University of Southern Indiana
Pott College of Science, Engineering, and Education
Engineering Department

8600 University Boulevard
Evansville, Indiana 47712

Cargo Development Redesign
O'Hare International Airport

Ali Lamb, Carlos Solis Rodriguez, and Andrew Routh
ENGR 491 – Senior Design
Fall 2023

Acknowledgements

In this section, we would like to acknowledge our civil engineering professors Dr. Adam Tennant, Dr. Jason Hill, and Dr. Kerry Hall for their guidance throughout our college careers and this senior design project. We would also like to acknowledge Dr. Paul Kuban for his encouragement throughout the project. Lastly, we would like to thank our industrial liaison Brian Quinlan for providing us with the work along with Jorge Rueda for his help as well. We were fortunate to receive assistance along the way from various other professionals not mentioned above as well.

ABSTRACT

The purpose of this project was to complete a redesign of a cargo development project recently completed at O'Hare International Airport (ORD) in Chicago, Illinois with the intent of analyzing how the change of design standards affects the design previously completed on this project. These changes affected the design of the proposed taxi-lane and drainage square yard items. A life cycle cost analysis was also conducted to decide which pavement to use for design. These objectives were completed using present day Federal Aviation Administration (FAA) and Illinois Department of Transportation (IDOT) standards. Overall, this redesign was completed to analyze discrepancies between past/current design standards and how the design would be done differently present-day.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

O'HARE INTERNATIONAL AIRPORT CARGO DEVELOPMENT REDESIGN

1 INTRODUCTION

1.1 PROJECT BACKGROUND

Over the last decade, Burns and McDonnell has been working with O'Hare International Airport (ORD) on a cargo development project on the northeast side of the airport. This area, displayed in *Figure 1: 2015 Project Area,* previously housed a military building that was not used anymore. Therefore, the airport decided to tear this building down with the military's permission and develop the area for cargo. This project consisted of three design/construction phases which resulted in two new cargo buildings, a new apron area for fueling and loading/unloading cargo planes, a taxi-lane within the apron area, and a new taxiway parallel to the existing Runway 4L-22R and Taxiway NN. Overall, the project was able to create an area for 11 cargo planes to park and around 900,000 square feet of developed cargo area.

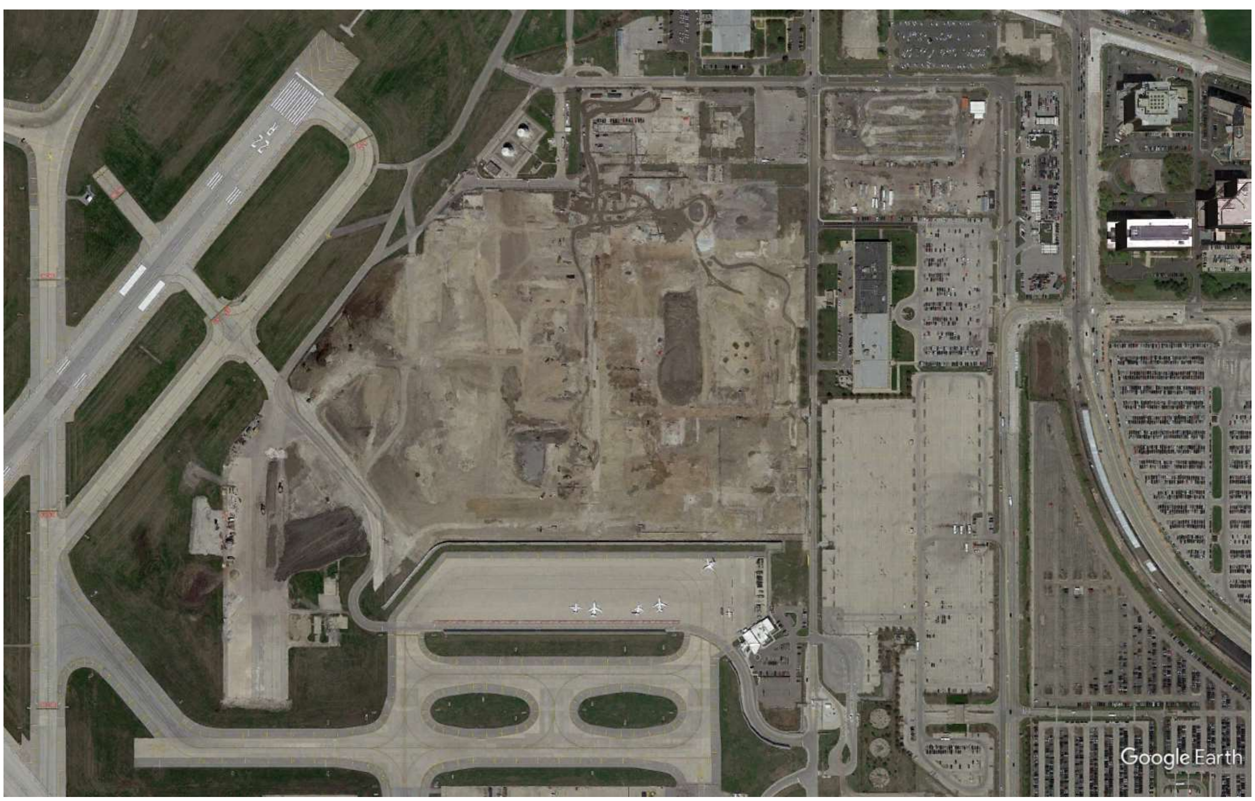

Figure 1: 2015 Project Area

1.2 INDUSTRIAL LIAISON

Brian Quinlan was the industrial liaison on this project. Brian has been a part of this cargo development project since the beginning as a licensed professional engineer at Burns and McDonnell. Because of his experience with the project, he was able to provide previous drawings and information from the initial design. Brian also provided the scope of work to complete for this project. His main goal in the redesign of his previous work on this project was to see how much new standards affect the design and cost of a decade old project.

1.3 SCOPE OF WORK

The scope of work provided by the industrial liaison was split into three parts: pavement design, storm water design, and cost estimation. Although the previous design consisted of three phases, the scope of this project only consists of work within the first phase of the initial project. This phase previously consisted of the design of the apron and taxi lane, storm water, and the south side cargo building. The same was completed within the redesign other than the design of the building. The cargo building design was not a concern for the redesign because of lack of knowledge in the structural field. The different items from the given scope are discussed in greater detail below.

1.3.1 Pavement Design

For this redesign, new geometry for the taxi-lane was the biggest task for pavement design. The Federal Aviation Administration (FAA) has changed their standards from the time of the initial design, 2015. Advisory Circulars are utilized and written standards by the FAA for guidelines within airport design. These standards are discussed in further detail in the following sections. Because of the changes to the standards, the taxi lane's geometry design will change as well. Based on the new changes to standards and current aircraft operating at the airport, the pavement design was also analyzed using FAA software and information from the life cycle cost analysis completed on concrete and asphalt. Aircraft are continuing to get bigger and heavier, so standards have been updated to reflect that, and pavement needs to have thicker sections of material. Typical sections were created to display this design. These tasks are discussed further in the following sections.

1.3.2 Stormwater Management

To analyze the change between standards involving stormwater design, the pipes of the project were to be reevaluated and compared to the previous design. The previous design was created utilizing Illinois State Water Survey (ISWS) Bulletin 70, which has now been updated to ISWS Bulletin 75 based on new rainfall intensities. With higher intensities and frequencies, the pipe sizes needed to be reevaluated to make sure they can withstand the new capacities required. These results and methods are discussed in greater detail in the following sections. Detention Basin Capacity was also estimated and compared to the capacity from the previous standards. This is also important to analyze with the new frequencies to see how much of the runoff the surrounding areas can withhold. Severe flooding can occur if pipes and detention basins are not sized properly, so it is important to analyze with new standards to ensure the airport has proper drainage for safety.

1.3.3 Cost Estimation

For cost estimation, a life cycle cost analysis needed to be performed to determine whether Hot Mix Asphalt (HMA) or Portland Cement Concrete (PCC) was a better choice for the pavement design. The life cycle cost analysis estimates the total cost the pavement will accrue throughout its estimated thirty-year life span. Often asphalt will be cheaper to construct initially but does not always have the cheapest long-term cost because of the extra maintenance it acquires. This also involved a cost estimate for whichever pavement was chosen to analyze how much it would cost to construct this pavement present-day. The software HeavyBid was utilized to get this estimate based on labor, material, and equipment necessary. Based on the results from the storm water design part of the project, a cost comparison of pipe size changes was also to be completed.

2 PROJECT STANDARDS AND RESOURCES

2.1 FEDERAL AVIATION ADMINISTRATION STANDARDS

The Federal Aviation Administration (FAA) has standards on their website for engineers and contractors to review when working on projects at airports across the country. These are especially important to follow when an airport project is funded with federal funds but are utilized for projects with other sources of funding as well. The FAA makes the process of reviewing these documents simple with outlines on their website with all new and recent PDFs of standards attached. They also provide design software in some cases as either a tool or a check for engineers to make sure they are meeting the FAA's requirements within design. Overall, the FAA website is the first place for engineers to look when designing projects within the aviation industry for regulations and specifications.

2.1.1 Advisory Circulars

Advisory Circulars (AC's) are the most prominent standards that the FAA supplies to the public. These regulations range from topics such as aircraft to airports depending on what type of project an engineer is working on within the aviation industry. The AC category that was utilized most within this project was within the "Airports" category found on the FAA website. Most importantly, AC 150/5370-10H "Standard Specifications for Construction of Airports" and AC 150/5300- 13B "Airport Design" were utilized within this project. The Advisory Circular 10H was utilized within the life cycle cost analysis and estimate because it provides information on material sections within the pavement and construction. Advisory Circular 13B was referred to for every other task because the information within the standard includes pavement design and water design in detail. These Advisory Circulars were crucial in this design as they provided guidance for the pavement thickness design and geometry of the pavement.

2.1.2 Design Software

The FAA also provides the public with design software to make some of the processes within design go quicker and be more accurate. Engineers can choose to use the software or the Advisory Circulars for some of the design work, but often it is easier to utilize the software. Within this project, the software from the FAA that was utilized was the Taxiway Fillet Design Tool and FAARFIELD 2.0 Software. These resources take information from the Advisory Circulars and combine the regulations into a program that produces a design output. For example, the Taxiway Fillet Design Tool outputs a DXF (AutoCAD) file with pavement geometry drawn in 2D. The FAARFIELD 2.0 Software outputs pavement layer thickness based on aircraft sizes. These design resources can be useful for design engineers but are not required to be used if the Advisory Circulars are followed.

2.2 OTHER STANDARDS AND RESOURCES

2.2.1 Bulletin 75

Bulletin 75 is a standard produced by Illinois Storm Water Survey (ISWS) that was adopted in 2019. This document is considered the updated Bulletin 70, which is a report that has been in place since 1989. This document was updated in 2019 due to the increases in rainfall due to climate change. Bulletin 75 was heavily utilized in the analysis of the pipe sizes in the previous pavement design. Although it is not required that the previously designed pipe sizes are changed based on this new standard for rainfall, it is important to analyze the pipes with the new rainfall frequencies to ensure they will not overflow in the 100-year storm. This standard focuses on the rainfall frequency in Illinois, so it is utilized greatly by agencies within the state when designing stormwater systems. This standard will continue to change as the decades pass due to everchanging climate conditions, so it is important to ensure older pipe networks and stormwater systems are adequately designed for these newly observed rainfall conditions that will most likely continue to increase.

2.2.2 Illinois Department of Transportation Flexure Flow

Illinois Department of Transportation (IDOT) has a useful program that gives the public information on previously bid projects and the prices that specific items were bid for. This resource was greatly helpful for the cost estimate when looking at unit prices for the pavement sections and other items. Looking at the flexure flow website allows engineers to get a better understanding of where unit prices are currently at and make an educated assumption in initial cost estimation. This resource was also useful when completing the life cycle cost analysis when getting an initial construction cost estimate per square yard of either asphalt or concrete. The necessary repair bid items are also listed on the flexure flow website, which could be utilized within the life cycle cost analysis as well.

2.2.3 Industry Professionals

Many industry professionals were contacted during the design process for a more accurate idea on pricing and methods for airport design/construction. This involved discussing ideas and methods with the industrial liaison, Brian Quinlan, as well. Brian was able to provide a spreadsheet to assist with the life cycle cost analysis and more in-depth information on certain tasks within the scope. For accurate maintenance intervals, the head of maintenance for the Evansville Regional Airport was contacted as well and was able to confirm the information that was gathered. For pricing subcontracted items, the companies that would perform the work were contacted to get a proper cost. Project managers at both Mt Carmel Soil Group and Ozinga Concrete and Aggregates were able to provide estimates for the work that would be performed.

3 CIVIL SITE DESIGN - PAVEMENT

3.1 TAXI-LANE GEOMETRY

When designing a runway, taxiway, or taxi lane, it is important to first look at the Airport Design Advisory Circular. In this project, the focus of redesign was the taxi lane. The taxi lane is the pavement area where the aircraft "taxis" to get from a taxiway to an apron area where it can park. Taxi lanes only connect to aprons and taxiways, whereas taxiways connect to the runways. Although these pavement areas have different uses, most of their standards are the same within the FAA Advisory Circulars. Therefore, most of the standards used to design the taxi lane are written under the taxiway category in the AC's. The different pavement areas are labeled in *Figure 2: Taxi Lane vs. Taxiway vs. Runway* for clarity.

