Non-Destructive Structural Asset Valuation of a Saskatchewan Rural Airfield Before and After Structural Upgrade.

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ABSTRACT
The Saskatchewan Ministry of Highways and Infrastructure is responsible for maintaining several northern Saskatchewan airfields. The Meadow Lake Airfield provides year round air service as well as a fire fighting support base to northern communities. In 2006, several areas of the Meadow Lake Airfield received structural rehabilitation treatments. The objectives of the structural asset management survey were to evaluate the potential use of ground penetrating radar (GPR) to quantify *in situ* structural composition, to evaluate the use of integrated GPR and heavy weight deflection (HWD) measurements and derive conventional Transport Canada Pavement Load Ratings (PLR), to quantify *a priori* structural asset management values of the airfield pavement sections, and to allocate and distribute funds into necessary rehabilitation and preservation treatments. An additional objective was to explicitly quantify the structural value added from the rehabilitation and preservation treatments performed in 2006.

Based on the structural asset management survey using non-destructive GPR and HWD measurements, it was found that the structural rehabilitation treatments improved the surface quality and the structural response of the Meadow Lake Airfield and reduced subsequent variability. In summary, the structural asset management GPR and HWD measurement approach to surveying airfield pavement before and after various rehabilitation treatments demonstrates a reliable and repeatable means to measure structural improvements without damaging the airfield asset with conventional PLR test methods.

INTRODUCTION

Saskatchewan Ministry of Highways and Infrastructure is responsible for the maintenance and operation of seventeen airfields in northern Saskatchewan (1). These airfields range from gravel runways to fully paved airports providing critical northern air services and serving as fire fighting support bases for protection of the northern boreal forest. The Meadow Lake Airfield is one of the major northern Saskatchewan paved airfields maintained by Saskatchewan Ministry of Highways and Infrastructure.

In June 2005, a non-destructive ground penetrating radar (GPR) and heavy weight deflection (HWD) structural asset management survey was performed on the airfield assets of the Meadow Lake Airfield. The six pavement sections surveyed included the turnabout, main runway, crosswind runway, parking apron, taxiway, and water bomber apron, as illustrated in Figure 1.

The objectives of the structural asset management survey were as follows:

- To evaluate the potential use of GPR to quantify *in situ* structural composition;
- To evaluate the use of integrated GPR and HWD measurements to derive conventional Transport Canada Pavement Load Ratings (PLR):
- To quantify the pre-design and pre-construction structural asset management values of the airfield pavement sections:
- To help allocate and distribute funds into necessary rehabilitation and preservation treatments; and
- To explicitly quantify the structural value added from rehabilitation and preservation treatments.

Table 1 summarizes the rehabilitation and preservation treatments performed on the Meadow Lake Airfield in 2006.

GROUND PENETRATING RADAR RESULTS

A GPR survey was performed to determine the structural layer thicknesses, the dielectric permittivity profiles, and the surface layer quality index across the airfield assets. GPR data was collected in several passes across the full width of each airfield asset.

GPR Asphalt Concrete Surfacing Thickness

Table 2 summarizes and Figure 2 illustrates the *a priori* asphalt concrete surfacing thickness measured across each asset section of the Meadow Lake Airfield. As seen in Table 2 and Figure 2, all the airfield assets showed relatively high variability in asphalt surfacing thickness, indicating that variable preservation treatments may have been previously constructed.

GPR Granular Base Structure Thickness

Table 3 summarizes and Figure 3 illustrates the *a priori* granular base structure thickness measured across each asset section of the Meadow Lake Airfield. As seen in Table 3 and Figure 3, the depth of the granular base structure on the main runway exceeded the limits of the GPR (greater than 750 mm). The moisture differential of the water bomber apron between the base and subbase interface was insufficient to provide meaningful results, therefore measurements could not be made for either of these sections. The granular base thickness was found to vary significantly across the airfield assets compared to the taxiway and parking apron.

GPR Granular Base Dielectric Permittivity

The Meadow Lake Airfield is located in a relatively low lying area with a high water table. As a result, moisture infiltration from the subgrade due to pumping related to slow-moving heavily loaded aircraft is a performance concern of the Saskatchewan Ministry of Highways and Infrastructure. Table 4 summarizes and Figure 4 illustrates the granular base dielectric permittivity summary statistics measured across each asset of the Meadow Lake Airfield. Based on the dielectric permittivity profiles, the main runway and crosswind runway exhibited relatively dry granular base dielectric permittivity values typical of thicker pavement structures. The taxiway, parking apron and water bomber apron showed increased dielectric permittivity values that may indicate wetting up of the *in situ* granular base. It is suspected that the high water table and heavily loaded water bombers may be pumping water up into the granular base.

GPR Surface Layer Quality Index

The surface layer quality index is a measure of the integrity and uniformity of the asphaltic surface to an approximate depth of 75 mm. Table 5 summarizes and Figure 5 illustrates the average surface layer quality index as measured across each asset of the Meadow Lake Airfield *a priori* (2005) and post construction (2007). As seen in Table 5 and Figure 5, the pavement rehabilitation and preservation treatments improved the surface layer quality index across all assets that received a hot mix asphalt concrete overlay.

The east end of the taxiway did not receive a rehabilitation/preservation treatment, therefore the mean surface layer quality index did not change significantly from *a priori* to post construction. The GPR survey was not performed post construction on the parking apron or on the water bomber apron due to operations restriction. Therefore, the results could not be compared.

HEAVY WEIGHT DEFLECTION RESULTS

Surface deflection measurements obtained by HWD testing are an indication of the structural response of the airfield pavement as an operating system. Due to the varying nature of the airfield assets, the testing load spectra were adjusted to represent field state conditions. The main runway was tested with additional weights in order to create loading spectra similar to operating weights commonly experienced. The thinner pavement structures, such as the taxiway and water bomber apron, were tested with lower weights in order to keep the deflections within the measurement limits of the HWD. On all of the airfield assets, four measurements were taken at varying loads and a regression analysis was performed to extrapolate the data over a minimum and maximum operating loadings.

Peak Surface Deflection Profiles

Peak surface deflection profiles were calculated across load spectra representative of the minimum and maximum load rating for a Convair 580 aircraft, representative of typical air traffic at this airport. In addition, peak surface deflection profiles for the minimum and maximum load rating for a Hercules C130 were also calculated as the airfield can be subjected to these heavier loadings in emergency situations.

