Thrust Restraint

Pipe joints do not provide enough restraint against longitudinal separation caused by unbalanced hydrostatic and hydrodynamic forces; these forces can cause joint separation unless restraint is provided to withhold thrust forces. Thrust blocks and/or restrained joints shall be used as specified to provide restraint where pipefittings such as tees and valves are present, and where the pipe experiences considerable horizontal and/or vertical changes in direction.

Thrust block

Thrust forces experienced with horizontal changes in direction were calculated using an internal pressure of 170 psi and were design for existing commercial bend angles (90°, 45°, 22.5°, 11.25°); Equation 1 was used for the computation of thrust forces. Figure 11 represents the layout of the horizontal direction changes.

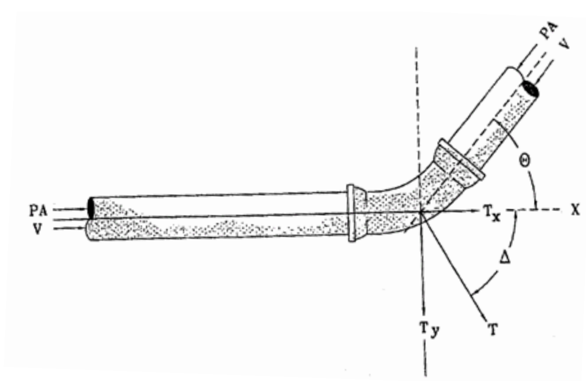

Figure 11- Thrust Force Layout

$$T = P \times A \times \sin\left(\frac{\theta}{2}\right) \quad \text{Eq. (1)}$$

T = resultant thrust force on bent (lbf)
P = Internal Pressure (psi)
A = pipe cross sectional area (in^2)

The required bearing block dimensions for horizontal bends were calculated using Equation 2, and is represented in Figure 12.

$$A_b = \text{h}\times\text{b} = \frac{\text{Sf}\times\text{T}}{\text{Sb}} \qquad \text{Eq. (2)}$$

A_b = required bearing block area
Sf = safety factor (50% safety factor was used)
T = thrust force
S_b = soil bearing strength

Thrust blocks should rest solidly against undisturbed soil. The following general criterions for bearing block design were used for dimension computations and are represented in Figure 12.

- Block height (h) should be equal to or less than one-half the total depth to the bottom of the block, (Ht) which is equal to 8ft, but not less than the pipe diameter (D′) which is 2ft.z
- Block height (h) should be chosen such that the calculated block width (b) varies between one and two times the height.

Given these criterion values, 4ft and 3ft were used for height (h), depending on the bent angle.

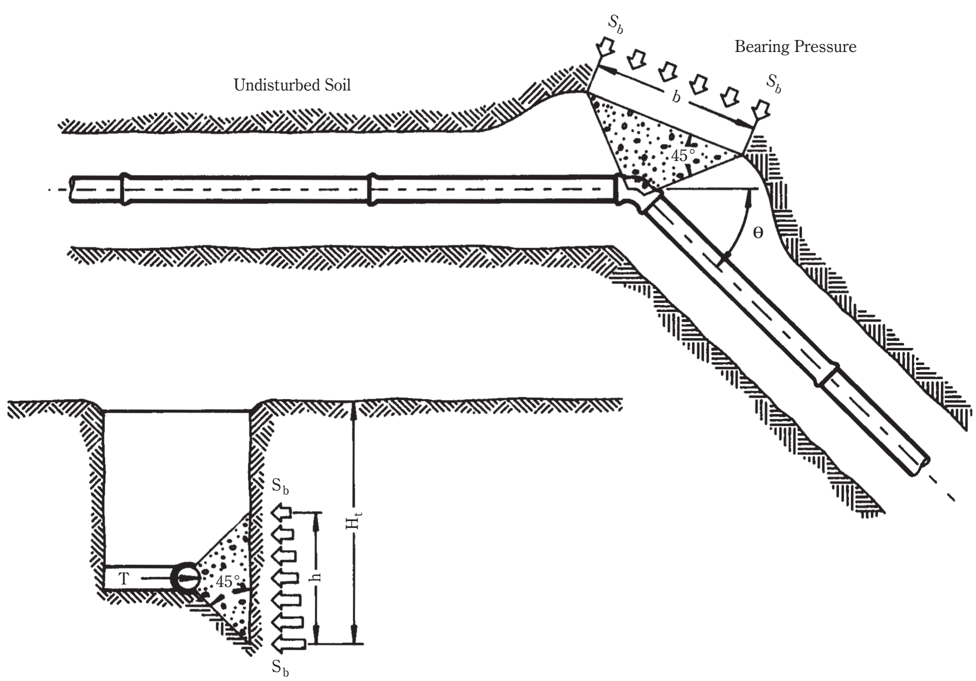

Figure 12 – Bearing Block Design

Three types of soils were considered for the thrust block design, in accordance to Sheet A11 from the geotechnical report by CQC, as shown in Table 6, and soil distribution was assumed as per the sample boring locations used for the geotechnical report; the assumed distribution for the soils is shown in Figure 13. Respective soil bearing strength for each soil was chosen from Table 5 taken from the DIPRA web page. The considered location for each soil, soil type and bearing strength are represented in Table 6.

Figure 13 – Considered Soil Distribution

Table 5 – Horizontal Bearing Strengths

Soil	Bearing Strength, S_b (Lb/Ft^2)
Muck	0
Soft Clay	1,000
Silt	1,500
Sandy Silt	3,000
Sand	4,000
Sandy Clay	6,000
Hard Clay	9,000

Table 6 – Considered Soil Type and Soil Bearing Strength for Thrust Block Calculations

Sta. location Range	Depth of boring (ft)	Soil type	Soil classification considered	Soil Bearing Strength - S_b (lb/ft^2)
Sta. 00+00 to 17+90	8.5' - 10'	GP-GC	Sandy clay	6,000
Sta. 17+90 to 41+65	5' - 6.5'	SC	Sand	4,000
Sta. 41+65 to 60+50	8.5' - 10'	SC	Sand	4,000
Sta. 60+50 to 77+50	5' - 6.25'	GP-GC	Sandy clay	6,000
Sta. 77+50 to 99+00	8.5' - 10'	SP-SM	Sandy silt	3,000

Results of trust block calculations from considered joint conditions are shown in Table 7. A minimum bearing area of eight squared feet shall be used for the smallest thrust blocks. To account for thrust forces caused by vertical changes in direction alternative methods of thrust restrain shall be used instead of using gravity blocks. Moreover, alternative methods of joint restraint shall be used if space on site is not adequate to allow for fitting of thrust blocks, such as proximity to utilities or lack of space for thrust block embedment.

