JTA U²C INFRASTRUCTURE ASSESSMENT

2/12/2018

RS&H

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EXECUTIVE SUMMARY

The U^{2}C Infrastructure Assessment is one component of the JTA's U^{2}C program. This U^{2}C Infrastructure Assessment report summarizes the analysis of the existing Skyway infrastructure to determine the feasibility of system conversion to accommodate rubber-tired autonomous vehicles. The report identifies key considerations that influence conversion options and identifies potential risks. Recommended next steps are also outlined.

Key considerations identified through assessment of Skyway infrastructure include:

- Design Life –As segments of the system degrade, future increases in maintenance costs and further reductions in the structure service life can be expected.

- Vehicle Considerations – The geometry of available autonomous vehicles (AV) appears manageable on the current system. However, the design vehicle chosen for this report does not meet the lateral clearance requirements for many of the horizontal curves on the system. Horizontal clearance in the small radius curves is an unresolved design constraint caused by retaining the existing superstructure. The manufacturer of the design vehicle (2getthere) does not have a solution to this constraint. Stopping sight distance is also a constraint due to several vertical sag curves along the existing guideway. Design specifications of other appropriate AV manufacturer's vehicles will need to be collected and additional studies based on this information will need to be conducted to identify an AV design vehicle that can meet these constraints.

- Guidebeam Removal – Removal of the concrete guidebeam and installation of a smooth running surface appears to be feasible. However, removal will require careful demolition to avoid adversely affecting the structural integrity.

- Profile Modifications at Stations – In order for the floor of the new AV vehicles to be level with the station platform, guideway modifications (Alternative Buildup) at stations will be required. These modifications will add additional weight that will reduce the structural capacity of the existing superstructure.

- Barrier Walls – Existing sidewalls are not adequate for crashworthiness of the design vehicle. Further investigation will be required for other available AV based on information provided from the manufacturer.

- Running Surface and Drainage – Installation of the new running surface is feasible but will require detailed design to accommodate superelevation and ensure drainage that meets standards for an elevated roadway.

- Maintenance Costs – Annual maintenance costs to keep existing infrastructure in a state of good repair and in operation are likely to increase significantly as the service life is approached.

Based on the analysis and consideration of key items above, four conversion options have been identified:

1. Remove Guidebeam, Add Running Surface, Alternative Buildup at Stations, Retain Existing Barrier
2. Remove Guidebeam, Add Running Surface, Replace Superstructure at Stations, Retain Existing Barrier
3. Remove Guidebeam, Add Running Surface, Replace Superstructure at Stations, Replace Barrier
4. New Superstructure Throughout

Recommended next steps that will assist in defining appropriate design standards, developing the scope of a preferred option(s) for conversion, and assess risks associated with delivery methods are included below:

1. **Conduct Value Metric Analysis** – In order to determine the scope of conversion that will offer the best value, we recommend that JTA perform a value metric analysis for each of the conversion options. This analysis will assist JTA in defining the option(s) which will offer the best value. The best value option may not be the option with the lowest initial cost.
2. **Delivery Method Risk Assessment** – In order to assess the delivery method that will provide the best value and minimize risk, JTA should perform a delivery method risk assessment for Design Build and P3 alternatives. The delivery method will affect definition of scope and design criteria, as well as life cycle cost, among other important factors. JTA's risk tolerance for these effects will help determine the right delivery method.
3. **Confirm Design Standards** – This infrastructure conversion is unprecedented and will require the development of unique design standards. The conversion is transforming an elevated rail system to an elevated roadway and therefore will require confirmation and approval of design standards in collaboration with agencies having jurisdiction, including JTA, FDOT, FTA and COJ. The required standards, which must include ADA, will affect the scope and cost of the conversion.

It is important to note that any decisions regarding the scope of the infrastructure conversion and delivery method must consider other project components. This report is intended to be included in the Transit Concept Alternative Review (TCAR) report that will be performed under a separate task. The TCAR study will further evaluate other program components including ridership, vehicles and operating system, operational requirements and funding strategies.

VALUE METRICS

DELIVERY METHOD RISK ASSESSMENT

CONFIRM DESIGN STANDARDS

CHAPTER 1

CONVERSION ASSESSMENT

1.1 INTRODUCTION

This report documents the assessment of the feasibility of converting the existing skyway infrastructure to accommodate rubber tired autonomous vehicles. This report will summarize the findings of the assessment and present potential options for the conversion. The assessment for other program components including vehicles and operating systems, performance requirements, operations and maintenance as well as evaluation of funding options will be performed as part of continuing development of the U^{2}C project. This report will also be included as part of the Transit Concept Alternatives Review Report that will be provided to FDOT.

The JTA Skyway infrastructure was analyzed for possible conversion to accommodate an autonomous vehicle that would operate on rubber tires without a guidebeam. The objective of this infrastructure assessment is to identify constraints to give the Jacksonville Transportation Authority a better understanding of the modifications that may be required and the feasibility of these modifications.

The existing infrastructure was built for the current transit vehicle, a Bombardier UMIII that runs on a straddle-type monorail. The Skyway system was built in 5 segments over a period of more than 10 years beginning in 1987, as outlined below (Figure 2). The result is varying typical sections and detailing throughout the guideway system.

This infrastructure evaluation will use design vehicle specifications to assess if it is feasible for AV technology to operate under the constraints of the current infrastructure and, if so, what concept-level structural changes would have to be made.

The "design vehicle" chosen for this assessment is the 2getthere vehicle (see Figure 1). This vehicle was chosen because it has the desired passenger capacity as well as performance requirements and other technical data readily available. It is also larger relative to other similar autonomous vehicles (AV), therefore it may be assumed that a conversion to accommodate this vehicle would also be suitable for other AV. The design vehicle was chosen only to investigate a baseline of potential infrastructure modifications and is not intended to be the preferred vehicle in possible AV implementation.

For reference, the design vehicle is a "self-driving electric vehicle" that is led by "detecting magnets embedded in the road bed using a patented magnet measurement system" (APMS). The design vehicle and other similar AV systems use a variety of navigation tools beyond that of magnet coursing capabilities.

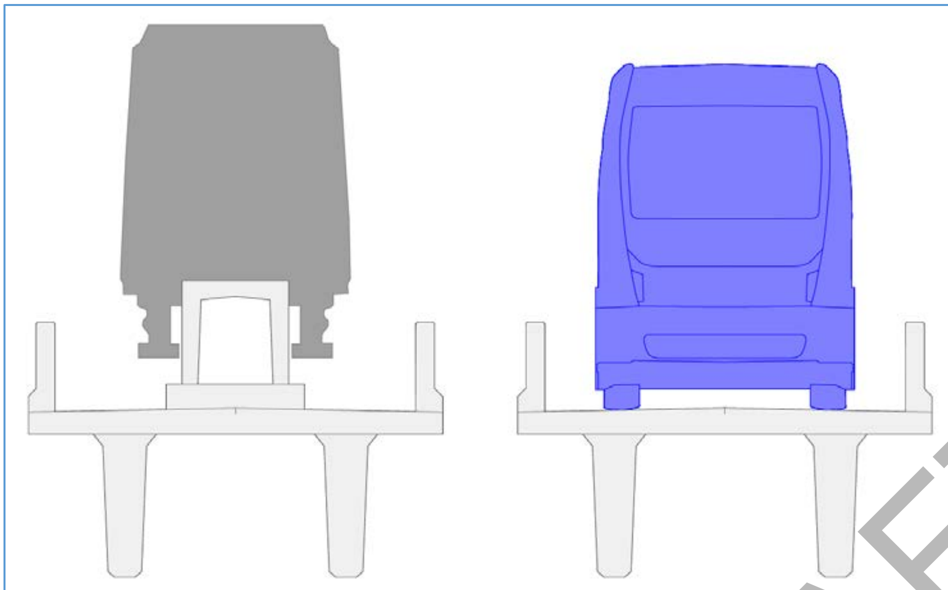


FIGURE 1: BOMBARDIER UMIII (LEFT) AND 2GETTHERE (RIGHT)

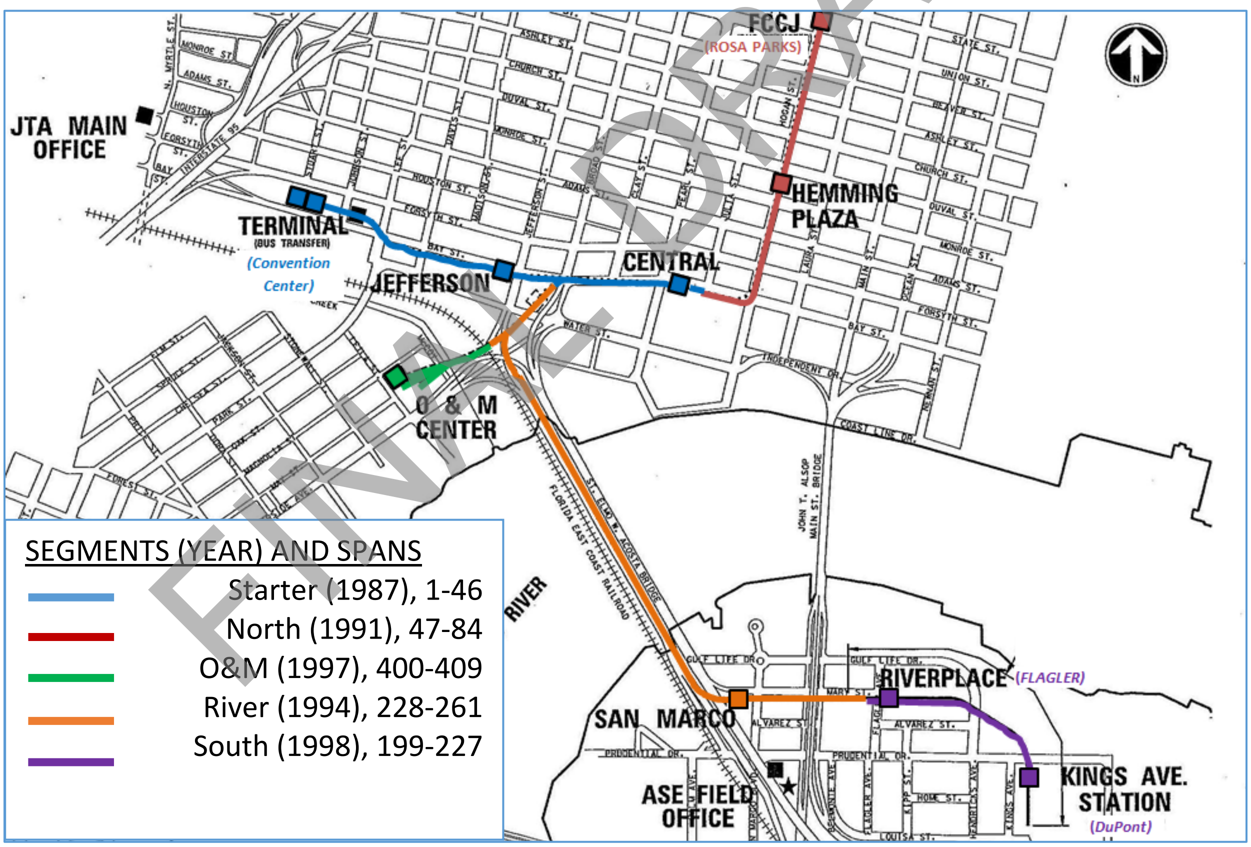


FIGURE 2: JTA SKYWAY MAP

1.2 DEFINITIONS

Guideway – This is the majority of elements at or above the superstructure of the Skyway system. Reinforced deck, riding surface, barrier and “guidebeam” all make up this description.

Guidebeam – For clarity, this term can be compared to a sort of track. It is a hollow, precast concrete beam on which the current Bombardier UMII travels on. This guidebeam sits on a concrete pedestal and is positioned in approximately the center of the guideway throughout its entire length.

Pedestal – A concrete block, presumably to adjust for superelevation, for the guidebeam to sit on. It varies from being continuous to intermittently spaced throughout the guideway. This pedestal is doweled into the deck surface and the guidebeam is doweled into the pedestal.

Floor Level – The height from the surface of the guideway to the floor surface of the passenger cabin in the design vehicle.

Crossover – These are portions of the guideway that are located between tangent guideway lanes. They allow for vehicle direction transfers. At these locations, switchbeams are installed to allow for the transfer movement.

Switchbeam – This is what the guidebeam is referred to at crossover locations. A switchbeam is steel rather than concrete. It facilitates train transfers to adjacent parallel tracks and merges between lines. They are controlled with a system of computer controlled hydraulic devices to shift the switchbeam from one location to another.

Dapped Beam End – A method where a beam end is notched out near the pier to reduce the overall superstructure height.

Segment – When used in context of guideway discussion, a segment refers to a particular phase of the system in which the Skyway was constructed.

Superelevation – A technique employed to maintain safety and user comfort while providing higher design speed.

(Vehicle) Manufacturer – This refers to 2getthere, the vehicle manufacturer.

Design Vehicle – This refers to the 2getthere vehicle.

Superstructure – portion of the bridge structure that is above the piers and directly receives the live load

Substructure – underlying structure that supports the superstructure and transfers the load into the foundations

1.3 EXISTING CONDITION AND INSPECTION REPORTS

The 2017 Routine Inspection Report summarizes a 31 day field inspection of the Skyway. Overall the structure was found to be in good condition with some areas of concern with the superstructure. The substructure units appear to be in good condition.

The most critical areas of concern are cracking at the dapped end sections of the pre-stressed double tee beams throughout the structure. JTA has performed routine maintenance at these areas by installing carbon fiber reinforced (CFRP) wraps on beams that have showed high levels of radial cracking at these dapped ends.

Another area of concern is the post tensioning of the prestressed double tee beams. It is likely that the void space between the post tensioning rods has accumulated water and that there is active corrosion of the rods. Because these rods are concealed within the structure it is difficult to assess the actual condition, however, this is an area of concern that should be carefully monitored throughout life of structure.

Other key maintenance needs include a significant portion of compression seal expansion joints that are in severe condition. Bearing pads are in relatively good shape with under ten in the entire system labeled as “poor”. A significant portion of the protective steel paint is in a poor state throughout the system and could be repainted during infrastructure conversion. Also significant portions of concrete prestressed and R/C tee beams show levels of spalling or cracking. This is especially true at the double tee dapped beam ends.

Due to possible modifications of the deck to accompany an AV, mostly all deck elements outlined in the inspection report would be either repaired or replaced.

The inspection report includes approximately $10M in recommended maintenance items that should be performed before or during the conversion to keep system in a state of good repair and extend service life of the system. See Appendix C for Maintenance Recommendations.

