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Reconstruction of I-94 and I-69 Interchange

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THE CARL AND WINIFRED LEE HONORS COLLEGE

CERTIFICATE OF ORAL DEFENSE OF HONORS THESIS

Andrew Dobbs, having been admitted to the Carl and Winifred Lee Honors College in the fall of 2008, successfully completed the Lee Honors College Thesis on April 17, 2012.

The title of the thesis is:

Reconstruction of I-94 and I-69 Interchange

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Reconstruction of I-94 and I-69 Interchange

Port Huron, Michigan

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Background and Description

In recent years, Michigan has emphasized the modernization of its interstate highway system in order to bring it up to current federal and state standards. I-94 to the south and I-69 to the west have been reconstructed to meet current standards. This project focuses on the reconstruction of the interchange of I-94 and I-69. This interchange consists of six bridges. In the middle of the interchange is Michigan Road, a local road that passes over the interchange and constricts the elevation of the freeway. Figure 1 shows the aerial view of the current interchange.

Many problems exist within the interchange because it does not meet current Michigan Department of Transportation (MDOT) standards. There have been flooding issues in the past because the current interchange was not designed for the 100 year storm. Because of the vast wetlands in and around the interchange, the infiltration of storm water is insufficient. Also, the current ramp configuration does not meet the desired design speed of 60 mph; moreover, in some locations the existing alignment only reaches a 40 mph design speed (according to current standards).

Another objective of the project is to redesign ramps so that traffic will enter the roadway from a more traditional location, the right hand side of the interstate. Entrances and exits from the right hand side are consistent with drivers' expectations. This is a key component to meeting current standards. Currently, the ramp from I-94 east to I-69 west enters the mainline on the left. The proposed design will address this deficiency by adjusting this ramp to travel over westbound I-69 and enter on the right.

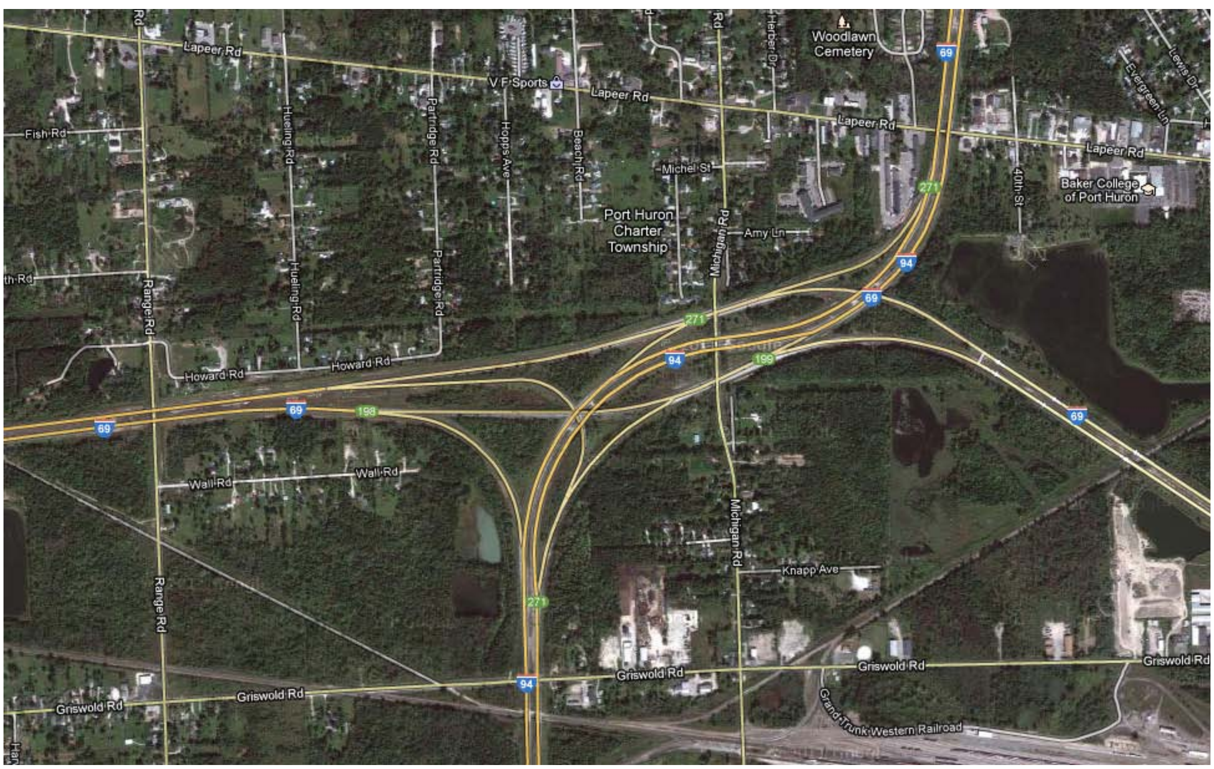

Figure 1 (Google Maps, 2012)

Scope of Work

Most of the problems with the interchange are on the west side of Michigan Road. Our team met with the client, Parsons Brinckerhoff, and decided that we should restrict our design work to the west half only. In addition, the time frame in which we had to complete our design was minimal. We felt that our client deserved our best work, and this could only be done if our design area was reasonable. Furthermore, Michigan Road serves as a tie in point with which to join the proposed roadways to the east side of the interchange.

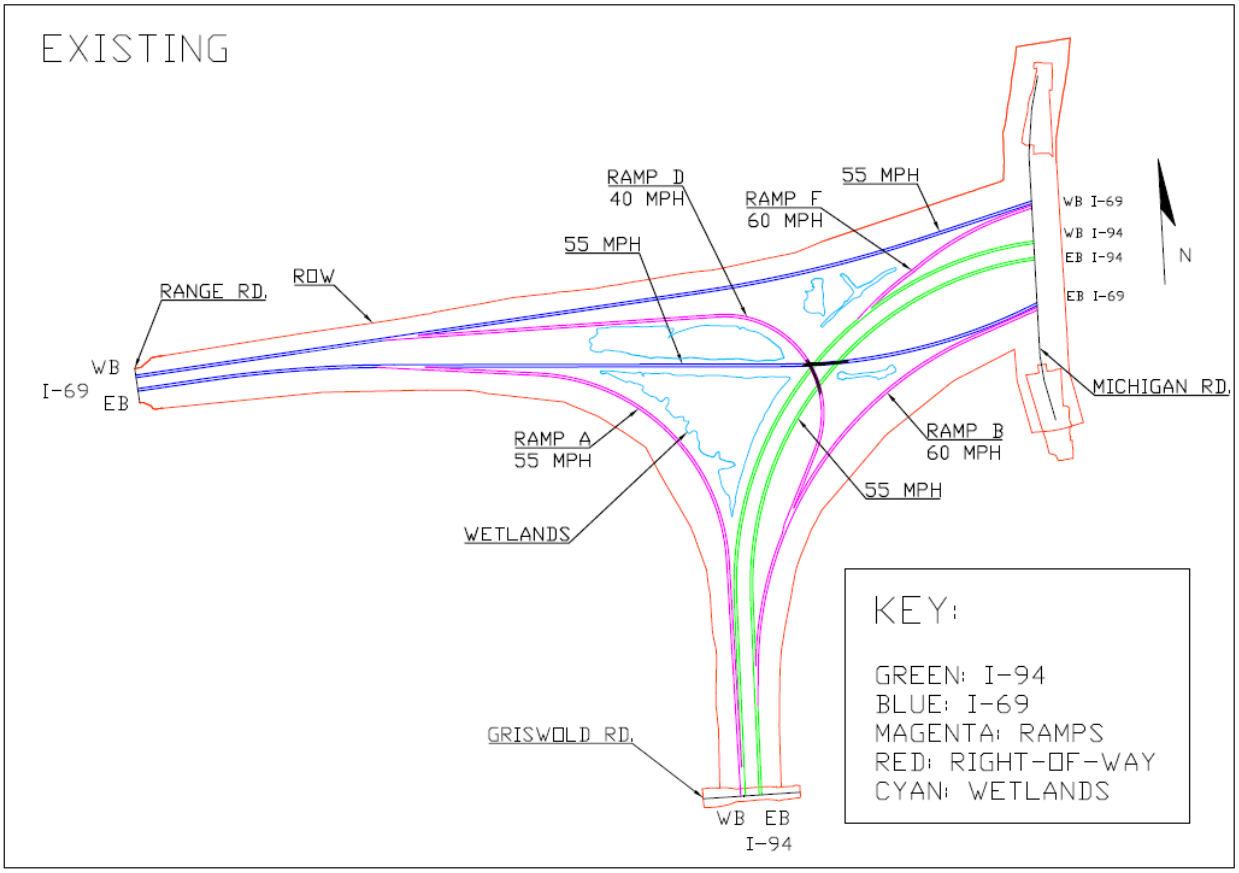

Figure 2

We first created three alignment alternatives based solely on horizontal curve calculations. We evaluated the advantages and disadvantages of each alternative according to our constraints and design criteria. Our recommendation was taken to our advisor and client who both agreed. In order to make sure our horizontal alignment was satisfactory, we determined superelevation transitions using MDOT standards.

With the horizontal alignment complete, our next step was to design the vertical alignment of the mainlines and ramps. We used Microsoft Excel first in designing our vertical curves to make sure we understood the criteria and formulas. After completion of the basic vertical alignment, we finalized the vertical curves by using professional software: Microstation and GeoPak.

What remained were many details that had to be clarified in order to provide a cost estimate. We assumed a pavement thickness, calculated earthwork, and determined the area of wetlands impacted. With these figures, we concluded with a cost estimate of the construction of our design.

Constraints

The interchange lies on several acres of dense wooded wetlands, and this has been known to cause flooding on the highway. Due to this serious issue, the proposed interchange and drainage design must account for the 100 year storm. This requires raising the elevation of I-94 and in turn raising the over passing roads to meet the minimum 16'-3" underclearance requirement (MDOT, 2012). In addition, the Michigan Department of Environmental Quality (MDEQ) requires a restoration or creation of two acres of wetlands for each acre disturbed (MDEQ, 2012).

The interchange is located in a suburban area, so the surrounding neighborhoods and local roads restrict the design of the reconstructed interchange. This results in a very narrow right-of-way. In addition, the proposed design must tie into three different points both horizontally and vertically; these points occur at Range Road, Griswold Road, and Michigan Road. For vertical alignment, the proposed design must match both the existing elevations and grades.

Horizontal Alignment

The first step in our design was to consider the horizontal alignment. When a vehicle moves in a circular path, it undergoes centripetal acceleration. Vehicles withstand this acceleration through superelevation (e) or "banking" of the roadway. Also, the side friction (f) between tires and pavement surface affect a vehicle's ability to sustain this acceleration. Using these two variables, we can determine minimum acceptable radii for different design speeds using basic mechanics.

$$R_{min} = \frac{V^2}{15(0.01e_{max} + f_{max})}$$

(AASHTO, 2004)

The maximum allowable superelevation is set by MDOT as 7% (MDOT, 2012). The side friction factor is a function of the design speed of the roadway.

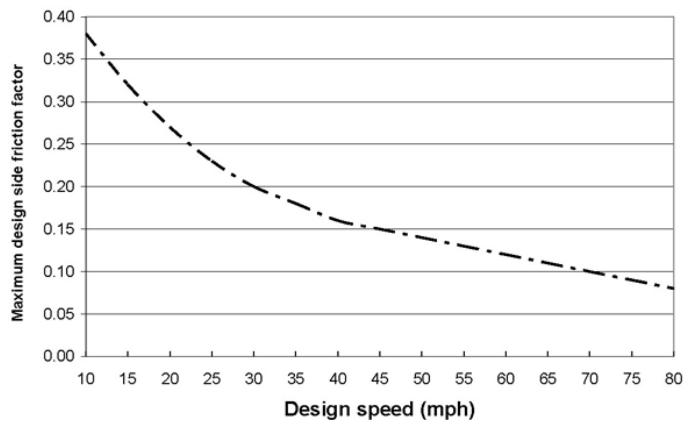

Figure 3 (AASHTO, 2004)

Figure 3 clearly demonstrates that the friction factor decreases as the design speed increases. Side friction factors were determined for design speeds from 30 to 75 mph using Figure 3 and placed in the minimum radius equation.

Friction Factor	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.18	0.20
Design Speed (mph)	75	70	65	60	55	50	45	40	35	30
Superelevation (%)	7	7	7	7	7	7	7	7	7	7
Radius (ft)	2344	1922	1565	1263	1008	794	614	464	327	222

Table 1

To confirm the accuracy of our calculations, we compared our minimum radii with MDOT standards (Table 2). They were found to be exactly equal. Knowing the minimum radius corresponding to each design speed enabled us to begin designing our alternatives within the boundaries of the right-of-way.

