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DESIGN OF THE INTEGRAL PARTS OF A BRIDGE SUBSTRUCTURE TO BE BUILT IN 15 DAYS

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OF A BRIDGE SUBSTRUCTURE

TO BE BUILT IN 15 DAYS

by

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ABSTRACT

DESIGN OF THE INTEGRAL PARTS

OF A BRIDGE SUPERSTRUCTURE

TO BE BUILT IN 15 DAYS

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The University of Texas at Arlington, 2017

Faculty Mentor: Jim Williams

Bridges are key elements of our transportation system. They allow one highway to go over another, or over railroad tracks. They allow highways and railroads to pass over water. In any bridge, the components can be separated into the substructure and superstructure. While they are both key parts of an overall structure, the structure would not exist if it did not have a foundation. The project was to design a fast-tracked bridge, one that could be built in 15 days. The bridge abutment and bent cap were designed in detail, and methods to facilitate the fast-track construction were considered in the design. Structural analysis of each member was conducted in order to ensure that they met their required standards and also confirm that the proposed reinforcement and geometry was sufficient to withstand the loads applied to the structure. This is a bridge replacement

over Salt Creek on FM 4 in Jack County, Texas. For the purposes of bridge replacement, a new design was made.

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CHAPTER 1

INTRODUCTION

1.1 Background

The bridge on FM 4 which crosses Salt Creek is due for replacement, as it received a rating below 50 in the structural sufficiency report. The bridge is 160 feet long and 42 feet wide. In order to facilitate rapid reconstruction, the new bridge foundations could not be placed on the old foundations. The existing pile foundations were driven into the ground. We cannot drive piles in the same location and ensure the proper stability of the bridge. The bridge design was based on the AASHTO LRFD Bridge Design Manual.

1.1.1 Accelerated Bridge Construction (ABC)

Accelerated Bridge Construction was selected as the procedure by which the bent caps and abutments were designed. It is a fast-tracked method of bridge construction, and for this reason, the use of pre-cast concrete units is recommended. It was necessary to construct the entire project in 15 days, so the abutment and bent cap had to be constructed in a fraction of this time. Use of concrete precast units is much quicker and easier than the traditional cast-in-place method. In the cast-in-place method, first the forms are constructed, then the components are constructed by placing reinforcing steel within the forms. Concrete is then poured over the steel, into the forms, and left to cure for a period of roughly 28 days, the concrete's ideal curing time.

1.2 Loads

For the design of a structure, the first step is to calculate the loads. This is the determining factor. The loads determine the required strength of a structure. There are several factors to take into consideration when calculating the loads, and several methods have been devised to do so. The loads are variable, so various limit states must be determined, and the selected ones are those that yield the needed strength to handle the combination of loads experienced by the bridge. Usually, the load factors that are chosen are the ones that provide the highest impact on the structure. In bridge design, the load path must be considered when determining how much load a certain element will withstand. The first portion of the bridge superstructure is called the bridge deck. The deck includes the weight of the slab, rail and current or future overlay. Secondly, bridge girders support the deck as well as the abutment back-wall at the two opposite ends of the bridge, as can be seen in Figure A.1. The bent cap supports the bridge girder and deck. Lastly, the foundation supports the entire structure. Therefore, it can be seen that the components of the bridge in the order specified depend on each other for the design.

1.3 Abutment Design

For the design of this component, the total superstructure loads (traffic and deck loads) would need to be taken into consideration as well as the weight of the abutment itself (self-weight). Each element of the structure supports all elements above it; identification of such load path is critical in determining the load which each element must support. After the loads have been determined, proposed dimensions of the abutment can be determined. The abutment of a bridge consists of the wing-wall, cap, piles and back-wall.

1.4 Bent Cap Design

The abutment and bent cap are in the same vertical location in the load path; however, since the bent cap serves as support to the bridge above the ground surface, the load considerations are different. The abutment, on the other hand, serves as a foundation. Once the loads on the bent cap have been determined, proposed dimensions would be given for the design. Since this is a method of Accelerated Bridge Construction, as previously mentioned, precast units will be used to expedite the process.

CHAPTER 2

LITERATURE REVIEW

2.1 Bridge Inspection

The project site is in a rural area with a hilly topography and is located sixteen (16) miles west of Jacksboro, Texas. The bridge is along FM 4, which is a major rural collector road that carries traffic over Salt Creek. The average daily traffic count is 230, with 9% of that being trucks, and no pedestrian traffic. The expected average daily traffic for 2024 is 470. There are residential and agriculture properties on either side of the roadway, and homes are located within 100 feet from the south approach of the bridge. The bridge is currently in operation but is in the design phase to be replaced as soon as possible.