Tables 6 and 7 summarize and Figures 6 and 7 illustrate the peak surface deflections *a priori* and post construction of the Meadow Lake Airfield pavement sections across minimum and maximum load ratings for the Convair 580 and the Hercules C-130 aircraft. As seen in Figures 6 and 7, the pavement assets at the Meadow Lake Airfield that received structural rehabilitation yielded a significantly lower mean and range in peak surface deflection primary response.

Both pre and post construction peak surface deflection responses of the main runway were the lowest of the airfield assets across the applied load spectra due to the increased pavement structure thickness required for landing aircrafts. Overall, with the exception of the taxiway, peak surface deflections reduced post construction. The portion of the taxiway that did not receive a structural treatment increased in mean primary structural deflection response from the *a priori* survey performed in 2005 to the post construction survey performed in 2007. These results show a reduction in structural performance from 2005 to 2007 without rehabilitation or preservation treatments.

PAVEMENT LOAD RATING MODEL ANALYSIS

Transport Canada employs empirical-based Pavement Load Rating (PLR) factors to rate the load carrying capacity of airfield pavement structures (2). The Transport Canada PLR values were developed to provide a performance based uniform measure of airfield structural performance across Canada. PLR values report the strength of airfield pavement and reflect which aircrafts can operate on them (2). Conventional PLR factors are used for new design and construction of airfields. To calculate the PLR values of airfields that require rehabilitation, a section of the airfield pavement is physically removed and the subgrade is tested. PLR values are then calculated based on assumed structural material properties (2). Based on the non-destructive structural asset management measures performed in this study, the PLR factors were calculated for all airfield assets sections of the Meadow Lake Airfield. The PLR factors are based on the non-destructive testing results and Transport Canada's calculation procedures for measuring airfield pavements (2).

The following assumptions were made to calculate the Transport Canada PLRs as specified by the Transport Canada manuals (2).

- Poor asphaltic surfacing
- Crushed gravel base
- Granular subbase
- Layer thicknesses as measured by ground penetrating radar, or assumed as-built thicknesses where ground penetrating radar could not measure
- One load repetition
- 457 mm load plate diameter
- Load applied on the surface to generate 1.25 mm deflection
- High plastic clay subgrade
- Water table within one meter of the surface

A Priori Pavement Load Rating

Figure 8 illustrates the PLRs determined for each Meadow Lake Airfield asset with respect to the subgrade bearing strength calculated using the HWD deflection measurements and the GPR measurement of pavement equivalent thicknesses calculated prior to the rehabilitation project. The PLR gradient lines presented were calculated using a computer model encoded with the Transport Canada PLR calculations. Table 8 summarizes and Figure 9 illustrates the PLRs calculated from each section of the Meadow Lake Airfield with respect to the subgrade bearing strength and the pavement equivalent thickness *a priori* and post construction.

As seen in Table 8 and Figure 9, the Meadow Lake Airfield sections that received structural rehabilitation showed an increase in Transport Canada mean PLRs, as well as a decrease in the variability of the PLR values. As seen in Figure 9, the minimum PLR across the airfield ranged from 13 on the main runway to six on the parking apron and the water bomber apron. In addition, it can be seen that some variability exists across each pavement section in terms of pavement load rating. The variability in PLR values concur with the variability observed in the primary deflection responses.

VALUE-BASED STRUCTURAL ASSET MANAGEMENT ANALYSIS OF PROPOSED PLR STRUCTURAL IMPROVEMENTS

A structural upgrade of the Meadow Lake Airfield was undertaken in the summer of 2006. The airfield was split into sections designated by either PLR 8 or PLR 6 based on the type and frequency of traffic set by the Ministry, as seen in Table 9. As seen in Table 9, the percentage of the airfield section that had a PLR less than the design PLR (PLR 8 or 6) *a priori* and post construction is summarized. This analysis was performed for each individual deflection measurement in order to determine percentage of measurements within each airfield section failing the target PLR. The main runway and turnabout proved to be structurally sound and therefore only required minor surface treatment in order to achieve a design PLR of 8. As seen in Table 9 and Figure 10, the south portion of the crosswind and west portion of the taxiway illustrate the highest value for money in terms of improved PLR. As seen in Figure 10 the parking apron and water bomber apron are also showing a high return on the capital investments in terms of improved PLR.

The empirical-based airfield pavement upgrade needs concurred with the mechanistic structural analysis performed across the Meadow Lake Airfield assets using the model developed in this study. As a result, the mechanistic based model developed in this study accurately determined the potential benefits of various airfield upgrade investment strategies.

CONCLUSIONS AND RECOMMENDATIONS

In 2006, the Meadow Lake Airfield received structural rehabilitation and preservation treatments. The objectives of the structural asset management survey was to evaluate the potential use of GPR to quantify *in situ* structural composition, to evaluate the use of integrated GPR and HWD measurements to derive conventional Transport Canada Pavement Load Ratings (PLR), to quantify the *a priori* structural asset management values of the airfield pavement sections and to help allocate and distribute funds into necessary rehabilitation and preservation treatments, and to explicitly quantify the structural value added realized from the rehabilitation and preservation treatments performed in 2006.

Based on the findings of the structural asset management survey, the Meadow Lake Airfield structural rehabilitation treatments improved the surface layer quality index, as well as the structural primary response. The primary deflection response profiles and the Transport Canada PLR measures also showed the same or slight reduction in the structural primary response of the portion of the taxiway that did not receive a structural rehabilitation treatment. Therefore, the mechanistic primary response based model correlated well with estimated PLR calculations employed by Transport Canada. An added benefit of the mechanistic structural asset management approach to structurally assessing airfield pavement assets and PLR values is the ability to directly quantify structural integrity as well as variability in structural integrity without damaging the pavement.

In summary, the integrated ground penetrating radar and heavy weight deflection approach to structural asset management of airfield assets has proven to provide reliable measures of pavement assets before and after various rehabilitation treatments. This study demonstrated the ability to employ mechanistic deflection response data to accurately predict the primary deflection response of airfield pavements as well as estimate Transport Canada PLR calculations.

REFERENCES

(1) *Ministry Overview*. Saskatchewan Ministry of Highways and Infrastructure, Government of Saskatchewan. www.highways.go.sk.ca/department-overview/. Accessed July 30, 2008.

(2) Public Works & Government Services Canada, Architectural and Engineering Services, Air Transportation. *Pavement Structural Design Training Manual.* Publication ATR-021(AK-77-68-300). Transport Canada, 1995.