Table 7 – Trust Calculation Results

Station Location Range	Joint Condition											
	90° bend			45° bend			22.5° bend			11.25° bend		
	A_b (ft^2)	dim. (ft)		A_b (ft^2)	dim. (ft)		A_b (ft^2)	dim. (ft)		A_b (ft^2)	dim. (ft)	
		h	b		h	b		h	b		h	b
00 + 00 to 17 + 90	29	4	7	16	4	4	8	3	3	4	3	1
17 + 90 to 41 + 65	44	4	11	24	4	6	12	3	4	6	3	2
41 + 65 to 60 + 50	44	4	11	24	4	6	12	3	4	6	3	2
60 + 50 to 77 + 50	29	4	7	16	4	4	8	3	3	4	3	1
77 + 50 to 99 + 00	59	4	15	32	4	8	16	4	4	8	3	3

Restrained Joints

Whenever space is insufficient to fit a trust block as per on site spacing or proximity to existing utilities, restrained joints shall be used to account for trust forces when necessary.

The type of restrained joint considered for the design was Restrained Push-On Gasket Joint. This joint consists of a single rubber gasket placed in a groove inside the socket at the bell end of the pipe; the other end of the pipe is pushed past the gasket, compressing it and forming a pressure-tight and dependable seal with the help of the gasket preventing leaking out of the pipe. Cross section of this type of joint is shown in Figure 14.

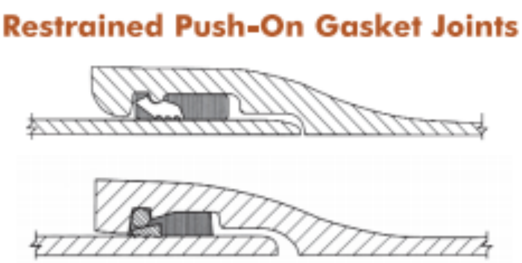

Figure 14 – Different Types of Restrained Push-On Gasket Joints

Restrained Push-On Gasket Joints feature several advantages such as: its compatibility with ductile iron pipe, easy assembly, and they offer better service than other commercial types of joints. Allowing DIP to expand its deflection up to 5 degrees, the Push- On Gasket Joints have other great advantages, since bell holes are not needed in the installation or the maintenance of this type of joint, the cost of the project is reduced substantially providing the contractor great savings. Finally these types of joints are the most economical and faster to install joints in the market.

DIP's Push-On Joint systems have been proven effective in actual tests with up to 1,000-psi internal pressure, 430-psi external pressure, and 14-psi negative internal air pressure with no leakage or infiltration. Although the Push-On Joint is normally rated for 350 psi, currently there are DIP Push-On Joint pipelines with operating pressures in excess of 1,000 psi.

Equation 3 was used to find the necessary number of joints that needed to be restrained in order to prevent any damage or leaks per pipe length. For designing purposes a pressure of 170 psi was assumed, with a required safety factor of 1.5. The calculations were made by the four different types of angles available on the market and also by the two different types of soils along the route and are shown in Table 8.

$$L = \frac{(S.F)(P)(A)\tan\left(\theta/2\right)}{F_S + R_b/2} \quad \text{(Eq. 3)}$$

Table 8 – Cohesive Granular Soil and Sand or Gravel with Silt Data

Cohesive Granular Soils		Sand or Gravel with Silt
$K_n = 1.00$		$K_n = 1.00$
⍰$_s$ = 148 pcf		⍰$_s$ = 130 pcf
$F_\Phi = 0.75$		$F_\Phi = 0.65$
$\Phi = 30$		$\Phi = 20$
$\delta = 22.5$		$\delta = 13$
C = 200		C = 0.00
$F_C = 0.40$		$F_C = 0.00$
W_e = 1984.45 lbs.		W_e = 1743.10 lbs.
$F_s = 1237.12$		$F_s = 1099.26$
$F_f = 879.97$		$F_f = 1099.26$
90°	35.26 ft.	29.14 ft.
45°	14.61 ft.	12.10 ft.
22.5°	7.01 ft.	5.79 ft.
11.25°	3.47 ft.	2.87 ft.
***These calculations also apply for vertical changes in the pipeline route.*		

According to the data shown in Table 8, two joints after and two joints before any 90-degree bent will be restrained to eliminate any concerns of infiltration or root intrusion. Also with bends smaller than 90 degrees just one joint before and one joint after the bent will be restrained regarding the type of soil in both cases.

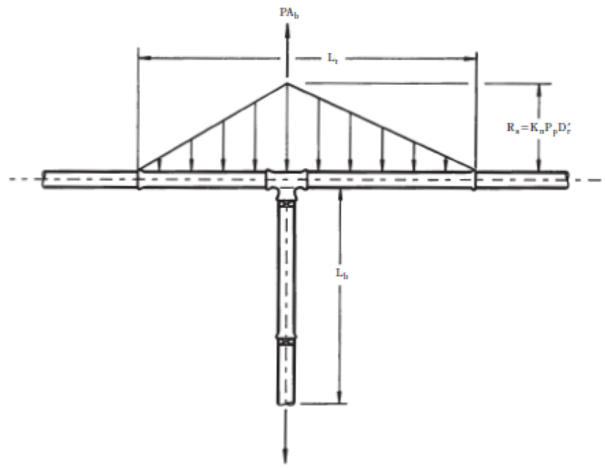

Figure 15 – Tees

Another conditions considered for joint restraint were fittings such as butterfly valves and tee connections, shown in Figure 15. Calculations were made to determine the length needed to be supported by a restrained joint in order to avoid any type of failure caused by the dead end or water hammering when butterfly valves are present. To be conservative in the design, two joints after and two joints before any butterfly valve and tee connections shall be restrained. The calculations were made using Equation 4 and Equation 5.

