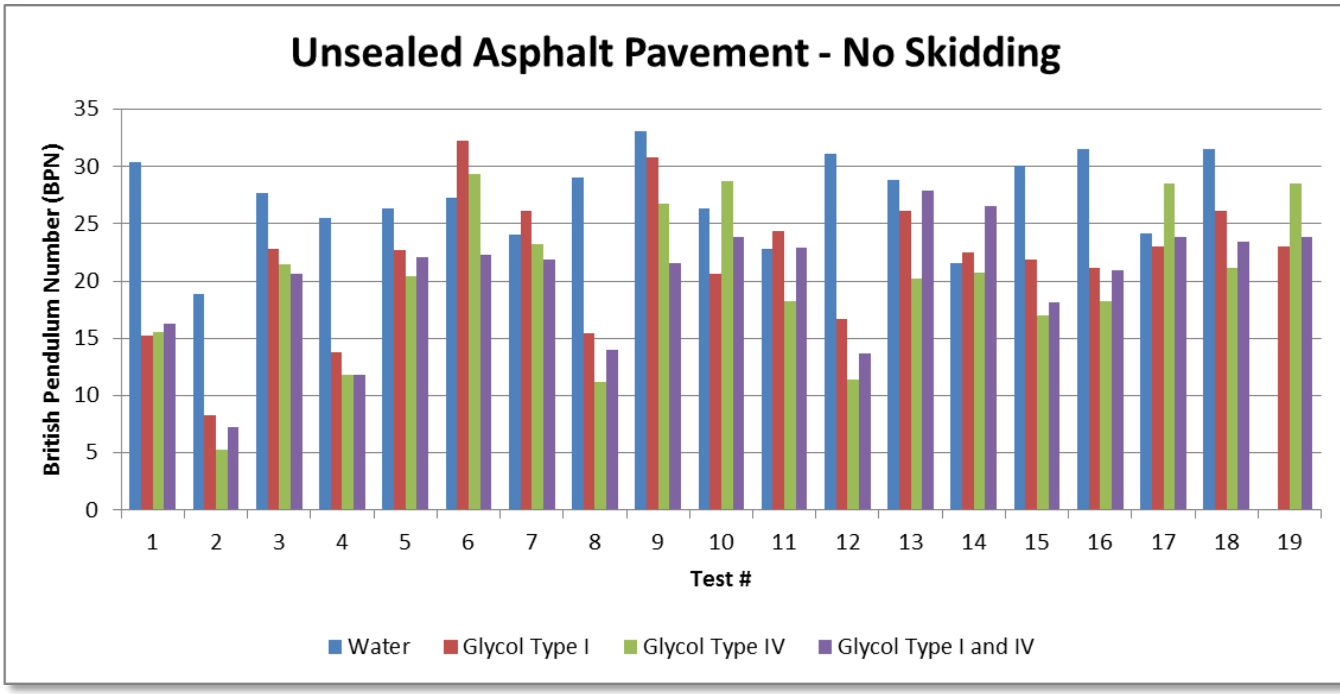

Figure 9: BPN Measurements on Unsealed Asphalt Pavements

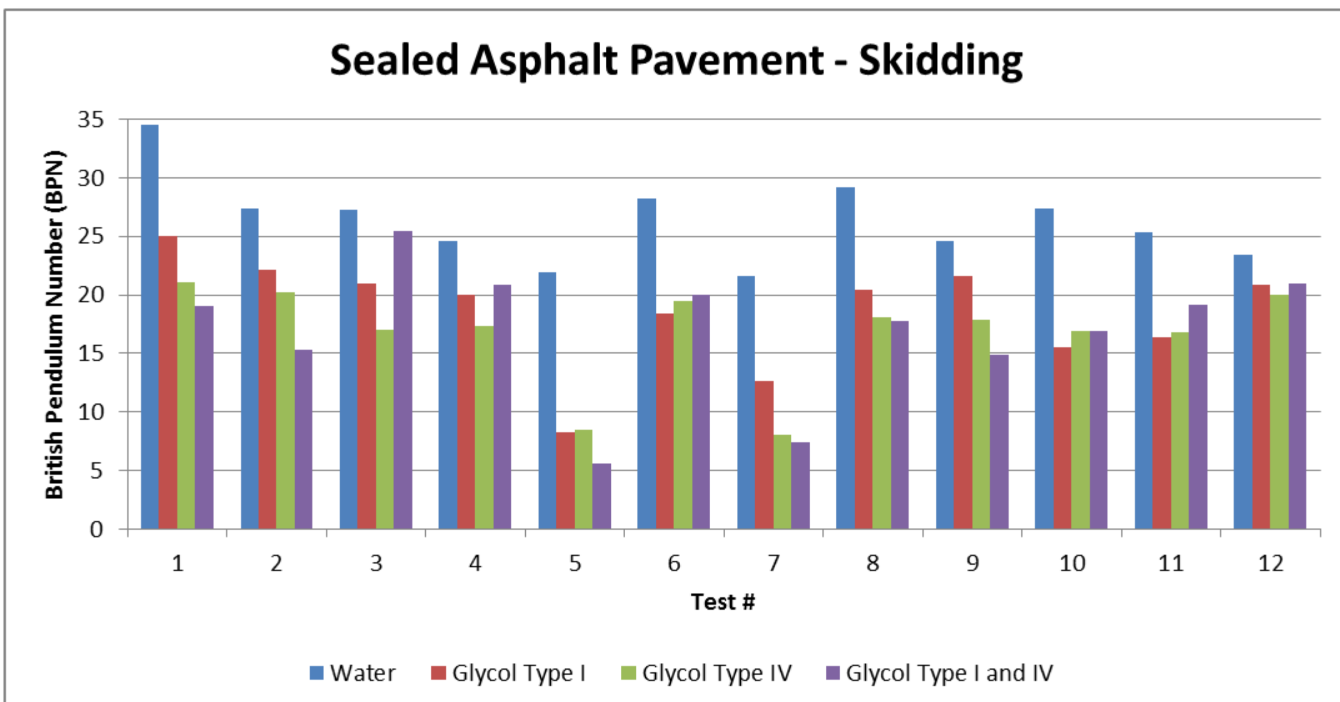

Figure 10: BPN Measurements on Sealed Asphalt Pavements

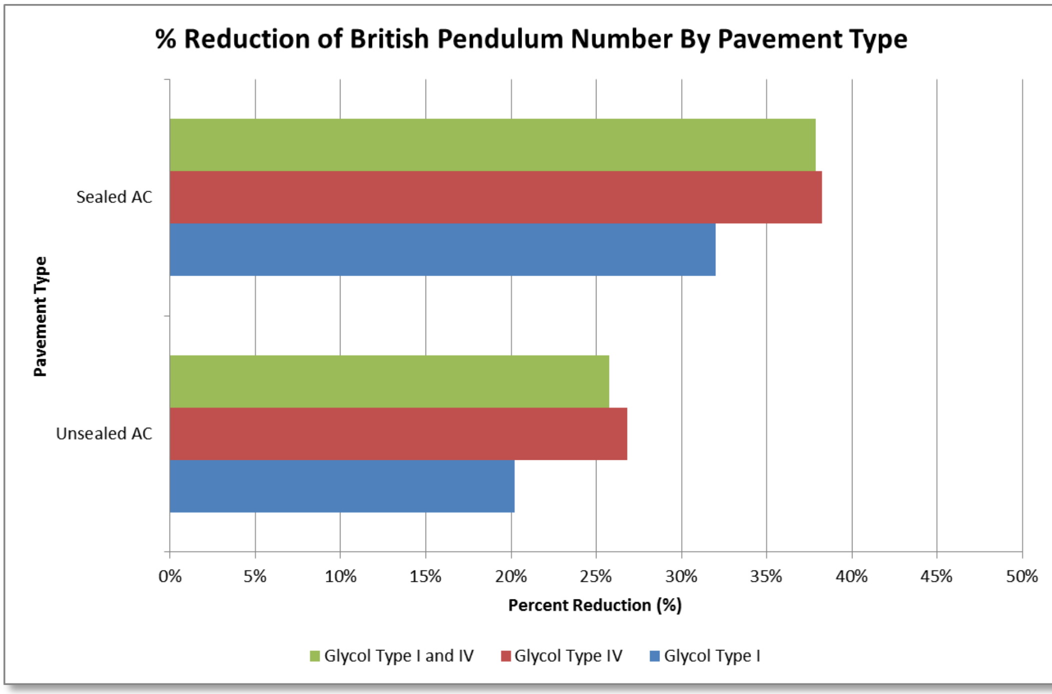

Figure 11: % Reduction in Skid Resistance by Pavement Type

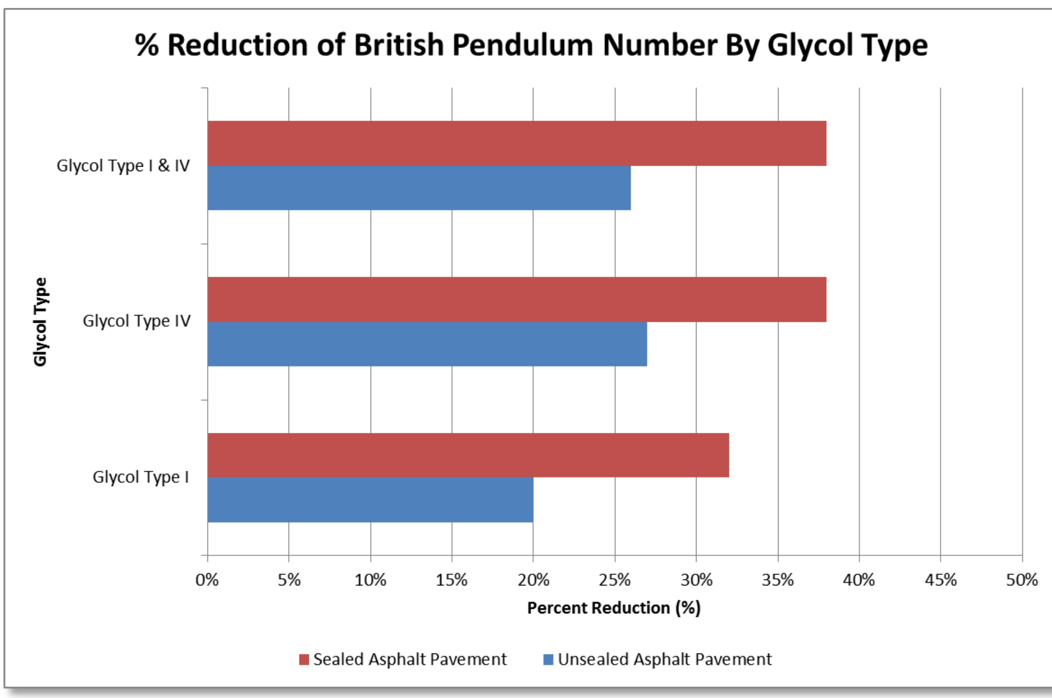

Figure 12: % Reduction in Skid Resistance by Glycol Type

Statistical Analysis – t-Test

A statistical analysis was used in order to help objectively evaluate the different BPN data sets taken from two pavement types and using four different wetting solutions. A t-test is a statistical examination of two sample population means. It is used to determine if two sets of data are significantly different from each other. For the purpose of this report, Welch's t-test was chosen for the analysis as the two sample sets had a possibility of having unequal variances.

The two sample means were compared using a two-tail distribution at a 95% confidence interval. If the determined p-value was calculated to be less than 0.05, the t-test would indicate that there was a significant difference between the two sample means. The results of the t-tests are summarized below in Tables 3 through 5.

Table 3: Difference in Skid Resistance Based on Solution Type

