FINAL

Typical Section Technical Memorandum

State Road 414 Expressway Extension
Project Development and Environment Study
From US 441 to SR 434
Orange County and Seminole County, Florida

CFX Project Number: 414-227

Prepared for:
Central Florida Expressway Authority
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PPS0724201202ORL

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CENTRAL FLORIDA EXPRESSWAY AUTHORITY

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Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
CFX	Central Florida Expressway Authority
FDM	*FDOT Design Manual*
FDOT	Florida Department of Transportation
LOS	Level of Service
PD&E	Project Development and Environment
ROW	right-of-way
SR 414	State Road 414
SR 429	State Road 429
SR 434	State Road 434
US 441	U.S. Highway 441
vpd	vehicle(s) per day

1. Project Overview

1.1 Project Background and Description

The Central Florida Expressway Authority is conducting the State Road 414 Expressway Extension Project Development and Environment Study to evaluate alternatives for a proposed grade-separated expressway extension of the tolled SR 414 (John Land Apopka Expressway). The existing SR 414 Expressway provides regional connectivity from State Road 429 and U.S. Highway 441 in Apopka and extends south and east to SR 414 (Maitland Boulevard) just east of US 441. Figure 1-1 presents the Regional Location Map. The study limits extend along the existing SR 414 (Maitland Boulevard) corridor from US 441 (Orange Blossom Trail) to State Road 434 (Forest City Road). Figure 1-2 presents the Project Location Map. The approximate 2.8-mile-long study corridor generally runs along the Orange and Seminole county lines and is located within the cities of Maitland (Orange County) and Altamonte Springs (Seminole County). Both CFX and the Florida Department of Transportation own portions of SR 414 within the project study limits. CFX owns and operates the SR 414 (John Land Apopka Expressway) from State Road 429 to just east of US 441 and FDOT owns and operates SR 414 (Maitland Boulevard) from just east of US 441 to U.S. Highway 17/U.S. Highway 92. The existing SR 414 (Maitland Boulevard) is a four-lane divided urban principal arterial with three major signalized intersections at Bear Lake Road/Rose Avenue, Eden Park Road and Magnolia Homes Road, and an unsignalized intersection at Gateway Drive between the grade-separated intersections of SR 414/US 441 and SR 414/SR 434. A minor grade-separated overpass exists over the Little Wekiva Canal and an access road between the Lake Lotus Park and Ride lot and Lake Lotus Park.

The PD&E Study is evaluating alternatives for a proposed grade-separated SR 414 Expressway Extension to provide system linkage between the western terminus of the SR 414 (John Land Apopka Expressway) and Interstate 4. The SR 414 Expressway Extension includes alternatives for a facility with up to two lanes in each direction from US 441 to SR 434. Project alternatives involve various configurations of grade-separated express lanes on SR 414 (Maitland Boulevard) to provide needed capacity between US 441 and SR 434 while maintaining the existing local access lanes. Alternatives considered include reversible, bi-directional and convertible express lanes along the project corridor to avoid right-of-way acquisition needs.

Prior to the PD&E Study, CFX completed the SR 414 Reversible Express Lanes Schematic Report that included an assessment of tolled, directional express lanes within the median of SR 414. The Report recommended a two-lane, reversible, grade-separated viaduct in the median of SR 414. The Report also found that a single lane bi-directional express lane would require a 75 percent wider bridge and was not considered viable (CFX 2019).

The proposed improvements also include reconfiguring the existing at-grade SR 414 (Maitland Boulevard) to accommodate the SR 414 Expressway Extension facility while maintaining two SR 414 (Maitland Boulevard) local access lanes in each direction. The study involves analysis of intersection improvements, bridge modifications at Lake Bosse and Little Wekiva Canal, stormwater management facilities, pedestrian and bicycle needs and access management modifications. A No-Build Alternative is also considered throughout the study.

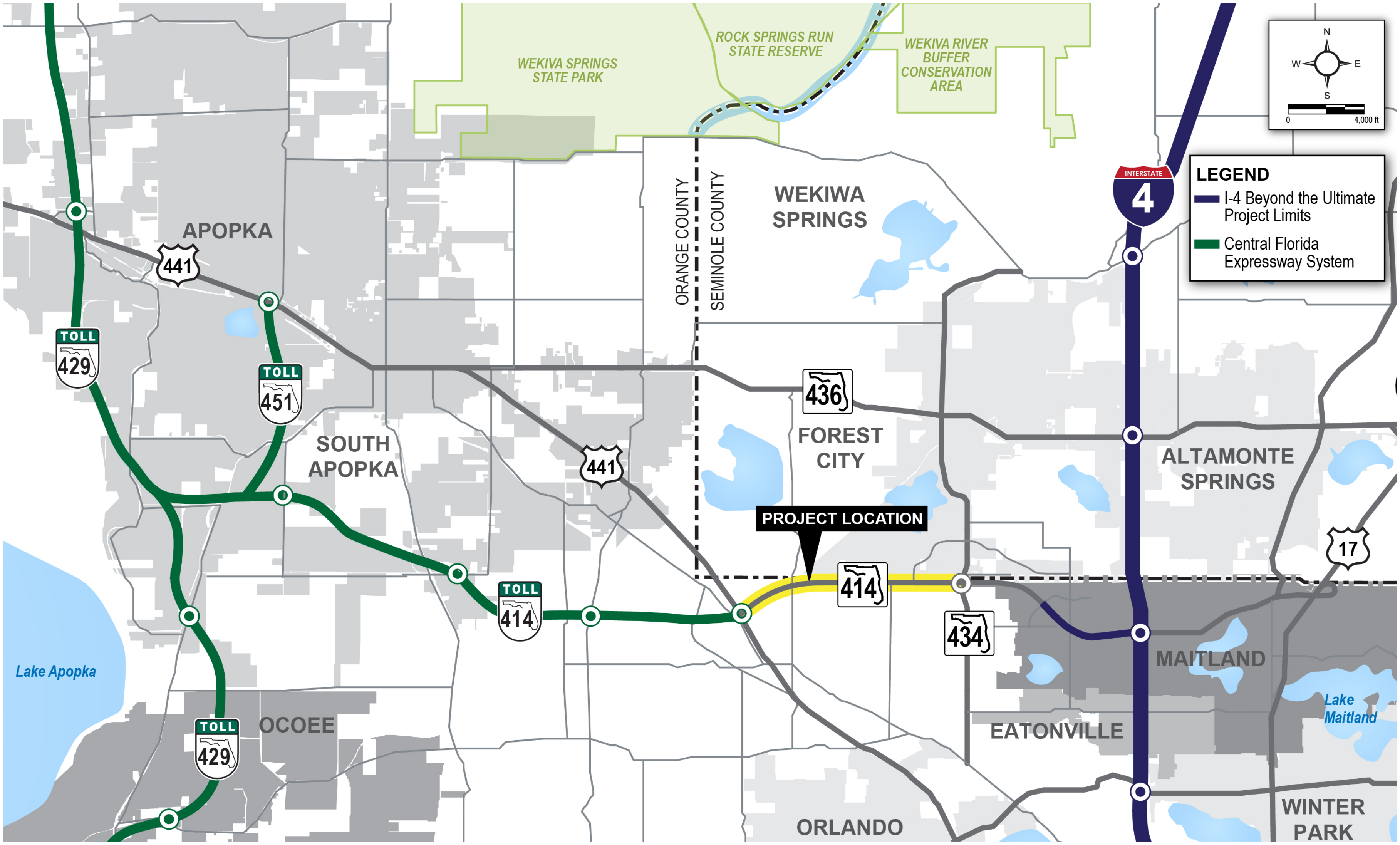


Figure 1-1. Regional Location Map

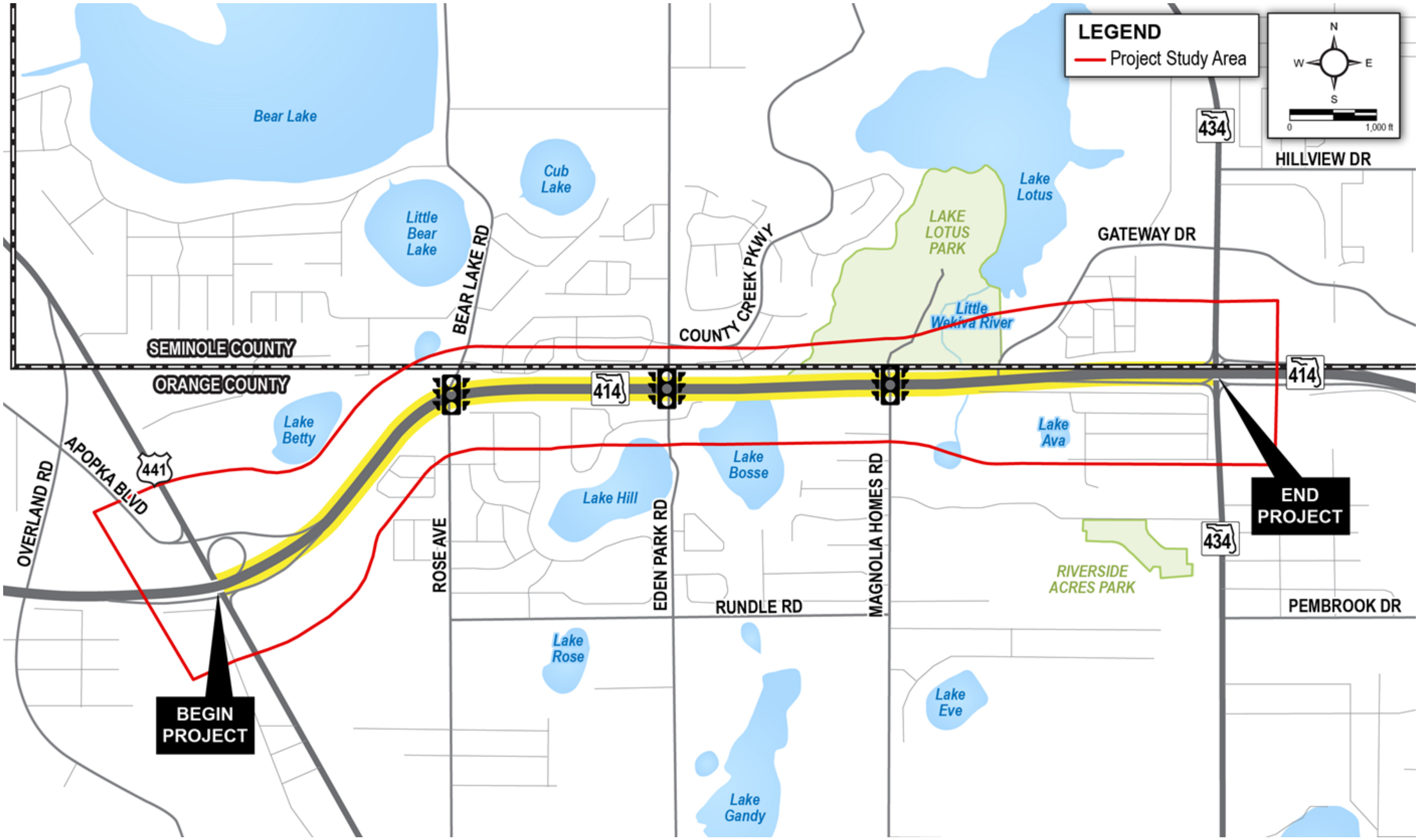


Figure 1-2. Project Location Map

1.2 Purpose and Need

The purpose of the proposed SR 414 Expressway Extension is to provide needed capacity on the SR 414 corridor and improve system connectivity between SR 429 and I-4 to meet future traffic needs. The 2.8-mile-long project corridor of SR 414 (Maitland Boulevard) is an arterial connecting two limited-access facilities. The proposed project will complete the limited-access gap between US 441 and SR 434 and provide limited-access regional connectivity between SR 429 and I-4. The proposed grade-separated SR 414 Expressway Extension will separate the through traffic from the local traffic, allowing for greater mobility and reduced congestion for both facilities. The proposed improvements are to 1) accommodate anticipated transportation demand, 2) improve safety, 3) improve system connectivity/linkage and 4) support multimodal opportunities.

1.3 Report Purpose

This *Typical Section Technical Memorandum* documents the typical section options identified for consideration during alternatives development and the methodology and evaluation of typical section options. It also documents the recommended typical section and design speed for the Preferred Alternative.

1.4 Alternatives Considered

Alternatives were evaluated for environmental and operational constraints. An at-grade alternative within the median of SR 414 (Maitland Boulevard) was eliminated because while it provided uninterrupted travel along the expressway, traffic from the local cross streets would not be able to cross SR 414 (Maitland Boulevard). Another alternative considered included an adjacent corridor to SR 414. However, because SR 414 (Maitland Boulevard) is mostly developed, this alternative would result in significant community impacts and was eliminated from further consideration. Finally, an alternative that included individual overpasses at each of the existing intersections was also considered. However, because of the limited spacing between each intersection, this alternative was not feasible and was, therefore, eliminated.

Viable alternatives were developed and presented for public input at the Alternatives Public Workshop held on February 10, 2021. These viable alternatives included roadway concepts for the SR 414 Expressway Extension project, including the SR 414 elevated lanes and the at-grade local access lanes. The viable alternatives were updated after the Alternatives Public Workshop to reflect ongoing alternatives refinements that avoid and minimize environmental impacts.

1.4.1 No-Build Alternative

The No-Build Alternative for the study area assumes previously programmed improvements are built including widening SR 414 (Maitland Boulevard) to six lanes (at-grade with no elevated expressway) from US 441 to SR 434 as noted in MetroPlan Orlando’s 2045 Metropolitan Transportation Plan Cost Feasible Plan, Revised June 9, 2021. The No-Build Alternative is not funded in the FDOT 5-Year Work Program, adopted July 2020, and is no longer programmed. Consistency with local transportation plans is being coordinated during the PD&E Study. The previously programmed improvements to SR 414 (Maitland Boulevard) do not meet the future traffic needs through the year 2045 nor the purpose and need for the project to accommodate future transportation demand or improve system connectivity. Therefore, the No-Build Alternative is not the Preferred Alternative. However, the No-Build Alternative shall remain under consideration throughout the PD&E Study for public input and to provide a comparison to the Preferred Alternative.

2. Existing Conditions

The existing roadway network in the study area consists of local roads, rural and urban arterials and limited-access facilities. The existing SR 414 (Maitland Boulevard) is an east-west oriented facility in the study area providing regional connectivity at the boundary of Orange County and Seminole County and connecting SR 429 and I-4. The study area includes two interchanges (US 441 and SR 434), three at-grade signalized intersections (Bear Lake Road/Rose Avenue, Eden Park Road and Magnolia Homes Road) and one unsignalized at-grade intersection (Gateway Drive). The SR 414 (Maitland Boulevard) project corridor has four bridges including one over US 441, one over Lake Bosse, one over the Little Wekiva Canal and one over SR 434.

2.1 Existing Typical Sections

The existing SR 414 (Maitland Boulevard) roadway between US 441 to SR 434 is an urban typical section approximately centered within the existing minimum ROW of 118 feet and has a closed drainage system with Type F curb to the outside and grassy swales in the median. The typical section occurs outside the interchanges between Bear Lake Road and Gateway Drive and consists of four 11-foot-wide lanes (two lanes in each direction), 4-foot-wide inside and outside shoulders and a 46-foot-wide median. All lanes slope to the outside with the inside lane at 0.02 feet per foot and the outside lane at 0.03 feet/foot, except where superelevated. Within this section are 5-foot-wide sidewalks adjacent to SR 414 on both sides (refer to Figure 2-1). There is an 1,800-foot-long section between the US 441 Interchange and Bear Lake Road that uses the same footprint of existing pavement but is striped so that each side consists of one 14-foot-wide lane and one 12-foot-wide lane (two lanes in each direction), a 46-foot-wide median and 4-foot-wide inside shoulder but no outside shoulder. Appendix A presents these existing typical sections. There is a 12-foot-wide shared use path on the north side of SR 414 that begins in Orange County ROW at US 441 and connects into SR 414 ROW for approximately 900 feet to the west of Bear Lake Road.

The western project limit within the US 441 Interchange includes approximately 1,700 feet from the bridge over US 441 to the CFX/FDOT boundary marked by signage and the end of a median barrier wall. This area transitions from a barrier-separated, closed 26-foot-wide median to tie into the grassy 46-foot-wide median described previously. This rural typical section includes 12-foot-wide lanes, 12-foot-wide inside shoulders and 10- to 12-foot-wide outside shoulders. There is a 5-foot-wide sidewalk on the south side of the limited-access ROW separated from the roadway by a fence.

The eastern project limit includes approximately 2,500 feet between Gateway Drive and the end project at SR 434, and the typical section transitions from urban to rural. This typical holds the 46-foot-wide median and includes 12-foot-wide lanes, 4-foot-wide paved inside shoulders and 8- to 10-foot-wide paved outside shoulders. There is no sidewalk on either side of SR 414 within this eastern section.

The posted speed is 50 miles per hour in the western portion of the project from US 441 to Gateway Drive and changes to 55 mph at Gateway Drive to the eastern limit at SR 434.

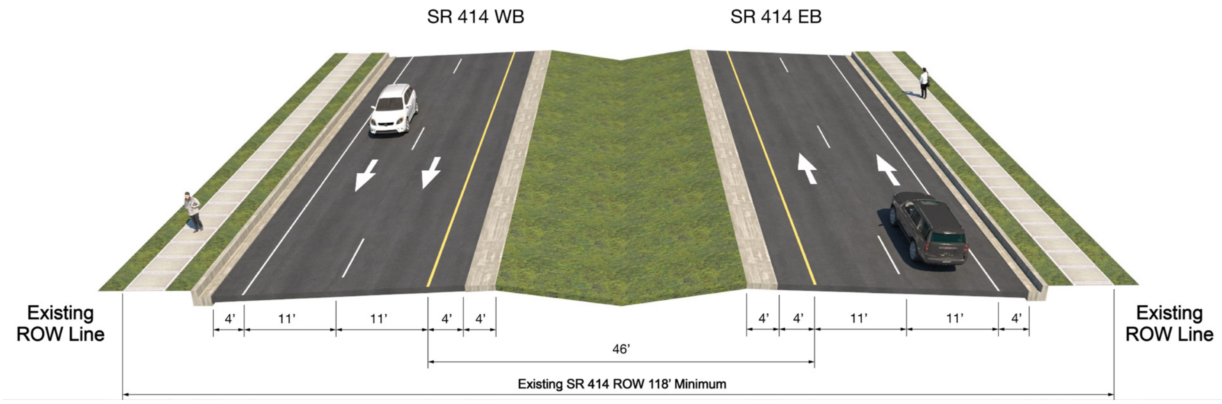


Figure 2-1. Typical Section

3. Typical Section Analysis

3.1 Design Criteria

The SR 414 Expressway Extension PD&E Study incorporates project elements with various design requirements. The existing four-lane SR 414 (Maitland Boulevard) facility will remain an at-grade urban principal arterial with local access maintained by FDOT and, therefore, FDOT design standards will be applied. The proposed expressway extension will be a limited-access facility, and accordingly CFX design standards will be applied. The development of this project is guided by the basic CFX, American Association of State and Highway Transportation Officials, FDOT and National Cooperative Highway Research Program design criteria and guidance as follows:

- CFX Design Guidelines (CFX 2021b)
- CFX Signing and Pavement Marking Details and CADD Files (CFX 2021a)
- CFX ITS Design Standards (CFX 2021c)
- *A Policy on Geometric Design of Highway and Streets* (AASHTO 2011a)
- *Roadside Design Guide* (AASHTO 2011b)
- *Research Report 835: Guidelines for Implementing Managed Lanes* (TRB 2016)
- *FDOT Design Manual* (FDOT 2021a)
- FDOT *Standard Plans for Road and Bridge Construction* (FDOT 2021b)
- FDOT *Drainage Manual* (FDOT 2021c)

Appendix B presents design criteria for the PD&E Study. Design speed for the proposed SR 414 Expressway Extension was initially considered at 55 mph for consistency with the adjacent expressway to the west. However, further analysis determined that the stopping sight distance requirements within the horizontal curve over Bear Lake Road could not be achieved without horizontal re-alignment, which would greatly increase structure costs and possibly result in ROW impacts. To avoid these impacts, the recommended design speed for the expressway is 50 mph and is reflected in the design criteria tables.

3.2 Design Constraints and Goals

The following design constraints and goals were considered in the development of typical section options for the proposed improvements:

- **Right-of-Way:** The proposed typical section options should maximize use of the existing 118 feet (typical) of ROW.
- **Context Sensitive:** Multimodal accommodations for pedestrians and bicyclists should be maintained or improved and should not preclude the opportunity to extend the shared use path on the north side of SR 414.
- **Access and Level of Service of Existing SR 414 (Maitland Boulevard):** Local access and intersection LOS will be maintained or improved.
- **Access Between Existing SR 414 (Maitland Boulevard) and Proposed SR 414 Expressway Extension:** Locations of slip ramps will be refined during the alignment alternatives analysis.

- **Emergency Management Access:** All elevated facilities propose outside shoulder widths of 12 feet for emergency use.
- **Landscaping/Hardscape Features:** For the Preferred Alternative, landscaping features will be provided throughout the corridor and evaluated in the design phase.

3.3 Initial Typical Section Options

The goal of the typical section option development was to identify viable typical section options to meet the future traffic demand with the least overall impacts. To avoid community and environmental impacts, a variety of options were developed within the existing typical section footprint of 118 feet wide.

As mentioned previously, the SR 414 (Maitland Boulevard) local access lanes would be maintained within the existing ROW. The typical section options for the at-grade SR 414 (Maitland Boulevard) considered including two lanes per direction (consistent with the existing condition) or three lanes per direction (consistent with the No-Build Alternative), depending on the overall capacity needs for the corridor. An at-grade widening of SR 414 (Maitland Boulevard) to six lanes would preclude a four-lane expressway within the median (at two lanes per direction) or require substantial ROW impacts to meet FDM criteria.

For all the typical section options, the SR 414 (Maitland Boulevard) local access lanes involve reconstruction of the median from rural (with paved shoulders) to urban with proposed Type F curb and gutter or consideration of concrete barrier wall. To accommodate this proposed change and meet current criteria, the design speed was reduced from 55 mph to 45 mph along the at-grade SR 414 (Maitland Boulevard) facility.