Figure 2: Taxi Lane vs. Taxiway vs. Runway

The first items to determine for the geometry design are the Airplane Design Group (ADG) and Taxiway Design Group (TDG). Both ADG and TDG rank from numbers one to six and are based on the biggest aircraft the design airport uses. TDG is determined based on gear widths and ADG is determined based on tail height and wingspan. In this case, the biggest aircraft at O'Hare

International Airport, based on public information, is the Boeing 787-10 Dreamliner. The design groups for this specific aircraft can be determined from the AC's tables or from the "FAA Aircraft Characteristics" spreadsheet that the FAA provides on its website. Due to the Boeing 787-10 Dreamliner being listed in the spreadsheet, this file was utilized to determine the ADG and TDG rather than the tables in the AC. This spreadsheet is displayed in Appendix A. From this spreadsheet, it was determined that the project has an ADG of V (5) and TDG of 6. As stated previously, these groups only go up to six, so the Boeing 787-10 Dreamliner, as shown in *Figure 3: Boeing 787-10 Dreamliner*, is a relatively large aircraft. Appendix A also includes some more detailed information on the Boeing 787-10 Dreamliner.

Figure 3: Boeing 787-10 Dreamliner

With this information, the necessary taxi-lane widths and safety areas can be determined for design. These numbers are also pulled from the Airport Design AC 13B. As shown in *0*, the taxi-lane width is 75 feet, taxiway safety area (TSA) is 214 feet, and the taxi-lane object free area (TLOFA) is 270 feet. The TSA and TLOFA are areas offset from the centerline of the taxiway or taxi-lane where objects are not allowed to be in for safety from aircraft wingtips hitting them. Objects not allowed in this area consist of anything from trees or vegetation to structures or buildings. It is important to design with these safety areas in mind so that injury and damage to planes or structures can be prevented as much as possible. If not accounted for, an aircraft wing can accidentally hit something and cause material damage or even fatalities in severe cases. This is important for both public safety and welfare, along with the safety of private airport structures. These lines are displayed on plan sheets for reference in construction but are not made visible in person. *Figure 4: TSA and TLOFA Design* displays the design with the safety lines outlined along with the necessary width of the taxi lane.

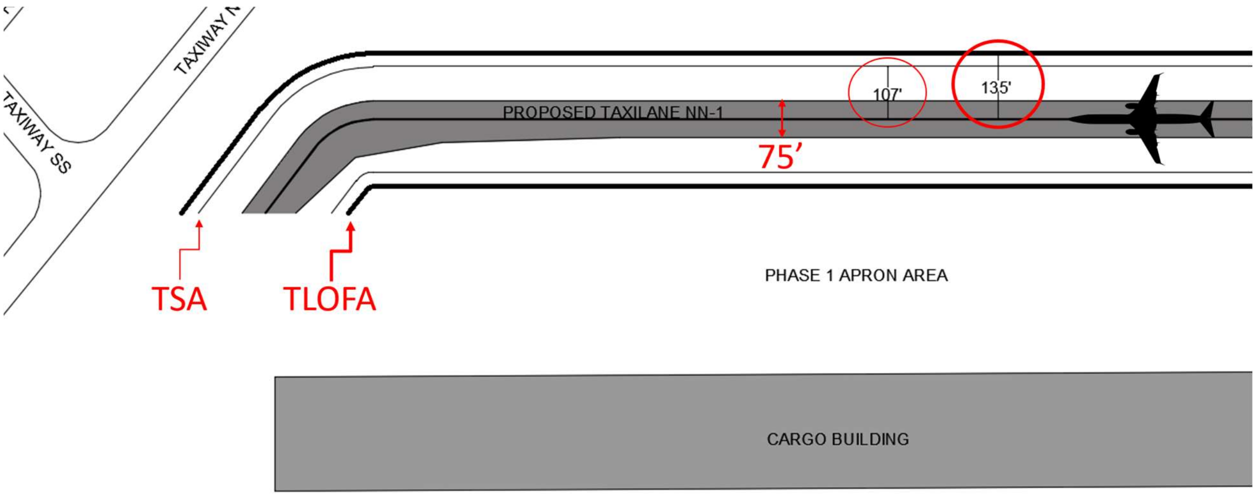

Figure 4: TSA and TLOFA Design

The last step for the taxi lane geometry design is to create the appropriate geometry for the turn based on the FAA's Advisory Circular standards. The geometry of the turn was the focus within the pavement scope of the redesign because of a drastic change the FAA made to these standards in the last decade. Before the change, the turn radius of taxi lanes and taxiways was a constant circle, but the geometry standards now consist of sharp angles for more safety around the curve. Because of the size of aircraft at major airports such as ORD, they must make bigger, sharper turns than smaller, older aircraft previously made. The FAA updated their standards to account for these bigger, sharper turns which changed the geometry design greatly from previous designs. An example of this is shown in *Figure 5: New Geometry Standard* pulled from the AC.

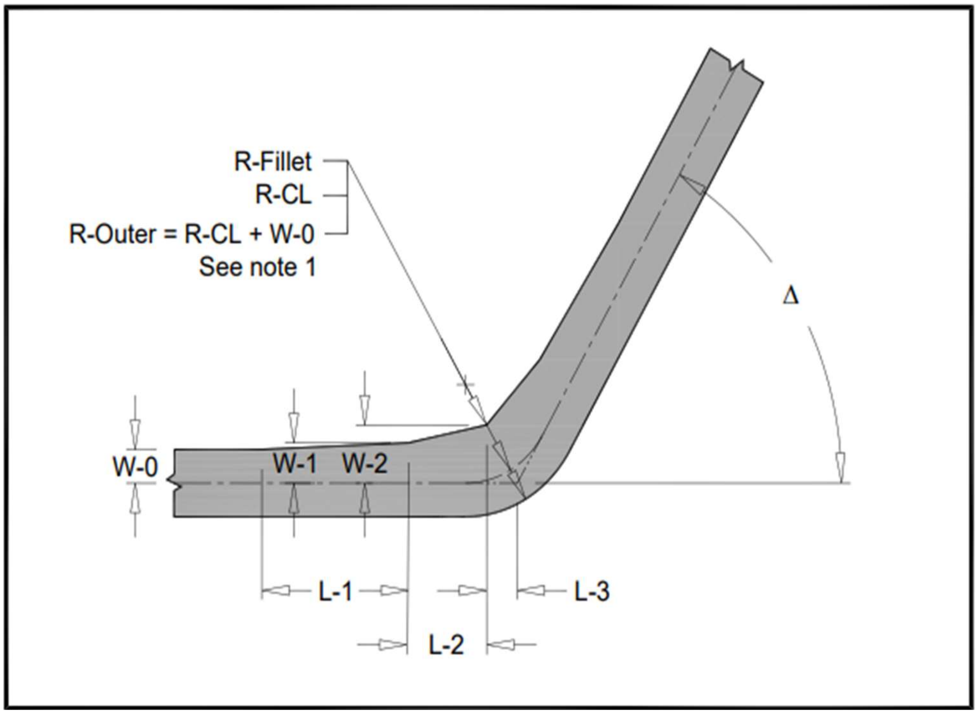

Figure 5: New Geometry Standard

Another FAA software, the Taxiway Fillet Design Tool, was used for this design as mentioned previously. This design tool also utilizes the TDG configured previously, TDG 6, to create the geometry of the taxi lane turn. As shown in *0*, the software is relatively simple and only requires the TDG and the angle of the turn to create the geometry. This angle was determined to be 53 degrees based on a measurement from the existing runway to the proposed taxi lane straightaway. Taken from centerline to centerline, this angle measurement is displayed in *Figure 6: Angle Measurement Between Existing Runway and Proposed Taxi Lane*. The existing runway and taxiway are parallel to each other. Thus, the measurement was taken from the taxiway to the proposed taxi lane for simplicity.

Figure 6: Angle Measurement Between Existing Runway and Proposed Taxi Lane

After putting this information into the software, it can use the current standards and produce a .DXF (AutoCAD) file with the appropriate geometry. The software determines the appropriate L and W values shown in *Figure 5: New Geometry Standard* above from the AC manual. The geometry output from the tool is shown in *Figure 7: Taxiway Fillet Design Tool Geometry* below.

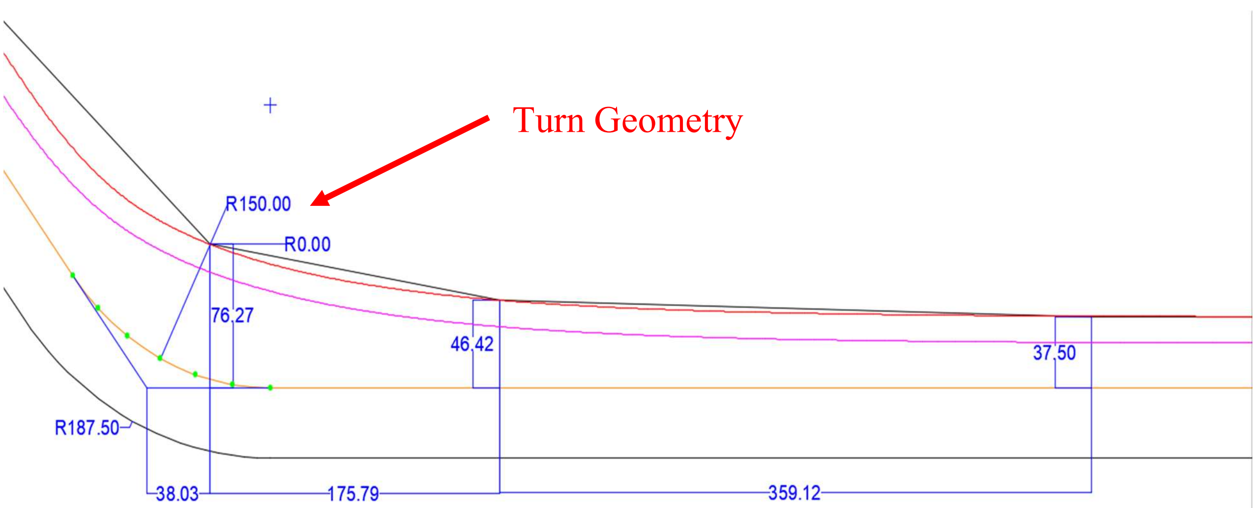

Figure 7: Taxiway Fillet Design Tool Geometry

From this, the geometry output can be rotated within the AutoCAD design and placed where necessary for the taxi lane. Now, the design can be completed with the information gathered from the Airport Design AC manual and software guidelines. The final taxi lane design is displayed in *Figure 9: Final Design* and *Figure 8: Final Geometry Design Zoomed In* below.