As mentioned earlier, the bridge was inspected and its sufficiency rating was below 50%. With a sufficiency rating below 50%, it is more economical to replace the bridge rather than to repair it. A rating of 50 to 80 means that the bridge can be replaced, and a rating over 80 means that the bridge is in good condition. Another problem was the lack of scour protection for the columns. Scour, or erosion, can be expected where the water flows past the bridge supports.

The Bridge Inspection Report gave a substructure and superstructure rating of 4/9, which is below standard. The bridge was then defined as being structurally deficient. The report can be seen in Figure A.2.

2.1.1 Structural Deficiency

A bridge is defined as structurally deficient if it has been restricted to only light vehicles, is not open to traffic or if it requires rehabilitation. In this case, the bridge required rehabilitation and for this reason needed to be replaced ("Bridge Inspection Definitions").

In some cases, structurally deficient bridges are not necessarily unsafe, but they require maintenance, inspection, or rehabilitation. A substructure or superstructure making a four or less indicates that a bridge is structurally deficient.

2.1.2 Functionally Obsolete

A functionally obsolete bridge is one that can no longer fit the standards that we use today. It may include bridges that do not geometrically meet the required standards of lane widths for the volume of traffic, and for this reason the bridge cannot function in the manner that is expected to ("Bridge Inspection Definitions").

2.2 Bridge Abutment

The two end supports of the bridge are its abutments. They are part of the bridge substructure and resist lateral forces such as forces from the soil beneath the bridge and vertical forces from the bridge superstructure. Each bridge abutment is composed of four parts. They include the abutment cap, back-wall, wing-wall and footing. The abutment wing-walls are short retaining walls that connect to the abutment to hold the soils that sit on an embankment. Their purpose is to prevent erosion and maintain stability. The back-wall of the abutment spans the entire bridge width and retains the soil beneath the bridge. The entire abutment acts as part of the bridge foundation.

2.3 Bridge Bent Cap

A bridge bent cap is “an intermediate support between bridge spans that transfers and resists vertical loads and lateral loads such as earthquake and wind from the superstructure to the foundation” (TxDOT 2016). The bent cap supports the span of the bridge deck and is placed at each span of the bridge deck.

CHAPTER 3

METHODOLOGY

3.1 Preliminary Site Investigation

3.1.1 Geotechnical Site Investigation

The geotechnical report describes the type and strength of the soils at the site. This information is based on borings made where the proposed structure rests on the ground. The soil consisted of mostly sand, gravel, limestone and shale. This report was used to determine the depth of the foundation of the abutment.

3.2 Estimation of Loads

In any structural design, the first step is to determine the loads. The abutment and the bent cap are in the same location in the load path and therefore experience similar loads. For load estimations, the dead loads and live loads were determined. Dead loads included the self-weight of the component and all loads placed above it that do not move, or in some cases will not move for a long time. Live loads are the loads which are constantly moving, such as vehicular loads. For the live loads an impact factor needed to be considered. This was necessary to design for the vehicular impact caused by the bouncing and swaying of vehicles. The recommended impact factor from AASHTO was 0.33.

3.3 Design of Members

The members were designed using the AASHTO LRFD Bridge Design Manual as well as the TxDOT LRFD Bridge Design Manual. One of the requirements was for the bridge to be designed according to the TxDOT Standards. All the members are composed of reinforced concrete with epoxy coated steel reinforcement to prevent corrosion.

3.3.1. Abutment Design

After the loads were determined for the abutment, the design of the abutment pile was done by firstly considering a two-lane roadway with traffic flowing in each direction. From there, the reaction of the abutment was found by factoring the loads which were due to the dead loads. In order to obtain the correct loading, several limit states had to be considered. Some of them included the Strength I Limit State and Service I Limit State *(AASHTO LRFD Bridge Design Manual).* After the applied loads on the abutment cap were determined, the amount of load that the cap in itself could hold was determined. This is known as the factored compressive resistance of components in compression, P_r. From there, the number of piles required were determined by dividing P_r by the loads applied, P_u.

