TASK 200: CIVIL ENGINEERING SCHEMATIC DESIGN

Civil Engineering Schematic Design

The civil engineering schematic design task involved creating essential design base files and a schematic roll plot for the preferred deck plaza concept and associated improvements, in collaboration with the Landscape Architecture team. The civil design procedure remained consistent across alternatives, with specific sub-tasks including developing plan and profile layouts along with typical sections, creating a preliminary 3-D Open Roads model for the proposed civil design features, verifying the Right-of-Way requirements, and planning construction sequencing, which encompassed layout, typical sections, and detailed descriptions of work activities and traffic management for each stage.

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3.1 General Information

3.1.1 REVISED SCHEMATIC

The schematic for the IH-10 Deck Plaza has been updated to reflect client-requested modifications. Key changes include the realignment of the westbound frontage road (Yandell Ave), the removal of U-turns at N Santa Fe Street and N Mesa Street, and adjustments to typical sections.

3.1.2 PRELIMINARY GEOMETRIC DESIGN

The project extends from the eastern edge of N Campbell Street to the western edge of Prospect Street.

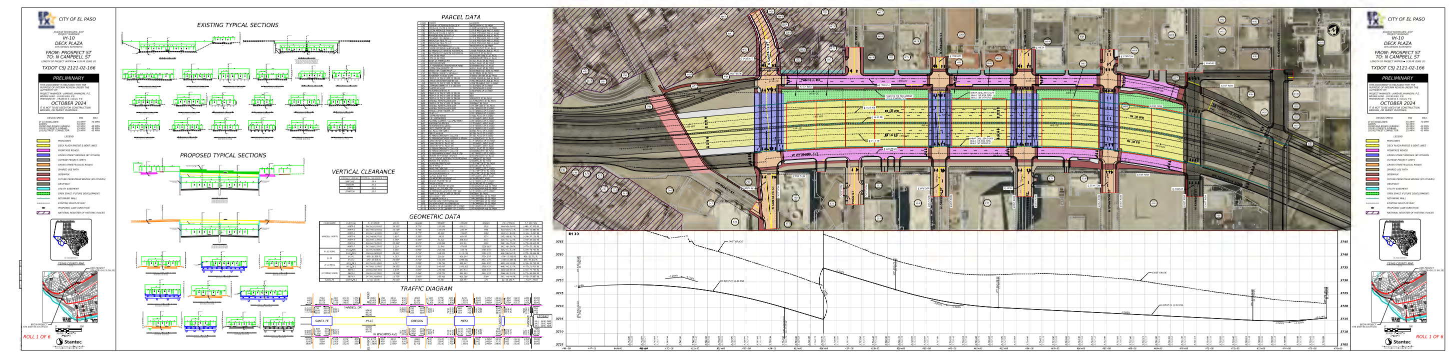

Figure-60 : El Paso Deck Plaza Civil Schematic Plan

3.2 Mainlane Roadway

3.2.1 The centerline alignment of the IH-10 mainlane roadway has been shifted approximately 45 feet north of the existing centerline. The roadway will now consist of four 12-foot lanes in each direction, with outside shoulders widened to 25 feet and inside shoulders to 13.5 feet, replacing the existing three 12-foot lanes, a 10-foot outside shoulder, and an 8-foot inside shoulder.

3.2.2 The profile of IH-10 remains unchanged from the original schematic, with a proposed lowering of the pavement by 12 to 17 feet below the existing grade.

3.2.3 A 2.5% mainlane cross slope was assumed.

TASK 200: CIVIL ENGINEERING SCHEMATIC DESIGN

3.3 FRONTAGE ROADS

3.3.1 EASTBOUND (W WYOMING AVE)

The Eastbound Frontage Road (EBFR), identified as W Wyoming Ave, has been shifted north to align parallel with the back of the IH-10 eastbound retaining wall. It retains the existing traffic layout with three 12-foot lanes, and its original profile was raised to tie in with the IH-10 eastbound retaining wall.

3.3.2 WESTBOUND (YANDELL DRIVE)

i. The Westbound Frontage Road (WBFR), designated as Yandell Ave, has undergone significant changes. Originally intended to shift south to align with the IH-10 westbound retaining wall, the refined schematic now positions it closer to the existing Yandell Ave footprint, maintaining a gap of approximately 50-55 feet from the wall.

ii. The WBFR profile has been adjusted to enhance cross-street tie-ins, reducing the lane configuration from four 12-foot lanes to three.

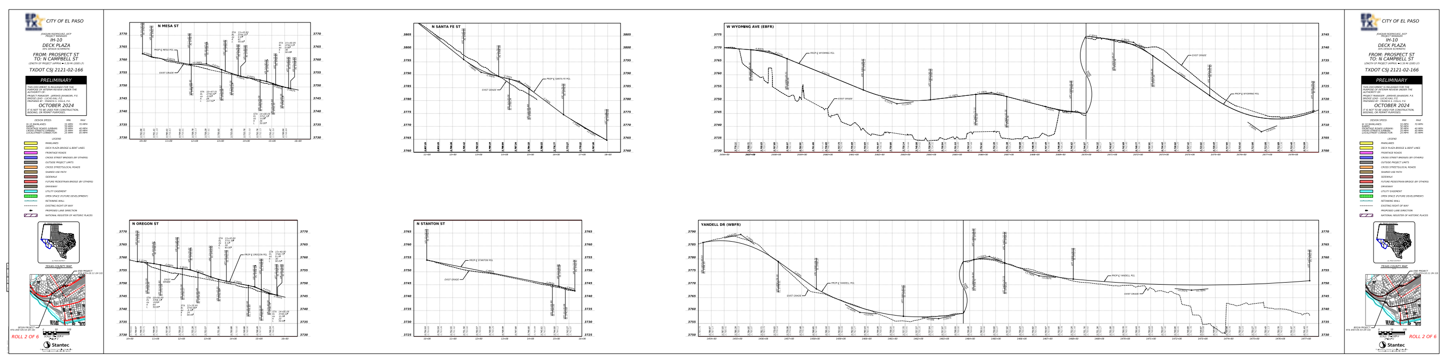

Figure-61 : El Paso Deck Plaza Civil Schematic Profiles

3.4 CROSS STREETS

3.4.1 N SANTA FE STREET

i. The refined schematic eliminates the West-to-East U-turn lane and narrows the crossing width to 107 feet.

ii. The vertical profile is unaltered.

iii. The crossing configuration includes two southbound through lanes, one southbound left turn lane, two northbound left turn lanes, and two northbound through lanes.

3.4.2 EL PASO STREET

i. The bridge crossing at El Paso Street has been removed.

3.4.3 N OREGON STREET

i. The crossing footprint remains unchanged as there was no U-turn lane in the original schematic.

ii. The vertical profile is unaltered.

iii. The crossing configuration features two southbound lanes (one through and one left turn), one northbound left turn lane, and two northbound through lanes.

3.4.4 N MESA STREET

i.The refined schematic removes both West-to-East and East-to-West U-turn lanes and reduces the crossing width to 110 feet.

ii. The vertical profile is unaltered.

iii. The crossing configuration includes two southbound through lanes, one southbound left turn lane, one northbound left turn lane, and two northbound through lanes.

3.4.5 N STANTON STREET

i. The crossing footprint is maintained, with no U-turn lane from the original schematic.

ii. The vertical profile is unaltered.

iii. The crossing configuration provides three northbound lanes.

3.5 VERTICAL CLEARANCES

The revised schematic ensures a minimum vertical clearance of 18 feet 6 inches for all bridge crossings above IH-10. The specific clearances are as follows:

N Santa Fe St – 29.4 ft

N Oregon St – 27.2 ft

N Mesa St – 34.2 ft

N Stanton St – 28.6 ft

These clearances at the eastbound mainlane wall face were calculated based on the following assumptions:

a. Mainlane cross slope = 2.5%

b. Bridge cross slope = 2.0 %

c. No superelevation

d. Deck slab thickness = 12 in

e. Deck girder thickness = 70 in

3.6 TRAFFIC DIAGRAM

The refined schematic includes a detailed traffic diagram that outlines the Average Daily Traffic (ADT) for all potential movements on IH-10, the frontage roads, and the cross streets between N Santa Fe St and N Kansas St for the years 2030, 2050, and 2060.

TASK 200: CIVIL ENGINEERING SCHEMATIC DESIGN

3.7 CONSTRUCTION SEQUENCING

The refined schematic (schematic rolls four through six) outlines a high-level design for the construction sequence within the project limits, detailing the following phases and major milestones.

3.7.1 PHASE 1

i. Shift all IH-10 lanes to existing eastbound mainlane pavement.

ii. Reduce westbound and eastbound down to (2) lanes each direction.

iii. Partially remove bridges over existing westbound mainlanes.

3.7.2 PHASE 2

i. Construct proposed westbound mainlane pavement.

ii. Construct portion of proposed cross street and deck plaza bridges.

iii. Construct portion of proposed westbound frontage road (Yandell Drive).

3.7.3 PHASE 3

i. Shift westbound frontage road (Yandell Drive) to newly constructed pavement.

ii. Construct remaining portion of proposed Yandell Drive.

3.7.4 PHASE 4

i. Shift westbound and eastbound IH-10 lanes to newly constructed pavement.

ii. Remove remaining portions of bridges over existing eastbound mainlanes.

3.7.5 PHASE 5

i. Construct proposed eastbound mainlane pavement.

ii. Construct remaining portion of proposed cross-street and deck plaza bridges.

iii. Construct proposed eastbound frontage road (Wyoming Avenue)

3.7.6 PHASE 6

i. Shift IH-10 mainlanes to final configuration.

ii. Shift eastbound frontage road (Wyoming Avenue) to newly constructed pavement.

iii. Construct remaining portion of cross streets, sidewalk and corridor.

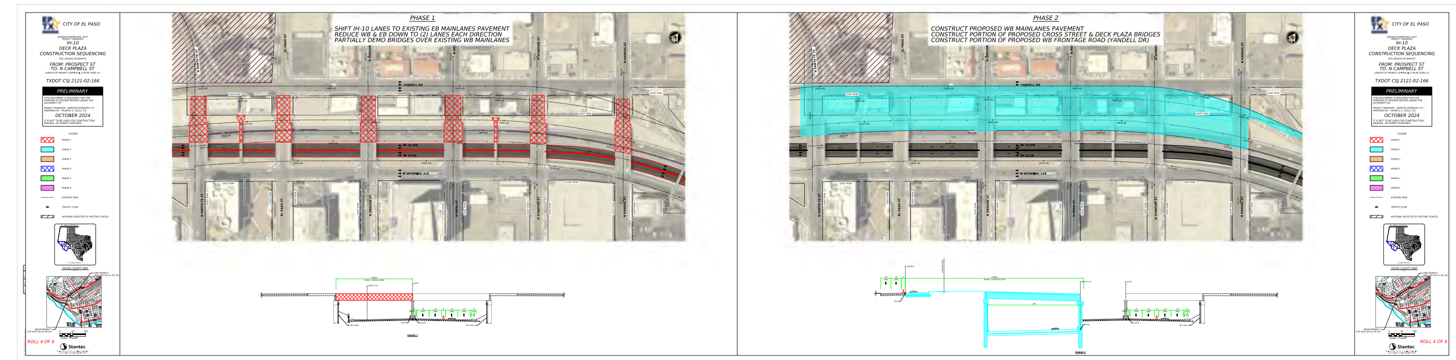

Figure-62 : El Paso Deck Plaza Civil Schematic Construction Sequencing Phase 1 & 2

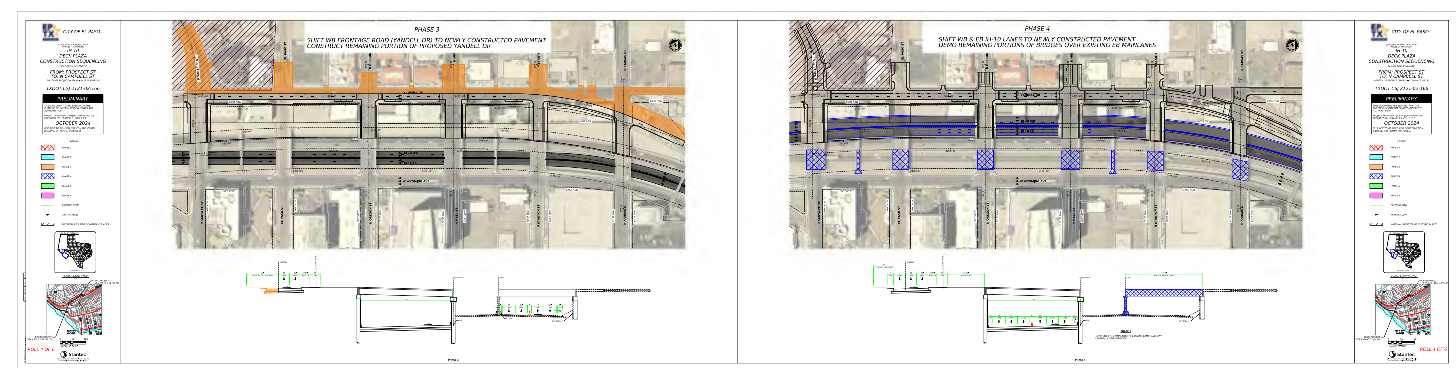

Figure-63 : El Paso Deck Plaza Civil Schematic Construction Sequencing Phase 3 & 4

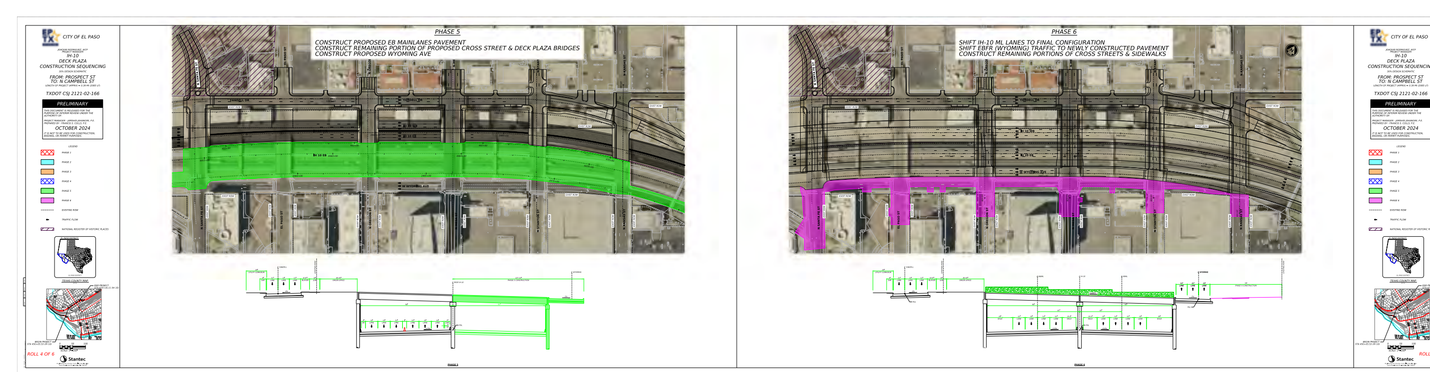

Figure-64 : El Paso Deck Plaza Civil Schematic Construction Sequencing Phase 5 & 6

VIEW FROM THE BIG VIEW OVERLOOK LOOKING EAST

TASK 300: STRUCTURAL SCHEMATIC DESIGN

TASK 300: STRUCTURAL SCHEMATIC DESIGN

Structural Schematic Design

The El Paso Deck Park Structural Schematic Design provides a preliminary framework for the project's key structural components. This phase includes schematic designs for the deck, beams, walls, piers, and foundations.

The deck schematic outlines the preliminary layout and structural requirements necessary to support the park's surface and amenities. The beam schematics detail the initial design for load distribution and support across the deck. Wall schematics are developed to ensure preliminary stability and safety considerations. The pier schematics indicate the strategic placement and design necessary to support the overall structure. Foundation schematics provide an initial plan for anchoring the entire system securely to the ground, ensuring durability and resilience.

It is important to note that this is only the schematic design phase, serving as a foundational blueprint to guide further detailed design and construction planning.

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4.6 RETAINING WALL

- 4.6.1 Retaining Wall Selection
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4.7 FUTURE WORK

4.1 Introduction

The El Paso Deck Plaza project focuses on creating a structurally sound deck over the I-10 freeway, transforming the area into a public space that reconnects downtown El Paso. Our structural design emphasizes the use of a robust superstructure composed of concrete deck supported by TX70 girders, which were chosen for their proven efficiency and adaptability to the project's requirements.

The foundation design includes drilled shafts, strategically spaced and dimensioned, to support the superstructure and handle various load conditions. By adhering to AASHTO and TxDOT standards, the design ensures optimal safety and stability during both construction and long-term use. This section emphasizes the schematic design for both the substructure and superstructure of this transformative project, which aims to create a safe and resilient urban space for the community.

4.2 General Information

The deck plaza consists of a concrete superstructure designed to carry a variety of loads from open spaces, landscaping, and buildings.

4.2.1 STRUCTURAL COMPONENT TYPE

- **Superstructure Type:** 1 ft thick concrete deck supported by TX70 girders
- **Substructure Type:** Piers and abutments designed to accommodate varying grade conditions. The abutments are supported by drilled shafts with a diameter of 5.5 ft spaced at 6 ft. The interior wall bent has a width of 2 ft 6 inches and is supported by drilled shafts with a diameter of 3 ft, spaced at 9 ft.
- **Retaining Wall Type:** Soil nail walls (designed by others).

4.2.2 GEOTECHNICAL BORINGS SUMMARY

Geotechnical borings were performed at 7 key locations within the project limits to gather information on soil and groundwater conditions. The borings data provide essential insights into subsurface stratigraphy, which have been used to refine the foundation design.

Borehole ID	Ground Elevation (ft)	Soil Description
B-1	3780	Silty sands, clay layers (CH), lean clays (CL)
B-2	3762	Poorly graded sands, fat clays (CH)
B-3	3766	Clayey sands (SC), lean clays (CL)
B-4	3750	Silty sands, clayey sands (SC)
B-5	3752	Sandy lean clays (SC)
B-6	3736	Silty sands, clayey sands (SC), lean clays (CL)
B-7	3743	Silty sands, lean clays (CL), poorly graded sands

Figure-65 : Summary of Geotechnical Borings Data

TASK 300: STRUCTURAL SCHEMATIC DESIGN

These findings indicate a varied subsurface profile, predominantly consisting of sandy and clayey soils. Groundwater levels were observed in some boreholes, which should be considered in the final design.