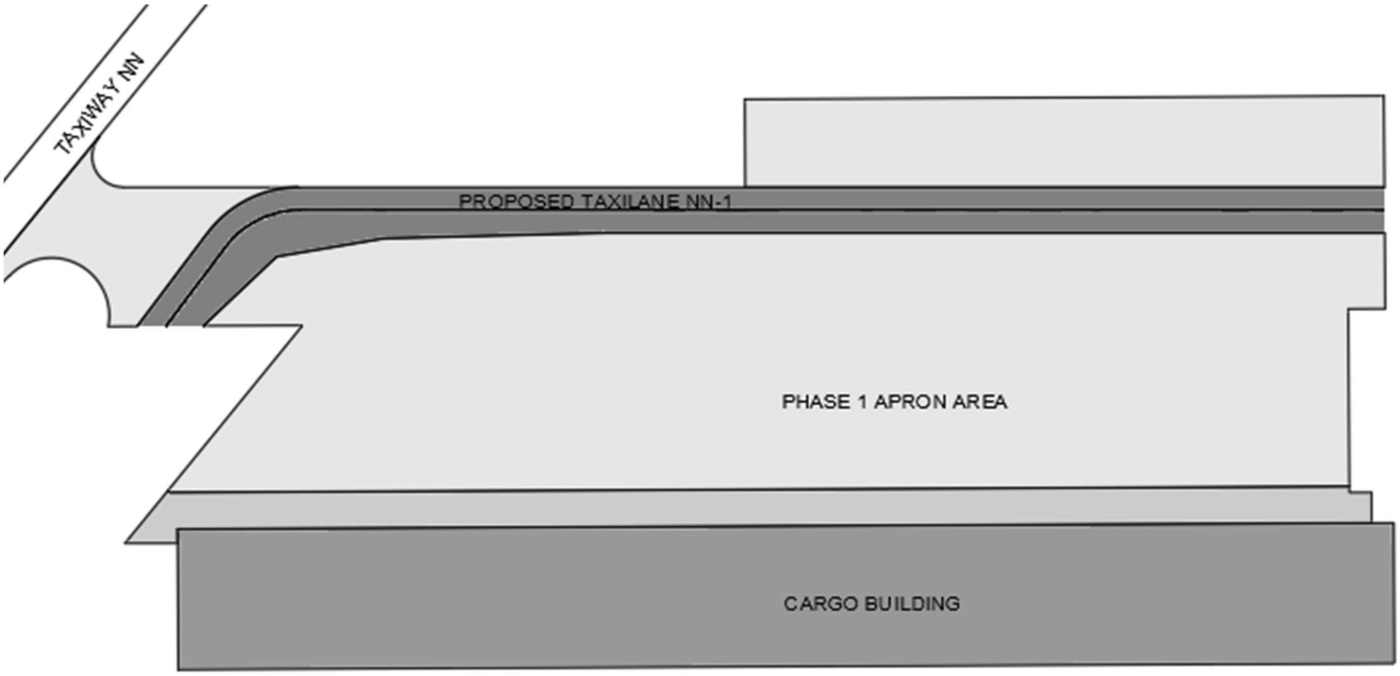

Figure 9: Final Design

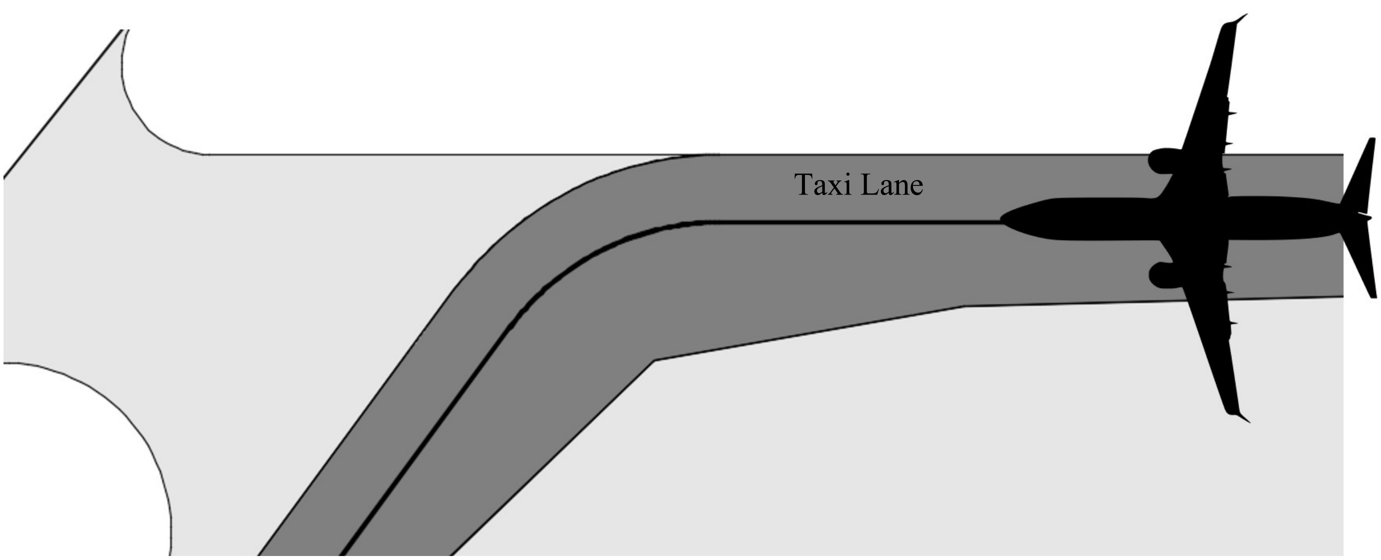

Figure 8: Final Geometry Design Zoomed In

3.2 *PAVEMENT DESIGN*

As stated previously, the FAA provides free design software, FAARFIELD 2.0, on its website which tests load ratings on pavement sections. This software was utilized for the pavement section design based on the largest aircraft that operates at O'Hare International Airport, which is also public information as mentioned previously. Most aircrafts' details are stored within the software as shown in *Figure 10: FAARFIELD Aircraft Library*.

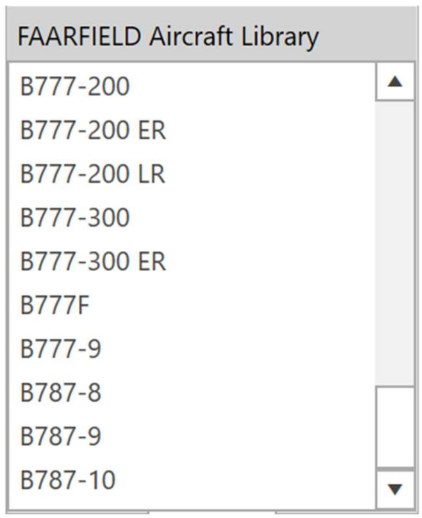

Figure 10: FAARFIELD Aircraft Library

This includes information such as the weight of the aircraft and its measurements, which is important for the pavement's load rating calculation. The Boeing 787-10 Dreamliner was selected for this calculation due to it being the largest aircraft at ORD. Although not a cargo plane, the apron area also acts as a fueling station, so this plane was accounted for in case it was to ever need to go in this area for fueling. It is not likely that aircraft other than cargo planes will be utilizing this area, but accounting for the larger aircraft adds extra safety measures to the design. Also, because of the area being a cargo area of the airport, the extra weight of this aircraft can help account for the weight of the other aircraft after they have been loaded with all of the cargo or shipments.

After selecting the aircraft in the software, the type of pavement to be used needs to be selected. The layers of pavement were selected based on the previous design – Portland Cement Concrete (PCC) surface course, PCC base course, frost protection course, and a lime stabilized subbase. These layers are typical pavement layers to use for concrete within airports in this area due to the weather. The thicknesses used on these layers vary based on the size of aircraft that operate at the airports. Once these layer selections are made, the software runs a load test and does calculations as to what the thicknesses of all the pavements need to be to sufficiently sustain the load of the aircraft. The results of the software calculation are displayed in ***Error! Reference source not found.***.

Table 1: FAARFIELD Pavement Design Thickness

No.	Type	Thickness (in.)
1	P-501 PCC Surface	17.1
2	P-304 Cement Treated Base	8.0
3	P-154 Uncrushed Aggregate	6.0
4	Subgrade	0

These results display the minimum thickness that each layer of the surface must be to sustain the aircraft. Due to these results, the same pavement section that was used in the previous design can be utilized within the redesign as well. Previously, the pavement section was designed for a 19.5" thick PCC Surface, 8" thick PCC Base Course, 6" thick Frost Protection Course, and 12" thick Lime Stabilized Course. These sections all proved to be thick enough based on the results from the software, so nothing needed to be changed with the thickness of the pavement. The typical sections of the pavement are shown in *0*.

3.3 Difference From Original Design

Although the geometry of the taxi-lane did change for the design, this did not affect the total pavement area. The taxi-lane and apron pavement sections consist of the same thickness and materials. The apron area contains the taxi-lane, so the area remained the same in quantity. If the taxi-lane and apron consisted of different pavement sections, then the change in geometry of those pavement areas would have mattered in the quantities. Thus, the design changed within the plan set, but the amount of pavement remains the same for construction. The new taxi-lane design versus the old design is shown below in *Figure 11: New Geometry Design Compared to Old*. The old design is shown in the black color, while the new design is underneath in the dark gray color. This adequately displays the difference between the constant radius geometry that was allowed within the older standards versus the new geometry required in the standards that is more angular and provides more room within the inside of the turn where airplanes are more likely to make a mistake with a sharp turn.

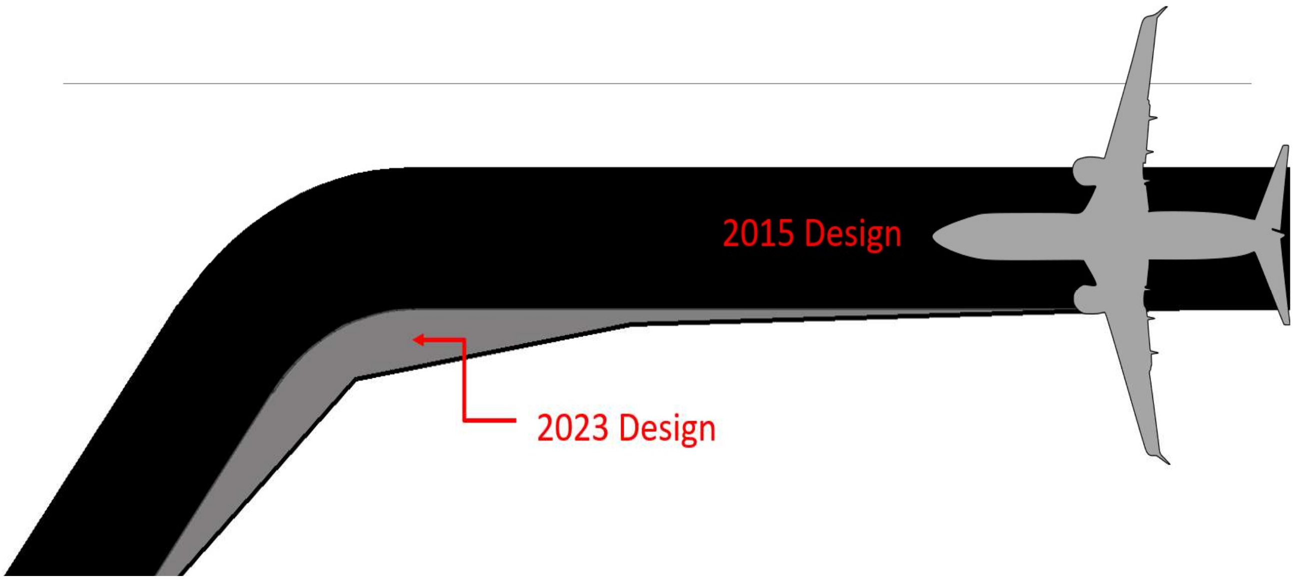

Figure 11: New Geometry Design Compared to Old

4 STORMWATER MANAGEMENT

Storm frequencies and their temporal distribution are significant in determining runoff or peak flow rate estimates for various engineering and hydrological problems. Bulletin 70 shows the frequency distributions and hydroclimatic characteristics of heavy rainstorm in Illinois and has been the established standard for design rainfall since its release in 1989 by the Illinois State Water Survey

Bulletin 70 was created by Floyd A. Huff and James R. Angel and reveals the findings of a comprehensive study on the occurrence of intense rainstorms in Illinois. The investigation relies on data collected from 61 precipitation stations spanning the years 1901 to 1983. The report illustrates frequency distributions of localized rainfall, encompassing timeframes from 5 minutes to 10 days and recurrence intervals spanning 2 months to 100 years (Huff and Angel).

Even though Bulletin 70 had the best reliable and available data when it was published, climate change and its impact on increased precipitation in Illinois has been a concern for the last decades. According to the Illinois Department of Natural Resources (IDNR) in cooperation with the Illinois State Water Survey, the Urban Flooding Awareness Act reported in 2015 impacts of increased in precipitation in Illinois. Over a ten years period, the IDNR documented $2.3 billion dollars in costs from flooding in urban areas. Some $1.6 billion in damages resulted from five severe storms, and more than 90% of these damages occurred outside the mapped 1% annual chance floodplain (Winters).

Due to the effects generated by the climate change, particularly the increase in heavy precipitation, Bulletin 70 has been updated to Bulletin 75. This updated version of Bulletin 70 offers fresh precipitation frequency data for 10 regions in Illinois, covering event durations from 5 minutes to 10 and recurrence intervals ranging from 2 months to 500 years. Additionally, updated time-distribution characteristics of rainfall events, referred to as "Huff curves," are included. It's important to note that the precipitation frequency estimates, and their time distributions presented in this report replace those previously published in Bulletin 70. Bulletin 75 was created by James R. Angel and Momcilo Markus and published by Illinois State Water Survey in 2020 (Angel et al.).

The main difference between Bulletin 70 and Bulletin 75 is that Bulletin 75 shows a higher rainfall than Bulletin 70. This difference is shown in *Figure 12: Difference in Rainfall Between Bulletin 70 and Bulletin 75 (inches).* It is noteworthy that the original design for this project relied on Bulletin 70 for the development of the stormwater design. The primary objective of this section is to assess the potential alterations in the original design when implementing Bulletin 75.

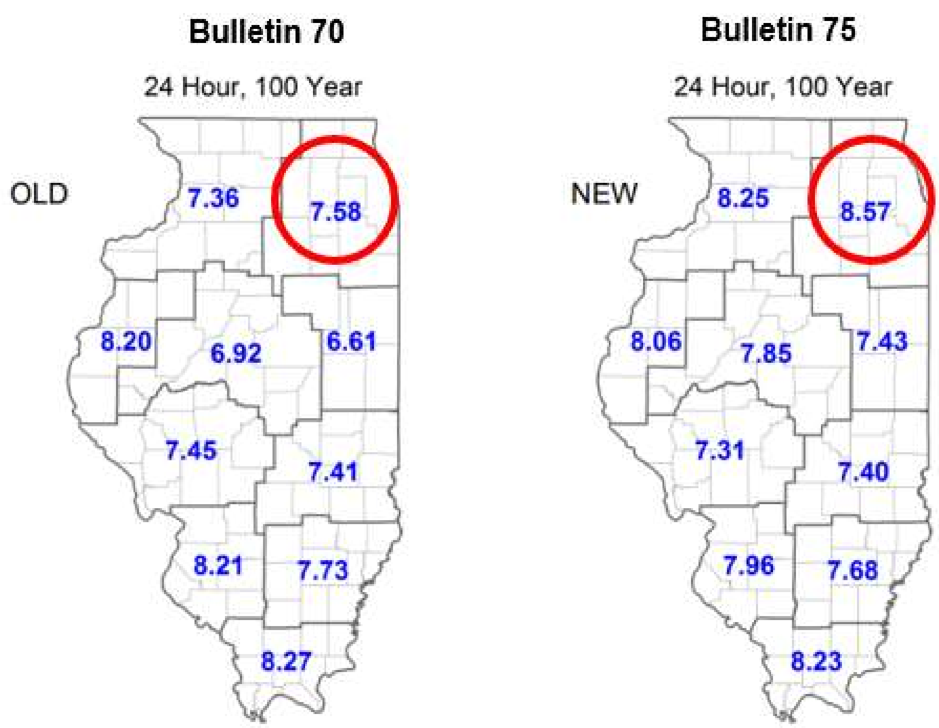

Figure 12 : Difference in Rainfall Between Bulletin 70 and Bulletin 75 (inches).