$$L = \frac{P*A*S_f}{F_f} \quad \text{(Eq. 4)}$$

$$L = [\frac{S_f*P*(A_1-A_2)}{F_f}] \quad \text{(Eq. 5)}$$

L = Length of the Pipe
P = Pressure inside the pipe.
A = Area of the pipe.
S_f = Safety Factor of 1.5
F_f = Frictional Force

Pipe Laying Condition and Embedment

Laying conditions are represented in Figure 16. Pipeline shall be bedded to its centerline in compacted granular material with four inch minimum soil under pipe. Backfill materials above the pipe zone shall be loose native soil excavated from the trench, free of rocks, foreign material. All backfill materials shall be placed in maximum eight inch uniform thickness loose lifts, and compacted to a minimum of 95 percent of maximum density as determined by ASTM D-1557

According to the geotechnical report by CQC, in-situ soil conditions are suitable for backfill. The suitable fill soils should be stripped of all vegetation, organic matter, clay lumps, topsoil, asphalt, construction debris and/or any foreign matter. Moreover materials should be free of clay lumps, deleterious materials, cobbles or boulders over three inches in nominal size.

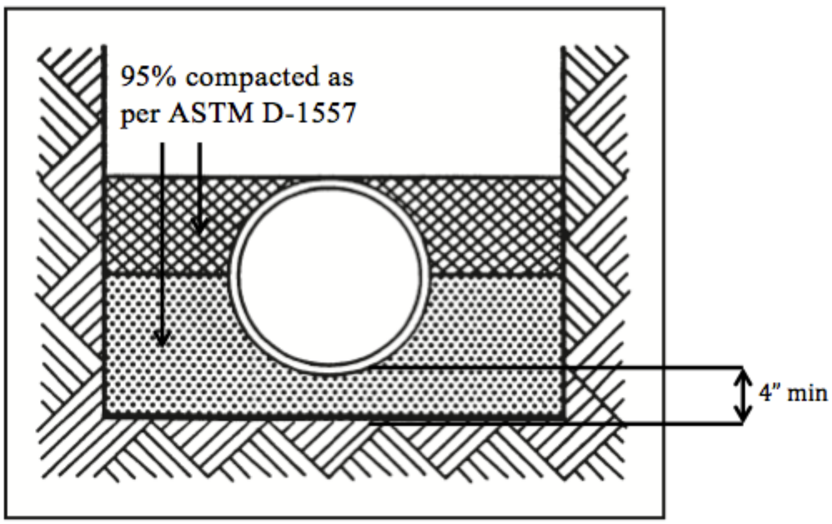

Figure 16 - Laying Conditions Chosen for Ductile Iron Pipe

Pipeline Casing under TxDOT Right of Way

The water transmission line crosses several street right-of-ways, such as Mesa Street and Resler Drive. In some cases when the right-of-way is a highly transited thoroughfare, special protection for the carrier pipe is needed. To provide extra protection against loading from the high traffic from Mesa Street, and to ensure double containment of the liquid flowing in the carrier pipe, a special casing is installed around the pipe. If the pipe were to break or leak, this casing would direct the liquid a safe distance away from the main street. Also, to protect the carrier pipe from corrosion and electrically isolate the carrier pipe from the casing pipe, special spacer/isolators are installed.

Considering the outer diameter of the carrier pipe of 25.61 inches, the designed minimum outer diameter of the casing pipe is 36.5 inches and it is made out of A36 steel with minimum yield strength of 36 ksi. To ensure no metal-to-metal contact between the carrier pipe and the casing pipe occurs, spacers/isolators are installed on the carrier pipe. The 12 inch bands of the hot rolled and pickled steel spacers/isolators are coated with a 10 to 16 milinches deep tough and durable fusion bonded cross-linked epoxy and it is lined with polyvinyl chloride with a thickness of 0.09 inches that provides electrical isolation for the carrier pipe. To ensure the carrier pipe is centered and restrained in the casing pipe, 10 inches high and 0.135 inches thick, risers are welded to the spacers/isolators to maintain the carrier pipe where desired.

As the carrier pipe's diameter is 24 inches, four risers and runners at the bottom of the pipe were used, at 15 and 60 degrees from the vertical respectively, and two on top at 45 degrees each. The runners are designed to ease the installation of the carrier pipe inside the casing pipe, with a low coefficient of friction of 0.1 to 0.6. The runners are attached to the risers with 3/8 inches in diameter studs, and are made of glass-reinforced nylon with a tensile strength of 17,600 psi, a compressive strength of 18,000 psi, and a flexural strength of 25,300 psi. The runners are two inches wide and 1.7 inches high. In summary, the carrier pipe sits on top of four runners/risers, centered inside the casing pipe with another pair of runners/riser on top with one inch of separation from the inside top of the casing pipe. Figure 17 depicts the carrier pipe centered and restrained by six spacers/isolators inside the casing pipe.