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Table 1 Meadow Lake Airfield Rehabilitation and Preservation Treatments

Pavement Asset	Structural Rehabilitation/Preservation Treatment
Main Runway	Mill 20 mm and fill 50 mm HMAC
Crosswind Runway (from Main Runway to Taxiway)	Mill 20 mm and fill 80 mm HMAC
Crosswind Runway (from Taxiway to North End)	Mill 20 mm and fill 40 mm HMAC
Taxiway (from East End to Parking Apron)	No treatment
Taxiway (from Parking Apron to Crosswind Runway)	Mill 20 mm and fill 80 mm HMAC
Parking Apron	Mill 20 mm and fill 80 mm HMAC
Water Bomber Apron	Rotomix top 200 mm existing, add 100 mm granular base coarse and 80 mm HMAC

Table 2 *A Priori* GPR Asphalt Concrete Surfacing Thickness Summary Statistics

	***A Priori* Average (mm)**	***A Priori* Minimum (mm)**	***A Priori* Maximum (mm)**
Main Runway	108	69	129
Crosswind Runway	111	57	140
Taxiway	85	60	103
Parking Apron	88	59	133
Water Bomber Apron	105	96	117

Table 3 *A Priori* GPR Granular Base Structure Thickness Summary Statistics

	***A Priori* Average (mm)**	***A Priori* Minimum (mm)**	***A Priori* Maximum (mm)**
Main Runway	>750	N/A	N/A
Crosswind Runway	293	105	447
Taxiway	226	175	301
Parking Apron	177	116	240
Water Bomber Apron	N/A	N/A	N/A

Table 4 *A Priori* GPR Granular Base Dielectric Permittivity Summary Statistics

	***A Priori* Average**	***A Priori* Minimum**	***A Priori* Maximum**
Main Runway	7.0	4.9	14.2
Crosswind Runway	6.4	4.9	10.4
Taxiway	12.5	7.4	18.6
Parking Apron	10.8	5.7	22.1
Water Bomber Apron	9.2	5.8	11.3

Table 5 GPR Surface Layer Quality Index Summary Statistics

	A Priori			Post Construction		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Main Runway	81	50	94	88	59	96
Crosswind Runway (Main to Taxiway)	73	43	90	89	74	97
Crosswind Runway (Taxiway to North End)	77	54	91	89	73	97
Taxiway (East End to Parking Apron)	71	34	88	72	27	92
Taxiway (Parking Apron to Crosswind)	71	13	90	91	73	97
Parking Apron	82	9	96	-	-	-
Water Bomber Apron	74	0	98	-	-	-

Table 6 Convair 580 HWD Peak Surface Deflection Summary Statistics

	A Priori			Post Construction		
	Average (mm)	Minimum (mm)	Maximum (mm)	Average (mm)	Minimum (mm)	Maximum (mm)
	Minimum Load Convair 580 (70.5 kN)					
Main Runway	0.9	0.4	1.4	0.7	0.4	1.2
Crosswind Runway (Main to Taxiway)	2.5	0.7	3.5	1.7	1.0	2.5
Crosswind Runway (Taxiway to North End)	2.8	2.3	3.8	2.3	1.7	2.9
Taxiway (East End to Parking Apron)	2.9	2.2	4.3	3.3	1.6	5.0
Taxiway (Parking Apron to Crosswind)	2.5	1.9	3.3	1.6	1.2	1.8
Parking Apron	2.7	1.8	3.7	1.7	1.2	2.3
Water Bomber Apron	2.4	1.0	3.9	1.4	1.0	2.2
	Maximum Load Convair 580 (121.8 kN)					
Main Runway	1.5	1.0	2.4	1.2	0.7	2.0
Crosswind Runway (Main to Taxiway)	4.7	1.1	6.6	3.1	1.7	4.6
Crosswind Runway (Taxiway to North End)	5.2	4.3	6.8	4.0	2.9	4.7
Taxiway (East End to Parking Apron)	5.5	4.3	8.3	6.2	3.0	9.9
Taxiway (Parking Apron to Crosswind)	4.7	3.4	6.2	2.9	2.2	3.3
Parking Apron	4.7	3.2	6.5	3.2	2.3	4.2
Water Bomber Apron	4.3	1.5	7.4	2.5	1.6	3.9

Table 7 Hercules C-130 HWD Peak Surface Deflection Summary Statistics

	A Priori			Post Construction		
	Average (mm)	Minimum (mm)	Maximum (mm)	Average (mm)	Minimum (mm)	Maximum (mm)
	Minimum Load Hercules C-130 (161.5 kN)					
Main Runway	2.1	1.4	3.2	1.6	0.9	2.6
Crosswind Runway (Main to Taxiway)	6.4	1.4	9.1	4.3	2.2	6.2
Crosswind Runway (Taxiway to North End)	7.2	5.9	9.4	5.3	3.8	6.4
Taxiway (East End to Parking Apron)	7.6	6.0	11.6	8.5	4.1	14.0
Taxiway (Parking Apron to Crosswind)	6.5	4.5	8.6	4.0	3.1	4.6
Parking Apron	6.3	4.3	8.6	4.4	3.2	5.7
Water Bomber Apron	5.9	1.9	10.3	3.3	2.0	5.5
	Maximum Load Hercules C-130 (329.2 kN)					
Main Runway	4.4	2.8	13.8	3.2	1.8	5.0
Crosswind Runway (Main to Taxiway)	14.5	2.6	20.7	9.3	4.2	13.4
Crosswind Runway (Taxiway to North End)	16.3	13.3	22.6	10.8	7.6	13.9
Taxiway (East End to Parking Apron)	17.4	13.0	27.2	19.2	9.3	34.0
Taxiway (Parking Apron to Crosswind)	14.7	9.1	20.3	9.2	6.6	10.8
Parking Apron	13.0	9.2	18.2	10.0	7.3	12.7
Water Bomber Apron	12.7	3.4	23.5	6.9	3.6	12.4

Table 8 Pavement Load Rating Summary Statistics

	A Priori			Post Construction		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Main Runway	13	11	13	13	12	13
Crosswind Runway (Main to Taxiway)	9	8	13	10	9	12
Crosswind Runway (Taxiway to North End)	9	7	10	13	13	13
Taxiway (East End to Parking Apron)	8	7	10	8	5	11
Taxiway (Parking Apron to Crosswind)	10	8	11	11	11	12
Parking Apron	9	6	13	11	9	11
Water Bomber Apron	9	6	13	11	9	12