4.1 DIFFERENCE IN DEPTH OF THE AGGREGATE STORAGE LAYER REQUIRED USING BULLETIN 75

In the original design, there is a pavement section in which its main function is to filter the oil and sediment out of the runoff before discharging downstream. This is one of the best storm water management practices to use for pervious concrete pavement. As it could be observed in *Figure 13: Previous Concrete and Underdrain Typical Section*, the pavement section consists of 6" of pervious concrete over 24" of open-graded aggregate base for temporary storage. This pavement section is in the Northeast Cargo of the O'Hare International Airport and is used as a volume control. The first objective of the stormwater management analysis was to find how the 24" of open-graded aggregate would change if Bulletin 75 is used.

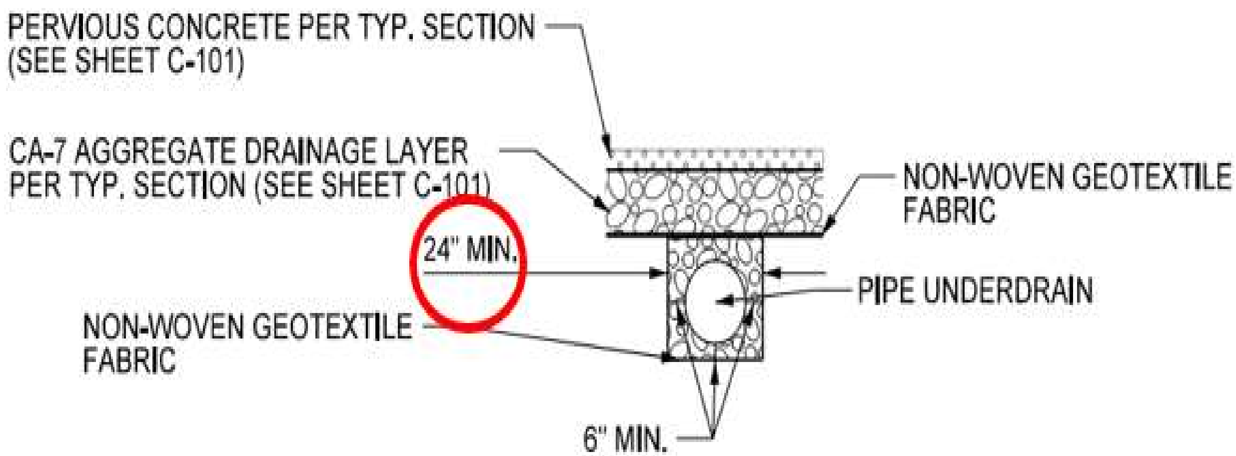

Figure 13 : Previous Concrete and Underdrain Typical Section

The City of Chicago requires that the required volume control is equal to 0.5" for all impervious areas. Since this concrete pavement is used as a volume control, the depth of the open-graded aggregate would not be affected by switching from Bulletin 70 to Bulletin 75 (City of Chicago Stormwater Management Ordinance Manual).

4.2 *DIFFERENCE IN PIPE SIZES USING BULLETIN 70 AND BULLETIN 75*

Similarly, to the concrete pavement analysis, there was an interest in knowing if the pipe sizes of the original design would change using Bulletin 75. To find the pipe sizes, the Rational Method was used to find the peak runoff.

$$Q = CiA$$

In this equation, Q represents the peak rate of runoff in (ft^3/s), C states for runoff coefficient (0.8 for pavement), i for the average intensity of rainfall (in/hr), and A for the watershed areas (acres). The intensity used in this equation was 3.34 in/hr for a 24 hours 2 years storm event.

Once Q was found, the Manning Equation was rearranged to find the diameter of each pipe.

$$Q = \frac{K}{n} A R^{2/3} S^{1/2}$$

$$D = \left(\frac{3.208\ Qn}{KS^{\frac{1}{2}}} \right)^{\frac{3}{8}}$$

In this equation, Q represents the discharge (ft^3/s),K is the unit factor (1.486), A is the cross-sectional area of flow (ft^2), H is the hydraulic radius (area/perimeter) (ft), S is the slope of hydraulic surface (ft/ft), N is Manning's roughness coefficient (0.009 for PPVC, 0.012 for RCP, and 0.014 for ESVCP), and D is the diameter of the pipe (ft).

After running the calculations, it was found that 11 of 102 pipes increased the diameter to the next available pipe size. In other words, if the pipe was 30" using bulletin 70, it would go to 36" with Bulletin 75.

4.3 *4.3 DETENTION BASIN CAPACITY REQUIRED USING BULLETIN 70 AND BULLETIN 75*

With the way O'Hare International Airport is set up, new projects do not need to provide additional detention because the airport already has excess detention basin capacity for the foreseeable future. For this project, it was assumed that this cargo development needs a detention basin.

The best way to calculate the volume of detention basin is to model the site for the existing and proposed conditions and create a hydrograph, which serves as a visual representation of water level data over a specific period. The hydrograph would generate two curves, one for the existing conditions and another one for the proposed conditions, and the area under those curves would display the volume of detention basin required. Since the information for the existing conditions was not provided, the Chicago Stormwater Ordinance and an acceptable release rate for proposed conditions were used. With this approach, existing conditions really do not factor into the design.

To compute the detention basin's volume, the site was partitioned into two designated areas (A and B), as illustrated in the *Figure 14: Designated Areas to Find the Detention Basin's Volumes.* Part A has an area of 28.2 acres, and the area of part B is 24.5 acres. Using the allowable release rate of 0.80 cfs / acre per the outlet capacity and the rational method, it was found that volume for part A using Bulletin 70 is 231,952 cf and using Bulletin 75 is 261,927 cf. Similarly, for part B, the volume would be 200,053 cf using Bulletin 70, and 225,956 cf using Bulletin 75.

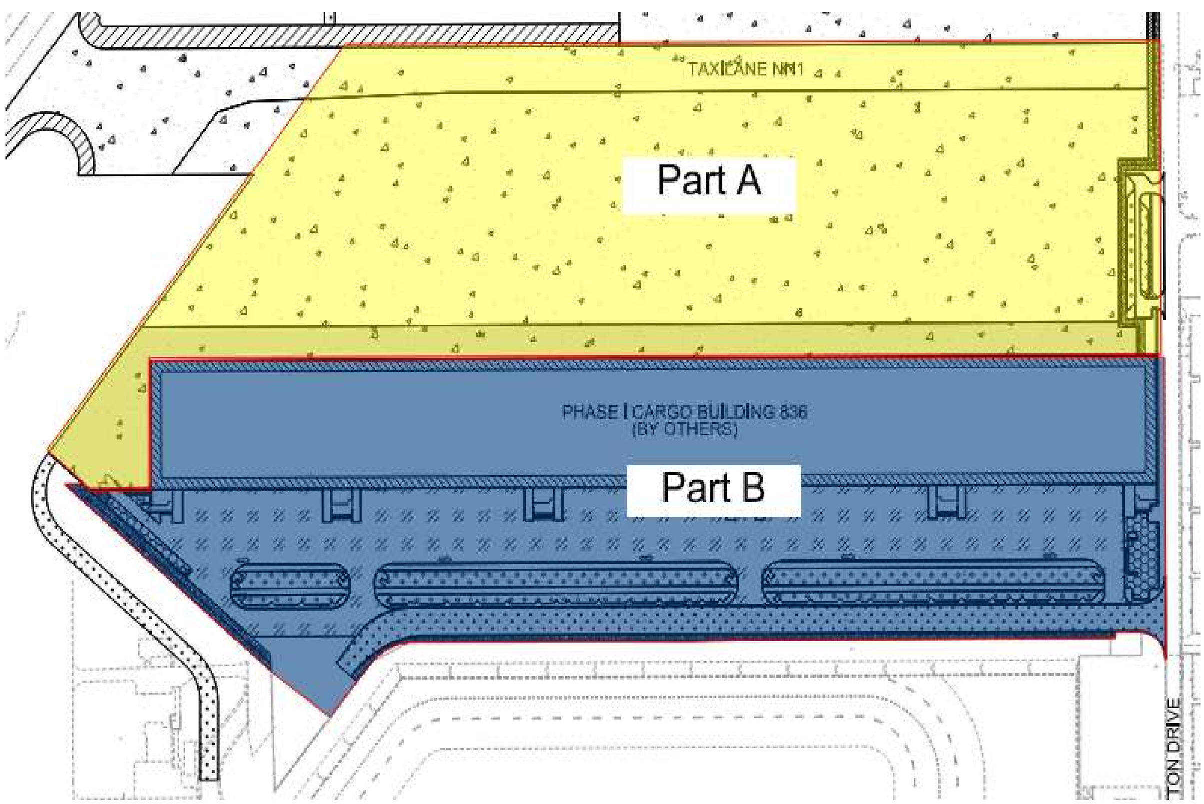

Figure 14: Designated Areas to Find the Detention Basin's Volumes

5 COST ESTIMATING

5.1 Redesigned Piping Estimate

As previously stated, the stormwater system has been redesigned to conform to the new standards of bulletin 75. With the rise in rainfall intensity, larger pipe sizes are needed to handle the greater volume of stormwater. For the pipes that are resized, the pipe materials are reinforced concrete pipe (RCP) and extra strength vitrified clay pipe (ESVCP). To provide a proper cost estimate for this change, all aspects of installation and material price must be considered. The pipe diameter changes can be seen in F*igure 15: Redesigned Material Cost***.**

When the size changes are considered, it can be assumed that there is no cost change for the installation of the redesigned pipes. Since there was no change to the pavement section or pipe bedding specifications, the cost of installing slightly larger pipes is negligible. With the largest upsize being 12" it can be assumed that the cost of labor and equipment will not change enough to consider. Material price will be the driving factor for the cost change caused by the new specifications.

For the pricing of reinforced concrete pipe, a price list from County Materials Corporation was used to get an updated price per length foot for 2023. To find pricing for extra strength vitrified clay pipe, Henry Frerk and Sons was contacted. This is a well-known pipe supplier near the city of Chicago, and they were able to provide accurate pricing per length foot for the redesigned pipes. For the eleven pipes that were upsized, the total cost increase is $117,651.11.

Pipe Material	Diameter (in)		Price Change Per LF	LF	Cost Change
	B70	B75			
RCP	18	24	$ 26.70	100	$ 2,670.00
RCP	24	30	$ 45.50	100	$ 4,550.00
RCP	30	36	$ 49.00	100	$ 4,900.00
ESVCP	15	18	$ 26.86	100	$ 2,685.71
RCP	24	30	$ 45.50	72	$ 3,276.00
RCP	18	24	$ 26.70	92	$ 2,456.40
ESVCP	18	24	$ 75.00	100	$ 7,500.00
RCP	42	48	$ 76.00	138	$ 10,488.00
ESVCP	18	24	$ 75.00	75	$ 5,625.00
RCP	60	72	$ 176.00	375	$ 66,000.00
ESVCP	18	24	$ 75.00	100	$ 7,500.00
				Total	$ 117,651.11

Figure 15: Redesigned Material Cost

5.2 HEAVYBID PAVING ESTIMATE

The next task was to create a detailed estimate of paving the new taxi lane area. For an accurate estimate, Heavybid was used. This software is widely used for estimating heavy civil projects. This helps to centralize material, equipment, and labor. Cook County labor rates were gathered for an accurate price for the Chicago area. The Army Corps of Engineers Equipment Manual was another resource that provided cost for each piece of equipment used in this project. The total cost of paving the taxi lane is 7.5 million dollars. This includes all items in the pavement section. For lime stabilization, and rock hauling, it is assumed that subcontractors will be used. Since the concrete pavement is a large portion of the project scope, the rest of the paving work will be self-performed by said contractor.

5.2.1 Activity Breakdown Lime Stabilization

The first layer of this pavement section is lime stabilization of the subgrade. This process involves spreading powered or liquid lime onto the graded soil. The lime is then milled into the soil to create a more stable foundation for the proposed taxi lane. This activity would be subcontracted since it requires specialty materials and equipment. One of the main contractors for this work is Mt. Carmel Soil Group. This company has a crew strictly dedicated to work performed at Ohare Airport, so this was a great resource for this estimate. I reached out to an estimator who works on projects at Ohare, and he was able to provide an estimate for the project. The pavement section calls for a 12” lime stabilized frost protection layer for which it is assumed a 5% lime application rate. The cost quoted is $5.40 per square yard, and that comes out to around $299,000 for the taxi lane.