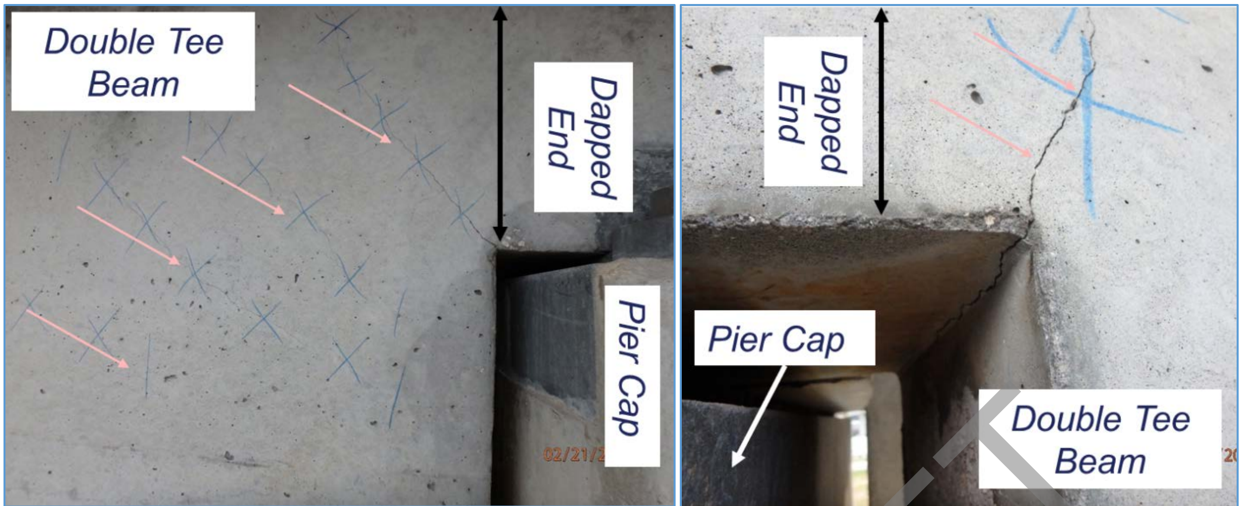


FIGURE 3: DAPPED BEAM END DETAILS

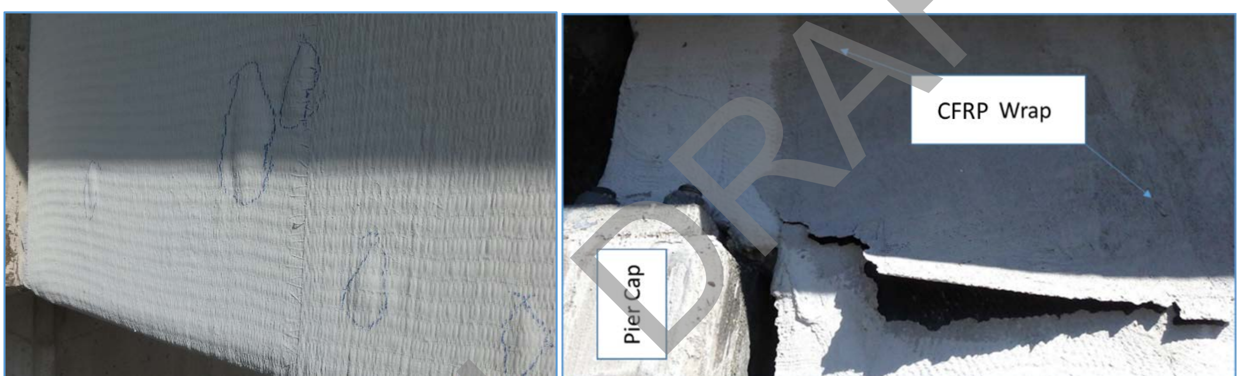


FIGURE 4: CRFP WRAP

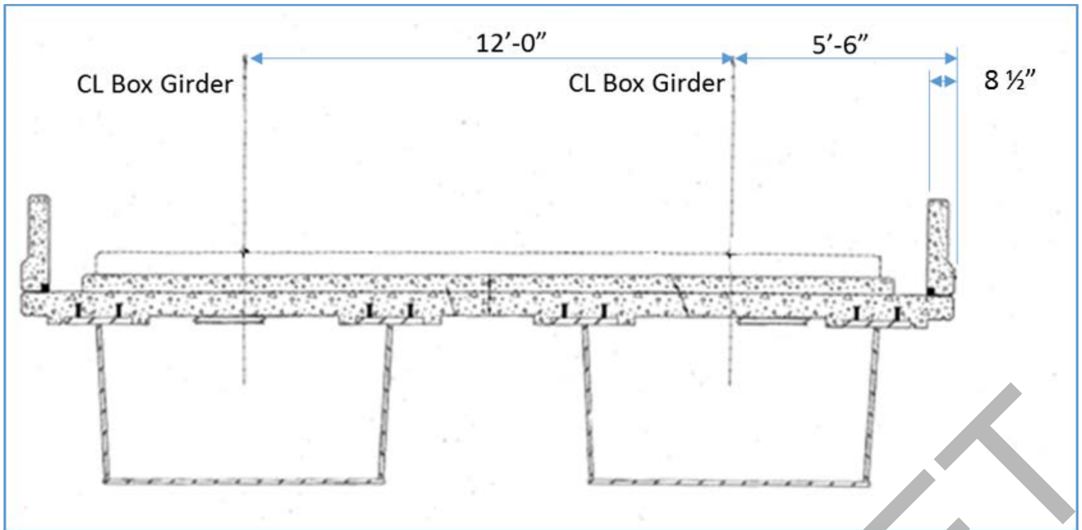


FIGURE 5: CROSS SECTION OF BOX GIRDERS

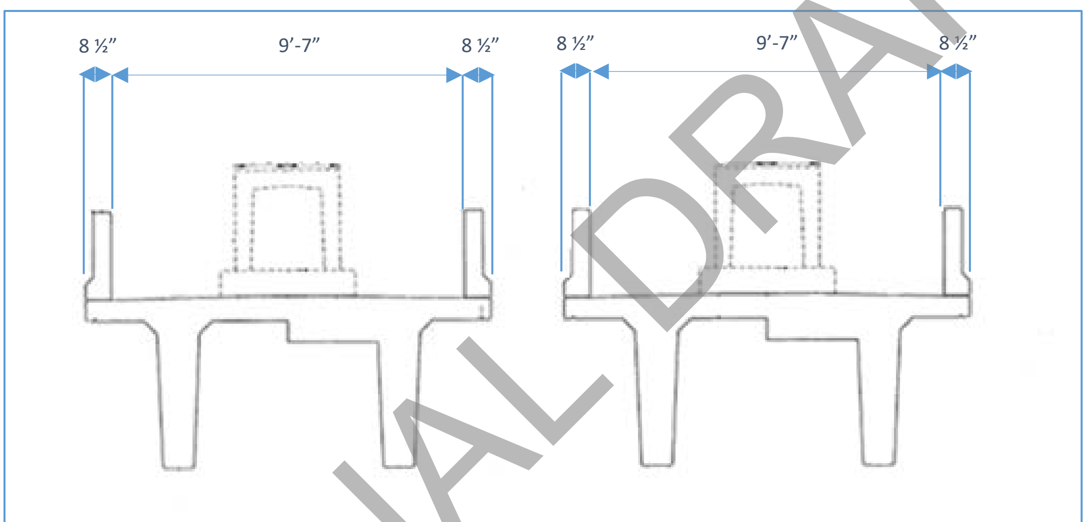


FIGURE 6: CROSS SECTION OF DOUBLE TEE BEAMS

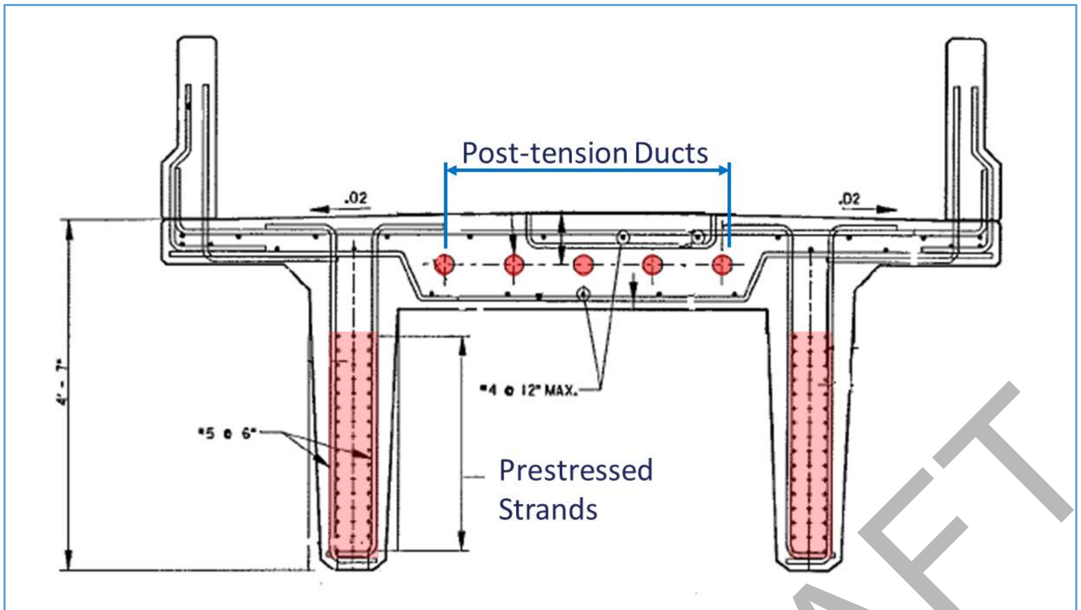


FIGURE 7: PRESTRESSED AND POST-TENSIONED DETAIL

1.4 REMAINING SERVICE LIFE & MAINTAINABILITY

A decision on the future of the Skyway infrastructure should take into account the expected service life of the existing structure. A structure's service life is the forecasted life expectancy based on everyday use.

During the second half of this structure's life, maintenance and repair costs will be expected to grow at an exponential rate (Figure 8). Additionally, it will be approximately 5 years until the new autonomous vehicle will be operating on the system, which will play into the available service life of the system that will support an AV. These costs need to be factored into any decision that is made regarding how to proceed with the current Skyway infrastructure.

Conditions that can affect a structure's service life include but are not limited to the quality and type of materials used, loading types and frequency design details, exposure to atmospheric conditions and corrosive environments.

At this time, substructure conditions offer no areas of concern, however several superstructure factors have a possibility to reduce or hinder the service life of the overall system.

The superstructure for the Skyway infrastructure is comprised of both steel girder and concrete beam spans. Steel girder spans will continue to require maintenance such as painting and regular inspections during their service life. Because of the large number of precast concrete spans, their remaining service life will likely be critical to the composite service life of the Skyway infrastructure. The concrete spans are framed with precast, concrete double tee beams that were constructed nearly 30 years ago. Most of these spans are part of continuous multispan superstructure units. The concrete double tees are constructed with prestressed strands and post-tensioned bonded tendons.

Elevated structures used for vehicular traffic are rarely framed with double tee beams. These beams are usually found in multi-level parking garages and industrial-type building facilities. The heavy and cyclic nature of loadings that these beams are experiencing on a daily basis creates maintenance issues such as cracks in concrete, problems with joints between superstructure units, and concrete spalls.

A critical item that will require immediate attention is the dapped ends of the concrete beams at pier locations. In order to reduce structure height, the ends of the concrete beams were notched out near the pier, which reduces structure depth but creates a problem with shear capacity and cracking due to a stress concentration. In effect, this detail provides less shear capacity where it is needed the most. Per the latest inspection reports, radial cracks have already formed from these locations at nearly every pier. Some crack repair, crack injection, and fiber wrap applications have been completed and more are being recommended. However, these repairs will not increase the service life of this structure and the need for these repairs is an indication that the structure is experiencing degradation.

The Skyway system operates in downtown Jacksonville, which is extremely close to the St. Johns River. For construction purposes, the environmental classification of the area is "extremely aggressive". For new projects, this classification would require an increase in the concrete cover to limit the stresses the precast beams could experience in order to minimize cracking. As stated previously and in the most recent inspection report, existing beams exhibit cracking, sometimes in multiple areas. Although the post-tension tendons are grouted throughout to reduce the risk of corrosion, the extent to which the prestressed strands are grouted is unknown. The sheathing surrounding these prestressed strands is already exposed in several areas of the system, and runs the risk of possible corrosion.

The post tensioning tendons that connect multiple spans and the prestressed strands within each beam have not been inspected in the 2017 Routine Inspection Report because all prestressing and post-tensioning is internal. However, because large cracking and concrete cover degradation allows for water intrusion, there is possible corrosion of the prestressed strands, the extent of which is unknown. This risk is lessened with the post-tensioned tendons because they are bonded with grout.

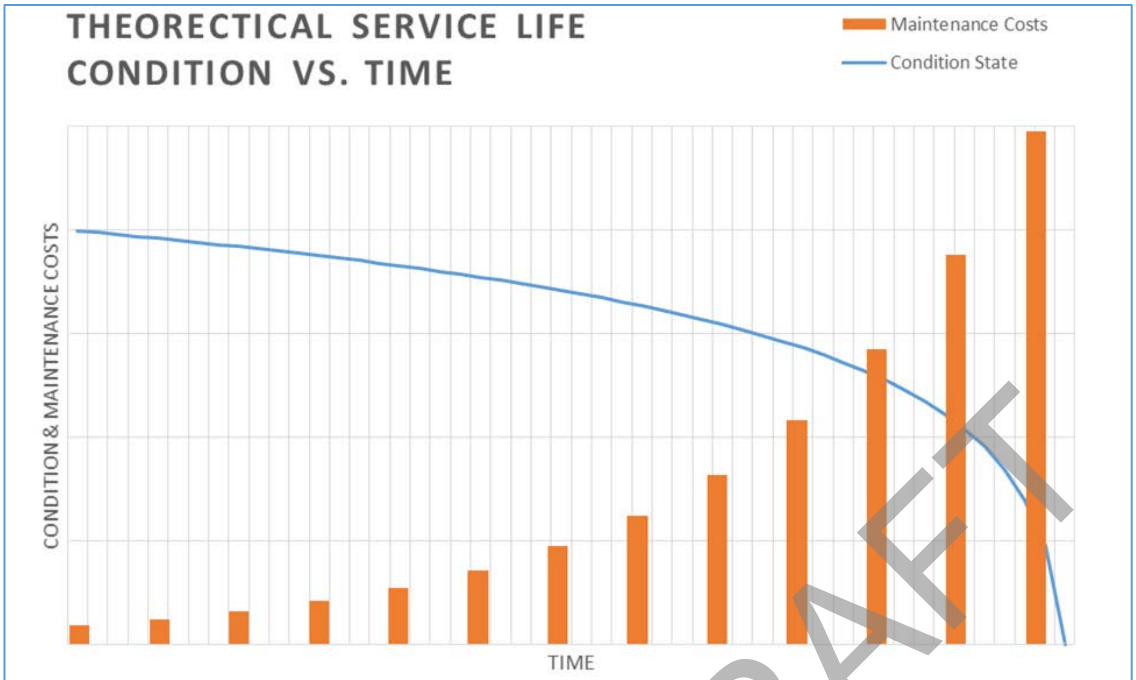


FIGURE 8, TIMELINE OF CONDITION AND MAINTENANCE

1.5 CONCEPTUAL GEOMETRY ASSESSMENT

The design vehicle specifications shown in Table 1 below were provided in the manufacturer's "GRT Vehicle Design Specifications" and "APMS Exported Constraints" included in Appendix A. These specifications, along with other engineering assumptions, were used in the Conceptual Geometry Assessment. This section will explore how the specifications interact with the current Skyway system and identify geometric constraints and potential infrastructure modifications required to accommodate the vehicle. Reference Appendix A for Table of "JTA Ultimate Urban Circulator Vehicle Comparisons".

TABLE 1: DESIGN VEHICLE SPECIFICATIONS

Parameter	Unit	Design Vehicle (2getthere)	Bombardier UMIII 2 car
LENGTH	FT	19.69	48
WIDTH	FT	6.89	7
HEIGHT	FT	9.19	9
FLOOR LEVEL	FT	1.35	4.2 (incl. beam)
EMPTY WEIGHT	KIP	7.72	26.10
VEH. MAX. WEIGHT	KIP	14.661	39.54
MAX. SPEED	MPH	25	35

1.5.1 Vehicle Comparison

Available autonomous vehicles were compared across a range of vehicle specifications. These specifications for available autonomous transit vehicles were assembled from information provided by the vehicle vendors and are summarized below.

The 2getthere GRT was chosen as the design vehicle to explore constraints of potential autonomous vehicle deployment on the existing skyway infrastructure. This vehicle had one of the larger cross sectional areas, weights and lengths out of the vehicles for which information is available. With these simple facts, it was assumed that this vehicle could impose more significant constraints on the existing infrastructure. Because of this, the assessment for this vehicle helps define a baseline for comparison to evaluate deployment of various autonomous vehicle options on the Skyway. Figure 9 compares the design vehicle to the current Skyway vehicle.

Figure 10 compares the design vehicle to other design vehicle options. Reference Appendix A for an autonomous vehicles comparison table.

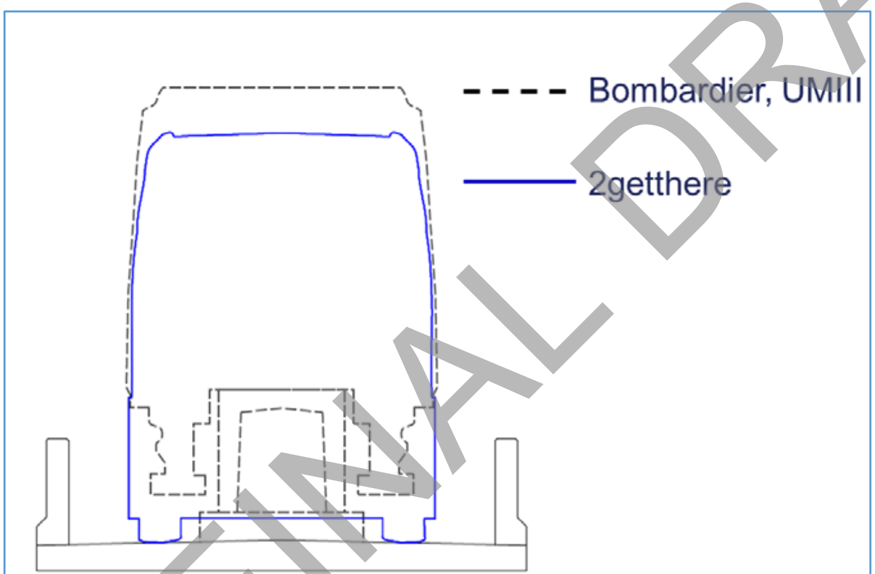
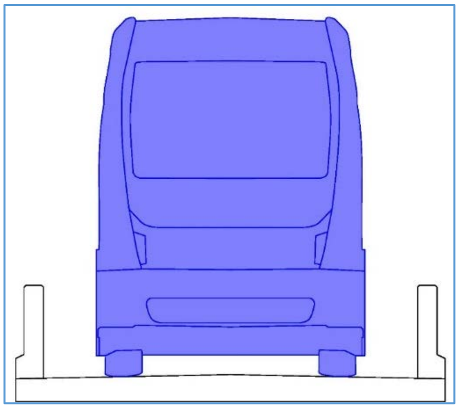
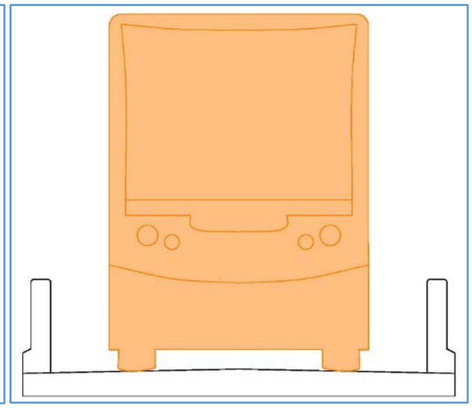


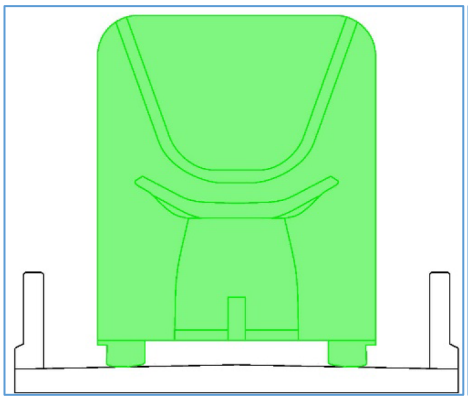
FIGURE 9: VEHICLE COMPARISON



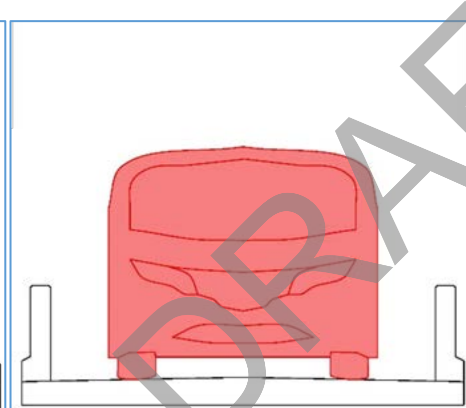
2getthere, GRT



EasyMile, EZ10



Navya, Arma DL4



Waymo, Chrysler

FIGURE 10: DESIGN VEHICLE OPTIONS

1.5.2 Guidebeam Removal

An assessment of available as-built plans for all segments of the JTA Skyway system indicates that it is feasible to remove the existing guidebeam through typical demolition methods. Guidebeam as-built plans vary from segment to segment. However, findings showed that the entire guidebeam is comprised of similar precast segments throughout. A common attribute of the guidebeam cross section is the voided interior to reduce the load applied on the superstructure. Guidebeam dimension continuity was assumed in estimating its average weight. Further described in 1.13 Conceptual Structural Capacity, the guidebeam removal weight was calculated at 0.87 kip/ft. Below are descriptions of each type per as-built plan sets:

- **Starter line and North segment** (Figure 11): This section was initially constructed to accommodate the Matra vehicle which operated on a running platform and steel guidebeam. These segments were modified and a concrete guidebeam was added when the system was converted to the current Bombardier UMIII vehicle.

- **River Crossing segment** (Figure 12 and Figure 13): The track shows a precast concrete guidebeam sitting directly on the deck which was constructed as an integral component of the Acosta Bridge.
- **O&M line and South segment** (Figure 14): This segment includes the guidebeam with an intermittently spaced concrete pedestal. These pedestals were presumably installed to adjust for superelevation of the guidebeam.

The concrete pedestal on which the guidebeam sits is only continuous at station locations. Throughout the rest of the guideway, the pedestal has transverse gaps at varying intervals. In order to arrive at conservative structural estimates, it was assumed that the existing guidebeam throughout the entire system has a constant pedestal and typical section matching that of Figure 11 and Figure 12. The guidebeam is precast in varying segment lengths and joined together by closure pours. Based on the existing configuration, it appears feasible to remove only the pedestal by demolition at its varying locations and then lift the guidebeam off the guideway.