For the flexural reinforcement design, the moments due to the applied forces needed to be found. The moments due to the applied loads were found, and the moment capacity of the pile cap was determined as well. In order to satisfy the requirements for design, the moment capacity needed to be greater than the moment caused by the applied loads. It was found to be so, and from there the reinforcement required was determined. For the calculation of moment capacity, an assumption needed to be made. This was to assume the bar number for the reinforcement. With the assumption made, once the moment capacity is greater than moment due to the applied load, it is known that the assumed reinforcement is sufficient for the structure.

$M_u = P_u l/4 + w_u l^2/8$, $M_n = A_s f_y(d_s - a/2)$

P_u = Load due to direct forces

W_u = distributed loads on the structure

Shear design was also found for the abutment cap to find the shear reinforcement required. In the same manner, the maximum load due to the components at the top of the abutment cap was found V_u, and the maximum load the abutment cap could hold was determined. This is known as the nominal shear resistance, V_r. All formulas used were from the AASHTO LRFD Bridge Design Manual.

$V_u = P_u + w_u l/2$

$V_n = V_c + V_s$ or $V_n = 0.25f'_c b_v d_v$ (the greater of the two) *(S5.8.3.3-1, S5.8.3.3-2)*

V_c = Shear due to concrete

V_s= Shear due to steel

f'_c = compressive strength of Concrete

b_v = effective shear from web width *(S5.8.2.9)*

d_v = effective shear depth *(S5.8.2.9)*

l = span length

As for the flexural reinforcement, the steel was also assumed for the shear reinforcement. The V_n yielded a greater value than the V_u, so the suggested reinforcement was sufficient.

The abutment was then analyzed on the CAP18 software to compare the hand calculations to the software given calculations. For the back-wall and wing-wall of the abutment, TxDOT standards were used. A full analysis was not required, as the AASHTO LRFD Bridge Design Manual does not provide any standards for it. TxDOT recommended details were then used. Figure A.3 shows the details for the abutment back-wall and wing-wall.

3.3.2. Bent Cap Design

The members were designed using the AASHTO LRFD Bridge Design Manual as well as the TxDOT LRFD Bridge Design Manual. One of the requirements was for the bridge to be designed according to the TxDOT Standards. The bent cap follows the same design process as the abutment with the exception of the foundation, wing-wall and back-walls.

The bent cap consists of the cap and columns to support the entire bridge superstructure. The design process will be identical to the abutment. The same load considerations are taken into account which includes the HL93 loading and dead load would include the self-weight of the cap and the dead load due to the other components of the superstructure.

One of the requirements of the project was for the entire bridge to be constructed in 15 days. Investigation showed that the precast abutment and bent cap can be constructed in 10.5 hours. Consequently, it would take approximately two days to construct the abutment and bent cap, leaving 13 days for the demolition of the old bridge and construction of the other components of the bridge structure.

CHAPTER 4

DISCUSSION

From proper speculation of the geotechnical report, the foundation was placed directly above the shale layer, which is a depth of about 34-ft below the ground level. Calculations show that the settlement was greater than one inch, so a deep foundation was required. For the results, it was decided that the columns on the bent cap should also be used as the foundation. From the calculations, it was found that the bent cap should have five piles equally spaced at 10-ft apart over a 40-inch width of the bridge roadway with a 5-ft end spacing. For the abutment, a total of six piles were found with a spacing of 9.5-ft apart and a 2-ft end spacing on either side. This is to comply with the spacing requirements provided by the AASHTO LRFD Bridge Design Manual *(S10.7.1.5).* See the Figure A.4 for the spacing of the abutment and bent cap pile.

4.1 Abutment Design

The Figure A.5 shows a compilation of the loads obtained for the abutment design. The live loads were calculated by considering a hypothetical live loading model called “HL93”. The loads from this model come from considering a hypothetical truck situated at a location on the bridge span, which gives the greatest loading impact. This loading model is shown in Figure A.6. As previously mentioned, the impact factor of 0.33 was used. This impact factor, however, is only applied to the vehicular load and is not applied to the lane load shown in Figure A.6. A maximum moment (M_u) of 136.5 kip-ft was obtained for the abutment due to the loads, and a moment capacity(M_r) of 366.4

kip-ft was obtainedfrom hand calculations. The CAP18 Software gave a maximum moment value of 370 kip-ft. The moment from CAP18 might be higher than the hand calculated value as the software might have been more conservative in the load considerations. For the results, six #11 bars of steel reinforcement were obtained, which were sufficient to hold the loads from the calculations.