Figure 16: Lime Stabilization

5.2.2 Furnish Stone Frost Protection

After the lime stabilization has been completed, a stone frost protection layer will be placed. This is a 6” layer of aggregate that will allow for drainage in the pavement section. Using the taxi lane area and depth of the frost protection course, it was calculated that 13,000 tons of aggregate will be needed. This activity will only include the cost of the material, and the hauling from the supplier to the project site. For accurate pricing, Ozinga Concrete and Aggregates was contacted to get a unit price for the aggregate needed. In the Chicago area, the price of aggregate such as Indiana 57’s is around $35 per ton. The hauling would depend on the quarry where the stone is coming from, so it was assumed that hauling rate would be around $15 per ton. This is a higher estimate for the hauling price, but this will always give extra money if it is needed for other activities. This work will be subcontracted by the aggregate supplier. The total cost of furnishing the stone frost protection course will be $650,000.

Figure 17: Furnish Stone

5.2.3 Place and Compact Stone

Once the stone has been delivered, it must then be placed and compacted. Since the previous activity is subcontracted and only includes material, the placement of the material must be estimated separately. Once the material has arrived, it must be placed and graded to proper elevation. The stone will be pushed with a Cat D6 dozer and then fine graded with a motor grader. Once the determined elevation has been reached, this stone layer will be compacted using a vibratory steel roller and a water truck. A pickup truck will be included in this crew as well since this work is over a large area. The crew will be made up of a laborer foreman, general laborer, three operators and one heavy truck driver. The stated crew will have a production rate of 200 square yards per hour. The cost of the labor and equipment totals $90,000.

Figure 18: Motorgrader for Crushed Aggregate Grading

Figure 19: Steel Roller for Stone Compaction

5.2.4 Cement Treated Permeable Base

After the drainage layer has been graded and compacted, an 8" cement treated permeable base will be placed over the frost protection layer. This is a mixture of crushed aggregate and cement that further stabilizes the base courses. This allows for drainage through the aggregate below as well as stability for the concrete pavement that will be placed over the top of this. To place this material, a CAT AP1055F paver will be used to ensure proper thickness of this section. The cement and aggregate are the only permanent materials needed and have already been priced. The crew will consist of a laborer foreman, two general laborers, an operator, and the CAT paver. With this crew, it will take 111 crew hours to place the cement treated base. This will cost $915,000.

Figure 20: Cement Treated Permeable Base

5.2.5 PCC Paving

The surface course of the pavement will be a 19.5” thick Portland Cement Concrete (PCC). The thick section of concrete will provide an adequately strong driving surface for the large cargo and passenger planes that will be traveling on the taxi lane. To pave the taxi lane, roughly 30,000 cubic yards of concrete will be needed. The current cost of a 5000 PSI concrete with included hauling is around $170. This will make up most of the material cost. The crew will include a laborer foreman, 3 general laborers, 4 concrete finishers, an operator and a Gomaco GP2600 Slipform paver. Concrete work tools will also be needed for finishing the formed pavement. With one crew, 100 square yards per hour can be placed. Since this pavement is not reinforced, contraction joints must be cut into the surface after placement. The production rate previously stated is very conservative and will help to account for the cutting of these contraction joints. It will take the crew roughly 70 days to pave the taxi lane. With material, labor, and equipment the cost comes to $5,600,000.

Figure 21: Slipform Paving

5.3 LIFE CYCLE COST ANALYSIS

The life cycle cost analysis is a task that is frequently performed by design firms, especially when using FAA funds for a project. This cost analysis will be able to predict the unit price per square yard for a specific pavement over its lifespan. For this analysis, a 30-year life is assumed, as it more accurately predicts the cost of the full life of the pavement. This analysis will include the initial cost of construction and any maintenance that will be performed over the 30-year life. It is assumed that there is no salvage value for the pavement at the end of its life. The end goal is to determine the present worth of each 30-year life. This will be calculated using 7% interest to give an accurate present worth value for each pavement.

5.3.1 PCC Pavement

The first pavement alternative is a rigid Portland Cement Concrete (PCC) Pavement. The pavement section considered (*Figure 22*) consists of a 12” Lime Stabilized Frost Protection Course, 6” Frost Protection Course, 8” Cement treated Permeable Base, and 19.5” of PCC Pavement. To determine the cost of initial construction, IDOT awarded bid items were used to find accurate unit prices for each activity. For the maintenance of a concrete pavement, minor repairs will be performed every 5 years. This will include resealing joints, pop outs, edge spalling, clearing vegetation and other maintenance. The pavement will need striping every 7 years. For a safe estimate, the striping will be placed on 50% of the pavement area. At 10 and 20 years, major repairs will be performed. The major repairs will include saw cutting and patching as well as any full depth replacement. To gather the information above, multiple experts were contacted to get accurate maintenance intervals. This information was confirmed by our industrial liaison, as well as the maintenance supervisor at the Evansville Regional Airport.

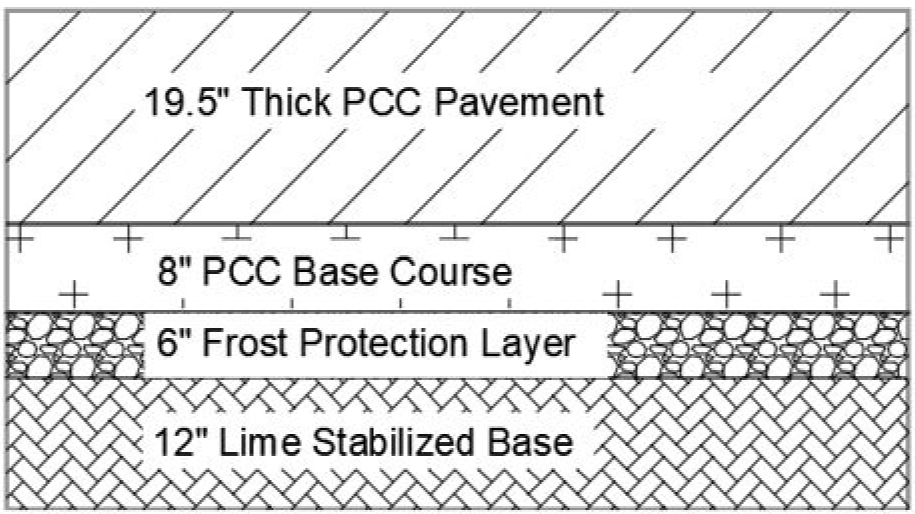

Figure 22: PCC Pavement Section

The cost of initial construction for PCC Pavement is $133.65 per square yard. The cost of lime stabilization is $5.40 per square yard. This course stabilizes the subgrade by spreading and tilling lime into the soil at a depth of 12". A 6" frost protection course will then be placed over the stabilized subgrade. This is a layer of permeable aggregate such as a #57 stone which will allow for proper drainage below the pavement. This will cost around $14.00 per square yard. The next layer that will be placed is an 8" cement treated permeable base. A water and cement mixture is placed over another layer of compacted aggregate to further stabilize the base of the pavement section. The cost of this activity will be around $20.00 per square yard. Finally, the PCC surface course is placed at a depth of 19.5”. The taxi lane and apron will be paved using a slip form paver. This will cost $94.25 per square yard.

To calculate the cost of joint sealing, both the removal and installation of the joint sealant is considered. A mobilization and traffic control cost are also calculated using the area and the cost of the activity. This is divided out by the area that is being sealed and for this analysis it is the taxi lane area. The removal of the joints will cost $0.75 per length foot and the installation is $2.76 per length foot. All things considered, the per square yard cost of joint sealing is $4.31. For the cost of minor repairs such as edge spalling and pop outs, it is assumed that 5% of the cost of joint sealing will cover any minor repairs. The equivalent per square yard price is $0.22. As previously stated, the major repairs will include saw cutting and patching as well as full depth replacement. For these activities, it is assumed that double the cost of joint sealing will cover these repairs. This comes out to $9.10 per square yard. Another maintenance item that will occur is pavement restriping. From a previous IDOT bid item, the cost for pavement striping is $5.00 per square yard. The equivalent cost will be $2.50 per square yard since the assumption is that half of the pavement area will need striped.

The overall current cost per square yard comes out to $170.88. When it is calculated to year 1, using 7% interest the present worth of the concrete over 30 years is $146.64. This includes initial construction and all maintenance performed.

5.3.2 Asphalt Pavement

The next pavement that will be evaluated is a flexible hot mix asphalt pavement. The pavement section will consist of a 10” subbase course of compacted aggregate, 16” base course, and 5” asphalt surface course. The same IDOT awarded bid items were used to estimate the cost of the asphalt pavement over its life. Aside from initial construction, typical maintenance will need to be done roughly every 2-3 years. This includes sealing any cracks that have formed in the surface course of the asphalt. Then, a friction seal coat will need to be re applied 3 times over the 30 years. Since the seal coat is applied to the full area of the pavement, this activity should also include the cost of restriping. For major repairs, a mill and overlay of the asphalt will need to be completed twice; roughly every 12 years.

The initial cost of placing the asphalt is $127.33. The uncrushed aggregate subbase will cost $24.00 per square yard. The base course to be placed is a layer of compacted crushed aggregate that will give a solid foundation to pave over. The cost of the base course is $50.00 per square yard. The surface course has a similar price at $53.33. The surface course is the final layer of asphalt that contains a finer aggregate for a smooth finish. The first repair that the asphalt will need is for any cracks to be sealed. It is assumed that cracks will develop at 100' intervals along the full length of the taxi lane. The cost per LF is $4.87 to repair the cracks. This is then divided by the total taxi lane area to arrive at a cost per square yard which is $0.69. The seal coat cost was calculated by gathering various prices of the sealant material and taking an average of these prices. The cost of a friction seal coat will be $1.55 per square yard. The costliest repair is going to be the milling and overlay. For an accurate estimate, the cost of asphalt, milling and striping will be considered. Asphalt costs $160 per ton and both striping and milling cost $5.00 per square yard. The calculated cost per square yard of a milling and overlay repair is going to be $37.69 per square yard.

The overall current cost per square yard comes to $177.26. When it is calculated to year 1, using 7% interest the present worth of the asphalt over 30 years is $160.00. This includes initial construction and all maintenance performed.

5.3.3 Conclusion

As seen above, a Portland Cement Concrete Pavement will be the most cost-effective option for a 30-year life span. For the taxi lane alone, it will save around $580,000. The initial construction of asphalt is cheaper by $6 per square yard, but it requires more frequent maintenance. Although cost is a major factor when choosing a pavement type, there are more considerations that can affect the decision-making process. For example, this project includes a taxi lane and cargo apron. When the airplanes are unloading cargo, they may be stationary for extended periods of time. Asphalt pavement is not well suited to being under such high static loads and would require even more frequent maintenance.

Also, the airplanes traveling through this area will be coming in to unload or leaving for another terminal. Having to maneuver into tight spots is going to make for sharp turns at very low speeds. This scenario will lead to serious damage to the asphalt, especially during warmer months. Concrete pavement is more well suited to handle these conditions. Finally, the cargo apron will also be a place for airplane refueling. This would cause a lot of problems for asphalt pavement. If jet fuel were to spill on the asphalt, it would eat at the surface course and once again lead to major damage.

Overall, a concrete pavement section is the best choice for the taxi lane and apron. When factoring in cost, it is the cheapest and will save close to three quarters of a million dollars in its 30-year life. The concrete is also better suited for the conditions of this section of the airport. It will hold up better under the high static loads and sharp turns. There is also less damage to concrete if fuel were to be spilled.

6 CONCLUSIONS AND RECOMMENDATIONS

Overall, this redesign showed that even small changes to standards can have a large impact on the design of projects. As the environment continues to change and engineering continues to evolve and develop, standards will continue to adapt as well. It is important to stay up to date with standards and ensure that they are always followed within engineering design. Standards, regulations, and specifications are made with the safety of the public in mind, so they hold great value. Within this redesign, a change in standards over a decade affected both the pavement design and stormwater management. While old standards will most likely still be deemed safe designs, the new design standards the FAA and Department of Transportations have established provide a more accurate and safe project design, which impacts both the engineers and the public in positive ways.

This group worked together very well during this project. Communication was completed through Microsoft Teams as well as during weekly meetings. There were not any disagreements because everyone provided timely, quality work and were all able to complete different aspects of the project. Because of the difference in objectives, the team did not help each other with each other's tasks unless specifically asked to do so. The team did a good job holding each other accountable even though we were all doing much different work. All assignments were completed as a team and the project had a good result due to the team's communication, willingness to help others, and individual accountability. Every team member was able to do an aspect of what they want to work on after they graduate, so the project benefited everyone. Tasks were assigned by the industrial liaison, an industry professional, so no issues came up with fairness of tasks or workloads either. Overall, the team worked well together and created a good project together.

REFERENCES

"Airport Design." *Federal Aviation Administration*, 22 March 2022, https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5300-13B-Airport-Design.pdf.

Angel, James R., et al. "Precipitation Frequency Study for Illinois." *Bulletin (Illinois State Water Survey) No. 75*, Illinois State Water Survey, 1 Mar. 2020, www.ideals.illinois.edu/items/114209.

City of Chicago Stormwater Management Ordinance Manual, www.chicago.gov/content/dam/city/depts/water/general/Engineering/SewerConstStormReq/2016StormwaterManual.pdf. Accessed 6 Dec. 2023.

Huff, Floy A, and James R Angel . "Bulletin 70 Frequency Distributions and Hydroclimatic Characteristics of Heavy Rainstorms in Illinois ." *Deparment of Energy and Natural Resources* , Illinois State Water Survey , 1989, www.isws.illinois.edu/pubdoc/B/ISWSB-70.pdf.