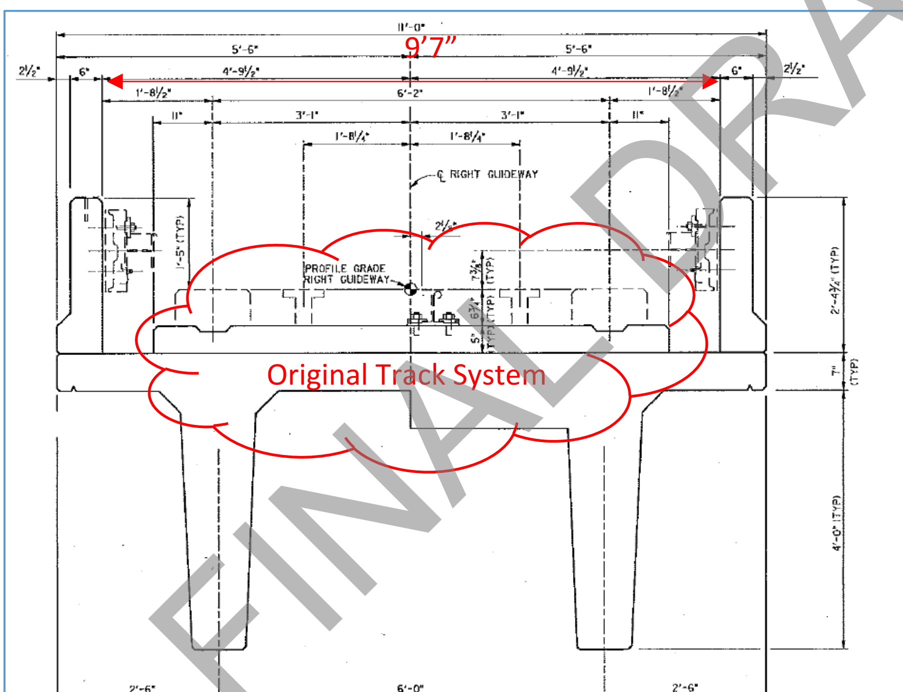


FIGURE 11: NORTH LINE AS-BUILTS

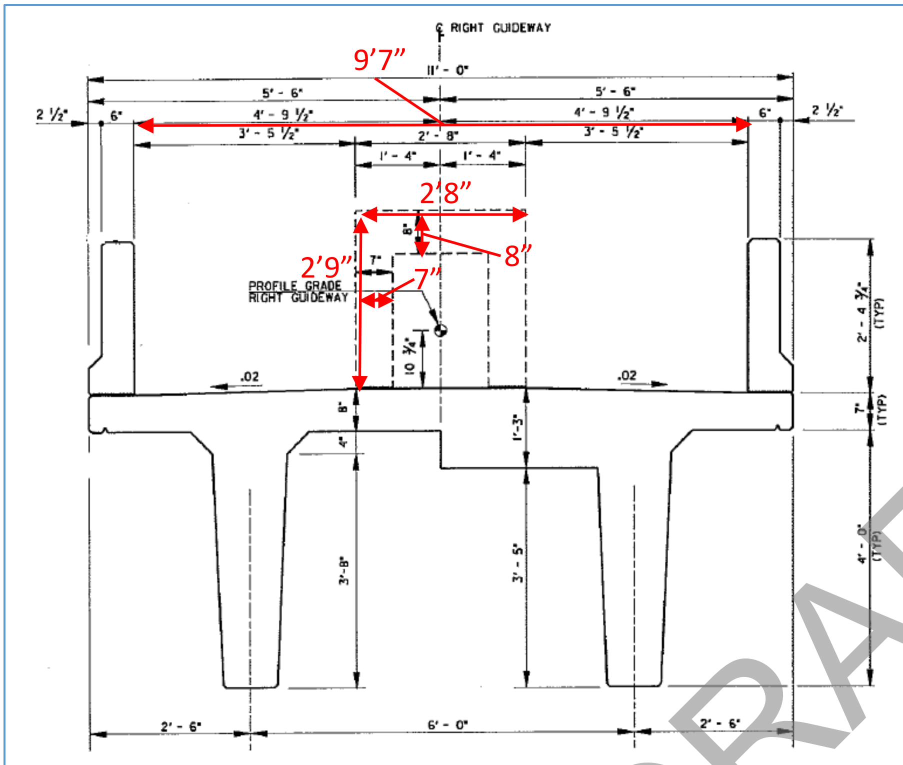


FIGURE 12: RIVER CROSSING AS-BUILTS

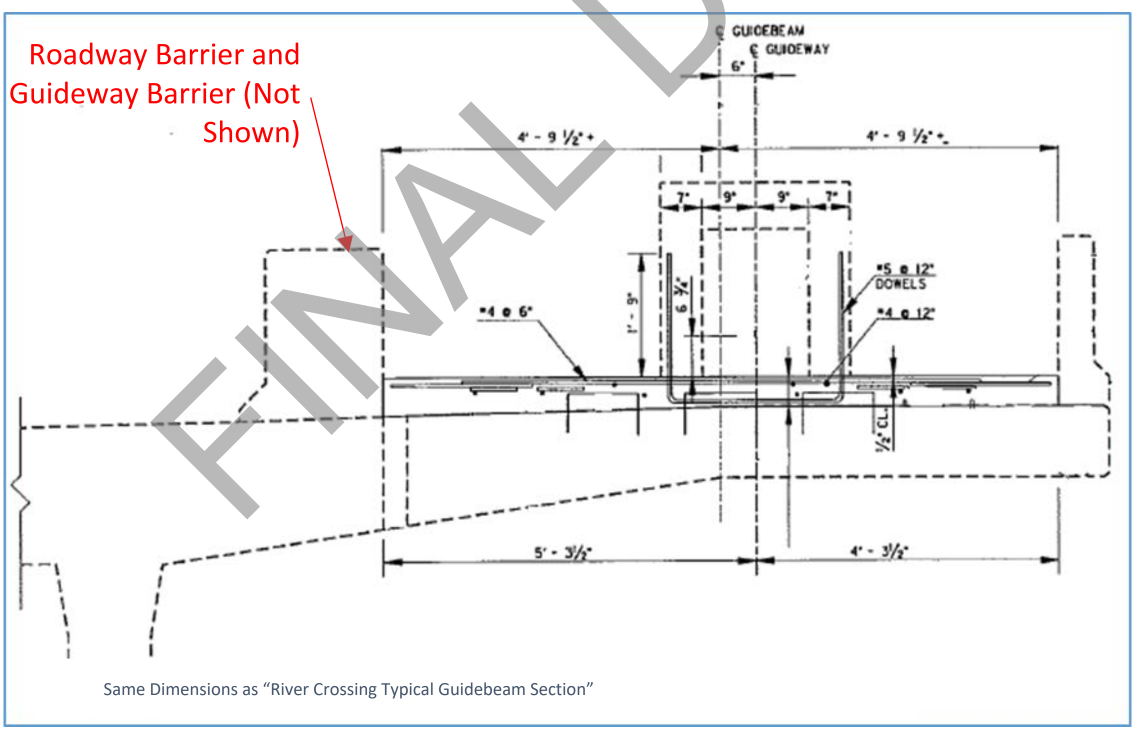
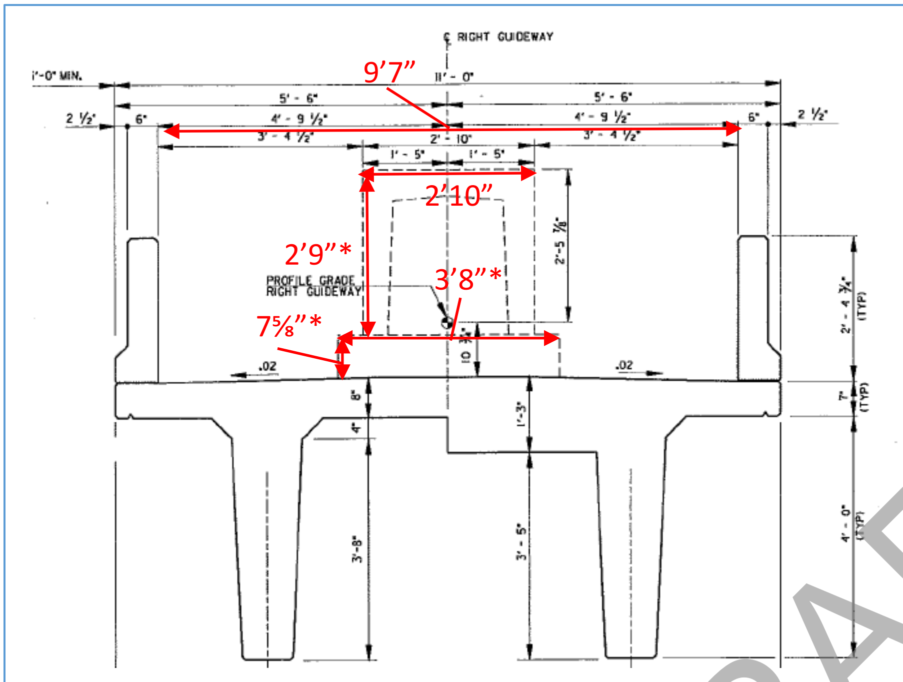


FIGURE 13: RIVER CROSSING AS-BUILTS



*These dimensions were not called out in as-builts and were calculated and/or estimated.

FIGURE 14: O&M LINE AS-BUILTS

Consideration must be given to the existing guidebeam steel reinforcement during removal. Typical guidebeam reinforcement into the deck as well as reinforcement throughout the deck is shown in Figure 15 and Figure 16. Areas of potential removal are highlighted in red. It is important to note that while removal of the guidebeam and pedestals appear to be feasible, care must be exercised during demolition to avoid damaging the existing superstructure and compromising the structural integrity of the guideway.

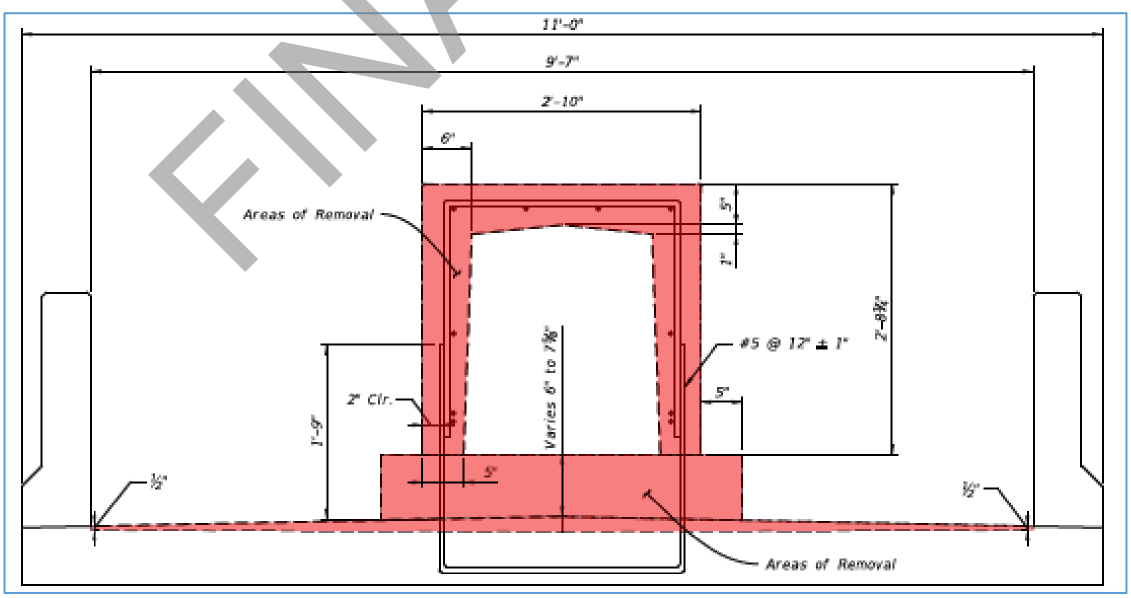


FIGURE 15: GUIDEBEAM REMOVAL

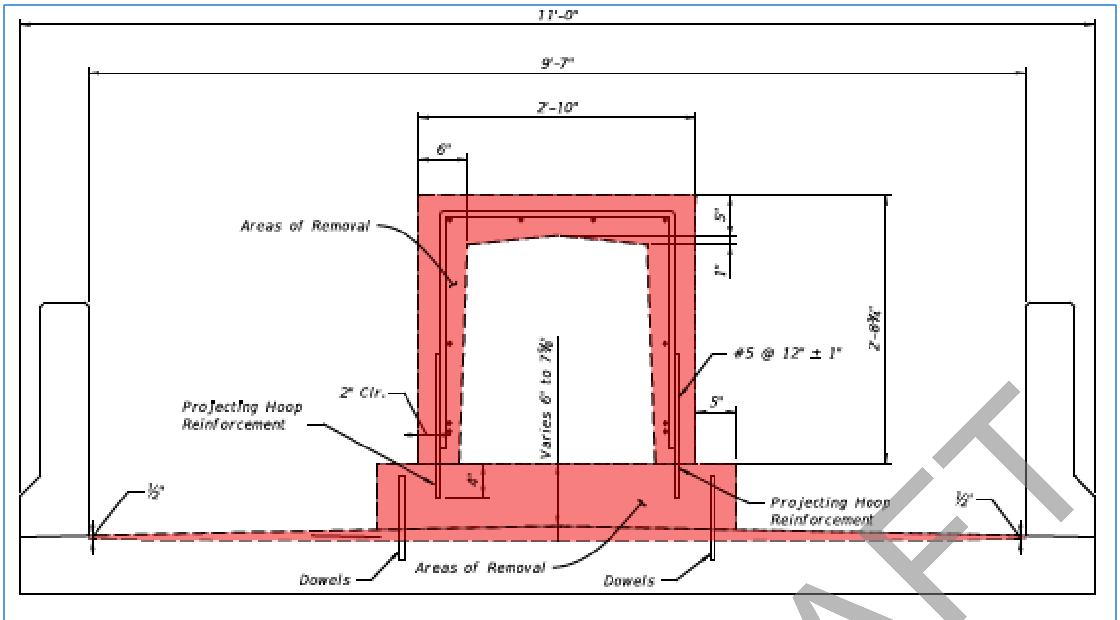


FIGURE 16: GUIDEBEAM REMOVAL

The current Skyway system includes several track switches where the vehicles transfer from one alignment to another by means of a crossover. These switches occur at several locations throughout the Skyway system (Figure 17). The guidebeam to acts as a switch and must translate to guide the existing vehicle from one guidebeam to another. The guidebeams at the guideway crossovers are called switchbeams. These switchbeams facilitate train transfers to adjacent parallel tracks and merges between lines. The switchbeams are steel guidebeams with a system of computer controlled hydraulic devices to shift the switchbeam from one location to another. The AV will not require these switch beams and they will be removed when the AV system is created. The devices removed will include the steel switch beam and the hydraulic switchbeam translation system.

FIGURE 17: EXAMPLES OF "SWITCHBEAMS", LOCATED ON NORTHLINE

1.5.3 Design Speed

Conversion of the system by removing the guidebeam and installing a smooth running surface will transform the Skyway from an elevated rail system to an elevated roadway. Therefore it is expected that design standards and criteria for roadways including design speed will apply to the conversion.

The current Bombardier UMIII vehicle has a design speed of approximately 35 mph. The design vehicle has a "custom" option of maximum cruising speed of approximately 37 mph, or 60 km/h (APMS Exported Constraints). However, the maximum cruising speed of the baseline model design vehicle is approximately 25 mph. The minimum speed for the design vehicle to safely navigate several curves with minimum radii is approximately 20 mph. Design speed ranges in accordance with horizontal curves are included in Subsection 1.5.5 Minimum Vertical and Horizontal Curve.

It is important that the design criteria, such as roadway classification and design speed, for the converted system be confirmed with authorities having jurisdiction including JTA, FDOT, FTA, COJ and others.

1.5.4 Maximum Grade

The preferred vehicle must have the power to climb the maximum grades and also have braking systems to safely stop when descending the maximum grades. The advised grade for the design vehicle is less than 6%. The maximum allowable grade for the design vehicle is 10% (GRT Vehicle Design Specifications). The maximum grade on the existing guideway is 8%. Therefore, the current grade throughout the system is suitable for the proposed vehicle, however power to ascend the 8% grades at desired speeds and sufficient braking on descending grades must be considered in the vehicle design specifications.

1.5.5 Minimum Vertical and Horizontal Curve

Vertical Curves
Stopping sight distance for AV on vertical curves must be considered. Sensory equipment varies between AV systems on the market. External sensors installed on the track itself may be required at certain locations for the vehicle to stop in time to avoid an obstruction. Based on the provided specifications, the design vehicle takes approximately 1 second to physically apply the brakes. At a cruising speed of 25mph, an emergency stop requires approximately 131'-2" of clear track. Comparatively, a typical stop at cruising speed that would maintain passenger comfort requires approximately 226'-4" of clear track. In using FDOT vertical curve criteria, an "eye height" of 3.5 feet and an object height of 6 inches is used in determining required stopping sight distance. It is not known at what height the design vehicle would detect obstacles from, therefore the stated FDOT eye height was assumed. Based on FDOT Plans Preparation Manual Table 2.8.5, "Minimum Lengths of Crest Vertical Curves Based on Stopping Sight Distance", the design vehicle traveling at 25 mph does not meet requirements at several

locations. Vertical curves on the Northern approach of the Acosta Bridge and several locations approaching the O&M Center are constraints. Under the FDOT methodology for calculating minimum stopping sight distance, the design vehicle would not be able to avoid collision at these locations given the assumptions stated in this section. For other AV in the industry, additional studies based on specifications provided by the appropriate manufacturer will need to be conducted in order to ensure proper minimum stopping sight distance is met.

Horizontal Curves

There are several horizontal curves with short radii, less than 200 feet, located throughout the length of the guideway, of which the minimum radius is 100’. Existing superelevation is developed on the actual guidebeam pedestal and not the guideway itself. Therefore, the entire length of the guideway deck has a normal crown. To maintain safe operation and passenger comfort in the AV, superelevation in accordance with the selected design criteria is recommended. A superelevation of 10.0% is reported for the design vehicle as the overall maximum superelevation (APMS), so this recommended value is within the vehicle tolerance (Table 2).

TABLE 2: SUPERELEVATION CONSTRAINTS

Passenger Comfort Limit	5%
Maximum Limit	10%

Due to the relatively low speeds the vehicle would be operating at, “Florida Greenbook” Figure 3-3 was used to analyze the speeds and superelevation requirements. The maximum speed with which the design vehicle could travel around a 100 foot radius curve with a normal crown is approximately 20 mph. The same curve with a 5.0% superelevation is 22 mph. Therefore, the additional increase in speed by adding superelevation may not necessarily be beneficial. As seen in Table 3, the design vehicle, which has a maximum cruising speed of 20 mph, will be constrained to under 35 mph for roughly 20% of the track length. In order to assess desired speeds at which the vehicle can travel certain radii, see also Table 4.

TABLE 3: CURVE RANGES THROUGHOUT THE GUIDEWAY

Curve Radius (ft)	Sum of Curves	% of Total Track Length	Speed Range (mph)
100 - 150	22	5.75	21-24
151 - 200	9	5.23	24-26
201 - 300	8	4.35	26-31
301 - 500	11	4.36	31-37
Totals	50	19.67	-

*Does not include curves within the O&M Center

TABLE 4: CURVE RADII AND ACCOMPANYING SPEEDS

	e = 0.0	emax = 0.05

Curve Radius (ft)	Design Speed (mph)	Design Speed (mph)
100	21	22
150	24	26
200	26	28
250	27	31
300	31	33
350	33	36
400	34	37
450	36	39

The effect of curve radii and superelevation rates on speed of the system must be considered in the operating plan in order to achieve the desired headways and incorporated into the design criteria.

1.5.6 Minimum Horizontal and Vertical Clearance

Vertical Clearances at Typical Tangent Sections

The design vehicle height is 9.19', not including the guidebeam. The current vehicle height is 9'. Given that the vehicle heights are very similar and the design vehicle will ride roughly 2'-9" lower than the current vehicle with the removal of the guidebeam, vertical clearance in these areas is not a constraint.

Horizontal Clearances at Typical Tangent Sections

The design vehicle has a width of 6.88', which is similar to other design. With a constant 9'-7" lateral clearance, this leaves approximately 1'-4" of horizontal clearance on either side from vehicle edge to the inside face of the barrier wall while travelling on a straight section of the guideway (Figure 18), which is similar to other design options (Table 5). This leaves little room for lateral deviation from the vehicle's center path when traveling.

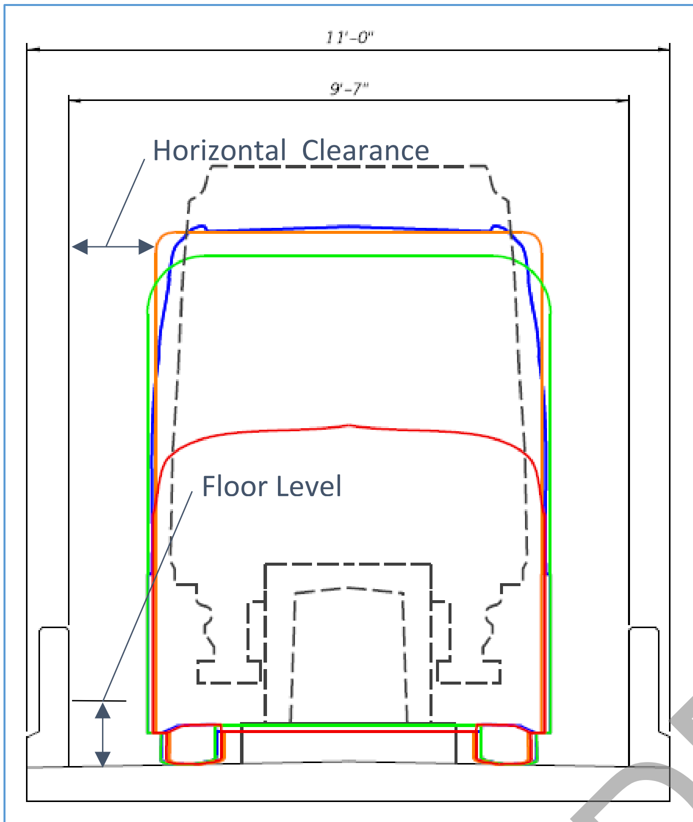


FIGURE 18: HORIZONTAL CLEARANCE

TABLE 5: HORIZONTAL CLEARANCE

Vehicle	Horizontal Clearance (ft)	Floor Level (ft)
Bombardier, UMIII	1.29	4.2 (incl. guidebeam)
2getthere, GRT	1.34	1.35
EasyMile, EZ10	1.49	1.2
Navya Arma DL4	1.34	0.76
Waymo, Chrysler	1.44	N/A

Horizontal Clearances at Curved Sections

Using AutoTURN, it was determined that when the design vehicle was rounding a 100' radius curve exactly on the centerline of the lane, the back left corner and front right corner of the vehicle would come within roughly 8" of the inside barrier face (Figure 19). Horizontal clearance for all vehicles analyzed is defined as the distance between the inside barrier face and the back left wheel. This is where the smallest horizontal clearance occurs for this curve orientation. Since it is currently unknown to what degree of accuracy the vehicle follows its magnetic path, this horizontal clearance scenario was found to be a constraint. Further discussions with the manufacturer indicate that the design vehicle has a steerable rear axle. This capability would allow this vehicle to track further away from the barrier. Although for this study, it was assumed that all assessed vehicles, including the design vehicles, had locked rear axles. It is not known if all vehicles in this class have steerable rear axle capability.

The “APMS Exported Constraints” offers an allowable clear width table, SE-1240, for the design vehicle (Table 7). This full table of lateral clearance requirements can be found in Appendix A. At a 100 foot radius curve, or approximately 31 meters, the design vehicle manufacturer recommends a clear width of 10 feet and the existing guideway provides 9’-7”. Based on simple interpolation of Table SE-1240, the smallest radius curve that the design vehicle could meet, according to the APMS Constraints, would be approximately 420 feet. With the smallest curve on the system being roughly 100 feet, there are many locations throughout the system that have curve radii well below the minimum possible radius of 420 feet. This means that, according to the manufacturer specifications, the 2getthere will not be able to traverse the guideway at these locations. Therefore, lateral clearance is a major constraint of the existing system.

Although the 2getthere is the larger of available AV in the industry, this does not ensure that other vehicles will be able to traverse these tight curves. Additional studies based on specifications provided by the appropriate manufacturer will need to be conducted in order to ensure proper minimum lateral clearance is met.