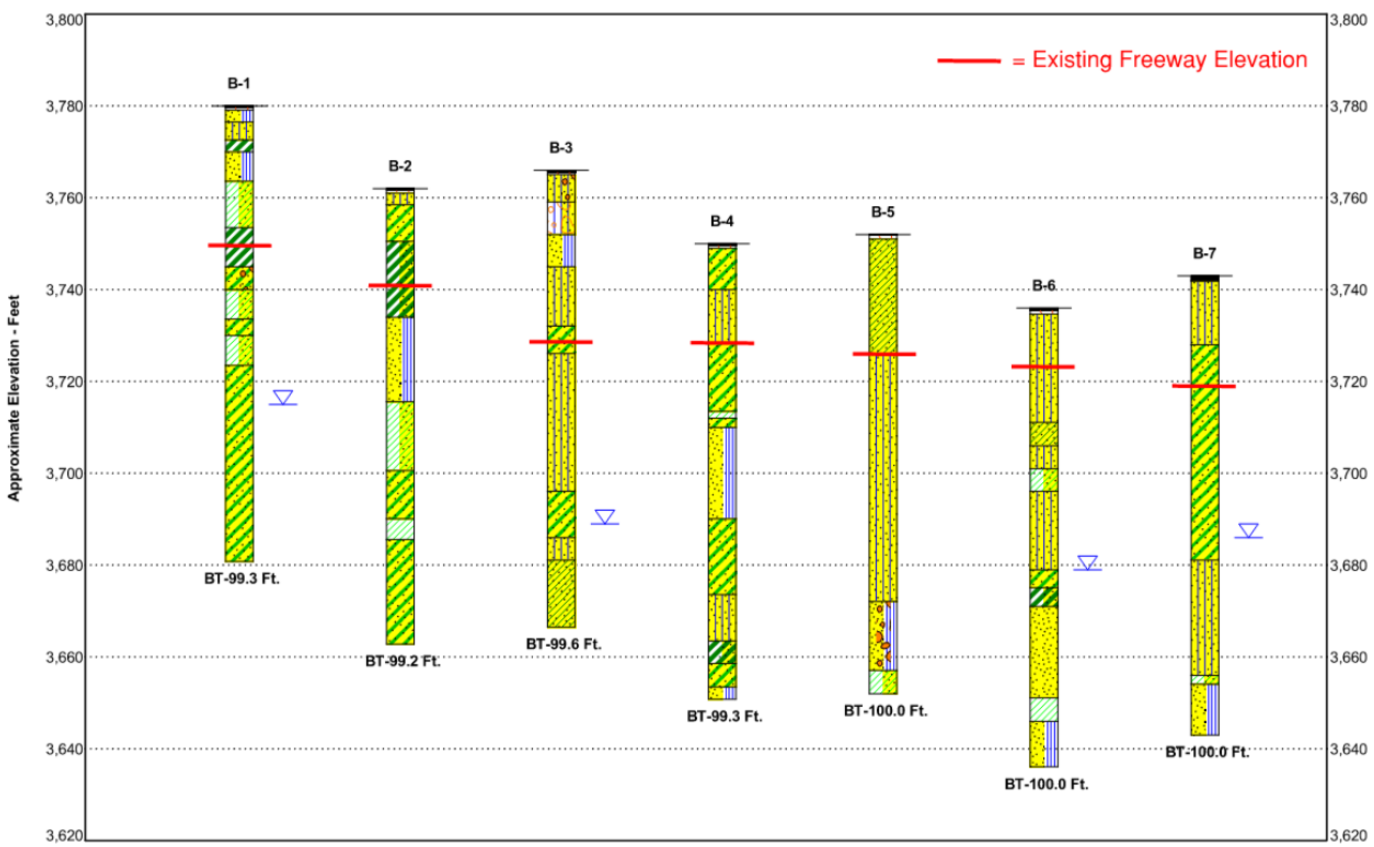


Figure-66 : Elevation Profiles of Ground, Existing Freeway, and Groundwater

4.2.3 ASSUMPTIONS AND RECOMMENDATIONS

Since geotechnical data for the project is yet to be finalized, conservative assumptions have been made to guide the foundation design, particularly concerning the soil properties and related calculations. Key assumptions include:

- **Soil Properties:** A conservative soil angle of internal friction and coefficient of friction between the soil and structural elements have been assumed to account for potential variations in soil conditions.
- **Bearing Capacity:** Normal soil bearing pressure is used for design calculations, accommodating the estimated bearing capacity of the soil to prevent undue settlement or failure of the foundation.
- **Material Densities:** Assumed values for normal concrete density and soil density are utilized in the analysis to estimate dead loads and pressure exerted by the soil on retaining walls and foundations.

4.3 Design Loadings And Criteria

The design of the El Paso Deck Plaza's structural system relies on a comprehensive assessment of the different types of loads it must bear. These loads are calculated to ensure safety, durability, and functionality over the structure's lifespan.

PRELIMINARY DESIGN LOADING TABLE			
DESCRIPTION	SERVICE I		
	DL (PSF)	PL OR LL (PSF)	DL+PL OR DL+LL (PSF)
OPEN SPACE	1001.5	250	1251.5
2-STORY BUILDING	542	200	742
3-STORY BUILDING	572	300	872
CONSTRUCTION		326	326

Figure-67 : Preliminary Design Loading Table

4.3.1 OPEN SPACE LOADING

The open spaces in the deck plaza are designed to accommodate large crowds, landscaping, and recreational features. The dead load (DL) for these areas is calculated as 1001.5 psf, accounting for the weight of the concrete deck, permanent fixtures, and typical landscaping. The live load (LL) is set at 250 psf, which considers crowds, light structures, and temporary installations such as benches, planters, and events.

4.3.2 BUILDING LOADING (TWO- AND THREE-STORY STRUCTURES)

The deck plaza design anticipates supporting two- and three-story buildings in certain sections. The building loading is set to account for both structural and operational requirements:

- **2-Story Buildings:** Dead Load (DL) = 542 psf, Live Load (LL) = 200 psf.
- **3-Story Buildings:** Dead Load (DL) = 572 psf, Live Load (LL) = 300 psf.

These values ensure that the deck can safely support the weight of the buildings and the people, equipment, and activities within them. These calculations account for the weight of building materials, internal fixtures, and typical occupancy levels expected in the proposed structures.

4.3.3 CONSTRUCTION LOAD CONSIDERATIONS

During construction, the deck plaza must support additional temporary loads from equipment, materials, and personnel. The live load (LL) for construction activities is set at 326 psf, considering:

- **Heavy machinery and equipment:** The design accounts for the movement and operation of construction vehicles, cranes, and other heavy machinery, ensuring the deck withstands temporary dynamic loads while maintaining stability.
- **Material storage and staging:** The design includes adequate provisions for staging areas where construction materials such as concrete, steel, and landscaping components will be stored. This ensures that the deck can support concentrated loads during the construction phase.
- **Compliance with AASHTO LRFD specifications:** The load factors and safety margins for temporary loads follow AASHTO LRFD guidelines, which specify criteria for live load factors, dynamic effects, and temporary support structures.

4.3.4 LOAD COMBINATIONS

The structural analysis for the El Paso Deck Plaza adheres to the load combination guidelines outlined by AASHTO LRFD Bridge Design Specifications and ASCE 7. These standards provide a framework for combining different types of loads to assess the overall stability, safety, and serviceability of the structure. Key load combinations are selected to reflect the most critical conditions the deck plaza may encounter during its lifespan.

TASK 300: STRUCTURAL SCHEMATIC DESIGN

AASHTO Load Combinations

The AASHTO LRFD Bridge Design Specifications define various load combinations to ensure the safety and stability of bridge structures. For the El Paso Deck Plaza, the following combinations are applied:

- **Strength I:** This combination includes dead load (DC), superimposed dead load (SDL), and live load (LL) along with dynamic effects. This combination represents typical loading conditions during regular usage.
- **Strength III:** Includes dead loads and wind loads to account for stability under wind effects. This combination is essential for evaluating the deck's performance in strong wind conditions.
- **Strength V:** Combines dead load, live load, and wind loads, with additional considerations for any significant dynamic effects, such as braking or starting of vehicles on the deck.

ASCE Load Combinations

The ASCE 7 standard offers additional load combination guidelines, particularly for structures supporting buildings or specialized installations on the deck. The following key combinations are relevant to the deck plaza design:

- **1.4D:** This combination considers only the dead load (D) and is crucial for evaluating the structural integrity of the deck under its self-weight.
- **1.2D + 1.6L + 0.5(Lr or S or R):** Combines dead load (D), live load (L), and either roof live load (Lr), snow load (S), or rain load (R). This combination is used to assess the deck's stability when supporting additional structures or installations.
- **0.9D + 1.0W:** Accounts for reduced dead load (D) combined with wind load (W). This combination is essential for stability under strong winds, especially in regions with significant wind activity.

4.4 Superstructure

The superstructure of the El Paso Deck Plaza is the critical component that spans the I-10 freeway, providing a solid base for the multi-use public space above. The design employs TX70 girders, which have been selected for their efficiency in spanning long distances while supporting the heavy loads expected from both open spaces and potential building areas on the deck.

4.4.1 SPAN LENGTH AND CONFIGURATION

The deck structure is designed with **two 100-foot spans**, each supported by piers placed strategically to minimize interference with the freeway traffic below. The span length was determined based on a combination of factors, including:

- **Maximizing usable space on the deck:** By opting for longer spans, the design creates more uninterrupted open space above the freeway, allowing for a versatile layout that can accommodate both green spaces and buildings without excessive structural intrusions.
- **Minimizing disruptions to freeway traffic:** The wall bent placements are carefully designed to ensure that they do not interfere with key freeway lanes, ramps, or overpasses, maintaining smooth traffic flow during and after construction.

The **longitudinal and transverse sections** of the deck are designed to accommodate the varying grades of the existing terrain. This involves a stepped deck profile that follows the natural elevation changes across the site, providing structural efficiency and reducing the need for excessive grading work.

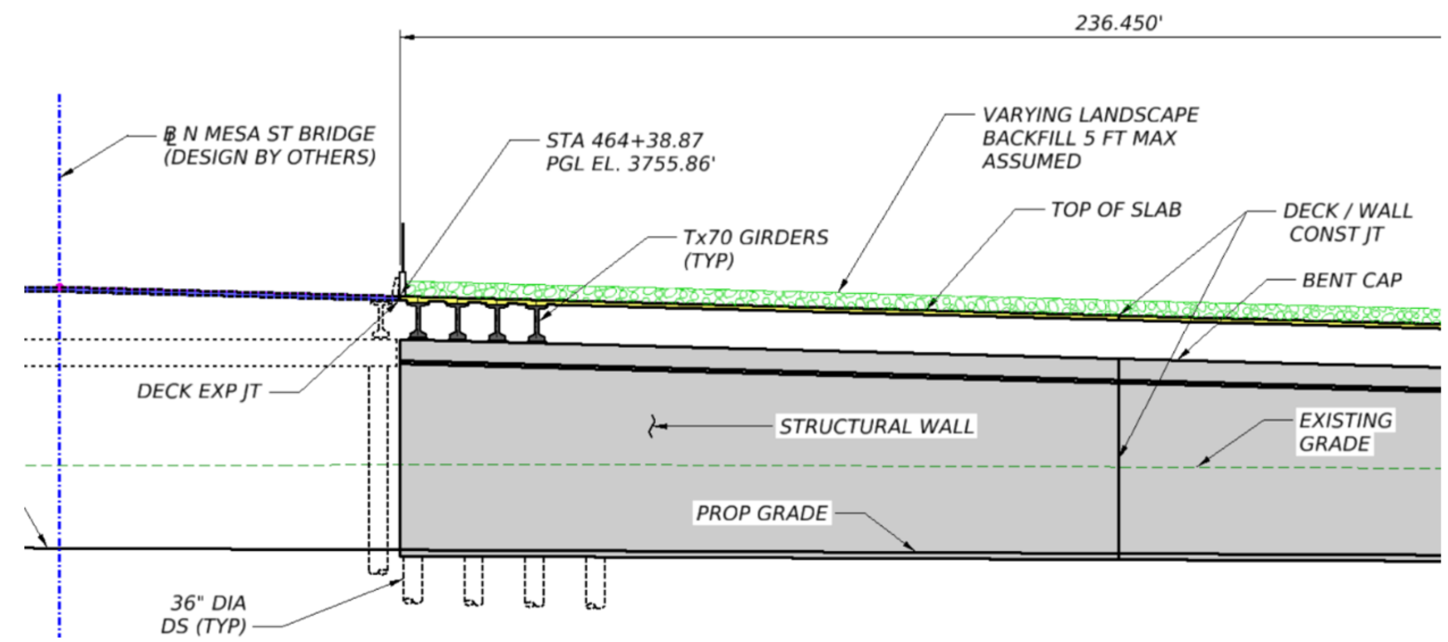


Figure-68 : Bridge Elevation View (Part)

TASK 300: STRUCTURAL SCHEMATIC DESIGN

4.4.2 BEAM SELECTION

The choice of **TX70 Prestressed Concrete I-Girders** spaced at 6 ft was made due to their high strength-to-weight ratio, which is ideal for the spans required by this project. These girders are widely used in bridge construction across Texas and are well-suited to the project due to their:

- **Proven performance in similar infrastructure projects:** TX70 girders are commonly used in highway overpass and deck projects, providing confidence in their ability to support the loads associated with the deck plaza.
- **Cost-effectiveness:** Concrete girders offer a balance of durability and affordability, which is crucial for a project of this scale.
- **Ease of construction:** TX70 girders can be fabricated off-site and transported to the project location, reducing on-site construction time and minimizing disruption to the surrounding urban environment.

Each girder will be designed to carry both dead loads (DL) and live loads (LL), with specific attention to the varied loading conditions across different sections of the deck.

4.4.3 DESIGN CODES AND STANDARDS

The bridge design follows strict TxDOT Standards, ensuring compliance with all relevant guidelines for bridges, highway structures and public spaces. These standards provide the framework for calculating loads, material strengths, safety factors, and deflection limits, ensuring that the deck will perform as required throughout its life cycle.

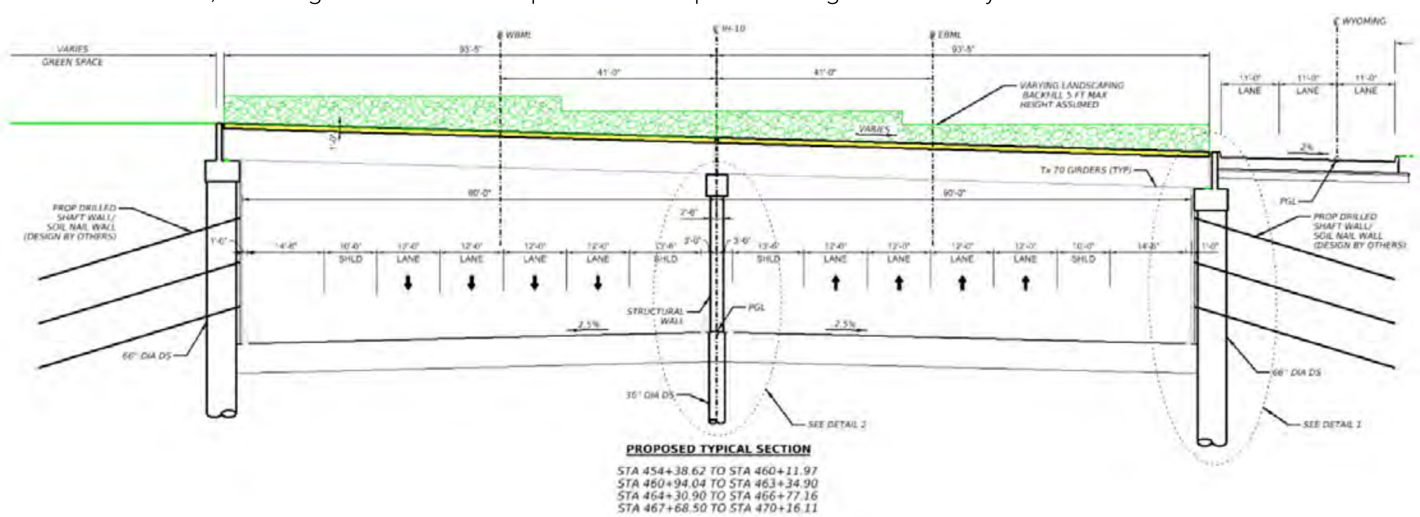


Figure-69 : Bridge Typical Section

4.5 Substructure

The substructure is designed to provide stable support for the superstructure, accommodating the varying elevation along the freeway corridor. The drilled shafts and interior wall bents are strategically designed to handle the substantial loads from the deck plaza while managing the challenging terrain conditions.

4.5.1 FOUNDATION

The foundation consists primarily of drilled shafts, which vary in diameter and spacing based on their location and the loads they must support. There are two primary types of drilled shafts in the substructure:

- **Drilled Shafts Supporting Abutments:** The drilled shafts are 5.5 feet in diameter and are spaced 6 feet apart. These shafts provide robust support for the piers, ensuring effective load transfer from the deck into the soil.
- **Drilled Shafts Supporting Interior Wall Bents:** The drilled shafts supporting the interior wall bents have a smaller diameter of 36 inches (2 feet 6 inches) and are spaced 9 feet apart.

These design parameters, verified through the RCPier analysis, guarantee that the foundation is capable of supporting the substantial loads expected from the deck plaza, including live loads from construction and public use.

4.5.2 ABUTMENTS AND BENTS

The abutments, which may reach heights of up to 38 feet, are designed to support the deck structure at its endpoints. These high abutments must resist both vertical loads from the deck and lateral earth pressures from the surrounding fill.

- **Vertical Load Support:** The abutments are designed to transfer the vertical loads from the superstructure into the drilled shafts, which are spaced to provide even support and prevent differential settlement.
- **Lateral Load Resistance:** The high abutments are reinforced to resist lateral earth pressures, which increase with height. The retaining walls integrated with the abutments provide additional support, preventing soil movement and maintaining the structural integrity of the deck.

The design of the abutments accounts for the following types of lateral pressures:

- **Active Earth Pressure:** Caused by the weight of the soil pressing against the abutments. This pressure is typically calculated using the Rankine's Theory, with additional considerations for surcharge loads from landscaping or structures on the deck.
- **Hydraulic Pressure:** The abutments are designed to resist additional hydraulic pressures caused by water buildup behind the wall.

The interior wall bents serve a dual purpose by dividing opposing traffic lanes and providing additional structural support. These bents are designed to accommodate changes in deck elevation, ensuring a smooth transition between varying heights. By effectively separating traffic, the wall bents enhance safety while maintaining the overall integrity of the structure. They also play a critical role in load distribution, helping to transfer forces to the foundation while minimizing potential risks associated with vehicle movement between lanes.

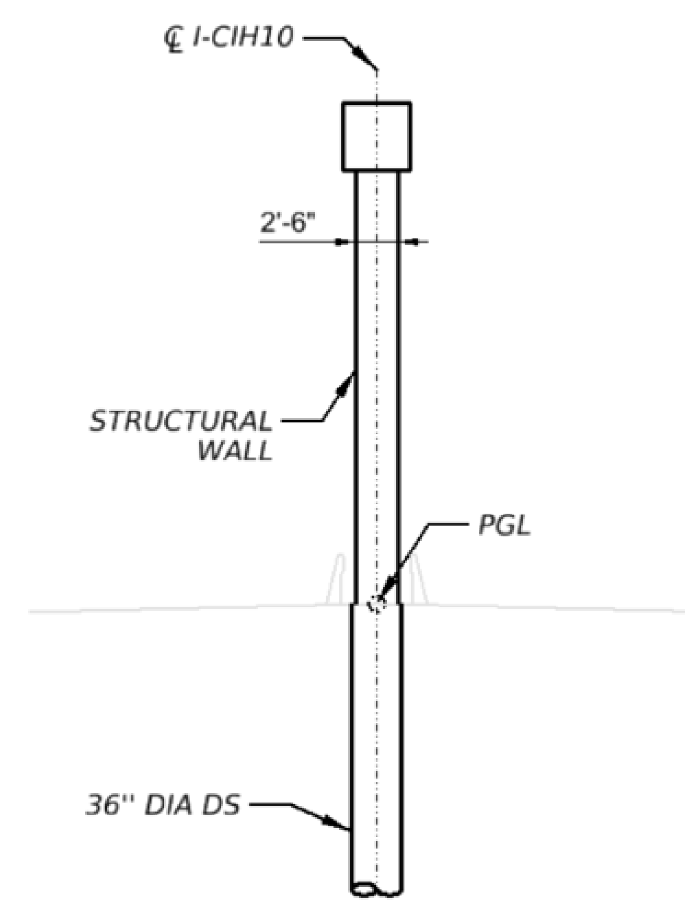


Figure-70 : Interior Wall Bent Typical Section

TASK 300: STRUCTURAL SCHEMATIC DESIGN

4.6 Retaining Wall

The retaining walls are a critical component of the deck plaza's substructure, providing support against lateral earth pressures while maintaining the stability of the deck and surrounding landscape. The walls consist of panels, closure pours, and soil nail walls, which will be designed by others.

4.6.1 RETAINING WALL SELECTION

Soil nail walls are used for retaining walls based on the height of the abutments and the need to resist varying levels of lateral earth pressure. Soil nail walls are the primary choice for areas requiring extensive support against horizontal forces. This type of wall uses a series of steel tendons (nails) that are inserted into the soil and secured with a facing material.

4.6.2 INTERFACE WITH SUBSTRUCTURE

The retaining walls interact closely with the abutments and drilled shafts, forming a continuous support system that manages both vertical and lateral loads. This interface is critical to maintaining the stability of the deck and preventing differential movement between the deck and the surrounding landscape.

- **Closure Pours:** Used at connection points between retaining walls and the deck to ensure a seamless transition, preventing water infiltration and soil movement.
- **Panels:** Panels are used in lower-height areas where the lateral pressures are relatively minor. These panels are connected to the main retaining walls and abutments, providing additional support for the soil and backfill.