For shear reinforcement, a maximum shear due to loadings (V_u) of 113.8 kips were found, and a shear capacity (V_r) of 205 kips were found from hand calculations. CAP18 gave a maximum shear of 260 kips. The shear reinforcement found was #5 bars at 10-inch spacing. These results obtained for the abutment design were in accordance with the TxDOT standards.

The abutment dimensions were found to be 4-ft by 4-ft for the cap and 34-ft deep pile foundation. The abutment back-wall spans 42 ft with a thickness of 1 foot. The abutment wing-wall has a depth of 5.25ft, a thickness of 1ft and a width of 12 ft by TxDOT standards.

4.2 Bent Cap Design

Figure A.7 shows the loads calculated for the bent cap design. As for the abutment, HL93 loading governed over HS20 and was therefore used as the hypothetical live load model.

Table A.1 shows the moments obtained for each type of load obtained from hand calculations and software. It can be seen that the hand calculations yielded a maximum ultimate moment of 1510.84 kip-ft while the CAP18 and Leap Bridge Software yielded maximum moments of 1229.11 and 1345.6 kip-ft respectively. The maximum moment obtained from the hand calculations yielded a flexural reinforcement of eight #11 bars to the top and bottom. This was found to be in accordance with the TxDOT standards, which were a requirement.

CHAPTER 5

CONCLUSION

To conclude, the integral parts of the bridge substructure were designed to meet the TxDOT standards and also the 15-day period required for the Accelerated Bridge Construction (ABC). The reinforcement met the TxDOT requirements and standards. It was observed that the only way the ABC method is possible is if only precast units are used. The use of precast concrete units not only has time benefits but also can save a lot. Using the ABC method, it is not required to have lots of heavy construction equipment and a big labor force. Consequently, it is much easier to have the units precast and simply hauled to the site to build.

5.1 Abutment Design Results

For flexural reinforcement, the maximum ultimate moment was 1510.84 kip-ft while the CAP18 and Leap Bridge Software yielded maximum moments of 1229.11 and 1345.6 kip-ft respectively. This yielded an overall flexural reinforcement of six #11 bars to the top and bottom of the abutment cap.

For shear reinforcement, a maximum shear due to loadings (V_u) of 113.8 kips was found, and a shear capacity (V_r) of 205 kips was found from hand calculations. CAP18 gave a maximum shear of 260 kips. The shear reinforcement found was #5 bars at 10-inch spacing. These results obtained for the abutment design were in accordance with the TxDOT standards.

The abutment dimensions were 4-ft by 4-ft for the cap and 34-ft deep for the pile foundation. The abutment back-wall spans 42-ft with a thickness of 1-ft. The abutment wing-wall has a depth of 5.25-ft, a thickness of 1-ft and a width of 12-ft by TxDOT standards.

5.2 Bent Cap Design Results

For flexural reinforcement, the maximum ultimate moment was 1510.84 kip-ft while the CAP18 and Leap Bridge Software yielded maximum moments of 1229.11 and 1345.6 kip-ft respectively. The maximum moment obtained from the hand calculations yielded a flexural reinforcement of eight #11 bars to the top and bottom. This was found to be in accordance with the TxDOT standards, which was a requirement.

For shear reinforcement, the design obtained met the TxDOT standards and results yielded the use of #5 rebar at 8.5-inch spacing.

APPENDIX A

TABLES

Type of Load	Max. Moment (+) kip-ft	Max. Moment (-) kip-ft	Leap Bridge (Max. Moment) kip-ft	CAP18 (Max. Moment) kip-ft
Dead Load	843.5	-839.8	-	646.5
Service Load	1047.41	-1045.87	-	945.4
Ultimate Load	**1510.84**	-1510.39	1229.11	1345.6

