Report No. KS-06-5
Final Report

AUTOMATED SMALL VEHICLE TRANSIT SYSTEM STRUCTURAL AND ARCHITECTURAL RESEARCH STUDY FOR A UNIVERSITY CAMPUS

October 2006
Kansas Department of Transportation

Prepared By:
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16 Abstract

The structural and architectural aspects of constructing an Automated Small Vehicle Transit System (ASVT) in a university setting have been studied to provide a cost comparison for the different design options. Vehicle size and capacity used for the study were determined and the corresponding live loads and dead loads were calculated for each structural option along with seismic, wind and snow loads. The optimum span between supports was determined to be ninety feet (90'). Several types of structures were considered and three types, pre-stressed concrete inverted T Beams, pre-stressed concrete K-3 beams and rolled steel girders, were studied. Each type of these three superstructure options was designed and a detailed cost estimate was prepared based on that design. Items such as snow melting systems and space for mechanical elements were also considered in the design.

In addition to the superstructure, arrival/departure stations were located along the route. One of the stations in this study was attached to an existing building, utilizing the existing elevators and waiting areas. The rest of the stations were free standing structures located for ease of access and utilization of existing parking areas. The stations were architecturally studied to blend with the existing environment of the campus.

Control and maintenance facilities were also addressed in this study. An ASVT system must have an operating control room and vehicle storage and maintenance facilities. These facilities need to be located outside the core of the campus and designed to blend with the existing surroundings.

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THE KANSAS DEPARTMENT OF TRANSPORTATION
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KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

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Index of Sheets

Introduction

This study focuses on the structural and architectural aspects of constructing an Automated Small Vehicle Transportation (ASVT) system on a university campus. Although this study is intended for use on any university campus, for conceptual focus Kansas State University (KSU) has been chosen as the site of the study. As such, it is important to note that **KSU Administration is in no way involved in this study and absolutely has no intent or plans to build an ASVT system on the KSU campus.**

The structural study begins with the determination of the optimal route for the ASVT to provide access to the campus. In a campus setting, it is important to meet the most needs with the smallest amount of congestion and greatest efficiency. To accomplish this, a single, raised, one-directional guideway is proposed for the main campus core running in the counter clockwise direction (1.36 mi.). The one-directional guideway in the core of the campus allows a narrower, less intrusive structure while also insuring travel time to the furthest station on the loop to be less than a 3.4 minutes of non-stop ride. Also by using a raised guideway, little of the existing travel area is sacrificed. As the need arises to connect with outlying areas of the campus or cross city thoroughfares, two-directional guideways are added to allow travel to and from these areas. After selecting the route for the ASVT, it was determined to use a completely raised guideway. This was because, on this study campus, there would be less than three-quarters of a mile (¾ mi.) that could be constructed on grade. These areas are heavily traveled making it difficult for pedestrians to safely cross the guideway and the area used for guideway would remove needed existing parking. See Figure 1 for a map of the proposed route on the study campus.

Included in the structural study for an ASVT system are the passenger arrival-departure stations, the storage of the passenger cars while not in use and the maintenance and control facility for the system. The stations are located along the route near each parking lot and at any location with a high concentration of potential passengers. A total of eleven (11) free-standing stations and one (1) station attached to an existing building have been proposed for the study site. Five (5) of these stations are along the main campus core segment with six (6) additional outlying stations to accommodate the outer edges of the campus. By connecting the system to outlying areas such as the stadium complex, the parking in those areas become viable for everyday use relieving parking problems in the close-in lots.

Like all transit systems, an ASVT system requires a maintenance and control center along with a storage facility for any vehicles not in use. The maintenance and control center shall be housed in a single building. The ground floor will house the maintenance area with the second story containing the control room, restrooms, break rooms, vending and any other offices as needed. The storage facility for the unused vehicles can either be placed at the same location as the maintenance facility or can be split between locations if the area required is to large for the maintenance site.

The geological characteristics of a proposed site are necessary to determine the type of sub-structure required to support the guideway of the ASVT system. However, the geology varies from site to site. For the purposes of this study, the geologic reports from previous construction sites on the study campus were used to determine the best type of foundation at this study site. The previous borings show drilled shaft piers to be the best option. This is also the best option for a campus setting due to lower noise levels and less equipment than using driven piles.

The guideway structure itself has been studied to determine the applicable design loads and compare various types of superstructure components, including pre-stressed concrete beams, inverted T-beams and steel beams. The resulting design, for all three types of superstructures, was controlled by deflection, i.e., the guideways would be operating at a stress level below that of their safe load-carrying capacity. The results are included in the Structural Loadings and Structural Components sections.

Since most of the United States contends with ice or snow each year, an open guideway transit system must be designed to provide for snow and ice removal. In this study, both hydronic (heated liquid) systems and electrical systems were studied. The hydronic system would require more physical equipment, but depending on the amount of annual snowfall, the electric system could be more expensive to operate. The two systems are discussed in detail in the Snow Melting System section.

Aesthetics are a major concern in a campus setting. Most campuses are designed to architecturally flow from one building to another, therefore it is important that the ASVT is designed to blend into the existing setting and not detract from the original design. Conceptual renderings of a station attached to an existing building and a free standing station can be viewed in Appendix C.

Since the design of the guideway is based on deflection considerations rather than strength considerations, the cost is not greatly affected by the weight of the vehicle. The final cost of the structural components of an ASVT system vary depending on the size and number of vehicles, length of guideway, type of superstructure, substructure and snow melting system, number of stations and support structures required. Total cost estimates are discussed in the last section of this report and a further breakdown of costs can be found in Appendix D.