Appendix C present the typical section options described in the following subsections. Overall, seven typical section options were considered for the project corridor. Two typical section options were considered for the at-grade SR 414 (Maitland Boulevard), which included the No-Build Alternative. Five typical section options were developed for the SR 414 Elevated Expressway involving local access lanes on SR 414 (Maitland Boulevard).

Each typical section option was evaluated for ability to meet the purpose and need for the project based on preliminary traffic analyses. Appendix D provides an excerpt of the *Project Traffic Analysis Report* summarizing the traffic analyses conducted for the typical section options (CFX 2021e).

3.3.1 Typical Section Option 1: SR 414 (Maitland Boulevard) Existing Condition with Bike Lanes

Option 1 maintains the existing at-grade SR 414 (Maitland Boulevard) facility that typically provides four lanes (two per direction). In this typical section, the existing pavement footprint of the four-lane facility is maintained but shifts and restripes the lanes to provide a 7-foot-wide buffered bike lane to meet FDM criteria and proposed Type F curb and gutter in the median. Based on the traffic analysis summarized in Section 3.4 and presented in Appendix D, Option 1 does not meet the purpose and need to provide needed capacity on SR 414 (Maitland Boulevard) nor improve system connectivity between SR 429 and I-4 to meet future traffic needs.

3.3.2 Typical Section Option 2: No-Build Alternative

Option 2 involves at-grade widening of SR 414 (Maitland Boulevard) to six lanes (at-grade with no elevated expressway) from US 441 to SR 434 as noted in MetroPlan Orlando's 2045 Metropolitan

Transportation Plan Cost Feasible Plan. While this alternative is no longer programmed, it provides a basis for comparison to other alternatives. An illustrative typical section depicting inside widening that maintains 4-foot-wide bike lanes and proposed Type F curb and gutter in the median is shown. Based on the traffic analysis summarized in Section 3.4 and presented in Appendix D, Option 2 does not meet the purpose and need to provide needed capacity on SR 414 nor improve system connectivity between SR 429 and I-4 to meet future traffic needs.

3.3.3 Typical Section Option 3: SR 414 Elevated Expressway (One Lane per Direction)

Option 3 provides an elevated expressway with two 12-foot-wide express lanes (one per direction) separated by a median barrier wall. The typical section will include 12-foot-wide outside shoulders and 6-foot-wide inside shoulders. The at-grade SR 414 (Maitland Boulevard) facility provides four lanes (two per direction), 7-foot-wide buffered bike lane and proposed Type F curb and gutter in the median. As shown in Appendix D, the build traffic volumes achievable for this typical section are approximately 94,200 vehicles per day as compared to the 112,100 vpd anticipated for Option 4, 5 and 6. This option does not meet the purpose and need to provide needed capacity on SR 414.

3.3.4 Typical Section Option 4: SR 414 Elevated Expressway (Two Lanes per Direction)

Option 4 provides the elevated expressway with four 12-foot-wide express lanes (two per direction) separated by a median barrier wall. The typical section will include 12-foot-wide outside shoulders and 6-foot-wide inside shoulders. The at-grade SR 414 (Maitland Boulevard) facility provides four lanes (two per direction), 7-foot-wide buffered bike lane and proposed Type F curb and gutter in the median. Based on the traffic analysis summarized in Section 3.4 and presented in Appendix D, Option 4 meets the purpose and need to provide needed capacity and improve system connectivity.

3.3.5 Typical Section Option 5: SR 414 Elevated Expressway (Two Reversible Lanes)

Option 5 provides the elevated expressway with two 12-foot-wide express lanes that are reversible (two lanes total). Reversible access requires advance signing and access equipment. Based on the traffic analysis summarized in Section 3.4 and presented in Appendix D, Option 5 does not meet the purpose and need to provide needed capacity.

3.3.6 Typical Section Option 6: SR 414 Elevated Expressway Convertible Express Lanes (Three Lanes with Movable Barrier)

Option 6 provides three 12-foot-wide express lanes separated by a movable barrier wall. In morning peak traffic, there are two lanes eastbound and one lane westbound. In afternoon peak traffic, there is one lane eastbound and two lanes westbound. The movable barrier would be shifted approximately 12 feet via specialty vehicle twice daily. This option is both reversible and convertible and requires advance signing, access equipment, specialty barrier and specialty vehicle with onsite or nearby storage. Based on the traffic analysis summarized in Section 3.4 and presented in Appendix D, Option 6 meets the purpose and need to provide needed capacity and improve system connectivity.

3.3.7 Typical Section 7: SR 414 Elevated Expressway (One Lane per Direction) with Three At-grade SR 414 (Maitland Boulevard) Lanes per Direction

Option 7 provides the elevated expressway with two 12-foot-wide express lanes (one per direction) separated by a median barrier wall. The typical section will include 12-foot-wide outside shoulders and 6-foot-wide inside shoulders. Additionally, Option 7 includes widening the existing at-grade SR 414 (Maitland Boulevard) to six lanes (three per direction). An asymmetrical pier would be needed to accommodate both the elevated expressway structure and allow left-turn lanes. Providing six lanes along SR 414 (Maitland Boulevard) while accommodating the elevated expressway piers in the median (at-grade) is only achievable within the existing ROW by removing the existing undesignated bicycle lanes, which does not meet FDM criteria. Based on the traffic analysis summarized in Section 3.4 and presented in Appendix D, Option 7 does not improve traffic operations to the degree Options 4 or 6 do and serves less overall projected traffic volumes (105,000 vpd versus 112,100 vpd).

3.4 Typical Section Evaluation

Each typical section option was qualitatively evaluated, and each option was rated against the following desirable criteria:

- Minimizes cost per mile – estimated costs for the typical section were developed
  - High = Lower cost compared to other alternatives
  - Low = Higher cost compared to other alternatives
- Improves corridor capacity – preliminary modeling was performed to provide comparative daily volume/capacity ratio in the Design Year
  - High = meets capacity demand
  - Low = does not meet capacity demand
- Minimize maintenance lifecycle costs – some options require additional equipment and annual maintenance costs
  - High = inexpensive maintenance
  - Low = expensive maintenance

Table 3-1 describes each typical section and summarizes the results of the qualitative analysis of each.

Table 3-1. Qualitative Evaluation of Typical Section Options

Typical Section Option	Number of Lanes per Direction (Expressway/ Maitland Boulevard)	Improves Corridor Capacity (Volume/Capacity Ratio)	Minimizes Cost per Mile	Minimizes Maintenance Lifecycle Costs	Viable Option
1 – Existing Condition with Bike Lanes	0/2	Low (1.50)	High	High	No, does not meet purpose and need
2 – No-Build Alternative	0/3	Low (1.25)	High	High	No, does not meet purpose and need
3 – Elevated Express Lanes (One Lane per Direction)	1/2	Low (1.20)	Medium	High	No, does not meet purpose and need

Table 3-1. Qualitative Evaluation of Typical Section Options

Typical Section Option	Number of Lanes per Direction (Expressway/ Maitland Boulevard)	Improves Corridor Capacity (Volume/Capacity Ratio)	Minimizes Cost per Mile	Minimizes Maintenance Lifecycle Costs	Viable Option
4 – Elevated Express Lanes (Two Lanes per Direction)	2/2	High (0.95)	Low	High	Yes
5 – Elevated Express Lanes (Two Reversible Lanes)	2R/2	Low (1.13)	Medium	Medium	No, does not meet purpose and need
6 – Elevated Convertible Express Lanes (Three Lanes with Movable Barrier)	3C/2	Low (1.14)	Low	Low	Yes
7 – Elevated Express Lanes (One Lane per Direction) and Three At-grade Lanes per Direction	1/3	Medium (1.06)	Medium	High	No, does not provide improved traffic operations compared to Option 4 or 6

3.5 Viable Typical Section Options

The qualitative evaluation in Table 3-1 results in two viable typical section options for the SR 414 Expressway Extension: Option 4 and Option 6. Additional comparison between both options results in the following considerations:

- **Bridge Construction Costs**: Preliminary construction costs developed for this typical section comparison are estimated at $185 per square foot for Option 4 assuming the elevated viaduct with I-girder and inverted tee caps. Option 4 is 89 feet wide; Option 6 is 77 feet wide and therefore is less expensive than Option 4.
- **Capacity**: Both alternatives are projected to meet the traffic demand. However, Option 4 provides greater capacity, better volume-to-capacity ratios, safer incident management access and the advantage of a continuous passing lane for slower/faster vehicles as compared to Option 6.
- **Preliminary Alignment Analysis:** The widest expressway typical section (Option 4) can transition within the ROW to existing conditions at both ends of the project. Therefore, both typical section options are constructible within the existing ROW. Refer to Appendix E for exhibits of preliminary alignment transitions that were evaluated to confirm the feasibility of both options.
- **Additional Costs**: Research on implementation of a movable barrier as required for Option 6 indicates it can be implemented successfully. However, the capital and operating costs are significant. Refer to sample specifications in Appendix F (p. 4) and relevant white paper, “Improving the Cost-Effectiveness of Urban Freeways” in Appendix G (Table 6 on p. 13).

- Capital Costs: movable barrier such as 18-inch-diameter concrete reactive tension system, barrier transfer machine (two may be required), gates, crossovers, advance signage and onsite location for transfer machine parking
- Operating Costs: repair to barrier and transfer machine, driver training for twice daily transfer

In summary, the higher cost of bridge construction with Option 4 is offset by the significant capital and operating costs for Option 6 associated with the movable barrier wall. Option 4 also provides better traffic operations and safer incident management. Therefore, the recommended typical section for the SR 414 Expressway Extension is Option 4.

3.6 Typical Section Refinements

Option 4 was further refined to develop the Build Alternative as documented in the *Preliminary Engineering Report* (CFX 2021d). Refinements of the typical section and alternative alignment analyses considered the following:

- Opportunity for Landscaping/Hardscape Features
- Minimizes potential impacts to:
  - adjacent parcels – horizontal alignment will maintain or improve offset to existing residential properties
  - environmental resources including wetlands and contamination sites
  - local traffic during construction
- Express lanes shoulder width:
  - The horizontal stopping sight distance for the curve over Bear Lake Road requires additional width to meet 50-mph criteria.
  - Compatibility with Left-Turn Lanes: To demonstrate local access compatibility, a refined Typical Section 4A is presented to detail the accommodation of intermittent left-turn lanes along the at-grade corridor (refer to Appendix H). Both alternatives will accommodate left-turn lanes.
  - A refined Typical Section 4B depicts the superelevated section and swaps the westbound inside/outside shoulder widths to meet horizontal stopping sight distance criteria (refer to Appendix H).

These two refined typical sections depict the recommended typical section at critical locations. The potential to implement barrier-mounted noise walls on the expressway viaduct (as needed for noise mitigation) is feasible for Option 4.

The method of median pier protection was coordinated between CFX and FDOT as part of this PD&E Study. While the exhibits presented herein predominantly depict concrete barrier wall in the median alternative, implementation of guardrail or curb-and-gutter barrier is viable. Each barrier offers varying initial construction costs, maintenance costs, median usability and expressway profile impacts resulting from minimum vertical clearance.

3.7 Recommendation

Based on the analysis provided, the recommended typical section for the Preferred Alternative is Option 4 that includes:

- SR 414 (Maitland Boulevard): Maintains the pavement footprint of the four-lane facility but shifts and restripes the lanes to provide a 7-foot-wide buffered bike lane; includes Type F curb and gutter in the median with split concrete barrier wall near the pier.
- SR 414 Elevated Expressway: Constructs a four-lane, grade-separated facility in the existing median with four 12-foot-wide express lanes (two per direction) separated by median barrier.

Using these recommendations, the alignment alternatives were developed for the corridor to consider connections between existing facilities and include operational improvements at intersections. More detail on the Preferred Alternative is provided in the *Preliminary Engineering Report* (CFX 2021d).

4. References

American Association of State Highway and Transportation Officials (AASHTO). 2011a. *A Policy on Geometric Design of Highways and Streets*. 6th Edition. November 1.

American Association of State Highway and Transportation Officials (AASHTO). 2011b. *ROADSIDE DESIGN GUIDE*. 4th Edition. November 1.

Central Florida Expressway Authority (CFX). 2019. *Final Technical Memo SR 414 (Maitland Blvd.) Reversible Express Lanes Schematic*. Prepared by Dewberry. July.

Central Florida Expressway Authority (CFX). 2021a. *Signing and Pavement Marking Details*. CENTRAL FLORIDA EXPRESSWAY AUTHORITY. February. https://www.cfxway.com/wp-content/uploads/2021/04/2021-CFX-SPM-Details.pdf

Central Florida Expressway Authority (CFX). 2021b. *2021 CFX DESIGN GUIDELINES*. CENTRAL FLORIDA EXPRESSWAY AUTHORITY. Orlando, Florida. March.

Central Florida Expressway Authority (CFX). 2021c. *CFX ITS DESIGN STANDARDS*. CENTRAL FLORIDA EXPRESSWAY AUTHORITY. Orlando, Florida. March.

Central Florida Expressway Authority (CFX). 2021d. *Preliminary Engineering Report*. Prepared for Central Florida Expressway Authority. Submitted by: Jacobs Engineering Group Inc. March.

Central Florida Expressway Authority (CFX). 2021e. *Project Traffic Analysis Report*. Prepared by CDM Smith, Inc. February.

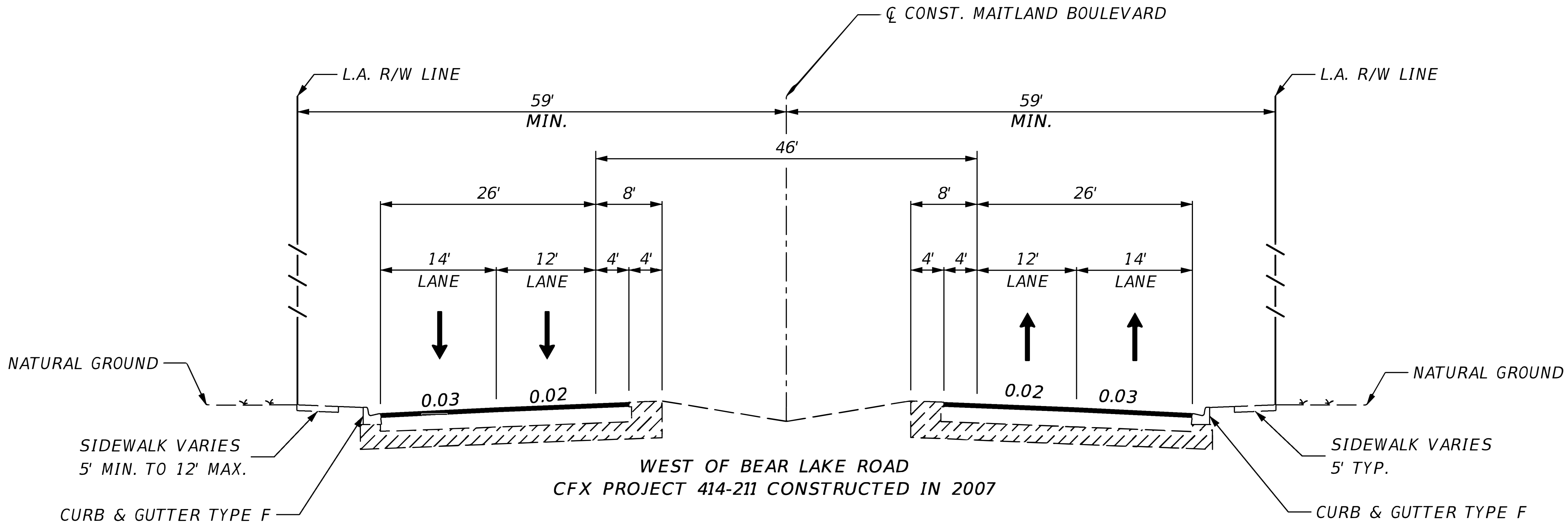
Florida Department of Transportation (FDOT). 2021a. *2021 FDOT Design Manual*. Topic #625-000-002. August 1. https://www.fdot.gov/roadway/fdm/

Florida Department of Transportation (FDOT). 2021b. "Standard Plans for Road and Bridge Construction (FY 2021-22)." Accessed August. https://www.fdot.gov/design/standardplans/sprbc.shtm

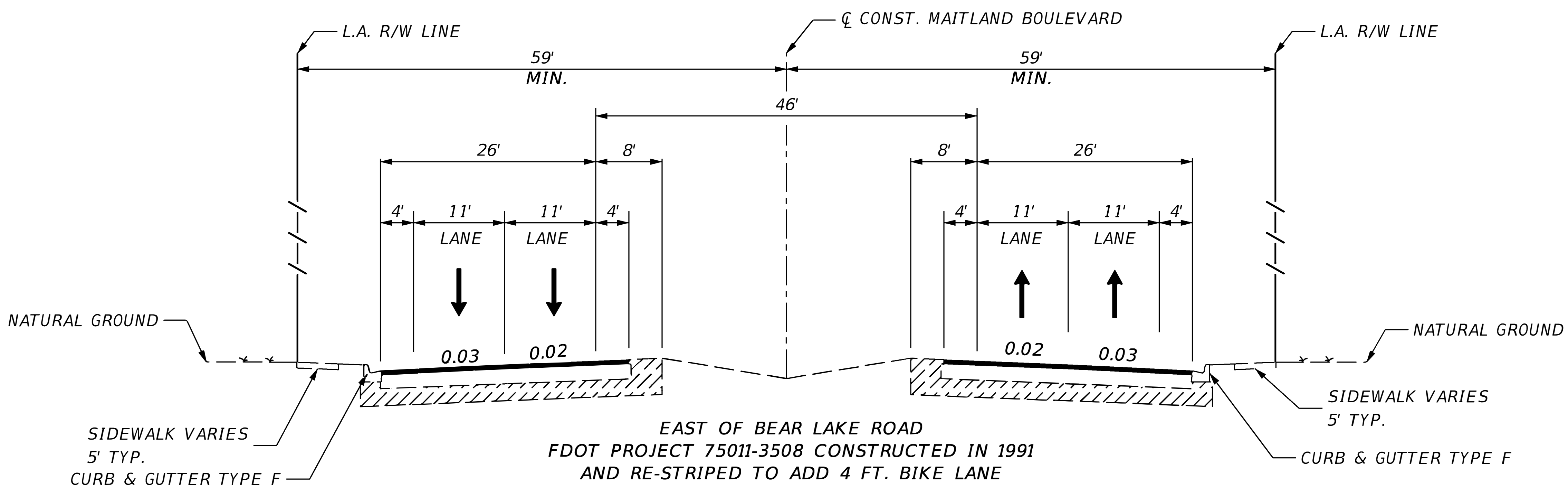
Florida Department of Transportation (FDOT). 2021c. *Drainage Manual, Topic No. 625-040-002*. January. https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/drainage/files/drainagemanual2021.pdf

Transportation Research Board. 2016. *NCHRP Report 835: Guidelines for Implementing Managed Lanes*. September 30.

Appendix A
Existing Typical Sections



WEST OF BEAR LAKE ROAD
CFX PROJECT 414-211 CONSTRUCTED IN 2007



EAST OF BEAR LAKE ROAD
FDOT PROJECT 75011-3508 CONSTRUCTED IN 1991
AND RE-STRIPED TO ADD 4 FT. BIKE LANE

TYPICAL SECTIONS OPTION 1
MAITLAND BOULEVARD EXISTING CONDITIONS
4-LANE SUBURBAN

DESIGN SPEED = 45 MPH (TYP.)
EXCEPT FOR HORIZONTAL CURVE
OVER US 441 = 55 MPH

PRELIMINARY - SUBJECT TO CHANGE	ENGINEER OF RECORD: KRYSTAL H. BURNS, P.E. P.E. LICENSE NO. 60883 JACOBS ENGINEERING GROUP INC. 200 S. ORANGE AVENUE, STE 900 ORLANDO, FL 32801; PHONE (407) 903-5001 CERTIFICATE OF AUTHORIZATION No. 000072	SR 414 MAITLAND BLVD. EXPRESSWAY EXTENSION US 441 TO SR 434 ROAD NO.: SR 414 PROJECT NO.: 414-227	CENTRAL FLORIDA EXPRESSWAY AUTHORITY	TYPICAL SECTIONS DRAFT	SHEET NO.