RADIUS (FEET)	30 MPH		35 MPH		40 MPH		45 MPH		50 MPH		55 MPH		60 MPH		65 MPH		FREEWAYS 70 MPH		FREEWAYS 75 MPH		URBAN FREEWAYS AND URBAN RAMPS 60 MPH	
	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%	e %	Δ%
23000	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----
20000	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----
17000	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----
14000	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	2.0	0.31	2.0	0.30	NC	----
12000	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	2.0	0.32	2.0	0.31	2.0	0.30	NC	----
10000	NC	----	NC	----	NC	----	NC	----	NC	----	NC	----	2.0	0.36	2.0	0.32	2.1	0.31	2.3	0.31	2.0	0.34
8000	NC	----	NC	----	NC	----	NC	----	2.0	0.40	2.0	0.38	2.1	0.36	2.3	0.33	2.6	0.32	2.9	0.31	2.0	0.34
6000	NC	----	NC	----	NC	----	2.0	0.40	2.0	0.40	2.3	0.39	2.7	0.37	3.0	0.34	3.3	0.33	3.7	0.33	2.4	0.36
5000	NC	----	NC	----	2.0	0.40	2.0	0.40	2.3	0.41	2.7	0.39	3.1	0.38	3.5	0.35	3.9	0.34	4.4	0.34	2.8	0.37
4000	NC	----	2.0	0.45	2.0	0.40	2.4	0.41	2.8	0.42	3.3	0.40	3.8	0.39	4.2	0.37	4.7	0.36	5.3	0.35	3.3	0.39
3500	NC	----	2.0	0.45	2.2	0.41	2.6	0.42	3.1	0.42	3.6	0.41	4.2	0.40	4.7	0.38	5.2	0.37	5.9	0.36	3.5	0.40
3000	2.0	0.50	2.0	0.45	2.5	0.42	3.0	0.43	3.5	0.43	4.1	0.42	4.7	0.41	5.2	0.39	5.9	0.38	6.5	0.37	3.8	0.41
2500	2.0	0.50	2.4	0.46	2.9	0.43	3.5	0.44	4.1	0.44	4.7	0.43	5.3	0.42	5.9	0.41	6.5	0.39	7.0	0.38	4.2	0.42
2000	2.3	0.51	2.9	0.48	3.5	0.45	4.1	0.46	4.7	0.45	5.4	0.44	6.1	0.43	6.6	0.42	7.0	0.40	R MIN. = 2344'		4.6	0.44
1800	2.5	0.52	3.1	0.49	3.8	0.46	4.4	0.47	5.1	0.46	5.7	0.45	6.4	0.44	6.9	0.43	R MIN. = 1922'				4.8	0.44
1600	2.7	0.52	3.4	0.50	4.1	0.48	4.8	0.48	5.4	0.47	6.1	0.45	6.7	0.44	7.0	0.43					4.9	0.45
1400	3.0	0.53	3.7	0.51	4.5	0.49	5.1	0.49	5.8	0.48	6.5	0.46	6.9	0.45	R MIN. = 1565'						R MIN. = 1412'	
1200	3.4	0.54	4.1	0.52	4.9	0.50	5.6	0.50	6.3	0.49	6.8	0.47	R MIN. = 1263'									
1150	3.5	0.55	4.3	0.53	5.0	0.51	5.7	0.50	6.4	0.49	6.9	0.47										
1000	3.8	0.56	4.6	0.54	5.4	0.52	6.1	0.52	6.7	0.49	R MIN. = 1008'											
900	4.1	0.57	4.8	0.55	5.7	0.53	6.4	0.52	6.9	0.50												
820	4.3	0.57	5.1	0.55	5.9	0.54	6.6	0.53	7.0	0.50												
800	4.4	0.58	5.1	0.56	6.0	0.54	6.7	0.53	7.0	0.50												
720	4.6	0.58	5.4	0.57	6.3	0.55	6.9	0.54	R MIN. = 794'													
700	4.7	0.59	5.5	0.57	6.3	0.56	6.9	0.54														
600	5.0	0.60	5.9	0.58	6.7	0.57	R MIN. = 614'															
500	5.4	0.61	6.4	0.60	7.0	0.58																
450	5.7	0.62	6.6	0.61	R MIN. = 464'																	
400	6.0	0.63	6.8	0.61																		
350	6.3	0.64	7.0	0.62																		
300	6.7	0.65	R MIN. = 327'																			
265	6.9	0.66																				
225	7.0	0.66																				
	R MIN. = 222'																					

RATE OF SUPERELEVATION AND SUPERELEVATION TRANSITION SLOPE

NOTES:

LOOP RAMPS SHALL HAVE A 7% RATE OF SUPERELEVATION.

SPECIAL CONSIDERATION SHOULD BE GIVEN TO CURVES WHICH APPROACH A RAMP TERMINAL (STOPPING CONDITION).

IF DELTA VALUES FROM THE CHART CANNOT BE OBTAINED FOR THE DESIGN RADIUS, USE THE MAXIMUM DELTA VALUE FOR THE CORRESPONDING SPEED.

FOR RADII LESS THAN THOSE TABULATED, (BUT NOT LESS THAN R MIN.), USE e_{max}. MAXIMUM SUPERELEVATION FOR URBAN FREEWAYS AND URBAN RAMPS (WITH A 60 MPH DESIGN SPEED) IS 5%. OTHERWISE e_{max} = 7%.

Table 2 (MDOT, 2012)

Alignment Alternative 1

In creating alternative 1, our main objective was to make all the design speeds as high as possible. We were able to achieve 65 mph on all the ramps while maintaining 70 mph on the mainlines. This resulted in several drawbacks however.

The design speed of Ramp A was increased from 55 mph to 65 mph. This entailed a large increase in the radius, causing Ramp A to be extremely close to the right-of-way. Even though it doesn't actually cross the boundary, it must be noted that there is likely to be disruption of land outside the right-of-way due to the shoulder and ditch.

The design speed of Ramp D was significantly improved in this alignment; it was increased from 40 mph to 65 mph. Eastbound I-94 now had to be shifted slightly to the right (east) to provide enough space for Ramp D to have the required clearances over westbound I-94. This creates a dilemma downstream on I-94. The westbound and eastbound roadways continually grow farther apart, and where eastbound I-69 crosses over I-94, the span of the bridge is considerably long.

The design of Ramps B and F had fewer constraints. We had plenty of space to adjust their positioning and tried to place them in the most efficient way. We designed them such that their roadway lengths would be minimized.

Some other problems that exist in alignment 1 are the sharp skew angles of the bridges and the weaving of traffic. The sharp skew angles of the bridges will increase the cost of the bridges because the length of the span of the bridges will be greater. Since eastbound I-94 is only a two lane freeway and has both an exit on the left hand side (Ramp D) and an exit on the right hand side (Ramp B) within a quarter mile of each other, traffic will be weaving in and out of lanes trying to get to their exit.

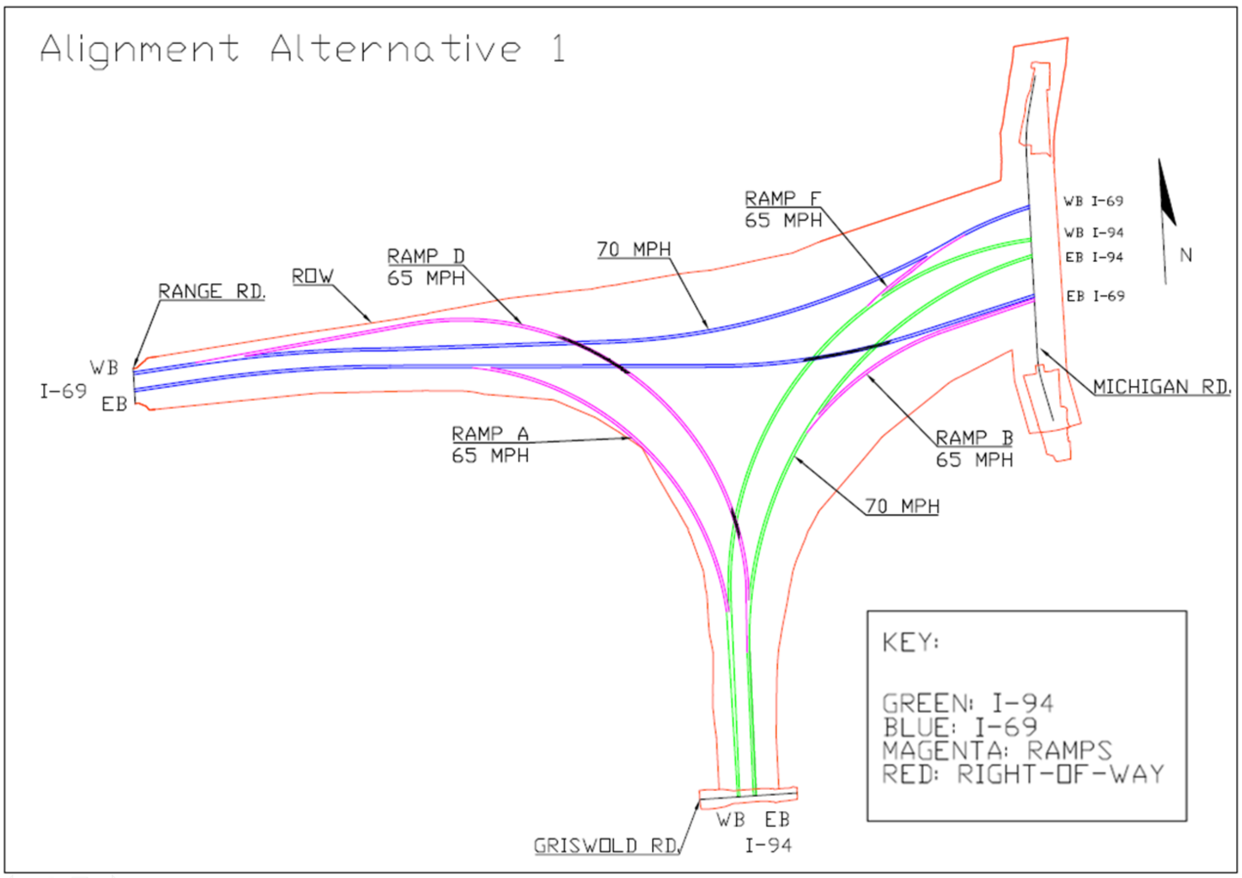

Figure 4

Alignment Alternative 2

Our goal when designing alternative 2 was to modify alternative 1 to increase feasibility and constructability. As mentioned above, alternative 1 solved the main problems but introduced more difficulties. We attempted to remove these difficulties in alternative 2.

The 65 mph design speed of Ramp D in alignment 1 was desirable but brought on more problems than it was worth. We were able to fix these problems while still maximizing the design speed. The left hand exit of Ramp D from eastbound I-94 was a safety issue that needed to be addressed. We resolved this issue by keeping the existing horizontal alignment of I-94 and having Ramp D exit on the right hand side. The right hand exit caused our design speed to be only 60 mph. The new curve introduced a problem with the entrance onto westbound I-69. This was solved by moving westbound I-69 south towards eastbound I-69. The proximity of eastbound I-69 to westbound I-69 reduced the bridge span of Ramp D, which will reduce the cost of the bridge.

The right-of-way problem in alignment 1 would have made the construction of Ramp A nearly impossible. To account for this, we determined a minimum distance between the ramp and the right-of-way that was needed in order for the entire roadway to stay within the right-of-way. This minimum distance was fixed, and we then found the highest design speed that would not result in a higher distance. The design speed was found to be 60 mph.

We also increased the design speed of Ramp F to 70 mph. This of course increased the radius of the curve and the length of the ramp. We felt that the increase in speed outweighed the cost of the extra length of the ramp.

In order to correct the weaving problem in alignment 1, we combined ramps B and D into a single exit off eastbound I-94. This increases the roadway length but drastically improves safety. The one problem that alignment 2 was not able to solve is the severe skew angles.