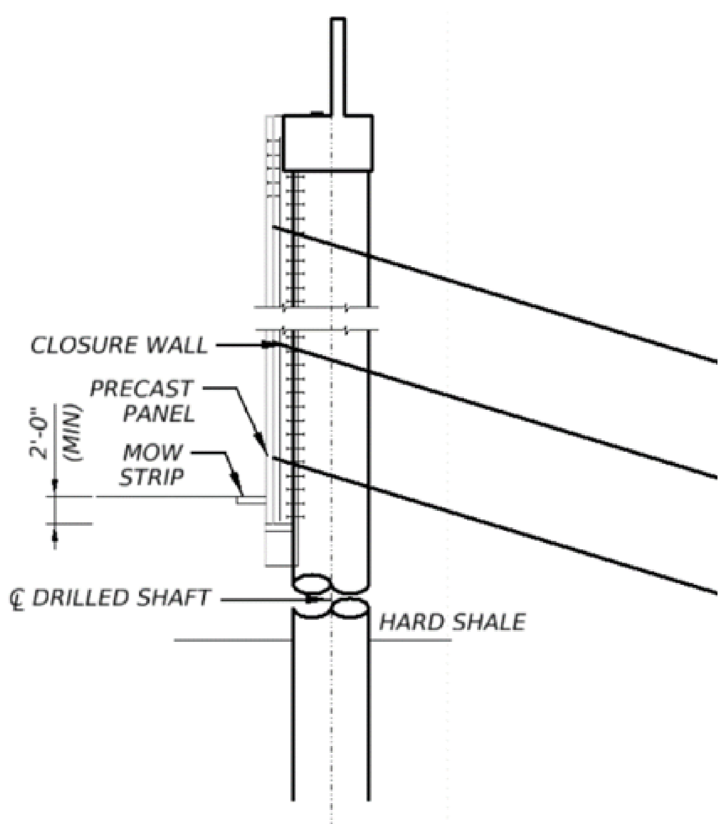
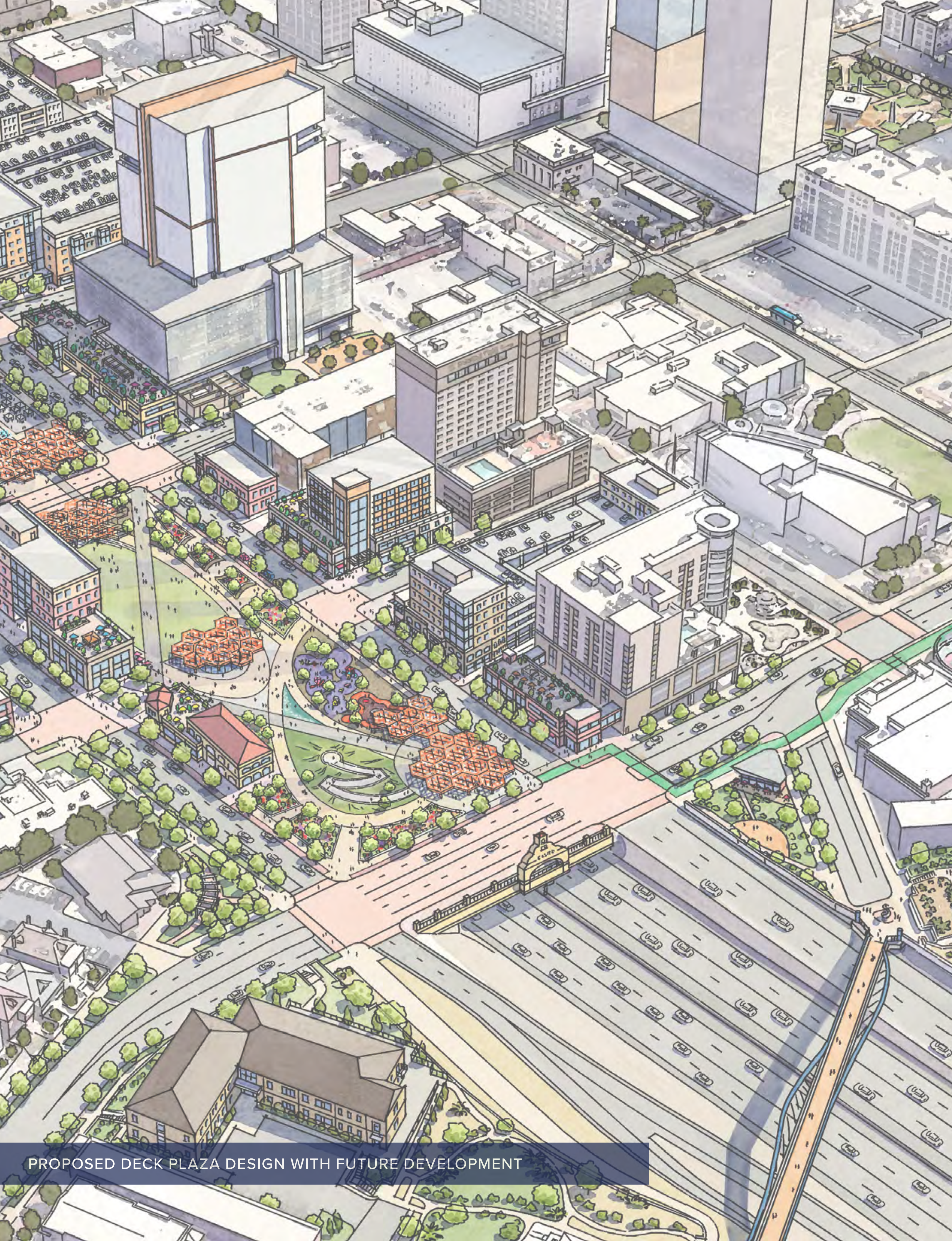


Figure-71 : Abutment and Retaining Wall Typical Section

4.7 Future Work

Currently, detailed geotechnical borings data has been obtained within the project limits. The borings data provides preliminary information on soil profiles and properties. Once a more comprehensive geotechnical report is finalized, it may lead to modifications in the existing design, providing precise data on soil strength and other essential properties. This could result in adjustments to the configuration of drilled shafts, piers, and other substructure components as now a conservative design is being implemented. Additionally, new findings regarding soil conditions may require changes to material specifications to enhance durability and resilience. If necessary, design revisions will be made in accordance with ASTM and AASHTO LRFD standards based on the findings of the report.


PROPOSED DECK PLAZA DESIGN WITH FUTURE DEVELOPMENT

EP TX
CITY OF EL PASO

TASK 400: TUNNEL SYSTEMS

City of El Paso | Downtown Deck Plaza Feasibility Study

Phase 2 Implementation Memorandum | April 2025

TASK 400: TUNNEL SYSTEMS

CONSULTING ENGINEERS


EL PASO DECK PLAZA

ELECTROMECHANICAL AND FIRE PROTECTION SYSTEMS - FEASIBILITY STUDY

30.09.2024 | Revision 0 ©ILF

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TASK 400: TUNNEL SYSTEMS

5.1 Introduction

The project of the El Paso Deck Plaza consists in the construction of a Deck Plaza over the federal Interstate 10 road, which crosses through the urban core of the city. Currently the road is a sunken freeway.

The creation of the Deck Plaza will transform the existing sunken freeway into a tunnel, which has a very different approach in the design, concerning the electromechanical equipment and fire safety. The guideline responsible of covering road tunnels is the NFPA 502 – Standard for Road Tunnels, Bridges and Other Limited Access Highways. This guideline will be used as a basis for this report for listing the required systems and procedures necessary for the tunnel.

The estimated date for the inauguration of the project is 2027.

The tunnel has length of around 1,800 ft and 4 lanes on each direction.

Figure-72 : Schematic drawing of the location of the tunnel under the deck

5.2 General Information

5.2.1 TUNNEL TYPE

The NFPA 502 has different requirements depending on the category of tunnel that is being design. The type of systems needed in the tunnel are basically determined by the length of the tunnel as well as the traffic; the classification can be better explained by the following graphic taken from the NFPA 502 guideline:

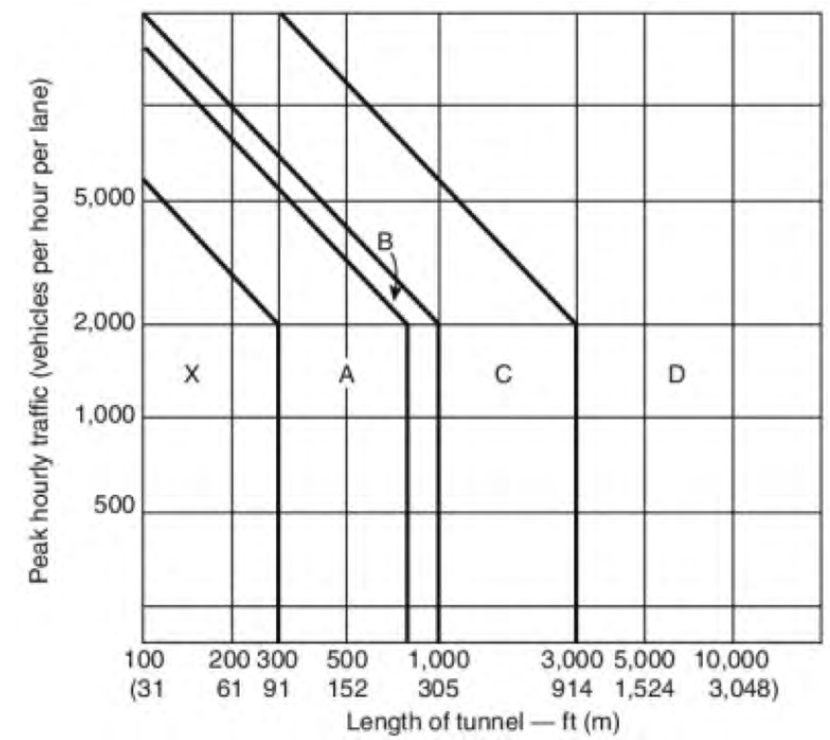

Figure-73 : Urban and Rural Tunnel Categories, taken from the NFPA 502

The length of the tunnel is expected to reach 1,800 ft so that would place it in the C category.

According to a traffic studio realized in the Trans-continental Interstate 10 by the Texas Department of Transportation (TxDOT) in 2016 the traffic projection for the year 2042 is of 300,000, which in light of the data taken from 2021 seems to be a rather conservative value, as the project is still on an early stage of development and in aim to better guard the safety of the tunnel occupants, this value will be taken in consideration to determine the category of the tunnel.

A K-factor of 0.1 in the tunnel will be considered, and knowing that it will have a total of 8 lanes, a peak hourly traffic of 3,750 vehicles per hour and per lane is taken in consideration. When looking at the Figure A.7.2 of the NFPA 502 the tunnel can be placed very close between the C and D Category, however as the project is still on early stages of development, is better to keep a much more conservative scenario, therefore category D would be assumed for the approach in the electromechanical and fire safety equipment.

From here on, all the conceptual decisions will be taken with the requirements for a tunnel of Category D.

TASK 400: TUNNEL SYSTEMS

5.2.2 ASSUMPTIONS AND RECOMMENDATIONS

As the tunnel design is yet to be determined and fixed, some assumptions have to be set in order to establish the needed systems, as well as recommendations for influencing on the final design of the tunnel so that it can function in the most efficient and integral way in conjunction with the electromechanical equipment, so that the final design allows to reduce the potential risks inside the tunnel as well as the costs of implementation, operation and maintenance of the tunnel.

The recommendations and assumptions are listed below:

- Due to the amount of lanes and traffic expected in the tunnel, it is strongly recommended to divide the tubes in order to generate unidirectional traffic. This simple decision for the tunnel infrastructure has a great impact in the systems of the tunnel as well as the risk tied to it. The closure of the middle section will allow air to flow via natural ventilation during normal operation, greatly reducing the amount of time that the ventilation system is used and therefore reducing the electric consumption as well as the maintenance needed for the equipment. Closing the walls between opposing lanes also greatly decreases the risk in the tunnel as it eliminates the risk of a vehicle jumping from one lane to incoming traffic, the risk of people running towards incoming traffic in case of an emergency and reduces the probability of having traffic in one of the sides of the tunnel during a fire. In general for several lanes and high amount of traffic is a best practice to divide the tunnel into two unidirectional tubes instead of one big bidirectional tube. With this in mind, the design will treat both tubes as individual tubes for the location of elements, but also consider them as a whole system when necessary, having always in consideration the life conservation, structural protection and costs in that order.
- Due to the high amount of traffic and that the freeway is located within an urban zone, it is assumed that traffic jams will occur to a point of complete stoppage of the flow. This information has a big influence in the emergency response plan, as well as in the considerations taken for the ventilation system dimensioning and operation. If possible, it is highly advisable to stablish a traffic control system in the tunnel that avoids vehicles to stagnate in the tunnel, and via a control point transports the traffic before and outside of the tunnel where the risk is significantly lower; as can be seen in the maps of the area, a deviation of traffic is also possible to avoid traffic in the tunnel, the deviations points are around 850 ft from the Portal in Santa Fe street and around 2050 ft from the Kansas Street portal, and can be used to deviate traffic in case of heavy congestion.
- Since there have been multiple registration of temperatures below 32 °F in El Paso, the possibility of freezing temperatures has to be taken in consideration. This consideration affects the selection of the fire standpipe type, so has to be considered in the earliest stages of the design.
- Due to the large amount of traffic, possibility of traffic jams and the increased risk presented by the environments inside our tunnel, it is strongly suggested to restrict the entry of dangerous goods vehicles in the tunnel, this can and will have a big impact in the dimensioning of all the emergency response systems and plans, as much of the design is done around the heat release rate expected in the worst case scenario. Heavy duty vehicles could be allowed, but dangerous goods are highly discouraged.

5.3 Fire Detection

5.3.1 DETECTION, IDENTIFICATION, AND LOCATION OF FIRE IN THE TUNNEL

Fire detection in the current system El Paso I10 road tunnel is essential for ensuring safe operations by enabling rapid and accurate identification of fires, which triggers the activation of tunnel systems and emergency response measures. Without proper detection, tunnel users may be unaware of a fire, risking their lives and causing severe vehicle damage. In a tunnel, fires can escalate quickly, potentially overwhelming firefighting efforts and leading to life loses and extensive structural damage and costly, long-term closures. If an event is not identified on time, a high-intensity fire could compromise the structural integrity of the tunnel.

Due to the enclosed nature of our tunnel: length and with low ceilings, heat is trapped, causing fires to spread faster and reach higher temperatures compared to open environments. This makes early detection crucial. The main goal of automatic fire detection and warning systems in our tunnel is to ensure prompt, precise, and reliable fire identification while minimizing false alarms.

Fire systems in tunnel are closely tied to fire detection, playing a vital role in managing safety and response:

- Initiating fire alarm systems: These systems alert motorists, pedestrians, and bicyclists about a fire through flashing beacons, audible warnings, and variable
- Closing tunnel portals: To prevent vehicles, bicyclists, and pedestrians from entering a potentially dangerous area, tunnel portals are closed once a fire is detected.
- Alerting the tunnel control console: Tunnel staff are notified to monitor the situation and contact 911 dispatch centers for emergency responders.
- Fire ventilation and sprinklers: Early detection enables ventilation systems (and fire sprinklers, if available) to respond while the fire is still in its early stages, reducing smoke and heat. This improves user safety and grants emergency responders easier access to the fire. Fire sprinklers can also speed up the reopening of the tunnel.

Integrating fire and life safety systems into a unified response is crucial for reducing life safety risks, protecting tunnel structures, and minimizing the economic impact of prolonged closures.

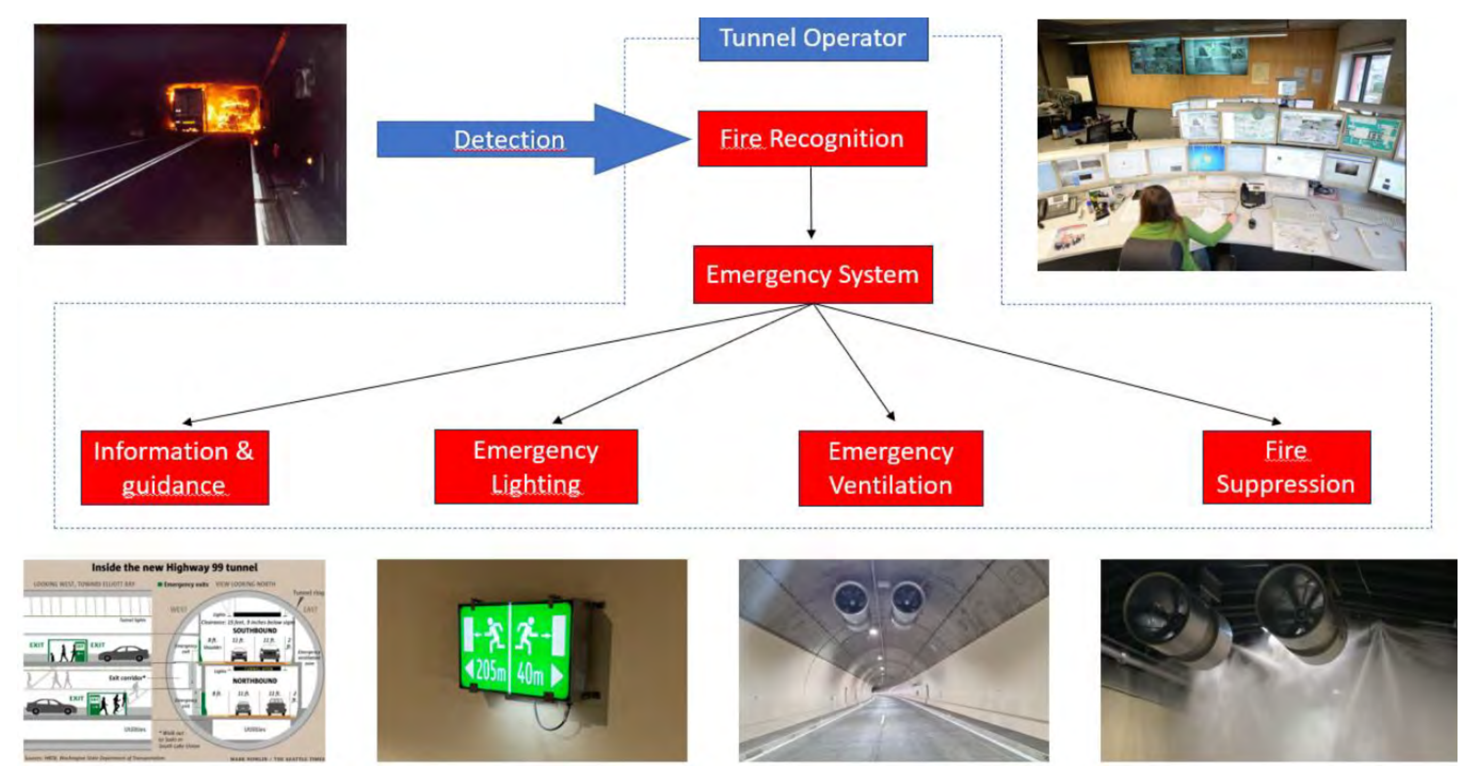

Figure-74 : Integrated approach to tunnel fire safety

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TASK 400: TUNNEL SYSTEMS

Being the project a category D tunnel, the NFPA 502 requires to have at least two independent means of identifying a fire and locating it along the tunnel.

There are several fire detection, identification, and location systems in existence but all of them have features and requirements in common:

- Early fire detection: As the NFPA 502 specifies, the emergency ventilation system shall reach its' full operational mode within a maximum of 180 seconds. As the ventilation system normally must be turned off and then gradually on in order to no override the electrical network, the time of detection always needs to be as short as possible.
- Accurate Fire Location: It is important that at least one of the systems in the tunnel can accurately identify the location of the fire. As the ventilation program runs depending on the location of the fire, a misplacement of the fire can have serious consequences in the occupants of the tunnel.
- Resistance to false alarms: Due to the close environment caused by tunnel, false alarms can be easily triggered by vehicle emissions, dust, and moisture.
- Long-range Monitoring: The systems must be able to cover the longitude of the tunnel without any "blind-spots"

Besides this systems, fire alarms can be triggered by the operator of the tunnel, emergency phones, the fire extinguisher being taken and others that can help as well in the detection but are perhaps not as accurate as the systems presented above.