Table A.1: Moments Obtained for Bent Cap Design

APPENDIX B

FIGURES

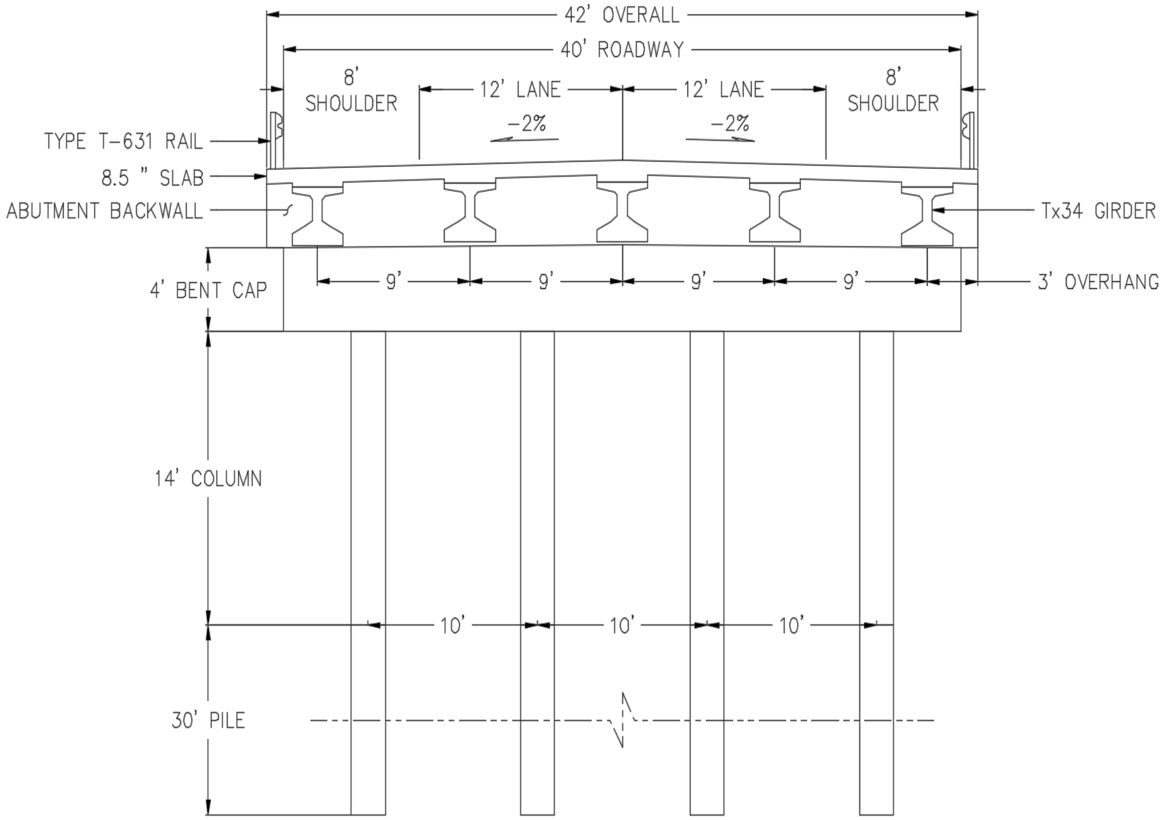


Figure A.1: Bridge Profile

TEXAS DEPARTMENT OF TRANSPORTATION

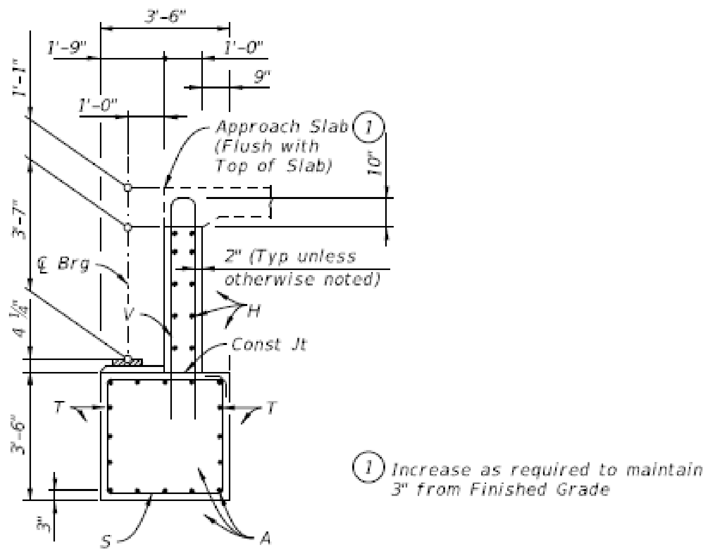
* BRIDGE INVENTORY AND INSPECTION FILE

**(006-1) FEATURE-X **(007-0)

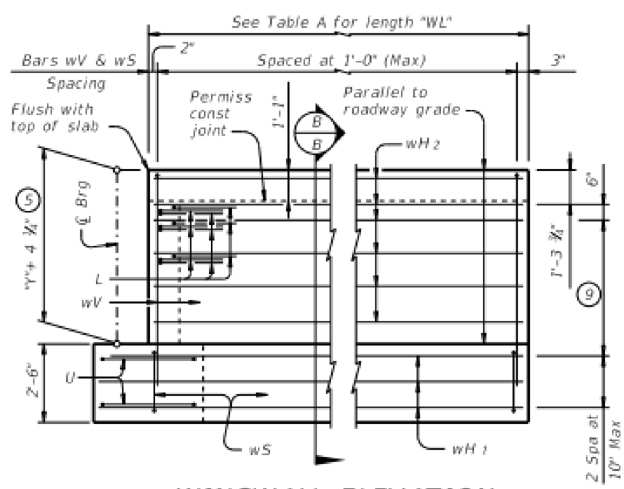
SALT CREEK FM 4

ITEM #	FIELD ===================		CODE
(045-2)	NO.MAJ APPR SPAN	....	
(045-3)	NO.MIN APPR SPAN	....	
(046-0)	TOTAL NUMBER SPANS	....	0005
(047-0)	TOTAL HORIZ CLR	....	0214
(048-0)	MAX.SPAN LENGTH	....	0025
(049-0)	STR.LENGTH	....	000125
(050-1)	LEFT SIDEWALK	....	000
(050-2)	RIGHT SIDEWALK	....	000
(051-0)	ROADWAY WIDTH	....	0214
(052-0)	DECK WIDTH	....	0234
(053-0)	VERT.CLR OV	....	9999
(054-1)	VERT.CLR REF FEAT	....	N
(054-2)	VERT.CLR UND	....	0000
(055-1)	LAT.CLR REF FEAT	....	N
(055-2)	RIGHT LAT CLEAR	....	999
(056-0)	LEFT LAT CLEAR	....	000
(058-0)	DECK COND	....	6
(059-0)	SUPERSTR COND	....	4
(060-0)	SUBSTR COND	....	4