Table 9 Percent Failing Desired Pavement Load Rating

	A Priori	Post-Construction	Value Added
		Design Target PLR 8	
Main Runway	1%	0%	1%
Crosswind Runway South	85%	23%	62%
Taxiway West	100%	17%	83%
		Design Target PLR 6	
Crosswind Runway North	0%	0%	0%
Taxiway East	20%	20%	0%
Parking Apron	64%	27%	47%
Water Bomber Apron	44%	0%	44%

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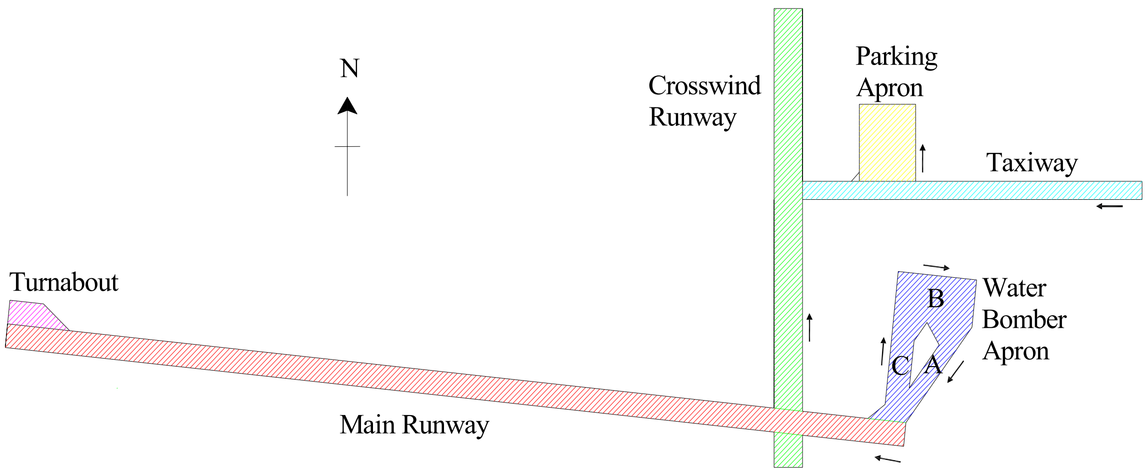


Figure 1 Meadow Lake Airfield Pavement Sections and Site Layout

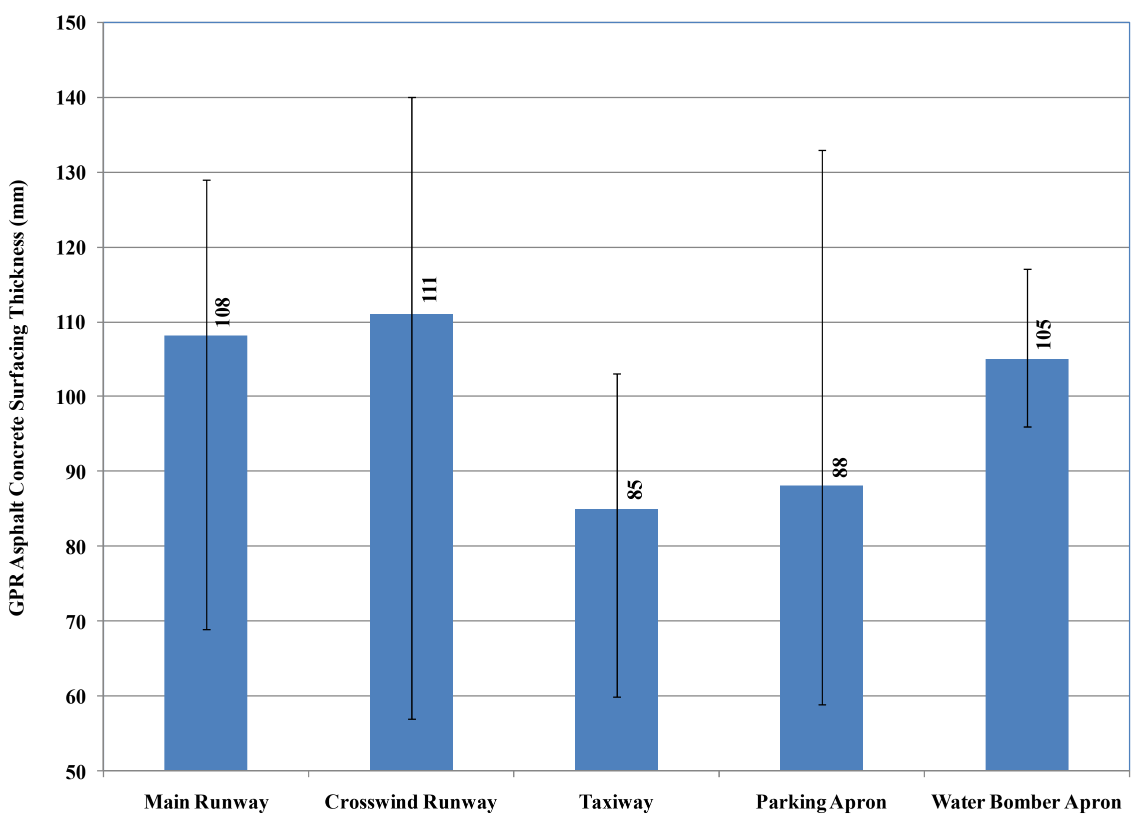


Figure 2 *A Priori* GPR Asphalt Concrete Surfacing Thickness Summary Statistics (±min/max)