"IDOT Bid Items." *Flexure Flow,* 2023, https://flexureflow.com/biditem/search/idot/1

"Standard Specifications for Construction of Airports." *Federal Aviation Administration*, 21 December 2018, https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5370-10H.pdf

Winters, B., J. Angel, C. Ballerine, J. Byard, A. Flegel, D. Gambill, E. Jenkins, et al. 2015. " for the Urban Flooding Awareness Act." Illinois Department of Natural Resources.

APPENDICES

Appendix A: FAA Figures and Tables

Appendix B: Pavement Redesign Information

Appendix C: Stormwater Management

Appendix D: Heavybid Estimating

Appendix E: Life Cycle Cost Estimating

Appendix F: Design Considerations and Standards

Appendix A: *FAA Figures and Tables*

Table 2: Design Standards Based on Airplane Design Group (ADG) (1)

Date Completed	Manufacturer	ICAO Code	Model	Physical Class (Engine)	# Engines	AAC	ADG	TDG
2016-Jun-30	Boeing	B772	777-200ER	Jet	2	C	V	5
2016-Jun-30	Boeing	B772	777-200LR	Jet	2	C	V	5
2016-Jun-24	Boeing	B773	777-300	Jet	2	D	V	6
2016-Jun-30	Boeing	B77W	777-300ER	Jet	2	D	V	6
2016-Jun-30	Boeing	B773	777-300F	Jet	2	C	V	5
	Boeing	B774	777-400	Jet	2	No Value	No Value	tbd
	Boeing	B77L	777F			No Value	No Value	tbd
2016-Jul-1	Boeing	tbd	787-10 Dreamliner (Preliminary Da	Jet	2	C	V	6
2016-Jul-1	Boeing	B788	787-8 Dreamliner	Jet	2	C	V	5

Table 3: Design Standards Based on Airplane Design Group (ADG) (2)

Item	ADG					
	I	II	III	IV	V	VI
Taxiway and Taxilane Protection						
TSA (maximum ADG wingspan)	49 ft (14.9 m)	79 ft (24.1 m)	118 ft (36 m)	171 ft (52 m)	214 ft (65 m)	262 ft (80 m)
TOFA [2]	89 ft (27.1 m)	124 ft (38 m)	171 ft (52 m)	243 ft (74 m)	285 ft (87 m)	335 ft (102 m)
TLOFA [2]	79 ft (24.1 m)	110 ft (34 m)	158 ft (48 m)	224 ft (68 m)	270 ft (82 m)	322 ft (98 m)
Taxiway and Taxilane Separation						
Taxiway centerline to parallel taxiway centerline [1]	70 ft (21.3 m)	101.5 ft (30.9 m)	144.5 ft (44 m)	207 ft (63 m)	249.5 ft (76.1 m)	298.5 ft (91 m)
Taxiway centerline to fixed or movable object [2]	44.5 ft (13.6 m)	62 ft (18.9 m)	85.5 ft (26.1 m)	121.5 ft (37 m)	142.5 ft (43 m)	167.5 ft (51 m)
Taxilane centerline to parallel taxilane centerline [1]	64 ft (19.5 m)	94.5 ft (28.8 m)	138 ft (42 m)	197.5 ft (60.2 m)	242 ft (74 m)	292 ft (89 m)
Taxilane centerline to fixed or movable object [2]	39.5 ft (12.2 m)	55 ft (16.8 m)	79 ft (24.1 m)	112 ft (34 m)	135 ft (41 m)	161 ft (49 m)
Wingtip Clearance						
Taxiway wingtip clearance	20 ft (6.1 m)	22.5 ft (6.9 m)	26.5 ft (8.1 m)	36 ft (11 m)	35.5 ft (10.8 m)	36.5 ft (11.1 m)
Taxilane wingtip clearance	15 ft (4.6 m)	15.5 ft (4.7 m)	20 ft (6.1 m)	26.5 ft (8.1 m)	28 ft (8.5 m)	30 ft (9.1 m)

Table 4: Design Standards Based on Taxiway Design Group (TDG) (1)

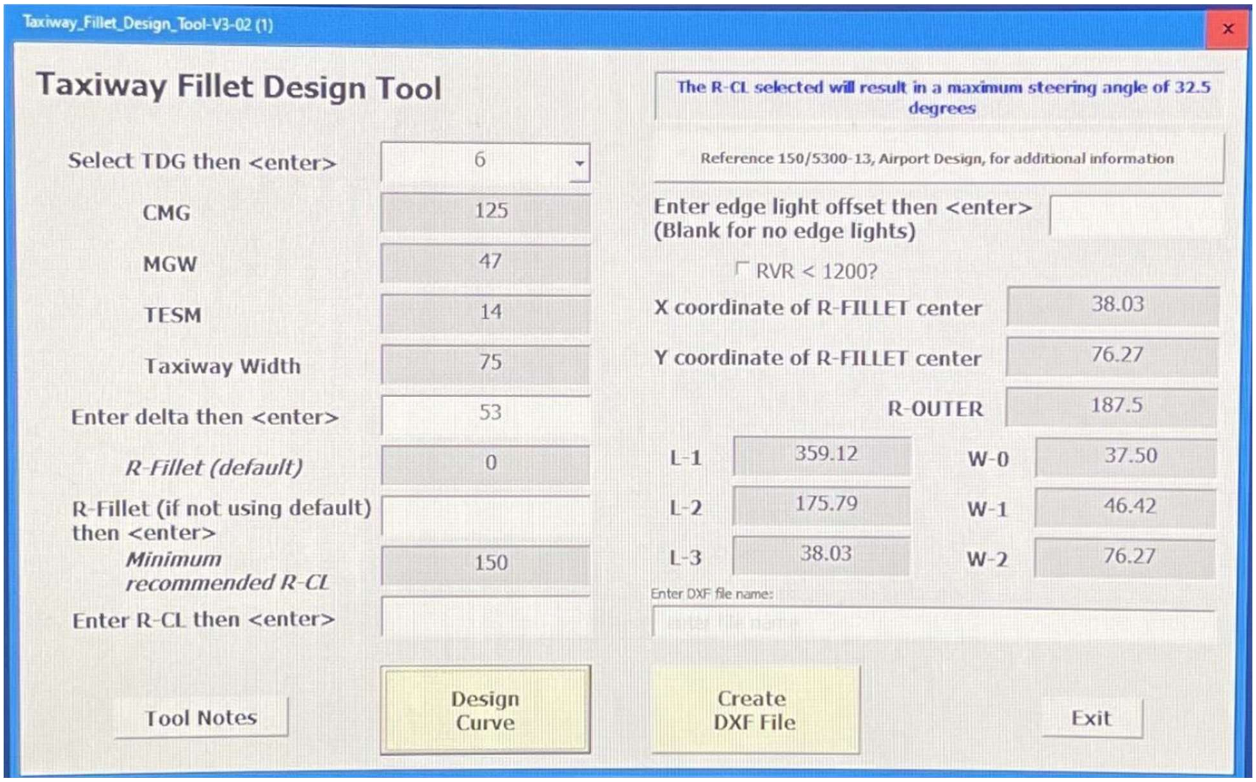

Table 5: Design Standards Based on Taxiway Design Group (TDG) (2)

Item	TDG							
	1A	1B	2A	2B	3	4	5	6
Taxiway/Taxilane Width [1]	25 ft (7.6 m)	25 ft (7.6 m)	35 ft (10.7 m)	35 ft (10.7 m)	50 ft (15.2 m)	50 ft (15.2 m)	75 ft (22.9 m)	75 ft (22.9 m)
Taxiway Edge Safety Margin [1]	5 ft (1.5 m)	5 ft (1.5 m)	7.5 ft (2.3 m)	7.5 ft (2.3 m)	10 ft (3 m)	10 ft (3 m)	14 ft (4.3 m)	14 ft (4.3 m)
Taxiway Shoulder Width [2]	10 ft (3 m)	10 ft (3 m)	15 ft (4.6 m)	15 ft (4.6 m)	20 ft (6.1 m)	20 ft (6.1 m)	30 ft (9.1 m)	30 ft (9.1 m)
Taxiway/Taxilane Centerline to Parallel Taxiway/Taxilane Centerline w/180 Degree Turn	See Table 4-6 and Table 4-7.							

Appendix B: *Pavement Redesign Information*

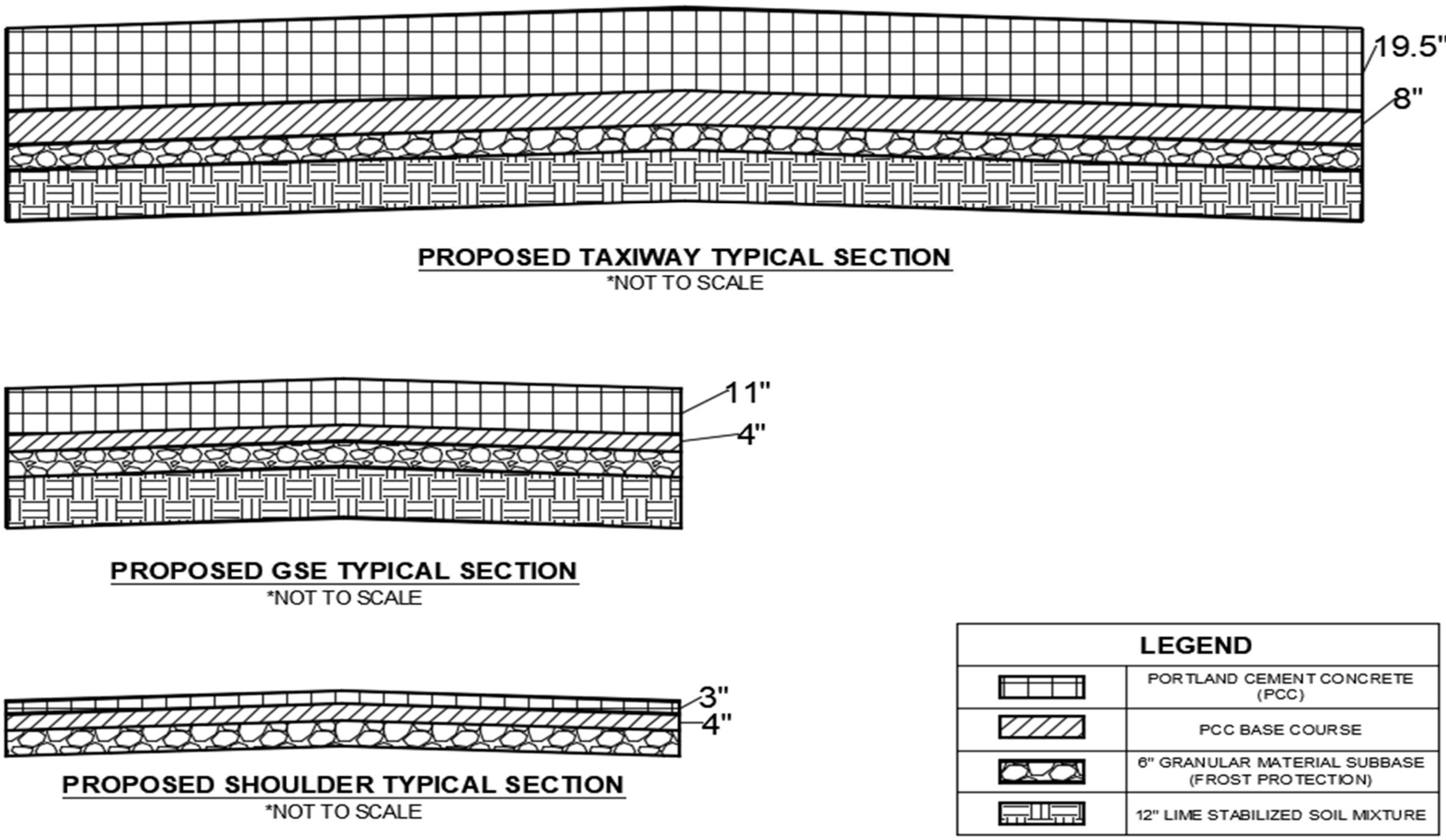

Figure 23: Pavement Typical Section

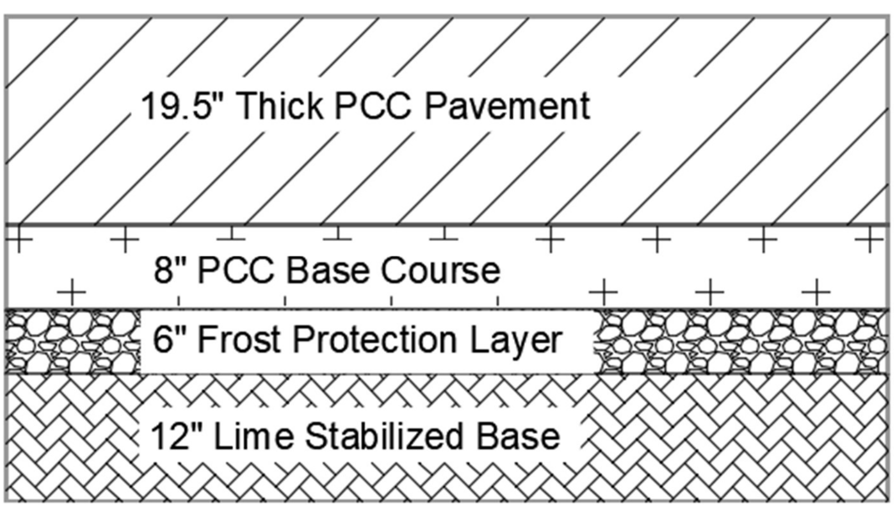

Figure 24: Closer Look at Taxi Lane Typical Section

Appendix C: *Stormwater Management*

Table 6 Outlet Sewer Capacity and Determine Release Rate

Name of Outlet Drainage Basin (as shown on the map):	
Outlet Sewer Capacity (cfs/ac):	**0.80**
Maximum Allowable Release Rate (cfs/ac):	**0.80**