Appendix B
Design Criteria

Table 4-1. SR 414 (Maitland Boulevard) (Urban) Design Criteria

Roadway Classification: Context Classification:	Urban Principal Arterial Other C3R-Suburban Residential and C3C-Suburban Commercial	Source		Comments
		FDOT[a]	CFX[b] AASHTO[c]	
Design Traffic				
Proposed Design Speed	45 mph (Existing Posted Speed = 50 - 55 mph therefore 50 mph criteria is also provided in tables)	-	-	Consistent with As Built Design Speed (Field Review)
Access Class	3	X		Straight-Line Diagram 75011002 & 77002000
Allowable Design Speed	35 - 55 mph	X		FDM Ch. 201, Table 201.5.1 Note: As-Built Construction Plans at 45 mph
	min. 30 mph for Major Urban Arterial		X	AASHTO pg. 2-58 (FDM Ch. 122, Table 122.5.1)
Design Vehicle	WB-62FL/ WB-67	X		FDM Ch. 201, Section 201.6.2
Design Year	2045		X	Scope of Services
Lane, Median & Border Widths				
Travel Lanes & Aux. Lanes	12 ft @ 50 mph 11 ft @ 45 mph	X		FDM Ch. 210, Table 210.2.1
	10 ft - Urban Arterial		X	AASHTO pg. 7-29 (FDM Ch. 122, Table 122.5.2)
Bicycle Lane	7 ft buffered lane (min. 4 ft) 7 ft buffered keyhole (min. 5 ft)	X		FDM Ch. 223, Section 223.2.1.1 and Section 223.2.1.3
Lane Configuration	4 (2/direction)		X	Scope of Services
Cross Slope	-0.02, -0.02, -0.03 Turn Lane, Bike Lane, match adj. thru lane	X		FDM Ch. 210, Figure 210.2.1
	Minimum 0.015		X	AASHTO pg. 7-29 (FDM Table 122.5.11)
Cross Slope - Bridge Section	-0.02 (no slope break)	X		FDM Ch. 260, Section 260.4
Max Lane Rollover	4.0% between adjacent through lanes; 5.0% between through lane & Aux. lane	X		FDM Ch. 210, Section 210.2.4 & Table 210.2.2
Shared Use Path	12 ft (Std.), Minimum 10 ft	X		FDM Ch. 224, Table 224.4
Median Width	30 ft @ 50 mph 22 ft @ 45 mph (19.5 ft @ 45 mph w/ constrained R/W) min. 30 ft to provide U-turns	X		FDM Ch. 210, Table 210.3.1 & FDM Ch. 212, Table 212.9.1
Border Width	29 ft @ 50 mph 14 ft @ 45 mph	X		FDM Ch. 210, Table 210.7.1
Sidewalk and Back slope				
Sidewalk Width	6 ft (up to 8 ft when demand is demonstrated)	X		FDM Ch. 222, Table 222.1.1
	min. 5 ft, or passing sections required		X	AASHTO pg. 4-56
Drop-off Hazard for Pedestrians	Protection required if conditions meet Case 1 or Case 2 within 2 ft of the path edge	X		FDM Ch. 222, Figure 222.4.1
Front and Back slope (Curbed)	1:2 or to suit property owner. Not flatter than 1:6.	X		FDM Ch. 215, Table 215.2.3
Drop-off Hazard ($D_s \leq$ 45mph)	6 ft or greater with a slope steeper than 1:3 within 22 ft of the travel way requires protection	X		FDM Ch. 215, Figure 215.3.3
Roadway Shoulder Widths				
Median/Left Shldr (not curbed)	8 ft Total/ 0 ft Paved Pave 4-ft in sag V.C; low side of SE	X		FDM Ch. 210, Table 210.4.1
	none - Urban Arterial 4 ft - Rural Arterial, 4-lane divided		X	AASHTO pg. 4-10, pg. 7-13 (FDM Table 122.5.3)
Median/Left Shldr adjacent to Barrier Wall	6 ft min. @ 50 mph 10 ft adj to continuous barrier 2.5 ft @ Curbed 45 mph	X		FDM Ch. 260, Figure 260.1.1 FDM Ch. 210, Table 210.4.1 FDM Ch. 260, Figure 260.1.3
Outside Cross Slope	-0.06%	X		FDM Ch. 210, Section 210.4.1
Median/Left Cross Slope	-0.05%	X		FDM Ch. 210, Section 210.4.1
Bridge Shoulder Widths				
Outside	4.0 ft (Existing median sep.) 2.5 ft min.; 7' with bike lane; 8 ft for bridges >500 ft @ 45 mph	X		FDM Ch. 260, Table 260.9.1 FDM Ch. 260, Figure 260.1.4
Median/Left	1.5 ft (Existing median sep.) 2.5 ft min. (Proposed median barrier); 6 ft for 2-lane bridges >500 ft @ 45 mph	X		FDM Ch. 260, Table 260.9.1 FDM Ch. 260, Figure 260.1.4
Roadside Slopes				
Front Slope	Height of Fill - Rate 0-5 ft - 1:6 5-10 ft - 1:6 to CZ, then 1:4 10-20 ft - 1:6 to CZ, then 1:3 > 20 ft - 1:2 with guardrail	X		FDM Ch. 215, Table 215.2.3
Back Slope	1:4 or 1:3 with standard width trapezoidal ditch and 1:6 front slope.	X		FDM Ch. 215, Table 215.2.3
Transverse Slope	1:10 (freeway) 1:4 (others)	X		FDM Ch. 215, Table 215.2.3

Table 4-1. SR 414 (Maitland Boulevard) (Urban) Design Criteria

Roadway Classification: Context Classification:	Urban Principal Arterial Other C3R-Suburban Residential and C3C-Suburban Commercial	Source		Comments
		FDOT[a]	CFX[b] AASHTO[c]	
Grades				
Max Grade (Flat Terrain)	6.0% @ 45-50 mph	X	X	FDM Ch. 210, Table 210.10.1 AASHTO pg. 7-29
Max Change Grade Change w/o Vertical Curve	0.60% @ 50 mph 0.70% @ 45 mph	X		FDM Ch. 210, Table 210.10.2
Req'd Base Clearance	3 ft	X		FDM Ch. 210, Sect 210.10.3
Minimum Distance between VPI's	250 ft	X		FDM Ch. 210, Sect 210.10.1.1
Minimum Grade	0.30%	X		FDM Ch. 210, Sect 210.10.1.1
Sight Distance				
Min. Stopping Sight Distance	425 @ 50 mph 360 @ 45 mph		X	AASHTO Table 3-1, pg. 3-4 (FDM Table 122.5.7)
Decision Sight Distance (B-Stop on Urban, E-Direction change on Urban)	910 ft, 1,030 ft @ 50 mph 800 ft, 930 ft @ 45 mph		X	AASHTO Table 3-3, pg. 3-7
Horizontal Curves				
Max Deflection w/o Horizontal Curve	0° 45' 00"	X		FDM Ch. 210, Section 210.8.1
Max Deflection Through Intersection	3° 00' @ 45 mph	X		FDM Ch. 212, Table 212.7.1
Max Superelevation (emax)	e max 10% @ 50 mph e max 5% @ 45 mph	X		FDM Ch. 210, Table 210.9.1
Transitions	80/20 transition split (50/50 min)	X		FDM Ch. 210, Section 210.9.1
Slope Rate	1:150 @ 45 mph (emax=0.05) 1:200 @ 50 mph (emax=0.10; 2-Lane)	X		FDM Ch. 210, Table 210.9.3
Length of Curve	Desired 750 ft @ 50 mph 675 ft @ 45 mph not less than 400ft	X		FDM Ch. 210, Table 210.8.1
Compound Curve Ratio	1.5:1 Open Highways ; 2:1 Turning Roadways	X		FDM Ch. 210, Section 210.8.2.2
Max Curvature	10° @ 50 mph (e max 10%) 8° 15' @ 45 mph (e max 5%)	X		FDM Ch. 210, Table 210.9.1 and Table 210.9.2
Max Curvature for NC (0.02)	R= 8,337 ft @ 50 mph R= 2,083 ft @ 45 mph	X		FDM Ch. 210, Table 210.9.1 and Table 210.9.2
Lane Drop Taper	L = WS @ >/= 45 mph	X		FDM Ch. 210, Section 210.2.5
Vertical Curves				
K Crest	136 @ 50 mph 98 @ 45 mph	X	X	FDM Ch. 210, Table 210.10.3 (FDM Table 122.5.8)
Min Length Crest Curve	300 ft @ 50 mph 135 ft @ 45 mph	X		FDM Ch. 210, Table 210.10.4
K Sag	96 @ 50 mph 79 @ 45 mph	X	X	FDM Ch. 210, Table 210.10.3 (FDM Table 122.5.8)
Min Length Sag Curve	200 ft @ 50 mph 135 ft @ 45 mph	X		FDM Ch. 210, Table 210.10.4
Clear Zone				
Travel Lanes	24 ft	X		FDM Ch. 215, Table 215.2.1
Auxiliary Lanes	14 ft	X		FDM Ch. 215, Table 215.2.1
Vertical Clearance				
Roadway over Roadway	16'-6"	X	X	FDM Ch. 260, Table 260.6.1 AASHTO pg. 7-38, 10-21
Overhead Sign Structure	17'-6" (new signs) 17'-0" (existing)	X	X	FDM Ch. 210, Section 210.10.3 AASHTO pg. 7-7, 38, 8-4
Overhead DMS	19'-6" (new signs) 19'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
New Signal Span Wire/Mast Arm	17'-6" (new signs) 17'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
Drainage	Min. 2 ft between the design flood stage and the lower members of the bridge	X		FDM Ch. 260, Section 260.8.1

Table 4-1. SR 414 (Maitland Boulevard) (Urban) Design Criteria

Roadway Classification: Context Classification:	Urban Principal Arterial Other C3R-Suburban Residential and C3C-Suburban Commercial	Source		Comments
		FDOT[a]	CFX[b] AASHTO[c]	
Lateral Offsets				
Conventional Lighting	20 ft from Travel Lane @ 50 mph 4 ft from face of curb @ 45 mph	X		FDM Ch. 215, Table 215.2.2
ITS Pole and Above Ground Fixed Objects	Outside Clear Zone @ 50 mph 4 ft from face of curb @ 45 mph	X		FDM Ch. 215, Table 215.2.2
Traffic Control Overhead Sign Supports	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2
Aboveground Utilities - Existing	Not required to be relocated unless the edge of traveled way is being moved closer; or they have been hit 3 times in 5 years	X		FDM Ch. 215, Table 215.2.2
Aboveground Utilities - New or Relocated	Outside Clear Zone @ 50 mph 4.0 feet @ 45 mph	X		FDM Ch. 215, Table 215.2.2
Canal Hazards	Not less than 60 ft from edge of travel @ 50 mph Not less than 40 ft from edge of travel @ 45 mph	X		FDM Ch. 215, Section 215.3.2
Bridge Piers and Abutments	Outside Clear Zone @ 50 mph; The greater of the following @ 45 mph: 16 ft from edge of travel (nearest lane); 4 ft from face of curb (if outside aux): 6 ft from edge of aux lane (if median aux)	X		FDM Ch. 215, Table 215.2.2

[a] FDOT Design Manual (2021)

[b] Central Florida Expressway Authority Design Guidelines (2021)

[c] AASHTO Greenbook (2011)

Table 4-2. SR 414 Expressway Extension Design Criteria

Roadway Classification: Context Classification:	Limited Access Express Lanes C3R-Suburban Residential and C3C-Suburban Commercial	Source		Comments
		FDOT[a]	CFX[b] AASHTO[c] FHWA[d]	
Design Traffic				
Design Speed - Express Lanes	50 mph	X		Scope of Services
Design Vehicle	WB-62FL/ WB-67	X		FDM Ch. 201, Section 201.6.2
Design Year	2045		X	Scope of Services
Lane, Median & Border Widths				
Express Lanes	12 ft	X		FDM Ch. 211, Section 211.2
Cross Slope	-0.02, -0.02	X		FDM Ch. 211, Figure 211.2.1
Cross Slope - Bridge Section	-0.02 uniform slope; two-way traffic may be crowned	X		FDM Ch. 260, Section 260.4
Max Breakover at Terminals D_s >35mph	5.00%	X		FDM Ch. 211, Table 211.2.2
Min. Median Width	26 ft with barrier	X		FDM Ch. 211, Table 211.3.1
	4 - 6 ft, constrained Continuous viaduct should be min. shldr + barrier		X	AASHTO, pg. 7-14, pg. 8-16
Border Width	Min. 10 ft from back of roadside barrier for maintenance	X		FDM Ch. 211, Section 211.6.1
Express Lane Shoulder Widths				
1-lane Outside Shldr	12 ft Total/ 10 ft Paved (apply Travel Lane criteria)	X		FDM Ch. 211, Table 211.4.1
1-lane Median/Left Shldr	8 ft Total/ 4 ft Paved (apply Travel Lane criteria)	X		FDM Ch. 211, Table 211.4.1
2-lane Outside Shldr	14 ft Total/ 12 ft Paved		X	CFX Ch. 211, Section 211.4
2-lane Median/Left Shldr	12 ft Total/ 12 ft Paved		X	CFX Ch. 211, Section 211.4
Outside Cross Slope	-0.06	X		FDM Ch. 211, Section 211.4.2
Median/Left Cross Slope	-0.05	X		FDM Ch. 211, Section 211.4.2
Bridge Shoulder Widths				
1-lane	6 ft Inside/ 12 ft outside	X	X	FDM Ch. 260, Figure 260.1.1 CFX Ch. 211, Section 211.4
2-lane	6 ft Inside (Min.)/ 12 ft outside		X	CFX Ch. 260, Figure 260.1.1 CFX Ch. 211, Section 211.4
Roadside Slopes				
Front Slope	1:6 for fill to 5' 1:6 to clear zone & 1:4 for fills 5' to 10' 1:6 to clear zone & 1:3 for fills 10' to 20' 1:3 with guardrail for fills over 20' and must include shoulder gutter		X	CFX Section 306.5, pg. 3-14
Back Slope	1:4 or 1:3 with standard width trapezoidal ditch and 1:6 front slope.	X		FDM Ch. 215, Table 215.2.3
Transverse Slope	1:10 (freeway) 1:4 (others)	X		FDM Ch. 215, Table 215.2.3
Grades				
Max Grade (Flat Terrain)	4.00%	X		FDM Ch. 211, Table 211.9.1
Max Change Grade Change w/o Vertical Curve	0.60%	X		FDM Ch. 210, Table 210.10.2
Minimum Distance between VPI's	5 x Design Speed = 250 ft		X	CFX Ch. 211, Section 211.9.1
Sight Distance				
Min. Stopping Sight Distance (for Expressways)	425 ft	X	X	AASHTO Table 3-1, pg. 3-4 & FDM Ch. 211, Table 211.10.2
Decision Sight Distance (B-Stop on Urban, E-Direction change on Urban)	910 ft, 1030 ft		X	AASHTO Table 3-3, pg. 3-8

Table 4-2. SR 414 Expressway Extension Design Criteria

Roadway Classification: Context Classification:	Limited Access Express Lanes C3R-Suburban Residential and C3C-Suburban Commercial	Source		Comments
		FDOT[a]	CFX[b] AASHTO[c] FHWA[d]	
Horizontal Curves				
Max Deflection w/o Horizontal Curve	0° 45' 00"	X		FDM Ch. 211, Section 211.7.1
Max Superelevation (emax)	0.10	X		FDM Ch. 210, Section 210.9
Transitions	80/20 transition split (50/50 min)	X		FDM Ch. 210, Section 210.9.1
Slope Rate	1:200	X		FDM Ch. 210, Table 210.9.3
Length of Curve	1,500 ft, not less than 750 ft @50 mph	X		FDM Ch. 211, Table 211.7.1
Compound Curve Ratio	1.5:1 Open Highways ; 2:1 Turning Roadways	X		FDM Ch. 210, Section 210.8.2.2
Max Curvature	8° 15' (e max 10%)	X		FDM Ch. 210, Table 210.9.1 and Table 210.10.1
Max Curvature for NC (0.02)	R= 8,337 ft	X		FDM Ch. 210, Table 210.9.1 and Table 210.10.1
Lane Drop Taper	L = WS @ >/= 45 mph	X		FDM Ch. 210, Section 210.2.5
Vertical Curves				
K Crest	185 (Int.), 136 (Exp.)	X	X	FDM Ch. 211, Table 211.9.2 CFX requires Interstate criteria unless approved by CFX Chief of Infrastructure
	84		X	AASHTO Table 3-34, 3-36, 6-3 (FDM Ch. 122, Table 122.5.8)
Min Length Crest Curve	1,000 ft 1,800 (within Interchanges)	X		FDM Ch. 211, Table 211.9.3
	Reduction in vertical curve length can be approved by CFX Chief of Infrastructure.		X	CFX Ch. 211 Footnote Table 211.9.3
K Sag	115 (Int.), 96 (Exp.)	X	X	FDM Ch. 211, Table 211.9.2 CFX requires Interstate criteria unless approved by CFX Chief of Infrastructure
	96		X	AASHTO Table 6-3, pg. 6-4 (FDM Ch. 122, Table 122.5.8)
Min Length Sag Curve	800 ft	X		FDM Ch. 211, Table 211.9.3
	Reduction in vertical curve length can be approved by CFX Chief of Infrastructure.		X	CFX Ch. 211 Footnote Table 211.9.3
Clear Zone				
Travel Lanes	24 ft	X		FDM Ch. 215, Table 215.2.1
Auxiliary Lanes	14 ft	X		FDM Ch. 215, Table 215.2.1
Vertical Clearance				
Roadway over Roadway Travel Lanes and Bike Lanes and/or Shoulders	16'-6"	X		FDM Ch. 260, Table 260.6.1
Roadway over Roadway Median Under Bridge	14'-0" Concrete Barrier = 0 ft. setback Guardrail = 5 ft. setback from face of barrier	X		FDM Ch. 260, Figure 260.6.5
Overhead Sign Structure	17'-6" (new signs) 17'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
Overhead DMS	19'-6" (new signs) 19'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
New Signal Span Wire/Mast Arm	17'-6" (new signs) 17'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
Lateral Offsets				
Conventional Lighting	20 ft from Travel Lane	X		FDM Ch. 215, Table 215.2.2
ITS Pole and Above Ground Fixed Objects	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2
Traffic Control Overhead Sign Supports	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2
Aboveground Utilities - Existing	Not required to be relocated unless the edge of traveled way is being moved closer; or they have been hit 3 times in 5 years	X		FDM Ch. 215, Table 215.2.2
Aboveground Utilities - New or Relocated	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2
Canal Hazards	Not less than 60 ft from edge of travel	X		FDM Ch. 215, Section 215.3.2
Bridge Piers and Abutments	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2

[a] FDOT Design Manual (2021)

[b] Central Florida Expressway Authority Design Guidelines (2021)

[c] AASHTO Greenbook (2011)

Table 4-3. Interchange and Slip Ramp Design Criteria

Roadway Classification	Interchange Ramps and Slip Ramps	Source		Comments
		FDOT[a]	CFX[b] AASHTO[c]	
Design Traffic				
Design Speed	50 mph - Directional and Slip Ramps 35 mph - Outer Cloverleaf 30 mph - Loop	X		FDM Ch. 201, Table 201.5.2
Design Vehicle	WB-62FL/ WB-67	X		FDM Ch. 201, Section 201.6.2
Lane & Border Widths				
1-Lane Ramp	15 ft	X		FDM Ch. 211, Section 211.2.1
2-Lane Ramp	12 ft	X		FDM Ch. 211, Section 211.2.1
Cross Slope	-0.02	X		FDM Ch. 211, Figure 211.2.1
Max Breakover at Terminals	5% for D_s >/= 35mph; 6% for Ds < 35mph	X		FDM Ch. 211, Table 211.2.2
Border Width	Min. 10 ft from back of roadside barrier for maintenance	X		FDM Ch. 211, Section 211.6.1
Ramp Shoulder Widths				
	Without Shoulder Gutter			
1-lane Outside Shldr	6 ft Total/ 4 ft Paved	X		FDM Ch. 211, Table 211.4.1
1-lane Median/Left Shldr	6 ft Total/ 2 ft Paved	X		FDM Ch. 211, Table 211.4.1
2-lane Outside Shldr	12 ft Total/ 10 ft Paved (Interstate)	X		FDM Ch. 211, Table 211.4.1
2-lane Median/Left Shldr	8 ft Total/ 4 ft Paved (Interstate)	X		FDM Ch. 211, Table 211.4.1
	Shoulder Cross Slopes			
Outside	-0.06	X		FDM Ch. 211, Section 211.4.2
Median/Left	-0.05	X		FDM Ch. 211, Section 211.4.2
Bridge Shoulder Widths				
Outside	1 Lane Ramp 6 ft 2 Lane Ramp 10 ft	X		FDM Ch. 260, Figure 260.1.1
Median/Left	6 ft	X		FDM Ch. 260, Figure 260.1.1
Roadside Slopes				
Front Slope	1:6 for fill to 5' 1:6 to clear zone & 1:4 for fills 5' to 10' 1:6 to clear zone & 1:3 for fills 10' to 20' 1:3 with guardrail for fills over 20' and must include shoulder gutter		X	CFX Section 306.5, pg. 3-14
Back Slope	1:4 or 1:3 with standard width trapezoidal ditch and 1:6 front slope.	X		FDM Ch. 215, Table 215.2.3
Transverse Slope	1:10 (freeway) 1:4 (others)	X		FDM Ch. 215, Table 215.2.3
Grades				
Max. Grade (Flat Terrain)	5% @ 50 mph 7% @ 30 mph	X		FDM Ch. 211, Table 211.9.1
Max Grade Change Without Vertical Curve	0.6% @ 50 mph 1.0% @ 30 mph	X		FDM Ch. 210, Table 210.10.2
Req'd Base Clearance	3 ft	X		FDM Ch. 210, Section 210.10.3
Sight Distance				
Min. Stopping Sight Distance	425 ft @ 50 mph 200 ft @ 30 mph	X	X	FDM Ch. 211, Table 211.10.2
Decision Sight Distance (B-Stop on Urban, E-Direction change on Urban)	910 ft, 1030 ft @ 50 mph 490 ft, 620 ft @ 30 mph		X	AASHTO Table 3-3, pg. 3-7
Entrance/Exit Ramps				
Ramp Terminals	Entrance - Parallel w/ 300 ft Taper Exit - Taper at 4 deg break		X	CFX Section 211.13
Spacing between terminals	500 ft between EXIT and ENT 1,000 ft between EXIT-EXIT or ENT-ENT		X	AASHTO Figure 10-68
$L_{acceleration}$ (45 mph to 50 mph)	-		X	AASHTO Table 10-3
$L_{deceleration}$ (50 mph to 45 mph)	175 ft		X	AASHTO Table 10-5