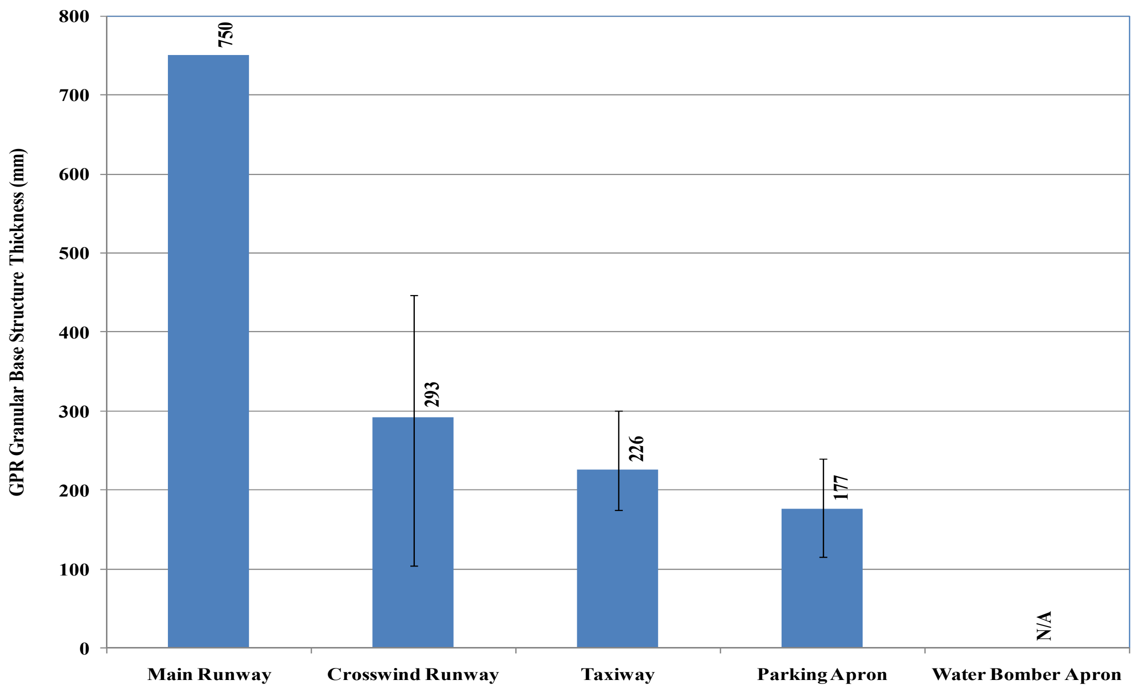


Figure 3 ***A Priori*** **GPR Granular Base Structure Thickness Summary Statistics (±min/max)**

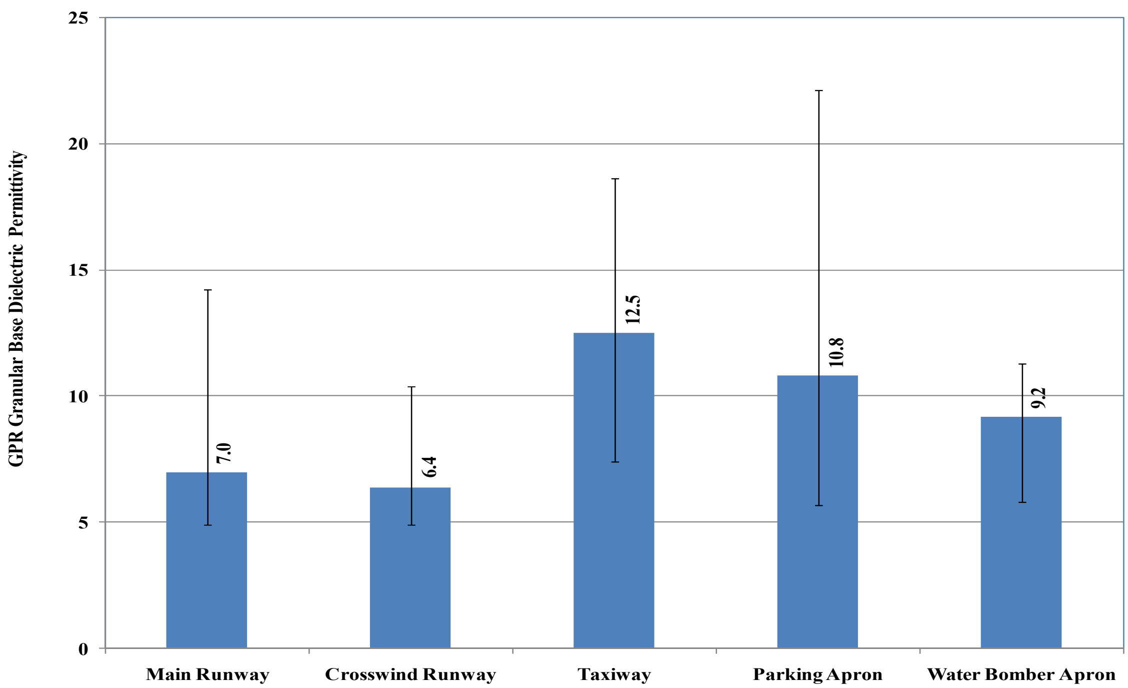


Figure 4 ***A Priori*** **GPR Granular Base Dielectric Permittivity Summary Statistics (±min/max)**