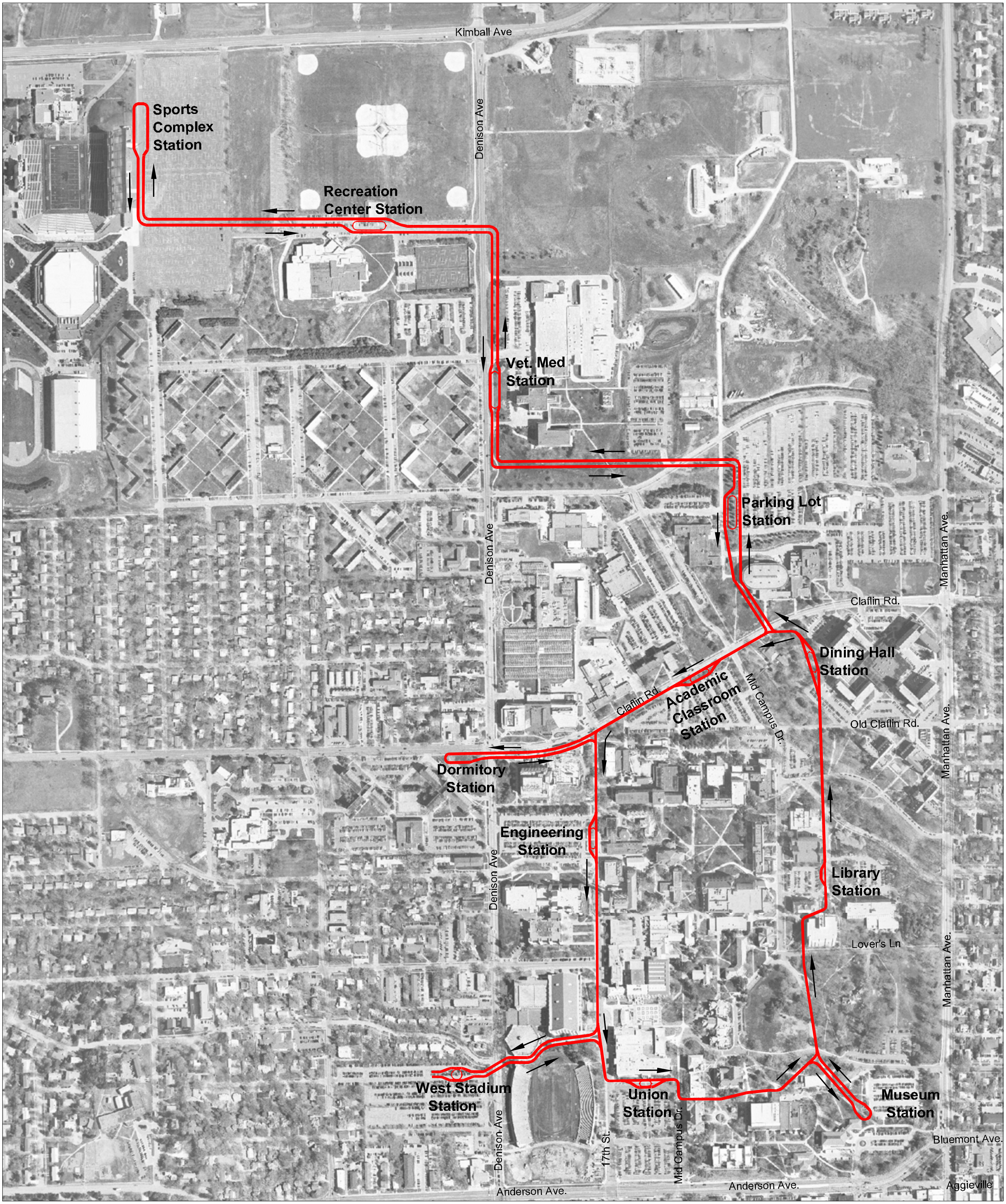


Figure 1

No Scale

ASVT RESEARCH STUDY ROUTE

Length of Two-Directional Track = 1.92 mi. Length of One-Directional Track = 1.36 mi.

Structural Loadings

Guideway System

There are several types of loadings that must be taken into consideration in the design of the ASVT guideway. The dead load of the structure itself, the weight of the mechanical components, the live load that it carries, occasional snow and wind loads and possible seismic loads all must be taken into consideration. Not all of these loads will be present at the same time so the worst case scenario is taken into account.

Live Load: Initially, live load must be determined so the structure can be sized to carry it. For this study, three (3) types of vehicles, which are in use at various facilities around the world, were considered. These vehicles were the CyberCab II, ParkShuttle II, and the Ultra. It was determined to use the ParkShuttle II as the design vehicle for this study because it is the largest in size and passenger capacity, therefore producing the largest live load. By using the larger vehicle, the most conservative results are received. If a system uses a smaller vehicle, the structure size would be adjusted accordingly. The full comparison of these vehicles can be seen in Table 1.

A ParkShuttle II vehicle at full capacity weighs 14,663 lbs. The minimum distance between the moving vehicles was determined to be 45 ft. for structural purposes only. This was calculated as speeds of 3 ft/sec. with a 15 second headway. The lowest travel speed at the Morgantown PRT system at the West Virginia University is 4 ft./sec. which would make the minimum distance between vehicles 60 ft. Therefore, using the 45 ft. spacing is conservative and the equivalent uniform live load calculates to 43 pounds per square foot (psf).

Snow Load: Due to climatic differences through out the U.S., snow load is variable with each specific location. At this study site, the flat snow load on the raised guideway is 15 psf. However, by adding a drift surcharge of 21 psf the maximum snow load would be 36 psf.

The snow load calculated did not control in the actual design loading, because if the snow removal system failed or there was a storm of the magnitude the snow system could not keep up the system would be shut down. Since the live load and the maximum snow load would not be applied at the same time, the larger live load was used in the design load.

Wind Load: The wind loads are applied as uniformly distributed loads on both the structure and the vehicles. Values for wind loading were studied in accordance with AASHTO Standard Specification for Highway bridges, Sec.3.15.2.1.3. The values used for wind on the superstructure are 50 psf transversely and 12 psf longitudinally with 40 psf in both directions on the piers. Wind on the live load vehicle is 100 pounds per linear foot (plf) transversely and 40 plf longitudinally.

Seismic Load: Seismic conditions vary across the U.S. Due to this, different seismic performance categories have been developed. The study site falls within Category A

VEHICLE COMPARISON SUMMARY*			
Item	**CyberCab II**	**ParkShuttle II****	**Ultra**
Seated Passengers	6	12	4
Standing Passengers	0	8	0
Length	12.53 ft. (3.820 m)	19.70 ft. (6.000 m)	12.14 ft. (3.700 m)
Width	4.46 ft. (1.360 m)	6.90 ft. (2.100 m)	4.60 ft. (1.400 m)
Height	6.40 ft. (1.950 m)	9.00 ft. (2.750 m)	5.90 ft. (1.800 m)
Floor Level	12 in. (300 mm)	14 1/2" (360 mm)	10" (250 mm)
Platform Level	10-12 in (260-300 mm)	13-14 1/2 in (325-360 mm)	N/A
Wheel Base	6.60 ft. (2.005 m)	9.50 ft. (2.900 m)	7.02 ft. (2.140 m)
Wheel Track	3.30 ft. (1.016 m)	5.90 ft. (1.790 m)	3.12 ft. (0.950 m)
Vehicle Weight	2,977 lb. (1,350 kg.)	10,253 lb. (4,650 kg.)	2,646 lb. (1,200 kg)
Payload	1,764 lb. (800 kg.)	4,410 lb. (2,000 kg.)	1,103 lb. (500 kg)
Maximum Total Weight	4,741 lb. (2,150 kg.)	14,663 lb. (6,650 kg.)	3,749 lb. (1,700 kg)
Maximum Speed	25 mph	25 mph	25 mph
Maximum speed @ 10% Grade	11.25 mph	7.8 mph	N/A
Advised Grade	< 5%	< 5%	<10% climb < 6.25% decline
Minimum Turning Radius	18 ft. (5.5 m)	25 ft. (7.5 m)	16 ft. (5.0 m)

* See Appendix A for additional manufacturer's information.
** ParkShuttle II Specifications used for structural analysis.

Table 1

which is the lowest risk area. There are no special seismic design factors required in this category for foundations and abutments. However, the connections between the piers and superstructure need to be checked for seismic movement on a multi-span structure. The additional reinforcement required to resist this seismic movement will not significantly affect the cost of the structure.

Stations and Maintenance Structures

This study includes eleven arrival-departure stations, along with the storage structure and Maintenance and Control building. One station would be attached to an existing building and the remaining stations are free standing structures. All of the structures besides the maintenance and control building will be at least partially open structures.

Snow Load: Unlike the guideway, snow load on the buildings must be taken into account. All of the open structures would be designed for a maximum snow load of 20 psf. Since the structures do not have curbs or raised edges like the guideway, no drift surcharge would need to be included. However, where the stations abut a solid structure or if the maintenance and control facility's roofline is different levels, a drift surcharge would be added. The total snow load would be 36 psf.

Wind Load: The average wind load on the closed structures would be 14.4 psf. The open structures would not have the normal wind load, however, uplift could be a major factor for these structures. Wind load and uplift depend on a final architectural design of the structures.

Seismic Load: Seismic load on a building structure depends greatly on the type of building. The lighter the structure, the less seismic affect on the structure. For instance, if the maintenance and control building is made of limestone to match the existing architecture of the campus, the seismic load would become a much greater factor than an open storage facility constructed of steel.