Statistical Difference in Skid Resistance Using Water/Glycol (Yes/No)		
Solution Type	**Sealed Pavement**	**Unsealed Pavement**
Water		**No**
Glycol Type I	Yes	Yes
Glycol Type IV	Yes	Yes
Glycol Type I/IV	Yes	Yes

Table 4: Difference in Skid Resistance Based on Pavement Type – Unsealed Pavements

Statistical Difference in Skid Resistance on Unsealed Pavements (Yes/No)				
Solution Type	**Water**	**Glycol Type I**	**Glycol Type IV**	**Glycol Type I/IV**
Water				
Glycol Type I	Yes			
Glycol Type IV	Yes	**No**		
Glycol Type I/IV	Yes	**No**	**No**	

Table 5: Difference in Skid Resistance Based on Pavement Type – Sealed Pavements

Statistical Difference in Skid Resistance on Sealed Pavements (Yes/No)				
Solution Type	**Water**	**Glycol Type I**	**Glycol Type IV**	**Glycol Type I/IV**
Water				
Glycol Type I	Yes			
Glycol Type IV	Yes	**No**		
Glycol Type I/IV	Yes	**No**	**No**	

In summary, there was no significant statistical difference in skid resistance between the unsealed and the sealed pavements. However, there was a significant statistical difference in skid resistance when introducing a glycol solution on the pavement surface for both pavement types.

Discussion

Very little pavement distress was observed on the asphalt pavements surrounding the terminal during the distress survey. This was expected as the asphalt pavements are relatively new since they were rehabilitated in 2010.

BPT measurements were collected on areas where the asphalt pavements were sealed and in areas where they were not sealed. Four different wetting solutions were used during testing in order to help identify the primary cause of the aircraft tire slippage in the ramp alley at the terminal.

Graphical and statistical analysis of the collected BPN measurements revealed that not one single element is driving the aircraft tire slippage, but a combination of factors is playing a part in the reduced skid resistance on the sealed pavement area. This is indicated by the similar BPN measurements, shown in Tables 1 and 2, on the sealed and unsealed pavements using water as a wetting solution. Furthermore the statistical analysis, shown in Table 3, demonstrates that there was no statistical difference in the frictional properties of the sealed and unsealed asphalt pavements using water as a wetting solution. The reduction in BPN is amplified by the glycol solutions on the sealed asphalt pavements as illustrated in Figures 11 and 12. Therefore, it can be inferred that the tire slippage is being caused by a combination of the asphalt sealant and the glycol solutions working collectively to reduce the frictional properties of the pavement.