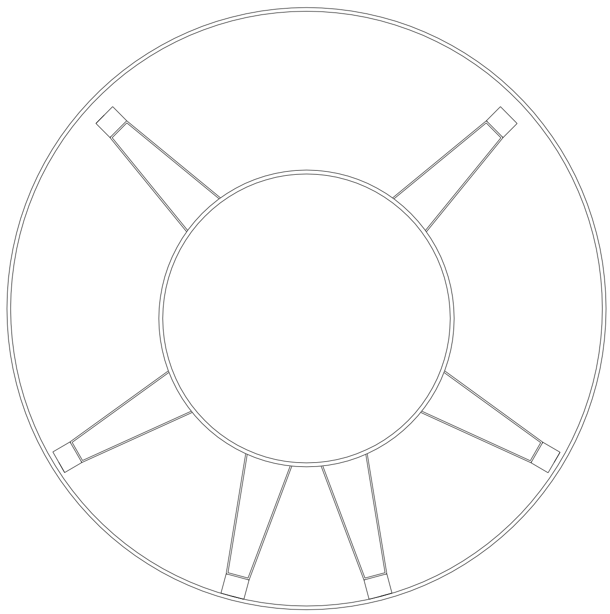

Figure 17 – Cross-sectional View of Casing and Carrier Pipes with Spacers/Isolators

Soil Corrosivity Considerations

Corrosion is the disintegration of a material due to chemical reactions with its surroundings. Any contact between the soil material and any concrete structures, steel piles, or metal will probably cause an outcome in corrosive reactions. In order to evaluate the potential corrosivity of the soils, sulfate, chloride, and pH tests were performed on soil samples by CQC.

Soils with a pH ranging from five to nine are usually not considered to be affected by corrosion rates. However, soils with a pH of four or less represent a serious corrosion risk to common construction materials. Different soil samples involving the soils affecting our pipeline's route were tested in the laboratory and the results are presented in the Table 9.

Table 9 – pH Values obtained from the Geotechnical Report

Borehole No.	Sample Depth (ft)	pH
B-1	2 ½ - 4	8.6
B-2	5 – 6 ½	8.7
B-3	2 ½ - 4	8.6
B-4	5 – 6 ½	8.6
B-5	2 ½ - 4	8.7

According to the geotechnical report performed by CQC, which tested 5 different boreholes, there was not much variance in the soil along the route. The pH levels in the soils are very similar. Because corrosion is caused by soils with a pH of four or less, the pipe will not need to take extra precautions to prevent corrosion in areas near the boreholes; however, in some stations considerations had to be taken due to the location of existing utilities such as water pipelines, gas pipelines, or electricity cables passing near the pipe. In some stations utilities were within ten feet of the pipeline, which affected the pipe by creating charges generated by the other pipes and producing corrosion. For this reason, cathodic protection was necessary in the areas near stations 95 + 00, 25 +20, 35 + 00, 55 + 20, 75 + 68, 85 + 25 and 95 + 53.

The field and laboratory work performed by CQC is shown in Figure 18. It indicates that the service life of an as-manufactured DIP could be quadrupled by the application of a current produced by a cathodic polarization potential of approximately 0.070 volts.

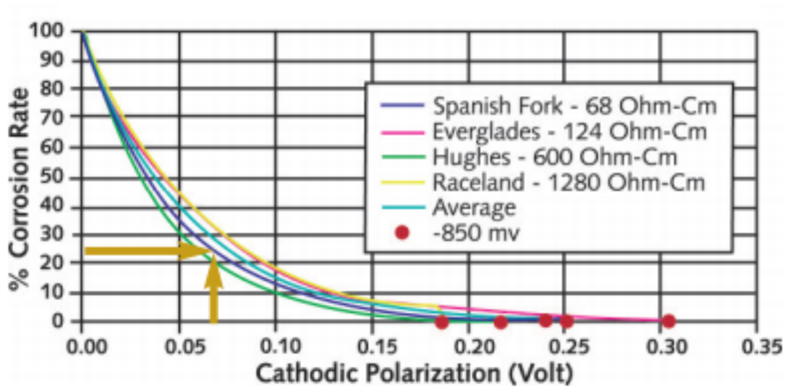

Figure 18 – Cathodic Polarization vs % Corrosion Rate

Traffic Control Plan

Temporary traffic control plans were devised to be used during the construction of the pipeline for the following streets which were affected by the rerouting of the pipe: Cloudview Drive, Colina Alta Road, Belvidere Drive, Resler Drive, Mesa Street, and Fountain Road. Each control plan is composed of four phases, the advanced warning area, transition area, activity area, and termination area.

The traffic control plan for the following stations is depicted in Figure 21: Cloudview Road from Station 33+00 to Station 41+00, Cloudview Road from Station 42+00 to Station 45+00, Cloudview Road from Station 44+00 to Station 70+00, and Colina Alta Road from Station 73+00 to Station 81+00.

In the advanced warning area for Figure 21, a total of three advanced warning signs were placed, the distances between each sign was determined using Table 10, taken from the Texas Manual of Uniform Traffic Control Devices (MUTCD), published by TxDOT. The transition area, where the traffic is moved out of its normal path, must measure a minimum of 50’ and a maximum of 100’. It includes an approach taper whose measurements were found using Tables 11 and 12. The activity area includes a buffer space which contains a shadow vehicle equipped with a truck mounted attenuator and the actual work area. The values found in Table 13 can be used to determine the length of the buffer space. The termination area also includes a buffer area and a downstream taper. Since a one-lane, two-way traffic control plan is necessary for this street the flagger method will be implemented. Flaggers are located within the advanced warning area and should communicate with each other orally, electronically, or with manual signals. MUTCD’s preferred method for hand-signaling device is the STOP/SLOW paddle because it gives road users more guidance than red flags, which is the method that will be utilized. Figure

19 depicts a flagger with a STOP/SLOW paddle. The signal requirements include that the street signs and channelizing devices meet the specifications provided in MUTCD. These specifications are shown in Figure 20.

Pedestrian considerations were also taken for our traffic control plan. In order to plan for the building of the pipeline, advanced notifications of sidewalk closures will be provided.

Figure 22 depicts the traffic control plan for the following stations: Cloudview Road from Station 39+00 to Station 43+00, Cloudview Road from Station 43+00 to Station 47+00, and Colina Alta Road from Station 79+00 to Station 86+00. For these stations, a traffic control plan for one-lane, two-way traffic was also implemented however, since it is curved street, extra precautions were taken due to the inadequate field of view of the construction. The termination area includes a larger buffer space after the work area and the opposite side of the road also includes an advanced warning area to alert drivers of the construction that is taking place beyond the curve.