Structural Components

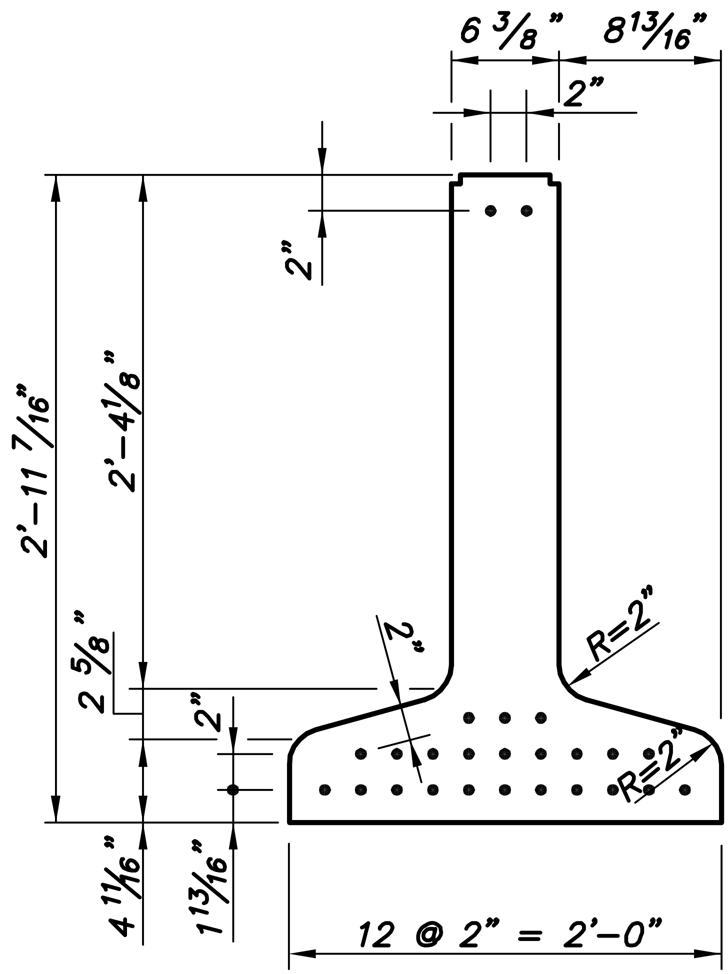
Guideway Structure

The ParkShuttle II vehicle was used as the design vehicle for the study of the guideway design. This vehicle requires a guideway 7'-6 ¾" wide, with 12 in. curbs. It is important in a campus setting to design a structure that will blend with the existing setting. Therefore, minimizing the size of the structure is essential to achieve this goal. Two ways to do this are to minimize the depth of the superstructure and maximize the distance between the supports. By using this criteria, the optimal span was determined to be ninety feet (90').

Several types of structures were considered, including a reinforced concrete haunch slab span bridge (RCHS), a rolled tubular steel structure, an inverted T-beam span bridge, a pre-stressed concrete girder bridge and a steel girder span bridge. The RCHS span bridge was not a viable option because it cannot support the span length required, it is a bulky, solid concrete structure which requires forming for cast-in-place construction, it has no place to install the mechanical systems needed without being visible and would overall not be aesthetically pleasing on a campus. Likewise, the tubular steel structure would need smaller spans, creating the need for more piers. Additional piers would cause more congestion in tight settings and would further distract from the traditional setting of the campus. Therefore, this option was not studied. Because of their structural capacity, the inverted T-beam structure, the pre-stressed concrete structure and the steel girder structure were studied.

Inverted T-Beam Structure (IT36): An inverted T-beam is a relatively new type of structure. This type of structure has several beams placed next to each other across the full width of the structure. The deck can be formed directly on top of the beam webs where the falsework boards will remain permanently in place. The underside of the guideway is completely enclosed leaving a smooth, finished structure. The longitudinal hollow voids between the beams can be utilized to enclose the mechanical and electrical elements to run the ASVT. Openings for manholes and junction boxes can be easily provided and accessed from the top of the guideway. The finished structure would require minimal maintenance.

The design inverted T-beam is thirty-six inches (36") deep and the "T" is twenty-four inches (24") wide. On the one-directional section of guideway four beams are required, while the two-directional sections will require eight beams. One advantage of the inverted T-beam design is the deck is only six inches (6") thick, as opposed to the standard eight inches (8") for other options, because the beams are placed so closely together. The total depth of the inverted T-beam structure will be approximately 3'-4 ¾". A twelve inch (12") curb on each side of the guideway allows the mounting of vehicle control guides, as well as containing the vehicle itself. Using these dimensions, the total dead load for the inverted T-beam superstructure used for study was 633 pounds per foot per beam. See Figures 2 & 3 for the guideway and inverted T-beam sections.