5.3.2 CCTV

Tunnel Closed-Circuit Television (CCTV) coverage ensures complete visibility throughout the tunnel and at its portals. CCTV as a fire detection system shall be used in this project as an advanced technology to enhance tunnel safety. While traditional fire detection methods rely on heat sensors, smoke detectors, or flame detectors, we suggest to implement modern video-based fire detection (VFD) systems which use CCTV cameras equipped with intelligent software to detect the early signs of a fire, such as flames, smoke, or abnormal heat patterns. This system offers significant benefits, especially in complex environments like tunnel, where early detection and rapid response are critical. The core of CCTV fire detection lies in specialized video analytics software that processes real-time footage from surveillance cameras. This software analyzes the video feed to detect visual signatures associated with fire, such as smoke movement, flickering flames, or changes in light intensity and color. Algorithms are trained to recognize these fire-related patterns and can distinguish between actual fires and false positives, such as car headlights or reflections.

The system can detect smoke in its early stages by identifying the characteristic motion and visual texture of smoke clouds, even before it becomes dense enough to trigger traditional smoke detectors. Smoke detection via CCTV is particularly useful in environments where airflow might dilute smoke, making conventional sensors less effective. Some CCTV systems use thermal imaging cameras to detect temperature anomalies, such as overheated equipment, vehicles, or structural components that could indicate a potential fire hazard. These cameras detect heat directly and can identify areas of concern even in low-visibility situations (e.g., smoke, darkness). Once a fire is detected, the system generates an automatic alert, which is sent to the tunnel's control room. Operators can then verify the fire through live footage and initiate appropriate emergency responses, such as activating ventilation systems, triggering alarms, or dispatching fire services.

In our tunnel, CCTV-based fire detection systems should be used in combination with traditional fire detection methods (e.g., smoke and heat detectors) to create a multi-layered fire detection approach. This redundancy ensures that any fire is detected as early as possible, even if one system fails or is delayed.

5.3.3 AUTOMATIC FIRE DETECTION SYSTEM

An Automatic Fire Detection System in our tunnel is essential for ensuring the safety of users and the effectiveness of emergency responses. By detecting fires early and triggering ventilation, alarm, and suppression systems, these systems help minimize the risk to human life and damage to infrastructure. Integration with other safety systems, zoning strategies, and the use of redundant technologies ensure a comprehensive approach to fire safety in tunnel.

The installation of Automatic When designed specifically for tunnel environments, these systems can:

- **Detect a fire,**
- **Identify the precise fire location,**
- **Send notification signals, and**
- **Trigger activation of fire-life safety systems, particularly mechanical ventilation.**

Early detection, accurate location identification, rapid notification, and timely activation of fire-life safety systems are crucial due to the quick loss of safe conditions (tenability) in the case of a tunnel fire. Without intervention, a fire will continue to grow until firefighters arrive or sprinklers activate. While mechanical ventilation can help by pushing smoke away from the fleeing paths and lowering the temperature, it does not stop the fire's growth and spread, making early intervention vital for minimizing damage and risk.

Depending on the nature of a fire and the fire detection system in place, various indicators such as smoke, flame, or heat may be detected first. Multi-sensor alarm systems, which can monitor multiple fire indicators, are often more effective for automatic control in tunnel. The most common fire detection methods are based on specific fire parameters and can be applied individually or in combination:

- **Smoke/gases**
- **Heat**
- **Flames (radiation)**

There are currently five available and widely used detection technologies each with more than one system that can be used, each alternative presents advantages and disadvantages; therefore, the selection of the technologies used for the tunnel must be so they can be complementary and increase the efficiency of the system as a whole. The existing technologies are listed and explained below:

- **Linear Heat:** Uses heat-sensitive cables or fiber optics that run along the tunnel and can detect temperature changes in any point along the tunnel.
- **Flame:** Use infrared and/or ultraviolet sensors to detect the radiation emitted by flames.
- **CCTV:** Uses specialized software to analyze the live footage for any sign of fire, such as smoke or flames
- **Spot-Type Heat:** Are placed in specific locations in the tunnel to monitor the temperature on this points, triggered if the temperature exceeds a programed threshold
- **Smoke:** Identify the presence of smoke particles in the air.

Choosing the appropriate fire detection system(s) depends on the fire safety objectives, such as notifying occupants for safe evacuation, modifying tunnel operations, activating fire-life safety systems, and alerting emergency responders. Combining multiple detection systems significantly enhances fire detection accuracy, reduces false alarms, and improves overall tunnel fire safety. For example, using a linear heat detection system alongside infrared (IR) cameras with CCTV allows for quick detection of shielded fires, which can then be verified by tunnel operators.

Linear heat detectors are designed to detect a rise in temperature along any point of the detector's length. Once a temperature increase is sensed, the system sends a signal to a control center, identifying the precise location of the alarm within the tunnel. These detectors typically cover 50-foot detection zones, aligning with ventilation or fire sprinkler zones, and are usually installed above each traffic lane throughout the tunnel's length. There are three primary types of linear heat detectors in use today: Analog (Integrating) Linear Heat Detectors, Digital Linear Heat Detectors, Fiber Optic Linear Heat Detectors. Each type offers different capabilities in terms of sensitivity, installation, and maintenance, making them suitable for various fire detection strategies in our road tunnel. Linear heat detectors can accurately detect both shielded and unshielded tunnel fires within 90 seconds or faster, making them highly effective for early fire detection. Their ability to quickly identify fires, combined with their relative simplicity and reliability, has made them one of the most widely used fire detection devices in our road tunnel today. These detectors provide a critical layer of protection, enabling rapid response and minimizing the risk of fire spreading within the tunnel environment.

CCTV Video Image Smoke Detection is a relatively new technology that uses real-time video images to detect smoke and fire. This system relies on proprietary software to analyze video feeds for changes in brightness, contrast, edge content, loss of detail, and motion to identify fires.

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The advantages of video smoke and heat detection include:

- **Multi-Functionality:** The same cameras used for smoke and fire detection can also serve other purposes such as traffic monitoring and security.
- **Wide Coverage:** Each camera can monitor a large area, providing comprehensive surveillance.
- **Detection of Fires on Moving Vehicles:** This technology can identify fires on vehicles moving through the tunnel, which is particularly useful for dynamic environments.
- **Real-Time Information:** Emergency responders receive real-time video footage of the fire, offering critical details such as fire size, source, and location. This information helps operators and responders to react more effectively and make informed decisions during an incident.

Flame detectors are fixed devices designed to sense fire by detecting the radiant energy emitted. These detectors come in several types, including ultraviolet (UV), infrared (IR), combination UVIR, or multiple-wavelength IR, and they rely on a clear line of sight to detect flames. Flame detection systems offer several advantages, particularly in the harsh environments of road tunnels. They are effective in detecting early-stage fires and can monitor a wide range of wavelengths, enhancing their flexibility in design and placement. This makes them well-suited for challenging tunnel conditions where quick and reliable fire detection is crucial.

5.3.4 FIRE ALARM CONTROL PANEL

The fire alarm control panel serves as the central hub for integrating multiple tunnel systems, such as fire detection, ventilation, communication, and CCTV. It ensures seamless coordination between these systems, enabling efficient monitoring and management of emergencies within the tunnel environment. This centralized control enhances response times and improves overall tunnel safety.

The Fire Alarm Control Panel (FACP) is proposed to include the following features and interfaces for comprehensive tunnel safety management:

- Fire detection system alarms, including linear heat and infrared flame detectors
- Activation of Variable Message Signs (VMS), portal signals, and lane use signs to close the tunnel and inform motorists
- Activation of emergency warning lights within the tunnel
- Monitoring the off-hook status of emergency phones
- Automatic activation of public address (PA) emergency messages
- PA microphone for ad hoc announcements
- Switching tunnel lights to full brightness
- Monitoring of tunnel radio systems
- Unlocking cross-passage emergency egress doors (if a locking system is installed)
- Monitoring the “door unlatched” status
- Control and monitoring of emergency ventilation modes through the Direct Digital Control (DDC) system
- Remote annunciator panels at each tunnel portal
- A computer graphic interface on the Tunnel Operator Console for system management

5.4 Emergency Communication Systems

Tunnel Emergency Communication Systems are essential for maintaining safety and facilitating effective responses during emergencies. By integrating various communication tools, including public address systems, emergency telephones, intercoms, and visual displays, these systems enhance the overall safety of tunnel environments. Proper design, maintenance, and compliance with safety standards are critical to ensuring that these systems operate effectively when needed most.

5.4.1 EMERGENCY TELEPHONE

Emergency telephones should be strategically placed throughout the tunnel, allowing users to contact authorities or emergency services quickly. These phones are often designed to operate independently of the main power supply to ensure functionality during outages. The telephones provide two-way communication, enabling tunnel users to relay their location and situation to responders.

Emergency telephones offer a direct line to local emergency services, allowing users to report incidents immediately and provide their location and details of the situation. These telephones typically enable two-way communication, allowing the caller to relay information and receive instructions from emergency operators. Emergency operators can give callers instructions on what to do while help is on the way, including evacuation procedures and safety measures.

Designed to withstand harsh conditions, emergency telephones are typically housed in weatherproof and vandal-resistant enclosures to ensure reliability in various environments and are equipped with backup power sources, ensuring functionality during power outages. They are prominently marked with bright colors and clear signage, making them easily identifiable in emergencies. Emergency telephones are designed for quick and easy operation, often featuring large buttons and simple interfaces that can be used even in stressful situations.

5.4.2 EMERGENCY RADIO

All fire, police, and medical units are equipped with either portable (handheld) or mobile (vehicle) radios. The frequencies for these radios are carefully organized into specific groups to minimize interference with radio communications from responders outside the immediate area. In the event of a mutual aid request involving units from outside the area, the radios can be manually switched to one of the mutual aid frequencies, or the radio dispatch center can implement this change remotely.

These radios are crucial for maintaining communication when conventional radio signals, like mobile networks, fail due to the underground environment of tunnel. They provide uninterrupted communication in enclosed spaces where traditional signals can’t reach. A special coaxial cables are installed along the length of tunnel. They act as antennas that transmit radio signals over long distances. They enable radios to function in otherwise signal-blocked environments.

Emergency radio systems can also be used to broadcast real-time emergency alerts and instructions to tunnel users, drivers, or pedestrians through radio frequencies accessible to car radios or personal devices.

5.4.3 CELLULAR PHONES

Cellular phones are frequently used by first responders as an alternative means of communication. Cellular phone coverage throughout the tunnel is essential to ensure continuous communication for first responders and to facilitate coordination and resource requests during an incident.

Distributed Antenna Systems (DAS) is one of the most commonly used solutions to provide cellular coverage inside the tunnel. It consists of a network of antennas distributed throughout the tunnel that relay signals from external cell towers or base stations. These antennas are connected to a central hub, which communicates with the cellular network, allowing continuous coverage. DAS can support multiple carriers, meaning users with different mobile operators can receive service in the same tunnel.

5.4.4 PUBLIC ADDRESS SYSTEM

Announcement Capabilities systems allow for real-time announcements to all tunnel users, conveying critical information such as evacuation instructions, safety alerts, and updates during emergencies. Also pre-recorded messages can be activated automatically in response to specific emergencies, such as fire or smoke detection.

The primary function of a tunnel Public Address (PA) system is to communicate vital information during emergencies, such as fires, vehicle accidents, or other hazardous incidents. This can include instructions on how to evacuate, the location of emergency exits, and any updates on rescue operations. PA systems can also be used for routine announcements, such as

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traffic advisories, maintenance warnings, or information on temporary closures. During crises, a PA system helps authorities manage the flow of people, ensuring safe evacuations and directing individuals away from danger. It's often used in coordination with lighting, signage, and other safety systems.

Loudspeakers are distributed throughout the tunnel, including along the walls, in emergency exits, and at other key points, ensuring announcements are clearly audible in all areas. They are designed to withstand harsh conditions, such as extreme temperatures, humidity, or vibrations caused by traffic.

Control Unit is the centralized hub that allows operators (often located in a tunnel control room) to make live announcements or play pre-recorded messages. In emergencies, the control unit can be linked to automatic alert systems that broadcast pre-set messages, ensuring a rapid response.

In tunnels serving international or diverse populations (such as airport tunnels, border crossings, or metropolitan areas), PA systems may broadcast messages in multiple languages to ensure that everyone understands the instructions.

By providing clear, real-time instructions, these systems help manage evacuations, minimize confusion, and potentially save lives. Their integration with other safety systems, like lighting, ventilation, and emergency detection, makes them a cornerstone of modern tunnel safety.

5.4.5 CCTV

Additionally to previous chapter CCTV under fire detection capital, tunnel CCTV (Closed-Circuit Television) systems are also an essential part of modern tunnel safety and management. These systems provide real-time surveillance, monitoring, and recording of tunnel activities to ensure traffic flow, enhance security, and assist emergency responses. They are critical in preventing accidents, managing incidents, and ensuring the safety of both road users and infrastructure.

CCTV cameras inside the tunnel help monitor traffic flow, detect congestion, and identify any irregularities, such as stalled vehicles or accidents. This allows tunnel operators to respond quickly to any incidents, divert traffic, or trigger emergency protocols. CCTV systems can identify accidents, fires, or other emergencies in real time. Some advanced CCTV systems are integrated with video analytics to automatically detect incidents (e.g., stopped vehicles, pedestrian movement in restricted areas) and alert control room operators. CCTV cameras will be used to monitor unauthorized access to tunnel, preventing vandalism, sabotage, or other security breaches. This is particularly important in tunnels that serve critical infrastructure or high-traffic areas. During emergencies, CCTV systems allow control room operators to have a clear view of the situation, helping to guide emergency services (firefighters, police, medical teams) to the exact location of the incident. Operators can track the progress of rescue efforts and adjust evacuation plans as needed.

CCTV cameras should be installed at various points along the tunnel. They are often high-resolution, rugged cameras capable of operating in harsh conditions (e.g., low light, high humidity, heat, and vibration). They are placed at key positions such as tunnel entrances/exits, emergency exits, ventilation shafts, and along the main road or rail corridors.

Tunnel operators monitor the live video feed from the CCTV cameras in a control room. The control center is typically staffed 24/7 to ensure continuous surveillance. Operators can zoom in on specific cameras, pan or tilt cameras, and review recorded footage when necessary.

Modern CCTV systems often include intelligent video analytics. This software can automatically detect anomalies like sudden stops, vehicle breakdowns, erratic driving, fires, or unauthorized pedestrian access and generate alerts.

Tunnels often have low lighting, so CCTV cameras are equipped with infrared (IR) capabilities or other low-light technologies to ensure clear images even in dark environments. In some tunnels, thermal cameras are used to detect heat signatures, which can be valuable for spotting vehicle fires, overheated machinery, or even human presence in low-visibility situations.

CCTV is often integrated with tunnel PA systems. In emergencies, operators can use CCTV to identify specific areas affected by an incident and then make targeted announcements over the PA system to guide people to safety.

CCTV systems are linked with other safety systems, such as fire detection and ventilation control. For example, if a fire is detected, operators can use CCTV to confirm the severity and location of the fire and adjust the tunnel's ventilation system accordingly to direct smoke away from escape routes.

5.5 Traffic Control

Tunnel Traffic Control refers to the systems and technologies used to manage the flow of vehicles through tunnel, ensuring safety, efficiency, and smooth traffic movement. Tunnels are often confined spaces where accidents, congestion, or emergencies can have severe consequences, so traffic control systems are vital to prevent accidents, reduce congestion, and provide guidance to drivers or operators in case of emergencies.

Traffic management systems (TMS) in our tunnel would continuously monitor traffic flow using sensors, cameras, and detectors. These systems track vehicle speeds, congestion levels, and traffic volumes, providing real-time data to tunnel operators. TMS can adjust traffic conditions by controlling signals, speed limits, and lane use based on real-time data. For instance, in the event of a traffic jam or accident, the system can alter traffic light timings or close lanes to maintain safety.

Electronic Signs are placed at tunnel entrances and within the tunnel to provide real-time information to drivers. Variable Message Signs (VMS) can display messages such as speed limits, lane closures, diversion routes, or warnings about congestion or accidents ahead. In the event of an incident such as a fire, accident, or traffic breakdown, VMS can direct drivers to follow specific routes or evacuate the tunnel. They can also be used for directing emergency vehicles to the scene.

Dynamic Lane Control Systems (LCS) are used to open or close lanes based on traffic flow. For example, during heavy traffic or maintenance work, certain lanes can be closed off, and this information is conveyed to drivers using lane control signals above each lane.

Real-Time Automatic Incident Detection (AID) systems use CCTV cameras combined with advanced algorithms to automatically detect incidents such as stopped vehicles, accidents, pedestrians in the tunnel, or even sudden changes in traffic flow. Once an incident is detected, the system alerts tunnel operators who can then implement traffic control measures, such as closing lanes, activating emergency signals, and guiding rescue teams to the scene.

In case of a fire or other emergency, the traffic control system can activate evacuation procedures, such as opening emergency exits, directing vehicles to alternative routes, and closing the tunnel. VMS, lighting, and audio systems guide drivers safely out of the tunnel.

Inductive Loop Sensors are embedded in the road surface. These sensors detect vehicle presence, speed, and flow. They provide data on how many vehicles are in the tunnel, helping operators manage traffic and detect any irregularities like congestion or stalled vehicles.

Radar and LIDAR Sensors are used for advanced traffic detection and monitoring. They can capture vehicle movements, measure distances, and provide real-time traffic density data to tunnel operators.

Implementing physical barriers, along with a comprehensive system of advance warning signs, Variable Message Signs (VMS), and flashing lights, offers an effective method to prevent traffic from entering the tunnel during an emergency.

Solid barriers are straightforward in design, requiring minimal control and maintenance. Their simplicity makes them a practical choice for effectively managing tunnel closures without the need for complex systems.

TASK 400: TUNNEL SYSTEMS

5.6 Fire Protection

Quick response is crucial during an emergency event involving fire in the tunnel. After the automatic systems in the tunnel have slowed down the propagation of the fire, the firefighting forces must act quickly to apply water over the fire to avoid it from spreading further in the tunnel.

This objective requires the joint operation from the automatic systems built in the tunnel, such as the tunnel emergency ventilation and the fixed water-based fire-fighting system, together with the whole system dedicated for the use of fire-fighters as is the adequate water supply, fire standpipes, appropriate hose connections, among others.

5.6.1 FIRE APPARATUS

The NFPA 502 defines a Fire apparatus as any vehicle that is designed to transport personnel and equipment to support in the mitigation of fires and mitigation o hazardous events.

As the tunnel is located in a congested urban area, it would be appropriate (but not mandatory) to keep a fire apparatus at the tunnel portal(s). The NFPA 502 guideline does not require to include the fire apparatus as part of the design for fire and safety, but suggest to either have one in the tunnel or in the vicinity of it.

As a requirement, the Fire apparatus located in the tunnel or close to it must have a capacity to fight a fire in the tunnel for a minimum of 30 minutes and additionally has to be able to connect to any of the fire standpipes and connections in the tunnel. These vehicles shall carry several multipurpose, dry-chemical fire extinguishers and additionally and agent to extinguish class D metal fires, as traditional extinguish methods can worsen the fire with these metals.

As can the tunnel is expected to have a high amount of traffic, the NFPA 502 suggest to house the fire apparatus at the tunnel portal if possible, and to combine it with the apparatus used to retrieve and remove damaged and disabled vehicles from the tunnel.

In case of the implementation of the fire apparatus in the tunnel, appropriate and timely maintenance has to be performed to ensure the quick response of the apparatus.

5.6.2 FIRE STANDPIPE

Fire standpipes are specialized, fixed piping systems that are designed to supply with a reliable water source to firefighters in the case of an event in the tunnel. The objective is to provide with the needed connection for the hoses and even to connect the fire apparatus if it's needed.

The fire standpipes are in essence a network of pipes that are located and run along the tunnel walls, and that are designed to carry high-pressure water and to withstand the high temperatures encountered in the case of a tunnel fire.

There are mainly two types of standpipes: wet or dry. The type needs to be decided depending in the climatic conditions, the fill times and requirements of the local government or any combination of them. Perhaps the most important variant to consider in the selection of the type of standpipe is the weather, in particular the lowest temperatures expected in the tunnel as areas that are subject to freezing can cause a blockage of the pipes due to the frozen water in them.

In case wet pipes are required by the local guidelines, the water shall be heated and circulated.

Dry standpipe systems prevent from freezing, but if implemented the design needs to consider that all the hose connections must be fed with water in no more than 10 minutes. Independently of if the standpipes are wet or dry, it is best practice to have them full of pressurized water and ready before the arrival of firefighters.