Table 4-3. Interchange and Slip Ramp Design Criteria

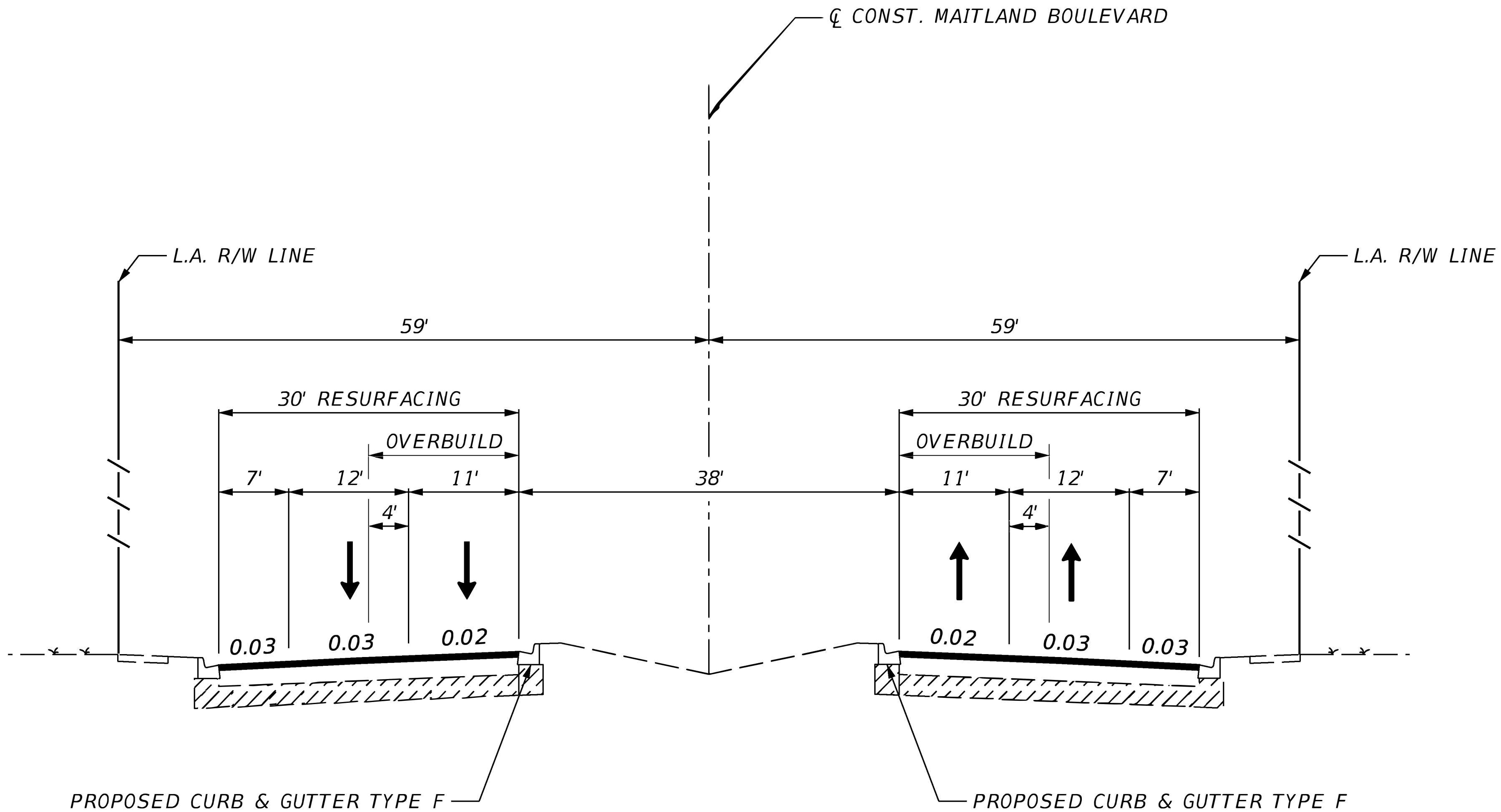
Roadway Classification	Interchange Ramps and Slip Ramps	Source		Comments
		FDOT[a]	CFX[b] AASHTO[c]	
Horizontal Curves				
Max Deflection w/o Horizontal Curve (no Curb and Gutter)	2° 00' 00" @ 30 mph 0° 45' 00" @ 50 mph	X		FDM Ch. 211.7.1
Max Superelevation (emax)	0.10	X		FDM Ch. 210, Section 210.9
Transitions	80/20 transition split (50/50 min)	X		FDM Ch. 210, Section 210.9.1
Slope Rate	1:200 @ 50 mph 1:175 @ 30 mph	X		FDM Ch. 210, Table 210.9.3
Length of Horizontal Curve	750 ft @ 50 mph 675 FT @ 45 mph min. 400 ft	X		FDM Ch. 211, Table 211.7.1
Compound Curve Ratio	1.5:1 Open Highways ; 2:1 Turning Roadways	X		FDM Ch. 210, Section 210.8.2.2
Max Curvature	8° 15' @ 50 mph 24° 45' @ 30 mph	X		FDM Ch. 210, Table 210.9.1 and Table 210.10.1
Max Curvature for NC (0.02)	R= 8,337 ft @ 50 mph R= 3,349 ft @ 30 mph	X		FDM Ch. 210, Table 210.9.1 and Table 210.10.1
Vertical Curves				
K Crest	136 @ 50 mph 31 @ 30 mph	X		FDM Ch. 211, Table 211.9.2
Min Length Crest Curve	300 ft @ 50 mph 90 ft @ 30 mph	X		FDM Ch. 211, Table 211.9.3
K Sag	96 @ 50 mph 37 @ 30 mph	X		FDM Ch. 211, Table 211.9.2
Min Length Sag Curve	200 ft @ 50 mph 90 ft @ 30 mph	X		FDM Ch. 211, Table 211.9.3
Clear Zone				
Multilanes	24ft @ 50mph 12ft @ 30 mph	X		FDM Ch. 215, Table 215.2.1
Single lane	14 ft @ 50 mph 10 ft @ 30 mph	X		FDM Ch. 215, Table 215.2.1
Vertical Clearance				
Roadway over Roadway	16'-6"	X		FDM Ch. 260, Table 260.6.1
Overhead Sign Structure	17'-6" (new signs) 17'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
Overhead DMS	19'-6" (new signs) 19'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
New Signal Span Wire/Mast Arm	17'-6" (new signs) 17'-0" (existing)	X		FDM Ch. 210, Section 210.10.3
Drainage	Min. 2 ft between the design flood stage and the lower members of the bridge	X		FDM Ch. 260, Section 260.8.1
Lateral Offsets				
Conventional Lighting	20 ft from Travel Lane, or Clear Zone width whichever is less	X		FDM Ch. 215, Table 215.2.2
ITS Pole and Above Ground Fixed Objects	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2
Traffic Control Overhead Sign Supports	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2
Aboveground Utilities - Existing	Not required to be relocated unless the edge of traveled way is being moved closer; or they have been hit 3 times in 5 years	X		FDM Ch. 215, Table 215.2.2
Aboveground Utilities - New or Relocated	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2
Canal Hazards	Not less than 60 ft from edge of travel	X		FDM Ch. 215, Section 215.3.2
Bridge Piers and Abutments	Outside Clear Zone	X		FDM Ch. 215, Table 215.2.2

[a] FDOT Design Manual (2021)

[b] Central Florida Expressway Authority Design Guidelines (2021)

[c] AASHTO Greenbook (2011)

Appendix C
Initial Typical Sections



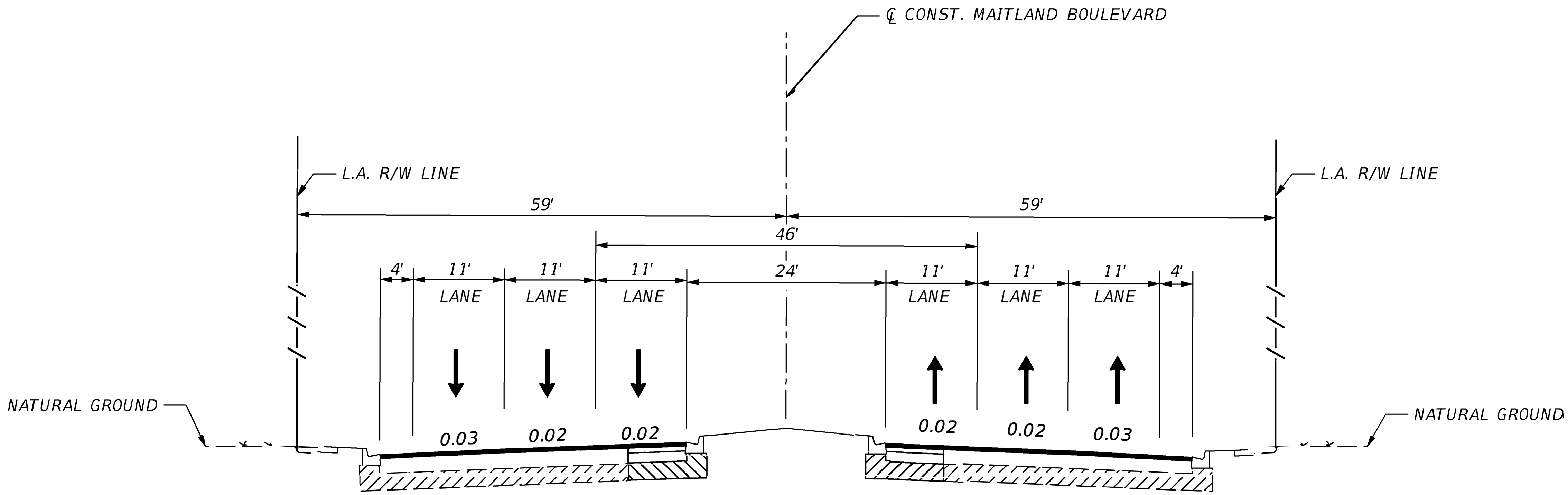
TYPICAL SECTION: OPTION 1

MAITLAND BOULEVARD OVERBUILD AND RESTRIPE

4-LANE URBAN

DESIGN SPEED:
MAITLAND BLVD = 45 MPH

PRELIMINARY - SUBJECT TO CHANGE	ENGINEER OF RECORD: KRYSTAL H. BURNS, P.E. P.E. LICENSE NO. 60883 JACOBS ENGINEERING GROUP INC. 200 S. ORANGE AVENUE, STE 900 ORLANDO, FL 32801; PHONE (407) 903-5001 CERTIFICATE OF AUTHORIZATION No. 000072	SR 414 MAITLAND BLVD. EXPRESSWAY EXTENSION US 441 TO SR 434 ROAD NO.: SR 414 PROJECT NO.: 414-227	CENTRAL FLORIDA EXPRESSWAY AUTHORITY	TYPICAL SECTIONS DRAFT	SHEET NO.



TYPICAL SECTION - OPTION 2

MAITLAND BOULEVARD INSIDE WIDENING (NO-BUILD)

NO ELEVATED EXPRESSWAY

DESIGN SPEED:
MAITLAND BLVD = 45 MPH

PRELIMINARY - SUBJECT TO CHANGE

ENGINEER OF RECORD: KRYSTAL H. BURNS, P.E.
P.E. LICENSE NO. 60883

JACOBS ENGINEERING GROUP INC.
200 S. ORANGE AVENUE, STE 900
ORLANDO, FL 32801; PHONE (407) 903-5001
CERTIFICATE OF AUTHORIZATION No. 000072

SR 414 MAITLAND BLVD.
EXPRESSWAY EXTENSION
US 441 TO SR 434

ROAD NO.	PROJECT NO.
SR 414	414-227

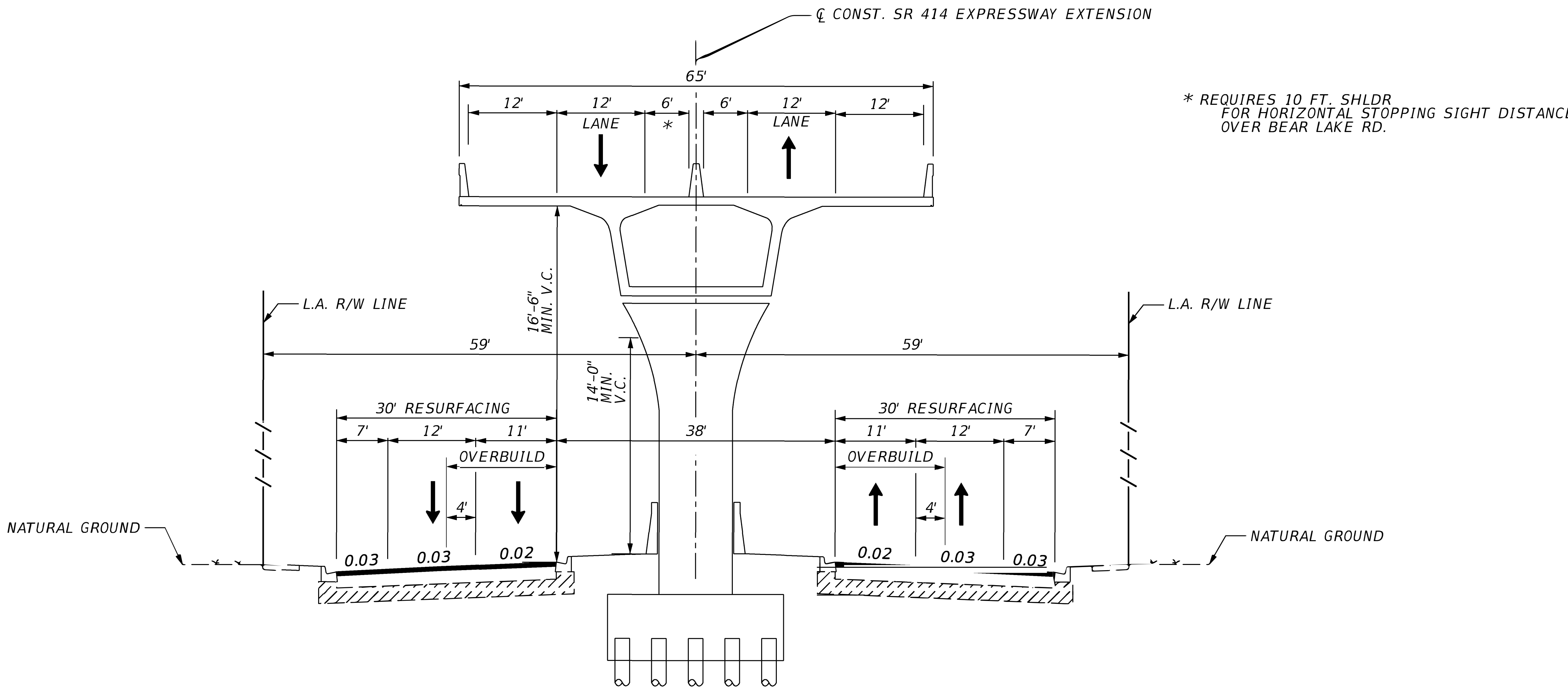
CENTRAL FLORIDA EXPRESSWAY AUTHORITY

TYPICAL SECTIONS

DRAFT

SHEET NO.

$USER$ $DATE$ $TIME$ $MODELNAME$ $FILE$



TYPICAL SECTION: OPTION 3

SR 414 EXPRESS LANES - ONE LANE PER DIRECTION

2-LANE BI-DIRECTIONAL

DESIGN SPEED:
EXPRESSWAY = 50 MPH
MAITLAND BLVD = 45 MPH

PRELIMINARY - SUBJECT TO CHANGE

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SR 414 MAITLAND BLVD.
EXPRESSWAY EXTENSION
US 441 TO SR 434

ROAD NO.	PROJECT NO.
SR 414	414-227

CENTRAL FLORIDA EXPRESSWAY AUTHORITY

TYPICAL SECTIONS
DRAFT

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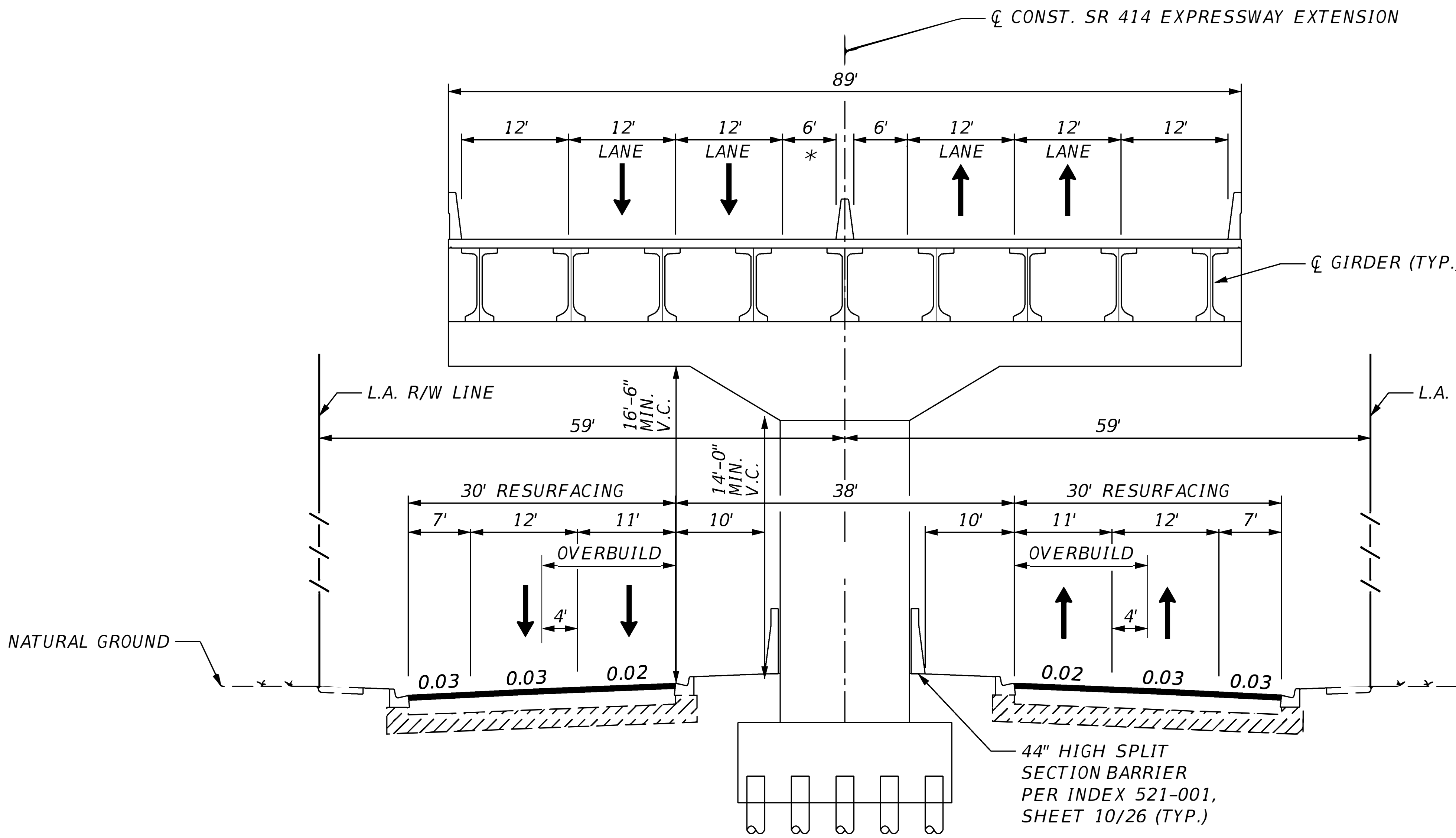

* REQUIRES 10 FT. SHLDR FOR HORIZONTAL STOPPING SIGHT DISTANCE OVER BEAR LAKE RD.

TYPICAL SECTION: OPTION 4
SR 414 EXPRESS LANES - TWO LANES PER DIRECTION
4-LANE BI-DIRECTIONAL

DESIGN SPEED:
EXPRESSWAY = 50 MPH
MAITLAND BLVD = 45 MPH

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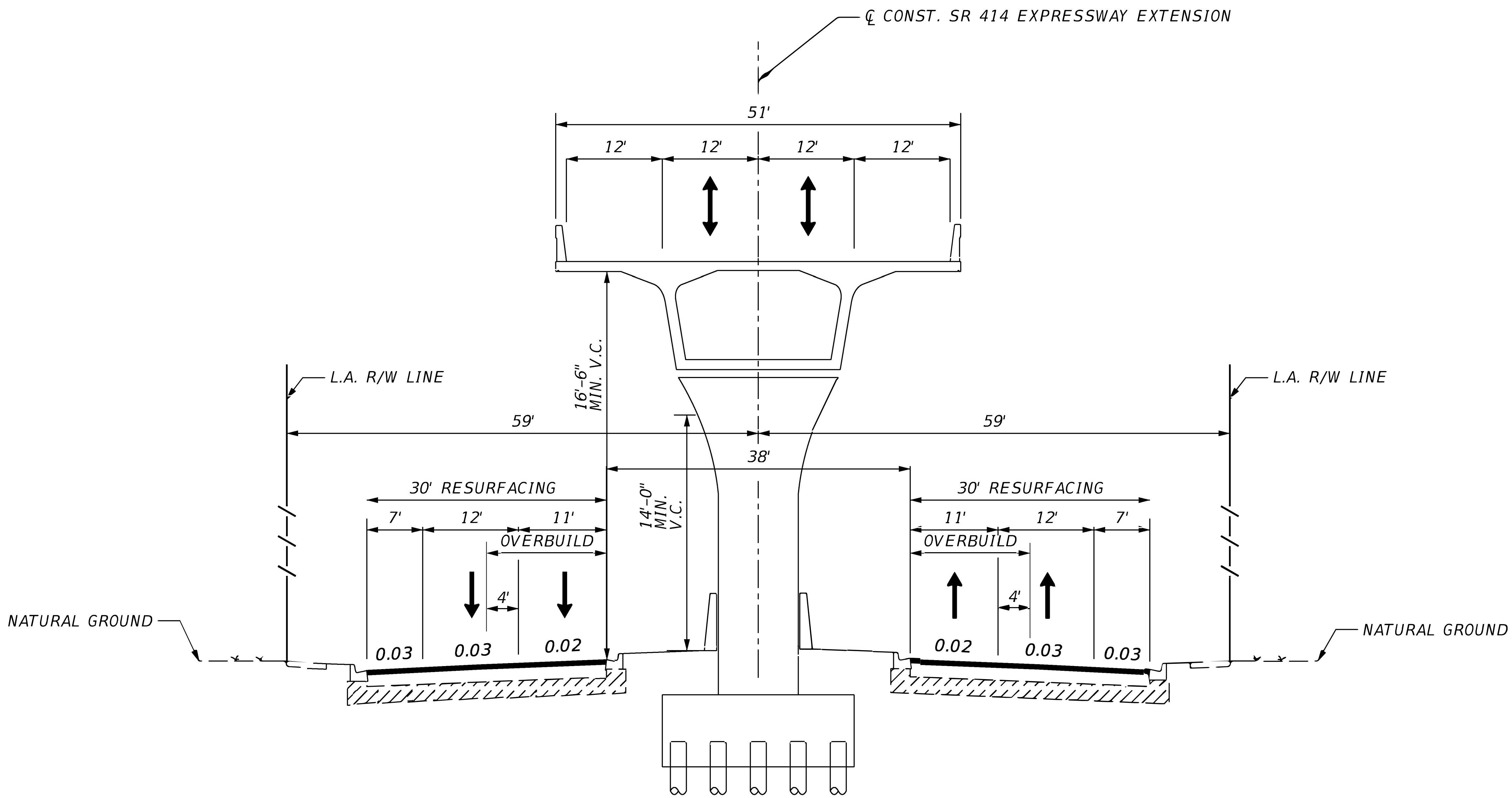