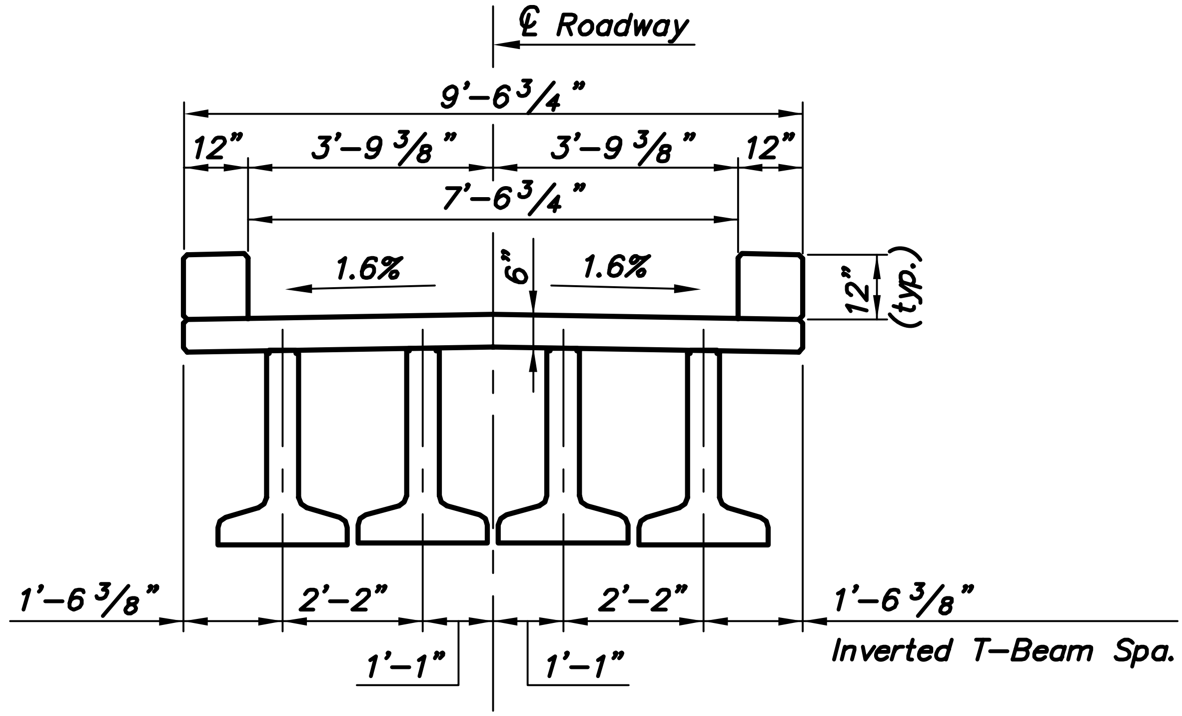


IT36 BEAM SECTION

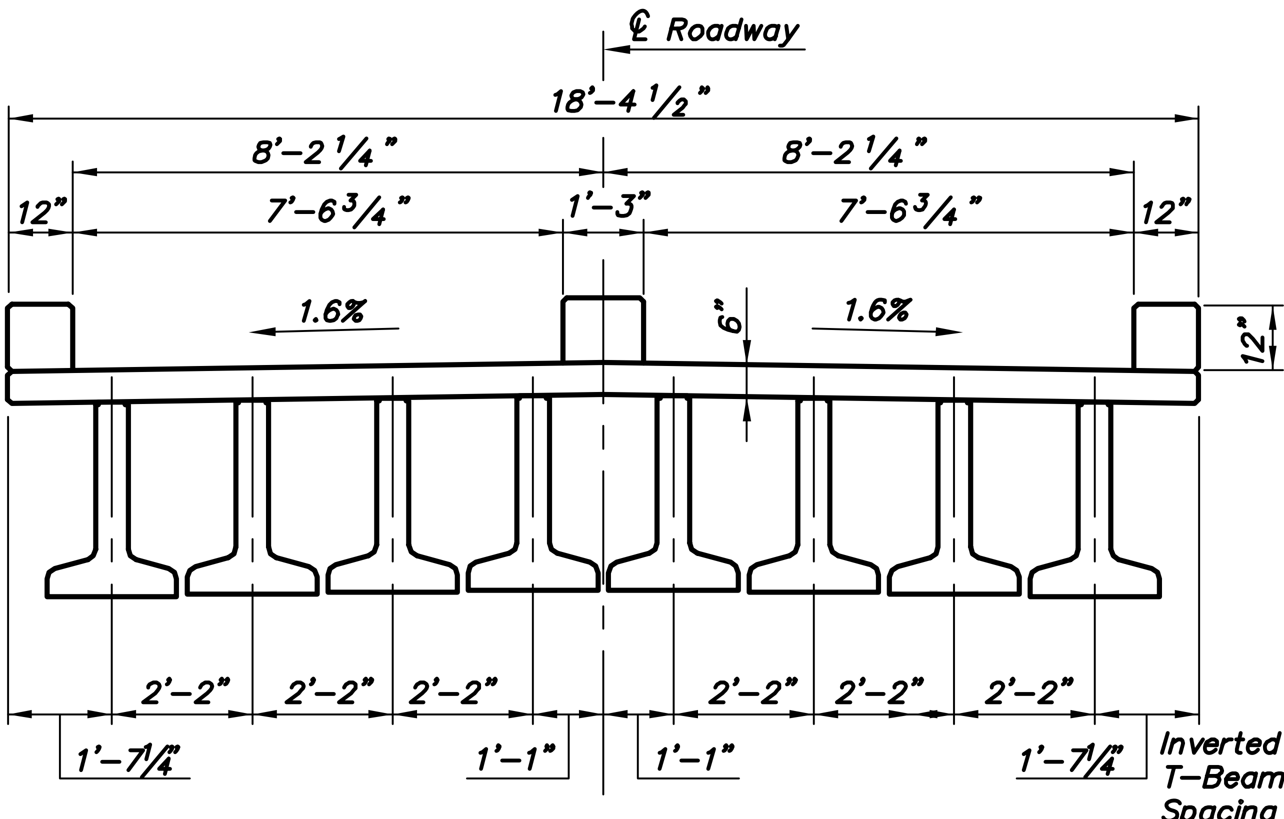
Untopped Section Properties

A	=	325.0	$in.^2$
Y_t	=	22.52	in.
Y_b	=	12.91	in.
I	=	37,866	$in.^4$
S_t	=	1,681	$in.^2$
S_b	=	2,932	$in.^2$

Figure 2



TYPICAL SECTION OF ONE DIRECTIONAL TRACK



TYPICAL SECTION OF TWO DIRECTIONAL TRACK

Figure 3

K-3 Beam Structure: The second type of superstructure studied was the standard K-3 beam. This type of structure has been used in construction for many years and can span the required distance without any difficulties. The K-3 beam is a heavier beam than the inverted T-beam and would need only two beams per direction of guideway. The falsework required for pouring the deck is attached to the beams and would not involve additional pile driving to construct. Once the deck is poured, the falsework would be removed leaving the underside of the structure open between the beams. This space can be utilized to house the mechanical and electrical elements of the system. The concrete structure itself would require minimum maintenance.

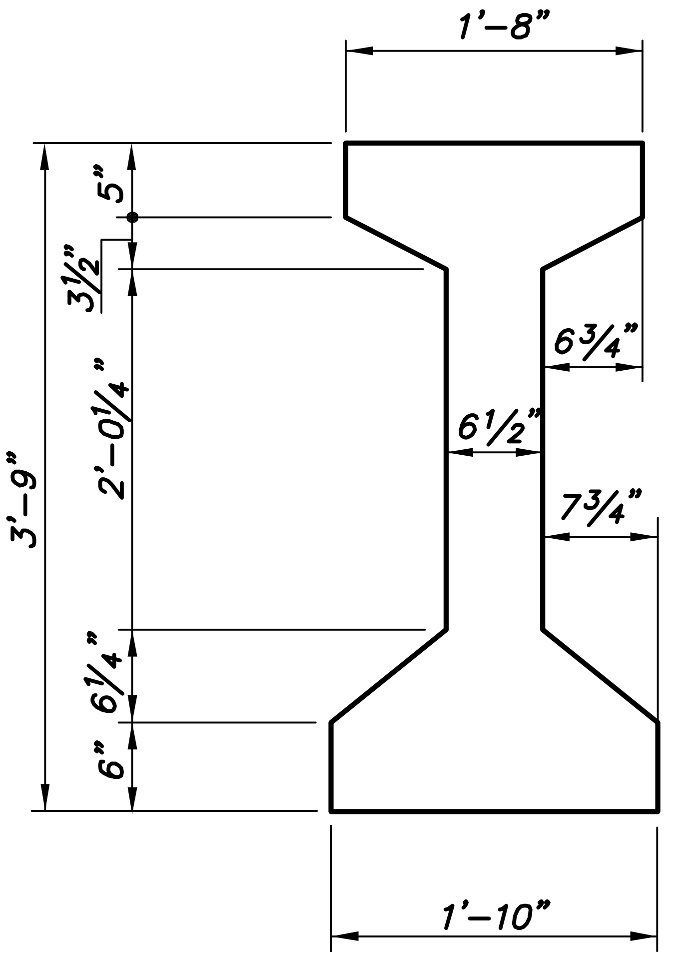
The design K-3 is forty-five inches (45") deep, with a twenty-two inch bottom flange. Because there are only 2 beams per direction of guideway, the space between the beams is such that an eight inch (8") deck is required. The total depth of a K-3 beam structure is 4'-5¾". With the addition of the twelve inch (12") curbs, the total design dead load for the K-3 beam structure was 1,447 pounds per foot per beam. See Figures 4 & 5 for K-3 structure sections.

Steel Girder Structure: The third superstructure type studied was a rolled steel girder structure. Like the K-3 beam, steel girders have been used in bridge structures for many years and can easily span ninety feet (90'). The construction would be similar to the K-3 beam and would require falsework hung from the beams to pour the deck. Once the falsework is removed, the underside of the structure would be open, with the steel beams exposed. The mechanical elements would be housed in this space, like the K-3 Beam. However, the steel beams will rust over time which is not only unsightly, but costly to maintain.

The design steel girder is a W36x150 section, which is thirty-six inches (36") deep with twelve inch (12") flanges. The spacing center-to-center of the beams is the same as that of the K-3 beams and also requires an eight inch (8") deck thickness. The total depth of the structure is 3'-9¼". Including the curb weight, the total design dead load for the steel girder structure is 1,050 pounds per foot per beam. See figures 6 & 7 for steel girder and structure sections.

A comparison of the three types of superstructures studied in this report is presented in Table 2. For the optimal span of ninety feet (90'), the design of the superstructure for each of the three options was controlled by deflection, i.e., the guideways would be operating under a stress level that is lower than that of their load-carrying capacity.

Substructure: The type of foundation for the pier supports will vary from site to site as the geology of the underlying strata dictates. For the purposes of this study, previous boring logs from various construction around the study campus were utilized to determine the most likely type of foundations required at this site. Foundation recommendations may vary within the same project as the construction moves from one area to another. However, by using boring logs from various areas of the campus, the study campus appears to be in an area of fairly consistent geological strata. Using this information, it was determined the best type of foundation for the piers would be drilled shafts.