Figure 23 depicts the traffic control plan for the following stations: Belvidere Drive from Station 5+00 to Station 9+00 and Resler Drive from Station 30+00 to Station 35+00. The stations included in Figure 23 have a four-lane roadway. Since only one lane is to be utilized and both directions of traffic have an adequate field of view of the construction, flaggers are not necessary for traffic control.

Figure 24 depicts the traffic control plan for the following stations: Belvidere Drive from Station 5+00 to Station 7+00, Resler Drive from Station 30+00 to Station 34+00, and Mesa Street from Station 87+00 to Station 91+00. Figure 25 depicts the traffic control plan for the stations located on Fountain Road from Station 82+00 to Station 86+00.

Both Figures 24 and 25 have a traffic control plan for stations that are located at the intersection of a roadway and an alley. The construction will take place in the alleys and they will be closed off to thru traffic.

Table 10 – Recommended Advanced Warning Sign Minimum Spacing

Road Type	Distance Between Signs		
	A	B	C
Urban (low speed)	100 feet	100 feet	100 feet
Urban (high speed)	350 feet	350 feet	350 feet
Rural	500 feet	500 feet	500 feet
Expressway/Freeway	1,000 feet	1,500 feet	2,640 feet

Table 11 – Taper Length Criteria for Temporary Traffic Control Zones

Type of Taper	Taper Length
Merging Taper	at least L
Shifting Taper	at least 0.5 L
Shoulder Taper	at least 0.33 L
One-Lane, Two-Way Traffic Taper	50 feet minimum, 100 feet maximum
Downstream Taper	50 feet minimum, 100 feet maximum
Note: Use Table 13 to calculate L	

Table 12 – Stopping Site Distance as a Function of Speed

Speed (mph)	Distance (feet)
20	115
25	155
30	200
35	250
40	305
45	360
50	425
55	495
60	570
65	645
70	730
75	820

Table 13 – Formulas for Determining Taper Length

Speed (S)	Taper Length (L)
40 mph or less	$L = WS^2/ 60$
45 mph or more	$L = WS$
Where: L = taper length in feet, W = width of offset in feet, S = posted speed limit, or off-peak 85th percentile speed prior to work starting, or the anticipated operating speed in mph	