Note: *APMS table SE-1240 is presented in its entirety for full reference in Appendix A.*

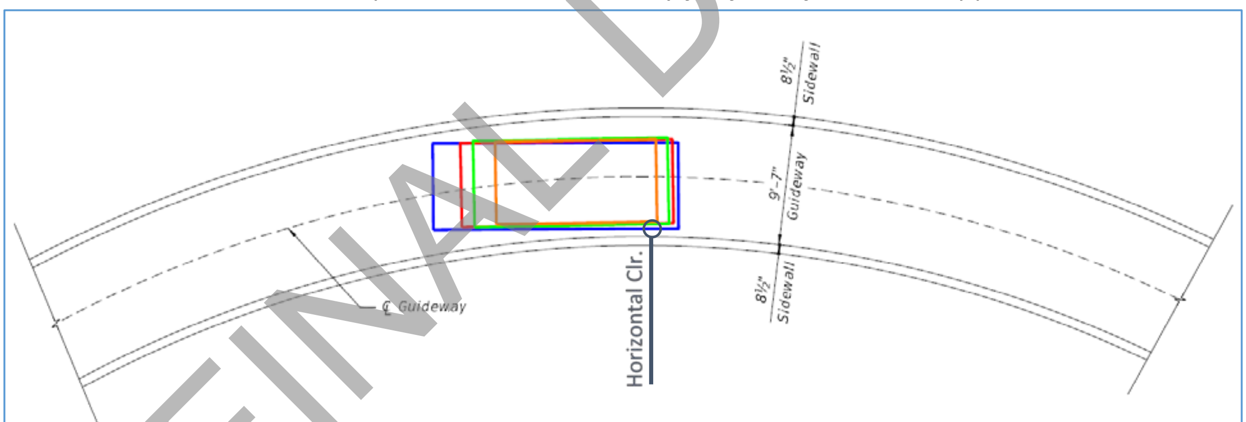


FIGURE 19: DEPICTION OF DESIGN VEHICLE ROUNDING A 100' RADIUS CURVE

TABLE 6: HORIZONTAL CLEARANCE ON 100' RADIUS CURVE

Vehicle	Horizontal Clearance
2getthere, GRT	8”
EasyMile, EZ10	1’-2”
Navya Arma DL4	1’-0”
Waymo, Chrysler	1’-1”

TABLE 7: CLEAR WIDTH COMPARISON

Curve Radius	Advised Clear Width (ft)*	Existing Clear Width (ft)
Straightaway	8.53	9.58
Station	8.53	9.58
100 ft (31 m)	9.97	9.58

*Values have been converted from meters

Horizontal Clearances at Stations
ASCE/T&DI requires the "horizontal gap between the station platform and the vehicle door threshold shall be no greater than 2 in." From site inspection photos, there is currently a bumper on the platform edge. The design vehicle would need to be able to maneuver slightly up to this bumper to ensure a 2" maximum gap is provided for passengers to ensure safety when boarding the vehicle. As mentioned, further discussions with the manufacturer indicate that the design vehicle has a steerable rear axle. This capability would allow the design vehicle to "crab up" against the bumper by turning both the front and rear steering gear in the same direction. However as mentioned, it is not known if all vehicles in this class have this capability so the tracking up to the station platform is still identified as a concern.

Vertical Clearances at Stations
Because of the proposed guideway removal and differences in vehicle heights, there will be a significant height deficit between the design vehicle floor level and the platform floor. ASCE/T&DI requires that the vehicle floor needs to be within 0.625" of the platform height. See Section 1.9 Riding Surface, for further detail on the proposed build up that would be required to create a level surface. To meet ASCE/T&DI requirements, the vehicle floor level was assumed to be even with the platform floor level.

All stations have a certain clear height from the platform surface to the metal station roof. The exact architectural drawings could not be found for Terminal, Jefferson or Central station, but it was assumed that these stations had the same clearance as all other public access stations. All other stations, except for the O&M station which was larger, had a clear height of 13'-8". See Figure 231 for vertical clearance depictions and Table 8 for a table of vertical clearances at stations. Please note, Figure 21 assumes roughly a 2'-9" necessary platform buildup, although this value would change slightly depending on the ultimate design vehicle chosen. A 2'-9 ¼" dimension is based on the 2getthere vehicle in order for the vehicle floor level to match up with the platform level.

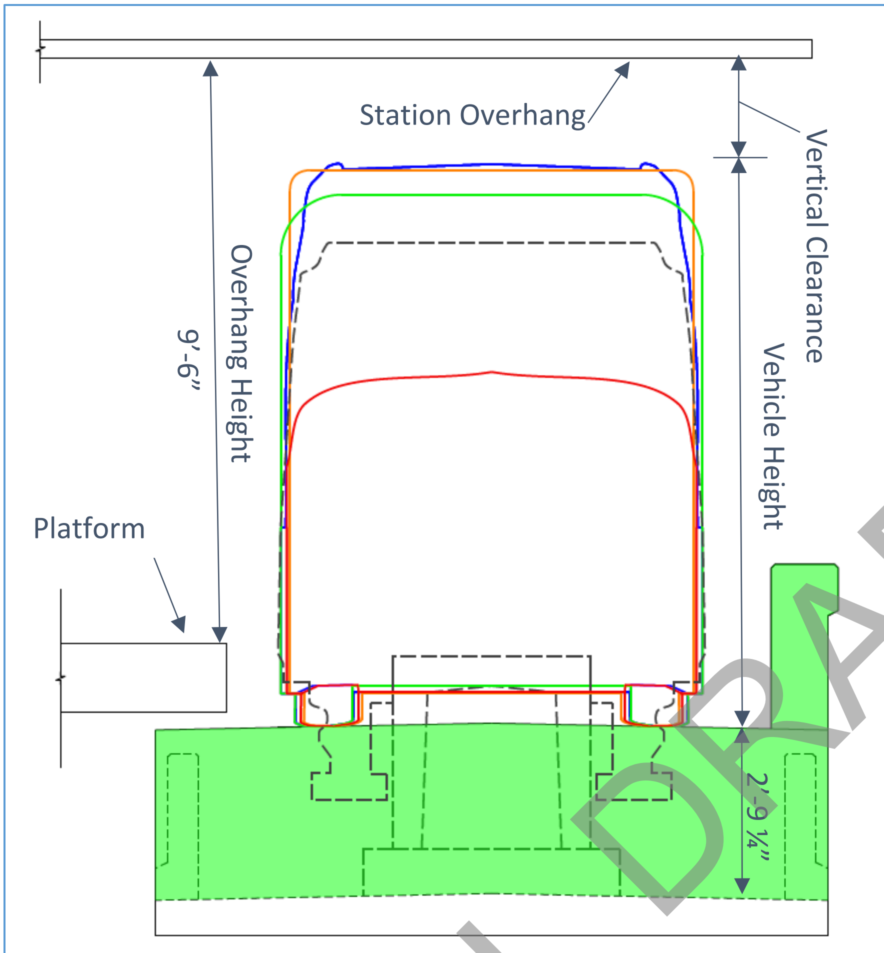


FIGURE 20: TYPICAL SECTION (KINGS AVE)

TABLE 8: VERTICAL CLEARANCE AT STATIONS

Vehicle	Vehicle Height (ft)	Vertical Clearance (ft)
Bombardier, UMIII	9.00	4.67
2getthere, GRT	9.20	1.70
EasyMile, EZ10	9.10	1.90
Navya Arma DL4	8.70	2.20
Waymo, Chrysler	5.80	5.10

1.7 BARRIER WALL

1.7.1 Design Criteria

The current typical barrier height across the entire guideway is 2'-4 ¼", measured from top of deck to top of wall, and does not include future height loss from a potential deck overlay. The APMS calls for a minimum barrier height of approximately 1'-2 ½", or 370 mm, to prevent the vehicle from leaving the guideway. However, this aspect of the APMS does not conform to current AASHTO standards. In addition, this height is presumably for safety considerations on an at-grade vehicle track and not an elevated system. SE-543 of APMS states that the maximum load that the design vehicle can exert while traveling at approximately 25 mph is roughly 14.84 kips. Although the vehicle could be traveling faster than 25 mph during some parts of the guideway, this data was used in barrier calculations.

The vehicle specifications did not state where the transverse load would be applied in the event of impact with a barrier. Applying the impact load at the top of the barrier is commonplace for AASHTO barrier design, although this assumption would presumably not meet the unique design needs of this project. In order to determine where to apply the load at the barrier, vehicle center of gravity was considered. 2getthere stated that the empty vehicle center of gravity was half the height of the wheels, or 1.21 feet. Upon further calculation, the maximum passenger loaded vehicle center of gravity was conservatively determined to be approximately 3 feet (Appendix A, Vehicle Center of Gravity). Therefore, the maximum passenger loaded center of gravity was higher than the barrier height. Given this reasoning, it was assumed that the 14.84 kip force would be applied at the top of the barrier at collision. It is important to note that applying a barrier impact load lower than the top of barrier height for future design would require approval by the proper authorities.

AASHTO LRFD Bridge Design Specifications outlines 6 Test Levels (TL) for barrier design. Per AASHTO, "it shall be the responsibility of the user agency to determine which of the Test Levels is most appropriate for the bridge site." The definitions of these Test Levels in this report are excerpts from AASTHTO. If a new barrier is to be designed for a design vehicle, it is most likely that the design will fall into one of the Test Levels outlined below:

- **TL-1:** generally acceptable for work zones with low posted speeds and very low volume, low speed local streets
- **TL-2**: generally acceptable for work zones and most local and collector roads with favorable site conditions as well as where a small number of heavy vehicles is expected and posted speeds are reduced
- **TL-3:** generally acceptable for a wide range of high-speed arterial highways with very low mixtures of heavy vehicles and with favorable sight condition
- **TL-4:** generally acceptable for the majority of high-speed highways with a mixture of heavy trucks and vehicles

Designated forces and dimensions are associated with each of these Test Levels. Their respective details are outlined in Table 9.

TABLE 9: TEST LEVEL DESIGN FORCES AND DESIGNATIONS

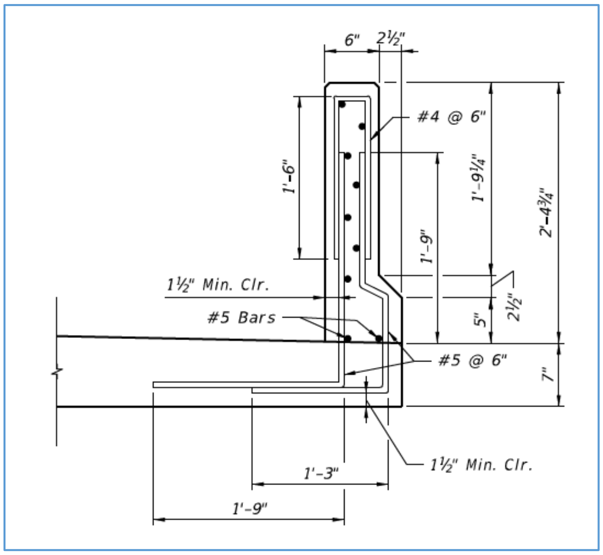
Design Forces and Designations	TL-1	TL-2	TL-3	TL-4
F_t Transverse (kips)	13.5	27.0	54.0	54.0
F_l Longitudinal (kips)	4.5	9.0	18.0	18.0
F_v Vertical (kips) Down	4.5	4.5	4.5	18.0
L_t and L_l (ft)	4.0	4.0	4.0	3.5
L_v (ft)	18.0	18.0	18.0	18.0
H_e (min) (in)	18.0	20.0	24.0	32.0
Min. H Height of Rail (in)	27.0	27.0	27.0	32.0

Initial assessment of the existing barrier shows that it is not adequate and would not meet a minimum crashworthiness. However, this is for the design vehicle mentioned throughout the report and does not necessarily apply to other autonomous vehicles. Because the guideway would serve as an isolated area for a design vehicle to travel on, with no other vehicle types or traffic to be accounted for, standard AASHTO design forces and dimensions may prove to be unrepresentative of the systems design needs. Any deviation from AASHTO specifications would need to be approved by governing agencies. In addition, an "isolated" system would no longer hold true if other vehicles were allowed access to the system. Because the existing barrier does not match a typical FDOT traffic railing type, further investigation will have to be performed to prove the existing barrier is sufficient and must consider the specifications of the vehicle and design speed of the system.

1.7.2 Removal & Replacement

Removal and replacement of the existing barrier would require extensive doweling or retrofitting along the length of the guideway. Careful consideration would also have to be taken in order to not damage deck reinforcement. A retrofitted standard barrier would most likely decrease horizontal clearance. For example, if a typical FDOT 32" F traffic railing was constructed the guideway would lose a minimum 8 ¼" on either side (Figure 21 and Figure 22).

River Crossing, O&M and South Line



Starter & North Line

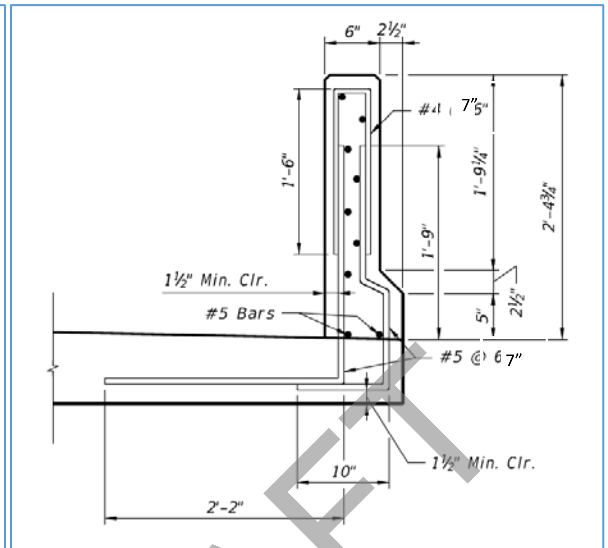
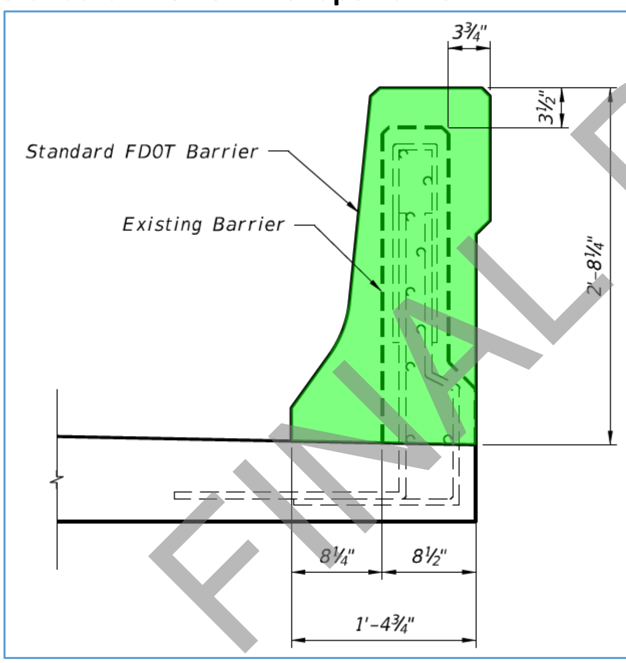


FIGURE 21: EXISTING SIDEWALL DETAILS

Standard FDOT 32" F Shape Barrier



Potential Replacement w/ Deck Bolting Detail

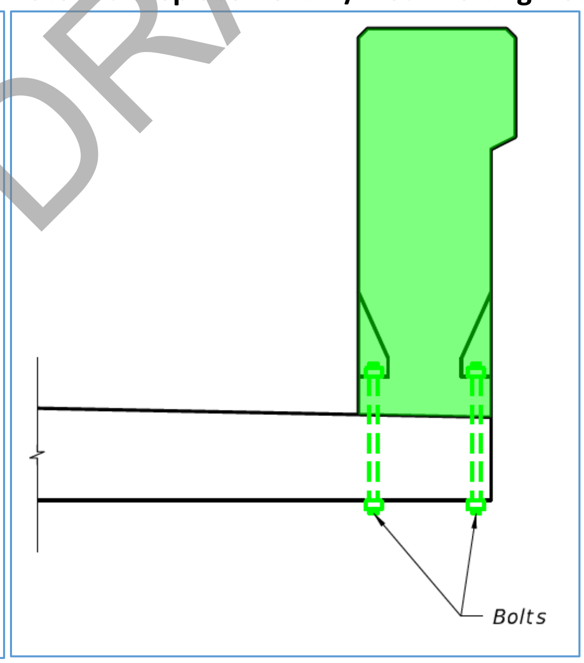


FIGURE 22: STANDARD FDOT AND EXISTING BARRIER (LEFT) & POTENTIAL DECK BOLTING DETAIL (RIGHT)

A possible option for barrier replacement is a special design barrier anchored by bolting through the existing deck. Further research and design would be needed for exact dimensions and spacing. It is important to note that given the unique nature of the Skyway as well as AV implication, a special designed barrier would most likely be required to provide adequate safety and horizontal clearance. Because of this, the design criteria would need to be approved by the proper authorities. Also the design may differ for the sections with concrete and steel superstructures.

General deck dimensioning needed for barrier bolting are shown in Figure 23:

Pretensioned Double Tee **Box Girder**

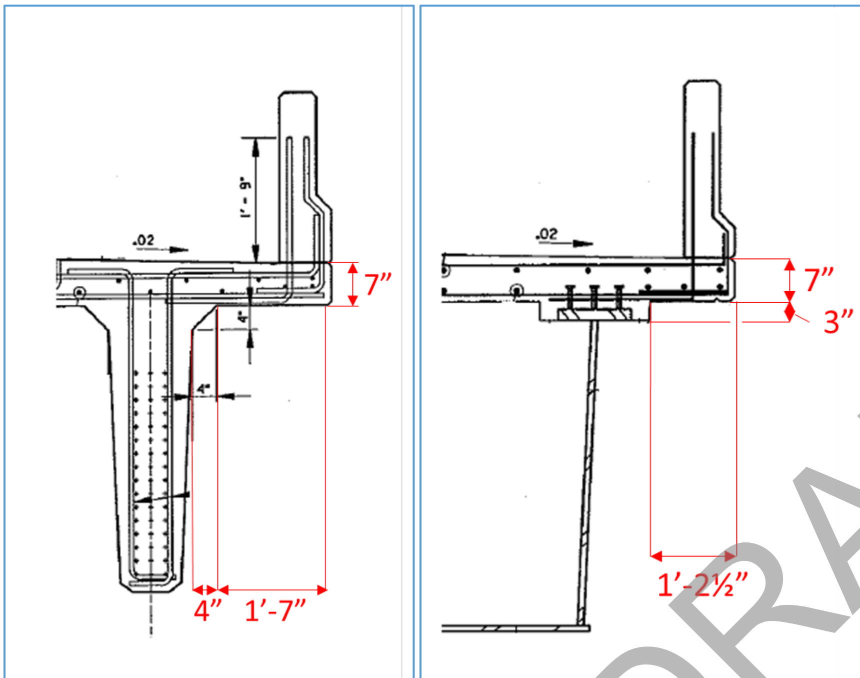


FIGURE 23: DECK SECTION DETAILS (SOUTH LINE AS-BUILTS)

Note: *Guidebeam not shown for clarity. Figures are not drawn to scale.*

1.7.3 Potential Barrier Options

Increase Existing Barrier Width

Barrier could be retrofitted to increase its width on the inside face to allow for additional strength. Increasing width on the outside face is not feasible because the existing barrier is flush with the deck edge. However, this will result in loss to horizontal clearance to the point where the AV might not be able to navigate around curves.

Removal and Replacement at Stations

This is an option if the existing barrier is found not to fail under the chosen design vehicle and retrofitting is not an option. It would entail removing all barrier along the station buildup or superstructure replacement length. Necessary doweling would have to be performed for barrier installation. Installation could also affect the existing deck. Design for new barrier installation would involve more steel reinforcement to the barrier. Appropriate design would possibly involve a thicker barrier and hinder horizontal clearance.

Removal and Replacement Throughout

This option would be for a scenario where the existing barrier does fail under the chosen design vehicle and retrofitting is not an option. It involves mirroring the work described above throughout the entire length of the track.

1.8 EMERGENCY EGRESS

1.8.1 Emergency Walkway

The emergency walkway was constructed under a separate contract from the guideway segments and exact dimensions of railings and walkways are not included in the overall plan set. However, the walkway does sit on top of the barrier wall for almost every scenario along the length of the guideway. These scenarios are detailed below (Figure 24.)

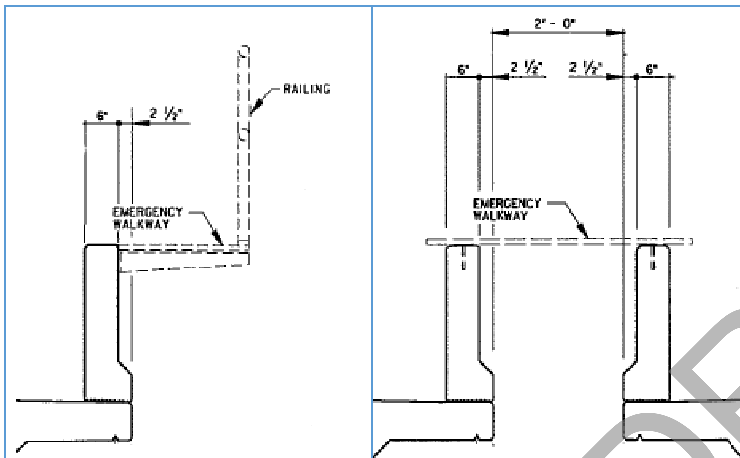


FIGURE 24: EMERGENCY WALKWAY FOR SINGLE (LEFT) & TANGENT (RIGHT) GUIDEWAYS

With the guidebeam removed, no deck overlay constructed and the design vehicle sitting on the existing track, there would be a roughly 1' deficit between the vehicle floor level and the walkway surface (Figure 25).