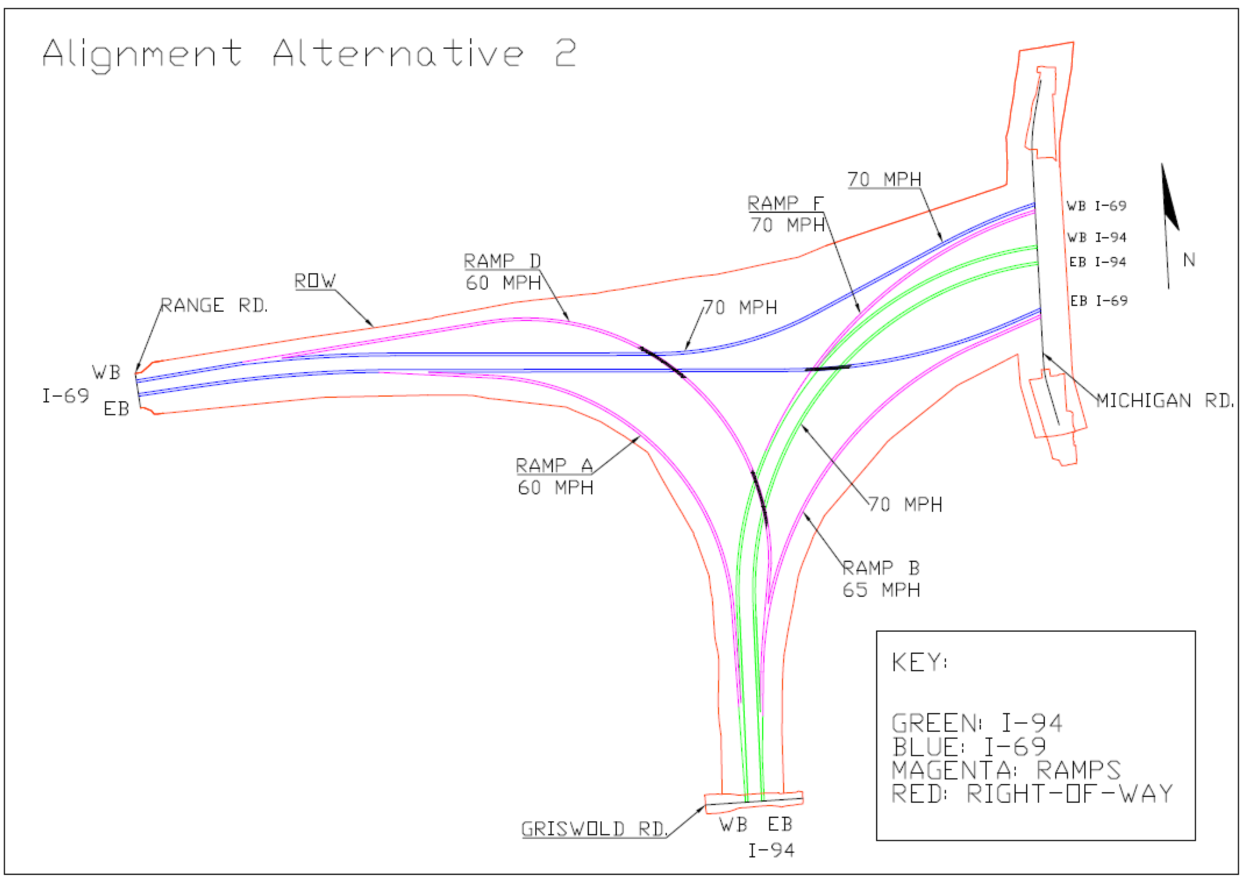

Figure 5

Alignment Alternative 3

The one problem that alignments 1 and 2 have in common is the severe skew angles of the bridges. Naturally, in our next alternative we made an effort to solve the skew problem. This would effectively decrease bridge span lengths and reduce cost. To achieve this we had to relocate many of the mainlines and ramps.

Ramp B and Ramp D both exit together as they did in alignment 2 but their divergence is very different. Ramp D does not separate from Ramp B until much further downstream in order to produce an almost perpendicular angle of Ramp D over eastbound I-69. Ramp D then bridges over both bounds of I-94 and westbound I-69 in one short bridge that is also nearly perpendicular. In order to make this work, the radius of Ramp D had to be small. The greatest design speed we could obtain was 40 mph, no improvement upon the existing design speed.

To keep the span of Ramp D over I-94 and westbound I-69 short, westbound I-69 had to be moved as close as possible to I-94, and the two bounds of I-94 had to be very closely spaced. This decreased the design speeds of the mainlines. All of I-69 is 65 mph and all of I-94 is 60 mph.

In conclusion, alternative 3 may be the least expensive option due to the bridges, but not the most favorable.

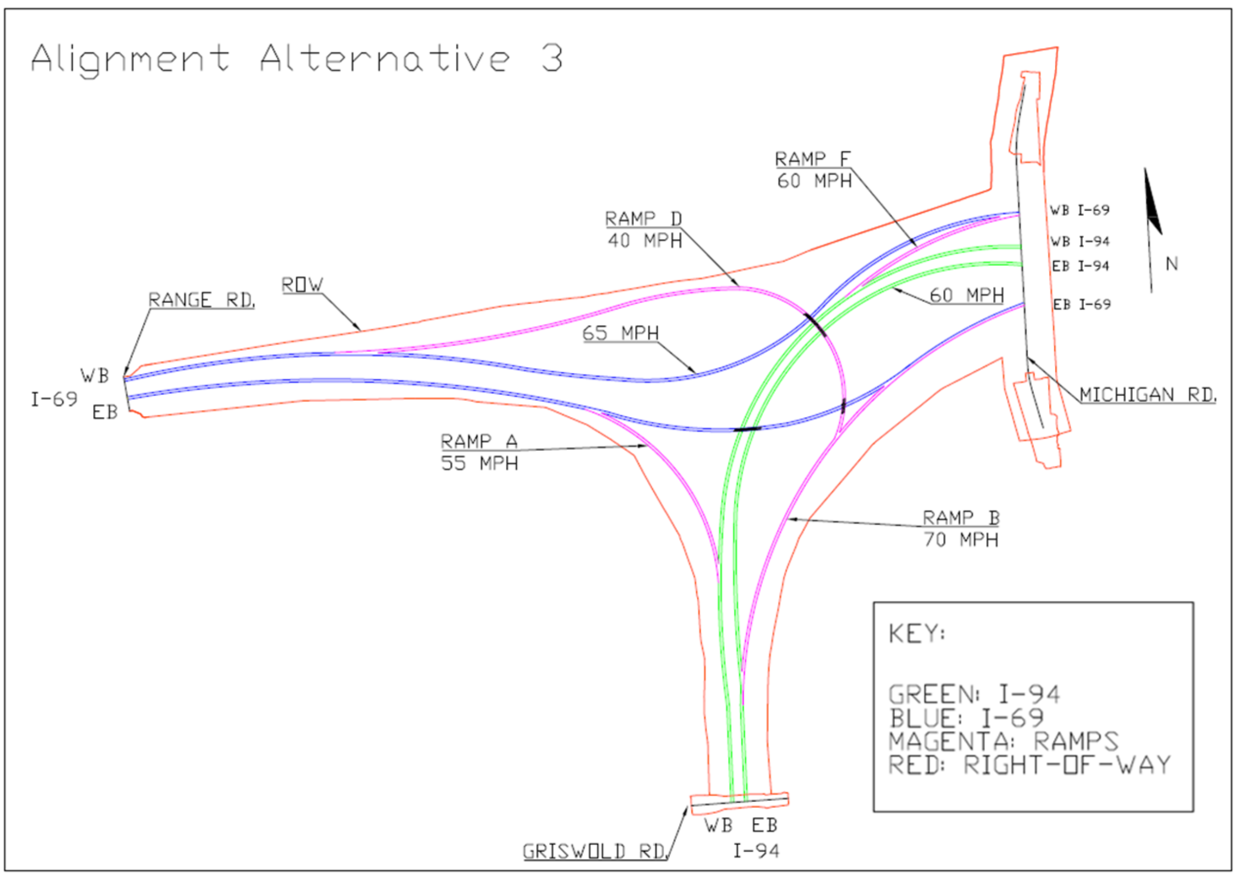

Figure 6

Analysis of Alternatives

Following the design of the three alternatives, a meeting was held with our advisor. Upon showing our first alignment, our advisor liked the fact that the design speeds were so high but did not like the safety hazard that presented itself with the left hand exit of ramp D from eastbound I-94. Alignment 2 was much more pleasing to him because of the right hand exit for ramp D from eastbound 1-94. The lower design speeds were not a major concern because our design still met our clients' requests. Our advisor immediately disliked alignment 3 because ramp D had such a low design speed. He explained that this did not improve the interchange at all. With the recommendations of our advisor, we then took the three proposals to our client.

The client was very pleased with the variety of the three alternatives we offered to them. We first showed them alignment 3 and explained that we were trying to think outside of the norm but relayed our advisor's opinion that this alignment would not be the best option. They liked the perpendicular angles of the bridges but realized this alignment didn't solve any of the constraints. Alignments 1 and 2 were shown to them at the same time because of their similarities. We highlighted the high design speeds of alignment 1 but also pointed out the difficulties that it created. We pointed out how those difficulties were solved in alignment 2 but the design speeds had to be reduced slightly. The higher design speeds of alignment 1 were lucrative to our clients, but with our persuasion and advice, they decided that alignment 2 was the best option. Adjourning the meeting, we only focused on alignment 2 for the rest of our design.

Other Horizontal Considerations

In order to complete our horizontal design, we had to establish lane and shoulder widths and design all entrance and exit ramps. These criteria are all set by MDOT standards. Figure 7 states that all freeway lanes should be at least 12 feet. MDOT provides guidelines on ramp lane widths; 3.07.02E of the Michigan Road Design Manual states that "single lane ramp widths are normally 16 feet 0 inches." (MDOT, 2012) Figure 8 dictates shoulder requirements for mainlines and ramps. Ramp shoulders are straightforward; 6 feet on the left and 8 feet on the right. Determination of mainline shoulders involves the amount of traffic on the freeway. At the request of the client, we used 8 foot shoulders for the median and 12 foot shoulders for the outside.

In summary:

	Lane Width (ft)	Left Shoulder Width (ft)	Right Shoulder Width (ft)
Mainlines	12	8	12
Ramps	16	6	8

Table 3

Element		Urban	Rural
Design Speed (see Section 3.06)	**Freeway**	60 mph (For posted urban freeway speeds greater than 55 mph, the design speed is 5 mph greater than posted speed.) but not less than 50 mph.	75 mph but not less than 70 mph.
	Non Freeway (Arterial)	Posted speed plus 5 mph but not less than 30 mph.	Posted speed plus 5 mph but not less than 40 mph.
	Collector Roads	5 mph over posted speed.	5 mph over posted speed.
Lane Width	**Freeway**	12 ft.	12 ft.
	Non Freeway (Arterial)	12 ft. lanes are most desirable and should be used where practical. 11 ft. lanes are often used for low speed (45 mph design) 10 ft. lanes may be used in restricted areas where there is little or no truck traffic. 12 ft. lanes are required on the National Network (also known as the National Truck Network).	(see Rural Non Freeway (Arterial) lane width table below)
	Collector Roads	Added turn lanes at intersections 10-12 ft. Where right-of-way is restricted. 11 ft. Industrial Areas 12 ft. Where shoulders are used, see guidelines for Rural Collectors ☞	(see Rural Collector Roads lane width table below)

Rural, Non Freeway (Arterial):

Design Speed, (mph)	Minimum Lane Width, ft. ADT, vehicles/day: Under 400	400 to 1500	1500 to 2000	Over 2000
40	11*	11*	11*	12
45	11*	11*	11*	12
50	11*	11*	12	12
55	11*	11*	12	12
60	12	12	12	12
65	12	12	12	12
70	12	12	12	12
75	12	12	12	12

*12 ft. desirable

Rural, Collector Roads:

Design Speed, (mph)	Minimum Lane Width, ft. ADT, vehicles/day: Under 400	400 to 1500	1500 to 2000	Over 2000
20	10*	10*	11*	12
25	10*	10*	11*	12
30	10*	10*	11*	12
35	10*	11*	11*	12
40	10*	11*	11*	12
45	10*	11*	11*	12
50	10*	11*	11*	12
55	11*	11*	12	12
60	11*	11*	12	12

*12 ft. desirable

Figure 7 (MDOT, 2012)

Element		Urban & Rural			
		Mainline		**Ramp** (one lane and two lanes)	
		Median	Outside	Left	Right
Shoulder Width	**Freeway**	8 ft. (4ft. paved) (8 ft. paved at bridge and barrier sections) For 6 or more lane sections (3 or more lanes directional) use 11ft. min (10 ft. paved) and consider 12 ft. paved where truck traffic exceeds 250 DDHV.	10 ft. min (paved) For non-interstate freeways, use 12 ft. paved where truck traffic exceeds 250 DDHV. For interstate freeways consider using 12 ft. paved where truck traffic exceeds 250 DDHV.	6 ft. (4 ft. paved)	8 ft. (7ft. paved)
		For new construction and reconstruction, the mainline outside paved shoulder is extended with 1 ft. of aggregate to the shoulder hinge for stabilization. When widening existing paved shoulders to meet current standard widths, it is desirable to provide the additional foot of aggregate when feasible.			

Non Freeway (Arterial):

Urban	Rural: Min paved shoulder, ft. for specified ADT, veh/day, Undivided Roadways*: Under 400	400 to 1500	1500 to 2000	Over 2000
In those instances where sufficient right-of-way exists to consider shoulders, refer to the guidance for non freeway rural shoulders. ☞	4	6	6	8
	*Use 8ft. right and 4 ft. left for divided arterials. Use full width (8 ft.) on both sides of divided arterials with 3 lanes in each direction. For new construction and reconstruction and when feasible on shoulder widening, the paved shoulder is extended with 1 ft. of aggregate to the shoulder hinge for stabilization.			

A minimum 4 ft. (3 ft. paved) shoulder is acceptable adjacent to right turn lanes.
Minimum shoulder widths apply for posted speeds greater than 45 mph. At lower speeds restrictions such as right of way and roadside context sensitivity issues may preclude the use of minimum shoulder within city, village and township limits.

Collector Roads:

	Min shoulder, ft. for specified ADT, veh/day: Under 400	400 to 1500	1500 to 2000	Over 2000
Where shoulders are used, refer to requirements for rural arterials. ☞	2	5	6	8
	The above ranges apply on uncurbed roads and when shoulders are feasible on curbed roads. A minimum paved width of 1 ft. is desirable.			