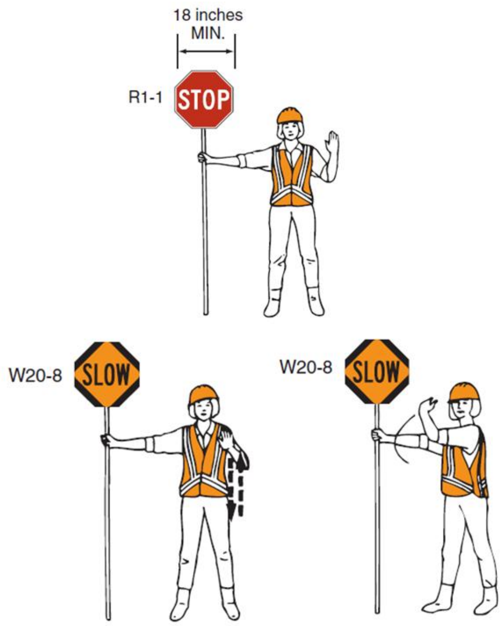

Figure 19 – A Flagger with a STOP/SLOW Paddle

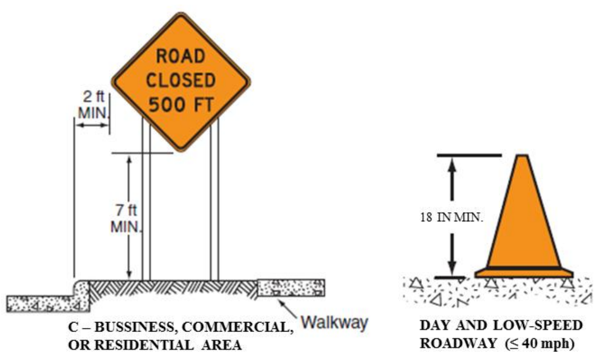

Figure 20 – Street Signs and Channeling Devices Specifications

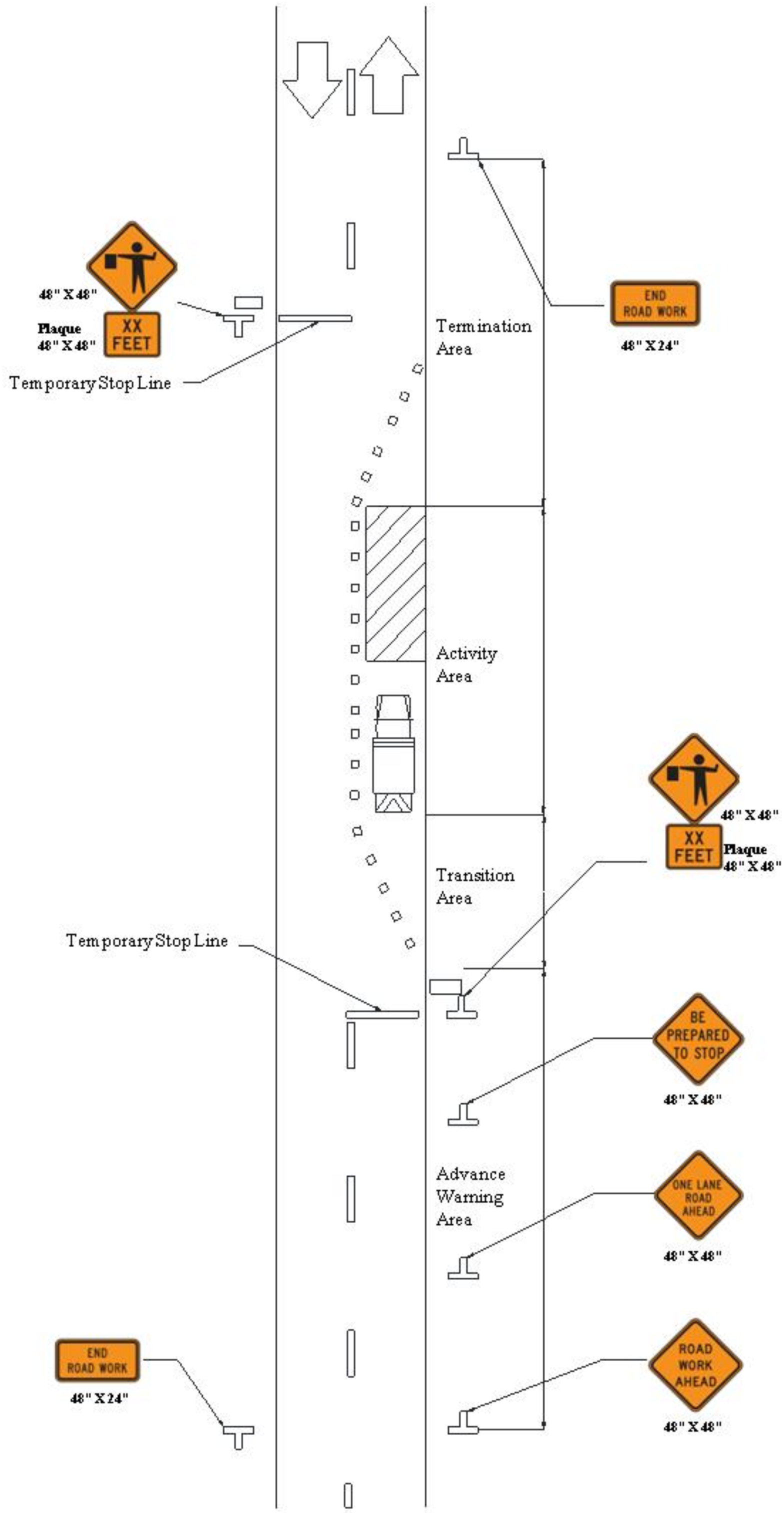

Figure 21 – Traffic Control Plan 1 (Station 33+00 to station 41+00, station 41+00 to station 45+00, station 44+00 to station 70+00, from station 73+00 to station 81+00)

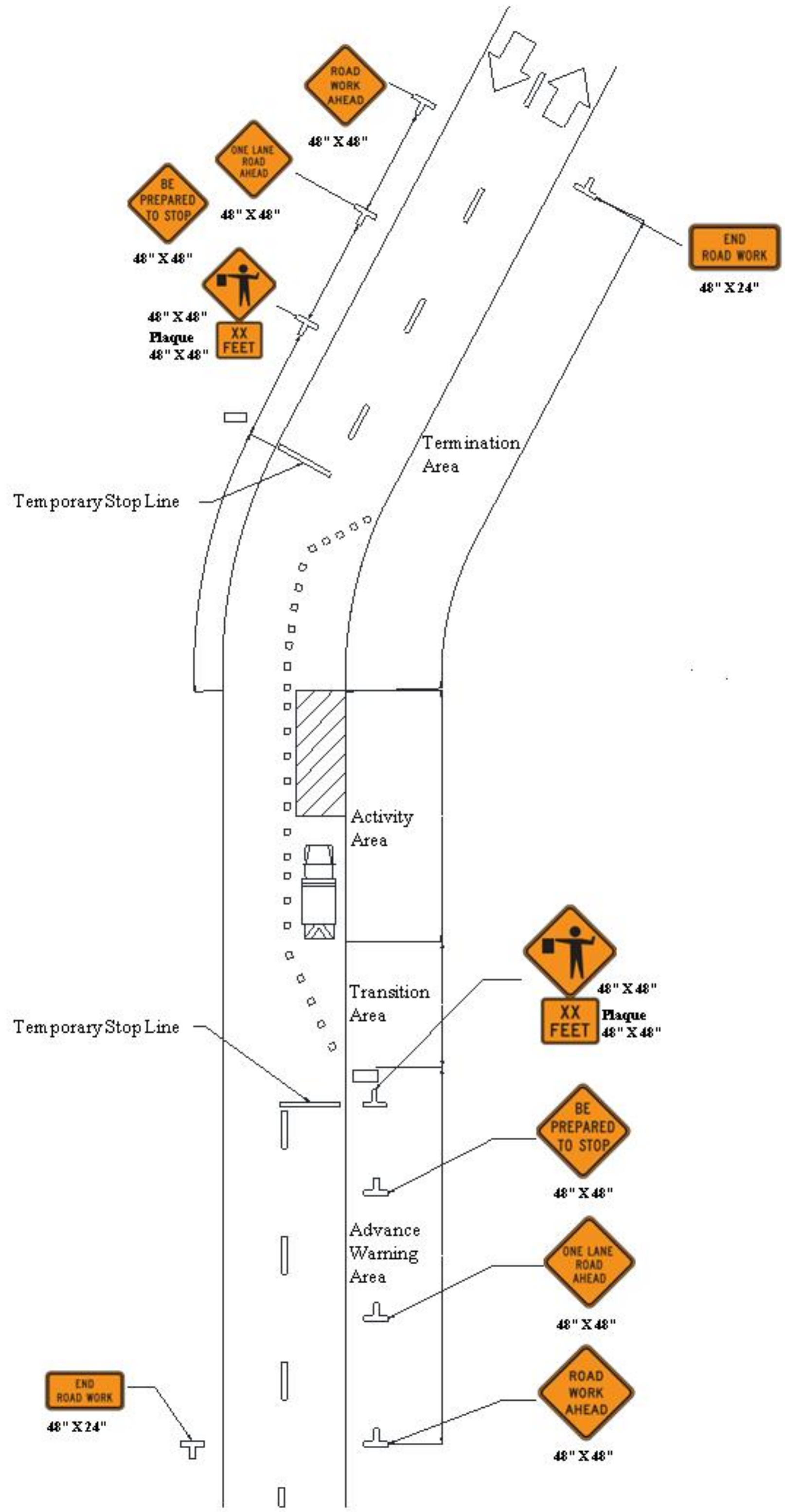

Figure 22 – Traffic Control Plan 2 (Station 39+00 to station 43+00, station 43+00 to station 47+00, station 79+00 to station 86+00)