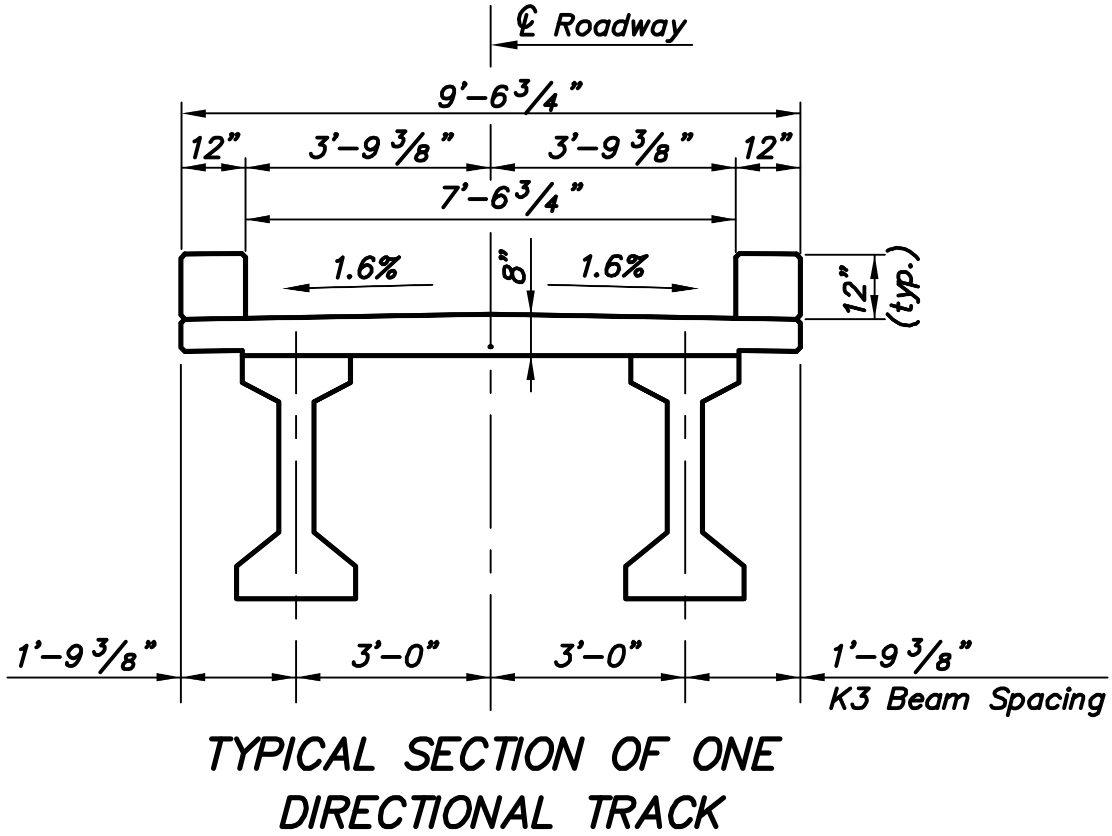


K3 BEAM SECTION

Untopped Section Properties

A	=	525.0	$in.^2$
Y_t	=	23.98	in.
Y_b	=	21.02	in.
I	=	127,490	$in.^4$
S_t	=	5,317	$in.^3$
S_b	=	6,065	$in.^3$
Vol./Surf. Area	=	3.56	in.
Wt./ft.	=	547	lbs.

Figure 4


℄ Roadway
9'-6 3/4"
12"
3'-9 3/8"
3'-9 3/8"
12"
7'-6 3/4"
1.6%
8"
1.6%
12" (typ.)
1'-9 3/8"
3'-0"
3'-0"
1'-9 3/8"
K3 Beam Spacing
TYPICAL SECTION OF ONE DIRECTIONAL TRACK

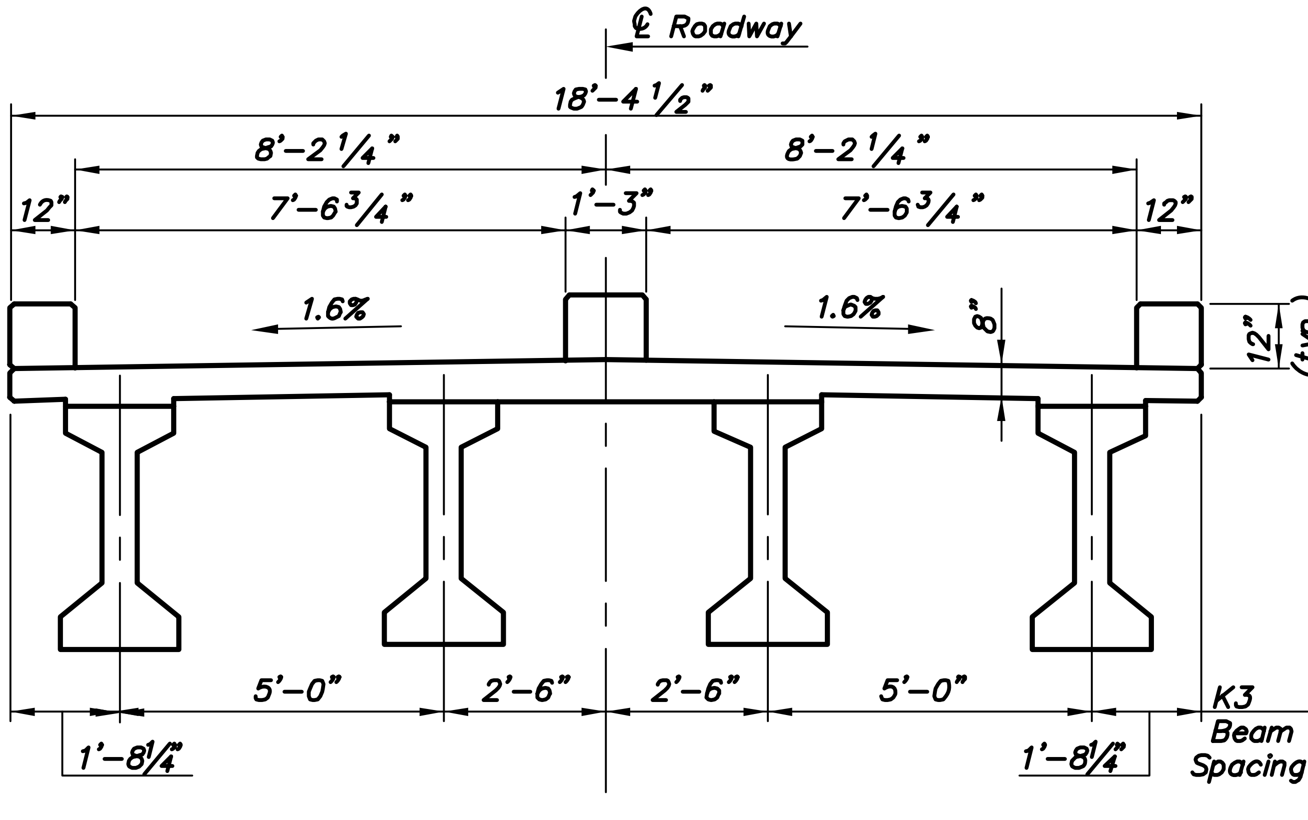
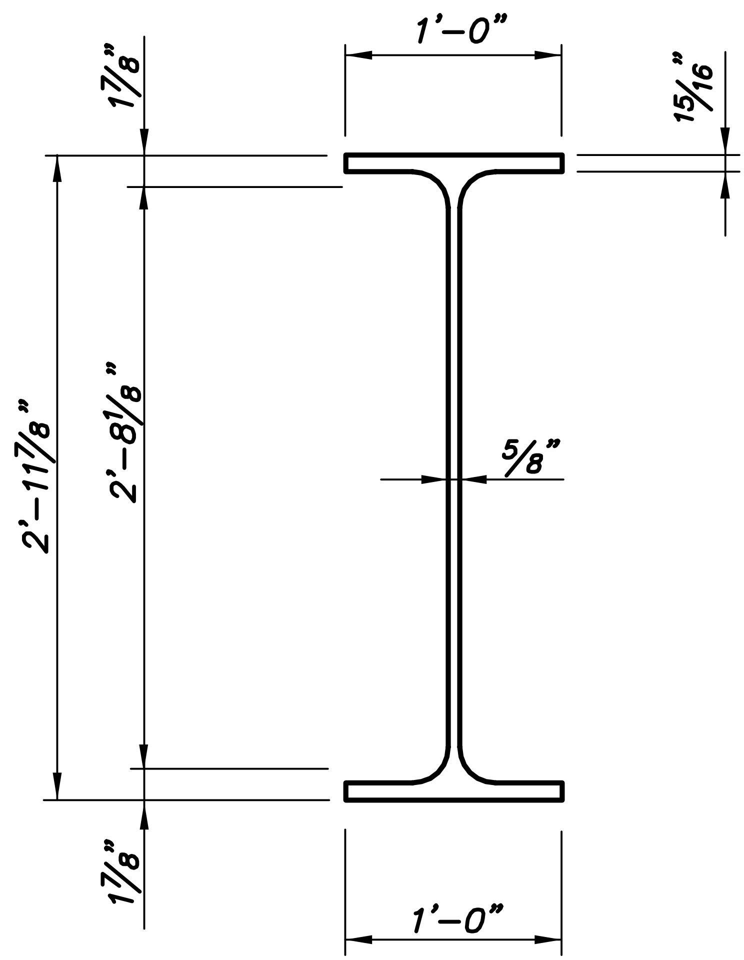