Figure 8 (MDOT, 2012)

Figures 8-11 present standards regarding minimum lengths for parallel entrance and exit ramps. Taper lengths should be at least 300 feet for entrance and exit ramps. For entrance ramps, the parallel section is given on the diagram (Figure 9) as L_{gap}. For a mainline design speed of 70 mph, L_{gap} is 360 feet (Figure

10). For exit ramps, a calculation is needed. L_d is 360 feet assuming a grade between -3% and 3% (Figure 12). Therefore, the parallel section is:

$$360 - 150 = 210\ feet$$

In summary:

	Taper Length (ft)	**Parallel Length (ft)**
Entrance Ramps	300	360
Exit Ramps	300	210

Table 4

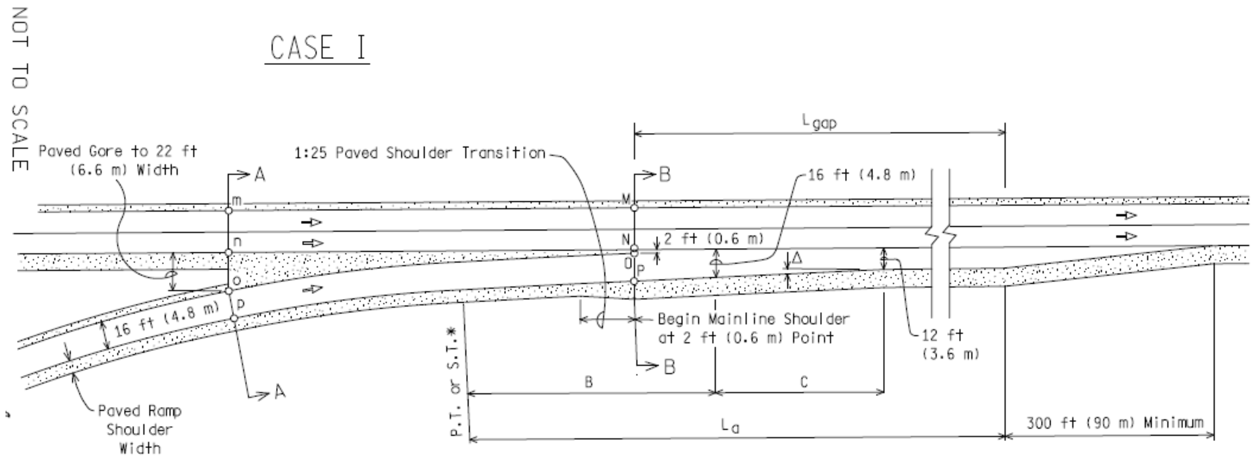

Figure 9 (MDOT, 2012)

MINIMUM ENGLISH LENGTHS FOR PARALLEL ENTRANCE RAMPS

RAMP DESIGN SPEED (MPH)	PERCENT GRADE OF THROUGH ROADWAY	TAPER=65:1 Δ=0°52′53″ ROADWAY DESIGN SPEED = 75 MPH B = 390 FT C = 260 FT Lgap = 390 FT	TAPER=60:1 Δ=0°57′17″ ROADWAY DESIGN SPEED = 70 MPH B = 360 FT C = 240 FT Lgap = 360 FT	TAPER=55:1 Δ=1°02′30″ ROADWAY DESIGN SPEED = 60 MPH B = 330 FT C = 220 FT Lgap = 330 FT	TAPER=50:1 Δ=1°08′45″ ROADWAY DESIGN SPEED = 55 to 50 MPH B = 300 FT C = 200 FT Lgap = 300 FT	TAPER=45:1 Δ=1°16′23″ ROADWAY DESIGN SPEED = 45 or less MPH B = 270 FT C = 180 FT Lgap = 270 FT
		La (FT)	La (FT)	La (FT)	La (FT)	La (FT)
20	-3 TO LESS THAN -5	978	912	660	506	450
	BETWEEN -3 AND +3	1630	1520	1100	810	450
	+3 TO LESS THAN +5	2528	2280	1540	1094	608
25	-3 TO LESS THAN -5	948	852	612	500	450
	BETWEEN -3 AND +3	1580	1420	1020	780	450
	+3 TO LESS THAN +5	2528	2201	1479	1092	608
30	-3 TO LESS THAN -5	906	810	550	500	450
	BETWEEN -3 AND +3	1510	1350	910	670	450
	+3 TO LESS THAN +5	2492	2160	1365	972	608
35	-3 TO LESS THAN -5	852	738	550	500	450
	BETWEEN -3 AND +3	1420	1230	800	550	450
	+3 TO LESS THAN +5	2450	2030	1200	798	608
40	-3 TO LESS THAN -5	696	600	550	500	450
	BETWEEN -3 AND +3	1160	1000	550	500	450
	+3 TO LESS THAN +5	2088	1700	825	725	608
45	-3 TO LESS THAN -5	650	600	550	500	450
	BETWEEN -3 AND +3	1040	820	550	500	450
	+3 TO LESS THAN +5	1924	1435	825	725	608
50	-3 TO LESS THAN -5	650	600	550	500	
	BETWEEN -3 AND +3	780	600	550	500	
	+3 TO LESS THAN +5	1482	1080	825	725	
55	-3 TO LESS THAN -5	650	600	550	500	
	BETWEEN -3 AND +3	650	600	550	500	
	+3 TO LESS THAN +5	1268	1080	825	725	
60	-3 TO LESS THAN -5	650	600	550		
	BETWEEN -3 AND +3	650	600	550		
	+3 TO LESS THAN +5	1268	1080	825		
65	-3 TO LESS THAN -5	650	600			
	BETWEEN -3 AND +3	650	600			
	+3 TO LESS THAN +5	1268	1080			
70	-3 TO LESS THAN -5	650	600			
	BETWEEN -3 AND +3	650	600			
	+3 TO LESS THAN +5	1268	1080			
75	-3 TO LESS THAN -5	650				
	BETWEEN -3 AND +3	650				
	+3 TO LESS THAN +5	1268				

Figure 10 (MDOT, 2012)

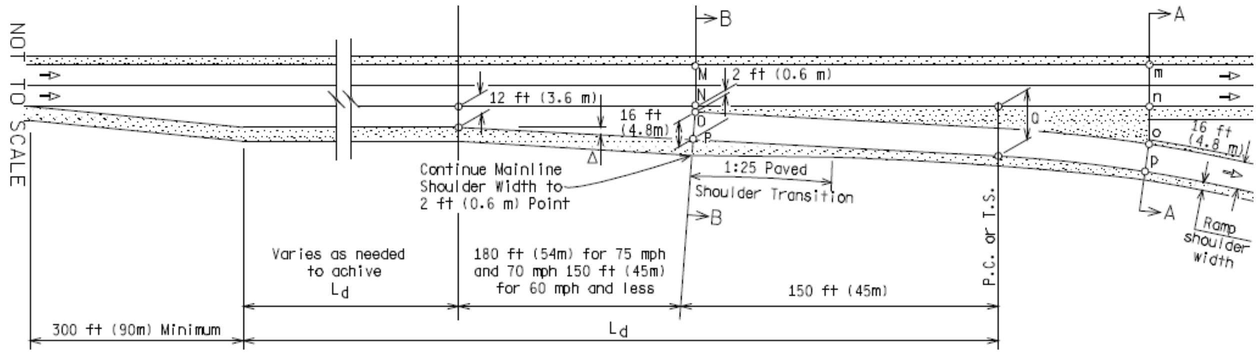

Figure 11 (MDOT, 2012)

MINIMUM ENGLISH LENGTHS FOR PARALLEL EXIT RAMPS

RAMP DESIGN SPEED (MPH)	PERCENT GRADE OF THROUGH ROADWAY	TAPER=30:1 Δ=1°54′33″ ROADWAY DESIGN SPEED = 75 MPH Q = 23′ L_d min = 350′	TAPER=30:1 Δ=1°54′33″ ROADWAY DESIGN SPEED = 70 MPH Q = 23′ L_d min = 350′	TAPER=25:1 Δ=2°17′26″ ROADWAY DESIGN SPEED = 60 MPH Q = 24′ L_d min = 300′	TAPER=25:1 Δ=2°17′26″ ROADWAY DESIGN SPEED = 55 MPH TO 50 MPH Q = 24′ L_d min = 300′	TAPER=25:1 Δ=2°17′26″ ROADWAY DESIGN SPEED = 45 MPH OR LESS Q = 24′ L_d min = 300′
		L_d (FT)	L_d (FT)	L_d (FT)	L_d (FT)	L_d (FT)
20	-3 TO LESS THAN -5	744	684	576	528	390
	BETWEEN -3 AND +3	620	570	480	440	325
	+3 TO LESS THAN +5	558	513	432	396	300
25	-3 TO LESS THAN -5	720	660	552	492	354
	BETWEEN -3 AND +3	600	550	460	410	300
	+3 TO LESS THAN +5	540	495	414	369	300
30	-3 TO LESS THAN -5	690	624	516	456	300
	BETWEEN -3 AND +3	575	520	430	380	300
	+3 TO LESS THAN +5	518	468	387	342	300
35	-3 TO LESS THAN -5	642	588	486	420	300
	BETWEEN -3 AND +3	535	490	405	350	300
	+3 TO LESS THAN +5	482	441	365	315	300
40	-3 TO LESS THAN -5	588	528	420	342	300
	BETWEEN -3 AND +3	490	440	350	300	300
	+3 TO LESS THAN +5	441	396	315	300	300
45	-3 TO LESS THAN -5	528	468	360	300	300
	BETWEEN -3 AND +3	440	390	300	300	300
	+3 TO LESS THAN +5	396	351	300	300	300
50	-3 TO LESS THAN -5	468	432	300	300	
	BETWEEN -3 AND +3	390	360	300	300	
	+3 TO LESS THAN +5	351	350	300	300	
55	-3 TO LESS THAN -5	468	432	300	300	
	BETWEEN -3 AND +3	390	360	300	300	
	+3 TO LESS THAN +5	351	350	300	300	
60	-3 TO LESS THAN -5	468	432	300		
	BETWEEN -3 AND +3	390	360	300		
	+3 TO LESS THAN +5	351	350	300		
65	-3 TO LESS THAN -5	468	432			
	BETWEEN -3 AND +3	390	360			
	+3 TO LESS THAN +5	351	350			
70	-3 TO LESS THAN -5	468	432			
	BETWEEN -3 AND +3	390	360			
	+3 TO LESS THAN +5	351	350			
75	-3 TO LESS THAN -5	468				
	BETWEEN -3 AND +3	390				
	+3 TO LESS THAN +5	351				

Figure 12 (MDOT, 2012)

Figure 13 verifies that we met the above requirements and represents a final horizontal design.

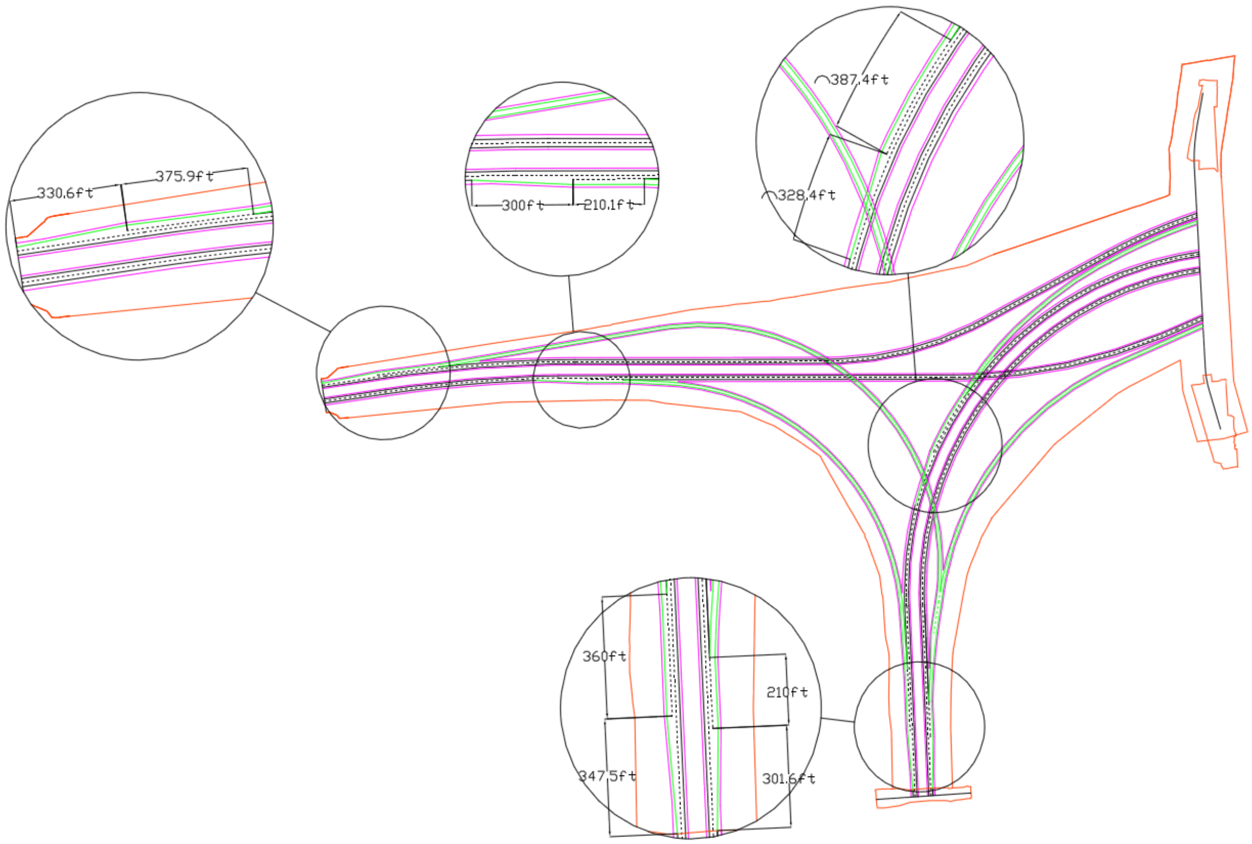

Figure 13

Superelevation

As previously mentioned, vehicles withstand centripetal acceleration during a horizontal curve through superelevation (e) or tilting of the roadway. This "banking" of the lanes is what permits vehicles to operate efficiently at realistic design speeds. Various factors have to be taken into consideration when determining a suitable superelevation rate. According to MDOT standards, the rate of superelevation (e %), as well as the transition slope of pavement edges (Δ %), depends on design speeds and radii. Table 2 clearly demonstrates this relationship. These two values were determined for each curve on our alignment and can be seen in Table 5.