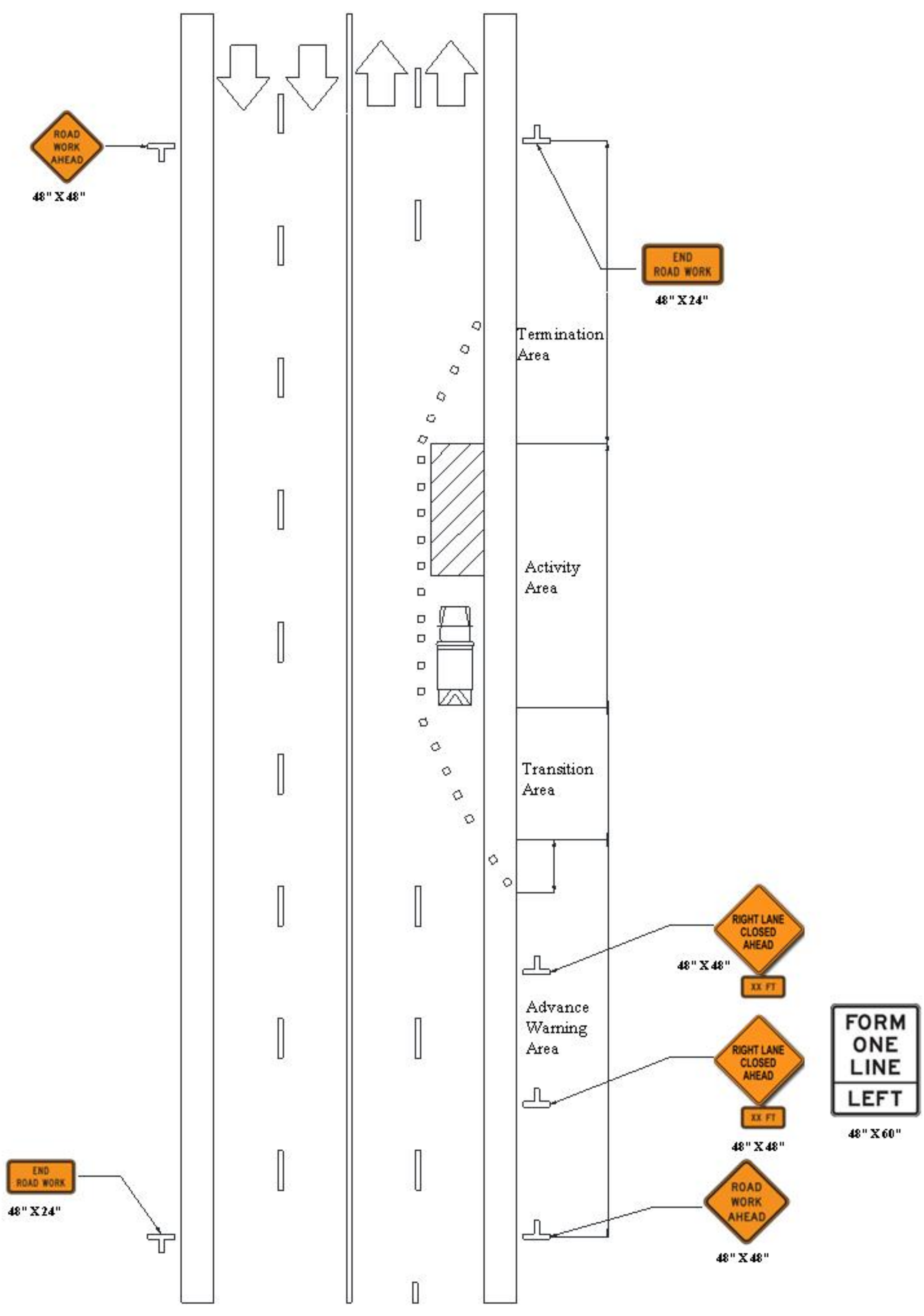

Figure 23 – Traffic Control Plan 3 (Station 5+00 to station 9+00, station 30+00 to station 35+00)