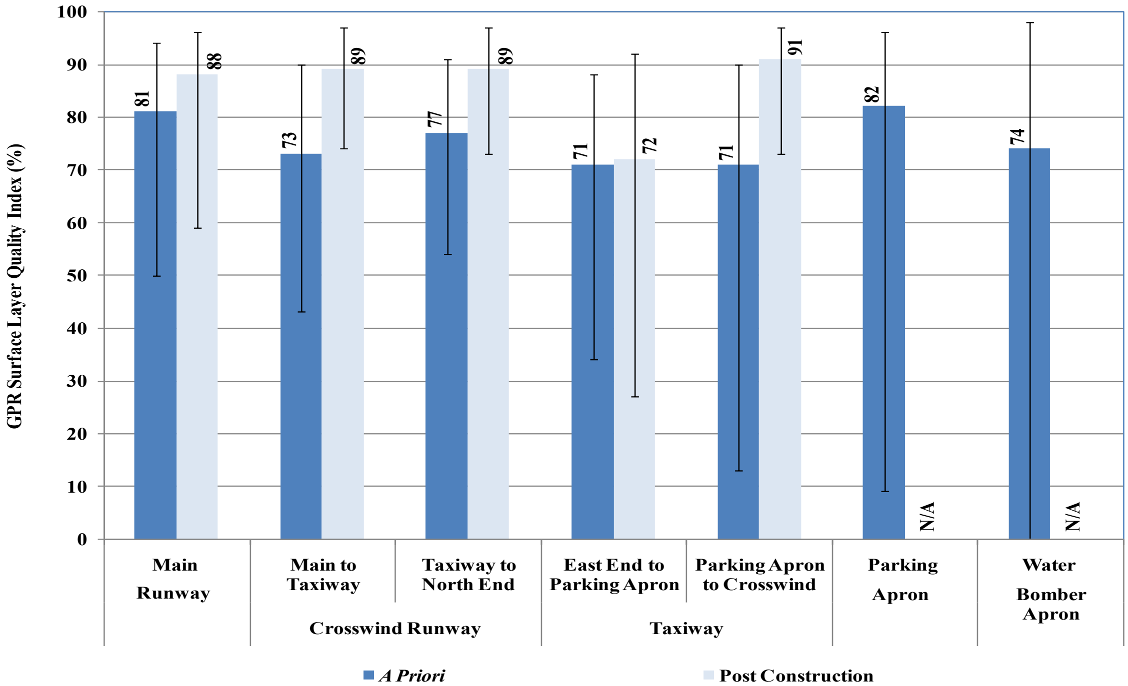
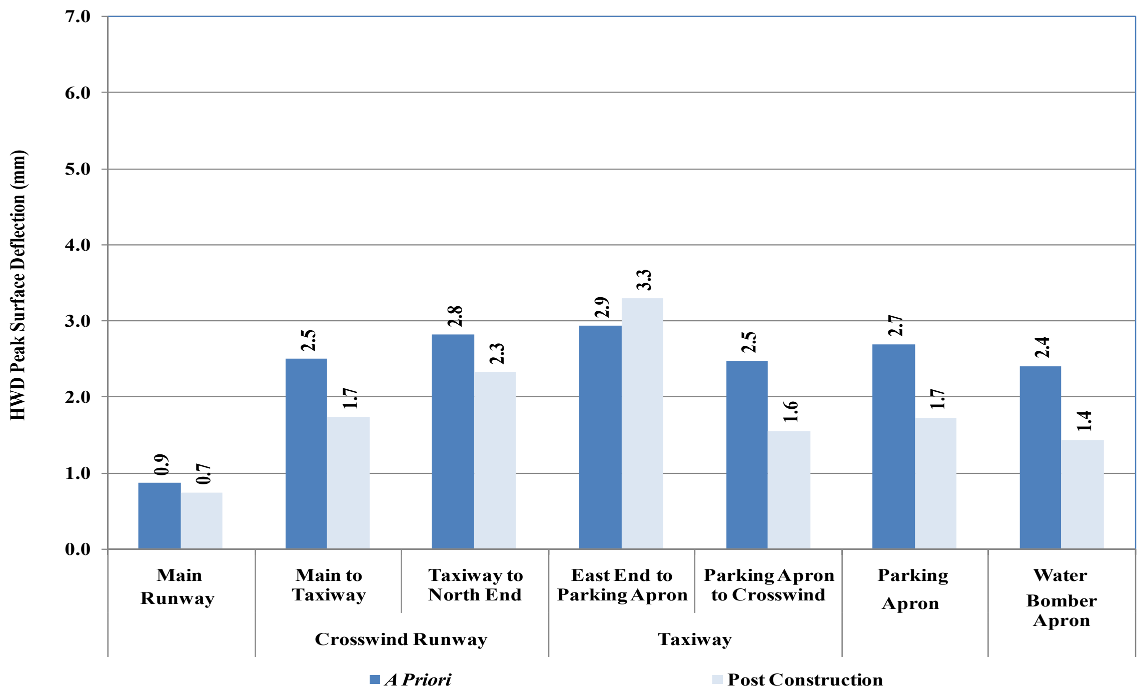
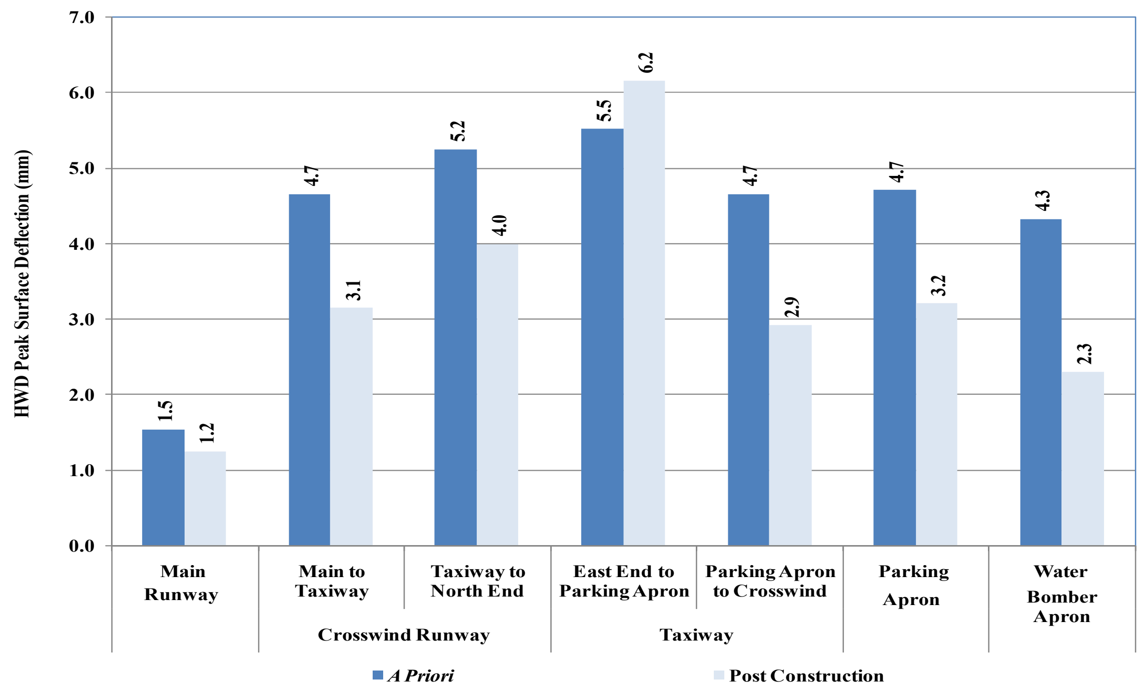


Figure 5 GPR Surface Layer Quality Index Summary Statistics (±min/max)