The normal crown rate (NC) is defined as 2% (MDOT, 2012). W is the distance from the axis of rotation to the farthest outside edge. This was simplified to be 12 feet for mainline lanes and 16 feet for all ramps. Using these values, we can determine C and L using the equations from MDOT standards below. C is the distance required to transition from normal crown to level, also known as tangent runout. L is the entire distance required to transition from level to the required superelevation, also known as superelevation runoff. MDOT allows a distance of 1/3 L after the point of curvature (PC), to fully transition to the required superelevation (MDOT, 2012). This is graphically represented in the upper left diagram on Figure 14. If the crown is in the same direction as the superelevation (upper right diagram on Figure 14), the actual transition distance is much less. This applies to ramp A and ramp B. Ramp F needs a full superelevation of 7%, as well as westbound I-94, which it ties into. Therefore, no transition is needed on ramp F, which is why it is excluded from Table 5. In addition, the lower diagram on Figure 14 is for the mainlines, where there are two lanes. In this case, the outside lane controls and has the same C and L equations as the ramps.

$$D = W * NC \qquad S = W * e \qquad C = \frac{D}{\Delta\%} * 100 \qquad L = \frac{S}{\Delta\%} * 100$$

(MDOT, 2012)

In Table 5 all the D, S, C, and L values were calculated for each curve. In addition, the transition distances on each side of the PC were calculated. For ramp A and ramp B, the transition distance was calculated as well.

See Appendix A for drawings of the superelevation transitions. Curve 1 on westbound I-69 does not include a drawing for the PC because this point occurs on the east side of Michigan Road, which is outside the scope of our project.

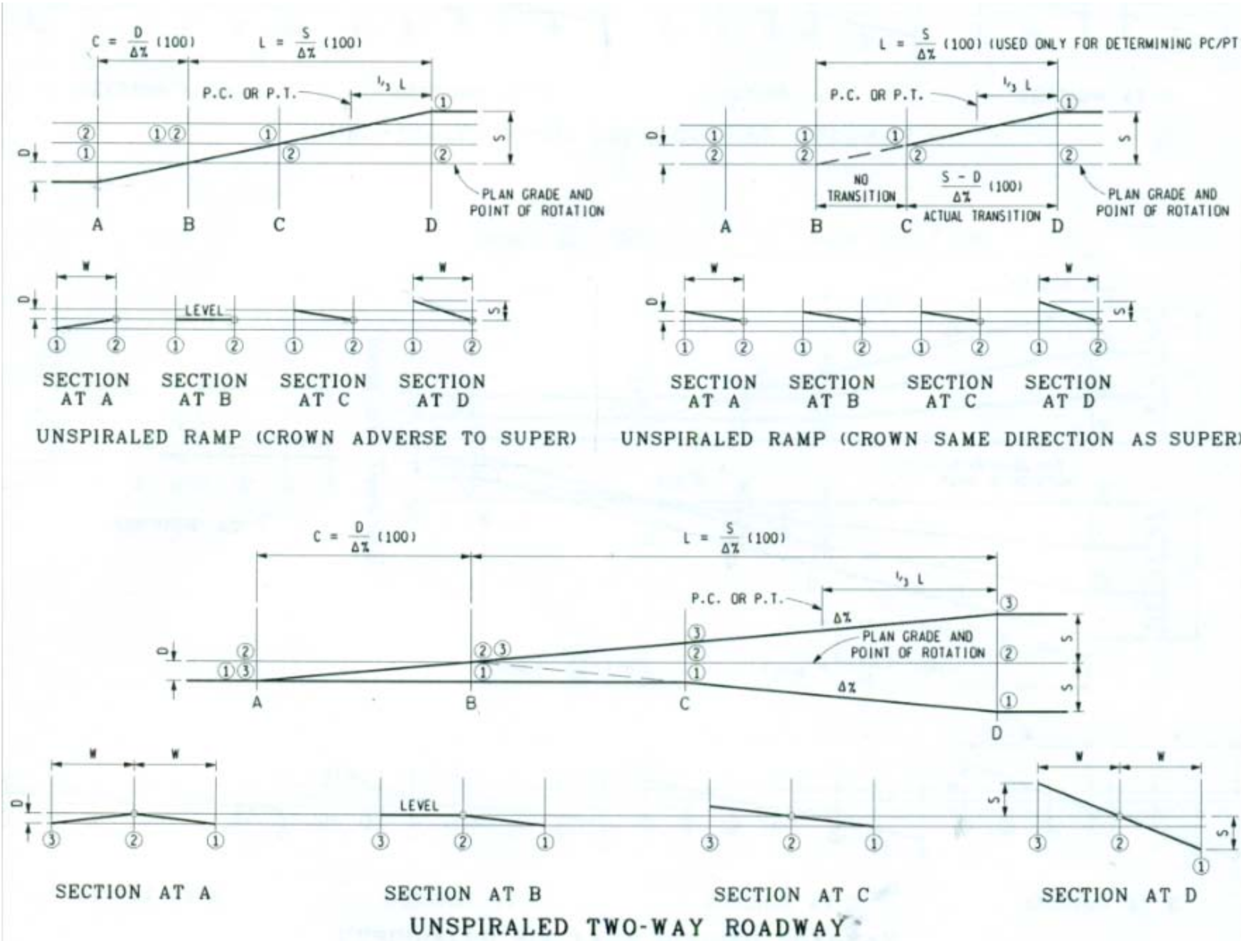

Figure 14 (MDOT, 2012)

	Speed (mph)	Radius (ft)	e %	Δ %	D	S	C	L	(S-D) / Δ % *100	1/3*L	2/3*L + C
I-69 WB (1)	70	3300	5.5	0.37	0.24	0.66	64.9	178.4	-	59.5	183.8
I-69 WB (2)	70	1950	7	0.4	0.24	0.84	60.0	210.0	-	70.0	200.0
I-69 WB (3)	70	7639	2.7	0.32	0.24	0.324	75.0	101.3	-	33.8	142.5
I-69 EB (1)	70	7639	2.7	0.32	0.24	0.324	75.0	101.3	-	33.8	142.5
I-69 EB (2)	70	3274	5.5	0.37	0.24	0.66	64.9	178.4	-	59.5	183.8
I-94 WB	70	2004	7	0.4	0.24	0.84	60.0	210.0	-	70.0	200.0
I-94 EB	70	1922	7	0.4	0.24	0.84	60.0	210.0	-	70.0	200.0
Ramp A	60	1450	6.9	0.45	0.32	1.104	-	245.3	174.2	81.8	-
Ramp B	65	1742	7	0.43	0.32	1.12	-	260.5	186.0	86.8	-
Ramp D	60	1412	6.9	0.45	0.32	1.104	71.1	245.3	-	81.8	234.7

Table 5

Storm Water Consideration

In order to design for the 100 year storm, a consultant provided us with information. They conducted a hydrological analysis and determined the required elevations of the ditches to prevent flooding. Then they created a map of these required elevations. For each ditch, they specified how much higher the shoulder needed to be than the ditch. We added this distance to each ditch elevation. However, since all our superelevation transitions rotate about the centerline of the road, the edge of the road could potentially be below the required elevation. In order to account for this, we determined the change in elevation of the edge of the shoulder due to a 7% superelevation, which is the maximum that occurs in our design. Lane widths are 12 feet and the largest shoulder width that occurs is 12 feet. Ramp lane widths are 16 feet with the right shoulder being 8 feet.

Mainlines: $$0.07 * (12 + 12) = 1.68\ ft$$

Ramps: $$0.07 * (16 + 8) = 1.4\ ft$$

Therefore, the maximum change in elevation of the edge of the shoulder is 1.68 feet. We conservatively added 2 feet to every point.

Figure 15 shows our calculated required roadway elevations. With the knowledge of these target elevations, we were able to begin vertical alignment.

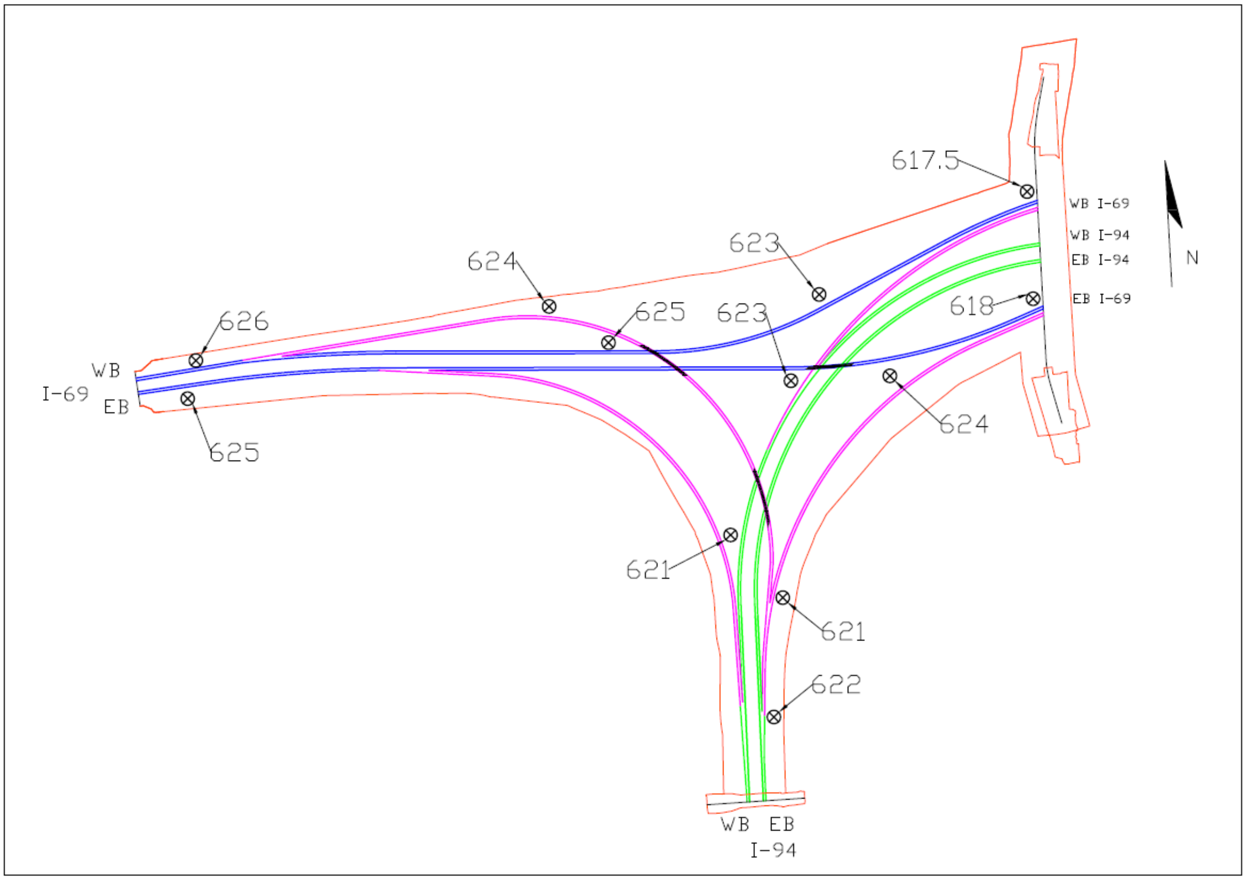

Figure 15

Vertical Alignment

A vertical alignment consists of differing grades connected by vertical curves. These curves are parabolic and can be either a crest or sag (Garber & Hoel, 2009). A crest occurs when the initial grade of the back tangent is greater than the final grade of the forward tangent. A sag occurs when the initial grade of the back tangent is smaller than the final grade of the forward tangent. Figure 16 illustrates this concept.