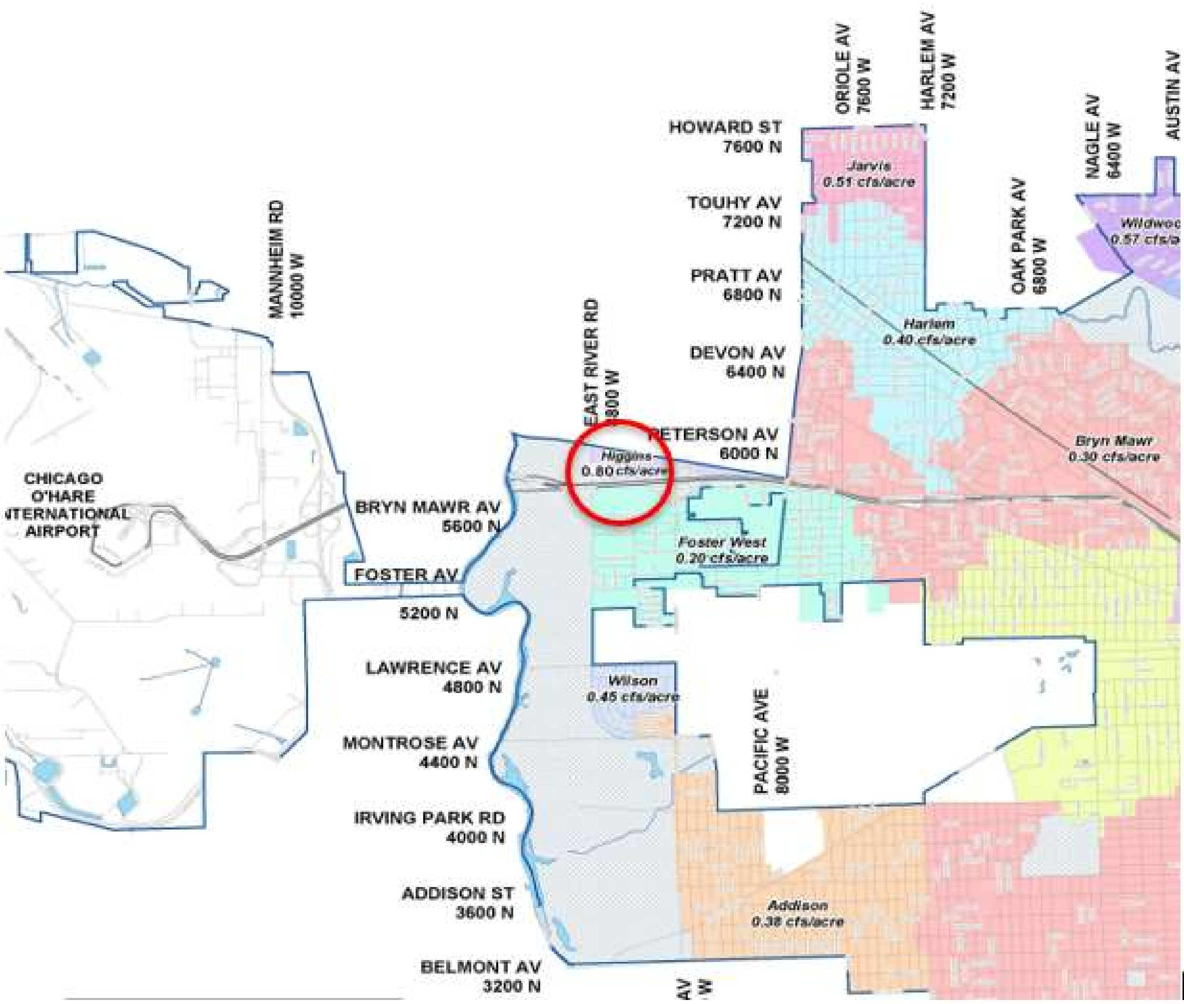

Table 7 Runoff Calculations for Part A

		Part A		
		Proposed Area (sq ft)	**C-Value 100-Year**	**Storage Volume (cu ft)**
Pervious Land	Lawns - Sandy soil, flat, 0% to 2%	43,560	0.18	
	Lawns - Sandy soil, avg, 2% to 7%		0.27	
	Lawns - Sandy soil, steep, >7%		0.36	
	Lawns - Heavy soil, flat, 0% to 2%		0.30	
	Lawns - Heavy soil, avg, 2% to 7%		0.42	
	Lawns - Heavy soil, steep, >7%		0.47	
	Woodlands, flat, 2%		0.39	
	Native Vegetation with prepared soils		0.10	
	Dry bottom basins to HWL		0.75	
	Wetland		0.80	
	Green Roof		0.50	
Impervious Land	Gravel		0.70	
	Pavement	1,184,832	0.95	
	Roofs (conventional)		0.95	
	Critical building sidewall (enter 25% of the face of the largest sidewall draining to lower level roofs or side gutters)		0.95	
	Wet bottom basins to HWL		1.00	
BMP areas	BMPs providing storage that WILL COUNT toward detention storage (from Worksheet 1.2)	0	1.00	
	BMPs providing volume control storage that WILL NOT BE COUNTED toward detention (from Worksheet 1.2)	0	Storage Provided will be used to factor the adjusted C-value in Cell D38	0

Summary	Total pervious area	43,560	sq ft		
	Total impervious area	1,184,832	sq ft		
	Total BMP area	0	sq ft		
	Total project area including sidewall	1,228,392	sq ft	28.20	acres
	Total project area excluding sidewall	1,228,392	sq ft	28.20	acres
	Weighted C- value (non BMP areas)	0.92	unitless		
	Adjusted C-value (including BMPs)	0.00	unitless		
	Notes:	*Make note of any adjustments made for purposes of detention calcs here (such as removal of roof area that will discharge directly to Waters)*			

Table 8: Allowable Release Rate Assessment for Part A

		Type Yes or No for all that apply	**Notes**
Question 1:	Does the site drain directly to Waters?	Yes	Roof area can be directed to Waters and not included in detention calculations, delete roof from table above and make note to that effect, release rate is based on 1 cfs/ac.
Question 2:	Does the site only include residential land use?	NO	
Question 3:	Is the Regulated Development a Lot-to-Lot Buillding (85% or more of site footprint is occupied by buildings)?	NO	

Question 4:	Do you plan to use the standard maximum release rate (only available to sites less than 1.75 acres)?	NO	Complete Tab 0.0 Release Rate to calculate the allowable release rate for the site unless a 1 cfs/ac release rate to waters will be used.
Question 5:	Is the site more than 75 percent of substantially contiguous at-grade open space that is conducive to ponding of surface waters (Answer "No" if site discharges to waterway or is a service station)?	NO	
Question 6:	Does the development involve flow diversions (existing sewer connection to be relocated to a different main) or multiple sewer connections (only available to sites over 1.75 acres)?	NO	
Question 7:	Are there widespread contaminated soils on the site, high ground water table, or is this development classified as a lot-to-lot building?	NO	Oversized detention is not allowed. Do not fill out Tab 2.1.9

Table 9: Achieving Rate Control Measures for Part A

Unadjusted Detention Release Rate	28.200	cfs	28.200	22.560
Average Dry Weather Flow Rate (From Tab 1.1)	0.000	cfs	Waiting for Dry Weather Flow worksheet to be completed	
Infiltration Facility Release Rate	0.000	cfs	No BMPs with infiltration beds entered on BMP Summary Worksheet or soil's infiltration rate is less than 0.5 in/hr	
Release rate for detention storage computations	**28.200**	cfs		
Required Storage Volume	231,952	cu ft		

Table 10: Calculations for the Required Detention Volume for Part A Using Bulletin 70

Bulletin 70								
Storm Duration	Runoff Coefficient	Rainfall Intensity	Drainage Area A	Rate Q=CIA	Total Storm Vol	Rate Qo	Rate Qi-Qo	Volume Rate (Qi-Qo)*t*60
(minutes)	C	(in/hr)	(acres)	(cfs)	(cu ft)	(cfs)	(cfs)	(cu ft)
5	0.922695	10.92	28.2	284.1384	85241.52	28.2	255.9384	76781.52
10	0.922695	10.02	28.2	260.7204	156432.2	28.2	232.5204	139512.24
15	0.922695	8.2	28.2	213.364	192027.6	28.2	185.164	166647.6
30	0.922695	5.6	28.2	145.712	262281.6	28.2	117.512	211521.6
60	0.922695	3.56	28.2	92.6312	333472.3	28.2	64.4312	231952.32
120	0.922695	2.235	28.2	58.1547	418713.8	28.2	29.9547	215673.84
180	0.922695	1.616667	28.2	42.06567	454309.2	28.2	13.86566667	149749.2
360	0.922695	0.946667	28.2	24.63227	532057	28.2	-3.56773333	-77063.04
720	0.922695	0.549167	28.2	14.28932	617298.5	28.2	-13.9106833	-600941.52
1080	0.922695	0.387222	28.2	10.07552	652893.8	28.2	-18.1244778	-1174466.16
1440	0.922695	0.315833	28.2	8.217983	710033.8	28.2	-19.9820167	-1726446.24
2880	0.922695	0.17	28.2	4.4234	764363.5	28.2	-23.7766	-4108596.48
4320	0.922695	0.121944	28.2	3.172994	822440.2	28.2	-25.0270056	-6486999.84
7200	0.922695	0.083	28.2	2.15966	932973.1	28.2	-26.04034	-11249426.9
14400	0.922695	0.046417	28.2	1.207762	1043506	28.2	-26.9922383	-23321293.9
							Required Detention Volume (cu ft)	**231952.32**

Table 11: Calculations for the Required Detention Volume for Part A Using Bulletin 75

Bulletin 75								
Storm	Runoff	Rainfall	Drainage	Rate	Total	Rate	Rate	Volume Rate
Duration	Coefficient	Intensity	Area A	Q=CIA	Storm Vol	Qo	Qi-Qo	(Qi-Qo)*t*60
(minutes)	C	(in/hr)	(acres)	(cfs)	(cu ft)	(cfs)	(cfs)	(cu ft)
5.00	0.92	11.88	28.20	309.12	92735.28	28.20	280.92	84275.28
10.00	0.92	10.38	28.20	270.09	162052.56	28.20	241.89	145132.56
15.00	0.92	8.92	28.20	232.10	208888.56	28.20	203.90	183508.56
30.00	0.92	6.10	28.20	158.72	285699.60	28.20	130.52	234939.60
60.00	0.92	3.88	28.20	100.96	363447.36	28.20	72.76	261927.36
120.00	0.92	2.39	28.20	62.19	447752.16	28.20	33.99	244712.16
180.00	0.92	1.76	28.20	45.80	494588.16	28.20	17.60	190028.16
360.00	0.92	1.03	28.20	26.84	579829.68	28.20	-1.36	-29290.32
720.00	0.92	0.60	28.20	15.57	672564.96	28.20	-12.63	-545675.04
1080.00	0.92	0.43	28.20	11.20	725958.00	28.20	-17.00	-1101402.00
1440.00	0.92	0.34	28.20	8.94	772794.00	28.20	-19.26	-1663686.00
2880.00	0.92	0.18	28.20	4.79	827123.76	28.20	-23.41	-4045836.24
							Required Detention Volume (cu ft)	**261927.36**

Table 12: Runoff Calculations for Part B

		Part B		
		Proposed Area (sq ft)	**C-Value 100-Year**	**Storage Volume (cu ft)**
Pervious Land	Lawns - Sandy soil, flat, 0% to 2%	43,560	0.18	
	Lawns - Sandy soil, avg, 2% to 7%		0.27	
	Lawns - Sandy soil, steep, >7%		0.36	
	Lawns - Heavy soil, flat, 0% to 2%		0.30	
	Lawns - Heavy soil, avg, 2% to 7%		0.42	
	Lawns - Heavy soil, steep, >7%		0.47	
	Woodlands, flat, 2%		0.39	
	Native Vegetation with prepared soils		0.10	
	Dry bottom basins to HWL		0.75	
	Wetland		0.80	
	Green Roof		0.50	
Impervious Land	Gravel		0.70	
	Pavement	542,322	0.95	
	Roofs (conventional)	480,467	0.95	
	Critical building sidewall (enter 25% of the face of the largest sidewall draining to lower level roofs or side gutters)		0.95	
	Wet bottom basins to HWL		1.00	
BMP areas	BMPs providing storage that WILL COUNT toward detention storage (from Worksheet 1.2)	0	1.00	
	BMPs providing volume control storage that WILL NOT BE COUNTED toward detention (from Worksheet 1.2)	0	Storage Provided will be used to factor the adjusted C-value in Cell D38	0