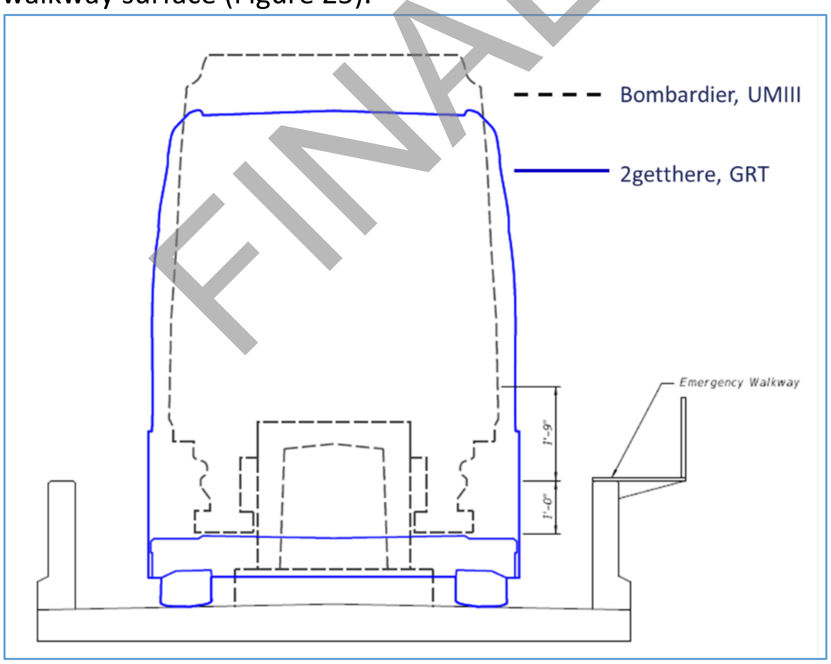


FIGURE 25: EMERGENCY WALKWAY

There is an option to have passengers exit directly onto the track in case of an emergency. However, the chosen design vehicle would need to have doors on either side. In the event an emergency exit was necessary and the vehicle was positioned in the middle of the guideway, the passengers would have roughly a 1'-4" pathway with which to exit past the vehicle. If the vehicle was positioned up against the barrier inside face, there would be slightly under a 3' pathway. ADA 2010 Standards require an accessible route width of 3'. Although the pathway taken into account would only be the length of the vehicle at the very max, this narrow exit width could pose as a constraint in the event an emergency exit is necessary.

Requirements for emergency egress must be confirmed with authorities having jurisdiction.

1.8.2 Emergency Maintenance

In the event the vehicle losses functionality on the guideway, there would be no typical means of removing the vehicle from the guideway to allow for continued traffic. Given that there is no access from at-grade at this time, removal of a disabled vehicle by towing would disrupt system operation. The existing guideway would also make it difficult to perform on-site repairs given the narrow horizontal clearances. Other methods of vehicle maintenance and removal would need to be established as part of an operating plan.

1.9 RIDING SURFACE

1.9.1 Deck Overlay

Most nearly all guideway typical sections show 1-1/2" concrete cover for top deck steel reinforcement. This would allow for removal of up to 1/2"of the existing concrete deck for preparation for deck overlay. Therefore, an approximately 1-2" overlay could be applied to provide a suitable riding surface. As seen in Figure 26, the 2" overlay would reduce the effective inside height of the barrier.

The most likely option for the future riding surface would be a lightweight concrete overlay. The typical section of deck removal for both double tee and box girder spans will be 9'-7" in width for each guideway. The weight of this overlay would not adversely affect load capacity of the structure.

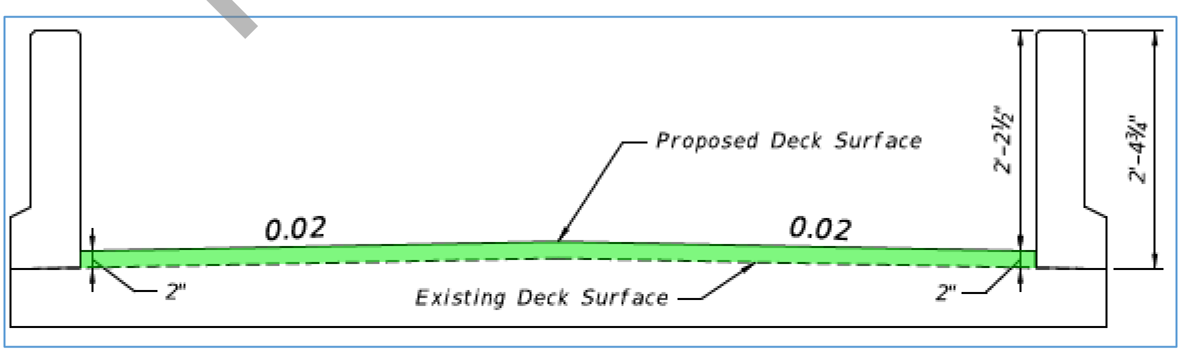


FIGURE 26: NORMAL CROWN TYPICAL SECTION WITH OVERLAY

1.9.2 Superelevation

As seen in the Minimum Vertical and Horizontal Curves Subsection, it is not necessarily beneficial to install superelevation along the track to gain more speed around tight curves. However, this section is meant to describe its effect on the overall track. If a 5% superelevation, which is same as the existing rate for the guidebeam (Figure 28), were installed on a portion of the guideway, then the outer most barrier inside height would be reduced by nearly 8”. This further reduces the effectiveness of the existing barrier. To see structural assessments of superelevation ranges see Section 1.13, Conceptual Structural Capacity Assessment.

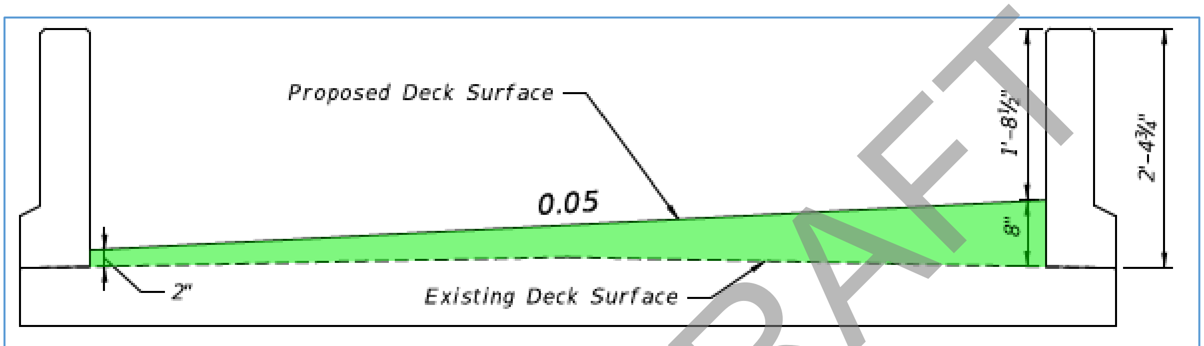


FIGURE 27: POTENTIAL 5% SUPERELEVATION

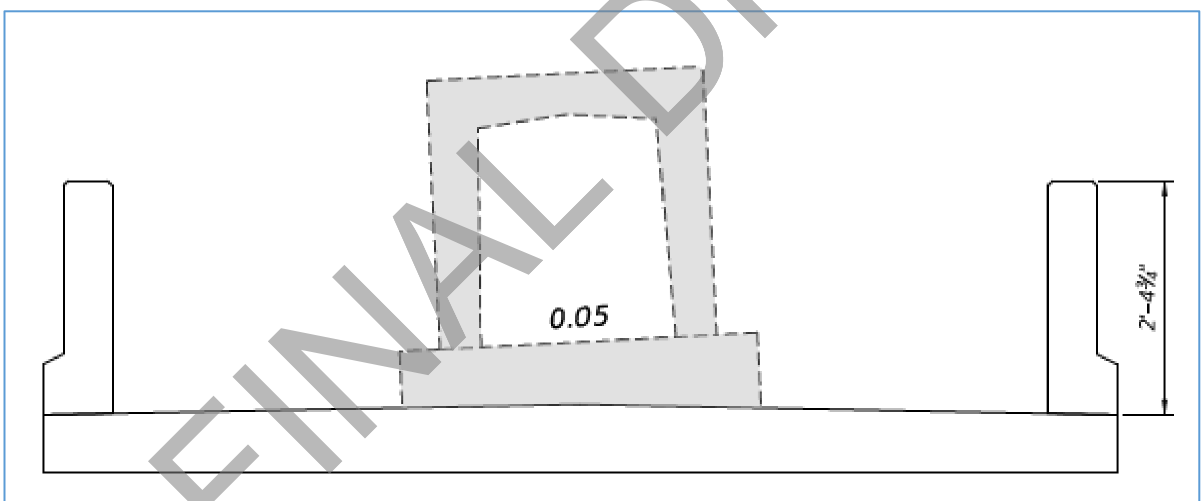


FIGURE 28: EXISTING 5% SUPERELEVATION

1.9.3 Drainage

Deck drains and scuppers are the primary avenue in which the current guideway system is drained. These scuppers are either flush with the deck or elevated as shown in the figures below. There are also weir type barriers to slow and collect the flow of water on down slopes (Figure 31). These barriers contribute to water ponding where scuppers are blocked. The current deck drains would need to be modified and weirs removed prior to the new riding surface installation. The drainage system design must be updated to accommodate the new drainage patterns caused by removal of the existing guidebeam and installation of the running surface.

Also conversion by removing the beam will create an elevated roadway and design standards for roadways will apply for drainage design to minimize potential ponding in wheel paths and therefore safety hazard due to hydroplaning. It is likely that additional drainage structures and levelling courses will be needed to ensure that the drainage design meets roadway design standards.

FIGURE 29: TYPICAL DECK DRAIN PLACEMENT

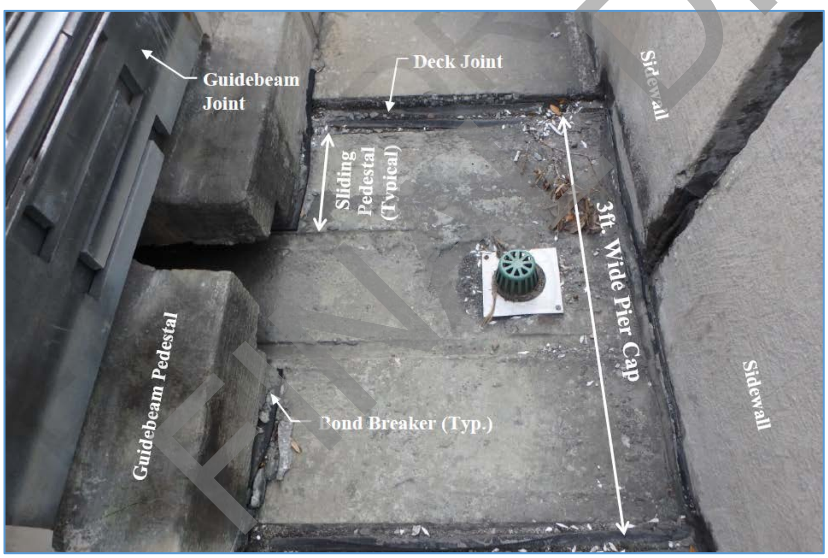


FIGURE 30: TYPICAL DECK DRAIN PLACEMENT

FIGURE 31: DRAINAGE BARRIERS (WEIRS)

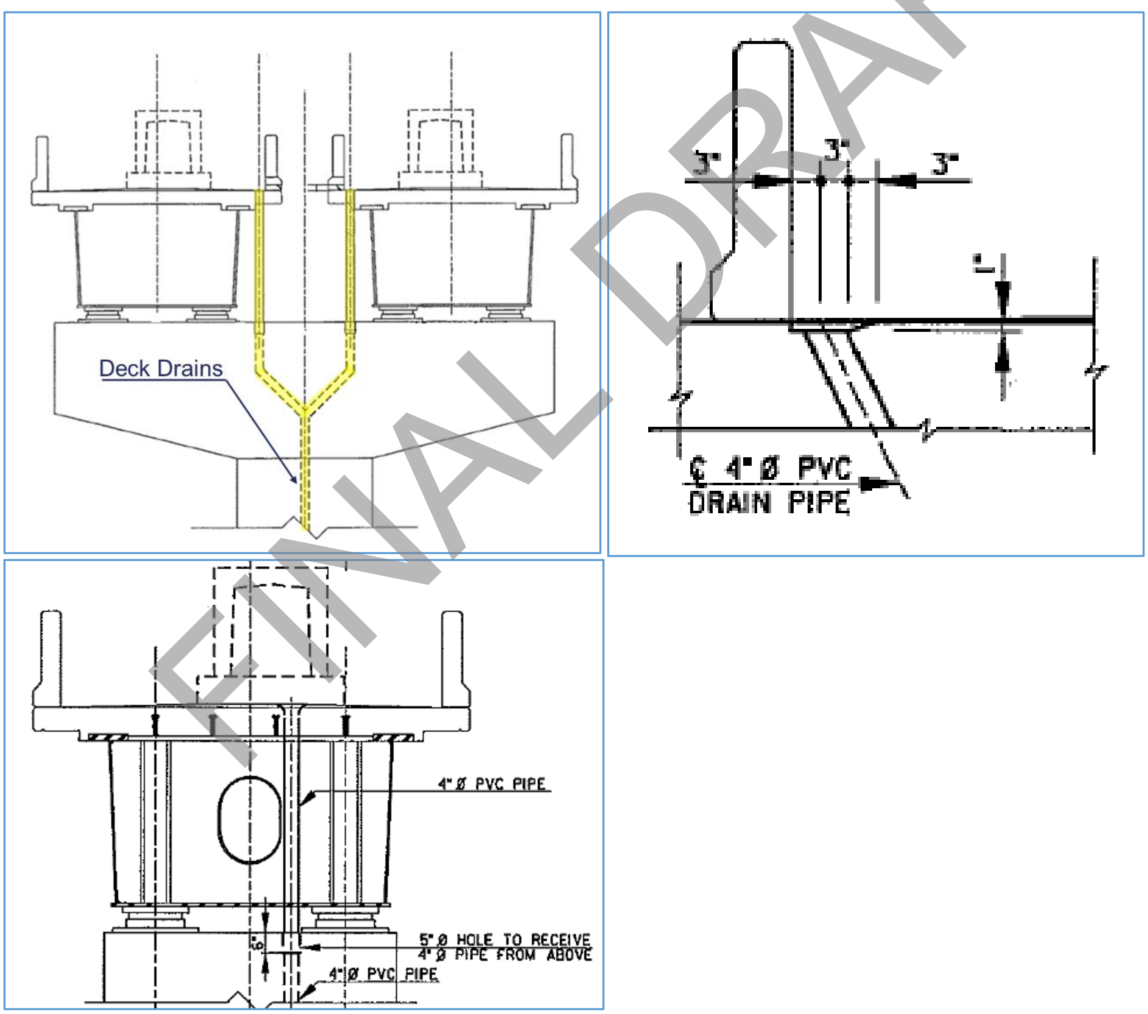


FIGURE 32: TYPICAL DECK DRAINAGE DETAILS

1.9.4 Station Platform Buildup

The existing station platform heights are designed to meet the floor level of the current UMIII Bombardier vehicle. The distance between top of station platform to top of guideway deck surface is most nearly identical for all stations, not including the O&M Center. The design vehicle, riding on the guideway with the guidebeam removed, would arrive at station platforms with a significant height deficit between the vehicle floor and the platform level. In order to be level at the platform, an elevated transition would have to be constructed. Figure 33 below show a concept of this buildup. The minimum buildup at the platform would be roughly 2'-9" from existing guideway surface to the proposed riding surface and will vary depending on the specifications of the selected AV.

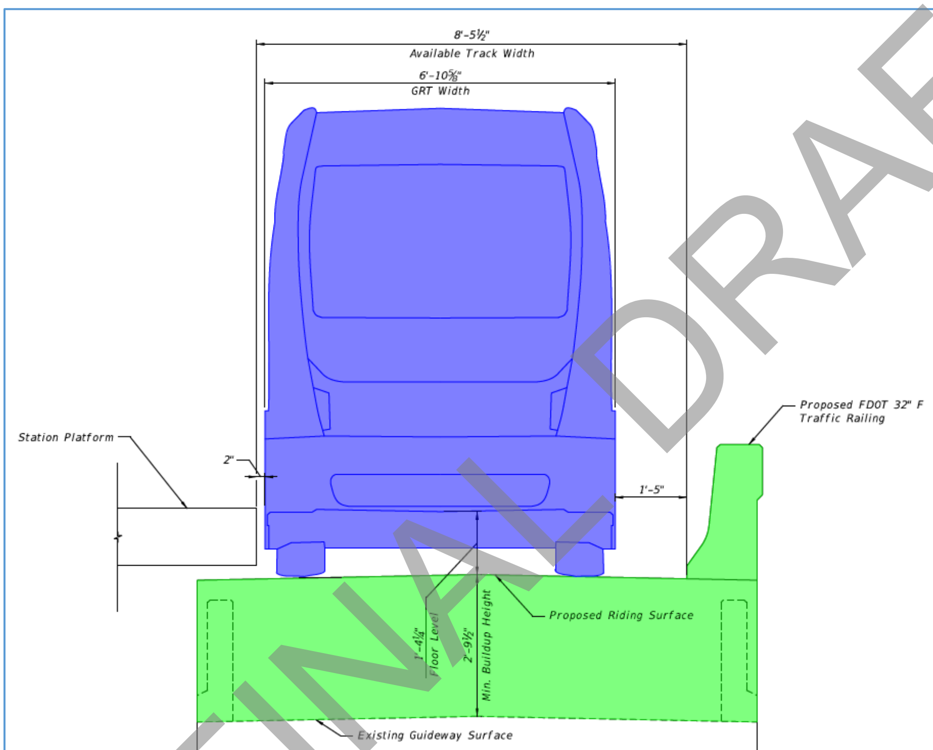


FIGURE 33: TYPICAL CROSS SECTION AT STATION PLATFORM

An elevation view can be seen below in Figure 34 to show the approximate transition required to meet a level surface for vehicle entering and exiting. If this transition and buildup were performed at all stations for both sides of the guideway, it would account for approximately 13.5% of the entire guideway length.

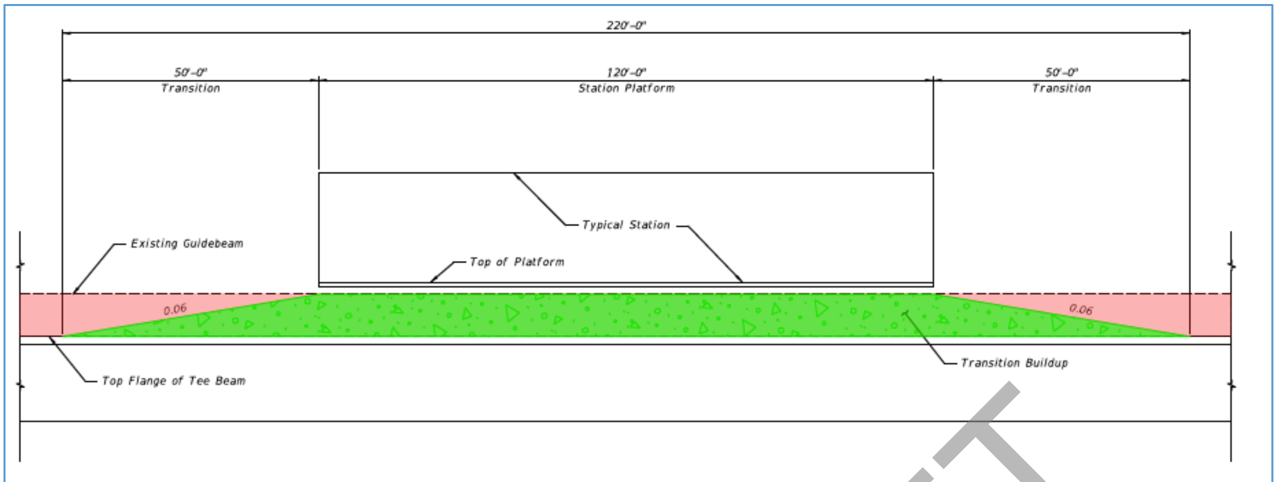


FIGURE 34: ELEVATION VIEW OF PLATFORM

1.9.5 Potential Modifications at Platforms

There are several options for constructing this station buildup. Each would be constructed using the same height differential described above, however with different materials and methods. Brief descriptions are provided below:

Superstructure Replacement
Superstructure replacement at transition areas could be performed to account for height buildup. This would require modifications to piers to increase pier cap elevation to the necessary height. Replacement of existing double tees, mostly likely with Florida I-beams, would also increase superstructure load capacity.