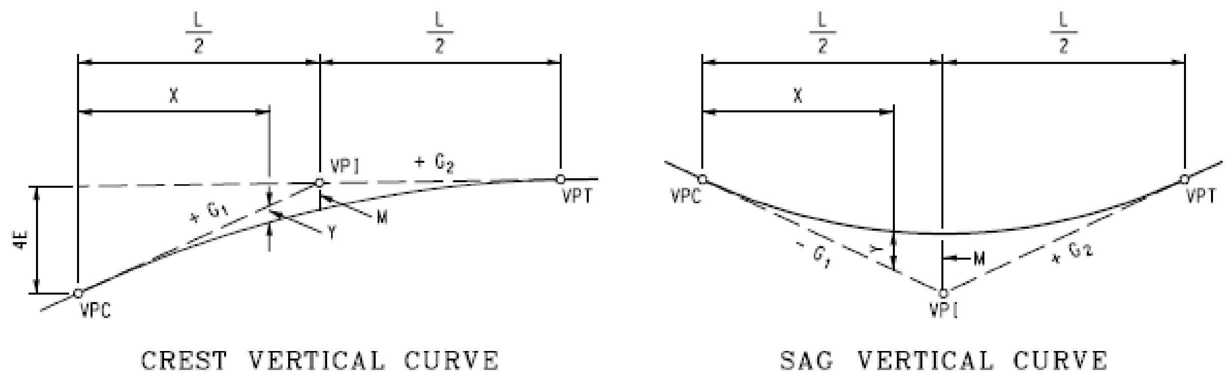

Figure 16 (MDOT, 2012)

The equation below is used to determine the elevation of the roadway at a specific point on a vertical curve. G_1 is the initial grade and G_2 is the final grade (both in decimal form), L is the length of the curve, and y_{PVC} is the elevation at the point of vertical curvature (in feet), which is the beginning of the curve.

$$y = y_{PVC} + G_1 x + \frac{(G_2 - G_1)x^2}{2L}$$

(Garber & Hoel, 2009)

The length of the curve is constrained by several criteria: comfort, appearance, drainage, and stopping distance. Since the design speeds are 60 mph or higher, stopping sight distance usually governs, and curves are often designed solely based on this (AASHTO, 2004). The minimum length of a curve can be established by using the equation below. The K factor is determined using only the stopping sight distance criterion and depends on the design speed (Table 6). A is the difference in grades G_1 and G_2.

$$L = KA$$

(AASHTO, 2004)

K Values for Crest Curves

Design Speed (mph)	K
15	3
20	7
25	12
30	19
35	29
40	44
45	61
50	84
55	114
60	151
65	193
70	247
75	312
80	384

K Values for Sag Curves

Design Speed (mph)	K
15	10
20	17
25	26
30	37
35	49
40	64
45	79
50	96
55	115
60	136
65	157
70	181
75	206
80	231

Table 6 (AASHTO, 2004)

There were three constraints we had to meet when designing vertical curves. We had to match the existing elevations and grades at every tie in point (Range Road, Griswold Road, and Michigan Road), we had to ensure that all bridges cleared underpassing roads by at least 16’3”, and we had to meet all the target elevations for storm water. In addition, MDOT restricts vertical grades between -3% and 3% on mainlines and -5% and 5% on ramps (MDOT, 2012).

We began our vertical alignment by utilizing the parabolic equation in Microsoft Excel. Table 7 is an example of this method. It represents ramp B. Figure 17 is a plot of elevation versus station for ramp B.

Station	Elevation					
0+00.00	645.00					
0+50.00	643.83					
1+00.00	642.65					
1+50.00	641.48					
2+00.00	640.30					
2+50.00	639.13	Distance	510.00		Curve type	STRAIGHT
3+00.00	637.95	PVC	645.00		K	
3+50.00	636.78	g1	-2.35		Min L	
4+00.00	635.60	g2	-2.35		CHECK	YES
4+50.00	634.43					
5+00.00	633.25					
5+10.00	633.02			**Exit Gore**		
5+50.00	632.12					
6+00.00	631.13					
6+50.00	630.27	Distance	321.28		Curve type	SAG
7+00.00	629.56	PVC	633.02		K	157
7+50.00	628.98	g1	-2.35		Min L	281.72
8+00.00	628.55	g2	-0.56		CHECK	YES
8+31.28	628.35			**B and D Separate**		
8+50.00	628.25					
9+00.00	628.00					
9+50.00	627.78					
10+00.00	627.60	Distance	1268.72		Curve type	SAG
10+50.00	627.44	PVC	628.35		K	157
11+00.00	627.32	g1	-0.56		Min L	259.12
11+50.00	627.24	g2	1.09		CHECK	YES
12+00.00	627.18					
12+50.00	627.16					
13+00.00	627.17					
13+50.00	627.22					
14+00.00	627.29					
14+50.00	627.40					
15+00.00	627.54					
15+50.00	627.71					
16+00.00	627.92					
16+50.00	628.16					
17+00.00	628.43					

17+50.00	628.73						
18+00.00	629.07						
18+50.00	629.44						
19+00.00	629.84						
19+50.00	630.27						
20+00.00	630.74						
20+50.00	631.24						
21+00.00	631.77						
21+50.00	632.29						
22+00.00	632.74						
22+50.00	633.14						
23+00.00	633.48						
23+50.00	633.76		Distance	1499.23		Curve type	CREST
24+00.00	633.97		PVC	631.77		K	193
24+50.00	634.13		g1	1.09		Min L	693.81
25+00.00	634.23		g2	-2.50		CHECK	YES
25+50.00	634.27						
26+00.00	634.25						
26+50.00	634.16						
27+00.00	634.02						
27+50.00	633.82						
28+00.00	633.56						
28+50.00	633.24						
29+00.00	632.85						
29+50.00	632.41						
30+00.00	631.91						
30+50.00	631.35						
31+00.00	630.73						
31+50.00	630.05						
32+00.00	629.31						
32+50.00	628.50						
33+00.00	627.64						
33+50.00	626.72						
34+00.00	625.74						
34+50.00	624.70						
35+00.00	623.60						
35+50.00	622.44						
35+99.23	621.24				**Under Michigan Road**		

Table 7

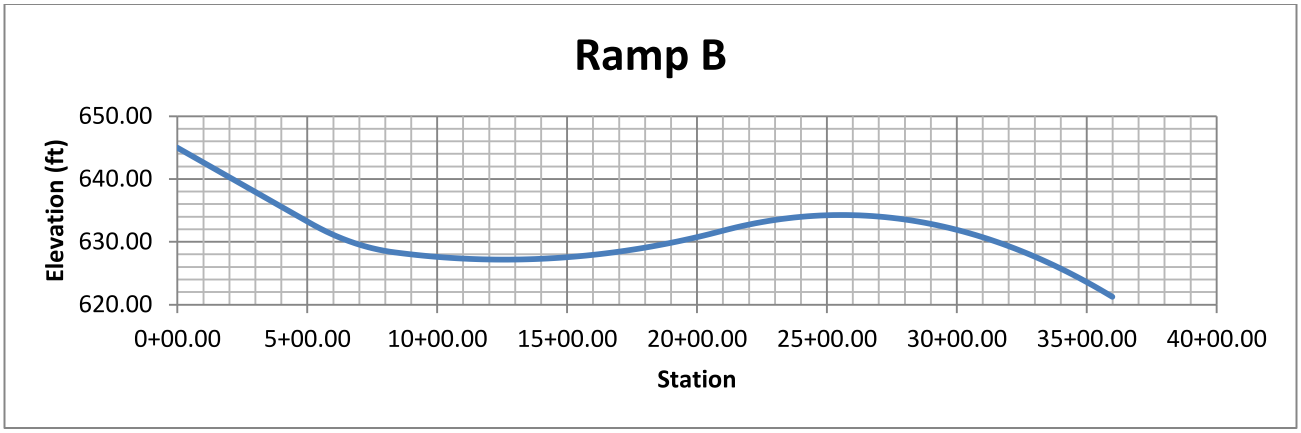

Figure 17

We took our Excel-generated vertical alignments to our faculty advisor. He explained that our process, although technically correct, was not the best way. He introduced Microstation and Geopak and gave us some helpful guidelines on how to use the software. With his help and the client's instruction, we were able to generate all vertical alignments on Microstation while still meeting the constraints. This also allowed us to take into account the existing ground profile so we could minimize earthwork. Our process consisted of designing the ground level roadways first, which included eastbound and westbound I-94 and westbound I-69. Next, we designed the roadways that overpass the ground level roadways. These are eastbound I-69 and ramp D. As previously mentioned, these had to conform to the MDOT clearance standard of 16'3". We assumed a conservative bridge thickness of 84". Therefore, the road to road clearance is 23'3". See Appendix B for proposed vertical alignment profiles.

Pavement Assumptions

Rigid pavements will be used for the entire interchange because, when properly designed and constructed, they have long service lives and usually are less expensive to maintain than flexible pavements. According to the MDOT Pavement Design and Selection Manual, the thickness for concrete (rigid) pavements in highways normally ranges from 6-13 inches (MDOT, 2012).

Types of rigid highway pavements:

- -Jointed Plain Concrete Pavement (JPCP)
- -Jointed Reinforced Concrete Pavement (JRCP)
- -Continuously Reinforced Concrete Pavement (CRCP)

(Garber & Hoel, 2009)

Jointed Plain Concrete Pavement (JPCP) will be used for this design. It is the most common type of rigid pavement, and it controls cracking by dividing the pavement into individual slabs. This type of pavement uses contraction joints placed transversely along the width of the pavement. Pavements that are subject to a decrease in temperature will contract if they are free to move. Therefore, contraction joints are placed in order to release some of the tensile stresses induced in the slab. These joints are typically spaced at 12-50 ft intervals in order to prevent cracking in the middle of the slab. Tie bars and dowel bars may also be used to assist in load transfer wherever slab thickness exceeds 8 inches (Garber & Hoel, 2009).

Directly under the surface course is the base course. According to MDOT standards, the thickness of this layer should not be less than 6 inches and should be extended to 1 to 3 ft outside the edge of the pavement structure (MDOT, 2012). The base course provides additional load distribution and it contributes to frost resistance, as well as drainage by effectively moving water from beneath the pavement and into an underdrain system (AASHTO, 2004).

For the purpose of earthwork computations, we assumed the thickness for the surface course (concrete pavement) to be 12 inches and the base course to have a thickness of 16 inches. The base course will also consist of Open-Graded Drainage Course material.

Earthwork

A preliminary estimate of the required amounts of cut and fill for the interchange has been computed using the average end area method. We obtained the proposed and existing elevations for each roadway at 100 feet intervals (each station) using a function on Microstation. Given this information, the assumed pavement thickness of 28 inches, and assumed embankment ratios, cross-sectional areas can be calculated. We assumed a 2:1 embankment, which is the steepest allowable slope, for ramp D and eastbound I-69, as these contain bridges and are at quite high elevations at times. Furthermore, a 4:1 embankment was assumed on all other roadways.

See Figure 18. For a fill calculation, the rectangular area underneath the roadway is:

$$A_1 = (Lanes + Shoulders) * (Proposed - Existing - Pavement)$$

And the area of one of the triangles is:

$$A_2 = {}^1\!/_2 * Embankment\ ratio * (Proposed - Existing - Pavement) * (Proposed - Existing - Pavement)$$

So the total area is:

$$A_1 + 2A_2 = (Lanes + Shoulders) * (Proposed - Existing - Pavement) + Embankment\ ratio * (Proposed - Existing - Pavement)^2$$

Using a similar derivation, the cut calculation is:

$$(Lanes + Shoulders) * (Existing - Proposed + Pavement) + Embankement\ ratio * (Existing - Proposed + Pavement)^2$$

Volume in cubic yards is calculated by multiplying the above area by the station increment of 100 feet and dividing by 27 ft^3/yd^3. This was performed in Microsoft Excel for each roadway and total volumes of cut and fill were computed (Table 8).