℄ Roadway
18'-4 1/2"
8'-2 1/4"
8'-2 1/4"
12"
7'-6 3/4"
1'-3"
7'-6 3/4"
12"
1.6%
1.6%
8"
12" (typ.)
5'-0"
2'-6"
2'-6"
5'-0"
K3 Beam Spacing
1'-8 1/4"
1'-8 1/4"
TYPICAL SECTION OF TWO DIRECTIONAL TRACK

Figure 5

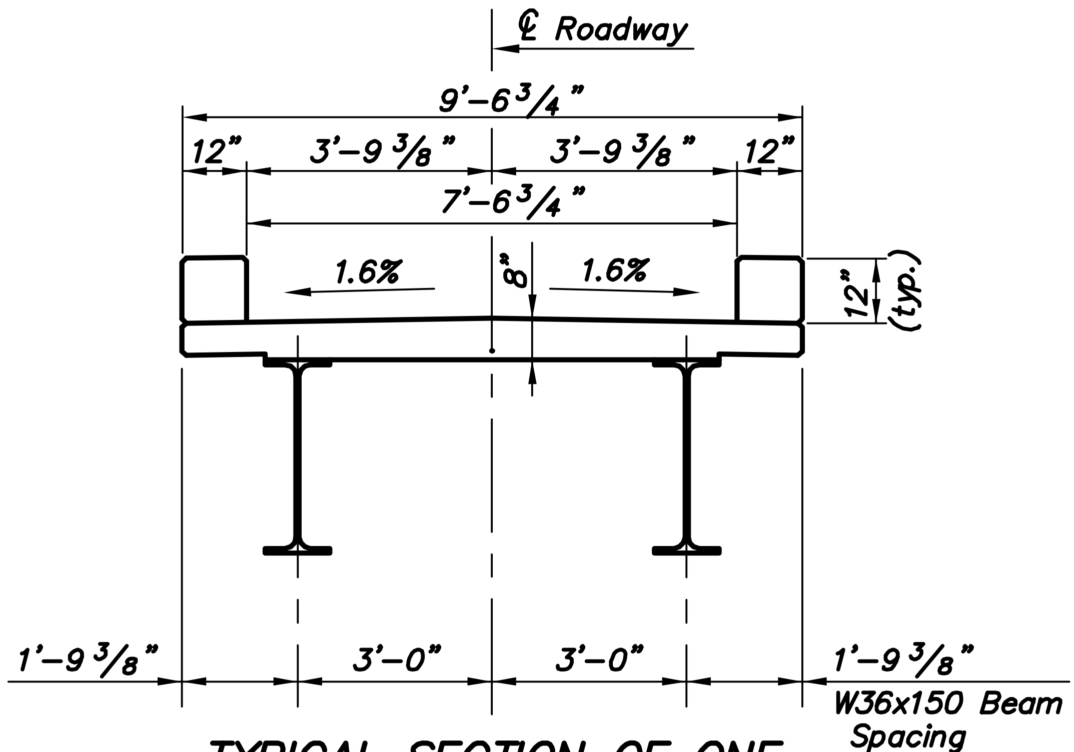


W36x150 BEAM SECTION

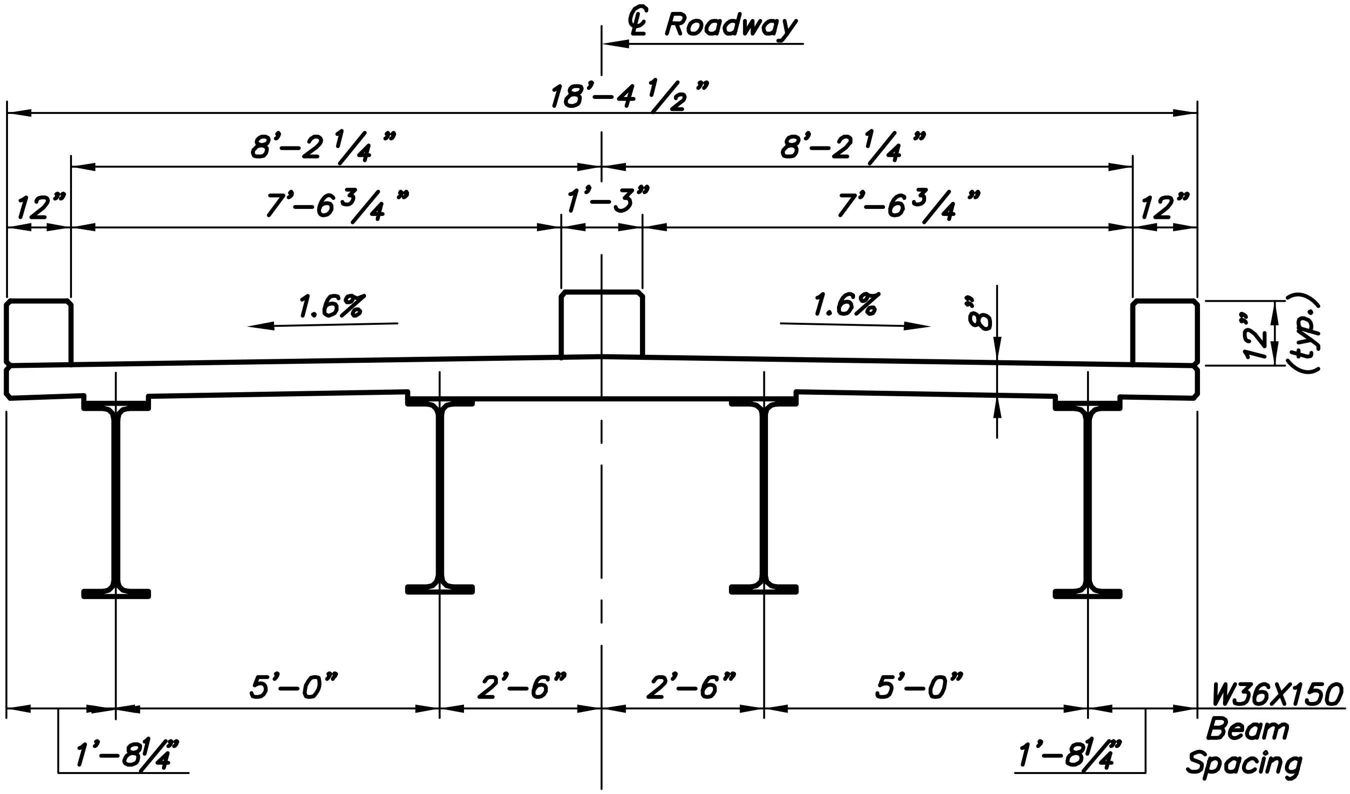
Untopped Section Properties

A	=	44.2	$in.^2$
Y_t	=	17.925	in.
Y_b	=	17.925	in.
I_x	=	9,040	$in.^4$
S_x	=	504	$in.^3$
S_y	=	45.1	$in.^3$
Wt./ft.	=	150	lbs.