As the state of Texas does recognizes the NFPA 502 and NFPA 14 as valid guidelines for the selection and design of fire standpipes, any of the possibilities are open. As the weather in El Paso has shown to go below freezing temperatures in some occasions, two options are open for the implementation of the fire standpipes; either a wet standpipe with a heating system or a dry standpipe. Regardless of the type, all piping and fittings that are exposed to freezing temperatures shall be heat-traced and insulated. Given that temperatures in the city can go below freezing point during some nights in winter months, a dry standpipe system could be the better solution as requires less maintenance than a heating system for the standpipe, considering that the freezing temperatures occur during few nights a year. This however must be studied much more in depth with meteorological data taken on site in the tunnel and a risk and cost analysis. It is recommended to make filling of the dry standpipe system automatic or semiautomatic in response to an emergency in the tunnel.

The NFPA 502 requires any tunnel longer than 300 feet to have a fire standpipe system and therefore it is necessary for the tunnel below the I-10 Deck. As the needed standpipes would only be used by firefighters, a Class I system should be needed according to the NFPA 14 "Standard for the Installation of Standpipe and Hose Systems" and maintained and inspected in accordance to the NFPA 25 "Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems".

Standpipe outlet locations should not exceed the maximum distance determined by the NFPA, and has to be coordinated with the different tunnel access points, so that firefighters can minimize the length of the hose to access to the connections from relatively smoke free sections of the tunnel. Considering that the tunnel will be an unidirectional tunnel, the standpipes shall be available to access in both tubes of the tunnel.

The NFPA 14 specifies the maximum travel distance in between the fire standpipes, as well as the maximum water pressure allowed and the system shall be built according to it unless the NFPA 502 specifies otherwise.

5.6.3 WATER SUPPLY

Regardless of the type of fire standpipe system selected for the tunnel, either wet (automatic or semiautomatic) or dry, the system shall count with an approved water supply with the capacity to supply the system demand for a minimum of 1 hour; nonetheless, the minimum capacity of the system should be determined by the duration of the potential fire and therefore will be further analyzed in a more advanced phase of the design.

The NFPA 502 details three acceptable water supplies for the fire protection system:

- *Municipal or privately owned waterworks systems that have adequate pressure and flow rate and a level of integrity acceptable to the AHJ (Authority having jurisdiction)*
- *Automatic or manually controlled fire pumps that are connected to an approved water source*
- *Pressure-type or gravity-type storage tanks that are installed, inspected, and maintained in accordance with NFPA 22*

The water supply system selected for the tunnel will have to be able to supply the enough water flow and pressure to supply the firefighting operations as well as the fixed water-based fire-fighting system in case of being needed for the tunnel.

According to the NFPA 14, the standpipe system shall provide at minimum a residual pressure of 100 psi at the most remote 2½ in hose connection, and 65 psi at the most remote 1½ in hose connection. Additionally, each standpipe shall be able to supply a minimum of 250 gpm with the minimum residual pressure.

As there is an existing road, and the tunnel is located in an urban setting, for the design a study of the existing conditions must be done in order to determine the best distribution of piping in the tunnel, determine if the water supply is adequate to the NFPA 502 conditions.

5.6.4 FIRE DEPARTMENT CONNECTIONS

The purpose of the Fire Department Connections (FDC) is to offer a connection supplemental water can be pumped into the fixed water-based fire-fighting system to support the fire extinguishing efforts of the existing systems in the tunnel. These connections are intended to be only for support and supplement the water supply, but does not need to be able to provide the entire system demand as they are not intended to deliver any specific volume of water.

Following the NFPA 14, the FDCs shall be located at no more than 100 ft from the nearest fire hydrant which is connected to an approved water supply. In tunnels, different than what is specified in the NFPA 14, the NFPA 502 requires for a minimum of two FDCs that are remotely located from each other and each of the FDCs in the tunnel shall be protected from any vehicular damage by implementing bollards or approved barriers; these barriers must still allow a clear and easy access for firefighters during an emergency, and should not hide the FDCs even during low visibility conditions. The locations of the connections shall be coordinated with the emergency access and response locations, as they shouldn't be blocked by any of the tunnel infrastructure or by traffic.

Every FDCs should be visible and easily recognizable from within 50 ft of the nearest point of fire apparatus access.

All of the connections shall consist in a 4 in quick-connect coupling that is compatible with the equipment used by the El Paso fire department and shall be equipped with approved plugs or caps to keep them properly secured when not in use and to also be easily removed by the fire department.

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It is crucial in future stages of the design to coordinate and consult with the local fire department to better understand their operational requirements both in hardware and management of events.

5.6.5 HOSE CONNECTIONS

Hose connections are fittings or outlets that allow the connection of hoses to a water supply for help in the fire suppression efforts. It is important to have access in several points of the tunnel, therefore the NFPA 502 stablish that no location in the tunnel shall be more than 150 ft away from any hose connection; as well as that the distance between hose connections shall not be bigger than 275 ft.

Hose connections along the tunnel should be located so that they are convenient and easy to access, but still protected against damage. It is important to consider that such protection or any other part of the infrastructure should interfere with the valve movement and connection of the hose itself. As protection to the hose threads, the connections shall be equipped with caps.

5.6.6 FIRE PUMPS

Fire pumps are critical equipment used for the fire protection of the tunnel to increase and control the pressure and flow of water inside the fire suppression system (such as standpipes) and the fixed water-based fire-fighting systems. To maintain a minimum pressure is critical to be able to reach and combat fires within the tunnel.

These systems help ensure the right pressure is available in all needed hose connections, as well as in the fixed firefighting system, allowing the dry standpipes to be filled and, in general, helping water to reach its desired pressure along the tunnel.

Because of the critical nature of the fire protection system in general, and especially in such a potentially dangerous environment as a tunnel, fire pumps must be reliable and have redundancy. It's important to have backup pumps or power sources in case one fails or is being maintained, and to ensure that the connections do not stop working if one fails, but can bypass it.

It is important to keep pumps in locations that are close to the firefighting system, but also well protected against heat or any products of the fire that could cause a malfunction.

Fire pumps are not mandatory according to NFPA 502, but their use must be backed by an engineering analysis, as it depends on the geometry and conditions of the tunnel. Being in the early stage of the design, it is not possible to discard or confirm the need for fire pumps in the system.

5.6.7 PORTABLE FIRE EXTINGUISHERS

A portable fire extinguisher can be considered any device that can be either carried or taken on wheels, is operated by hand, and has the purpose of using an extinguishing agent expelled under pressure to suppress or, if possible, extinguish a fire in the tunnel.

According to the NFPA 502, the extinguishers have to be of rating 2-A:20-B:C which means it has the capacity to put out fires of class A equivalent to 2.5 gallons of water of ordinary combustibles as wood, paper, cloth or some plastics. This extinguisher is also capable of putting out a 20 square foot Class B fire, which means a fire from flammable liquids such as gasoline, oil, grease or paint. Additionally this fire extinguisher is able to extinguish fires type C, meaning it is able to deal with electrical fires as it's non-conductive.

In order to make it easier to use by the firefighting team and motorists in the tunnel, the fire extinguishers must weight a maximum of 20 lb.

The portable fire extinguishers shall be installed along the whole tunnel with distances of no more than 300 ft between each other, meaning that the tunnel will need at least 6 portable fire extinguishers on each tube.

5.6.8 FIXED WATER-BASED FIRE-FIGHTING SYSTEMS

Fixed water-based fire-fighting systems (FFFS) is a system that is fixed permanently to the tunnel and that is able to spread a water-based extinguish agent along the tunnel or in different zones of it.

As have been mentioned previously in several occasions, due to the nature of our tunnel and how fire behaves in one, the quick response to an event can be of great difference between a minor accident and a major tragedy. The FFFS use water as a primary agent, and which can be deployed through different systems. The importance of these systems lies in their ability to mitigate fires early, reducing heat, controlling smoke and protecting mainly the occupants of the tunnel as well as the structure. The primary objective is to increase the tenability for tunnel occupants by slowing, stopping or even reversing the growth of the fire.

The NFPA 502 subjects the installation of FFFS to an engineering analysis to determine their necessity. However, its implementation is strongly advised for the tunnel below the El Paso Deck Plaza, as the tunnel allows the entry of heavy vehicles and has a large amount of traffic hourly. The implementation of these systems not only help the firefighting efforts once the third party rescue entities arrive on site, this system also assists and facilitates the emergency ventilation system; as the heat load is importantly reduced and the smoke amount reduced, the ventilation requirements in the tunnel can be greatly reduced while at the same time reducing the risk for the tunnel users. However, the introduction of mass to the tunnel also affects the ventilation, therefore its effects must be taken into consideration in the design of the ventilation system.

The type of systems can be qualified between the following categories:

- **Fire Suppression System:** This systems aims to sharply reduce the heat release rate (HRR) of a fire and prevent its growth by direct application to the burning fuel surface.
- **Fire Control System:** The aim of this system is to limit the size of the fire by using the extinguishing agent to reduce the HRR and pre-wet combustibles in the vicinity, as well as reducing the air temperature.
- **Volume Cooling System**: This system does not affect the HRR, but rather the products of the combustion.
- **Surface Cooling System:** Does not affect the HRR, but cools the infrastructure to avoid important structural damage.

Within these categories, the following systems can be classified as one or several of the categories above, but are mostly categorized as fire suppression, fire control, and/or volume cooling systems, which are the most commonly used in tunnels:

- **Automatic Sprinkler Systems:** These systems consists of sprinklers distributed all along the tunnel, but the fire triggers individual sprinkler heads, meaning the response to the fire is localized just in the area of the event. These systems can be categorized mainly as fire control with effects also as fire suppression.
- **Deluge Systems:** This system releases the water-based extinguishing agent from all nozzles simultaneously once the fire detection system is triggered. This allows a broad coverage, therefore it is normally used when fast-spreading fires are expected. These systems can be categorized mainly as fire control with effects also as fire suppression.
- **Water Mist Systems:** These type of systems use very fine droplets of water to suppress fires. The system is much more efficient in water consumption as well as a better heat absorption. These systems are primarily categorized as fire suppression and volume cooling, with additional effects of fire control.
- **Foam-Water Systems:** These systems use a mixture of water and concentrates to create foam. These type of systems are very effective against fires involving flammable liquids as fuel spilling. These type of systems are especially useful for stopping the fire from reigniting. Can be categorized mainly as fire suppression, but also as fire control.

The NFPA establishes different guidelines for the types of FFFS, as well as the needed specifications and requirements, among other information, for these systems. Depending on the choice, a different guideline might ensue.

As mentioned before, the water supply should be capable of supplying the FFFS for a minimum of 1 hour.

As mentioned briefly above, the implementation of this system affects other systems in the tunnel, therefore, during the design phase, all these systems have to take the FFFS into consideration. The impact directly affects the drainage requirements and the tenability during an event, as it modifies the humidity in the air as well as the possibility of reduction in stratification and visibility.

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Given that the system will allow the entry of heavy good vehicles, but is assumed to not allow the entry of dangerous goods vehicles, a representative HRR of 150 MW is taken from the NFPA 502 table of fire data for typical vehicles as a value for the design. The table is detailed below:

	Experimental HRR		Representative HRR		Experimental HRR with FFFS	
Vehicles	Peak HRR (MW)	Time to Peak HRR (min)	Peak HRR (MW)	Time to Peak HRR (min)	Peak HRR (MW)	Time to Peak HRR (min)
Passenger car	5–10	0–54[a]	8	10	—	—
Multiple passenger car	10–20	10–55[b]	15	20	10–15[g]	35[g]
Bus	25–34[c]	7–14	30	15	20[g,h]	—
Heavy goods truck	20–200[d]	7–48[e]	150	15	15–90[g]	10–30[g]
Flammable/ combustible liquid tanker	200–300	–	300	–	10–200[f]	

Figure-75 : Fire Data for Typical Vehicles, taken from the NFPA 502

While lower than when considering dangerous good, the HRR is still a high power fire, and considering the short length of the tunnel, the ventilation requires as much assistance as possible due to the limited placement available for jet fans. Therefore the type of FFFS shall be considered between a Fire Suppression and Fire Control System which reduce the HRR. From the systems both the deluge and mist systems are the most widely used and deeply studied systems for usage in tunnels.

During an event the response time from the moment the fire starts to the activation of the FFFS shall not exceed a time of three minutes.

5.6.9 EMERGENCY VENTILATION SYSTEM

As the tunnel for I-10 in El Paso is considered a category D; despite it being shorter than 3,280 feet long, the amount of traffic pushes the category from C to D, and ventilation is therefore a mandatory requirement. This means that the first step towards the design is to decide which kind of ventilation better suits the project.

The objectives of a ventilation system in a tunnel can be separated in two main objectives:

- **During normal operation and maintenance:** The objective of the ventilation system is to keep the air quality to a level that is appropriate for the people occupying the tunnel. This means that the ventilation must supply enough fresh air and remove the exhaust air for people in the tunnel, as well as to ensure the sufficient visibility in the tunnel. Despite the NFPA 502 and ASHRAE only providing a threshold value for the CO concentration, it is highly advisable to keep turbidity in check, as more often than not this is the higher threshold when it comes to normal operation.

  * CO concentration: The ASHRAE provides values for tunnels in a range from 35 ppm for 60 minutes to 120 ppm for 15 minutes. So the value would depend on the time the vehicles spend on the tunnel. With the length of the tunnel the exposure when traveling at 50 mph would be of no more than 30 seconds, while the maximum time will depend on the speed, amount of traffic and how long it takes to allow a flowing traffic again.

- **During emergency operation:** The ventilation system must comply with what is specified in the NFPA 502 guideline. The objective of the system is to reduce the effects of the smoke and heat on the escape and rescue routes of the tunnel, as well as to enable the self-rescue of tunnel users keeping the fleeing paths free of smoke and finally, to support the external rescue and fire-fighting teams once they arrive to the facilities. For the analysis of operation during and event, the NFPA 502 not only requires to analyze cases of fire inside of the tunnel, but also cases outside of the tunnel in which the products of the fire could have a negative impact in the tunnel environment.

The ventilation strategy of the ventilation system is mostly based in the control of the smoke, meaning it will try to keep the fleeing paths as smoke-free as possible. For that, the strategy changes depending on the tunnel traffic operation, either unidirectional or bidirectional. As the traffic operation also affects the risk in the tunnel, it will affect the selection of not only the ventilation strategy, but the selection of the ventilation system itself.

The tunnel under the El Paso Deck Plaza is highly suggested to be unidirectional, and therefore such operation will be taken in consideration.

In case of unidirectional traffic, it is expected that motorists would only be located upstream of the fire site. The ventilation objectives for unidirectional traffic varies depending on the type of ventilation system:

- **Longitudinal systems:** The main objective is to prevent back-layering of the smoke column by producing a longitudinal air velocity along the tunnel in direction of travel. The activation of the fans has to be done in a way that it initially does not disturb the smoke layer.

- **Transverse or reversible semi-transverse systems:** For these systems, the objective is to maximize the exhaust rate in the fire zone and minimize the amount of outside air introduced by the semi transversal system, and the second objective is to create a longitudinal airflow in direction of travel.

However, the high traffic and the freeway located in an urban area increase the risk and frequency of traffic jams, therefore the ventilation system will need to consider the existence of motorists on both sides of the fire, and therefore the affected tube for calculations would be considered similar to a bidirectional case. For a bidirectional case the ventilation strategy is divided in two phases.

During the first phase, motorists would be trapped on both sides of the fire and therefore the prime objective of the ventilation is to ventilate the tunnel keeping a low air velocity as to not disturb the stratification of the smoke. During the second phase, the objective would be to reach a critical velocity to control the back-layering of the smoke and allow fire-fighters to get closer to the fire.

In case of traffic trapped on both sides of the fire and if the cross sectional area of the tunnel allows for it, it is highly encouraged to use semi-transversal or fully transversal ventilation systems. However, being a short tunnel, longitudinal systems can work well.

Given that there is a possibility of both: the existence or non-existence of traffic on the hot side of the fire, the ventilation system can be programmed to always activate the ventilation of phase one to not disturb the smoke layer, but if there are no cars on the hot side of the fire, and by decision of the tunnel operator, the ventilation system can change to the second phase to avoid the backlayering of the smoke. It has to be clear to the operator that the decision of activating the second phase will disturb the smoke layer, causing the totality of the cross section filled with smoke, and therefore shall not be activated if a traffic jam is in place. Another option is to use an automatic CCTV traffic detection system to determine on the exact moment of the fire and the type of ventilation program to be started.

However, if possible, it is highly advisable to allow a traffic control system to avoid traffic congestion to form in the tunnel. It can be placed before the tunnel to avoid vehicles from entering all at once and regulate the flow, allowing in this way to keep the traffic congestion outside of the tunnel where the risk is significantly less.

Each tunnel represents a unique challenge for the design of the ventilation system, and as explained before, the first step in tunnel ventilation is to determine which concept is the most appropriate for the tunnel itself, and in case of urban tunnels, for the surroundings of the tunnel. For the El Paso Deck Plaza is important to consider that not only is the tunnel placed in a populated area, but the project contemplates the construction of a park on top of the tunnel, therefore adding a restriction to the treatment and direction of exhaust gases or in case of an event, of the smoke. The concentration of the exhaust gases to exit from the portals should be reviewed by an environmental analysis to explore the magnitude the impact of the concentration of the exhaust gases in the areas near the portals instead of going to the open air as is the current situation. Any of the ventilation concepts can provide solutions in case the filtering of exhaust air is needed, but being that a very costly solution to implement and maintain, an environmental analysis should be done.

There are in general four concepts for ventilation, more ventilation techniques and strategies can be made out of the combination of the following concepts:

- **Natural ventilation:** Natural ventilation of a tunnel implies the nonexistence of a mechanical ventilation system and reliance only in the natural airflow, typically caused be difference of temperature or pressure between the tunnel entrances. This type of ventilation can be found in very short and low-traffic tunnels. These systems can be very inefficient in case of emergency and its effectiveness depends on very specific environmental and geometric factors such as strong winds and steep slopes.

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- **Longitudinal ventilation:** After natural ventilation, longitudinal ventilation is perhaps one of the simplest and most common systems, in which air is move along the tunnel. The system is most commonly using jet fans, introducing fresh air through one of the portals and exhaust the polluted air or smoke through the other portal. As mentioned, there can be some variations to it, including shafts in the middle of the tunnel and using Saccardo Nozzles on these shafts to create the longitudinal air flow.

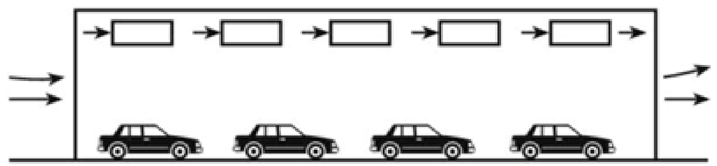

Figure-76 : Classic longitudinal ventilation system: Image taken from NFPA 502

- **Transversal ventilation:** A fully transverse ventilation system is one in which the air is supplied and extracted along the whole tunnel through dampers connected to exhaust and supply ducts. These concept variations come from mixing it with longitudinal ventilation and having a semi-transverse ventilation, in which either the exhaust or supply is provided by a variant of the longitudinal ventilation kind. This system requires of the construction of the ducts as well as ventilation buildings in one or both of the portals of the tunnel. This type of ventilation is normally selected for long and heavy-traffic tunnels, as it extracts the smoke on the area of the fire instead of pushing it on the rest of the tunnel.

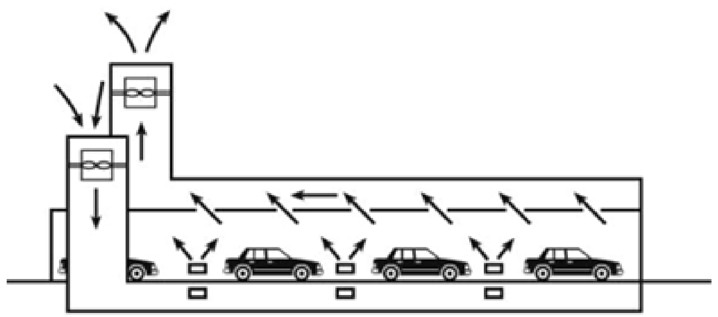

Figure-77 : Full transverse ventilation system: Image taken from NFPA 502

- **Single point extraction ventilation:** The concept is very similar as in a semi-transversal ventilation, with the exception that the exhaust of the polluted air and smoke is made in a singular point (damper) in the tunnel.