Lightweight Concrete Buildup
Lightweight concrete (LWC) would be the most efficient concrete option. LWC could be formed and poured to the height needed. However because of the large buildup area, LWC would still result in a large increase in deadload, approximately 1.7 kip/ft to the tee beams. Because of this, it would most likely not be a feasible option without replacing the superstructure at station sections.

Precast Segments Throughout
Proposed precast segments are theorized as a solution for deadload minimization. For this proposal, there is a configuration of precast units that would be attached to the guideway. The precast width was proposed as the entire width of the guideway. Preliminary analysis on a theoretically simple precast design of this nature shows that the existing superstructure still incurs a large increase in deadload relative to that of the existing condition. It is important to note that this option will still involve guidebeam and barrier removal with a newly designed barrier required.

Precast Segments Throughout with Geofoam Alternative

This option mirrors the option above with several exceptions. Similar if not identical precast segments, as described prior, would be installed along the discussed guideway areas at the stations. However, the voided areas that the precast segments would create would theoretically be filled with a geofoam substance. Because geofoam is used industry wide as an earthwork alternative and not for direct structural applications, it would not be able to act as a superstructure alternative. For the purpose of this project, it could not be used as a component of the superstructure that would directly receive vehicular live loads.

Steel Plate Supported by Bracing

A braced beam system would be placed on the existing deck. This would require certain details, such as an installed pedestal and anchoring, to allow for proper installation. Cross bracing would be installed intermittently along the beams. A reinforced deck surface would be installed along the top of the beams. Given a simple configuration assumed for this system, a preliminary analysis found that a large deadload would be applied on the existing superstructure relative to the existing condition.

Superstructure jacking was analyzed as a potential modification at station platforms. This option would entail placing temporary shoring at each of the continuous span units and jacking the double tee beams up to the appropriate elevation. Pier cap heights would be permanently modified to adjust to the elevation change. However, findings with existing conditions of the superstructure showed that this option was possible but highly impractical. The system currently has a significant number of beams with "fixed ends". This means that the beam ends are tied into their respective pier caps with reinforcement and any gaps sealed with closure pours. These fixed ends occur where pier caps support concrete double tee beams between the continuous spans (Figure 35). Therefore in order for span jacking to occur, each of these fixed ends would have to be cut from the existing pier cap and, once jacked, a fixed end would have to be reestablished with the modified pier cap to ensure structural integrity that a diaphragm would otherwise contribute. This type of work is typically only performed in isolated scenarios and not a scale such as the Skyway.

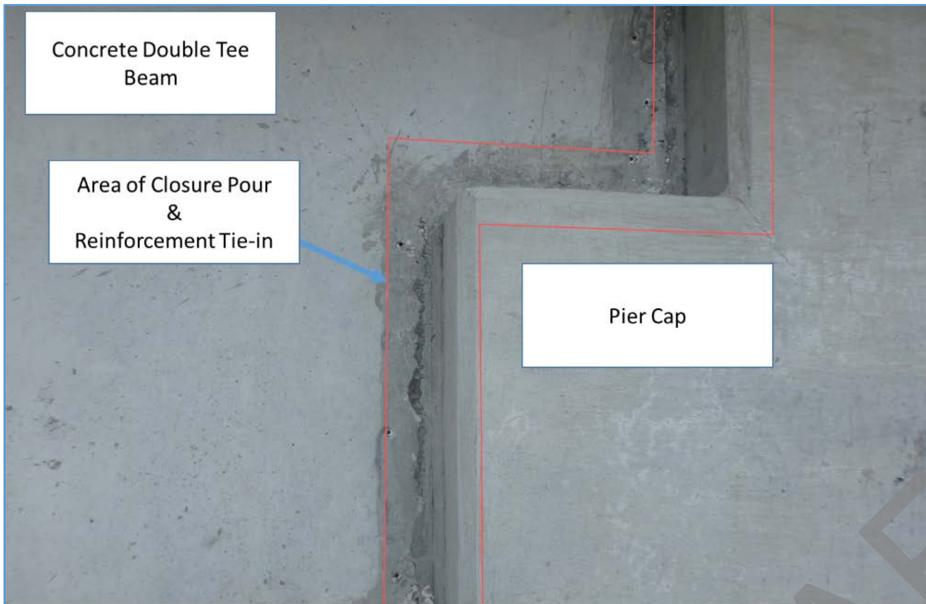


FIGURE 35: FIXED BEAM END DETAIL

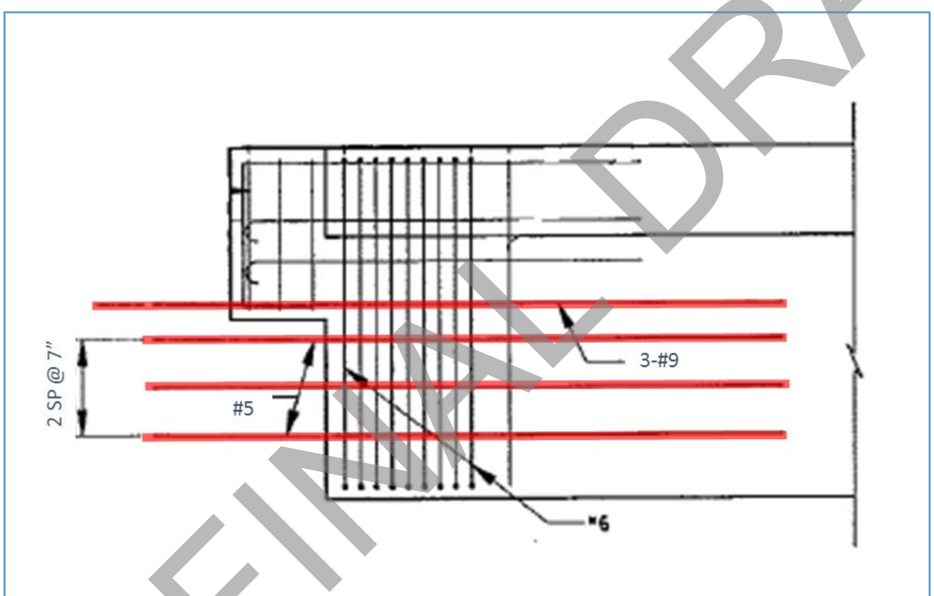


FIGURE 36: FIXED BEAM END (ELEVATION VIEW)

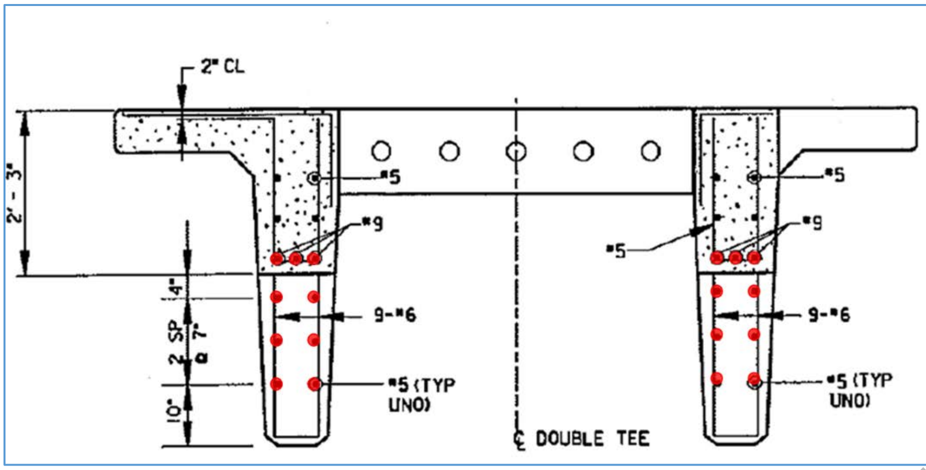


FIGURE 37: FIXED BEAM (END VIEW)

1.10 COMMUNICATIONS & POWER SYSTEMS

Signal and power rails are installed along both sides of the guidebeam for most of its length. One side is the low voltage carrying the signal loop and the other side is the high voltage side.

JEA and JTA fiber runs through cable trays alongside the edge of the system track (Figure 40). It also crosses under the guidebeam at several locations to either loop into the guidebeam or travel to the other side of the track (Figure 41). Most nearly all of these areas of cable crossover occur at stations and switch beam locations. A site map showing fiber locations was provided by Exum Communications Exum Electric Inc. and can be found in Appendix B. The relocation of the cable and power lines will have to be carefully coordinated during construction to ensure these lines are maintained.

The reconfiguration of the Skyway will require that power and communications systems be located so they are not within the limits of the barrier wall. This could require relocation to the exterior of existing barriers, underneath the superstructure or embedded into new features if all or part of superstructure is replaced.

FIGURE 38: EXAMPLE OF POWER RAILS AND CONDUIT ATTACHED TO GUIDEBEAM, RIVER CROSSING

FIGURE 39: CONDUIT CONDITION ALONG GUIDEWAY SECTION

FIGURE 40: EXAMPLE OF POWER RAIL & CABLE TRAY ALONG GUIDEWAY

FIGURE 41: EXAMPLE OF TRANSVERSE CONDUIT ALONG GUIDEWAY

1.11 OTHER MODIFICATIONS

Charging stations along active track lengths could be designed to allow for the vehicle to pull off and charge for short periods of time, relative to allowing for a full charge, and quickly brought back into service. Opportunity charging times vary and are unique to certain manufacturers. Several scenarios for space for vehicle charging are outlined below. These figures depict geometrical characteristics and are not meant to represent engineering design.

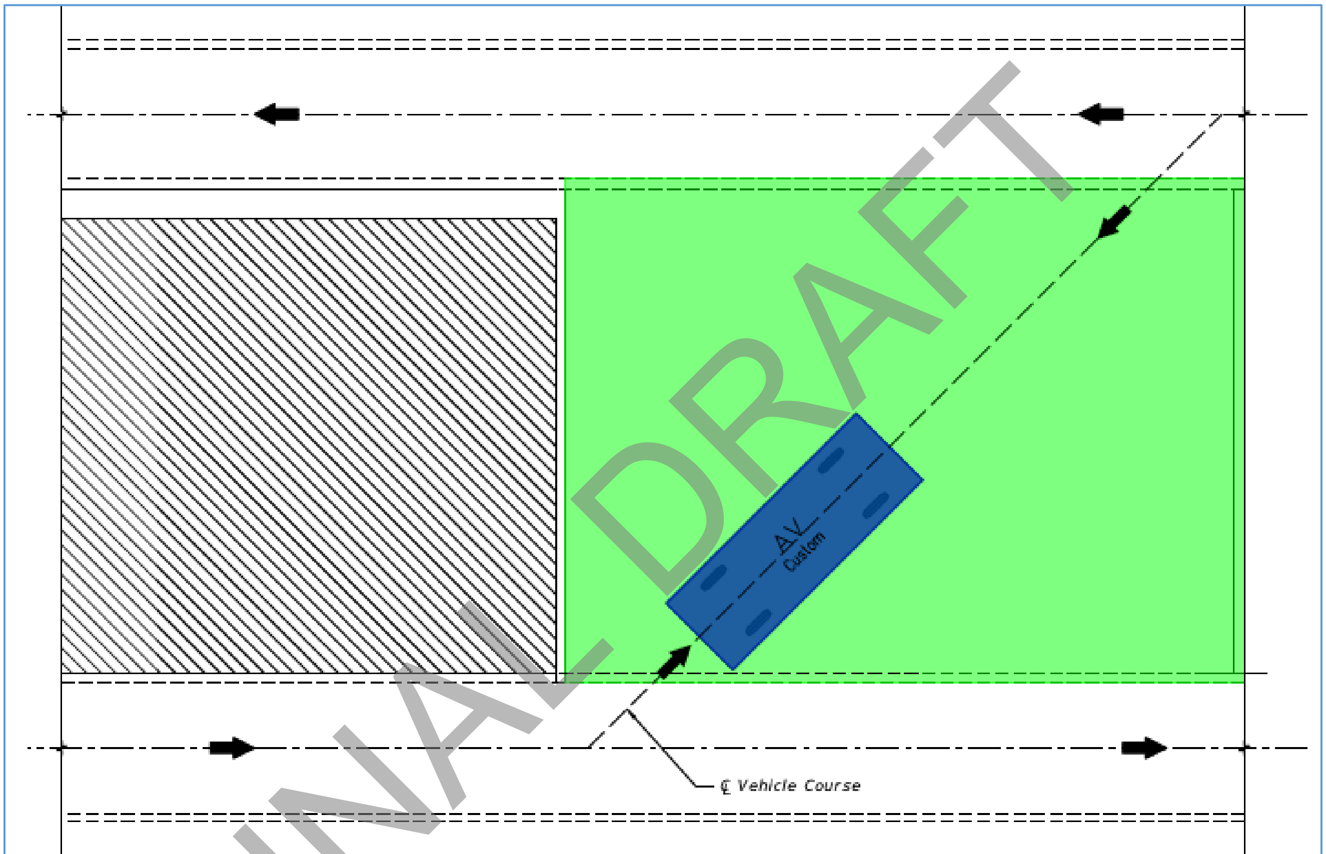


FIGURE 42: CHARGING AREA & CROSSOVER

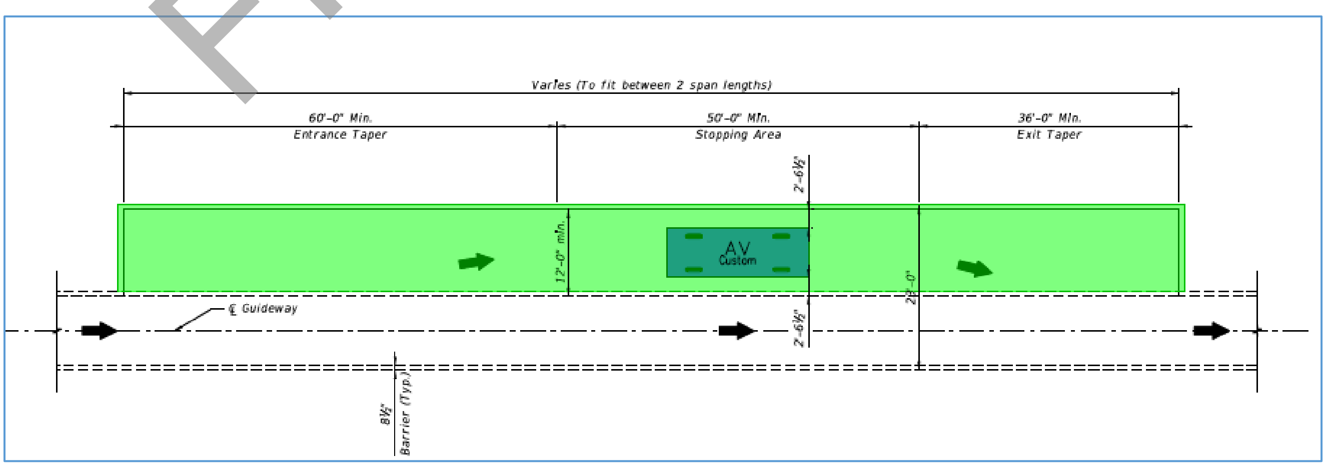


FIGURE 43: CHARGING AREA AT TYPICAL SECTION

The By Pass depiction (Figure 44) dimensions are based off of TCRP Report 19, "Guidelines for the Location and Design of Bus Stops". As seen, a typical tangent track straightaway would not allow for the assumed size by pass bay shown given the space between guideways.

There are several existing cross over points throughout the system that allow for direction change. These could either continue to be used for their intended purpose or as a possible turn out for charging. There are also track extensions that exist at switch beam locations to allow for switch beam movement that could possibly provide additional space for alternate uses.

The minimum turning radius of the GRT is approximately 20.01 feet or 6.1 m (APMS). A possible method of direction change for the proposed vehicle is to construct additional guideway around "dead-end" stations. Such stations are Terminal, Rosa Parks and Kings Ave. A depiction of this additional guideway is shown below.

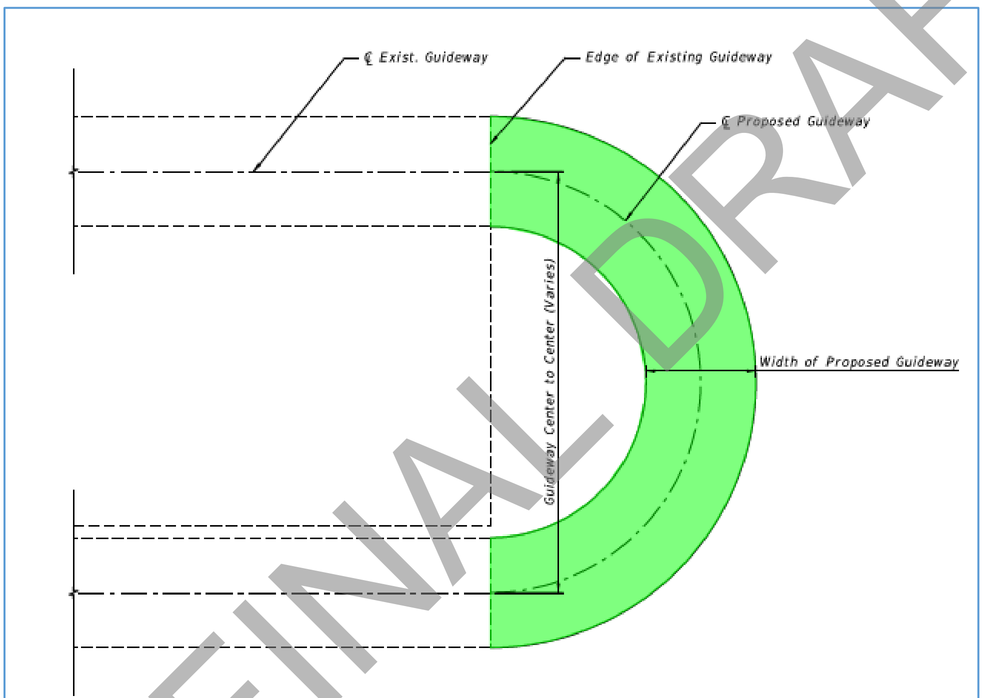


FIGURE 44: VEHICLE TURN-AROUND

"Guideway Center to Center" lengths are given below for each applicable station along with the minimum curve radius that would allow a turn around.

TABLE 10: VEHICLE TURN-AROUND DIMENSIONS

Station	Guideway Center – Center	Min. Curve Radius	Required Guideway Width
Terminal	36'-8"	18'-4"	See Note
Rosa Parks	44'-8"	22'-4"	See Note
Kings Ave.	40'-8"	20'-4"	See Note

Note: 2getthere APMS Exported Constraints Table SE-1240 outlines what would be the minimum guideway width for given curve radii.

Although the minimum curve radius meets the vehicle specifications, the required width would need to be met to accommodate the curve.

It is important to note that the addition of elevated space will most likely require construction of additional substructure and superstructure and could have impacts to existing ground features, and possibly require additional right of way. All of these could add significant cost to the project.

1.12 CONSTRUCTION STAGING CONSIDERATIONS

It is anticipated that the skyway will be taken out of service during the conversion. Construction will be performed in an urban environment impacting the streets in downtown Jacksonville. Consideration must be given to the potential effects on the traffic at streets that cross underneath as well as the Acosta Bridge. In many areas, particularly at the approaches to the Acosta Bridge, access is difficult due to terrain and complex geometry.

It is important to note that the Acosta Bridge is maintained by FDOT so that any modifications on the Acosta Bridge and approaches and construction staging must be coordinated with and approved the FDOT. Similarly any impacts to the local traffic on City Streets must be coordinated and approved by the City of Jacksonville.

Therefore an important consideration when developing the scope of the conversion will be the construction staging length of time the skyway will be out of service and the effect on the local transportation network.

1.13 CONCEPTUAL STRUCTURAL CAPACITY ASSESSMENT

1.13.1 Guidebeam Removal

The guidebeam runs for nearly the entire length of the guideway, which is approximately 29,275 feet. Because guidebeam typical sections are different in several plan sets, removal estimates were based on the assumption that the entire guidebeam typical section was that of the most recent JTA Skyway plan set, the South Section. Although the pedestal is not continuous throughout the system, it was assumed continuous for structural estimates. The Table below outlines approximate total volume and weight removals:

TABLE 11: GUIDEBEAM REMOVAL

Guidebeam Removal		
Total length*	29275.00	ft
Hollow beam cross section	3.39	ft2
Pedestal piece cross section	2.39	ft2
Total cross section	5.78	ft2
Total volume	**169209.50**	**ft3**
Total weight**	**0.87**	**kip/ft**

*Taken from numbers provided in the JTA Skyway 2017 Routine Inspection
**Normal 150 pcf concrete was assumed as the construction material

1.13.2 Concrete Deck Removal

The area of deck needing to be removed was typical throughout the guideway and is from inside sidewall face to inside sidewall face, approximately 9'-7". Height Removal is estimated at ½", which stated in 2.2.6 Overlays, FDOT Bridge Maintenance & Repair Handbook. ½" was taken from the edge of the deck and is considered to be deck preparation for the concrete deck overlay. This removal is considered incidental in terms of a structural capacity assessment.