It is important to note, that the BPN threshold for aircraft tire slippage was not identified as part of this study. However, since the BPT measurements were conducted with the same environmental conditions and test procedure utilizing the four different wetting solutions, it was possible to quantify the amount each experimental variable was contributing to the overall reduction in skid resistance. The three different glycol solutions used in the study were determined to contribute anywhere from 20% to 27% of the reduction in skid resistance, while the bituminous sealant used on the asphalt pavement was determined to contribute approximately 11% to 12% of the overall reduction in skid resistance.

Since the testing was done on both the unsealed and sealed pavements with all other variables being equal, the 11% to 12% additional reduction in BPN caused by the bituminous sealant in combination with the 20% to 27% reduction from the glycol solutions appears to be causing the aircraft tire slippage on the sealed asphalt pavements surrounding the gates at the terminal.

Recommendations

Several rehabilitation treatments were considered for the removal of the bituminous asphalt sealant on the pavements surrounding the ramp alley at several gates. These treatments included: conventional mill and overlay, micro-milling, non-structural overlay, diamond grinding, shot blasting and water blasting. Since the pavement structure is relatively new and appears to be in good overall condition, a maintenance treatment is the preferred treatment for a pavement in this condition.

In order to restore skid resistance to the asphalt pavements surrounding the gates at the terminal, it is recommended that the bituminous sealant be removed by shot or water blasting. This treatment will remove the thin film of the bituminous sealant and restore the macro- and microtexture of the pavements.

Short or water blasting was selected because it is cost-effective, relatively quick when compared to conventional pavement rehabilitation treatments and environmentally friendly. The process uses no chemicals or solvents, emits no pollutants or dust, and the removed material can be fully recycled. This treatment will restore both the macro- and microtexture on the asphalt pavement surface. It will allow the majority of the gates at the terminal to remain open with only minimal disruption and redirection of traffic while the contractor performs the specified number of passes over the sealed asphalt pavements.

Rehabilitation Strategy Implementation

It was decided to proceed with the water blasting rehabilitation strategy rather than shot blasting due to the fact that there was more local contractor experience with the water blasting treatment. In order to determine the water blasting setting and the required number of passes, several test strips were conducted by the selected contractor.

A Dynatest 6875 Runway Friction Tester (RFT) was used to quantify the increase in the pavement's frictional properties with varying water blasting settings and number of passes by measuring the non-dimensional friction coefficient (μ).

This force (μ) is the ratio of the tangential friction force (F) between the rubber tire tread and the horizontal traveled surface to the perpendicular force (Fw) and is computed using the equation below (NCHRP 2009):

$$\mu = \frac{F}{Fw}$$

The higher the measured friction, or (μ), the more force available to resist the forward motion of a vehicle's tire with relation to the pavement surface.

The friction testing was conducted using the ASTM E1551 test tire on the RFT. A similar test procedure to the one used for the BPT was applied. There were three sets of tests conducted on six different surface types:

Tests

1. Using water to wet the pavement surface
2. Using the deicing fluid (glycol) to wet the pavement surface
3. Vacuuming the deicing fluid (glycol) wetted surfaces prior to testing

Surface Types

1. Unsealed pavement surface
2. Sealed pavement surface

3. WB1 – water blasting setting 1
4. WB2 – water blasting setting 2
5. WB3 – water blasting setting 3
6. WB4 – water blasting setting 4

The measured friction (µ) as well as the standard deviation for each test and surface type is shown below in Table 6.

Table 6: Measured Friction (µ) Using the RFT

Surface Type	Water on Surface		Glycol on Surface		Vacuumed Surface	
	µ	St. Dev.	µ	St. Dev.	µ	St. Dev.
Unsealed	0.688	0.078	0.498	0.059	0.512	0.058
Sealed	0.606	0.072	0.374	0.053	0.401	0.056
WB1	0.713	0.095	0.397	0.082	0.513	0.088
WB2	0.65	0.077	0.601	0.084	0.613	0.078
WB3	0.632	0.091	0.454	0.124	0.576	0.096
WB4	0.725	0.084	0.595	0.152	0.519	0.077

Similar to the BPN results shown above, the presence of the glycol solution on the pavement surface provides a significant drop in measured friction (µ). It is also important to note that the vacuumed surface does not provide a significant improvement over the glycol wetted surfaces. Each of the water blasting settings provides an improvement in the frictional characteristics of the pavement surface. From the measured values, it was determined that the WB2 setting provided the most consistent improvement across all conditions and was selected for use in the rehabilitation of the sealed pavement surfaces.

References

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