Figure 6



TYPICAL SECTION OF ONE DIRECTIONAL TRACK



TYPICAL SECTION OF TWO DIRECTIONAL TRACK

Figure 7

The design piers are made up of two 18”x18” columns with an 18”x24” beam. The top of the pier beam must be sixteen feet (16’) above the ground to allow any necessary service vehicles access to travel under the guideway. The two column design, opposed to a single column design, was considered so that a large portion of the guideway could travel above the existing walkways. This design serves two purposes. The first is while keeping with the existing walkways, less additional land will be needed to build the guideway. The second is the guideway provides a covered walkway for pedestrian traffic during inclement weather.

COMPARISON OF STRUCTURAL OPTIONS			
	IT36 Beam	**K-3 Beam**	**Rolled Steel Girder**
Depth	36"	45"	36"
Width	24"	22"	12"
No. Required	4 or 8	2 or 4	2 or 4
Deck Thickness	6"	8"	8"
Total Depth of Superstructure	3'-4¾"	4'-5¾"	3'-9½"
Dead Load/Beam	633 lb/ft/beam	1,447 lb/ft/beam	1,050 lb/ft/beam
Falsework Required	no	yes	yes
Beam Maintenance	low	low	high

Table 2

Arrival-Departure Stations

The campus layout showed a need for eleven (11) arrival-departure stations. Five (5) of these stations are in the main core of the campus. One is attached to a building which can utilize the existing elevators and can be accessed from inside the building. The other four are located at high traffic areas, near parking lots and class or dorm hubs. There are six (6) additional out-lying stations to facilitate easy access to and from the outer sections of the campus. One (1) station connects to the sports complex which allows the daily use of the large parking area instead of use only on event days.

Station structures will be partially open with a foot print area of 41’x 30’. Vehicles will arrive on the raised guideway at an elevation sixteen feet (16’) above ground level. The platform can be accessed either by stairways or a handicap accessible elevator. The entire structure will be covered, however, the elevator area is the only completely enclosed section of the structure. The guideway will separate at each arrival-departure station to insure uninterrupted service for the vehicles not stopping at that station.

<u>Maintenance - Control and Storage Facilities</u>

Maintenance-Control Facility: An ASVT system requires a fleet of vehicles, which requires a facility to maintain them. After reviewing similar systems, it was determined that a 80’x120’ facility would be adequate for this purpose. This building would be an enclosed structure where the vehicles could be serviced out of the weather.

Without a control room, an ASVT system cannot function. The control room houses the computerized equipment and operators required to let the system run smoothly and safely. A 24’x 30’ room should be ample space for this purpose. This area, along with offices, restrooms, break rooms, vending areas, etc., can be housed in a second story of the maintenance building. If the maintenance-control facility is located near the main campus, it will be desirable to use materials similar to the existing architecture, limestone in the case of the study site. However, if the control facility is located in an out-lying area, a less costly steel structure could be considered depending on client preference.

Vehicle Storage Facility: In an ASVT system the size required to service a campus, the fleet of vehicles will be substantial. However, there will be times when all or part of these vehicles will not be in use which creates a need for a vehicle storage facility. The vehicles will be called from this facility as they are needed on the guideway. Estimating the need for eighty (80) vehicles, using ParkShuttleII dimensions, a 95’x210’ structure would be required. The structure itself will be a roofed structure with open sidewalls. The type of construction materials used for this facility would depend on the architectural needs in the area it is built.

Geological Investigation

Geologic stratum is site specific and as such cannot be generalized for all ASVT systems. For the purpose of this report, the geology around the study campus was studied to determine the best type of foundation system to use for the guideway supports.

The study campus has grown in recent years and therefore, records of previous bore logs were available for various sites around the campus. It is not uncommon for the geologic stratum to vary across the same construction site, which would require different types of foundation systems within the same network. After studying the available boring logs, it was determined the site lies upon fairly consistent strata. The recommended foundations across the campus are either drilled shafts or auger cast piling. The depths varied from site to site, or even within the same site, from twenty-five feet (25') to forty-five feet (45'). A summary of the sites considered are in the Table 3 below and the locations of the bore hole sites are shown on Figure 8.

GEOLOGICAL SUMMARY*				
Bore Hole	**Location**	**Recommended Foundation**	**Depth of Pile**	**Allowable Load**
No. 1	Football Complex	Drilled Piers or Auger Cast Piles	25'-35'	D.P.: 50-66 tons/pile A.C.P.: 19-33 tons/pile
No. 2	Research Building	Auger Cast Piles	35'-45'	30 ton/pile
No. 3	Academic Classroom Building	Drilled Piers	25'-35'	50,000 psf
No. 4	Engineering Classroom Building	Drilled Piers	35'-45'	50,000 psf
No. 5	Academic Classroom Building	Drilled Piers	25'	50,000 psf
No. 6	Museum	Drilled Piers	26'-45'	30,000 psf
* See Appendix B for additional geological information obtained from previous university construction.				

Table 3

Figure 8

BORE HOLE LOCATIONS

No Scale

Snow Melting System

Guideways for the Automated Small Vehicle Transit system (ASVT) require a snow melting system. Good traction between the ASVT vehicle’s rubber tires and the guideway is essential to prevent vehicle skidding and to improve control of the vehicle in snow conditions. It is also necessary to prevent snow from blocking the guideway and ultimately shutting down the system.

There are three kinds of systems that can be used for melting snow off of ASVT guideways. The first system is the spreading of de-icing salt, the second system is an electric system that uses wires embedded in the concrete deck to radiate heat, and the third system is the liquid system (also known as hydronic system). In the hydronic system, a mix of hot water and ethylene or propylene glycol is pumped through pipes embedded in the concrete deck to radiate heat.

Spreading of de-icing salt may cost less than the other two systems, but will result in the rapid deterioration of the structure, and the shortening its life expectancy. A concrete guideway, deteriorated due to salt, can only be repaired by milling and overlaying. This process would be difficult to perform on a narrow guideway without causing damage to the power and control lines attached to its sides. For these reasons this system was considered not to be a viable option and was not studied further.

An electric system has a lower initial cost, however, its operating cost depends substantially on the climate of the region in which it is installed, i.e., the amount of snowfall in that region. This system involves transformers, a series of control switches, thermostats, and snow sensing apparatus. One such system consists of heat tapes (flat wires) that automatically stop heating when sufficient energy is released. When they cool, the wires then allow more heat through them.

Liquid systems (hyrdronic systems) have a higher initial cost, but generally a lower operating cost. Hot water systems consist of flexible pipes, pipe manifolds, pumps, switches, thermostats, and snow sensors. They typically rely on a single central boiler, or multiple boilers along the guideway to heat the liquid mix.

Snow melting systems generally do not completely dry the ASVT guideway surface. Rather, they melt the snow to water; which flows from the guideway through drains then downspouts to the storm sewer system. Completely evaporating the water off the guideway’s surface is not economically practical since it requires more energy than melting snow to water. Occasionally, snowfall or drifting may exceed the heat output of the snow melting system.

The performance of a snow melting system is measured in inches (cm) of snow melted per hour. Its performance is based on heat output measured in BTUs (British Thermal Units) or watts per square foot (Sq.ft.) of guideway. Performance depends on consideration of three overall design factors. First is the rate of snowfall. Second is the temperature of the snow, influenced by the air temperature. About 90% of all snow falls between 35° F (2° C) and 10° F (-12° C). On average, snow falls at about 26° F (-3° C). The lower the air temperature, the less dense the snow, therefore, for warmer, wetter, and more dense snow, more energy per area of guideway is required to melt it. Third, wind conditions greatly influence performance of a snow melting system. Strong winds remove heat from a guideway faster than calm air. Location of buildings, walls, landscaping, and guardrails will influence the amount of wind across a guideway, heat loss, and ultimately the design and performance of snow melting systems.