DESIGN SPEED:
EXPRESSWAY = 50 MPH
MAITLAND BLVD = 45 MPH

TYPICAL SECTION: OPTION 5

SR 414 EXPRESS LANES - REVERSIBLE TWO LANES

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TYPICAL SECTIONS
DRAFT

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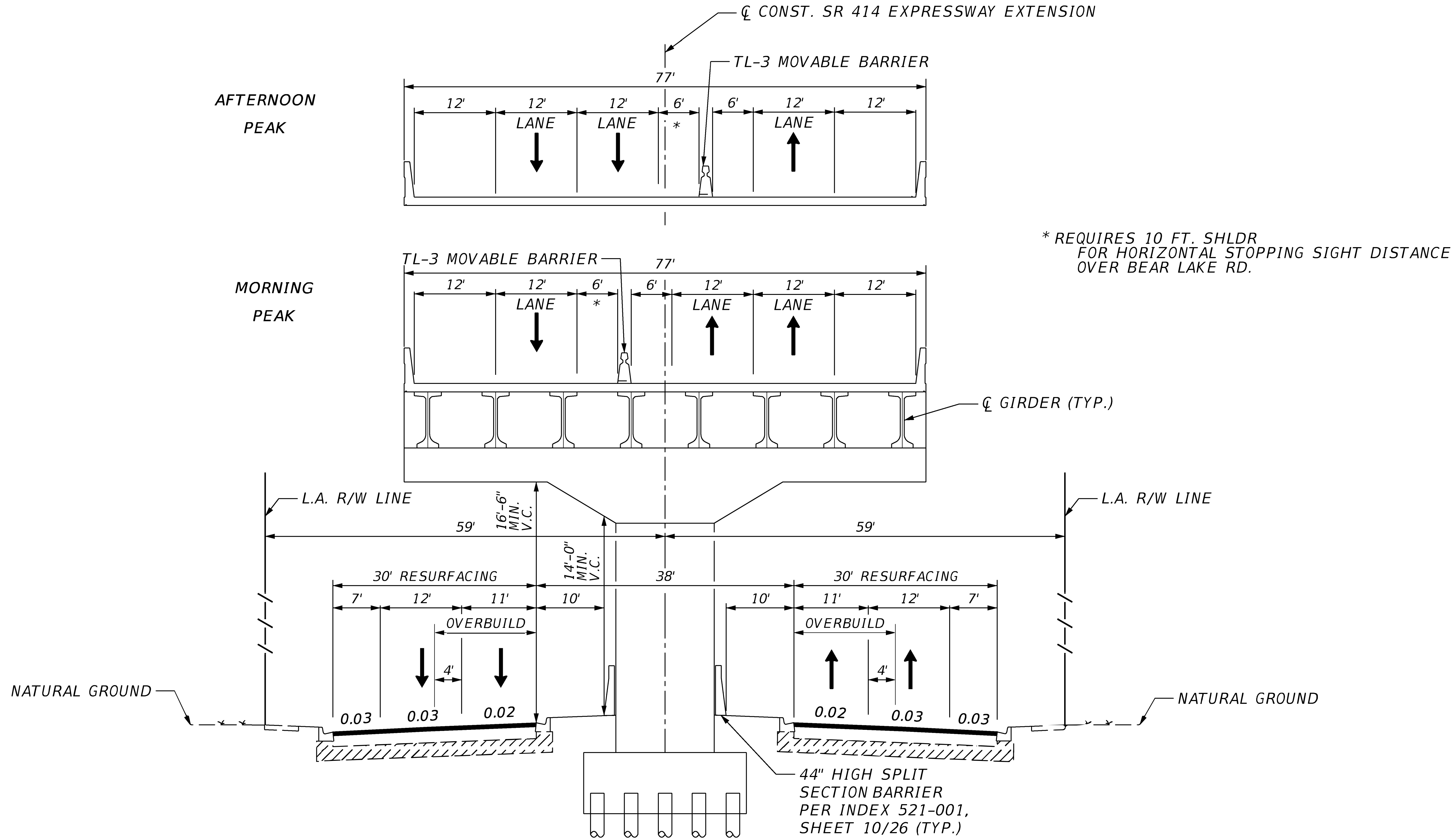

TYPICAL SECTION: OPTION 6

SR 414 EXPRESS LANES - CONVERTIBLE THREE LANES

WITH MOVABLE BARRIER

DESIGN SPEED:
EXPRESSWAY = 50 MPH
MAITLAND BLVD = 45 MPH

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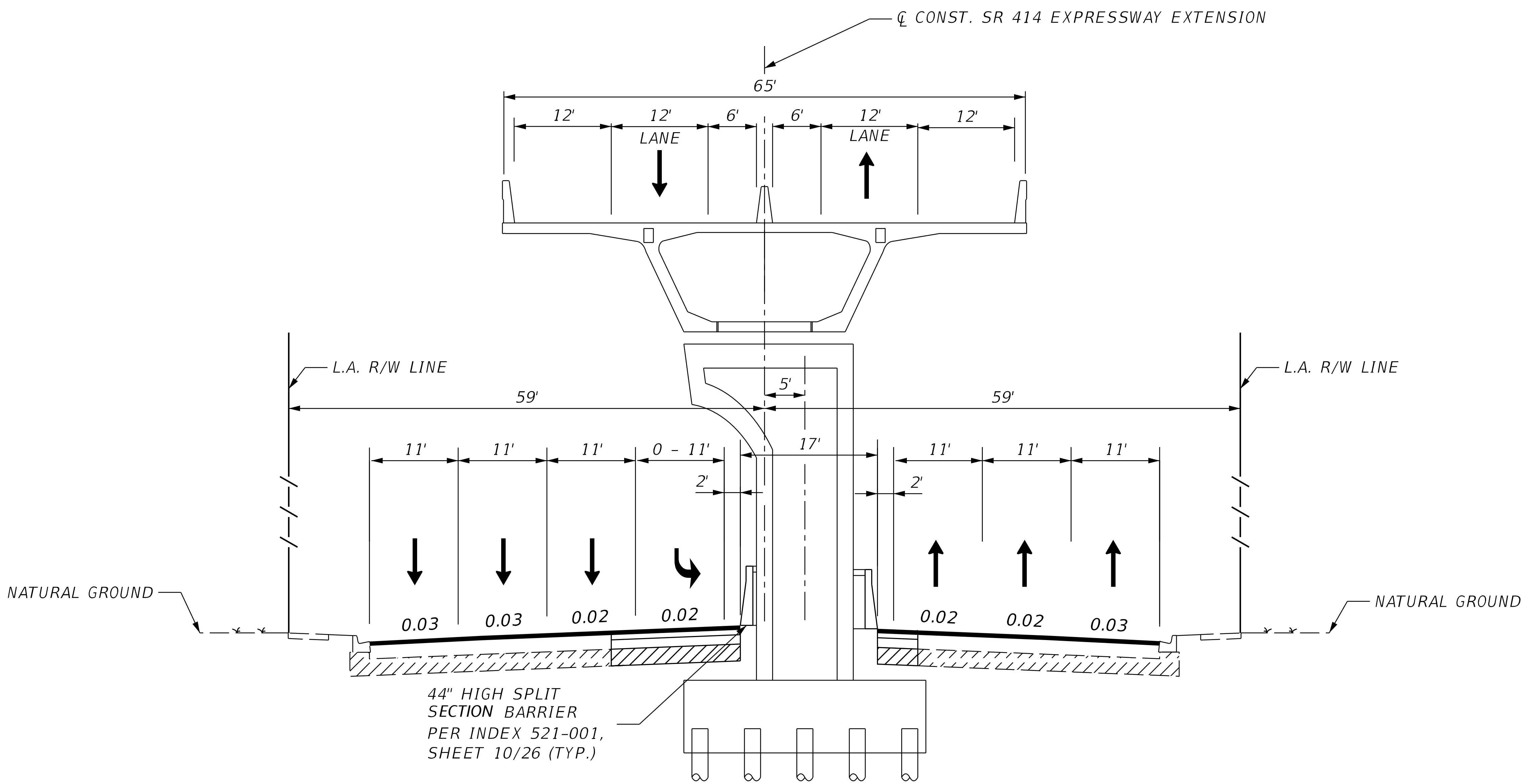

TYPICAL SECTION OPTION 7

WITH LEFT TURN LANE ON MAITLAND BOULEVARD

NO BIKE LANES

DESIGN SPEED:
EXPRESSWAY = 50 MPH
MAITLAND BLVD = 45 MPH

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TYPICAL SECTIONS

DRAFT

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Appendix D
Traffic Analysis

5. Alternatives Analysis

This section provides a description of the traffic analysis completed in the typical section selection and alternatives analysis phases of the study. This section also provides the AADT and DDHV for the preferred alternative in the design year.

5.1 Typical Section Analysis

With the project being in the existing SR 414 corridor, the traffic analysis commenced with a study of several proposed typical sections. In addition to the existing (Typical Section 1) and the No-Build (Typical Section 2), five Build typical sections were developed for the study. In the Metroplan Orlando 2040 LRTP, a SR 414/Maitland Boulevard improvement to a 6-lane arterial from US 441 to SR 434 is listed in the Cost Feasible Plan. Since this is a planned improvement in the LRTP, it was considered the No-Build condition. The Build typical sections included an elevated expressway with varying numbers of lanes above a 4-lane arterial, unless otherwise noted, and include:

- Typical Section 3 – 1 lane/direction on the elevated Expressway Extension;
- Typical Section 4 – 2 lanes/direction on the elevated Expressway Extension;
- Typical Section 5 – 2-lane reversible on the elevated Expressway Extension, i.e., two lanes in the peak direction and no lanes in the off-peak direction reversed by time of day; and
- Typical Section 6 – Convertible 3-lane section on elevated Expressway Extension, one lane in each direction with the center lane being physically reversed twice a day; and,
- Typical Section 7 – 1 lane/direction on Expressway Extension & 3 lanes/direction on arterial.

The travel demand model was run for the typical sections under a tolled and non-tolled condition. Using a simple LOS analysis, the typical sections were compared for LOS using volume to capacity ratios in the daily, AM peak and PM peak-hours based on the 2020 FDOT Generalized LOS Tables. The results of the typical section analysis are shown in **Table 5-1**. The red highlighted cells represent a v/c ratio higher than 1.1 or a generalized LOS E condition. This simple LOS analysis provided a high-level capacity analysis to compare the typical sections and help the project team eliminate typical sections from further analysis.

Table 5-1. Typical Section LOS Analysis

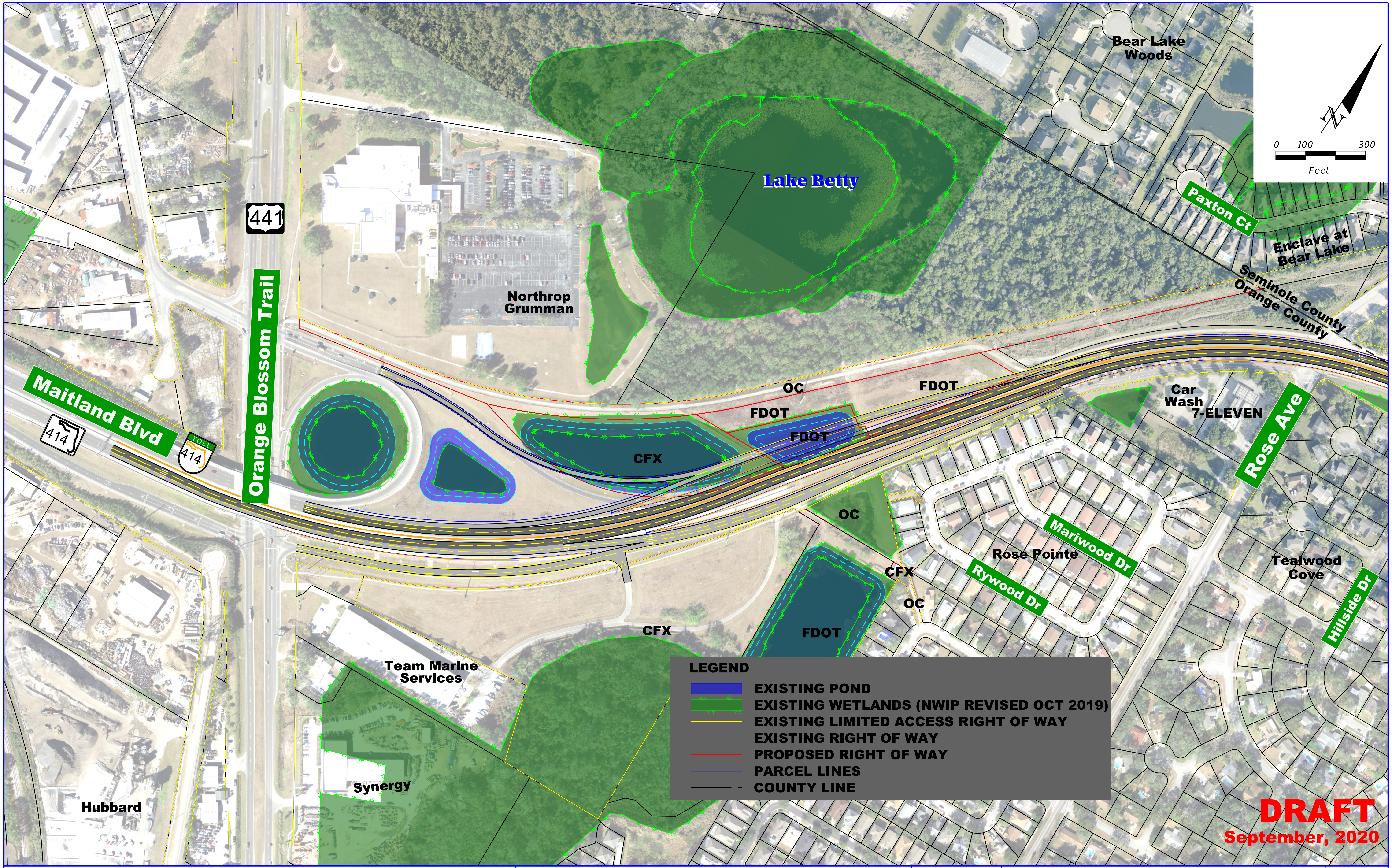
Typical Section	Description	Lanes per Direction			Volume						Growth Rate
		Expressway		Arterial	Volume			V/C			
		Peak Dir	Off-Peak Dir		AADT	Peak Hour Peak Dir	Peak Hour Off-Peak Dir	Daily	Peak-Hour Peak Dir	Peak-Hour Off-Peak Dir	
1	2019 Existing – 2 lanes/direction on arterial	0	0	2	59,910	2,500	1,688	1.50	1.25	0.84	n/a
2	No-Build – 3 lanes/direction on arterial	0	0	3	75,300	4,070	2,715	1.25	1.34	0.90	1.0%
3	1 lane/direction on Elevated Expressway Extension	1	1	2	94,200	5,090	3,395	1.20	1.32	0.89	2.3%
4	2 lanes/direction on Elevated Expressway Extension	2	2	2	112,100	6,055	4,040	0.95	1.07	0.71	3.5%
5	2-lane reversible on Elevated Expressway Extension	2	0	2	112,100	6,055	4,040	1.13	0.91	1.34	3.5%
6	Convertible 3-lane section on Elevated Expressway Extension	2	1	2	112,100	6,055	4,040	1.14	1.07	1.05	3.5%
7	1 lane/direction on Elevated Expwy Extension & 3 lanes/direction on arterial	1	1	3	105,000	5,670	3,780	1.06	1.17	0.78	3.0%

Service Volume Source: 2020 FDOT Generalized LOS Tables
Travel Demand Model: SR 414 EE (CFX Model 414) - Validated to SR 414 Corridor
AADT/DDHV: Cross-section on SR 414 just east of Magnolia Homes Rd
Toll Rate: $0.18/mile ~ $0.50 for corridor in 2019

The typical section analysis demonstrated that the Existing (Typical Section 1), No-Build (Typical Section 2) and Typical Section 3 would be well below the LOS standards in both the daily and peak-hour/peak-direction conditions, i.e., operate with LOS worse than the standard. Typical Section 5 would also be below the LOS standard in daily and peak-hour/off-peak direction, Typical Section 6 would be below the LOS standard for daily volumes, and Typical Section 7 was below the LOS standard in the peak-hour/peak-direction. The only typical section that was within LOS standards for all three time periods was Typical Section 4. Typical Sections 4 and 6 were selected as viable and given further considered.

Typical Section 4 was developed in an engineered concept, which include the east and west end ramps to the existing facilities. The engineered concepts were developed for a two-lane expressway ramp with a one-lane arterial ramp connection as well as a one-lane expressway ramps with a two-lane arterial ramp connection. The east and west end concepts with two lane expressway ramps and one lane arterial ramps are shown in **Figure 5-1** and **Figure 5-2**.

Appendix E
Exhibits of Preliminary Alignment Tie-Ins



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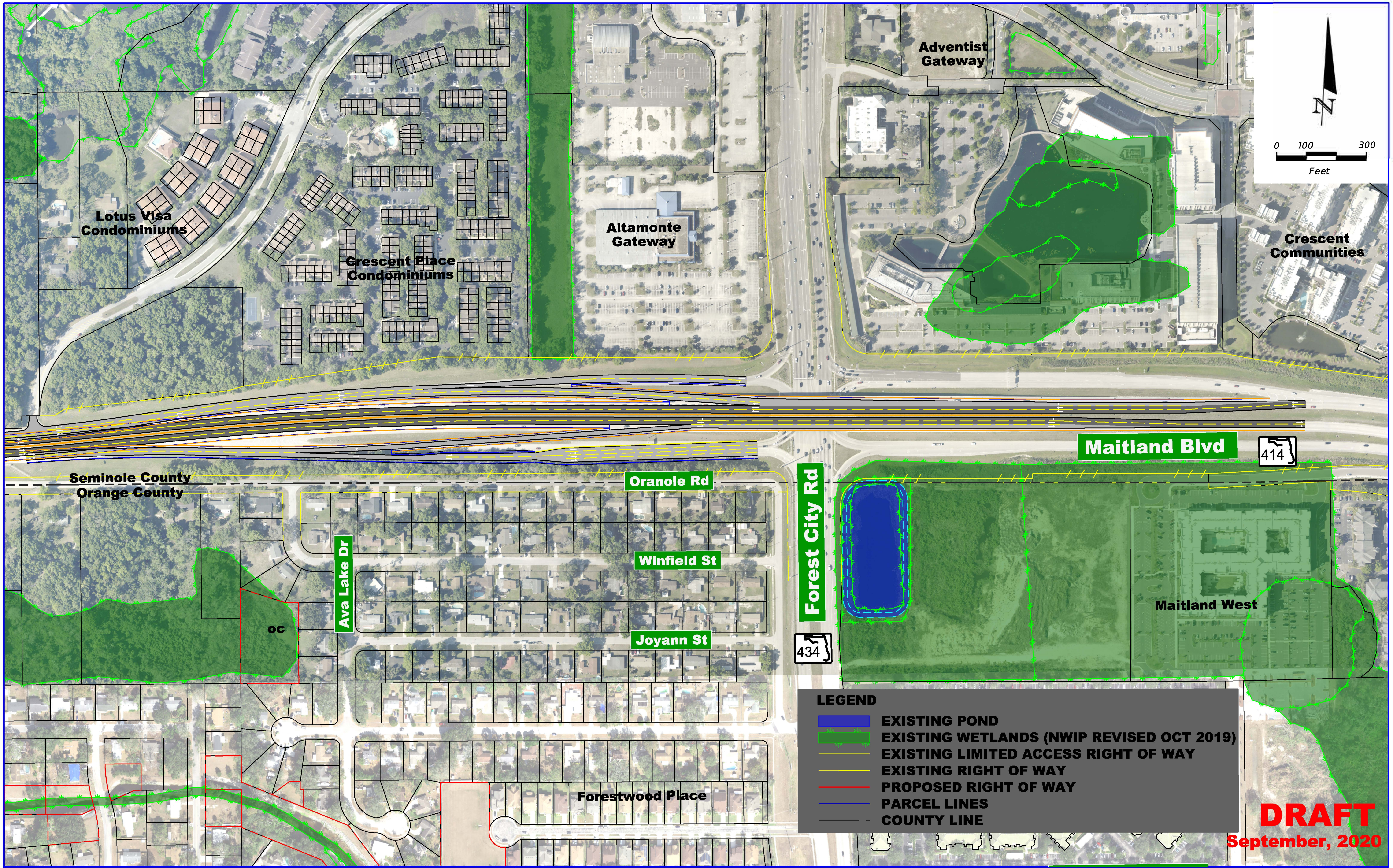
SR 414 - PRELIMINARY TRANSITION (1 OF 2)

SHEET NO.



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SR 414 - PRELIMINARY TRANSITION (2 OF 2)

SHEET NO.

Appendix F
Road Zipper System Specifications

MOVEABLE BARRIERS

THE ROAD ZIPPER SYSTEM™

FOR MANAGED LANES

ROAD ZIPPER™

BY LINDSAY

Quickchange® Moveable Barrier (QMB™) is designed to cost effectively increase capacity and reduce congestion by making more efficient use of new or existing roadways. Applications include high volume highways where additional right-of-way may not be available, where environmental concerns may exist, or where the lack of funding may slow or inhibit support for new construction. The system can transfer a mile (1.6 km) of high performance concrete barrier up to two lanes in less than 10 minutes, offering DOT's an innovative strategy for making our congested highway system more efficient, safe and functional. These benefits can be realized in less than one year and at a fraction of the cost of new construction. Moveable barrier technology provides a quick and cost-effective solution for highway capacity improvements, without having to wait for time consuming study reviews. It allows DOT's to preserve their corridor options (Managed Lanes, Bus Rapid Transit (BRT), Reversible Lanes, Contraflow, HOV and HOT Lanes), while providing a "fast-build" solution for mitigating congestion.