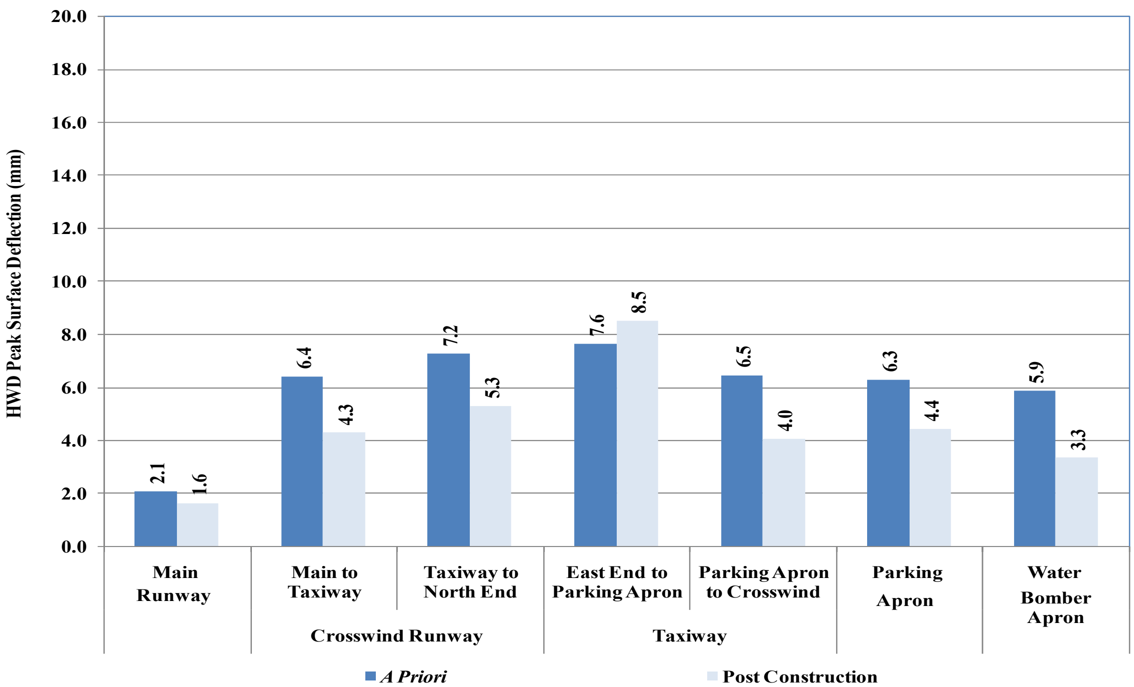


(a) Minimum Load

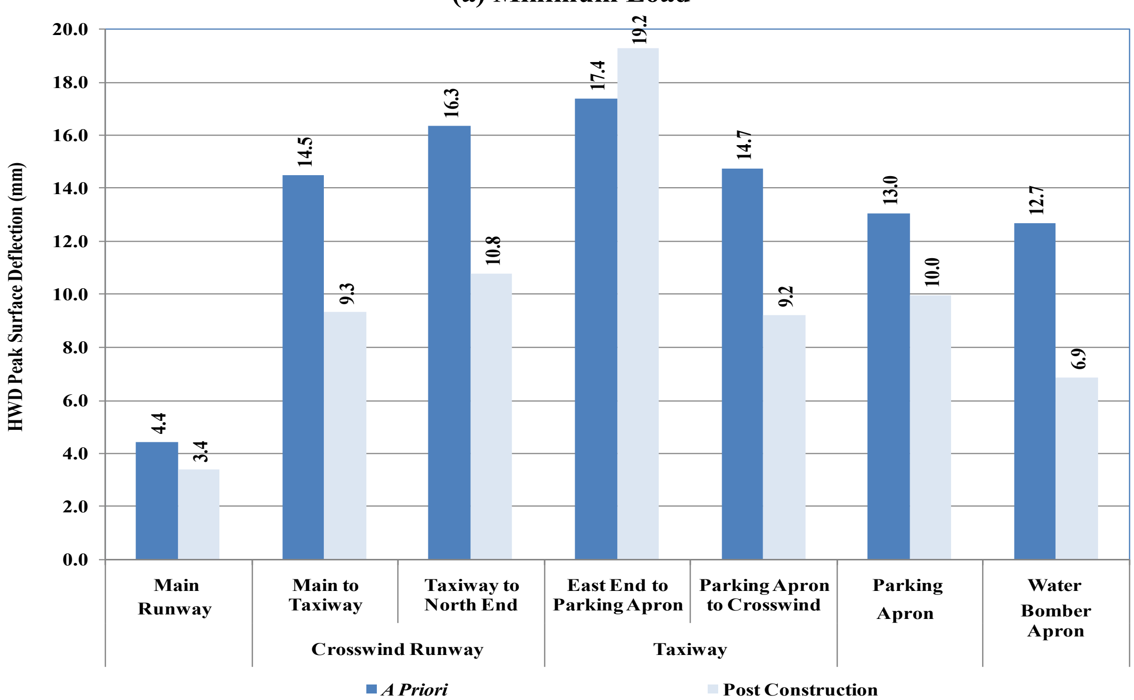


(b) Maximum Load

Figure 6 Convair 580 HWD Peak Surface Deflection Summary Statistics



(a) Minimum Load



(b) Maximum Load

Figure 7 Hercules C-130 HWD Peak Surface Deflection Summary Statistics