Figure A.2: Bridge Inspection Report



SECTION A-A



WINGWALL ELEVATION

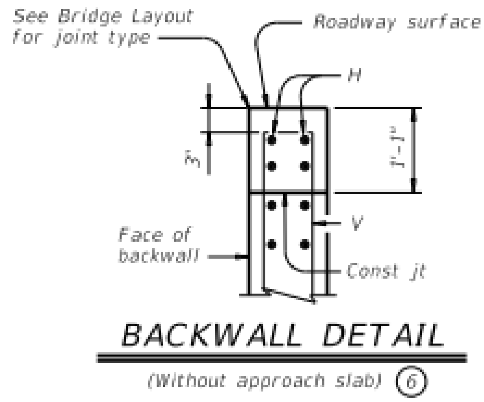


Figure A.3: Abutment Back-Wall and Wing-Wall Details

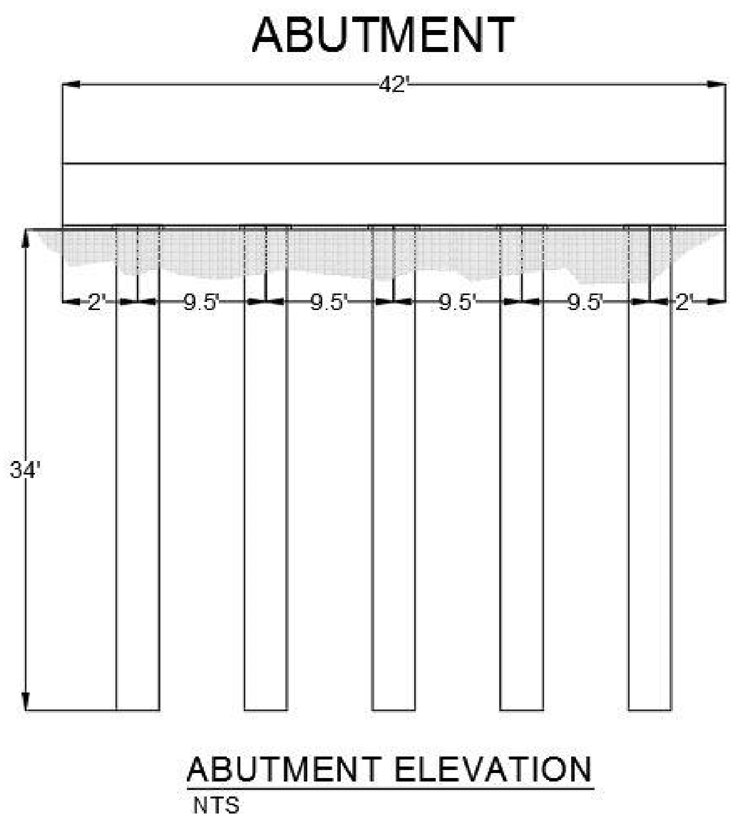


Figure A.4: Abutment Elevation

Abutment Design *(AASHTO LRFD Bridge Design Specifications, 2012)*

Loads:

- Dead Loads *(Table 5.3-3)*
  - Total Non-composite (girder + slab + pile cap) = 67.93 kip/girder
  - Total Composite (parapets + future wearing surface) = 9.93 kip/girder

Figure A.5: Abutment Loads

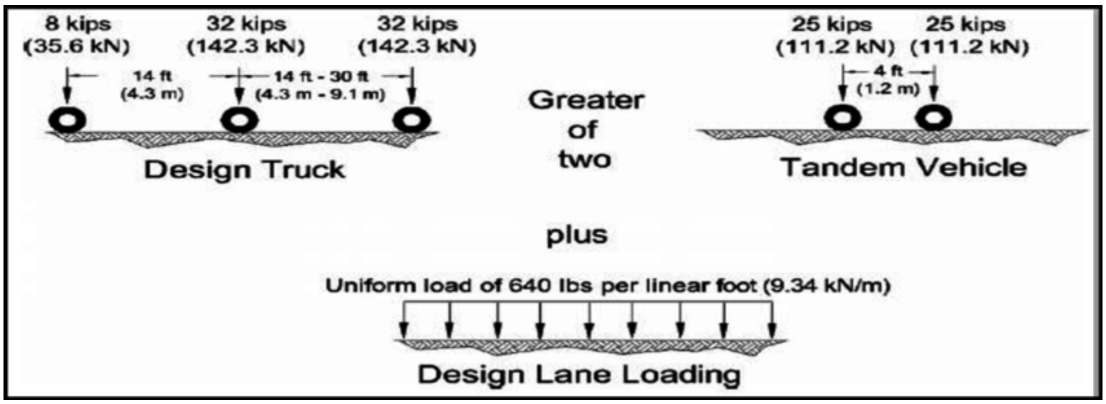


Figure A.6: HL93 vs. HS20 Loading

Loads

- **Dead Loads**
  - Total Non-composite (rail + girder + slab) = 71.933 kip/girder
  - Total Composite (parapets+ future wearing surface) = 9.93 kip/girder
- **Live Loads** *(AASHTO LRFD 3.6.1.2.2 and 3.6.1.2.4)*
  - Design Truck
  - HL93
  - Max Live Load Reaction = Design Truck + Design Lane = 126.36 kip/lane
  - Limit State Strength (I) governed
    - Live and Dynamic Load Allowance (LL + IM) = 1.75
    - Dead Load Components (DC) = 1.25
    - Dead Load Wearing Surface (DW) = 1.5

Figure A.7: Bent Cap Loads

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BIOGRAPHICAL INFORMATION

Nyoka Amy Florius graduated from the University of Texas at Arlington with an Honors Bachelor of Science in Civil Engineering in Fall 2017. She was heavily involved on campus as part of the Tau Beta Pi Engineering Honor Society, the Chi Epsilon Civil Engineering Honor Society and the Phi Kappa Phi General Academic Honors Society. She also served as an on-campus Housing Ambassador and was a former President of the Caribbean Students' Union. Nyoka was also a previous Dwight Eisenhower Transportation Fellowship Scholar, for which she served as an ambassador for UTA at the Transportation Research Board annual conference. She also served as a part of the executive council (ambassador) of the Chi Epsilon Honor Society in Spring 2017.

Nyoka Amy Florius completed an internship at the Goodridge and Associates Structural Engineering Firm in Castries, St. Lucia. At her internship she conducted several site visits and gained experienced. She assisted in preparing Computer-aided Design and Drafting (CAD) drawings for the Project Manager and also reviewed drawings.

Nyoka interns at WSP USA, formerly WSP-Parsons-Brinckerhoff Company, and plans to continue her career as a Transportation/Structural Engineer and earn Master's degrees in both disciplines.