Summary	Total pervious area	43,560	sq ft		
	Total impervious area	1,022,789	sq ft		
	Total BMP area	0	sq ft		
	Total project area including sidewall	1,066,349	sq ft	24.48	acres
	Total project area excluding sidewall	1,066,349	sq ft	24.48	acres
	Weighted C- value (non BMP areas)	0.92	unitless		
	Adjusted C-value (including BMPs)	0.00	unitless		
	Notes:	*Make note of any adjustments made for purposes of detention calcs here (such as removal of roof area that will discharge directly to Waters)*			

Table 13: Allowable Release Rate Assessment for Part B

		Type Yes or No for all that apply	Notes
Question 1:	Does the site drain directly to Waters?	Yes	Roof area can be directed to Waters and not included in detention calculations, delete roof from table above and make note to that effect, release rate is based on 1 cfs/ac.
Question 2:	Does the site only include residential land use?	NO	
Question 3:	Is the Regulated Development a Lot-to-Lot Buillding (85% or more of site footprint is occupied by buildings)?	NO	
Question 4:	Do you plan to use the standard maximum release rate (only available to sites less than 1.75 acres)?	NO	Complete Tab 0.0 Release Rate to calculate the allowable release rate for the site unless a 1 cfs/ac release rate to waters will be used.
Question 5:	Is the site more than 75 percent of substantially contiguous at-grade open space that is conducive to ponding	NO	

	of surface waters (Answer "No" if site discharges to waterway or is a service station)?		
Question 6:	Does the development involve flow diversions (existing sewer connection to be relocated to a different main) or multiple sewer connections (only available to sites over 1.75 acres)?	NO	
Question 7:	Are there widespread contaminated soils on the site, high ground water table, or is this development classified as a lot-to-lot building?	NO	Oversized detention is not allowed. Do not fill out Tab 2.1.9

Table 14: Achieving Rate Control Measures for Part B

Unadjusted Detention Release Rate	24.480	cfs	24.480	19.584
Average Dry Weather Flow Rate (From Tab 1.1)	0.000	cfs	Waiting for Dry Weather Flow worksheet to be completed	
Infiltration Facility Release Rate	0.000	cfs	No BMPs with infiltration beds entered on BMP Summary Worksheet or soil's infiltration rate is less than 0.5 in/hr	
Release rate for detention storage computations	**24.480**	cfs		
Required Storage Volume	200,053	cu ft		

Table 15: Calculations for the Required Detention Volume for Part B Using Bulletin 70

Bulletin 70								
Duration (minutes)	Coefficient C	Intensity (in/hr)	Area A (acres)	Q=CIA (cfs)	Storm Vol (cu ft)	Qo (cfs)	Qi-Qo (cfs)	(Qi-Qo)*t*60 (cu ft)
5	0.918546	10.92	24.48	245.5471	73664.12	24.48	221.0671	66320.12309
10	0.918546	10.02	24.48	225.3097	135185.8	24.48	200.8297	120497.8085
15	0.918546	8.2	24.48	184.3852	165946.6	24.48	159.9052	143914.6519
30	0.918546	5.6	24.48	125.9216	226658.8	24.48	101.4416	182594.8443
60	0.918546	3.56	24.48	80.05014	288180.5	24.48	55.57015	200052.5366
120	0.918546	2.235	24.48	50.2562	361844.6	24.48	25.7762	185588.6749
180	0.918546	1.616667	24.48	36.35236	392605.5	24.48	11.87236	128221.5334
360	0.918546	0.946667	24.48	21.28674	459793.6	24.48	-3.19325	-68974.262
720	0.918546	0.549167	24.48	12.34856	533457.8	24.48	-12.1314	-524078.041
1080	0.918546	0.387222	24.48	8.707077	564218.6	24.48	-15.7729	-1022085.1
1440	0.918546	0.315833	24.48	7.101827	613597.8	24.48	-17.3782	-1501473.75
2880	0.918546	0.17	24.48	3.822619	660548.6	24.48	-20.6574	-3569594.6
4320	0.918546	0.121944	24.48	2.742042	710737.4	24.48	-21.738	-5634477.46
7200	0.918546	0.083	24.48	1.866338	806257.9	24.48	-22.6137	-9769100.16
14400	0.918546	0.046417	24.48	1.043725	901778.4	24.48	-23.4363	-20248937.7
							Required Detention Volume (cu ft)	**200052.54**

Table 16: Calculations for the Required Detention Volume for Part B Using Bulletin 75

Bulletin 75								
Storm Duration	Runoff Coefficient	Rainfall Intensity	Drainage Area A	Rate Q=CIA	Total Storm Vol	Rate Qo	Rate Qi-Qo	Volume Rate (Qi-Qo)*t*60
(minutes)	C	(in/hr)	(acres)	(cfs)	(cu ft)	(cfs)	(cfs)	(cu ft)
5.00	0.92	11.88	24.48	267.13	80140.09	24.48	242.65	72796.09
10.00	0.92	10.38	24.48	233.40	140042.78	24.48	208.92	125354.78
15.00	0.92	8.92	24.48	200.58	180517.57	24.48	176.10	158485.58
30.00	0.92	6.10	24.48	137.16	246896.23	24.48	112.68	202832.24
60.00	0.92	3.88	24.48	87.25	314084.39	24.48	62.77	225956.40
120.00	0.92	2.39	24.48	53.74	386939.01	24.48	29.26	210683.05
180.00	0.92	1.76	24.48	39.58	427413.81	24.48	15.10	163029.85
360.00	0.92	1.03	24.48	23.20	501077.93	24.48	-1.28	-27689.97
720.00	0.92	0.60	24.48	13.45	581218.02	24.48	-11.03	-476317.79
1080.00	0.92	0.43	24.48	9.68	627359.28	24.48	-14.80	-958944.42
1440.00	0.92	0.34	24.48	7.73	667834.07	24.48	-16.75	-1447237.53
2880.00	0.92	0.18	24.48	4.14	714784.83	24.48	-20.34	-3515358.38
4320.00	0.92	0.13	24.48	2.95	764973.57	24.48	-21.53	-5580241.24
							Required Detention Volume (cu ft)	**225956.40**

Appendix D: *Heavybid Estimate*

Table 17: Frost Protection Crew Breakdown

Place and Compact Stone				
Crew	Quantity	Unit	Price/Unit	Cost
Dozer - Cat D6	87.5	HR	$ 213.00	$ 18,637.50
CAT 12G Motorgrader	87.5	HR	$ 95.00	$ 8,312.50
Vib steel roller	175	HR	$ 78.00	$ 13,650.00
Pickup truck	87.5	HR	$ 11.20	$ 980.00
Water truck, 3500 GAL	87.5	HR	$ 100.00	$ 8,750.00
Labor Foreman	87.5	MH	$ 49.65	$ 5,517.55
General Laborer	87.5	MH	$ 48.90	$ 5,439.29
Operator - Scraper, Grdr	87.5	MH	$ 54.80	$ 6,054.92
Operator - Dozer, Ldr	87.5	MH	$ 51.00	$ 5,658.41

Table 18: Cement Treated Base Crew Breakdown

Cement Treated Permeable Base				
Crew	Quantity	Unit	Price/Unit	Cost
Graded aggregate base	17250	TON	$ 35.00	$ 603,750.00
Cement for Base	47.04	TON	$ 135.00	$ 6,350.40
Hauling sub - by the cy	17250	TON	$ 15.00	$ 258,750.00
AP1055F	110.77	HR	$ 150.00	$ 16,615.50
Labor Foreman	221.54	MH	$ 49.65	$ 13,969.79
General Laborer	110.77	MH	$ 48.90	$ 6,885.82
Screed/curbformer oper	110.77	MH	$ 66.05	$ 9,255.36

Table 19: PCC Paving Crew Breakdown

PCC Paving				
Crew	Quantity	Unit	Price/Unit	Cost
5000-psi concrete	30000	CY	$170.00	$5,100,000.00
Gomaco GP 2600	553.85	HR	$266.69	$ 147,706.26
Concrete work tools	1661.55	HR	$ 8.00	$ 13,292.40
Walk Behind Concrete Saw	553.85	HR	$ 25.00	$ 13,846.25
Conc. mason/finisher	2215.4	MH	$ 48.90	$ 138,165.53
Labor Foreman	553.85	MH	$ 49.65	$ 34,924.46
General Laborer	2215.4	MH	$ 48.90	$ 137,716.46
Screed/curbformer oper	553.85	MH	$ 66.05	$ 46,276.81

Appendix E: *Life Cycle Cost Analysis*

Table 20: PCC Pavement 30 Year Life Cycle Cost

PRESENT WORTH LIFE-CYCLE COSTING						
CONCRETE PAVEMENT ALTERNATIVE						
Year No.	Interest Rate	Description of Activity	Current Cost of Activity per Unit	Units	Present Worth Factor (1/(1+r))^n	Present Worth of Activity
	7.0%	Concrete Construction	$133.65	SY	1.0000	$133.65
1	7.0%			SY	0.9346	
2	7.0%			SY	0.8734	
3	7.0%			SY	0.8163	
4	7.0%			SY	0.7629	
5	7.0%	Minor Repair	$0.22	SY	0.7130	$0.16
6	7.0%			SY	0.6663	
7	7.0%	Striping	$2.50	SY	0.6227	$1.56
8	7.0%			SY	0.5820	
9	7.0%			SY	0.5439	
10	7.0%	Major Repair	$8.83	SY	0.5083	$4.49
11	7.0%			SY	0.4751	
12	7.0%			SY	0.4440	
13	7.0%			SY	0.4150	
14	7.0%	Striping	$2.50	SY	0.3878	$0.97
15	7.0%	Maint./Joint Sealing	$4.64	SY	0.3624	$1.68
16	7.0%			SY	0.3387	
17	7.0%			SY	0.3166	
18	7.0%			SY	0.2959	
19	7.0%			SY	0.2765	
20	7.0%	Major Repair	$8.83	SY	0.2584	$2.28
21	7.0%			SY	0.2415	
22	7.0%			SY	0.2257	
23	7.0%			SY	0.2109	
24	7.0%	Striping	$5.08	SY	0.1971	$1.00
25	7.0%	Maint./Joint Sealing	$4.64	SY	0.1842	$0.85
26	7.0%			SY	0.1722	
27	7.0%			SY	0.1609	
28	7.0%			SY	0.1504	
29	7.0%			SY	0.1406	
30	7.0%			SY	0.1314	
Sub Total			$170.88			$146.64
Salvage Value						
Total			**$170.88**			**$146.64**

Table 21: Asphalt Pavement Life Cycle Cost

PRESENT WORTH LIFE-CYCLE COSTING						
ASPHALT PAVEMENT ALTERNATIVE						
Year No.	Interest Rate	Description of Activity	Current Cost of Activity per Unit	Units	Present Worth Factor (1/(1+r))^n	Present Worth of Activity
	7.0%	Asphalt Construction	$127.33	SY	1.0000	$127.33
1	7.0%				0.9346	
2	7.0%	Maintenance	$0.69	SY	0.8734	$0.60
3	7.0%				0.8163	
4	7.0%	Seal	$4.05	SY	0.7629	$3.09
5	7.0%	Maintenance	$0.69	SY	0.7130	$0.49
6	7.0%				0.6663	
7	7.0%				0.6227	
8	7.0%	Maintenance	$0.69	SY	0.5820	$0.40
9	7.0%				0.5439	
10	7.0%	Maintenance	$0.69	SY	0.5083	$0.35
11	7.0%				0.4751	
12	7.0%	Mill and Overlay	$37.69	SY	0.4440	$16.73
13	7.0%			SY	0.4150	
14	7.0%				0.3878	
15	7.0%	Maintenance	$0.69	SY	0.3624	$0.25
16	7.0%				0.3387	
17	7.0%	Seal	$4.05	SY	0.3166	$1.28
18	7.0%				0.2959	
19	7.0%				0.2765	
20	7.0%	Maintenance	$0.69	SY	0.2584	$0.18
21	7.0%				0.2415	
22	7.0%	Mill and Overlay	$37.69	SY	0.2257	$8.51
23	7.0%			SY	0.2109	
24	7.0%				0.1971	
25	7.0%	Maintenance	$0.69	SY	0.1842	$0.13
26	7.0%				0.1722	
27	7.0%	Seal	$4.05	SY	0.1609	$0.65
28	7.0%				0.1504	
29	7.0%				0.1406	
30	7.0%			SY	160.0000	
Sub Total			$177.26			$160.00
Salvage Value						
Total			**$177.26**			**$160.00**

Appendix F: ABET Outcome 2, Design Factor Considerations

ABET Outcome 2 states "*An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health safety, and welfare, as well as global, cultural, social, environmental, and economic factors.*"

ABET also requires that design projects reference appropriate professional standards, such as IEEE, ATSM, etc.

For each of the factors in Table F.1, indicate the page number(s) of your report where the item is addressed, or provide a statement regarding why the factor is not applicable for this project.

Table F.1, Design Factors Considered

Design Factor	Page number, or reason not applicable
Public health safety, and welfare	Page 9
Global	The FAA is a U.S. agency, so these standards do not apply to airports globally.
Cultural	Because this only impacts the U.S. and people that travel through this specific airport, there are not cultural impacts.
Social	Section 4 (page16)
Environmental	Section 4 (page 16)
Economic	Section 5 (pages 27-31)
Ethical & Professional	Page 6
Reference for Standards	Pages 4-5, 7-12, 16-19, 21-22