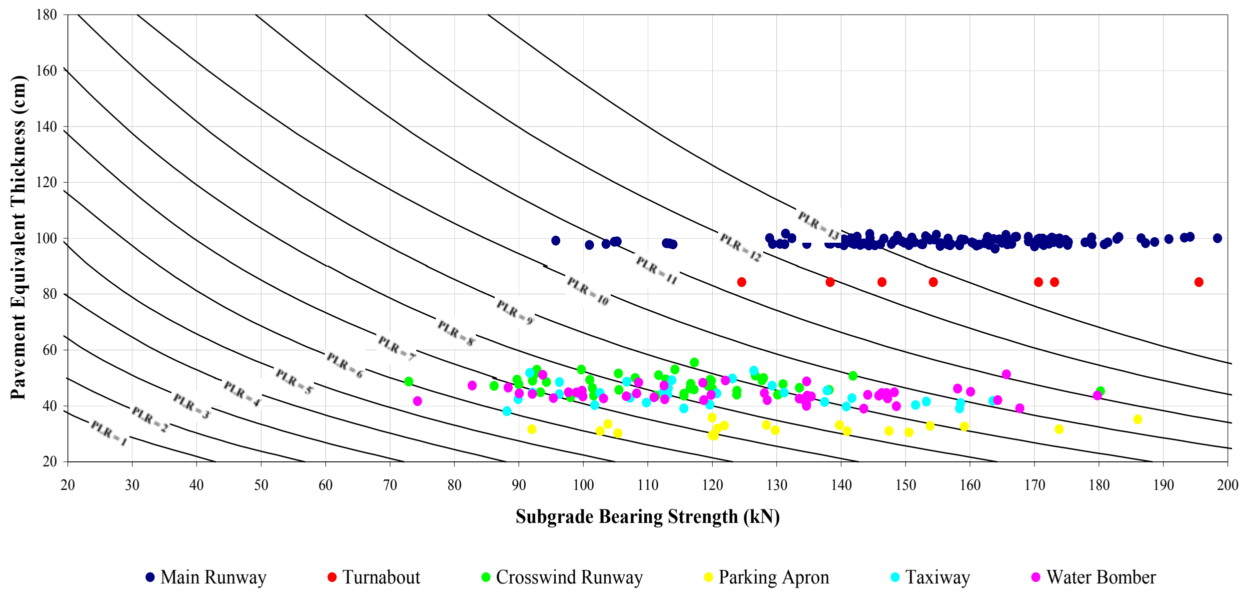


Figure 8 ***A Priori*** **Transport Canada Pavement Load Ratings**

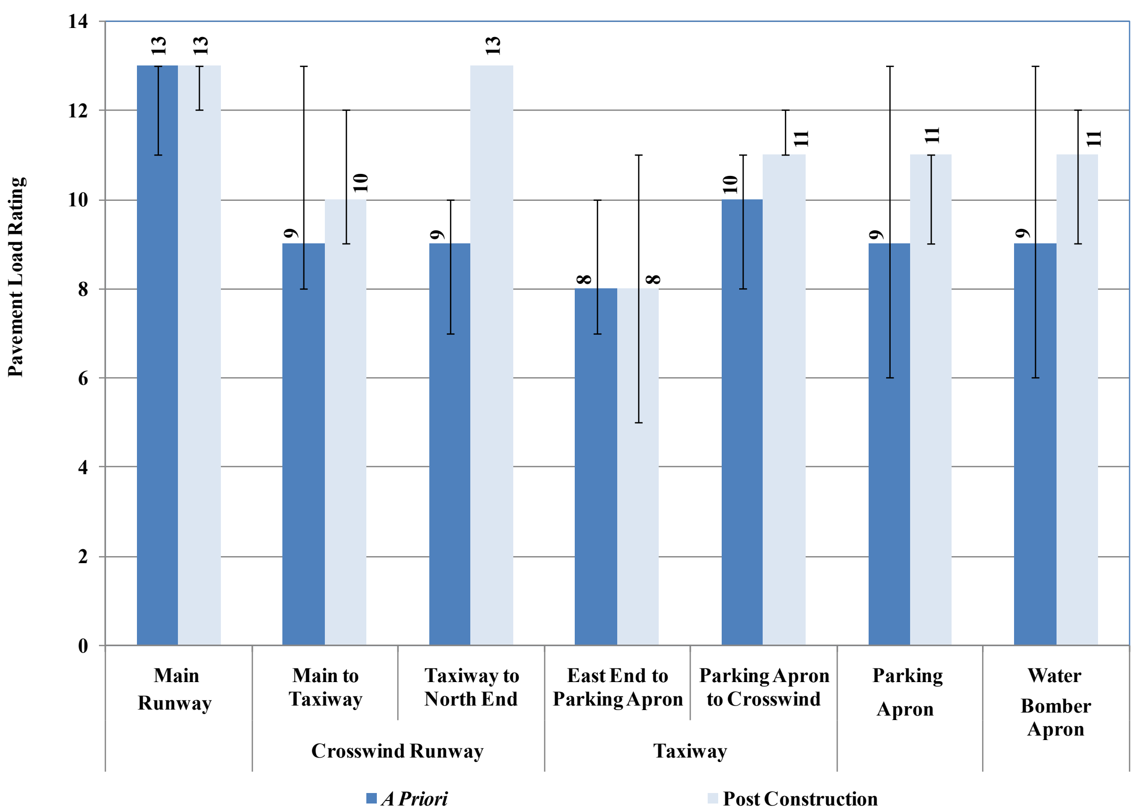


Figure 9 Pavement Load Rating Summary Statistics (±min/max)

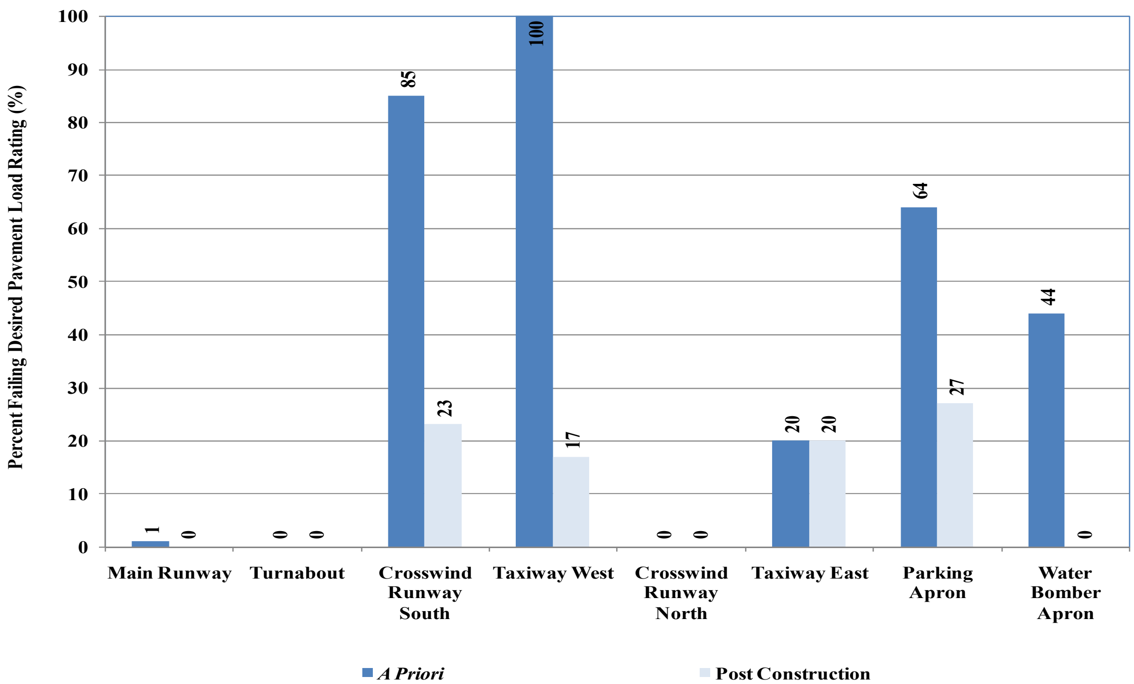


Figure 10 Percent Failing Desired Pavement Load Rating