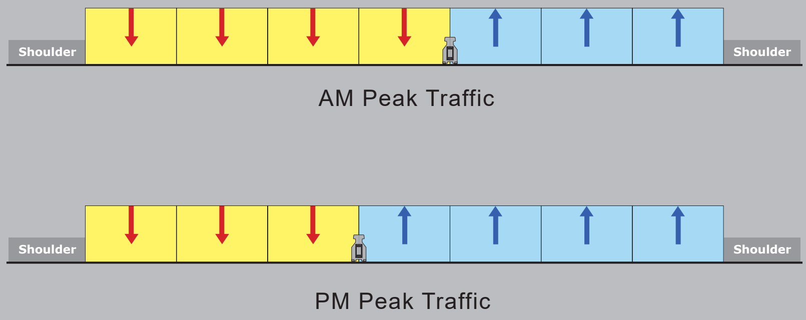
MOVEABLE MEDIANS

The moveable median is perhaps the most simple way of optimizing highway capacity. In this case, there is no fixed barrier on the highway, and the moveable barrier is the only barrier. The barrier is moved back and forth multiple times per day to reconfigure the roadway based on the needs of peak traffic. The moveable median is most commonly applied to bridges and other highway applications with few center structures (viaducts or elevated structures also fit this model).

A moveable median creates a 4/3, 3/4 traffic pattern using 7 lanes.

Ben Franklin Bridge | Philadelphia, PA

MOVEABLE MEDIAN CROSS SECTIONS



REDUCES CONGESTION
Moveable barrier gives more lanes to the peak of traffic direction for AM and PM commuters.

INCREASES SAFETY
Positive barrier protection eliminates the possibility of cross over, head-on accidents.

"FAST-BUILD" SOLUTION
New construction can take years for planning and environmental reviews. Moveable barrier can often be deployed in less than one year.

GREEN BENEFITS
Benefits include improved air quality, improved fuel efficiency, and reduced atmospheric CO_2.

QUALIFIES FOR MAP-21
Federal funds are available to help create managed lanes in the US.

STRETCHES TRANSPORTATION BUDGETS
According to the FHWA, new urban freeway construction can cost up to $15.4 million per urban lane mile. Moveable barrier is a fraction of this cost.

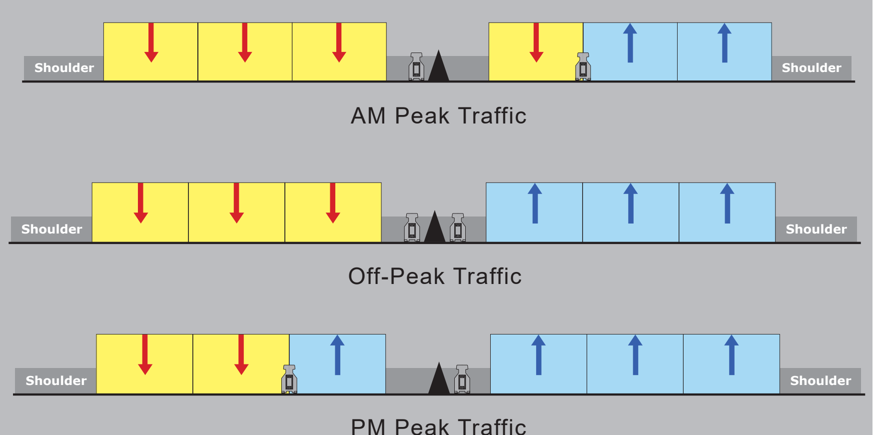
CONTRAFLOW LANES

A single moveable median barrier may not be practical in some situations. This may be because the two directions of the highway are on different elevations or structures, because there is a substantial existing median barrier, or because there are many center structures. In these cases, two moveable walls are used, one on each side of the roadway, in order to take unused capacity from the off-peak side of the road and allow traffic from the peak side to cross over and use the new lane, thus gaining additional capacity. This system provides the same optimization and efficiency as a moveable median despite the geometric challenges.

Contraflow lanes use one wall of barrier for each traffic direction.

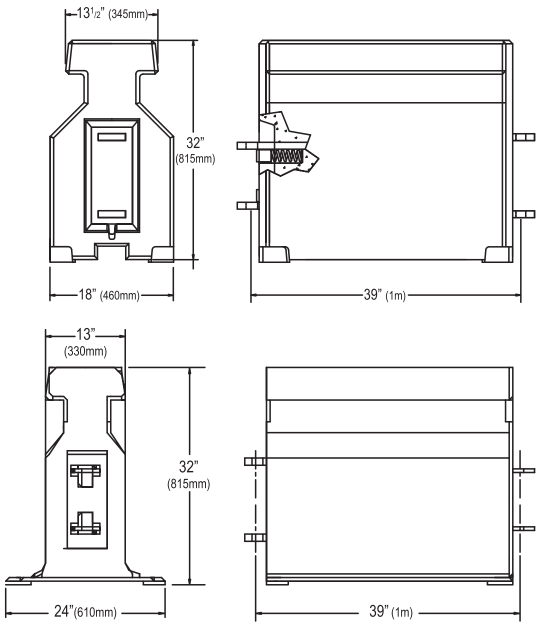
I-30 | Dallas, TX

CONTRAFLOW CROSS SECTIONS



BARRIER TRANSFER MACHINE

Transfer Speed	8-10 mph (13-16 km/h)
Roading Speed	20 mph (32 km/h)
Lateral Transfer	30 ft (9.1 m)
Transfer Time	1 mile (1.6 km in 6-8 minutes)



PHYSICAL SPECIFICATIONS

18" Concrete Reactive Tension System (CRTS)

Heavily reinforced concrete barrier sections have superior deflection and vehicle stability when compared to Temporary Concrete Barrier.

Permanent Deflection
MASH TL-3: 39 in. (990mm)
NCHRP 350 TL-3: 24 in. (610mm)
EN 1317-2 N2: 27.5 in. (700mm)
EN 1317-2 H2: 55 in. (1.4m)
EN 1317 (TB21): 10 in. (260mm)
EN 1317 (TB41): 37.5 in. (950mm)

Mass of Each Barrier Element
Approximately 1500 lbs (680 kg)

13" Steel Reactive Tension System (SRTS)

High strength steel structure filled with concrete and Reactive Tension elements resulting in the narrowest profile and low deflection. Ideal for use where low deflection is required and minimum lane width exists.

Permanent Deflection
NCHRP 350 TL-3: 27.5 in. (700mm)

Mass of Each Barrier Element
Approximately 1500 lbs (680 kg)

ROAD ZIPPER CASE STUDY | DALLAS, TX I-30

- 15,000 commuters daily in the HOV lanes
- Saves 14 minutes per trip = 1 million hours per year
- Benefit to Cost ratio of 6.5 to 1
- Helps Dallas meet air quality goals
- Average US vehicle occupancy = 1.1, Dallas HOV = 2.9
- Most cost-effective way to mitigate congestion (system expanded 3 times)

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Appendix G
White Paper: Improving the Cost-Effectiveness of Urban Freeways
(December 20, 2017)

White Paper

Improving the Cost-Effectiveness of Urban Freeways

Through Flexibility in Operations and Design

December 20, 2017

Produced by Daniel B. Rathbone, Ph.D., P.E., DBR & Associates

Commissioned for Lindsay Transportation Solutions

Executive Summary

The level of future uncertainty in transportation planning, and more specifically in addressing prevailing congestion on urban freeways, has increased significantly over the past few years. The impact of connected and autonomous vehicles on traffic flow, of Mobility as a Service (MaaS) initiatives, particularly the car-sharing elements, and exciting advances in traffic operations are some of the factors contributing to this uncertainty. The FHWA recently acknowledged uncertainty in its recent publication “Advancing Transportation Systems Management and Operations through Scenario Planning.”

Thus, investment of billions of dollars in projects to widen congested urban freeways has become risky and might be a misappropriation of scarce transportation funds. This white paper provides solutions to future uncertainty when addressing congestion. Specifically, it explains how flexibility can be incorporated in urban freeways to cope with unexpected developments and alternative futures while also addressing prevailing traffic congestion at low cost.

As part of this white paper, two options were considered: a comparison was made between widening a congested urban freeway by constructing one additional lane in each direction, or providing a reversible lane using movable barrier to create an additional lane during the peak period in the peak direction for both the a.m. peak and the p.m. peak. Here are the main findings:

- Cost for constructing a lane mile to widen an urban freeway averages $28 million. In contrast, the cost to provide a reversible contraflow lane is $1.4 million per mile.
- The typical length of time to plan, design and construct an additional lane is 10 years. Equivalent time for a reversible lane is 1-4 years.
- The environmental impact associated with construction of an additional lane is significant and requires an environmental impact statement which typically takes 3 years to complete. The impact of a reversible lane is minor and does not require an environmental impact statement. In most cases it qualifies for a categorical exclusion.
- Once funds are spent on construction of additional freeway lanes it is not possible to recoup or change this significant investment. The high cost of this alternative, therefor is potentially a high risk, considering the uncertainty of the future. Reversible lanes using movable barrier are flexible by contrast in terms of coping with existing and future innovations by changing the number of contraflow lanes; when contraflow lanes are implemented; and even where they are applied. Because of the relatively low cost of this alternative, the associated risk is also low.

The white paper also provides information about the impact of an additional lane on a congested urban freeway in terms of growth of traffic in the years following the widening. From available literature it was determined that “new vehicles” attracted to a freeway (induced traffic, and excluding diverted traffic) will typically result in the freeway experiencing the same level of congestion as prior to the added lanes within ten years or less from the opening the new lanes. The same applies when the additional lanes are provided in the form of reversible lanes using movable barrier. However, the critical factor is the order of magnitude difference in capital funds invested in providing the additional capacity. This variance in capital expenditure is highlighted in a benefit-cost analysis included in the white paper and summarized in the paragraph below.

A straightforward addition of a lane in each direction of a congested freeway over ten miles was assumed for the benefit-cost analysis. Results show that when the additional lanes were provided through construction the benefit-cost ratio was only 0.24. When reversible lanes using movable barrier were added, the benefit-cost ratio was found to be 3.4. That the benefit-cost ratio for reversible lanes is higher than that for adding lanes by construction is intuitively what can be expected. However, what is significant is that the option to add the lanes through construction does not get close to 1.0. This indicates that if the sole purpose of constructing additional lanes on a congested urban freeway is to relieve congestion, then there is a probability that it will not be a viable project in terms of the return on the investment.
To obtain a benefit-cost ratio of more than 1.0, the additional lanes needs to be constructed at less than $4 million per lane mile.

As shown in the table below, a directionality split of as low as 43%/57% can be good enough for a reversible lane on an eight-lane freeway. If a limited amount of congestion can be tolerated in the off-peak direction, considering that overall there will be significantly less delay on the freeway, the directional split can be lower than the percentages in the table.

Table 12. Minimum Directional Split Requirement for Contraflow Lane Application on a Freeway

Number of Lanes (total,both directions)	Percentage Traffic in Off-Peak Direction	Percentage Traffic in Peak Direction
4	33	67
6	40	60
8	43	57
10	44	56

This paper also illustrates several ways reversible lanes using movable barrier can be applied and is summarized in the table below.

Options for Applying Reversible Managed Lane Systems Using Movable Barrier			
Contraflow	Movable Median	Contraflow Within a Two HOT Lane per Direction System	Contraflow HOT Lanes Using Existing HOV Lanes
Option 1 Provide one or two additional lane(s) depending on directional split, in a.m. peak period direction. Option 2 Provide one or two additional lane(s) depending on directional split, in p.m. peak period direction.	Option 1 Provide one or two additional lane(s) depending on directional split, in a.m. peak period direction. Option 2 Provide one or two additional lane(s) depending on directional split, in p.m. peak period direction.	Option 1 Provide one additional HOT lane in a.m. peak period direction for a total of three HOT lanes in a.m. peak direction. Option 2 Provide one additional HOT lane in p.m. peak period direction for a total of three HOT lanes in p.m. peak direction.	Option 1 Provide one additional lane in a.m. peak period direction for a total of two HOT lanes in a.m. peak direction. Option 2 Provide one additional lane in p.m. peak period direction for a total of two HOT lanes in p.m. peak direction.

Note:
The reversible managed lanes are ideal facilities for accommodating express buses and autonomous vehicles.

On September 23, 2016, the California state legislature passed Bill AB 2542 that requires that, prior to the California Transportation Commission (CTC) approving a capacity-increasing project or major street or highway lane realignment project, the California Department of Transportation (Caltrans) or a regional transportation planning agency must demonstrate that reversible lanes were considered for the project. This legislation recognizes the cost-effectiveness of reversible lanes.

In summary, this white paper provides solutions to future uncertainty when addressing congestion. More specifically it explains how flexibility can be incorporated in urban freeways at low cost to be able to cope with unexpected developments and alternative futures, while also addressing prevailing traffic congestion and accommodating express bus services, autonomous vehicles, and carpool vehicles.

1. Purpose of this White Paper

The following factors have changed the outlook for addressing congestion on urban freeways:

- The extremely high cost to physically add capacity in built-up locations particularly where there is not sufficient right-of-way available.
- Advances in urban freeway operations such as Reversible Lanes, Integrated Corridor Management (ICM) including Active Traffic Management (ATM) and Corridor and Arterial Traffic Management as well as Travel Demand Management.
- Recent successful Mobility as a Service (MaaS) initiatives, particularly the car-sharing components.
- Connected vehicles and autonomous vehicles.

The last two items above have introduced a measure of uncertainty in the planning of urban freeways particularly since they have only come about recently, begging the questions, what next? The FHWA recognized the need to look at alternative futures in its recent publication "Advancing Transportation Systems Management and Operations through Scenario Planning" (https://ops.fhwa.dot.gov/publications/fhwahop16016/fhwahop16016.pdf). The message is clear that the future is not as predictable as it has been in the past. If this uncertainty is not recognized and addressed as part of the planning of urban freeway corridors there is a real likelihood that mistakes might bel be made. These mistakes are typically recommendations for significant capital investment to reduce congestion by constructing additional traffic lanes when an alternative approach might be at least as effective in reducing congestion at a fraction of the cost.

This white paper provides solutions to future uncertainty when addressing congestion. It explains how flexibility can be incorporated in urban freeways at low cost to cope with unexpected developments and alternative futures, while also addressing prevailing traffic congestion.

2. Reducing Congestion and Increasing Safety of an Urban Freeway: A Comparison of Two Alternatives

There are two main alternatives for reducing congestion and increasing safety on congested urban freeways. The first approach is the conventional practice which is to add freeway lanes through construction. The second approach is to rely on improved traffic operations including reversible lanes. Each of these two approaches will be described in terms of critical factors and then compared.

2.1 Alternative A – Constructing Additional Freeway Lanes

It is common practice to reduce congestion on urban freeways by constructing additional lanes. The following are key characteristics of such an approach:

2.1.1 Key Characteristic 1: Typical Cost to Add Lanes

See Table 1 below.

Table 1. Typical Costs per Lane Mile of Freeway for Adding a Lane (TOTAL COST)
(Cost Includes Bridges, Interchanges, and Right-of-Way)

Type of Urban Area	Add Lane, Normal Cost (2017 $s, millions)	Add Lane, High Cost (2017 $s, millions)
Large Urban Area (population between 200,000 and 1,000,000)	$5.4	$18.1
Major Urban Area (population of more than 1 million)	$10.8	$44.9

Source:
2015 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance, USDOT
Note:
"Normal Cost" reflect costs of projects for which sufficient right-of-way is available or readily obtained to accommodate additional lanes.
"High Cost" are intended to reflect situations in which right-of-way is extremely expensive and conventional widening is infeasible and alternative approaches are required to add capacity to a given corridor.

2.1.2 Key Characteristic 2: Length of Time to Implement Additional Lanes

U.S. Government Accountability Office study:
According to a report by the U.S. Government Accountability Office (GAO), it typically takes between 9 and 19 years to complete the planning, gain approval of, and construct a new major

federally-funded highway project (Opportunities for Oversight and Improved Use of Taxpayer Funds, United States General Accounting Office).
In addition, the project might take longer when funding is uncertain, considering the high cost of expanding an urban freeway, as provided in Table 1.

Illinois Department of Transportation Experience:
A further source addressing the time it takes for a major construction project to be completed is provided by the Illinois Department of Transportation: "The funded highway project process can involve as many as 55 steps and take many years to finish. A major construction project involving a new highway, for instance, can take from five to 20 years to complete all the steps." (It Takes Time – Highway Construction From Start to Finish).

Virginia Department of Transportation Experience:
The Virginia Department of Transportation provides the following information on the time it takes for each of the major steps to be completed for highway project:

1. Planning Phase may last from 1-24 months.
2. Scoping Phase may last between 1-8 months depending on project complexity.
3. Preliminary Design Phase may range from 1-18 months.
4. Detailed Design Phase may last between 1-12 months.
5. Final Design and Right of Way Acquisition Phase may range from 1-24 months.
6. Advertisement Phase may last from 1-5 months.
7. Construction Phase may range from 1 to over 36 months.

The total time ranges from less than a year to 10 years.

Table 2 below provides a summary of the three sources of information.

Table 2. Typical Length of Time to Construct Additional Lanes to an Existing Urban Freeway	
Source	Number of Years for Planning, Design, Approval and Construction of Lane Additions to an Existing Freeway)
U.S. Government Accountability Office	9 to 19
Illinois Department of Transportation	5 to 20
Virginia Department of Transportation Experience	1 to 10
Average	**10 years**

2.1.3 Key Characteristic 3: Length of Time Before Same Level of Congestion is Reached After Constructing Additional Lanes

After lanes are added to an existing urban freeway, the additional capacity reduces peak period congestion and speeds increase. The reduced level of congestion on the freeway is attractive to motorists that might have travelled other routes, other times, or may not even have made a trip at all due to congestion. The result is a higher level of growth in peak period traffic, and particularly peak hour traffic. This higher level of growth continues until congestion again limits further peak-period traffic growth.

The general term used for the additional traffic is “generated traffic.” Generated traffic consists of diverted traffic and induced traffic.

Diverted Traffic

Diverted traffic consists of trips that shifted in time (e.g. a commuter finding it possible to leave home a bit later to go to work since the level of congestion has decreased at the later time), shifted in route (e.g. a commuter changing his/her route from an arterial running parallel to the freeway where lanes have been added since the travel time is lower), and shifted in destination (e.g. a person changing the location to obtain gas by using the freeway where lanes have been added since the travel time is lower).

Induced Traffic

Induced traffic consists of trips that shifted in mode (e.g. a commuter changing from using transit to a car since the reduced congestion on the freeway where lanes have been added make the trip by car quicker), shifted in distance (e.g. to a better shopping center that can be reached in the same time as a less preferred shopping center), and a new vehicle trip (e.g. conducting a meeting in person rather than by phone since the trip time is acceptable).

A Safety Benefit of Diverted Traffic

Typically, diverted traffic results in an increase in traffic on the freeway where lanes have been added but also results in a reduction in traffic on routes that run parallel or reasonably close to the freeway. Diverted traffic is often a safety benefit since the crash rate on freeways is lower than other road types, as shown in Table 3.

Table 3. Crash Rate of Freeways and Other Urban Road Types

Urban Road Type	Crashes per 100 Million Vehicle Miles Traveled
Freeway	130
Multilane divided road	440
Multilane undivided road	550
Two-Lane road	380

Source: Adapted from - HERS-ST Highway Economic Requirements System - State Version: Technical Report - Chapter 5: Estimation of Impacts, FHWA (Updated June 2017)

Induced traffic is additional travel including new trips which increases the growth of traffic at a higher rate than what would have taken place without the road widening. Table 4 provides information on studies conducted to determine induced travel as a percentage of all future travel.

Table 4. Induced Traffic as a Percentage of Additional Capacity		
Author of Study on Induced Traffic	Induced Traffic as a Percentage of Additional Capacity Within 3 Years	Induced Traffic as a Percentage of Additional Capacity in the Long Term (3+ years)
Goodwin	28%	57%
Fulton, et al	10 – 40%	50 - 80%
Noland	20 - 50%	70 – 100%
Source: Adapted "Generated Traffic: Implications for Transport Planning" by Todd Litman, Victoria Transport Policy Institute, April, 2017		

Table 4 provides information on induced traffic only. In addition to induced traffic, there is also diverted traffic and the growth of traffic that has been on a freeway where additional lanes were constructed.

Of note is a study conducted by Mark Hansen and Yuanlin Huang entitled "Road Supply and Traffic in California Urban Areas", Transportation Research A, Vol. 31, No. 3. They found that 60% to 90% of increased road capacity is filled with new traffic within five years (as cited by Todd Litman, "Generated Traffic: Implications for Transport Planning", Victoria Transport Policy Institute, April 2017).

Based on the information in Table 4 and the above paragraph, it is reasonable to assume that the same level of congestion as existed before the addition of freeway lanes will again take place within approximately 10 years of implementation of the additional lanes.

In urban areas, where congestion is common, the percentage of induced traffic due to adding lanes to a freeway tends to be higher. The amount of induced traffic provided in Table 4 is significant. Induced traffic also has an impact on the benefit-cost ratio of a freeway widening where, when taken into consideration, there is a likelihood for the ratio to be less than one and therefore not a good investment, economically.

2.1.4 Key Characteristic 4: Environmental Impact

The following are possible environmental impacts associated with widening an urban freeway:

- During construction:
    - Additional traffic congestion.
    - Possible delay to first responders.

    - Short-term degradation of air quality may occur due to the release of particulate emissions (airborne dust) generated by excavation, grading, hauling, and other activities related to construction.
    - Emissions from construction equipment also are anticipated and would include CO, NOx, VOCs, directly-emitted particulate matter (PM10 and PM2.5), and toxic air contaminants such as diesel exhaust particulate matter.
    - Noise (particularly at nighttime) and vibration.
- If additional right-of-way is required, residential and/or commercial property might have to be taken through eminent domain.
- Induced traffic will increase air pollution from fossil (and some biofuel) powered vehicles. Emissions include particulate emissions from diesel engines, NOx, volatile organic compounds, carbon monoxide and various other hazardous air pollutants including benzene. The impact is further increased if the widening of the freeway results in vehicles traveling closer to adjoining developments particularly residential development. concentrations of air pollutants and adverse respiratory health effects are greater near the road than at some distance away from the road.
- Adding additional lanes will increase impervious surfaces. Urban runoff from roads and other impervious surfaces is a major source of water pollution. Rainwater and snowmelt running off of roads tends to pick up gasoline, motor oil, heavy metals, trash and other pollutants. Road runoff is a major source of nickel, copper, zinc, cadmium, lead and polycyclic aromatic hydrocarbons (PAHs), which are created as combustion byproducts of gasoline and other fossil fuels.
- Noise pollution will increase due to the higher overall traffic volume and possibly due to vehicles being closer to adjacent developments.

2.1.5 Key Characteristic 5: Coping with Uncertainty

It is generally recognized that urban transportation is undergoing fundamental changes. Two examples are provided below.