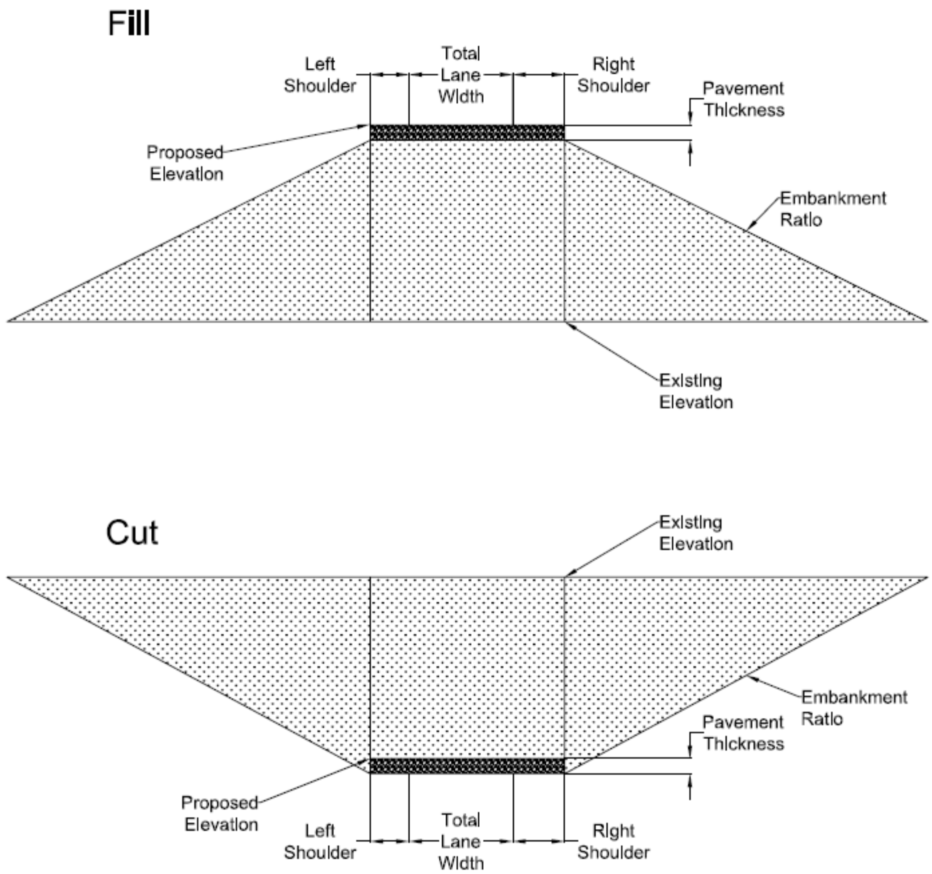

Figure 18

EARTHWORK (cyd)		
ROADWAY	CUT	FILL
WB94	10,081	3
EB94	22,700	-
WB69	134,825	444
EB69	6,784	141,871
RAMPA	1,212	88,991
RAMPB	36,884	14,165
RAMPD	-	297,638
RAMPF	2,631	3,926
	CUT	FILL
TOTAL	215,117	547,038
TOTAL FILL NEEDED	331,922	

Table 8

Note that earthwork was excluded from the calculation on portions of roadways where bridges exist. In addition, due to unknown soil conditions, swell and shrinkage factors were not taken into consideration. See Appendix C for detailed Excel calculations for every station.

Wetlands Impact

To determine the acreage of disturbed wetlands, we had to establish slope stake lines for our design. These lines represent where the embankments of the roadways meet the existing ground profile. Everything within these lines is part of the footprint of the proposed interchange. Therefore, any wetlands that fall within the lines will be disturbed.

Using the same embankment ratios as stated in the earthwork section, the following equation was utilized to determine the perpendicular distance from the edge of the shoulder to the slope stake line:

$$L = Embankment\ ratio * (Proposed - Existing)$$

This equation was used for every station, or 100 feet. Then all the points were connected to generate the slope stake lines. Figure 19 shows the slope stake lines in black and the wetlands in blue. Figure 20 shows only the parts of the wetlands that fall within the footprint. Using the area function on AutoCAD, the total area of disturbed wetlands was determined to be 7.7 acres. In accordance with Michigan Department of Environmental Quality (MDEQ) requirements, we will restore twice this amount (MDEQ, 2012), or 15.4 acres. The restored wetlands must be constructed within the same watershed. The client has offered us the use of a wetlands bank in order to achieve this. The wetlands bank is a reserve of wetlands that lies within the watershed.

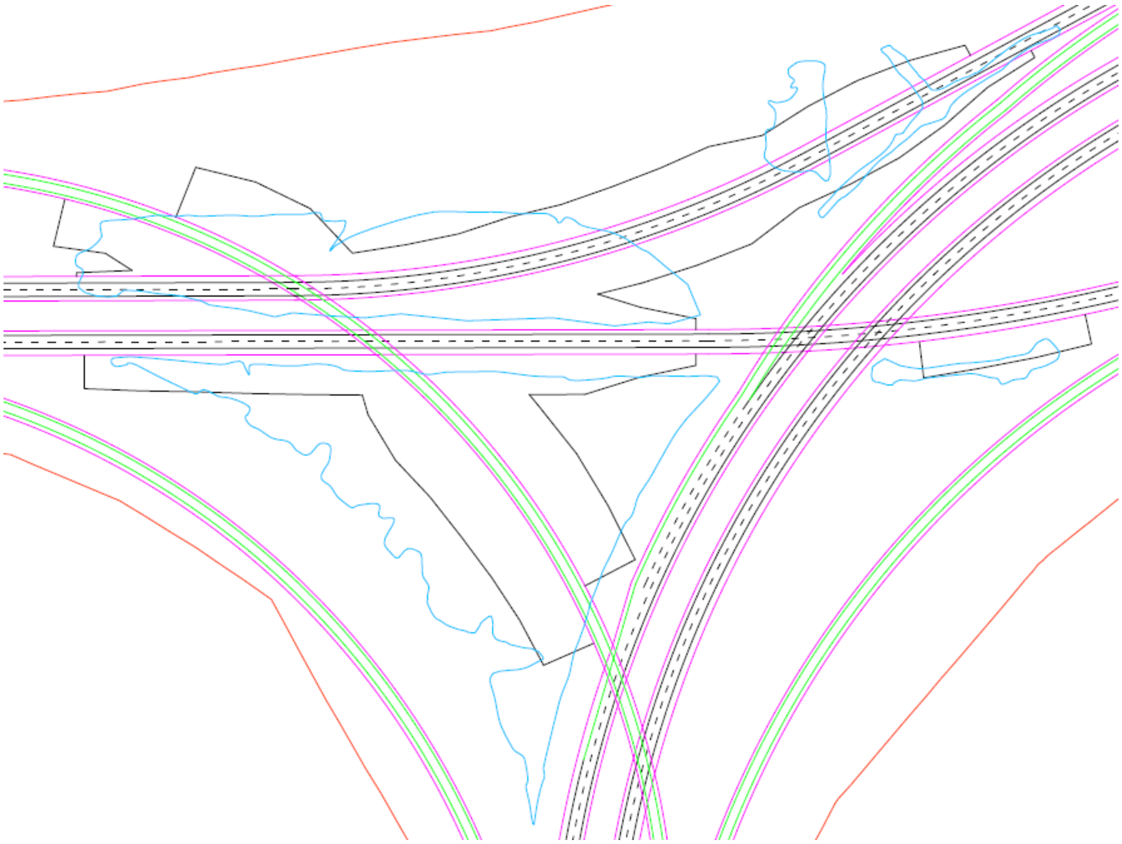

Figure 19

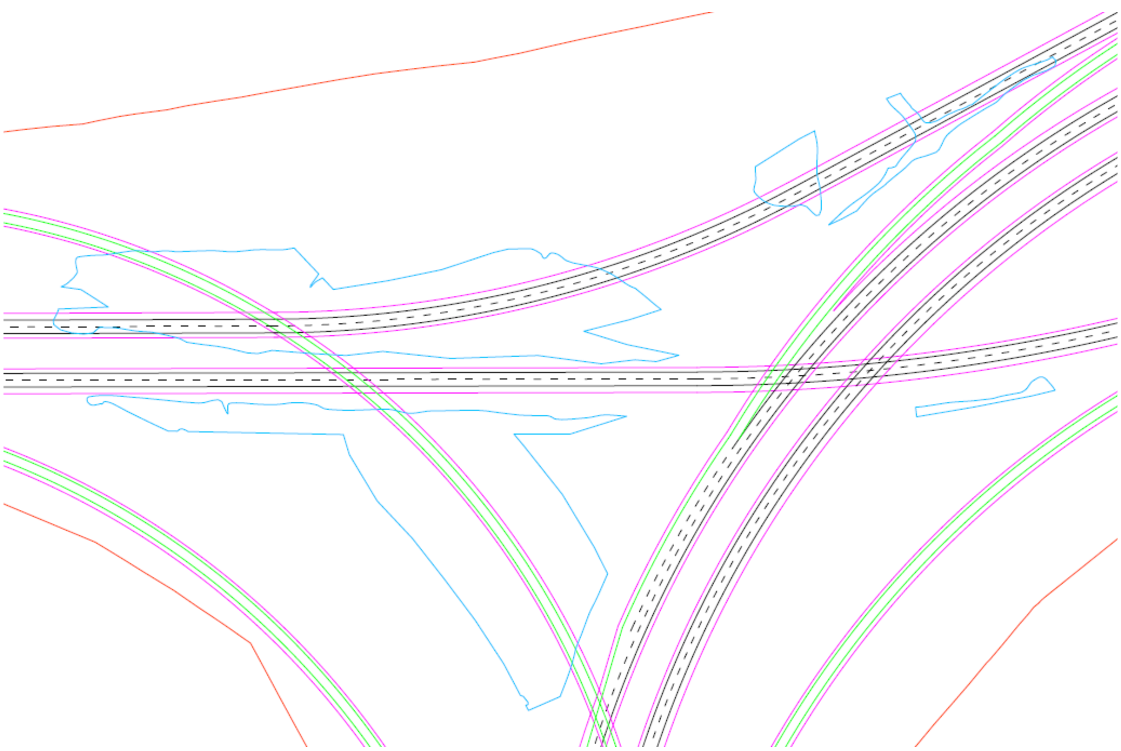

Figure 20

Cost Estimate

A basic cost estimate is usually done with a square footage estimate while the final estimate is performed by itemizing. Considering the amount of design that we had done, we felt a square footage estimate would not be adequate. We came up with a balance of the two estimate configurations. There are five sections to the cost estimate, and the roadway section is the only section that we itemized. The structure section estimate was done by an outside client, and the other three sections (maintaining traffic, signing, and mobilization) were all calculated by using a percentage of the roadway and structure estimates.

The roadway section of the cost estimate has four subcategories: removal and construction, drainage, safety, and total cost estimate. The following bullets explain how each calculation was performed for each subcategory.

Removal and Construction

- Clearing: The area of disturbance, equal to the 7.7 acres calculated in the wetlands section
- Tree Removal: This was calculated with the use of a table that gave the number of trees per acre by the diameter and basal area (Coder, 1996)
- Curb and Gutter Removal: There are no existing curbs or gutters
- Fence Removal: The length of the right-of-way boundary
- Pavement Removal: We assumed all existing pavement would be removed
- Excavation and Embankment: This was calculated in the earthwork section
- Geotextile: Equal to the area of open graded drainage course
- Open Graded Drainage Course: The area of the fill needed 16" below the pavement (width of the roadway plus width of the shoulders plus a conservative four feet)
- Class 2 Fill for Shoulder: Half of our shoulder volume is class 2 fill
- Underdrain Outlet: Where there is a barrier between the mainlines and ramps, an underdrain structure is needed every 300 feet for proper drainage
- Underdrain Pipe: Where there is a barrier between the mainlines and ramps, an underdrain pipe is needed to connect all of the underdrain structure
- Concrete Shoulder: Half of our shoulder volume is concrete
- Concrete Pavement: The volume of concrete needed for the mainlines and ramps
- Fence Install: The length of the right-of-way boundary
- Turf Establishment: The surface area of the proposed embankments
- Shoulder Corrugations: The length of roadway times two (for both sides of the road)

Drainage

- Culvert Removal: There is only one existing culvert in the interchange
- Culvert End Removal: There are two ends to the one culvert
- Culvert Concrete: The length of the culvert is 50 feet
- Culvert End Section: There are two ends to the new culvert

Safety

- Guardrail Removal: There was no information on existing guardrails so an approximation was made
- Guardrail Install: The length of roadway that has an embankment slope of 2:1 or steeper
- Guardrail Anchor Bridge: The total number of anchors that are needed when the guardrail intersects with a bridge
- Guardrail Approach Terminal: The number of approaches for the guardrail system
- Guardrail Departing Terminal: The number of departing structures in the guardrail system

Total Cost Estimate

- Mobilization: A conservative 5% of the other roadway and construction costs was used
- Staking: 2% of the other roadway and construction costs was used
- Cleanup: 1% of the other roadway and construction costs was used

The total roadway estimate is $10,790,578 and the structures estimate is $14,829,000. The total of these two estimates was used for the estimates of the three other sections. Maintaining traffic was calculated as 8% of the total cost. Signing was estimated to be 1% of the total cost. Mobilization was estimated to be 5% of the total cost. Our client wanted a 10% contingency which totals $2,561,958. The total estimate of the whole interchange is $31,768,277.

Summary

The three main problems with the existing interchange are the 40 mph design speed of Ramp D, the left-hand entrance of Ramp D onto westbound I-69, and the flooding due to the wetlands. We began by calculating minimum radii associated with different design speeds and using this data to design three horizontal alignment alternatives. We selected alternative 2 for further design. Then we designed the entrance and exit ramps. Next, we calculated required superelevation transition lengths to certify that our horizontal alignment met these requirements. We designed vertical alignments for each roadway using three criteria: tie in points, storm water target points, and bridge underclearances. Then we assumed a pavement thickness for the purpose of earthwork calculations. The cut volume was computed as 215,117 cubic yards, and the fill volume was computed as 547,038 cubic yards. In addition, we established slope stake lines so we could determine the area of impacted wetlands. Using MDEQ's replacement ratio, we calculated a restoration area of 15.4 acres. We concluded with a preliminary cost estimate for construction of the interchange: $31,768,277.