1.13.3 Concrete Overlay Addition at Typical Sections

The concrete overlay would be poured with a normal crown in the same area from which the existing concrete deck would be removed. The concrete overlay described in this subsection extends the entire length of the guideway and excludes the superstructure buildup at stations and accompanying transition zones. This is why total length differs slightly from previous calculations. The Table below shows approximate volume and weight additions:

TABLE 12: CONCRETE OVERLAY AT TYPICAL SECTIONS

Concrete Overlay (@ Typical Section)		
total length	28315.00	Ft
typical width	9.58	ft
overlay	0.17	ft
total cross section	1.60	ft2
total volume	**45304.00**	**ft3**
total weight*	**0.18**	**kip/ft**

*110 pcf lightweight concrete was assumed as the construction material

TABLE 13: SUPERELEVATION CONCRETE OVERLAY

Superelevation		
Superelevation Rate	**cross section (ft2)**	**weight (kip/ft)****
0.01	2.08	0.23
0.02	2.56	0.28
0.03	3.03	0.33
0.04	3.51	0.39
0.05	3.99	0.44

*For a conservative estimate, an extra inch was added to the recommended 1” overlay per 2.2.6 Overlays, FDOT Bridge Maintenance & Repair Handbook

**110 pcf lightweight concrete was assumed as the construction material

1.13.4 Summary at Typical Sections

The table below shows the structural changes at typical sections with the exception of guideway adjacent to the stations. Existing Removal includes both guidebeam and deck removal. The Proposed Addition is solely the 2” concrete overlay installed for the running surface. Any type of potential superelevation at curves has not been included but will increase the deadload imposed on the system.

TABLE 14: STRUCTURAL CHANGES AT TYPICAL SECTION

Structural Changes at Guideway Typical Sections		
Existing Removal	0.87	kip/ft
Proposed Addition	0.18	kip/ft
Delta	**0.69**	**kip/ft**

1.13.5 Lightweight Concrete Buildup

The Table below shows approximate volume and weight additions:

TABLE 15: CONCRETE BUILDUP AT PLATFORM STATIONS

Concrete Buildup (@ Typical Platform Section)		
Transition volume	1317.71	ft3
Transition weight*	1.45	kip/ft
Constant buildup volume	3162.5	ft3
Constant buildup weight*	2.90	kip/ft
Avg total (per station)	**2.24**	**kip/ft**

*110 pcf lightweight concrete was assumed as the construction material

The table below shows the structural changes that would be incurred by the tee beams at constant buildup sections. Existing Removal is defined solely as guidebeam removal and does not include deck removal. Proposed Addition is defined as concrete buildup from the previous table and concrete overlay. All categories indicate a high increase in kips/ft. The remaining average indicates a 2.24 kip/ft increase imposed on the double tees across the 220 foot station buildup areas.

TABLE 16: STRUCTURAL CHANGES AT TYPICAL STATION

Structural Changes at Typical Station		
Length at Constant Buildup	220.00	ft
Existing Removal	0.87	kip/ft
Proposed Addition	2.42	kip/ft
Avg. delta	**1.55**	**kip/ft**

Existing Removal includes the guidebeam only. Proposed Addition is the reinforced lightweight concrete buildup with the additional overlay. This concludes that a potential deadload increase 1.55 kip/ft will exist at the station guideway. This increase is relative to the existing deadload imposed on the system.

1.13.6 Precast Segment Buildup

Constant buildup was applied along the length of the existing platform. A transition length was applied based on a 6% grade for the vehicle to meet with the platform floor level. The precast configuration was comprised of three 8" walls and an 8" top slab that extended the full width of the guideway. Issues exist in the functionality of its design, however appropriate values are presented below:

TABLE 17, PRECAST BUILDUP AT PLATFORM STATIONS

Precast Segments (@ Typical Platform Section)		
Constant Buildup*	1.50	kip/ft
Transition Buidup*	1.23	kip/ft
Overlay	0.18	kip/ft
Weight/Ft at Stations*	**2.90**	**kip/ft**

*130 pcf reinforced lightweight concrete was assumed as the construction material

TABLE 18, STRUCTURAL CHANGES AT TYPICAL STATION

Structural Changes at Typical Station		
Length at Constant Buildup	220.00	ft
Existing Removal	0.87	kip/ft
Proposed Addition	2.90	kip/ft
Avg. delta	**2.09**	**kip/ft**

CHAPTER 2

SUMMARY OF KEY CONSIDERATIONS

This chapter outlines key considerations from the assessment summarized in Chapter 1 that are important to consider during further project development.

REMAINING SERVICE LIFE & MAINTAINABILITY (SECTION 1.4)

The current system was constructed nearly 30 years ago, with the majority of its superstructure consisting of double tee beams. These beams were constructed with dapped ends, and according to recent inspection reports exhibit cracking at these areas.

CONCEPTUAL GEOMETRY ASSESSMENT (SECTION 1.5)

Guidebeam Removal (Subsection 1.5.2)

According to plan sets, there were 3 variations of guidebeam construction between the 5 segments of the Skyway. However according to findings, the current guideway has the same guidebeam installation throughout. It consists of reinforced precast sections that are on average 40 feet in length. At typical sections, the precast guidebeam is supported by a concrete pedestal that is spaced intermittently. At station sections, this pedestal is continuous. At all sections, the guidebeam is tied into the pedestal through rebar hooks and the pedestal is tied into the deck through dowels. It is possible that the dowels be removed through demolition and the precast segments can then be lifted off the track.

Design Speed (Subsection 1.5.3)

Speeds around tight curves on the guideway will be significantly below 35 mph. The minimum curve radius on the system is 100’, of which there are several throughout the track. The speed around these curves will be roughly 20 mph. The percentage of guideway where the vehicle will be reduced to under 35 mph is approximately 20%.

Max Grade (Subsection 1.5.4)

There are no foreseeable constraints with the vehicle climbing the current system’s maximum grades. The maximum grade of the system is 8% and the maximum allowable grade for the design vehicle is 10%.

Minimum Curves (Subsection 1.5.5)

There are many tight horizontal curves throughout the system. Although the vehicle will be able to handle operation around these curves, the design speed will be limited to under 35 mph for roughly 20% of the track.

Vertical Clearance (Subsection 1.5.6)

There are no vertical clearance concerns for the vehicle.

Horizontal Clearances (Subsection 1.5.6)

For horizontal clearance, the vehicle only has roughly 1’4” on either side for straight travel and has less than 8” on a 100’ radius curve. There are at least 100-150’ radius curves in the system and they account for roughly 6% of the total track length.

BARRIER WALL (SECTION 1.6)

AASHTO outlines 6 Test Levels for barrier design. If a new barrier is required, it must be determined which Test Level is appropriate. Any special case considerations for barrier design that deviate from AASHTO Specifications must be accompanied by proper approval. Existing barrier may be feasible given the design vehicle. However, further investigation is required regardless of range of vehicle types to determine barrier sufficiency.

EMERGENCY EGRESS (SECTION 1.8)

Given that the existing guidebeam will be removed, the design vehicle floor level will be roughly 1 foot lower than the surface level of the emergency walkway. Given the current horizontal clearance constraints, there is a concern that in the event of a vehicle breakdown it would be difficult if not impossible to remove the vehicle by typical means of towing. Requirements for passenger evacuation must be confirmed with Authority with Jurisdiction.

RIDING SURFACE (SECTION 1.9)

Deck Overlay (Subsection 1.9.1)

A proposed normal crown of LWC as a riding surface poses no concerns as far as constructability and imposed load on the superstructure. In any option for a riding surface, deck drainage must be maintained or modified.

Station Platform (Subsection 1.9.4)

At station sections, an elevation increase must occur for the new vehicle to meet the existing platform level. This report has outlined several options for this approach, all posing different issues.

Options:

1) Superstructure Replacement
2) LWC Buildup
3) Precast Dual Ramp Segments
4) Steel Plate Supported by Bracing
5) Other Alternatives
    a) Geofoam
    b) FRP

The recommendation based on the station platform findings is to replace the superstructure, at a minimum, at the station locations. At this time, this option is the most structurally feasible. All other options are found to have constraints that greatly hinder its implementation on the current system.

COMMUNICATIONS AND POWER SYSTEMS (SECTION 1.10)

Power rails and communication are installed on either side of the guidebeam. These rails serve for carrying signal to the vehicle as well as power. JEA and JTA fiber runs in cable trays along the outer edge of the track. Consideration must be made to relocate and/or maintain this fiber as part of the conversion.

OTHER MODIFICATIONS (SECTION 1.11)

Existing crossovers and extensions may be utilized for use in AV operation. There are currently 6 crossover and extension locations on the Skyway. Turnouts may be needed for changing vehicle direction at or in between stations. By passes are a possible need in order to allow multiple vehicle operation on the same stretch of track and also for periodic charging. Turn arounds may be constructed at the ends of certain stations to allow for vehicle direction change by looping around the station. It will require both additional superstructure and substructure.

CONCEPTUAL STRUCTURAL CAPACITY ASSESSMENT (SECTION 1.13)

With guidebeam removal, a LWC normal crown at typical sections raises no foreseeable issues as the proposed deadload will be lighter than existing deadload.

There are also no foreseeable structural capacity issues with a new superstructure if the existing system were to be replaced. If a LWC buildup at station sections is chosen the double tee beams will see a nearly 1.55 kip/ft increase relative to existing loads.

CHAPTER 3

CONVERSION OPTIONS

The findings outlined throughout this report have brought together four options for consideration by the JTA. Figure 45 summarizes the options by key factors. These options are described below:

Key Factors	Option 1	Option 2	Option 3	Option 4
Remove Guidebeam	√	√	√	√
Modify Drainage	√	√	√	√
Retrofit Commun./Power	√	√	√	√
Install Running Surface	√	√	√	√
Replace Barriers at Station	√	√		
Replace Barriers Throughout			√	√
Replace Superst. at Stations		√	√	
Replace Superst. Throughout				√

FIGURE 45: CONVERSION OPTION FEATURES

- **Option 1:** If the barrier wall is determined to be adequate under the chosen design vehicle specifications, then it can remain throughout the majority of the system. It is assumed that modification at station platforms is feasible by adding a ramp on top of existing superstructure.

  The following are considerations for each of the possible alternatives for Option 1:

  A. Steel Bracing: This option would most likely require the highest maintenance costs. This is due to the large area of steel that would need to be periodically painted. The only foreseeable riding surface that would support a new barrier would be a reinforced concrete deck, which will drastically increase the potential deadload. In addition, matching beams to the existing camber of the deck to supply height buildup will pose a problem. Therefore, a pedestal will most likely need to be constructed.

  B. Precast Segments: This option will add roughly 200 lbs/ft to the superstructure at stations. There is also a possible issue anchoring the precast segments to the existing deck.

  C. Geofoam: this material is only used in industry for earthwork alternatives. Because it cannot directly receive the live load of the vehicles, it would have to be incorporated with a buildup option similar to precast segments described above. Therefore, the price would be roughly the same but the design would be more involved.

- **Option 2**: If the barrier wall is determined to be adequate under the chosen design vehicle specifications, then it can remain throughout the majority of the system. This also assumes that it ramp buildup by modifying and adding to superstructure is not feasible and superstructure replacement is required at each station platform.

- **Option 3:** If the barrier wall is determined to be inadequate under the chosen design vehicle specifications, then it will be removed and replaced throughout the entire system. This also assumes that ramp build-up at stations will require superstructure replacement.

- **Option 4:** If the barrier wall is not adequate under the chosen design vehicle and barrier replacement is not cost effective, then existing superstructure will be removed and replaced throughout the entire system. For purposes of estimating we have developed an order of magnitude cost estimate for new superstructure with same square footage as existing. It is possible that the footprint could be reduced depending on operational requirements of new autonomous system resulting in lower costs.

JTA should carefully consider the assumptions within each option when making the decision on the scope of the conversion. Options 1 and 2 assume that the existing barrier wall strength and configuration will meet current safety and design requirements for the selected vehicle. Option 3 assumes the existing deck has the sufficient strength to support a newly installed barrier. We recommend that JTA perform a valuation metric analysis for each option.

Although repairs to the existing superstructure, such as FRP beam wrapping and cracking injection, offer a short term fix to the system, they should not be expected to extend the Skyway's useful life.

In addition, Option 4 could free future design from the current superstructure footprint of the system and allow for a wider range of possibilities. Turnouts, bypasses and crossovers could be placed in a multitude of locations. It also offers prospects such as the possibility to have "combined" tangent guideways, eliminating the transverse gap in between. This could possibly reduce the number of barriers needed transversely from four on the existing structure to two. Overall superstructure width could possibly be reduced through this implementation. These, among other factors, present the potential for cost savings from the order of magnitude estimates presented. Also an important consideration is that any demolition of structure components could result in damage to the existing structure thereby resulting in increased costs and longer structure durations.

Figure 46 illustrates how these key factors affect the conversion options.

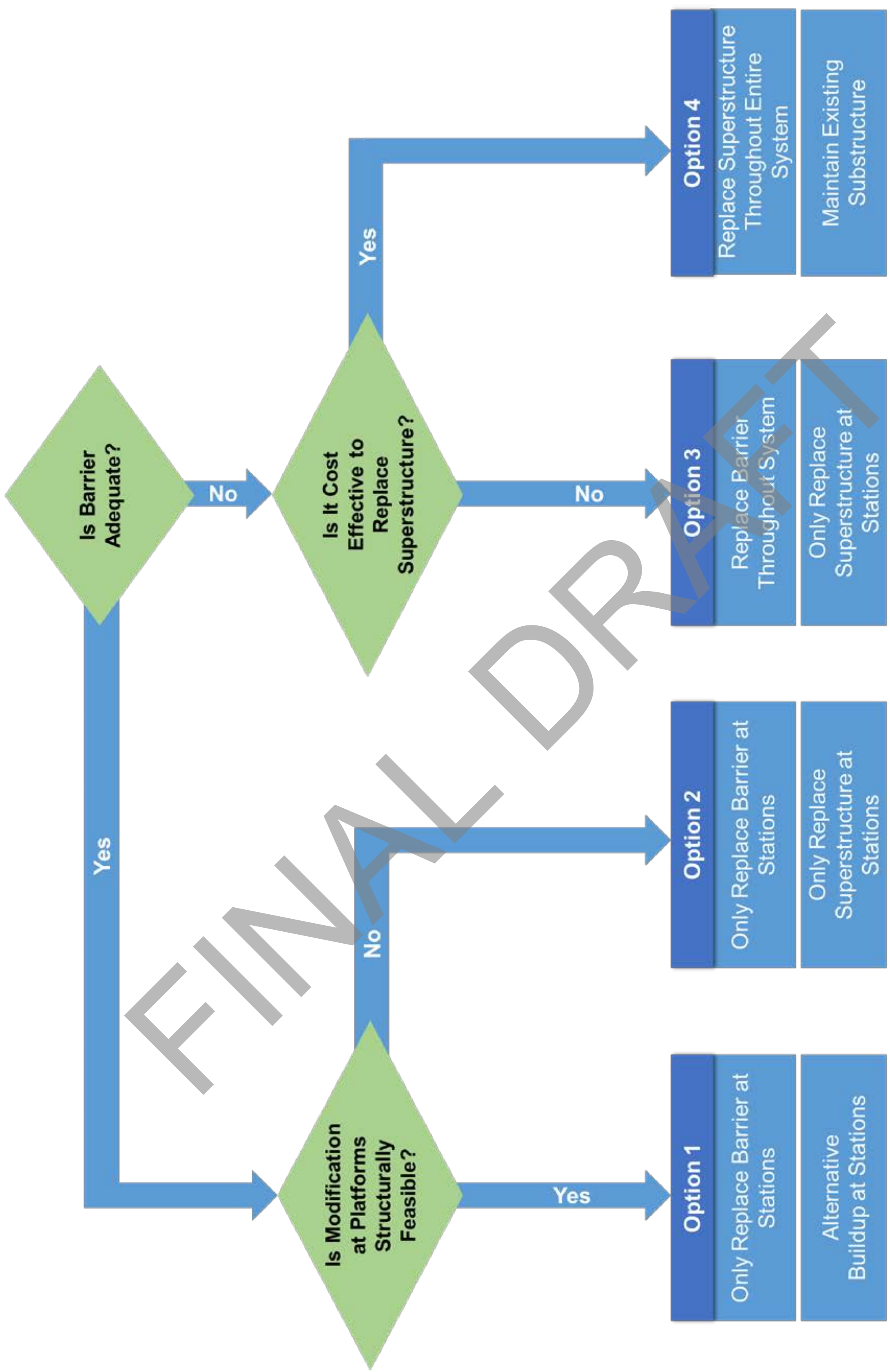


FIGURE 46: CONVERSION OPTION FLOW CHART

CHAPTER 4

RECOMMENDATIONS

There are many factors that affect the decision of the preferred option for the infrastructure conversion that must be carefully considered. Key factors for consideration are summarized in Section 2. To assist with evaluating these factors, their relationship to other program components and developing the implementation plan for the conversion, three follow up actions for next steps are recommended:

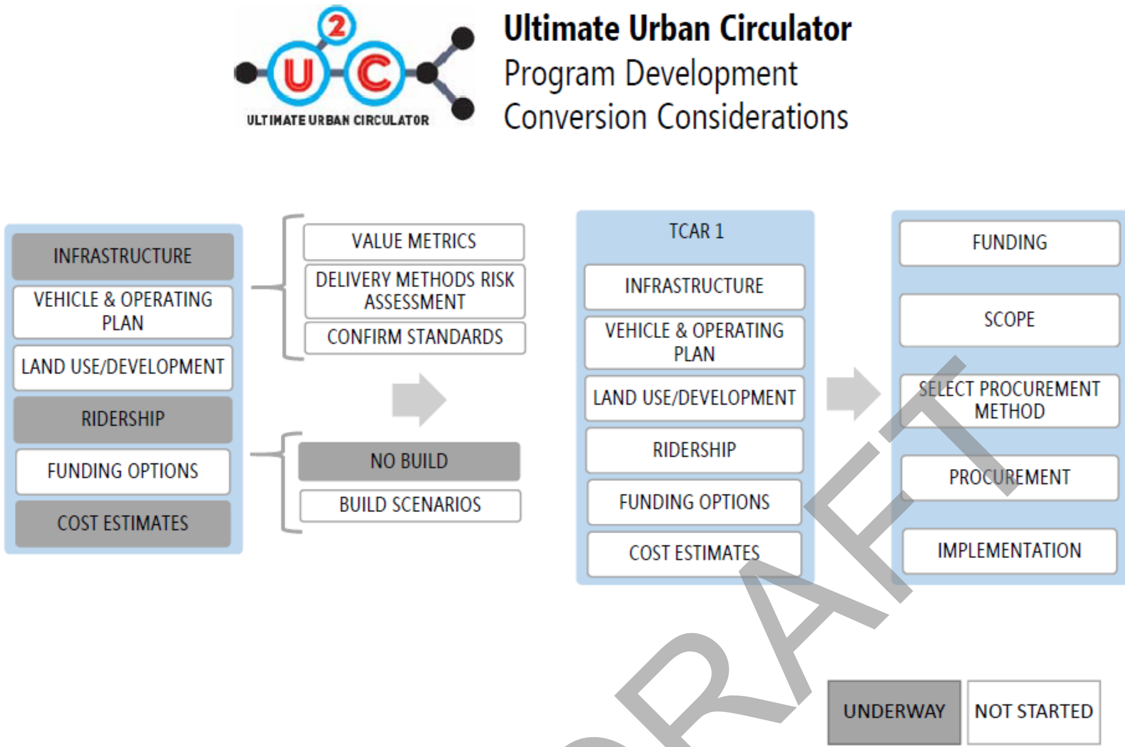
1. Value Metrics
2. Delivery Methods Risk Assessment
3. Confirm Standards

It is important to recognize that this infrastructure assessment represents one component to ensure successful delivery of the U^2C program. Any decisions regarding infrastructure conversion must consider the other program components, which will be developed as part of the Transit Concept Alternative Review (TCAR1) Study and other subsequent project tasks.

The following flow chart illustrates how this infrastructure assessment fits within the larger project and how the key recommendations fit in with overall project development. This assessment is one component of the subsequent Transit Concepts Alternative Review for phase 1 (TCAR1) process that will include assessment and cost estimates for other components.

At the time of this summary the work order for TCAR1 was in process. In addition to the infrastructure assessment TCAR1 will include further assessment of the vehicle and operating system, land use/development, ridership, funding options and cost estimates for other project components. This chart illustrates the key components of the TCAR process with the gray shading indicating tasks that are underway.