Mobility as a Service (MaaS)

MaaS includes car-sharing services such as Zipcar, ride-sharing services such as Lyft or Uber, and bike-sharing. A recent study co-sponsored by the Minnesota Department of Transportation and the Minnesota Local Road Research Board entitled "The Transportation Futures Project: Planning for Technology Change" with principal investigator David Levinson, Professor, Civil, Environmental and Geo-Engineering at the University of Minnesota, addressed MaaS in terms of its impact on transportation planning. The following implications of MaaS were determined:

- "A smaller, more modern fleet that is used more efficiently and turns over faster."
- "Greater coverage in urban areas with higher demand."
- "Fewer trips for people who give up on vehicle ownership and opt to pay by trip."

- “Greater viability for the electrification of the vehicle fleet.”
- “Demand for new street designs that emphasize pick-up and drop-off locations rather than on-street parking.”

Ken Buckeye, program manager with MnDOT’s Office of Financial Management said “importantly, transportation sharing is likely to encourage rational consumer behaviors that will have consequences for system performance.”

The Impact of Connected Vehicles (CV) and Autonomous Vehicles (AV) on Freeway Capacity

A study entitled “Effects of Next-Generation Vehicles on Travel Demand and Highway Capacity” by the FP Think Working Group members Jane Bierstedt, Aaron Gooze, Chris Gray, Josh Peterman, Leon Raykin, and Jerry Walters analyzed by means of VISSIM simulation the impact of “next generation vehicles” on freeway capacity. The study concluded that “capacity benefits are likely to occur only on freeways when the fleet mix is at least 75% autonomous and assuming performance is programmed at intermediate levels between conservative and aggressive. At that point, likely post-2035, the AV fleet mix is likely to achieve traffic flow benefits of 25-35%. Beyond that, when regulations, liability concerns and driver comfort allow much more aggressive car-following algorithms, vehicle delays may be reduced by 45% or more.”
Another study conducted by Dwight Farmer, P.E., published in the ITE Journal of November 2016, concluded that fully autonomous vehicles will enable the headway vehicles to be reduced to such a degree that the maximum freeway flow rates will increase “from approximately 2,000 vehicles per hour per lane to approximately 4,000 vehicles per hour per lane.”
There is at this stage still some uncertainty on how much CV/AV will change the capacity of freeway lanes, but there seems to be increased consensus that CV/AV will increase the capacity of freeway lanes.

Considering the issues addressed above, there is presently more uncertainty in urban transportation planning. Under these circumstances, the ability for freeways to be flexible in terms of accommodating future traffic volumes is a distinct advantage. When widening an urban freeway by constructing additional lanes there is an acceptance of the existing capacity of freeway lanes (maximum vehicles per lane per hour as determined, for example, by applying the Transportation Research Board’s Highway Capacity Manual techniques) and that innovative services such as MaaS and the capacity impact of CV/AV will not significantly impact travel. This implicit assumption is highly unlikely and extremely risky considering the significant amount of capital cost at play.

2.1.6 Summary of Alternative A

Table 5. A Summary of How Alternative A (Addressing Congestion by Constructing Additional Freeway Lanes) Performs in Terms of Key Characteristics	
Key Characteristics	Performance
1. Cost to add lanes	\$11 - \$45 million per lane mile[1]
2. Length of time to implement additional lanes	Approximately 10 years[2]
3. Length of time before same level of congestion is reached after constructing additional lanes	Less than 10 years[3]
4. Environmental impact	Significant impact requiring an environmental impact statement which takes an average of 3 years to complete (included in the 10 years for key characteristic 2).
5. Coping with uncertainty	Limited and therefore a high risk.
Notes: [1]Assume freeway is located in a larger urban area. [2]Includes planning, gaining approval, and construction. [3]In some cases it can be closer to 4 or 5 years, depending on the level of congestion in the general corridor.	

2.2 Alternative B - Reversible Lanes (Contraflow)

Application of reversible lanes using movable barrier technology to create an additional lane in the peak direction is much more cost-effective than widening a freeway by constructing additional lanes. Reversible lanes have been successfully applied at 21 locations in the U.S. and elsewhere.

2.2.1 Key Characteristic 1: Typical Costs to Add Contraflow Lanes

See Table 6 below.

Table 6. Typical Costs to Add Contraflow Lanes	
Typical Cost Items for Movable Barrier Creating a Contraflow Lane in the Morning and Evening Peaks	Cost (2017 $s, millions)
Capital Costs	
Movable barrier per mile	$1,386,000
One Barrier transfer machine[1]	$1,600,000
Other costs (gates, crossovers, signage, etc.)	$3,000,000
Operating Costs	
Operating cost per year for 10 miles, both directions of freeway[2]	$840,000

Notes

[1]Usually two machines are required.

[2]As estimated by Lindsay Transportation Solutions, manufacturers of the movable barrier systems.

2.2.2 Key Characteristic 2: Length of Time to Implement Contraflow Lanes

Table 7 below provides real world examples.

Table 7. Length of Time to Implement Contraflow Lanes to an Existing Urban Freeway	
Source	Number of Years for Planning, Design, Approval and Construction of Contraflow Lanes
System can be built in less than one year. Planning and approval is dependent on the agency and is typically 1-3 years.	1 to 4 years

2.2.3 Key Characteristic 3: Length of Time Before Same Level of Congestion is Reached After Constructing Additional Lanes

Same as for Alternative A

2.2.4 Key Characteristic 4: Environmental Impact

The following are possible environmental impacts associated with implementing a contraflow lane on an urban freeway:

- During construction: no impact.
- Additional right-of-way is not required.
- Induced traffic will increase air pollution from fossil (and some biofuel) powered vehicles. Emissions include particulate emissions from diesel engines, NOx, volatile organic compounds, carbon monoxide and various other hazardous air pollutants including benzene.
- Impervious surfaces will be increased by an extremely small amount.
- Noise pollution will increase due to the higher overall traffic volume and the barrier transfer operation.

2.2.5 Key Characteristic 5: Coping with Uncertainty

Contraflow lanes are flexible in terms of addressing unexpected events. See more information about this in Section 3.

2.2.6 Summary of Alternative B

Table 8. A Summary of How Alternative B (Addressing Congestion by Implementing Contraflow Lanes) Performs in Terms of Key Characteristics	
Key Characteristics	**Performance**
1. Cost to add lanes	Movable barrier $1,386,000 per mile. Annual operating cost[1] Fixed costs[1]
2. Length of time to implement additional lanes	1-4 years
3. Length of time before same level of congestion is reached after constructing additional lanes	Less than 10 years[2]
4. Environmental impact	Minor impact which will not require an environmental impact statement and will in most cases qualify for a categorical exclusion.
5. Coping with uncertainty	Application of reversible lanes using movable barrier is flexible in terms of coping with existing and future innovations as explained in Section 3. Because of the relatively low cost of this alternative, the associated risk is also low.
Notes: [1]Actual costs depend on specific circumstances of project. [2]In some cases it can be closer to 4 or 5 years, depending on the level of congestion in the general corridor.	

2.3 Comparison Between Two Alternatives (A and B) to Reduce Severe Congestion: Widening a Freeway by Constructing Additional Lanes or Applying Contraflow Reversible Lanes

Table 9. Comparison of Key Characteristics of Constructing Additional Lanes or Implementing Contraflow Lanes to Address Congestion on an Urban Freeway		
Key Characteristics	Construction of Additional Lanes	Implementation of Contraflow Lane
1. Cost to add lanes	\$11 - \$45 million per lane mile[1]	\$1,386,000 per mile plus operating cost and fixed costs
2. Length of time to implement additional lanes	Approximately 10 years[2]	1-4 years
3. Length of time before same level of congestion is reached after constructing additional lanes	Less than 10 years[3]	Less than 10 years[3]
4. Environmental impact	Significant impact requiring an environmental impact statement which typically takes an average of 3 years to complete (included in the 10 years for key characteristic 2).	Minor impact which will not require an environmental impact statement and will in most cases qualify for a categorical exclusion.
5. Coping with uncertainty	Limited and therefore a high risk.	Application of reversible lanes using movable barrier is flexible in terms of coping with existing and future innovations as explained in Section 3 of this white paper. Because of the relatively low cost of this alternative, the associated risk is also low.
Notes: [1]Assume freeway is located in a larger urban area. [2]Includes planning, gaining approval, and construction. [3]In some cases it can be closer to 4 or 5 years, depending on the level of congestion in the general corridor.		

Table 10. Benefit/Cost Analysis of Widening Freeway by Constructing Lanes		
Assumptions: 1. Simplified analysis for 10 miles on six-lane urban freeway. 2. One additional lane per direction is constructed at a cost of $28 million per mile (based avg. costs in Table 9). 3. Total implementation time is 10 years. Construction starts 7 years out for three years. 4. Due to induced traffic, both alternatives experience same level of traffic congestion as before congestion after 10 years of improvements becoming operational. 5. Benefit-cost analysis is performed for 20 years starting at planning of project. 6. Congested speed is 30 mph, uncongested speed is 65 mph. Speed during construction of lanes drops from 30 mph to 25 mph. No reduction in speed is assumed with implementation of reversible lanes. 7. Vehicles per hour per lane during peak hours is 2,000 and congestion is assumed to last 2 hours. 8. Value of time is $16 per vehicle hour for commuting. 9. Discount rate = 3% per year.		
	Actual Costs and Benefits	**Present Value of Costs and Benefits**
Costs:		
Capital Costs	$560,000,000	$442,000,000
Operational and Maintenance Cost Per Year	$940,000	--
Present Value of O and M Costs (over 10 years)	--	$5,966,000
Cost of additional delay per year due to construction (over 3 years)	$6,720,000	--
Present value of additional delay due to construction	--	$15,458,000
Total Present Value Costs		**$463,424,000**
Benefits:		
Commuter time savings per year	$17,232,000	--
Present Value of commuter time savings (over 10 years, starting 10 years out in future)	--	$109,374,000
Total Present Value Benefits	**--**	**$109,374,000**
Benefit/Cost Ratio	**--**	**0.24**

To obtain a benefit / cost ratio of more than 1.0 (benefits = costs), the additional lanes needs to be constructed at less than $4.4 million per lane mile. Typically a benefit cost ratio should be in the region of at least 2.0 to be sure the project will be a good investment.

Table 11. Benefit/Cost Analysis of Reversible Lanes		
Assumptions: 1. Simplified analysis for 10 miles on six lane urban freeway. 2. One additional lane is provided in peak direction for a.m. and p.m. peaks. Costs from Table 6 are used. 3. Total implementation time for reversible lane is two years. Construction starts one year out for one year. 4. Due to induced traffic, both alternatives experience same level of traffic congestion as before congestion after 10 years of improvements becoming operational. 5. Benefit-cost analysis is performed for 20 years starting at planning of project. 6. Congested speed is 30 mph, uncongested speed is 65 mph. No reduction in speed is assumed with implementation of reversible lanes. 7. Vehicles per hour per lane during peak hours is 2,000 and congestion is assumed to last 2 hours. 8. Value of time is $16 per vehicle hour for commuting. 9. Discount rate = 3% per year.		
	Actual Costs and Benefits	**Present Value of Costs and Benefits**
Costs:		
Capital Costs (Includes movable barrier, 2 transfer machines and other fixed costs such as gates, crossovers, signage, etc.	$34,920,000	$33,904,000
Operational and Maintenance Costs Per Year	$846,446	--
Net Present Value of O and M Costs (over 10 years)	--	$6,806,000
Total Present Value Costs		**$40,710,000**
Benefits:		
Commuter time savings per year	$17,232,000	--
Present Value of commuter time savings (over 10 years)	--	$138,552,000
Total Present Value Benefits	**--**	**$138,552,000**
Benefit -Cost Ratio (over 10 years)	**--**	**3.4**

Table 10 and 11 did not include vehicle operational cost and safety costs. The amount of vehicle miles traveled is not impacted in this example and the reduction in costs due to a reduction in speed change cycles is considered low and will not have a meaningful impact on the magnitude of the benefit / cost ratio.

3. Reversible Freeway Lanes and the Associated Flexibility in Design and Operations

3.1 Overview – Why Flexibility?

In section 2.1.5 of this white paper, the possible impact of critical items such as Mobility as a Service (MaaS), particularly the ridesharing component of MaaS, and the headway reduction that will be realized by connected vehicles (CV) and autonomous vehicles (AV) addressed. There is no doubt that these initiatives will have a significant impact on future urban travel. The question is how and how much?

Tables 10 and 11 provide information to show how the approach of widening a freeway by constructing additional lanes is not cost-effective when generated traffic and, in particular, induced traffic are taken into consideration. In fact, providing additional lanes by reversing traffic flow is much more cost-effective (B/C ratio of 3.4 vs. 0.24). State DOTs have, as far as can be ascertained, often not taken into consideration the impact of induced travel. In addition, there are now many researchers who are confident that CV/AV will increase capacity. Some research indicates that AV will increase vehicle miles traveled, but nearly all research indicates that the increase in capacity is most likely higher than the increase in VMT.

All considered, if the following conditions exist:

- prevailing congestion along an urban freeway corridor, and
- a reasonable amount of directionality (see table 12 below),

then applying a reversible lane will outperform adding additional lanes by widening of the freeway.

As shown in Table 12, a directionality split of as low as 43%/57% can be good enough for a reversible lane on an eight-lane freeway. If a limited amount of congestion can be tolerated in the off-peak direction, considering that overall there will be significantly less delay on the freeway, the directional split can be lower than the percentages in Table 12.
Considering the above and the information provided in section 2, it is highly advisable to be able to maintain flexibility in terms of meeting the demands of present and future initiatives. Application of reversible lanes using movable barrier provides a significant amount of flexibility as shown in the next sections.

Table 12. Minimum Directional Split Requirement for Contraflow Lane Application on a Freeway		
Number of Lanes (total,both directions)	Percentage Traffic in Off-Peak Direction	Percentage Traffic in Peak Direction
4	33	67
6	40	60
8	43	57
10	44	56

Note:
The directional split calculation assumes 2,000 vehicles per hour per lane in the peak direction (at capacity) and the same for the with-flow lanes in off-peak direction once a lane is reversed in the off-peak direction for a minimum directional split calculation. The minimum directional split is the lowest directional split necessary for the reversal of the traffic flow on the median lane of the off-peak side not to cause any congestion on the with-flow lanes on the off-peak side.
For example, for a 6-lane freeway (3 lanes per direction) the volume on the peak side is 3 x 2,000 = 6,000 vehicles per hour. On the off-peak side, it is assumed the median lane traffic flow is reversed. The remaining two lanes will carry a volume of 2 x 2,000 = 4,000 vehicles. The directional split is therefore 4,000/10,000 = 40% on the off-peak side and 60% on the peak side.

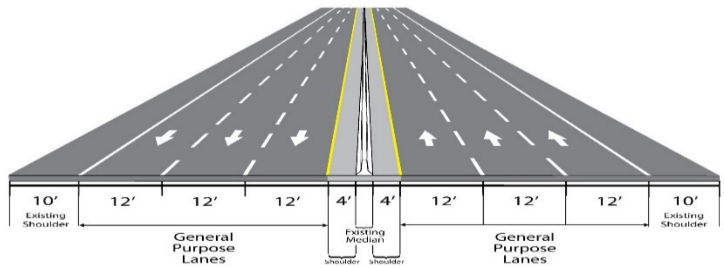
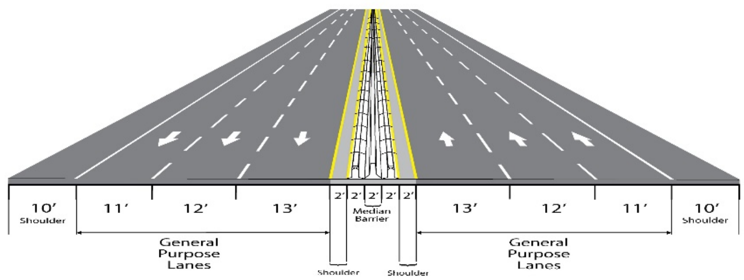
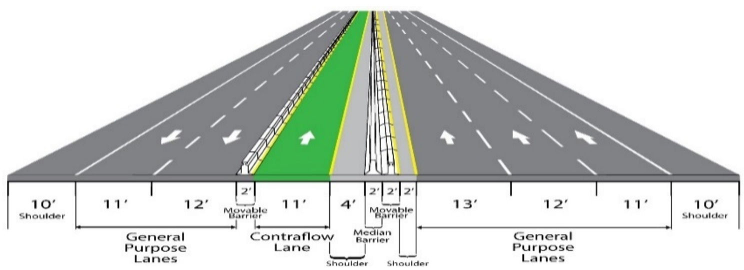
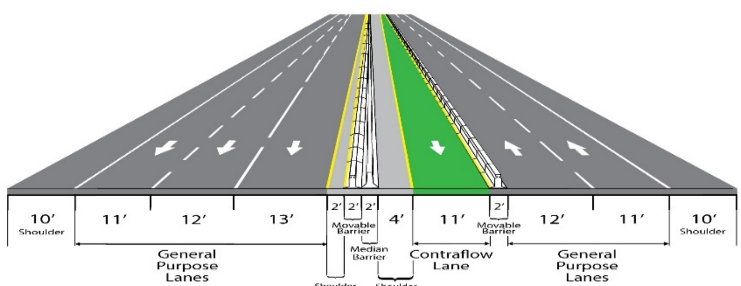
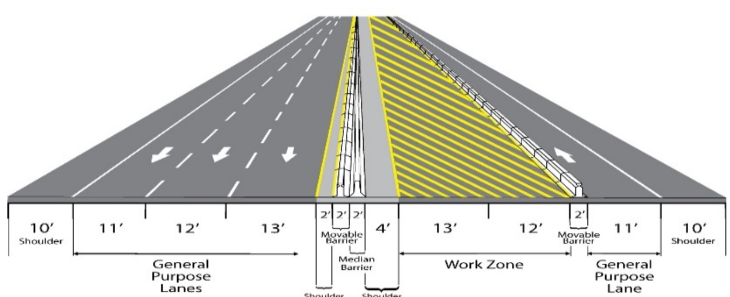
3.2 Illustrations on Flexibility Provided by Reversible Lanes Using Movable Barrier

Tables 13 to 16 on the following pages provide illustrations on how movable barriers can be applied to address congestion on urban freeways.

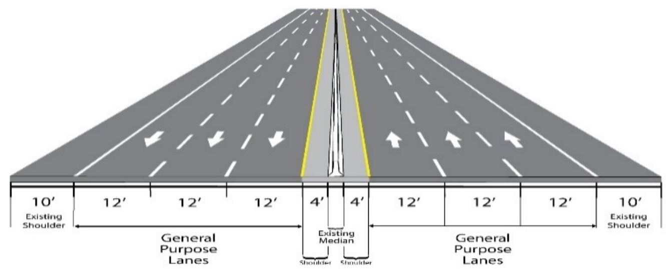
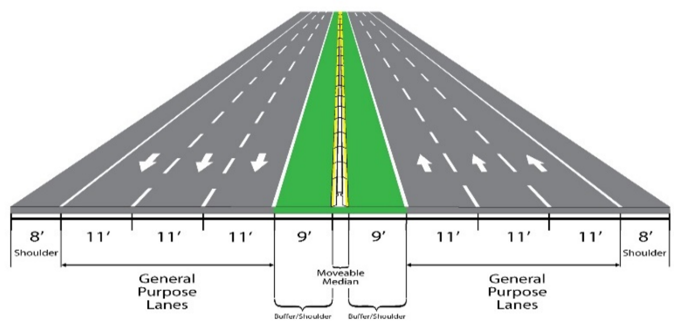
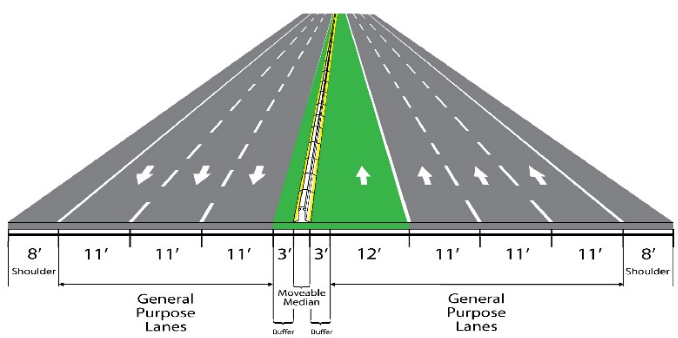
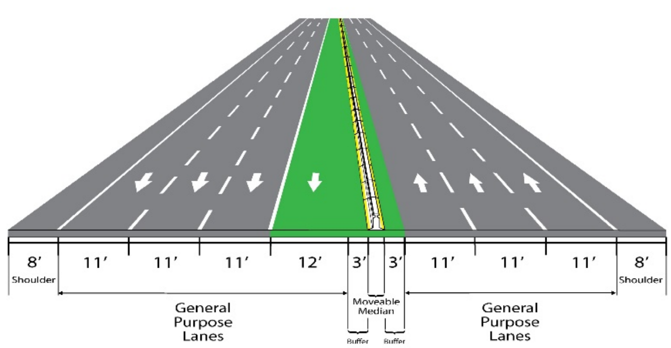
Notes about Tables 13-16:

1. Green generally indicates additional lanes provided by the movable barrier system.
2. The application of a movable median can be simplified by designing freeway overpasses without median columns. If median columns are present, a go-around can be applied but it increases operational time and narrows outside shoulders for a limited distance. The longer span required will increase the depth of the girders which can impact access to driveways adjacent to the road crossing the freeway.
3. The benefit in providing an additional (third) HOT lane in the peak direction as provided for in Table 15 might or might not increase revenue. If toll elasticity is higher than -1.0 then the revenue will most likely increase when the toll rate is reduced to attract additional toll-paying vehicles. If the elasticity is less than -1.0 then most likely there will not be a toll revenue increase.
4. Where the number of HOV vehicles that do not have to pay toll when using the HOT lanes is high, then a third HOT lane will come in handy. An additional peak-period lane will also benefit an existing HOT facility where there is only one HOT lane per direction.