The required rate of snow melting will vary with the region in which the guideway structure is constructed. The design of a liquid or electric snow melting systems shall involve the calculation of the BTUs per square foot (watts/Sq.m.) required to melt a range of snow storms for a given region. The factors that affect the design of the snow melting system are the snow temperature (density), ambient temperature, exposure of the guideway to wind, and unusual site conditions. The Radiant Panel Association provides design guidelines for liquid snow melt systems.

The design shall provide recommendations on the size and spacing of pipes or wires required, as well as the temperature of the fluid, its rate of flow, or the electricity required and controls for activating the snow melting system when snow or ice falls. Sometimes a low level of heat is maintained in the pipes or wires and is increased by the sensor when snow falls.

Snowfall data for Northeast Kansas was obtained for the purpose of this study from Ms. Mary Knapp, the Kansas State Climatologist, Department of Communication, Weather Data Library.

The following is a comparison between the initial cost for an electric snow melting system and a hydronic snow melting system calculated in terms a single mile of one directional track of guideway:

	Electric System	Hydronic System
Equipment	$357,000	$315,000
Labor	$130,000	$220,000
Hydronic Structure (Boiler)	$0	$210,000
Energy Feed	$64,000	$48,000
TOTAL	**$551,000**	**$793,000**

The operation cost for both systems was calculated based on an estimated 1.5”/hr of snowfall to be melted. This rate of snowfall requires 28-30 w/sq.ft. for the heating cables or 95-100 BTU/sq.ft. for the hydronic system. The required snowmelt time was estimated to be 130 hours. The boiler efficiency/losses for the hydronic system was assumed to be 85%, and the idling operation hours were assumed to be 160 hours/yr. at 50% of the snowmelt. The energy cost was assumed to be \$0.08/kwh, and \$1.15/therm natural gas (\$0.039/kwh equivalent).

Operating Cost Calculation

1. Electric

$$\frac{30\text{w} / \text{ft}^2}{1000\text{w/kw}} \times 39{,}600\ \text{ft}^2 \times 130\ \text{hr} \times \frac{\$0.08}{\text{Kwh}} = \$12{,}355$$

2. Hydronic Snowmelt

$$\frac{102\ \text{Btu}}{\text{hr - ft}^2} \cdot \frac{\times\ 39{,}600\ \text{ft}^2 \times 130\ \text{hr} \times \$1.15 / \text{therm}}{.85\ \text{eff} \times 100{,}000\ \text{Btu / therm}} = \$7{,}104$$

3. Hydronic Idling (50% Snowmelt Rate)

$$\frac{102\ \text{Btu}}{\text{hr - ft}^2} \times 50\% \cdot \frac{39{,}600\ \text{ft}^2 \times 160\ \text{hr} \times \$1.15 / \text{therm}}{.85\ \text{eff} \times 100{,}000\ \text{Btu / therm}} = \$4{,}372$$

The following is a comparison between the annual operation cost for an electric snow melting system and a hydronic snow melting system calculated in terms a single mile of one directional track of guideway:

	Electric System	Hydronic System
Snowmelt Time (130 hr)	\$12,355	\$7,104
Idling Time (160 hr)	\$0	\$4,372
Maintenance	\$2,000	\$4,500
TOTAL	**\$14,355**	**\$15,976**

The comparison shown above depends greatly on the cost of energy, the climate in the region in which the guideway is constructed and the site conditions regarding the availability of land for building boiler(s) in a congested university campus. There are other considerations, besides the cost, that make the electric snow melting system more attractive. The electric system has no environmental emissions caused by “greenhouse” gases produced by the boilers. Also, no environmental pollution can be expected due to a leakage of glycol from a pipe in the hydronic system. There are also aesthetic advantages to use the electric snow melting system. These include the elimination of boiler building(s) in the middle of campus and the elimination of the unsightly supply and return pipes attached to the guideway.

Architectural Design

The design of the stations for the Automated Small Vehicle Transit system was based on themes of modernity and context. The notion of modernity stemmed from an attempt to understand how the built environment could comment on the technology it was created to support, as it is a reflection of the modern age – the vehicle. The post and beam construction of reinforced concrete, placement of metal stairs, and lightweight roofing structures, commented on the visual lightness of modern materials and construction techniques, creating physical nodes where the technology of the vehicle could momentarily pause to gather and disperse people throughout the campus environment. Louvered screens were placed between tracks to shield people from passing vehicles and represent the idea of movement in its horizontality.

The stations were also designed to reflect the context in which they are placed. Through the incorporation of limestone, the stations relate to local construction material and the natural presence of limestone in the study area. The limestone creates a link between the station and the campus, while bridging the universality of modern materials - which can be devoid of origin - with the site. Galvanized steel reflects not only modernity, but comments on its presence in the physical fabric of campus, exposed in the form of existing copings or storefront. These materials help maintain continuity and create a dialogue between the existing built environment and the proposed.

The station attached to the student complex was designed to respond to the massing of the original building. The visual weight of the platform, covering shade, and horizontal louvered screen were designed to balance the placement of the station in front of the building's vestibule and vertical expanses of glazing, creating harmony in appearance, balance, and practicality in use. Free standing stations were designed to reference the massing of the union station and maintain architectural continuity between nodes of transit on the campus. The free standing stations also provide covered shade structures that would protect waiting pedestrians from the environment and also offer places for spontaneous encounters and areas for study or relaxation, between pick-up and drop-off at nodes of transit. (See Appendix C for renderings)

Construction Cost

In this section, the cost for a single and a double track guideway is presented per mile and calculated for the three different guideway alternatives presented in this report. The cost analysis in this report was based on the actual quantities calculated from the design of the guideway. Since the design of the guideway is based on deflection consideration rather than strength considerations, the cost is not greatly affected by the weight of the vehicle. The unit prices used in this analysis were obtained from KDOT's most recent published contract bid averages for the study region. Inflation factors should be applied to these values for a year of construction beyond 2006. A summary of the opinion of construction probable cost for the guideway is presented in Table 4. The values in this table are obtained from the detailed analysis presented in Appendix D.

PROBABLE CONSTRUCTION COST PER MILE OF GUIDEWAY		
Guideway Type	**Single Track**	**Double Track**
IT-36 Prestressed Beams	$6,905,490	$10,641,400
K-3 Prestressed Beams	$6,571,200	$9,631,870
Rolled Steel Beams	$6,981,706	$10,284,610
*See Appendix D for additional cost breakdown.		

TABLE 4

The numbers presented in the table above are based on using the electrical snow melting system and include architectural enhancements specific to the university campus of this study. Also, an additional 15% for contingency was included in the total cost.

The average probable construction cost for a free standing station was estimated to be approximately $1.8M and for the attached station was $2.4M. This cost includes all the mechanical and electrical equipment such as elevators, doors, etc. and the architectural enhancement to blend the station with the adjacent campus environment.

The building used for maintenance and control was estimated to have a probable construction cost of $3.26M. This cost also includes all the mechanical and electrical equipment such as elevators, doors, heating and cooling, etc. However, it does not include the cost of computers and electronic equipment in the control room. The cost of the architectural enhancement to blend the building with the adjacent campus environment was also included.

The storage facility described in the “Structural Components” section of this report was estimated to have a probable construction cost of $2.87M. This cost does not include any allowances for architectural enhancement, as the remote location of this facility will not be encroaching the campus setting.

The total probable cost of the project’s structural components was calculated for the three different types of guideway using the proposed route, which includes 1.36 miles of one-directional track and 1.92 miles for two-directional track. This cost also includes ten (10) free standing stations and one attached station, in addition to the maintenance and control building, and the storage facility. Table 5 below presents a summary of the total probable cost of the project’s structural components.

TOTAL PROBABLE CONSTRUCTION COST OF PROJECT STRUCTURES	
Guideway Type	**Cost in Million $**
IT-36 Prestressed Beams	$56.33M
K-3 Prestressed Beams	$53.96M
Rolled Steel Beams	$55.95M

Table 5