The intent of the TCAR process is to enter into consideration for state and/or federal funding. It is anticipated that the at the completion of the TCAR process that JTA will have a better understanding of funding options and regulatory requirements and be in a position to determine the scope of the project as well as selection of the appropriate delivery method.



1) **Value Metrics**

The best value option for the conversion is unlikely to be the least cost option. In order to determine the best value we recommend that JTA carefully evaluate each of the options provided in this report, by performing a value metrics analysis. This process is similar to the best value approach used for Design Build Procurements where selection is based on a combination of technical score and process.

A value metrics analysis should be developed well in advance of procurement so that JTA can identify a best value among the various infrastructure options under consideration for the U²C. This process considers technical qualities and estimated cost to evaluate the desired scope of conversion.

Value metrics can be developed as part of a valuation workshop. Representatives from the various JTA departments should attend and evaluate the technical merits of various conversion options as they relate to cost. Integrating their diverse perspectives into the evaluation will produce a holistic understanding of what the best value choice may be.

Performing the value metrics will assist in defining the desired scope for the infrastructure conversion. The analysis will consider JTA's minimum requirements for other project components, including system capacity, vehicle specifications, operating speed, ADA accessibility, emergency egress, vehicle charging and communications.

The desired outcome of the value metrics analysis is a general scope that conveys the intent of the project. The scope should also allow room for innovation, provide a safe and efficient system that is cost effective with a suitable service life.

2) **Delivery Methods Risk Assessment**

Implementation of this project offers great opportunity for JTA however also poses significant risk to the authority. It is essential that JTA select a delivery method that effectively manages risk and offers the best value for the U^{2}C project. There are several options for the procurement of the infrastructure conversion including Design Build and Public-Private Partnership (P3). There are several variations in between including Design-Build-Finance (DBF) and Design-Build-Finance-Operate and Maintain (DBFOM).

Fundamental to any procurement is defining the scope of the project. In this case the scope of the conversion may depend on the delivery method chosen and must be defined to provide enough information to potential proposers so that they can provide a competitive technically sound proposal that will meet JTA's needs and properly identify and assign risk for each project component.

JTA must assess how prescriptive the scope should be. For example, the scope could be very definitive and require beam removal and barrier replacement. Alternately, it may be less prescriptive and state that design may optionally include barrier modifications, barrier replacement or superstructure replacement. Options can be evaluated on technical viability and price to offer best value to JTA. There are merits to both approaches that should be vetted by JTA to minimize risk and obtain best value.

In order to assist JTA with defining the desired scope of conversion and delivery method, we recommend that JTA include a delivery method risk assessment as part of the value metrics discussed in the previous section.

The assessment should develop a risk profile for various delivery options including DB, DBF, DBFOM and P3. Each must consider not only the initial capital program for conversion and deployment but also the long term operations and maintenance plans. While the focus should be on the first phase, the long term plan for extensions should be considered as part of the assessment.

3) **Confirm Standards**

This unprecedented infrastructure conversion will essentially be converting a system designed as an elevated railway to an elevated roadway for which standards do not exist. It is anticipated that development of applicable design standards could be a lengthy and complex process that must include technical coordination with and approval by authorities having jurisdiction including JTA, FDOT, FTA, and the City of Jacksonville.

JTA must confirm approval of any variations or exceptions from accepted standards with authorities having jurisdiction prior to development of project scope and design criteria. The required standards will have a direct effect on project feasibility including the scope of the conversion and cost. To ensure safe system performance, standards for design speed, barrier wall design and drainage design should be of particular importance.

The design standards required for the infrastructure conversion will depend on the desired vehicle specifications which also must be determined based on the constraints of the existing or proposed infrastructure. Criteria such as passenger capacity, vehicle dimensions, maximum weight will need to be determined based on the preference and needs of JTA. Once a baseline set of requirements is established, these can be included in the design criteria of the procurement package.

The vehicle criteria should be based on current or eventual autonomous transit vehicles and should have enough flexibility to allow for the opportunity of multiple vehicle choices in the future.

APPENDIX A
TABLES & CALCULATIONS

4.1.1 Vehicle Comparison Table

JTA Ultimate Urban Circulator Vehicle Comparisons

Characteristics	Existing System	Autonomous Vehicle					
	Bombardier	Navya	2getthere	EasyMile	LocalMotors	RDM Group	Waymo
	UMIII VAL 2-Car Op	NAVYA ARMA DL4	GRT	EZ10	Olli	Pod-Zero (4-Seater)	Chrysler Pacifica Hybrid
Length (ft)	48	15.6	19.7	12.9	12.86	8.9	17
Width (ft)	7.0	6.9	6.9	6.6	6.73	4.6	6.7
Height (ft)	9.0	8.7	9.2	9.1	8.2	6.6	5.8
Wheel base length (ft)	2.83	9.3	12.1	9.2	8.29		10.1
Ground Clearance (ft)	N/A	0.66	0.54	0.55			0.425
Floor height (ft)	4.2 (includes beam)	0.76	1.35	1.2			
Unloaded Weight AW0 (lb/car)	26,100	5,291	7,720	4,400	3,300	1,323	6,300
Crush load Weight AW3 (lbs/car)	39,540	7,716	14,440	6,614	5,500		
Charging Time	N/A	8 hr (90%, induction) / 4 hr (90%, plug)	10 min (30%→80% charge, induction)	5 hr	4.5 hr	< 3 hr	
Battery Charge Life	N/A	9 hr	30 min	14 hr		4-6 hr	
Door Openings	One	One	Both	One	One	Both	One
Passenger Capacity	56 (2-car)	15	24	12	12	4	7
Maximum Speed (mph)	35	30	25	25	25	15	115*
Maximum Percent Grade (%)	8%	12	10	15			
Turning Radius (ft)	100	<14.75	25	16.5			

Data retrieved from respective vehicle's website or literature unless otherwise specified.
*source:Industry reports, presentations or online articles.

Updated: 9/19/2017







4.1.2 APMS Exported Constraints Table SE-1240, Clear Width

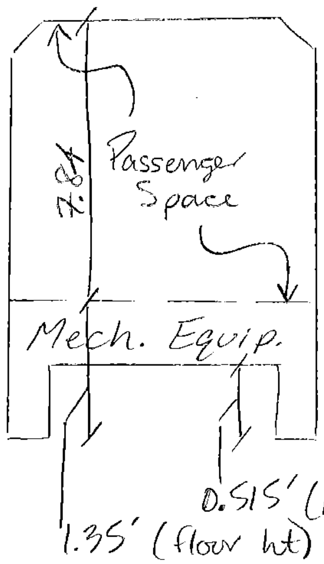
R		Clear Width		R		Clear Width	
m	ft	m	ft	m	ft	m	ft
Straight	Straight	2.6	8.530	26	85.302	3.066	10.059
Stations	Stations	2.6	8.530	27	88.583	3.06	10.039
17.5	24.606	3.424	11.234	28	91.864	3.055	10.023
8	26.247	3.396	11.142	29	95.144	3.05	10.007
9	29.528	3.346	10.978	30	98.425	3.045	9.990
10	32.808	3.306	10.846	31	101.706	3.04	9.974
11	36.089	3.273	10.738	32	104.987	3.036	9.961
12	39.370	3.244	10.643	33	108.268	3.032	9.948
13	42.651	3.22	10.564	34	111.549	3.028	9.934
14	45.932	3.198	10.492	35	114.829	3.025	9.925
15	49.213	3.18	10.433	36	118.110	3.021	9.911
16	52.493	3.164	10.381	37	121.391	3.018	9.902
17	55.774	3.149	10.331	38	124.672	3.015	9.892
18	59.055	3.136	10.289	39	127.953	3.012	9.882
19	62.336	3.124	10.249	40	131.234	3.01	9.875
20	65.617	3.114	10.217	41	134.514	3.007	9.865
21	68.898	3.104	10.184	42	137.795	3.005	9.859
22	72.178	3.095	10.154	50	164.042	2.988	9.803
23	75.459	3.087	10.128	75	246.063	2.959	9.708
24	78.740	3.08	10.105	100	328.084	2.945	9.662
25	82.021	3.073	10.082	125	410.105	2.936	9.633

* Highlighted rows indicate the smallest curves that exist on the current Skyway system.

4.1.3 Vehicle Center of Gravity

RS&H

SUBJECT GRT Center of Gravity		AEP NO	
DESIGNER		SHEET	OF
CHECKER		DATE	
		DATE	



Passenger ht = 6'
cg ~ 2/3 · ht

AW0 = 7.717 kip
AW2 = 14.661 kip
Max Pass. Wt = 6.944 kip

← Passenger wt → ✕ ← empty Vehicle wt →

$$C.G. = \frac{[6(2/3)+1.35]\,6.944 + [(1.35-.515)(2/3)+.515]\,7.717}{14.661}$$

= 3.098'

Height Deficit

Starter & North line Barrier

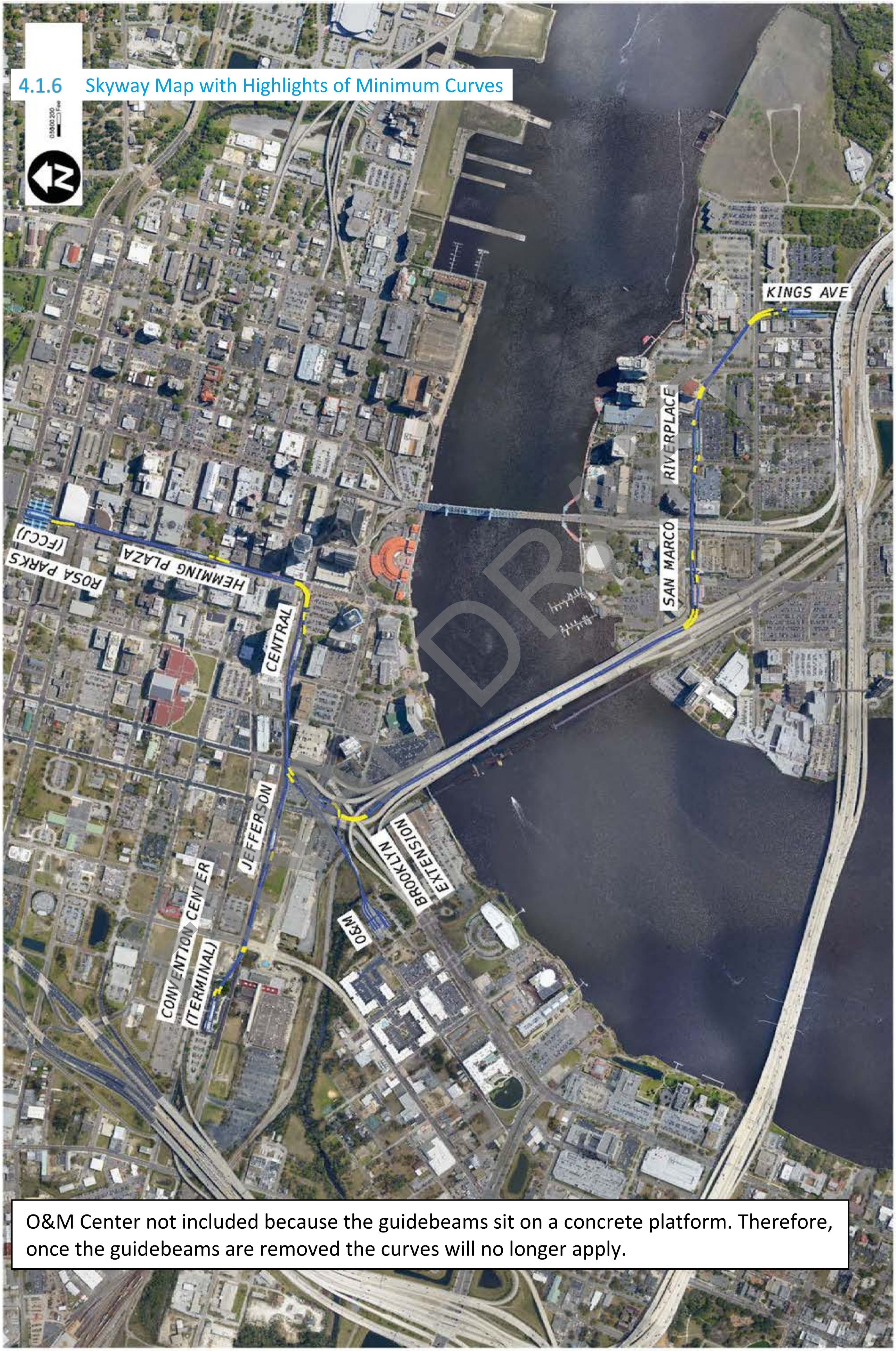
barrier ht w/o overlay = 2.375' ⇒ −.723'

barrier ht w/ overlay = 2.175' ⇒ −.923'

APPENDIX B
MAPS & OVERVIEWS

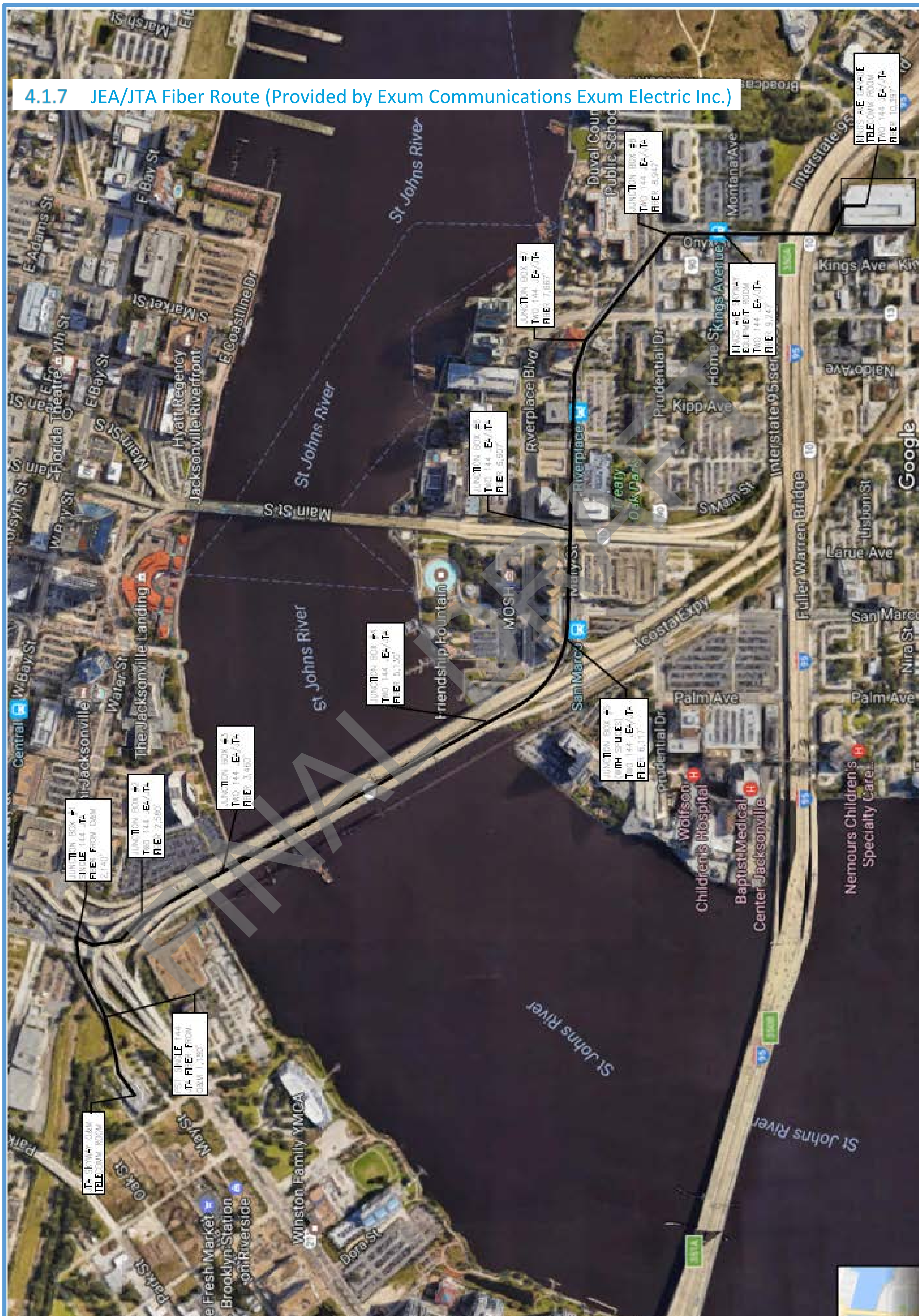
4.1.4 Skyway Reference Map

4.1.6 Skyway Map with Highlights of Minimum Curves



O&M Center not included because the guidebeams sit on a concrete platform. Therefore, once the guidebeams are removed the curves will no longer apply.

4.1.7 JEA/JTA Fiber Route (Provided by Exum Communications Exum Electric Inc.)



APPENDIX C
MAINTENANCE RECOMENDATIONS

Recommendation Number(s)	Item	Quantity	Unit	Unit Price	Estimate	N/L
Non-Structural Related Concerns						
Deck Elements						
1,4, 8, 38	Clean out drains and joints	79	EA	$ 600	$ 47,400	N
2-3,5-7, 17	New drains & epoxy overlay	65	EA	$ 4,055	$ 263,600	L
Electrical						
9-16	Electrical maintenance	1	EA	$ 20,000	$ 20,000	N
Vegetation						
18-20	Initial tree trimming at piers	48	hr/ crew	$ 160	$ 7,700	N
18-20	Recurring tree trimming	10	cycle	$ 4,800	$ 48,000	L
Deck Elements						
Emergency Walkway						
21	Misc Metal for walkway cover plates	4	EA	$ 250	$ 1,000	N
22-23, 33	Walkway corrosion inhibitor	39,000	SF	$ 8	$ 312,000	L
Expansion Joints						
24-30	Replace compression seals	2,109	FT	$ 100	$ 210,900	L
24-30	Replace modular seals	283	FT	$ 920	$ 260,400	L
Deck and Tee Beam Top Flange/Sidewalls						
31,32, 35-36, 41, 44, 46	Repair spalls	19.2	CF	$ 271	$ 5,300	L
31,32,34, 37, 45-46	Seal cracks	114	LF	$ 123	$ 14,100	L
Superstructure						
Concrete Tee Beams						
42-43	CFRP wrap repair	1,350	SF	$ 150	$ 202,500	L
44, 46	Patch spalls	3.5	CF	$ 271	$ 1,000	L
45-46	Seal cracks	825	LF	$ 123	$ 101,800	L
Steel Box Girders and Pier Crossheads						
47	Organic debris specialty removal (40,000 SF)	1	LS	$ -	$ -	L
11, 39-40, 48-54	Paint total exterior, spot interior and switchbeam, and bearing work	190,000	SF	$ 29	$ 5,553,700	L
Substructure						
Substructure Elements						
46, 56, 57, 59-60	Patch spalls	3.3	CF	$ 271	$ 1,000	L
46, 58, 60	Seal cracks	21	LF	$ 123	$ 2,600	L
Near Term Subtotal					$ 76,100	
Contingency (Mobilization, Engineering, etc.)				30%	$ 22,830	
Near Term Total					$ 98,930	
Long Term Subtotal					$ 6,976,900	
Contingency (Mobilization, Engineering, etc.)				30%	$ 2,093,070	
Long Term Total					$ 9,069,970	
Overall Total					$ 9,168,900	

APPENDIX D
REFERENCES & AVAILABLE AS-BUILTS

References:

1) APMS Exported Constraints, Version 2.1, Document No.: 2GT-ENG
   Jean-Luc Valk, 2getthere
   July 26th, 2016
2) GRT Vehicle Design Specification, Version 2.0
   Martijn Huizer, 2getthere
   October 26th, 2015
3) JTA Skyway 2017 Routine Inspection of Bridge Structures, Final Report
   Sanya Johnson, PE, CBI, FIT Engineering, LLC
4) RS&H Assessment of JTA Skyway Storm Damage
   RS&H
   January 2017

Available As-Builts upon Request:

1) Starter Line (1988)
   Version: Issued for Construction
   Description: Design drawings for that phase
   Location: RS&H Server
2) North Line (1991)
   Version: Issued for Construction
   Description: Design drawings for that phase
   Location: RS&H Server
3) River Crossing (1994)
   Version: Issued for Construction
   Description: Design drawings for that phase
   Location: RS&H Server
4) O&M Line (1997)
   Version: Issued for Construction
   Description: Design drawings for that phase
   Location: RS&H Server
5) South Line (1998)
   Version: Issued for Construction
   Description: Design drawings for that phase
   Location: RS&H Server
6) JTA Automated Skyway Finger Joint Repair
   Version: N/A
   Description: N/A
   Location: RS&H Server
7) Overhead Protection
   Version: N/A
   Description: N/A
   Location: RS&H Server

8) Guidebeam Plan Set
   Version: N/A
   Description: Guidebeam plan, profile and details
   Location: RS&H Server
9) Pier Sheets
   Version: N/A
   Description: Structural details for piers
   Location: RS&H Server