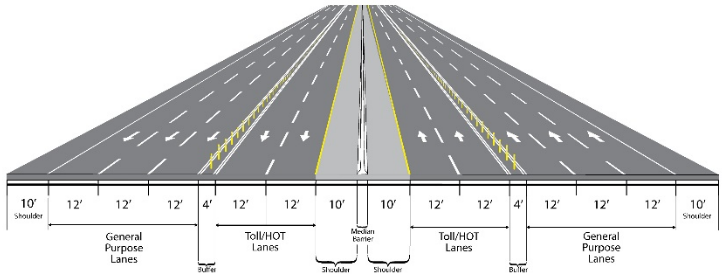
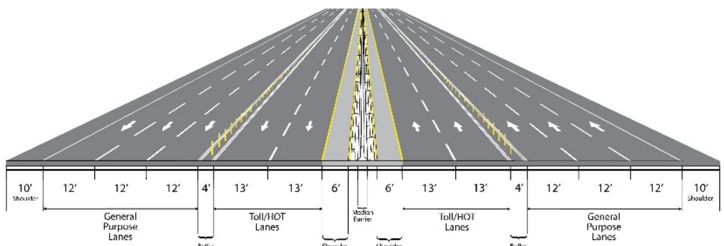
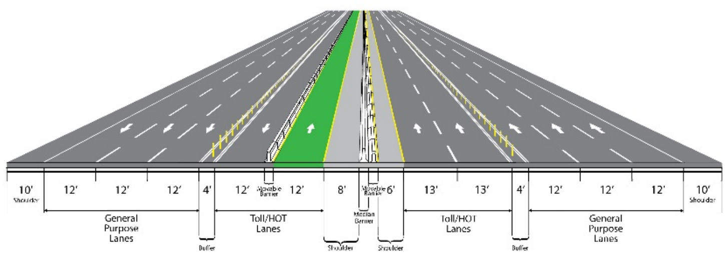
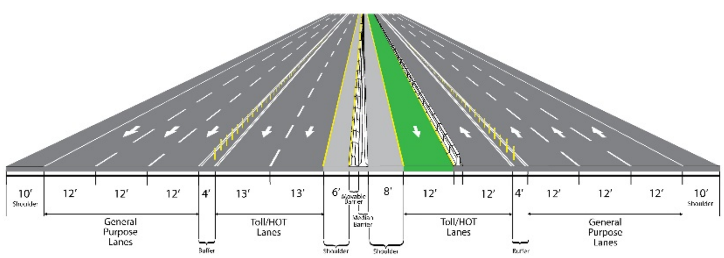
3.2.1 Contraflow System

Table 13. Flexibility Provided by Contraflow System Using Movable Barrier		
Typical Cross Section Before Implementation of Contraflow Lane System		A typical urban freeway cross section is assumed with 4 ft. inside shoulders, 12 ft. lanes and 10 ft. outside shoulders.
Contraflow System Movable barrier in neutral position.		Both movable barriers are placed next to the fixed median barrier during the off-peak periods.
Contraflow System Option 1: Provide one additional lane in a.m. peak period direction. Two lanes can also be provided depending on directional split.		For the implementation of the contraflow lane system, only restriping is necessary between crossover points including the lengths of the crossover points.
Contraflow System Option 2: Provide one additional lane in p.m. peak period direction. Two lanes can also be provided depending on directional split.		Depending on traffic characteristics, a contraflow lane can be added to the a.m. peak direction or the p.m. peak direction, or both.
Contraflow System Option 3: Use movable barrier system to open and close a work zone to minimize traffic disruption.		One or two lanes can be opened or closed with the movable barrier. This option can be particularly helpful along bridges and tunnels where shoulders are often non-existent or extremely narrow.

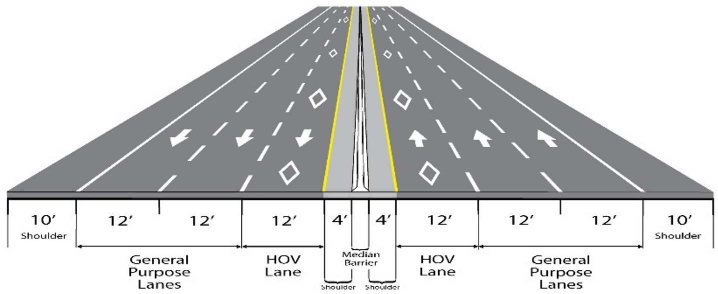
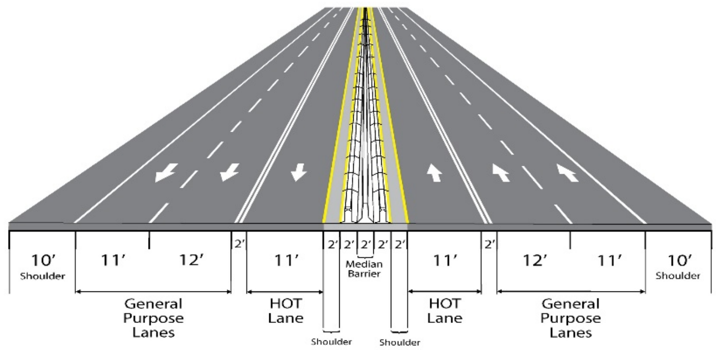
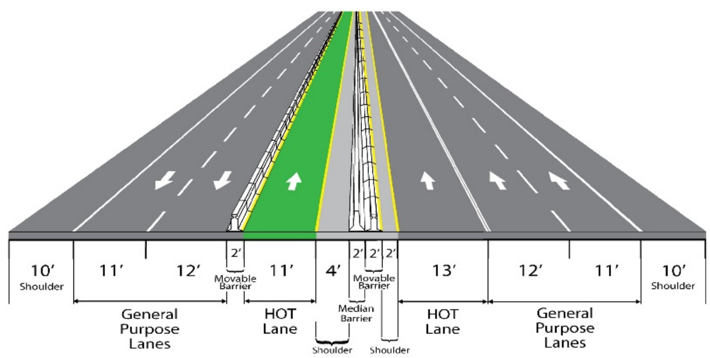
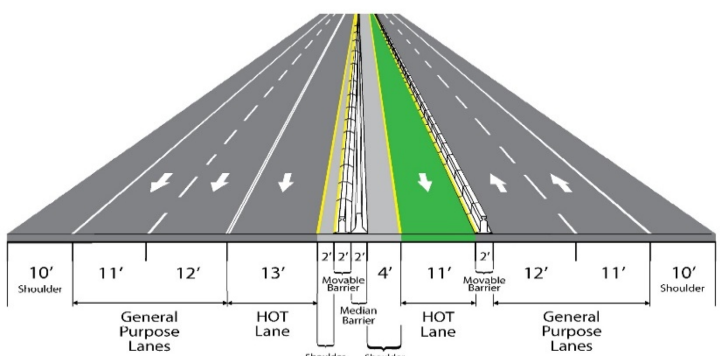
3.2.2 Movable Median System

<table>
<tr><th colspan="3">Table 14. Flexibility Provided by a Movable Median System Using Movable Barrier</th></tr>
<tr><td>Typical Cross Section Before Implementation of a Movable Median System</td><td>
</td><td>A typical urban freeway cross section is assumed with 4 ft. inside shoulders, 12 ft. lanes and 10 ft. outside shoulders.</td></tr>
<tr><td>Movable Median System
Movable barrier in neutral position.</td><td>
</td><td>For the implementation of the movable median system on an existing freeway, a fixed median barrier, light standards, signs and stormwater provisions might have to be removed. In addition, restriping of lanes might be necessary. A work-around is available for median columns, but requires additional operations. Because of the high level of flexibility provided by a movable median, where possible, the placement of utilities in the median should avoided.</td></tr>
<tr><td>Movable Median System Option 1:
Provide one additional lane in a.m. peak period direction.
Two lanes can also be provided depending on directional split.</td><td>
</td><td>The movable barrier can be moved to create two lanes in the peak direction if required.</td></tr>
<tr><td>Movable Median System Option 2:
Provide one additional lane in p.m. peak period direction.
Two lanes can also be provided depending on directional split.</td><td>
</td><td>A movable median provides significant flexibility to address changes in traffic flow over time, and can allow reasonable capacity to be maintained during major incidents, and maintenance.</td></tr>
</table>

3.2.3 HOT Managed Lane System with Contraflow Lanes

<table>
<tr><th colspan="3">Table 15. Flexibility Provided for HOT Managed Lanes by Using Movable Barrier to Provide a Contraflow Lane System within HOT lanes</th></tr>
<tr><td>Typical Cross Section Before Implementation of Contraflow Lane System within HOT Lanes</td><td>
</td><td>A typical urban freeway with HOT lane cross section.</td></tr>
<tr><td>Contraflow Lane System in neutral position</td><td>
</td><td>The neutral position will typically be in place during off-peak times.</td></tr>
<tr><td>Contraflow Lane System Option 1 Provide one additional HOT lane in a.m. peak period direction.</td><td>
</td><td>Providing an additional HOT lane during a peak period will allow the lowering of toll charges to draw more traffic to the HOT lanes which in turn will reduce congestion. The impact on toll revenue will depend on the price elasticity of drivers.</td></tr>
<tr><td>Contraflow Lane System Option 2: Provide one additional HOT lane in p.m. peak period direction.</td><td>
</td><td>The provision of the movable barrier will allow more options to address incidents and capacity reduction due to maintenance.</td></tr>
</table>

3.2.4 HOT Managed Lane System Created by Using Existing HOV Lanes

Table 16. Flexibility by Movable Barrier to Provide a Viable HOT Managed Lane System Using Existing HOV Lanes to Operate as Contraflow and With-Flow Lanes		
Typical Cross Section Before Implementation of a Movable Barrier System		A typical urban freeway cross section is assumed with 4 ft. inside shoulders, 12 ft. lanes and 10 ft. outside shoulders.
HOT Managed Lane System in Neutral position (off-peak)		The conversion of existing HOV lanes to HOT lanes and the application of the movable barrier to create two HOT lanes operating in the peak direction has potential for revenue stream requiring minimal capital costs.
HOT Managed Lane System Option 1 Provide one additional HOT lane in a.m. peak period direction.		For the implementation of the contraflow lane HOT lanes, only restriping is necessary. Plastic pylons might be necessary to prevent general purpose lane vehicles from moving in and out of the HOT lanes.
HOT Managed Lane System Option 2 Provide one additional HOT lane in p.m. peak period direction.		The conversion of HOV lanes to HOT lanes using the movable barrier will allow toll pricing to make carpooling more attractive if high occupancy vehicles are allowed to use the HOT lanes free of charge.

4. Flexibility and Highway Design

Tables 13 to 16 provides illustrations showing how the movable barrier system can be applied to reduce congestion on urban freeways. As can be seen, there are many variations in the application of the movable barrier system.

One of the most flexible configurations is illustrated in Table 14 with the movable barrier operating as a movable median. Movable median application can also be applied with two movable barriers running parallel to each other. This provides further possibilities such as a central, barrier separated reversible managed lane (one or two lanes), and can operate as an HOV lane or an HOT lane.

When an urban freeway is reconstructed or when a new freeway is constructed, the accommodation in the design of a movable median will significantly increase the ability to respond to unforeseen future circumstances. In accommodating a movable median, there should be no or limited median obstructions, particularly bridge columns. Lateral grades, storm water management, and the placement of light standards and signs should also be taken into consideration. A further consideration is the increase in the depth of girders when the span of the girders increases. For example, a span of 150 feet might require a girder depth of 6 feet. This might require some re-grading of cross street approaches to a bridge.

All considered, a design that can eliminate median columns and enhance the application of a movable median system will ensure that the freeway will be able to function optimally many more years in future than a conventionally designed inflexible freeway.

What is also of note is that the “green” lanes in Figures 13-16 are ideal lanes for the accommodation of express bus service and/or the accommodation of autonomous vehicles during the initial stages of deployment.

5. New California Legislation

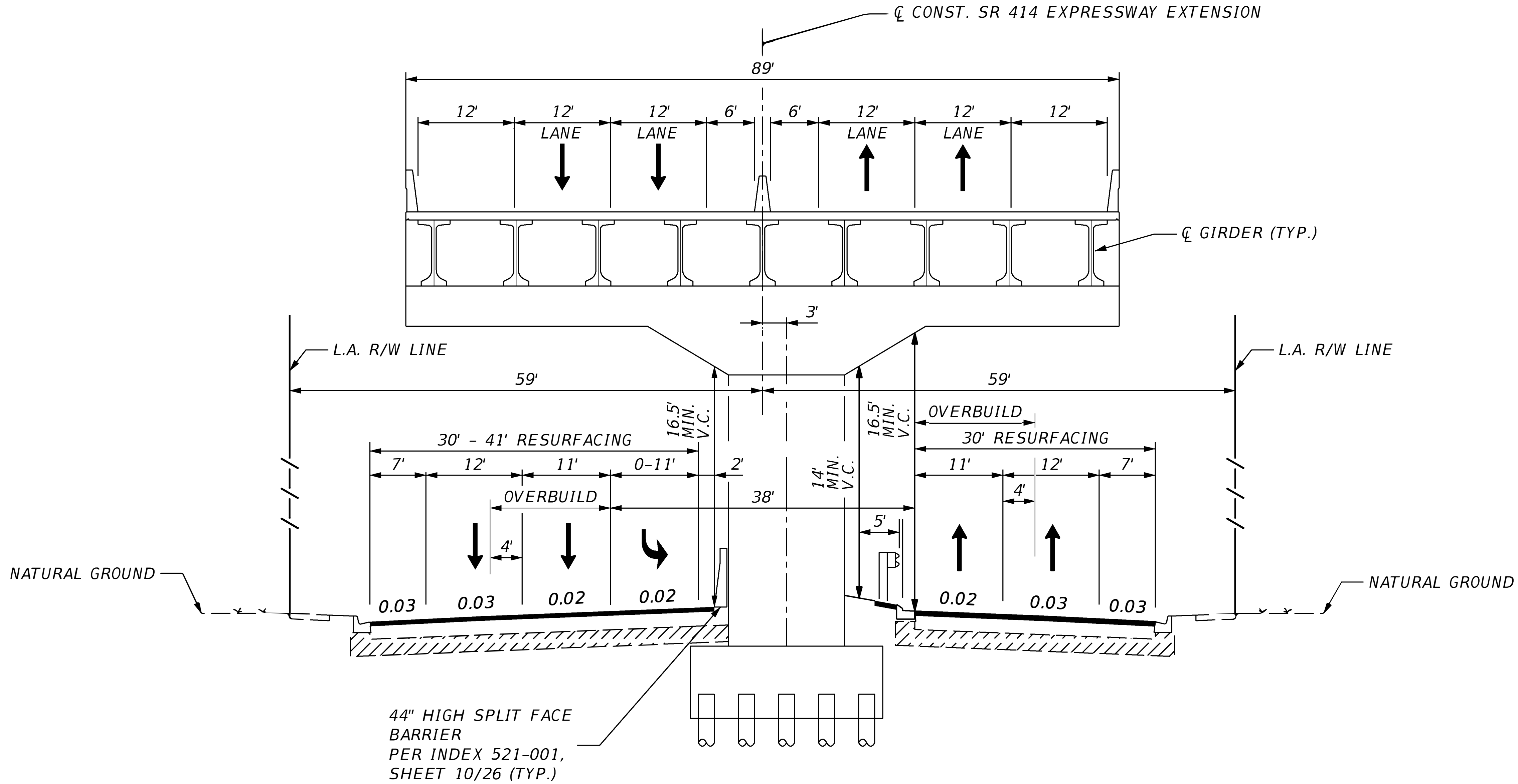
On September 23, 2016, the California state legislature passed Bill AB 2542 that requires, prior to the California Transportation Commission (CTC) approving a capacity-increasing project or major street or highway lane realignment project, the California Department of Transportation (Caltrans) or a regional transportation planning agency must demonstrate that reversible lanes were considered for the project.

The legislature provided the following further comments during hearings:

- Reversible lanes add peak-direction capacity to a two-way road and decrease congestion by "borrowing" available lane capacity from the other (off-peak) direction. The lanes are particularly beneficial where the cost to increase capacity is especially expensive, like on bridges and in dense urban areas.
- Reversible lanes are not new to California. In fact, reversible lanes were first inaugurated on the Golden Gate Bridge in October 1963. While they worked to reduce serve traffic in the peak direction, they were labor intensive to operate and posed serious safety problems because they led to the increase in head-on collisions. Now the lanes are adjusted with the aid of a "zipper"-a moveable barrier machine that transfers a heavy concrete and metal barrier across one lane and related labor and safety problems have been minimized. Today, in addition to the Golden Gate Bridge, reversible lanes are used on the San Diego-Coronado Bridge, Interstate 15 in San Diego, and, until recently, in the Caldecott Tunnel (in California). Furthermore, the use of reversible lanes is increasing, for example, during large sporting events, traffic incidents, construction, and evacuations.

- According to the Texas A&M Transportation Institute (TTI), the decision to consider reversible lanes is usually based on the need to mitigate recurrent congestion. Reasons agencies give for using reversible lanes include: congestion mitigation, queue length, the need to decrease travel time, and the need to improve the overall corridor level of service. TTI asserts that planning of specific reversible facilities does not differ substantially from conventional facilities. It also suggests that "the vast majority of reversible lanes are implemented on lanes not originally planned or designed for bi-directional use. Most reversible lanes are incorporated into conventionally designed roadways that were later reconfigured for permanent or periodic flow conversions using various permanent or temporary design and control features. The exceptions to this case are applications on freeways, in particular freeway high occupancy vehicle (HOV) and transit reversible lanes, where transition termini and lane separations are planned, designed, and constructed specifically for the purpose of a reversible lane."

Appendix H
Recommended Typical Section Refinements



TYPICAL SECTION 4A

OPTION 4 REFINEMENT

WITH LEFT TURN LANE ON MAITLAND BOULEVARD

PRELIMINARY - SUBJECT TO CHANGE

ENGINEER OF RECORD: KRYSTAL H. BURNS, P.E.
P.E. LICENSE NO. 60883

JACOBS ENGINEERING GROUP INC.
200 S. ORANGE AVENUE, STE 900
ORLANDO, FL 32801; PHONE (407) 903-5001
CERTIFICATE OF AUTHORIZATION No. 000072

SR 414 MAITLAND BLVD.
EXPRESSWAY EXTENSION
US 441 TO SR 434

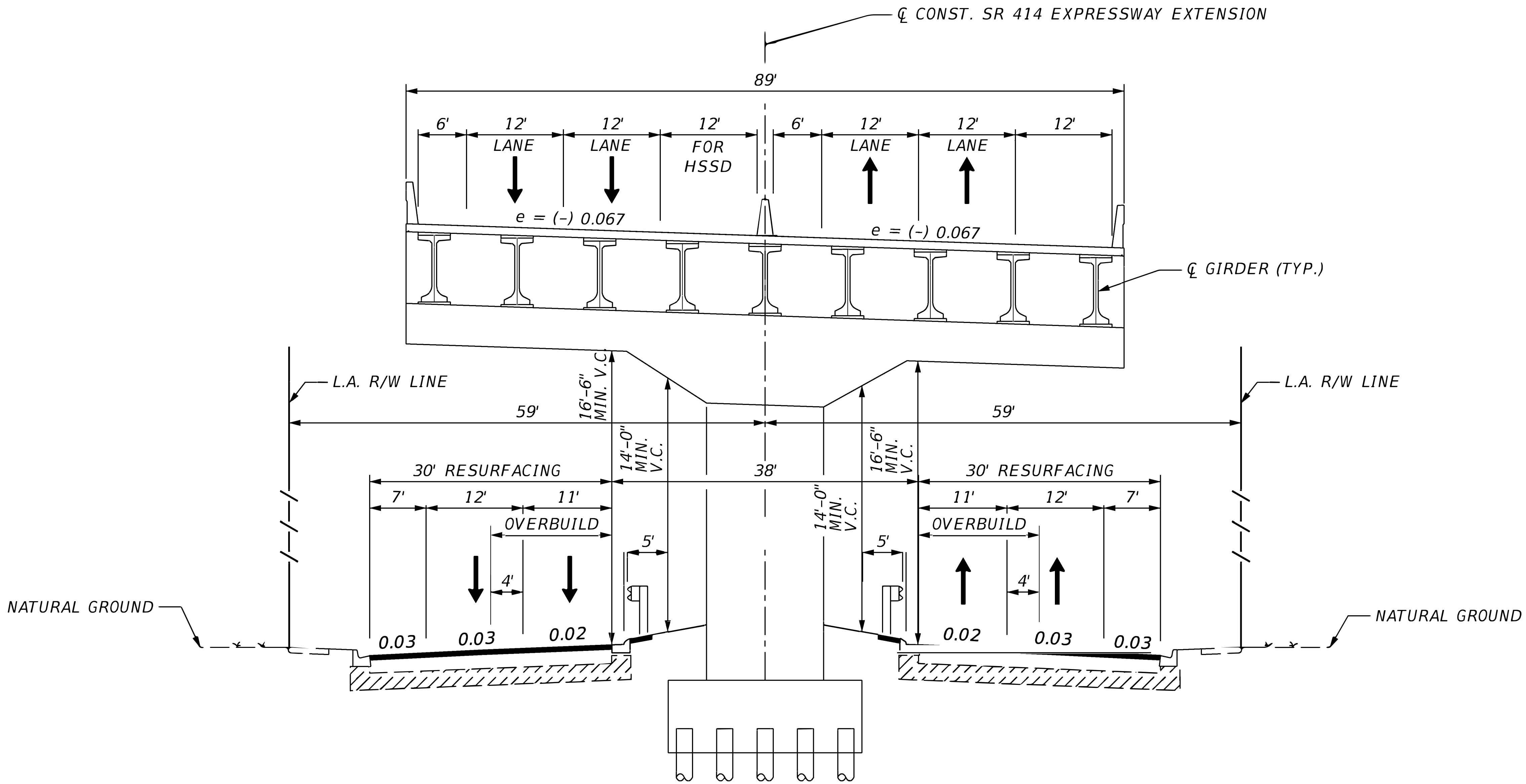
ROAD NO.	PROJECT NO.
SR 414	414-227

CENTRAL FLORIDA EXPRESSWAY AUTHORITY

TYPICAL SECTIONS

DRAFT

SHEET NO.



TYPICAL SECTION 4B

OPTION 4 REFINEMENT

SUPERELEVATION NEAR BEAR LAKE RD

PRELIMINARY - SUBJECT TO CHANGE

ENGINEER OF RECORD: KRYSTAL H. BURNS, P.E.
P.E. LICENSE NO. 60883

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TYPICAL SECTIONS

DRAFT

SHEET NO.