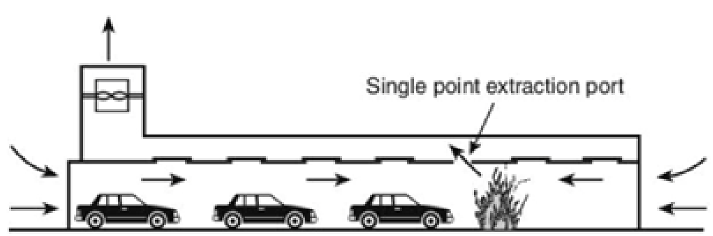

Figure-78 : Single point extraction system during an event: Image taken from the NFPA 502

An important criteria for the ventilation concept selection and design is the selection of a fitting Heat Release Rate (HRR). This variable directly affects all the emergency response systems and therefore it is important to set as a design boundary early in the project development phases.

The NFPA 502 does not establish a way to determine an exact value for the HRR, but the ranges depend on the type of traffic allowed in the tunnel. As heavy goods truck are allowed to transit through the tunnel, but not flammable/combustible liquid tankers, the heat release rate measured in an experimental way can range between 20 and 200 MW, being the majority around 130 MW with a development time between 7 and 48 minutes; however, the representative HRR established by the NFPA 502 is of 150 MW and the time to reach it is of 15 min, and therefore this value is to be taken into consideration for the future design and selection of the ventilation system.

Additional to the tunnel ventilation, the emergency ventilation system of a tunnel shall consider the escape routes, meaning the ventilation has the objective to keep the escape areas without smoke. This is accomplished by generating an overpressure behind the escape doors. This will be expanded in the analysis of the Means of Egress.

The ventilation is also heavily influenced and depending in the geometry of the tunnel. Both the cross-section along the tunnel as well as the longitudinal geometry can drastically affect the ventilation.

According to the drawings provided, the road of the tunnel has a gradient in one direction and the final value of it is still to be determined, however, the road slope has an important effect during a fire in the tunnel due to the buoyancy of the fire. Being the slope only in one direction, it is possible that one of the tubes could need less ventilation equipment as the fire will cause a natural flow towards the portal; however the other tube will have the opposite impact, the ventilation will have to overcome the flow induced by the buoyancy of the fire.

The cross section on the other hand limits size of the jet fans, as there are considerations regarding the space between the tunnel walls and tunnel clearance space. It is best practice to keep a minimum distance of around 7 inches from the tunnel walls to the Jet Fans to maintain a high efficiency, as well as no less than 7 inches from the tunnel clearance to allow the back-up structure to catch the jet fan in case of failure of the main fixing mechanism.

The most restricting measurements in the tunnel will be the ones to determine the maximum size of the system or equipment required. Given the provided drawings, and considering a clearance profile of 14.75 ft, the schematic layout of the biggest possible jet fans that can be fitted in the tunnel can be seen below. This restriction can limit the thrust of the jet fans, depending on the provider of choosing.

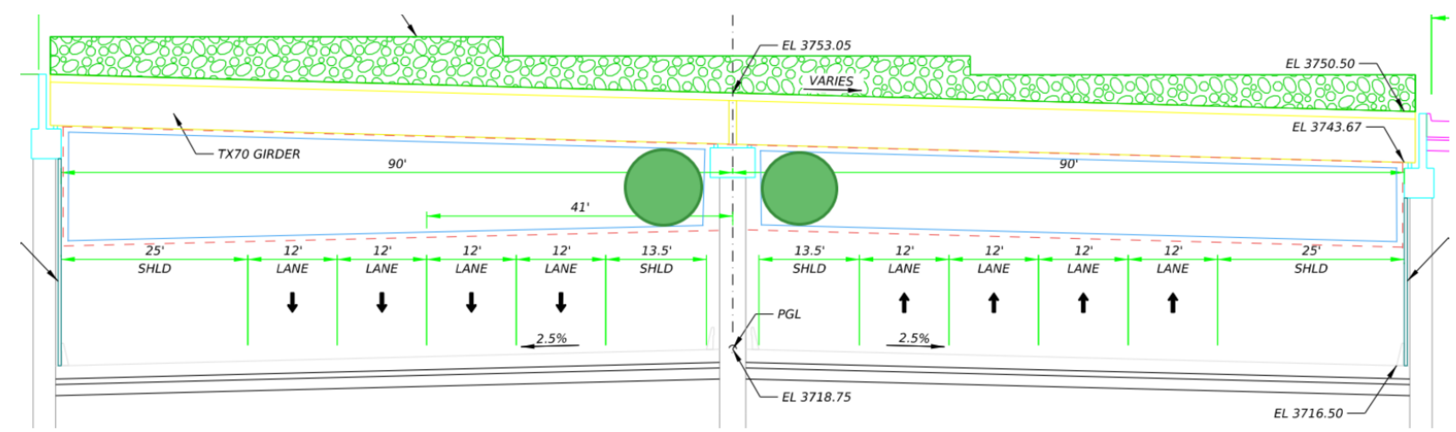

Figure-79 : Considerations for the largest size of jet fans on the most critical cross section of the tunnel

However, longitudinal ventilation as was detailed before can also be implemented with a Saccardo nozzle which can be placed over the deck. Considering the dimensions displayed in the drawing, and depending on the clearance profile, the size would be enough to implement any of the ventilation systems described above. For the determination of the most suiting ventilation system, more information regarding the traffic, operation and geometry of the tunnel has to be developed.

The length of the tunnel is also an important factor as it limits the space available for the placing of ventilation and other tunnel elements. The efficiency of jet fans can be severely affected by obstacles such as signs in the tunnel, additionally as best practice is suggested to keep a distance between jet fan positions as well as air velocity measurement devices in order to take advantage of the full thrust of the fans and to take reliable measurements respectively.

Along with the ventilation system, the control of it has to be determined, and can only be done by the inclusion of measurement devices along the tunnel. The type of measurement devices needed for the tunnel are: air velocity sensors, CO-measurement device, temperature sensors and turbidity sensors are highly advised. The amount of sensors has to be determined in future stages of the project.

Tunnel drainage system

The tunnel drainage system consists of a network of pipes, channels, sumps and pumps that are in the tunnel to relocate the water and any liquid out of the tunnel. These systems are strategically located along the tunnel, specially at low points where liquids tends to accumulate. The objectives of the drainage system change depending on if the tunnel is in normal operation or during an event.

- **Normal operation:** The main objective during normal operation is to collect any water that gets into the tunnel either by rain, water from cleaning the tunnel, water from vehicles, etc. A secondary but equally important objective is to collect any vehicle-related fluids, either being oil, fuel or any other fluid that could leak onto the floor, as these could cause hazardous conditions in the tunnel.
- **Emergency operation:** During an emergency operation, the system plays an even more critical role as the amount of fluids in the tunnel can increase fast. The drainage has the objective to collect and divert the large amounts of water used by the FFFS or firefighter teams to suppress or reduce the fire. Quick removal of the water is important to avoid flooding and hazardous situations. A second objective of the drainage during an emergency is to be able to collect any chemical, fuel or hazardous spill to avoid them from accumulating and spreading, this avoids the expansion and increase of the power of a fire, as well as reducing the chance or reignition.

As for the use of the drainage not only for water, but hazardous materials, it shall be constructed entirely by noncombustible materials. The design shall consider a capacity to handle the rate of flow of all design road sources without causing flooding, and also the design should consider any liquid expected in the tunnel such as the flow rate for standpipe systems discharge, environmental sources, tunnel washing, any other catchment sharing the tunnel drainage and the spill rate for fuel or other hazardous liquids.

For the case of the tunnel under the El Paso Deck Plaza, the design shall consider the existing piping and drainage system and take into consideration the existing infrastructure, possibly expanding or complementing it.

As the drainage takes all kind of liquids, for environmental reasons the collected liquids shall not directly be discharged to the environment, and therefore should contain mechanisms to separate the hazardous materials and contamination materials from the water.

For these means, the drainage discharge system shall be provided with a separator and drainage storage capacity.

As the full drainage system is used to collect hazardous materials, the storage tanks and wet wells, as well as the chambers of pump stations, shall be classified as hazardous locations, and all of the electromechanical equipment shall be designed considering the requirements of the hazard classification.

5.6.10 HYDROCARBON DETECTION

Hydrocarbons are organic compounds that are commonly found in fuels such as gasoline, diesel and natural gas and therefore the implementation of a detector of these substances can help in the quick reaction of the emergency system, perhaps even before the ignition of a fire.

Therefore, the NFPA 502 requires the installation of Hydrocarbon detection in the storage tanks and pump stations, and if detected its presence, the system shall initiate a local and remote alarm.

5.6.11 FLAMMABLE AND COMBUSTIBLE ENVIRONMENTAL HAZARDS

Flammable and combustible hazards refer to any substance or condition that can ignite or explode, and can pose a serious risk for both the tunnel structure and the motorists going through the tunnel.

The design however, should not only center in the operation of the tunnel, but during all stages, from construction, to operation and maintenance, and shall consider the risks of hazards natural and constructed environmental hazards.

The NFPA 502 sets this part of the design as a conditionally mandatory requirement (CMR), meaning that an engineering analysis must be done to detect the hazards and determine the appropriate mitigation measurements.

5.7 MEANS OF EGRESS

According to the NFPA 101, the definition of Means of Egress is *"A continuous and unobstructed way of travel from any point in a building or structure to a public way consisting of three separate and distinct parts: (1) the exit access, (2) the exit, (3) the exit discharge."*

Means of egress according to the NFPA 502 shall be designed by following the guidelines of the NFPA 101, Chapter 7 unless any specification is modified by the NFPA 502.

5.7.1 EMERGENCY EGRESS

All the means of egress must be design and implemented according to the NFPA 101.

Tunnel emergency egress refers to the design and implementation of escape routes and systems that allow people to safely evacuate a tunnel in the event of an emergency, such as a fire, vehicle accident, explosion, or hazardous material spill. Because tunnels are confined spaces with limited access points, ensuring quick and effective evacuation is critical to minimize injuries or fatalities during incidents.

Reflective or lighted directional signs indicating the distance to the two nearest emergency exits must be placed on the side walls at intervals of no more than 25 meters (82 feet). Additionally, wayfinding measures should be implemented to assist in the safe evacuation of the tunnel, ensuring that occupants can easily locate and reach the nearest exits during an emergency.

5.7.2 EXIT IDENTIFICATION

Tunnel exit identification is a vital element of tunnel safety, providing clear, accessible, and visible routes for evacuation during emergencies. Whether through illuminated signs, dynamic messaging, emergency lighting, or reflective markers, these systems ensure that people can quickly and safely exit tunnel when needed.

The NFPA 502 requires the implementation of either reflective of lighted directional signs that inform the fleeing tunnel occupants the distance to the two nearest emergency exists and shall be located on the side walls with a spacing between each sign of no more than 25m (82 ft). Signs can be either internally or externally illuminated. While photoluminescent paint can enhance visibility, it increases the need for regular tunnel cleaning to maintain its effectiveness.

The NFPA 101 pinpoints the NFPA 170 guideline for the selection of the exit symbols, from which a variety can be chosen for its installation in the tunnel. The symbol is a pictogram of a fleeing person, indicating with arrows the direction of the exits. The distance to the exits must be added to comply with NFPA 502. Exit identification in tunnel should follow internationally recognized symbols to avoid language barriers. Tunnel exit identification systems are connected to emergency power supplies, ensuring that lights and signs remain operational even if the main power supply is compromised.

5.7.3 TENABLE ENVIRONMENT

The NFPA 502 defines tenable environment as *"An environment that permits evacuation or rescue, or both, of occupants for a specific period of time"*, and is a requirement for the means of egress.

The main objective for a tenable environment is to make the escape routes safe and as comfortable for the users as possible, therefore some factors to be considered are listed below. These factors are being taken from the Annex B of the NFPA 502, and therefore do not form part of the requirements, but are to serve as information to take in consideration during the future stages of the design:

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- **Heat effects:** Heat exposure has to be controlled in order to avoid life threatening conditions as can be hyperthermia, body surface burns, and respiratory tract burns. As burns to the respiratory system occurs only after skin burns, only the first two have to be considered in the design. The Annex in the NFPA 502 offers the following table to determine the time of exposure a human can tolerate different temperatures:

Table B.2.1 Exposure Time and Incapacitation

Exposure Temperature °C	Exposure Temperature °F	Maximum Exposure Time Without Incapacitation (min)
80	176	3.8
75	167	4.7
70	158	6.0
65	149	7.7
60	140	10.1
55	131	13.6
50	122	18.8
45	113	26.9
40	104	40.2

Figure-80 : Exposure Time and Incapacitation, taken from the NFPA 502

- **Air Carbon Monoxide Content:** The exposure to carbon monoxide can also be found in a quantity-time relation in the NFPA 502, going from 225 ppm for 30 minutes, up to 1150 ppm for as low as 6 minutes, and a maximum of 2000 ppm for a few seconds.
- **Toxicity:** This value would depend on the components of the elements that are feeding the fire.
- **Smoke Obscuration Levels:** During an event in a tunnel without the proper mitigation systems, the smoke can quickly cover the whole cross section of the tunnel making it impossible to see few meters ahead, therefore the visibility should be kept in such level that illuminated signs (with a luminance of 8.6 cd/m^2) can be seen as far as 100 ft, and doors and walls should be recognizable at 33 ft. This is important in order to allow people to easily find the tunnel emergency signs and escape routes.
- **Air Velocities:** Air velocities should be kept between a range of 150 – 2200 fpm. Lower velocities can cause the smoke to enter escape routes such as cross passages or emergency stairwells; on the other hand, high velocities can violently close the emergency doors, make it hard or dissuade people from entering a room.
- **Noise Levels:** The control of the noise levels of the systems in the tunnel is important, as the activation of them shall not make the instructions through the emergency communication systems unintelligible. Silencers for fans should be considered and an analysis of the sound of the tunnel might ensue in case fans are too loud and impede the clear listening of instructions through the tunnel emergency communication system.

5.7.4 WALKING SURFACE

The walking surfaces shall comply with the NFPA 101, therefore they should comply with three criteria:

- **Changes in elevation:** Changes in elevation shall not be abrupt and hence shall not exceed ¼ in. If the change is higher than ¼ in but smaller than ½ in it shall be beveled with a slope of 1:2. Bigger changes shall be considered as change in level.
- **Changes in Level:** Walking surfaces shall be nominally leveled and the slope shall not exceed 1:10 in the direction of walk, unless it is considered a ramp, and therefore is subject to different standards, and shall not exceed 1:48 perpendicular to the direction of walk. A change in level is considered when the elevation difference exceeds 21 inches, and if a stair is required in any of the means of egress, the minimum thread of the stair is 13 inches.
- **Slip resistance:** Surfaces for walking shall be slip resistant for foreseeable scenarios.

The NFPA 502 also specifies that the tunnel roadway surface can serve as an egress pathway when supported by a traffic management system. This egress pathway must have a minimum clear width of 3.7 feet, lead directly to an emergency exit, and be protected from traffic to ensure the safety of evacuees.

Execution will be coordinated with civil engineers.

5.7.5 EMERGENCY EXIT DOORS

Emergency exit doors are the shields between the fire and smoke in the tunnel tube and the cross passages or emergency stairwells, therefore they shall provide protection and resistance against fire, as well as allow the pressurization of the escape route.

There are two type of emergency exit doors, they can either be leaf doors or sliding doors. For traditional leaf doors, they shall be opened in the direction of escape; while sliding doors can open either way but must have a sign identifying the direction of opening.

The doors facing the tube shall be 1 ½ hour-rated, using the Rijkswaterstaat time-temperature curve and be installed according to NFPA 80. All other doors shall comply with the NFPA 101.

Emergency exit doors should be strategically located at regular intervals within the tunnel, not more than 300m (1000 ft) to ensure that occupants can quickly reach an exit.

The doors shall be able to be opened by applying as low force as possible to the latch side; this force shall not exceed 50 pounds. As previously mentioned, the system in most cases would require the generation of an overpressure to avoid the products of the fire interfering with the escape route. The maximum force allowed for opening the door shall consider the overpressure and aging of the mechanism. If the pressure in the tunnel requires a generation of a bigger overpressure, door opening assistance shall be installed in the doors.

Despite the low opening force requirements, the doors themselves and the hardware of the system shall be able to endure both positive and negative pressures that could be generated by the passing of vehicles.

Emergency exit doors shall be self-closing without relying in any external power.

5.7.6 EMERGENCY EXITS

The NFPA 502 requires the existence of at least one emergency exit of the tunnel every 1000 ft, and therefore the road tunnel below the El Paso Deck Plaza shall have at least 1 emergency exit. As the tunnel is unidirectional, does not have pedestrian or biking lanes, and the space between tubes does not allow the construction of cross passages or stairwells between the tubes, the emergency exits shall be installed on the external sides of the tunnel, meaning that at least two emergency exits will be needed, one per tube.

To keep an equal distance to all the exits, it is recommended to place the emergency exits close to the middle of the tunnel.

The precise amount of emergency exits needed to maximally reduce the risk will have to be determined by an engineering analysis that takes into consideration several factors, among which the NFPA 502 lists the following:

- Category, including types and classes of tunnels
- Design fire scenario
- Egress analysis
- Fire-life safety systems analyses to provide tenable environment in tunnel in accordance to 7.16.2 (This includes type and operation of tunnel ventilation, detection, fire protection, and control systems.)
- Traffic management system
- Emergency response plan
- Consideration of uncertainties of people's behavior during a fire event and of those who are unable to self-rescue

Illuminated exit signs that remain lit during power outages will mark those exits.

Accessibility is a key consideration in the design of emergency exits, which are constructed to accommodate all individuals, including those with disabilities. Features such as ramps, handrails, and adequate space for wheelchairs are often included to facilitate safe evacuations for everyone.

During an emergency, such as a fire or power failure, emergency exits are automatically highlighted with flashing lights and audible alarms, alerting tunnel users to their location. Exits should be integrated with the tunnel's overall safety and emergency communication systems, ensuring a coordinated response during critical situations.

TASK 400: TUNNEL SYSTEMS

As the tunnel is located below the El Paso Plaza Deck, the best option would be to consider an emergency stairwell which connects the tunnel with an outside escape route as well as installing stairwells outside of the portals so the fleeing motorists can go to the park or to a safe place to wait. If the stairwell is constructed as an emergency exit from the tunnel, the design should accommodate for individuals with disabilities who may not be able to use stairs. A safe waiting area should be provided where they can wait comfortably until assistance arrives.

Regardless of the emergency exit choice, all of them shall be equipped with a ventilation system as well. This system is normally inactive and only is activated during emergency and during scheduled runs to avoid damage of the equipment for not being used in long time.

The ventilation system normally consists in an axial fan injecting fresh air in the emergency exit (cross passage or staircase) to generate an overpressure inside of the escape route, and by this, avoiding the entry of the products of the fire. To avoid the generation of excessive pressure that can cause difficulty in opening the emergency doors, a pressure relief damper is normally used to keep the pressure under a certain threshold. The rest of the system consists in ducts, grills, and/or dampers to guide, filter and block or allow the passage of air.

The design of the emergency exit ventilation shall keep in mind the tenability of the environment inside of the tunnel, especially regarding air velocities through the door as well as the noise; axial fans depending on the side can be very loud, and therefore the inclusion of silencers could be necessary.

Figure-81 : The Highway 99 tunnel north portal, near Harrison Street, heads south under downtown Seattle to the stadium district. Signage shows drivers where the nearest escape exit is in case of an emergency. (Mike Siegel / The Seattle Times)

5.8 Electrical Systems

5.8.1 GENERAL

Tunnel electrical systems play a vital role in maintaining safety, efficiency, and user comfort within tunnel environments. By integrating power supply, lighting, ventilation, communication, and safety systems, these electrical infrastructures support the complex demands of modern tunnel operations while adhering to stringent safety and regulatory standards. Proper design, maintenance, and operation of these systems are essential for the safe travel of users and the effective management of emergencies.

Power supply is based on utility power (tunnels rely on a connection to the local electrical grid for their primary power supply) and emergency power (backup power sources, such as generators or Uninterruptible Power Supply – UPS systems, ensure that critical systems remain operational during power outages).