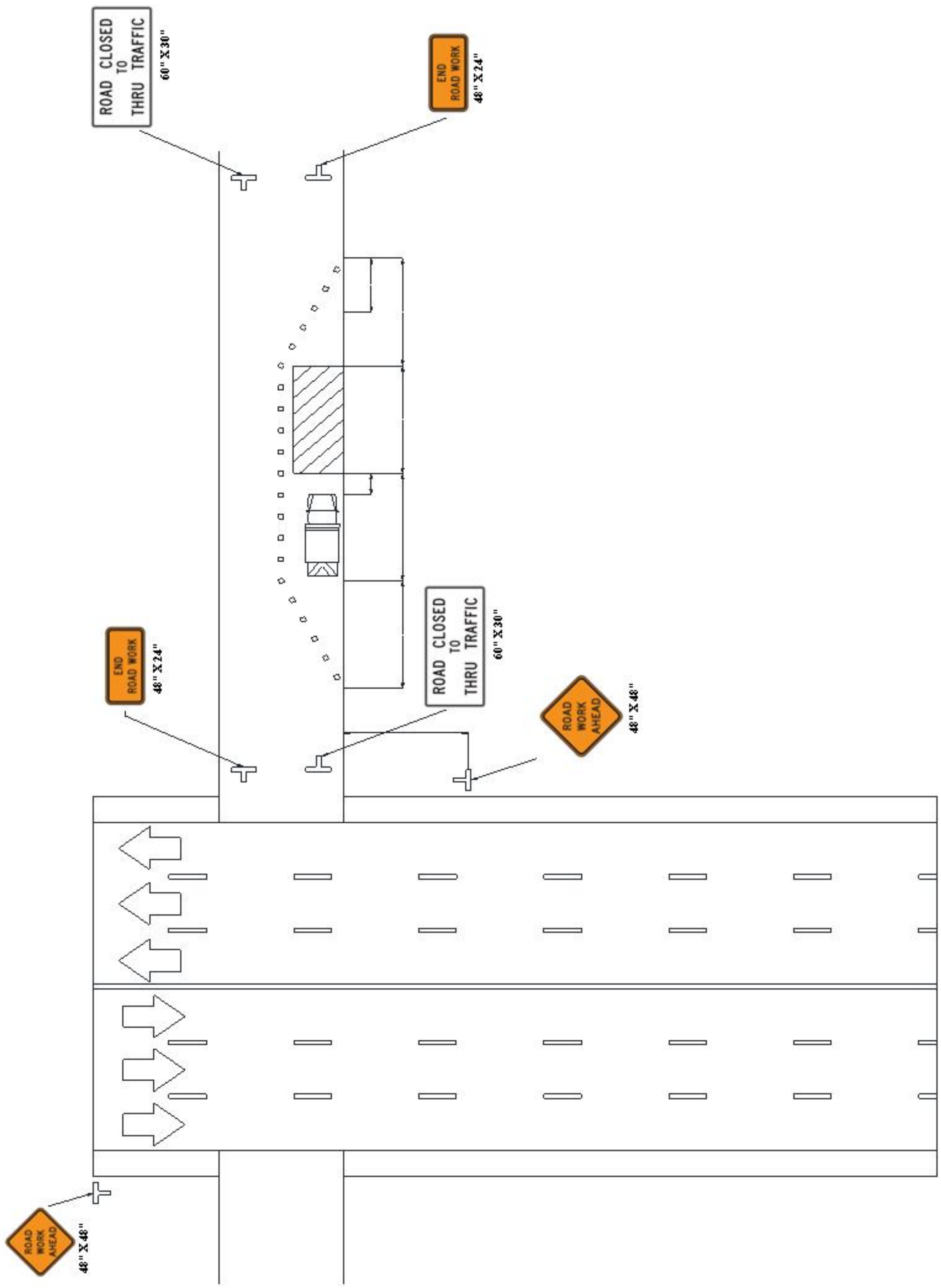

Figure 24 – Traffic Control Plan 4 (Station 5+00 to station 7+00, station 30+00 to station 34+00, station 87+00 to station 91+00)

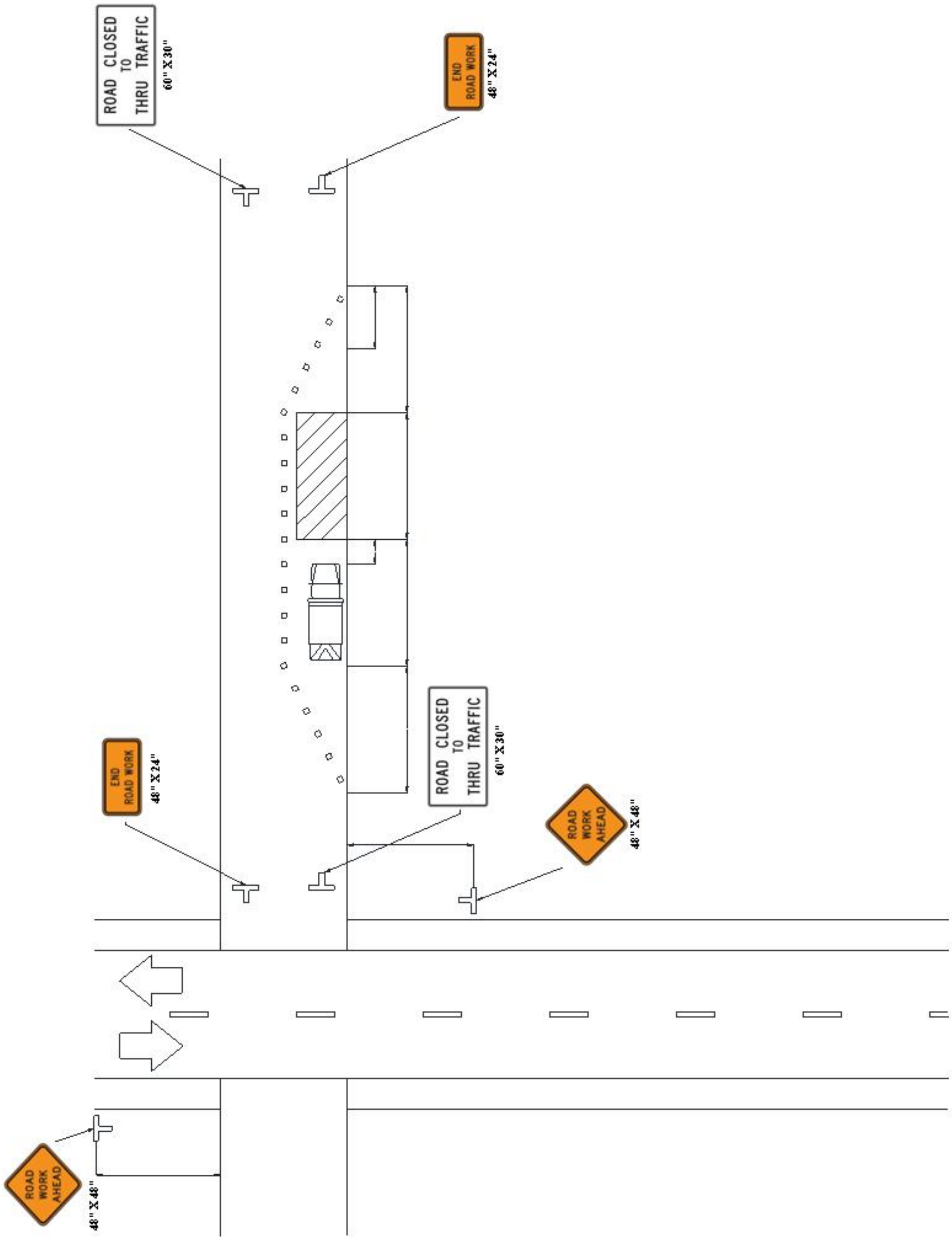

Figure 25 – Traffic Control Plan 5 (Station 82+00 to station 86+00)