Power supply is need for Lighting systems (general and emergency), ventilation systems (in case of smoke or pollution and as fresh air supply), control systems (SCADA control and monitoring system), communication systems (intercoms and emergency phones), safety and security systems (fire detection and Surveillance).

5.8.2 CONTROL BUILDING

The electrical systems must support life safety operations, fire emergency operations, and normal operations. This ensures that the tunnel remains operational and safe under all conditions, including during emergencies and routine use.

A tunnel facility building provides a secure space to house all the essential support systems needed for tunnel operations, such as ventilation systems, power distribution equipment (transformers, switchgear, etc.), and life safety systems (fire suppression, emergency lighting, etc.). The building also serves as the control center for traffic surveillance, monitoring tunnel systems like ventilation, lighting, and fire detection, and managing the overall operational safety of the tunnel. Operators can respond quickly to emergencies and monitor tunnel conditions in real time. It includes rooms for Uninterruptible Power Supply (UPS) systems and batteries, ensuring continuous power to critical systems, like lighting and fire detection, in case of a power outage. The facility typically consists of rooms separated by fireproof doors, ensuring the containment of any fire and protecting critical equipment. This setup is vital for maintaining safety and minimizing damage in the event of a fire. It provides a centralized location for maintenance personnel to manage the infrastructure, handle equipment repairs, and perform regular system checks, ensuring the tunnel operates efficiently.

5.8.3 EMERGENCY POWER

Emergency power in a tunnel is crucial for maintaining safety and functionality during power outages or other emergencies.

Emergency power systems in a tunnel should follow guidelines set by organizations like the National Fire Protection Association (NFPA), particularly NFPA 70 (National Electrical Code) and NFPA 502 (Standard for Road Tunnels). These standards define the requirements for ensuring sufficient backup power is available to meet safety demands during emergencies.

In summary, emergency power is essential for tunnel safety, enabling the continuous operation of critical systems that protect human lives and the infrastructure during power outages or emergencies.

In the event of a power failure, critical safety systems must remain operational. These include emergency lighting, fire detection, ventilation, and fire suppression systems, which are essential for safe evacuation and fire control.

Tunnel ventilation systems remove smoke and control air quality. During a fire or hazardous event, emergency power ensures that these systems continue operating to manage smoke flow, prevent its spread to safe areas, and aid in safe evacuation.

Emergency power supports essential tunnel lighting, including emergency and evacuation lighting, to guide drivers and personnel safely out of the tunnel during incidents or power outages.

Maintaining power to traffic signals, surveillance cameras, and communication systems is vital for monitoring the situation inside the tunnel, coordinating emergency response, and guiding traffic flow to prevent accidents.

Emergency power is required for systems such as deluge valves and other firefighting equipment, ensuring that fire suppression can be activated immediately when needed.

Critical tunnel monitoring and control systems, including SCADA (Supervisory Control and Data Acquisition), rely on emergency power to ensure operators can monitor tunnel conditions and respond to incidents.

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Typical Emergency Power Setup:

- **Uninterruptible Power Supply (UPS):** A UPS system provides immediate, short-term power to critical systems when the primary power fails, preventing any gap in service until backup generators kick in.
- **Backup Generators:** Diesel generators or other alternative power sources are often used to supply longer-term emergency power. These generators automatically start when primary power is lost, ensuring continued operation of essential systems.
- **Dual Power Sources:** Some tunnels use dual utility feeds from separate substations to ensure redundancy. If one power source fails, the second source can take over, reducing the risk of total power failure.
- **Automatic Transfer Switches (ATS):** These systems are used to seamlessly switch between the main power source and backup power without manual intervention, ensuring minimal disruption to critical operations.

5.8.4 EMERGENCY LIGHTING

Emergency lighting is a critical safety feature in tunnel systems, enabling safe and visible evacuation routes and supporting critical operations during power outages or emergencies. It operates on UPS and backup power systems to ensure continuous operation and complies with regulatory standards for reliability and performance.

In the event of an emergency such as a fire, power outage, or accident, emergency lighting helps guide drivers and tunnel users safely to exits. It illuminates escape routes, emergency doors, and critical signage. The tunnel is dark environment, and any loss of lighting can cause panic or confusion. Emergency lighting ensures that visibility is maintained, reducing the risk of accidents or further incidents during an emergency. Emergency lighting also helps first responders by illuminating the tunnel environment, enabling them to navigate safely and respond effectively to incidents.

General Emergency Lighting provides basic illumination throughout the tunnel during power failures. It ensures that the entire tunnel remains visible, minimizing confusion and ensuring safe vehicle movement.

Escape Route Lighting is specifically designed to highlight evacuation routes, this lighting illuminates emergency exits, refuge areas, and signage that leads people out of the tunnel safely.

Safety Lighting for Equipment focuses on critical safety systems such as fire extinguishers, emergency phones, and control panels. It ensures that people can easily locate and operate emergency equipment when needed.

Emergency lighting is typically powered by a UPS system, ensuring that there is no gap in lighting when the primary power source fails. The UPS system provides short-term power, usually for a few minutes to an hour, until backup generators start. After the initial UPS power is used, emergency lighting is typically maintained by backup generators. These generators provide long-term power until the main power supply is restored. The emergency lighting system is usually connected to an ATS, which automatically switches the power source from the primary to the UPS or backup generator during an outage, ensuring continuous lighting. In some systems, battery-powered emergency lights are installed. These lights automatically turn on when the power supply fails and can operate independently for a specified amount of time (usually 90 minutes or more).

Emergency lighting in tunnels must comply with strict safety standards and regulations, such as: NFPA 70 (National Electrical Code) and NFPA 502 (Standard for Road Tunnels)

5.8.5 EXIT SIGNS

Tunnel exit signs are a fundamental safety feature, providing clear, illuminated guidance toward exits and safe zones during emergencies. Strategically placed, powered by emergency systems, and compliant with safety standards, they ensure that tunnel occupants can safely and efficiently evacuate in case of an incident. Exit signs are powered by the tunnel's emergency power system, which is typically supported by an Uninterruptible Power Supply (UPS) and backup generators. This ensures they stay illuminated even when the main power is down. In case of an emergency, such as a fire or power failure, tunnel exit signs automatically switch to emergency power and remain lit. This automatic system prevents any gaps in visibility for those seeking to exit the tunnel.

In an emergency, especially in low-visibility conditions (like smoke or darkness), tunnel exit signs provide clear visual cues that guide users toward exits or safe zones. Properly illuminated and strategically placed exit signs help minimize confusion and panic by directing drivers and pedestrians to the nearest exit or emergency refuge area. Exit signs form an essential part of the tunnel's emergency evacuation plan, ensuring that users are aware of the quickest and safest routes out of the tunnel in case of an emergency. Exit signs are mandated by safety standards and codes, ensuring that tunnel meet regulatory requirements for the safety of all occupants.

Tunnel exit signs are usually illuminated to remain visible in dark or smoky conditions. They are often equipped with LED lighting or powered by the tunnel's emergency power supply to ensure continuous operation during power failures. Exit signs are strategically placed at regular intervals along the tunnel. They are located near emergency exits, evacuation doors, and refuge areas, ensuring that users can easily find them no matter where they are in the tunnel. Exit signs use universally recognized symbols and colors (usually green for exits, with directional arrows) to ensure they are easily understood, even by users who may not speak the local language. This also helps comply with international safety standards.

Tunnel exit signs must comply with various safety codes and standards to ensure they function effectively, such as: NFPA 502 (Standard for Road Tunnels), ISO 3864 and ISO 7010.

5.8.6 SECURITY PLAN

A tunnel security plan is a comprehensive approach to safeguarding tunnel infrastructure from a wide range of threats, ensuring the safety of tunnel users, and maintaining operational continuity. It incorporates physical, digital, and procedural measures to prevent, detect, and respond to security incidents, and requires ongoing training, monitoring, and coordination with emergency services. By addressing both immediate and long-term risks, the plan helps create a secure and resilient tunnel environment.

By identifying potential vulnerabilities, a security plan helps minimize disruptions caused by security breaches, ensuring the tunnel remains operational and safe for users. Security plans address how to handle various threats, from cyberattacks to physical damage, ensuring there are clear procedures in place to mitigate risks and manage emergencies effectively. A well-structured plan helps deter and respond to crimes, such as vandalism, theft, or human trafficking. It also ensures the safety of users by maintaining a secure environment.

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5.9 Emergency Response Plan

An Emergency Response Plan is a document that contains the strategy that outlines the planned response to various emergency situations. It is a proactive measure that aims to minimize the impact of possible emergencies. Establishing clear communication protocols with local law enforcement, fire departments, and security agencies is essential for ensuring a rapid and efficient response to security incidents. Pre-defined procedures are crucial for facilitating seamless cooperation and coordination during emergencies. Developing detailed evacuation plans is necessary to provide clear instructions and designated routes for safely evacuating tunnel users in the event of an attack or other security emergency. Emergency exit signs, appropriate lighting, and audio communication systems play a critical role in guiding people to safety.

Regularly conducting security drills and exercises for tunnel personnel is important to ensure they are familiar with emergency procedures. These drills should also include coordination with local emergency services to test response capabilities and maintain a high level of preparedness.

The Emergency Response Plan must be unique and tailored specifically for the tunnel under the El Paso Deck Plaza, considering its location, the access roads as well as the locations, distances and time of response of the agencies around it.

The NFPA 502 lists the following typical incidents that have to be taken in consideration as a minimum for the emergency response plan:

- Fire or a smoke condition in one or more vehicles or in the facility
- Fire or a smoke condition adjoining or adjacent to the facility
- Collision involving one or more vehicles
- Loss of electric power that results in loss of illumination, ventilation, or other life safety systems
- Rescue and evacuation of motorists under adverse conditions
- Disabled vehicles
- Flooding of a travel way or an evacuation route
- Seepage and spillage of flammable, toxic, or irritating vapors and gases
- Multiple casualty incidents
- Damage to structures from impact and heat exposure
- Serious vandalism or other criminal acts, such as bomb threats and terrorism
- First aid or medical attention for motorists
- Extreme weather conditions, such as heavy snow, rain, high winds, high heat, low temperatures, or sleet and ice, that cause disruption of operation
- Earthquake
- Hazardous materials accidentally or intentionally being released into the tunnel

Different agencies shall be considered and involved in the plan and different agencies have to be included depending on the emergency, they shall be clearly identified and the roles of each agency shall be clear. The roles as to which agency is in command, which is responsible for supervision, correction or alleviation must be stated clearly.

Once the plan is done, it shall be approved by the authority having jurisdiction (AHJ).

5.10 Literature

[1] *NFPA 502: Standard for Road Tunnels, Bridges, and Other Limited Access Highways. National Fire Protection Association. 2020 Edition*

[2] *NFPA 101: Life Safety Code. National Fire Protection Association. 2024 Edition*

[3] *NFPA 14: Standard for the Installation of Standpipe and Hose Systems. National Fire Protection Association. 2019 Edition*

[4] *Downtown Deck Plaza Foundation, Community Advisory Committee. El Paso Deck Plaza Feasibility Study presentation. July 2024.*

[5] *Traffic study: I-10 expansion, El Paso, Texas. Retrieved from:*

https://pirg.org/resources/i-10-expansion-el-paso-texas/

[6] *The Seattle Times:*

https://www.seattletimes.com/seattle-news/transportation/highway-99-tunnel-is-loaded-with-safety-tech/

NIGHT VIEW OF MULTI-CULTURAL FORUM

TASK 500: ILLUMINATION

TASK 500: ILLUMINATION

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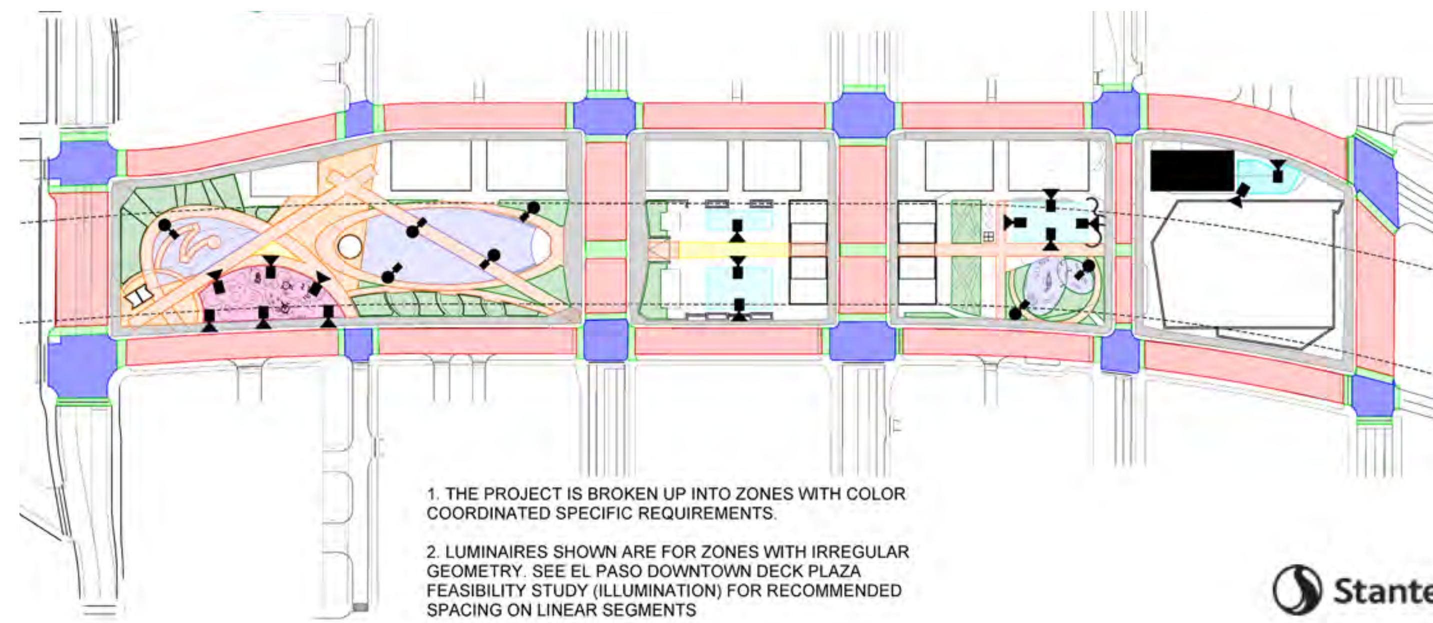
6.13 Intersections and Crosswalks

Attachment: Project Overlay Sheet

6.1 Project Overview

Stantec has performed an engineering feasibility study for illumination of the El Paso Downtown Deck Plaza. The project is a "lid" where a bridge is built over I-10 in downtown El Paso for park spaces. Stantec has developed a lighting scheme to create an applicable lighting design based on recommended lighting levels from Illuminating Engineering Society (IES) and City of El Paso lighting codes.

By selecting a luminaire and walkway width, Stantec determined a typical spacing on a small scale to meet the lighting design criteria and place lights along zones of irregular geometry shown on the concept to develop a schematic. With this approach, Stantec has implemented "modern" aesthetic lighting, which follows the City of El Paso's Energy Conservation Code for outdoor lighting, and ordinance to promote Dark Skies.



TASK 500: ILLUMINATION

6.2 References

IES Standards and City of El Paso Lighting Codes Referenced:

- **RP-6-22** – Recommended Practice: Lighting Sports and Recreational Areas
- **RP-8-22** – Recommended Practice: Lighting Roadway and Parking Facilities
- **RP-43-22** – Recommended Practice: Lighting Exterior Applications
- **LP-11-20** – Lighting Practice: Environmental Considerations for Outdoor Lighting
- **G-1-22** – Guide for Security Lighting for People, Property, and Critical Infrastructure
- **El Paso, Texas – Code of Ordinances Title 18** – Building and Construction Chapter 18.18 – Outdoor Lighting Code

Notes:

- **RP-43-22** was referenced for all areas outside road right-of-way.
  - ◊ LZ-3 was used to determine lighting criteria from **RP-43-22** Table A-3: Recommended Illuminance Criteria For People In Outdoor Environments.
  - ◊ These areas include:
    - * Trees, gardens, landscape
    - * Walking surfaces
    - * Amphitheater, grass areas
    - * Playground
    - * Art, sculpture, monuments, fountains
    - * Amenity areas
- **RP-8-22** was referenced for all areas inside road right-of-way
  - ◊ All calculations were performed using the illuminance method, measured in foot-candles.
  - ◊ Street classification was determined to be local streets.
  - ◊ Pedestrian activity classification was determined to be high as the City of El Paso is expecting more than 100 pedestrians during the highest nightly average 1-hour volume period.
  - ◊ Intersections were determined to be local/local classifications (fewer than 1500 vehicles ADT.
  - ◊ Vertical illumination desired in crosswalks to improve pedestrian visibility recommends the maintained average vertical levels meet or exceed the maintained average horizontal design levels for the intersection.
  - ◊ Vertical calculation points were placed at 5ft. elevation spaced at 1.65ft. along the middle of proposed pedestrian walkways.
  - ◊ Horizontal calculation points were placed evenly at 10ft. spacing at 0ft. elevation for all zones.
- **LP-11-20** was used to determine the lighting zone for the El Paso project
  - ◊ As used in the Joint IDA-IES Model Lighting Ordinance (MLO), the lighting zone determined was LZ-3.
  - ◊ LZ-3 moderately high ambient light includes areas of human activity (i.e, habitation, recreation, and/or work) where electric lighting may be continuous and is required for convenience at night.
  - ◊ The vision of human residents and users of these areas is adapted to moderately high light levels, and they have moderate to high expectations of electric lighting.
  - ◊ Lighting is expected to be continuous (e.g. lighting delivered fairly evenly along the length of a path or street).
  - ◊ After curfew, both light levels and uniformity may be reduced in some areas as activity levels decline.
  - ◊ Recommended default zone for large cities business districts.
  - ◊ Includes business zone districts; commercial mixed use; heavy industrial and/or manufacturing zone districts.
- **El Paso, Texas – Code of Ordinances Title 18** – Building and Construction Chapter 18-18-Outdoor Lighting Code.
  - ◊ Although this ordinance exempts the El Paso Downtown area from all the requirements of this chapter, the proposed developments are assumed to be outside of the downtown area per the downtown area limits specified in the ordinance. City of El Paso may decide to adjust the exemption limits to allow additional flexibility in the lighting design for the proposed developments in this area.
  - ◊ Lighting Zone is considered as "Lighting Zone E4" due to the project limits falling in zoning district C-4 and C-5.
  - ◊ Outdoor lighting to illuminate roadways and walkways are considered to be "Class 2 Lighting". Class 2 lighting area allows only fully shielded light fixtures
  - ◊ Outdoor lighting to illuminate the proposed park and recreational facilities are considered to be "Class 1 Lighting".
  - ◊ Class 1 lighting for Zone E4 with initial input greater than or equal to 1800 lumens allows only fully shielded light fixtures to be used.
  - ◊ Class 2 lighting for Zone E4 with initial input greater than or equal to 1800 lumens allows only full shielded light fixtures to be used.
  - ◊ For commercial and industrial use, the total lumen caps (full cutoff + unshielded) can reach up to 1,000,000 lumens per acre.
  - ◊ Referenced for shielding and light trespass standards.
  - ◊ The use of spot or floodlights was avoided in order to limit the light trespass.
  - ◊ Sets the foundation for luminaires to be Dark Sky compliant.
    - * In accordance with city code of ordinance, Stantec meets specifications such as glare (G) rating restriction of 2 and uplight (U) rating restriction of 0 in appropriate areas to meet Dark Sky compliance.

TASK 500: ILLUMINATION

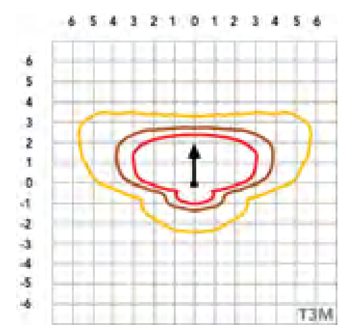
6.3 Luminaires

The luminaires selected for this project align with the “modern” aesthetic chosen by project architects. They comply with Dark Sky regulations, which aim to reduce light pollution and preserve the night sky. Additionally, they meet BABA (Buy American, Build America) requirements as per the preference of the City of El Paso. After thorough research, Stantec identified these luminaires as the best fit for the project.

The three luminaires used for Stantec’s calculations are the DSX0, DSX1, and the DSX2 model, all manufactured by Acuity. The BUG (Backlight, Uplight, Glare) rating of these fixtures helps to avoid any light trespass and meet dark sky compliance. Stantec uses each type based on the specific lighting needs of different areas. The DSX2 offers the best results for roadway light level criteria. The DSX1 offers higher output and broader coverage, making it ideal for large spaces or areas requiring more intense illumination to ensure safety and visibility. The DSX0 is suitable for smaller or less critical areas where lower light levels are sufficient. Using the two models together allows for more flexibility in pole spacing options to meet the illumination criteria.

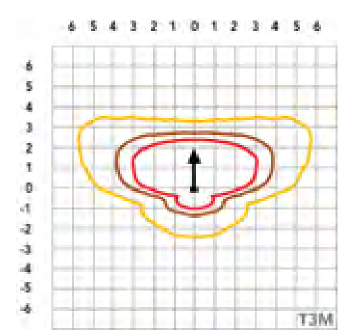
Typical Light Loss Factors (LLF) for approved luminaires range from 0.7-0.9. An LLF of 0.8 was assumed for the determination of pole spacing and illuminance schematics. Pole placement was also limited to minimize interference when placed underneath the honeycomb-like shade structures erected at specific locations throughout the project limits.

DSX0 LED P1 40K 70CRI T3M



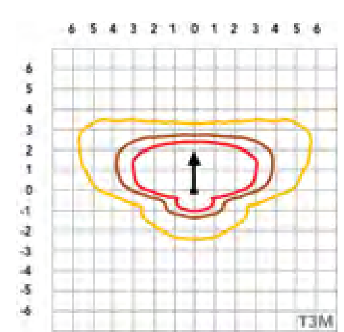
https://lithonia.acuitybrands.com/products/detail/196671/lithonia-lighting/d-series-area-size-0/dsx0-led-area-luminaire

DSX1 LED P3 30K 70CRI T1S



https://img.acuitybrands.com/public-assets/catalog/209326/dsx1-led.pdf?abl_version=09%2f25%2f2024+16%3a06%3a19&DOC_Type=SPEC_SHEET

DSX2 LED P1 40K 70CRI T3M



https://lithonia.acuitybrands.com/products/detail/209327/lithonia-lighting/d-series-area-size-2/dsx2-led-area-luminaire

6.4 Roadways

In this section, small sections of unique roadways are analyzed to determine the typical light pole spacing on a small scale to meet the lighting design criterion. The lighting criteria referenced is **IES RP-8-22.**

Table 11-1. Lighting Design Criteria for Streets

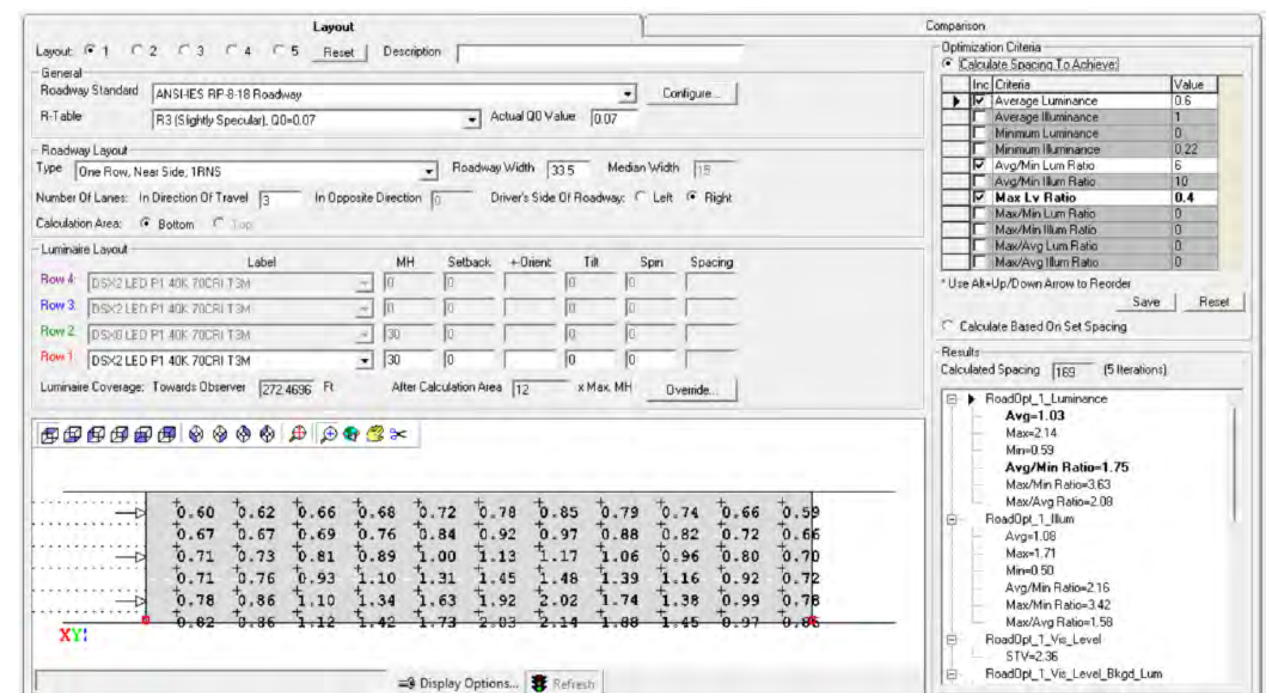
Street Classification	Pedestrian Activity Classification*	Average Luminance L_{avg} (cd/m²)	Average Uniformity Ratio L_{avg}/L_{min}	Maximum Uniformity Ratio L_{max}/L_{min}	Maximum Veiling Luminance Ratio $L_{V,max}/L_{avg}$
Major	High	1.2	3.0	5.0	0.3
	Medium	0.9	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Collector	High	0.8	3.0	5.0	0.4
	Medium	0.6	3.5	6.0	0.4
	Low	0.4	4.0	8.0	0.4
Local	High	0.6	6.0	10.0	0.4
	Medium	0.5	6.0	10.0	0.4
	Low	0.3	6.0	10.0	0.4

YANDELL DR. AND WYOMING AVE (33FT. WIDTH)

- 3-LANE PORTION OF YANDELL DR. AND WYOMING AVE

DSX2:

Spacing: 169ft. at 30ft. mounting height with one-row spacing

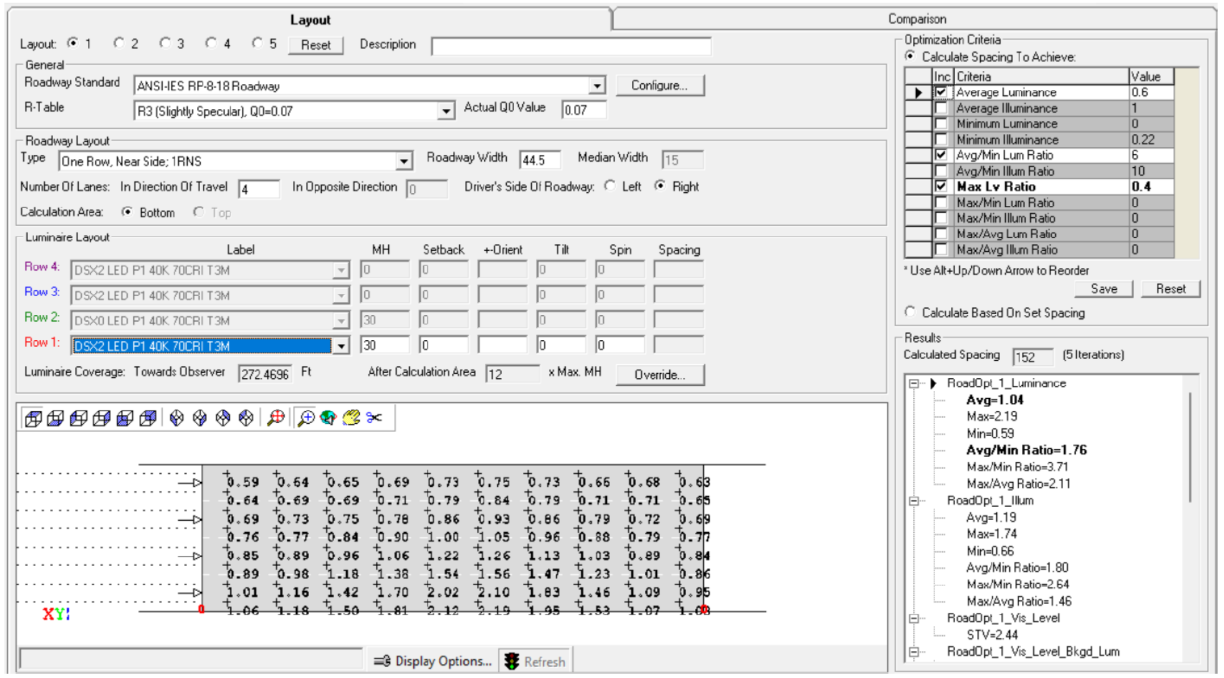


TASK 500: ILLUMINATION

- 4-LANE PORTION OF YANDELL DR. AND WYOMING AVE

DSX2:

Spacing: 152ft. at 30ft. mounting height with one-row spacing



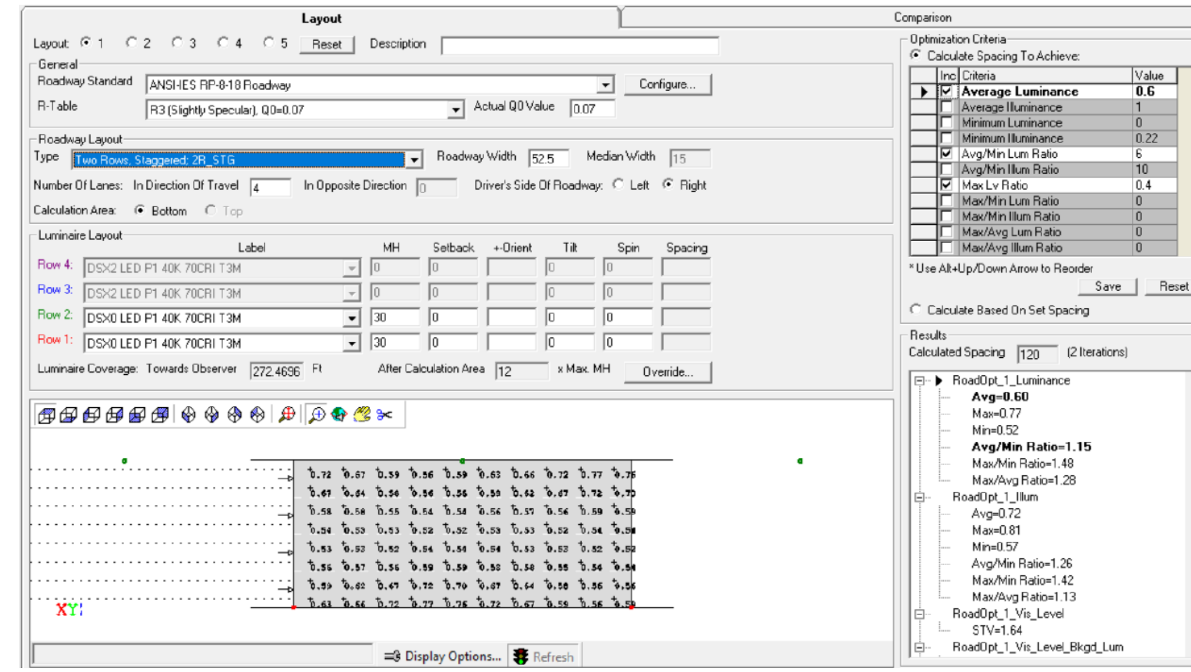
6.5 Crossroads

In this section, small sections of unique crossroads are analyzed to determine the typical light pole spacing on a small scale to meet the lighting design criterion. The lighting criteria referenced is **IES RP-8-22.**

N. OREGON (52.5FT. WIDTH)

DSX0:

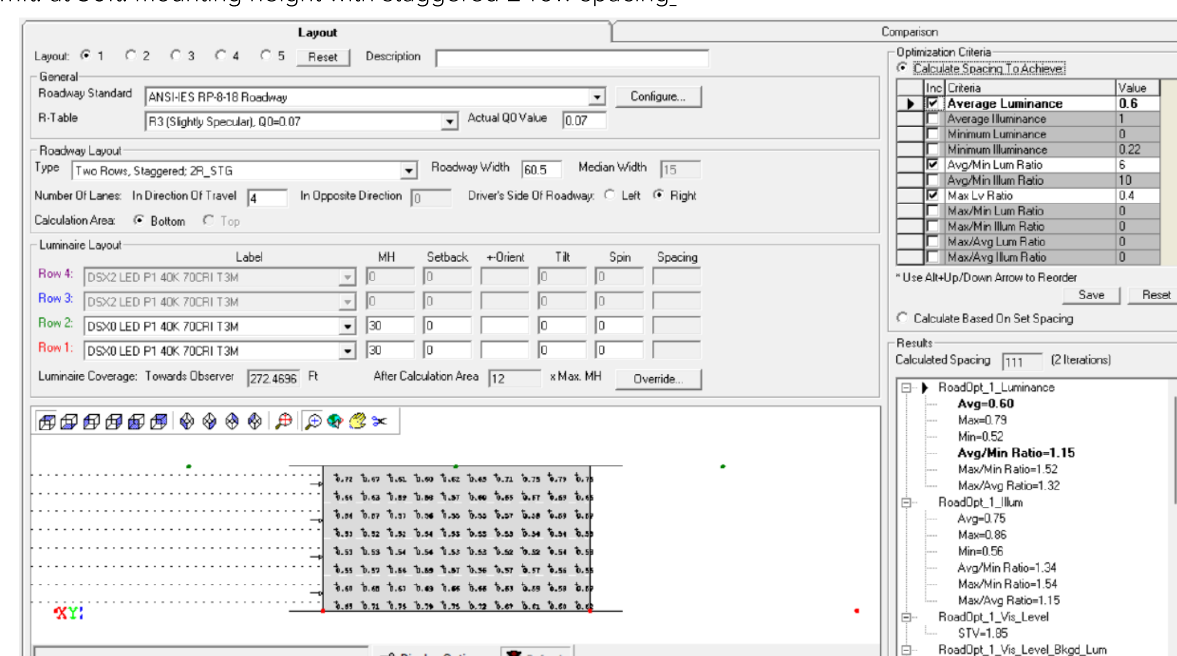
Spacing: 120ft. at 30ft. mounting height with staggered 2-row spacing



N. MESA (60.5FT WIDTH)

DSX0:

Spacing: 111ft. at 30ft. mounting height with staggered 2-row spacing

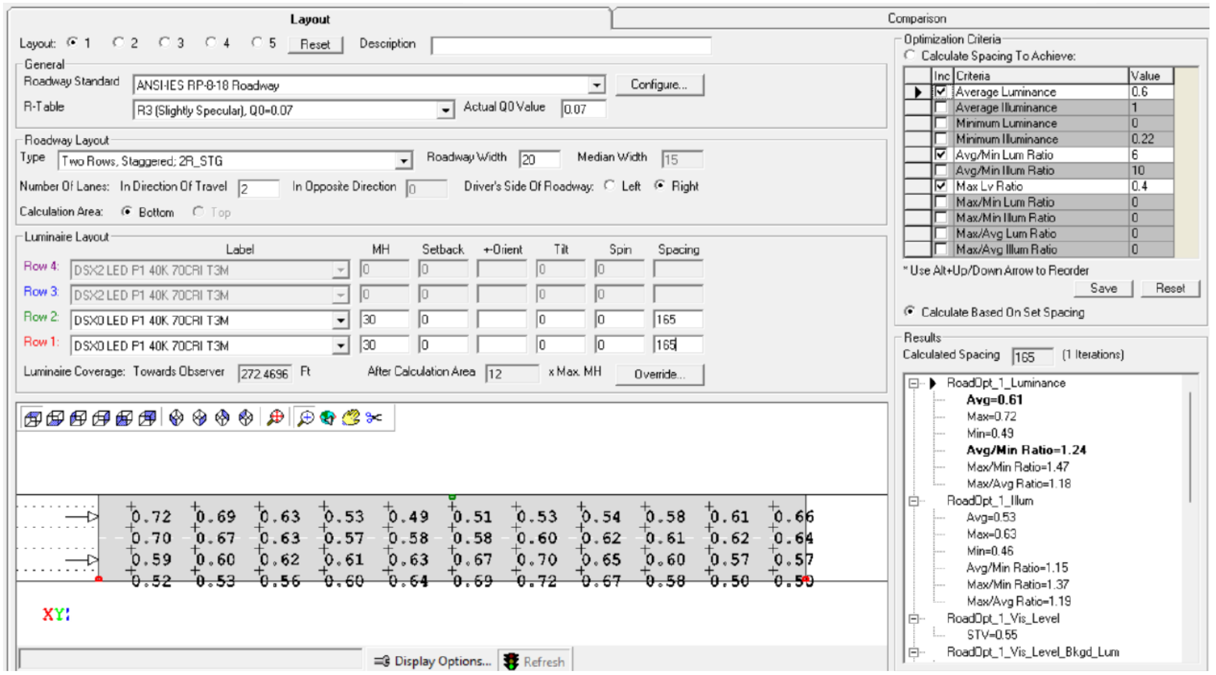


TASK 500: ILLUMINATION

STANTON ST. (20FT. WIDTH)

DSX0:

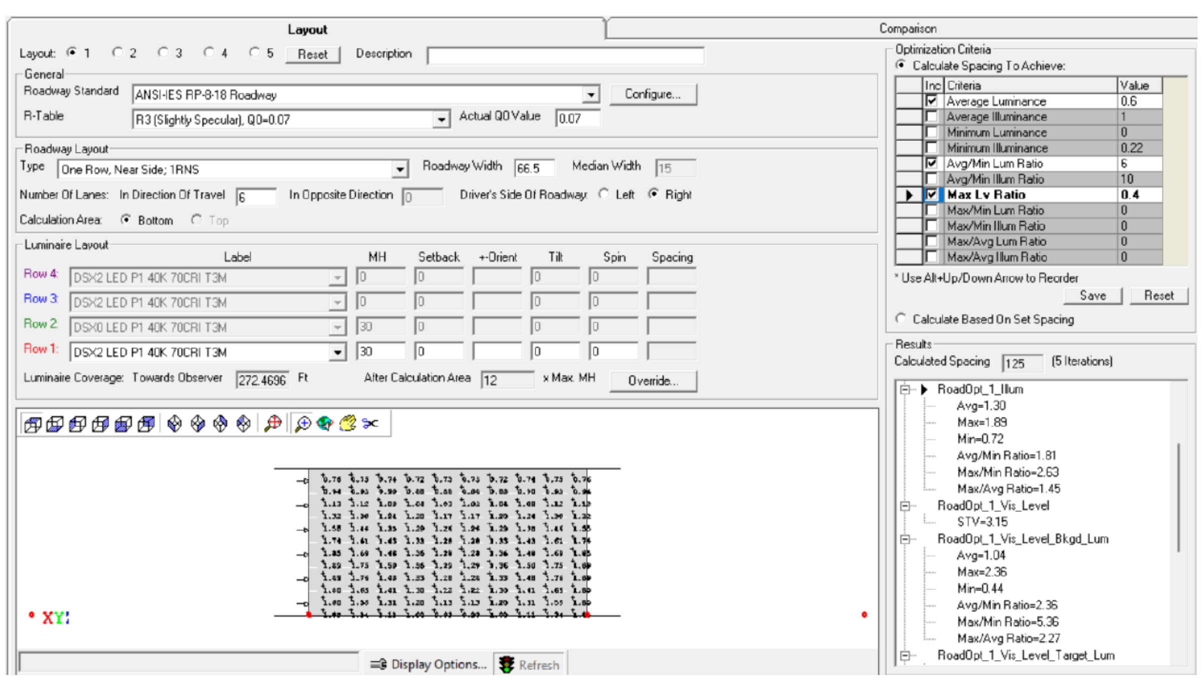
Spacing: 155ft. at 30ft. mounting height with staggered 2-row spacing



SANTA FE ST. (66.5FT. WIDTH)

DSX2:

Spacing: 125ft. at 30ft. mounting height with one-row spacing



N. KANSAS ST. (48FT. WIDTH

DSX2:

Spacing: 149ft. at 30ft. mounting height with one-row spacing