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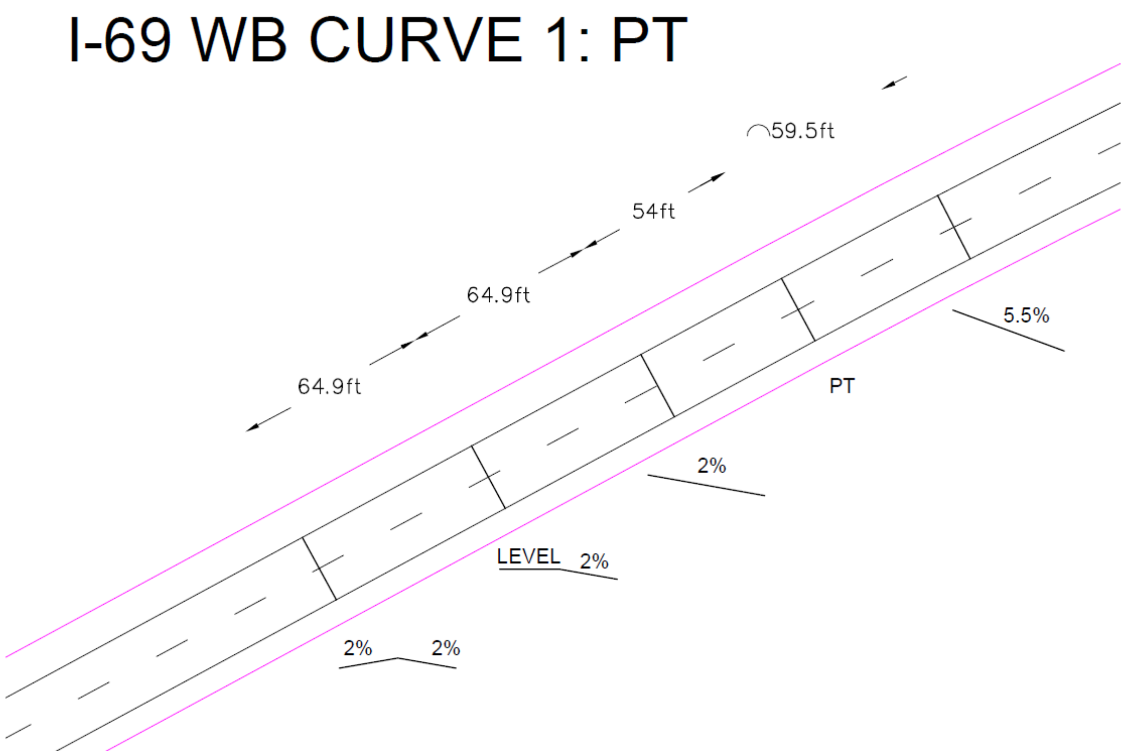
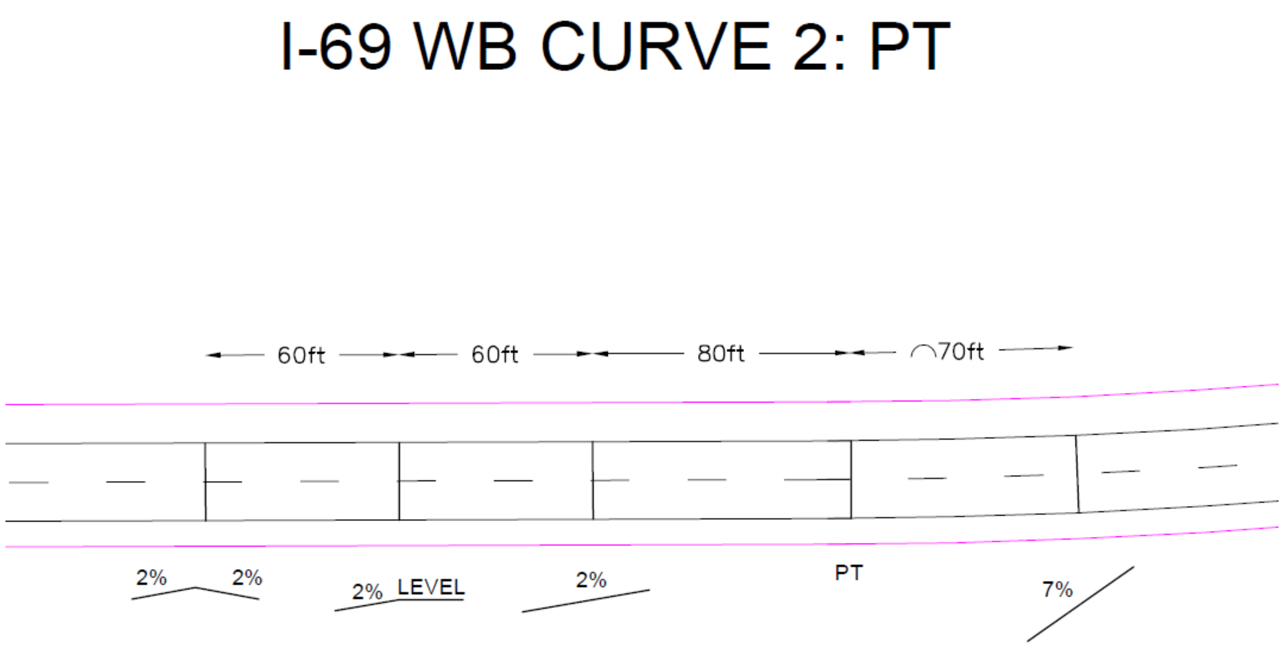
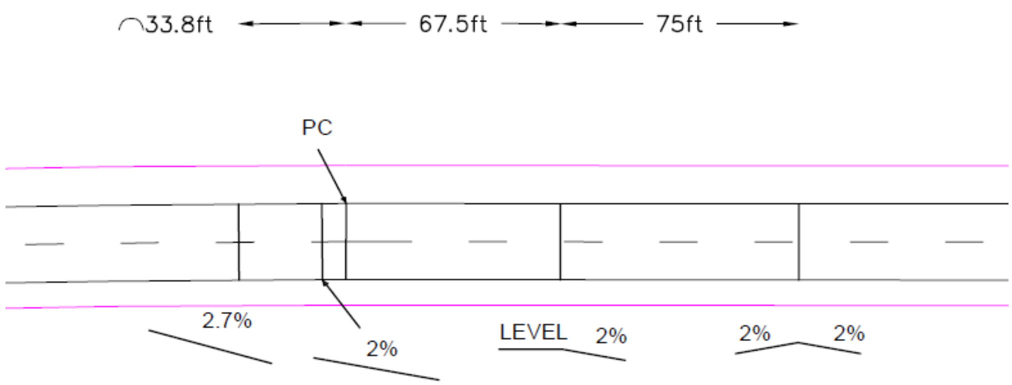
Appendix A: Superelevation Transitions

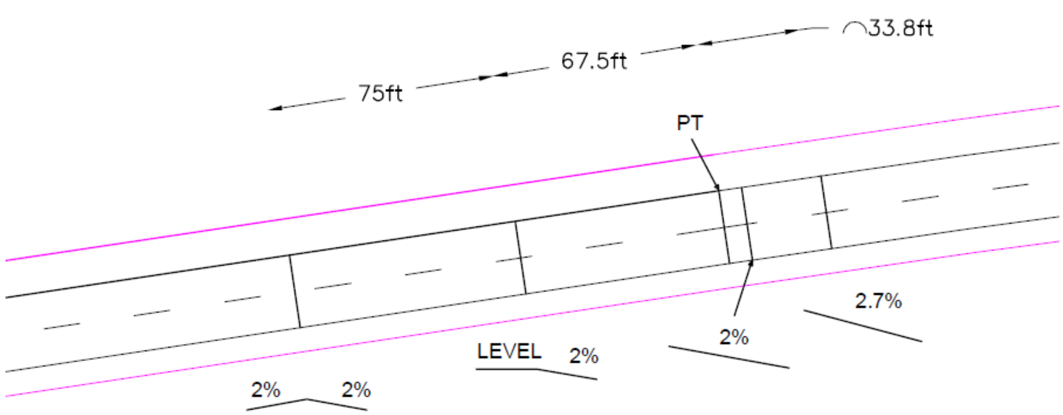




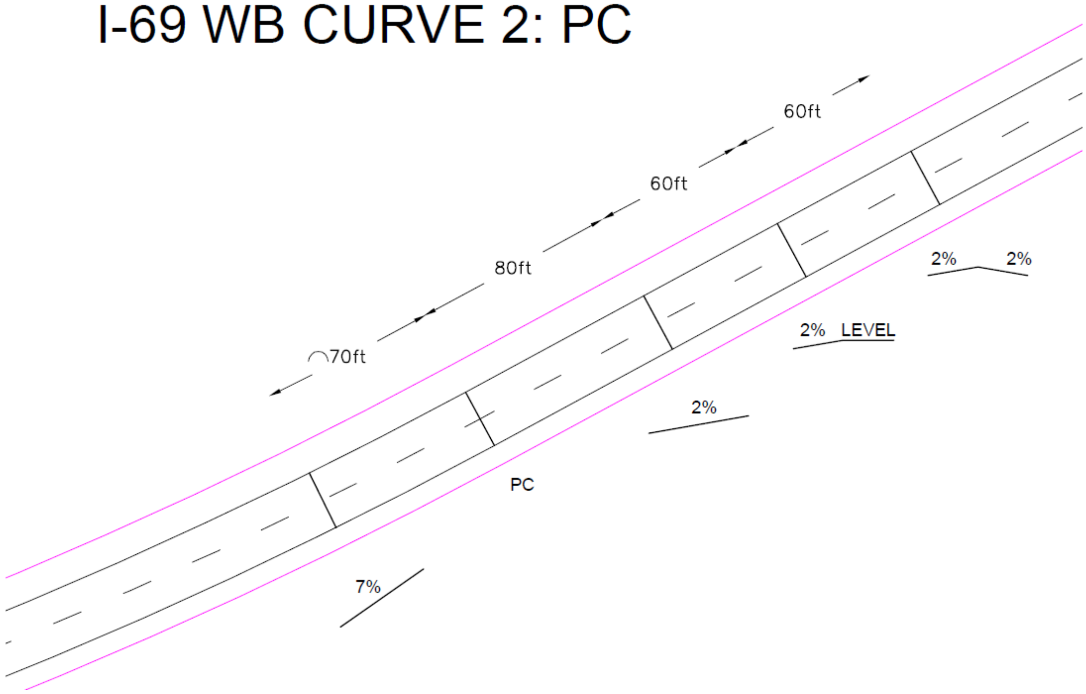
I-69 WB CURVE 3: PC



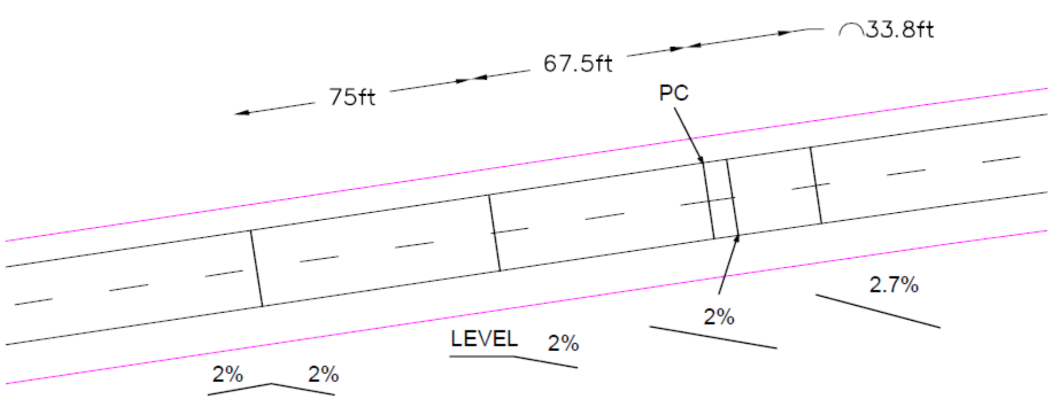
I-69 WB CURVE 3: PT



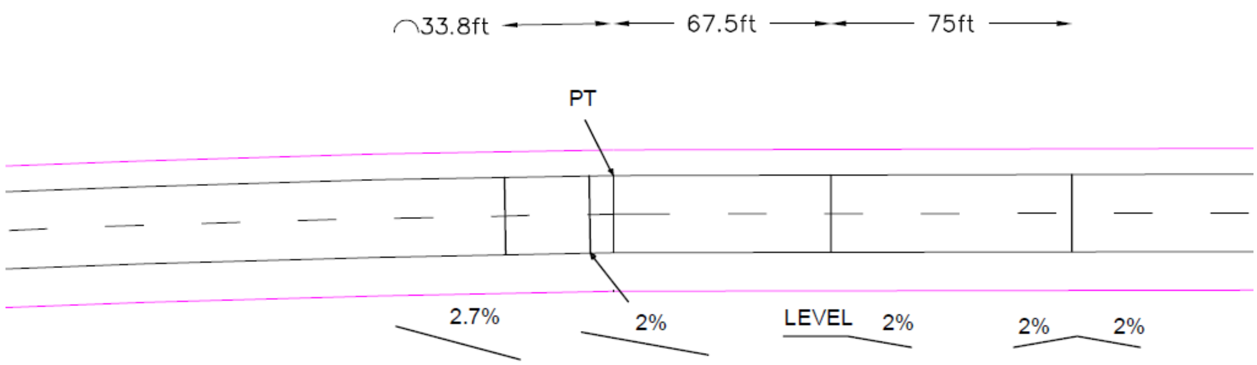
I-69 WB CURVE 2: PC



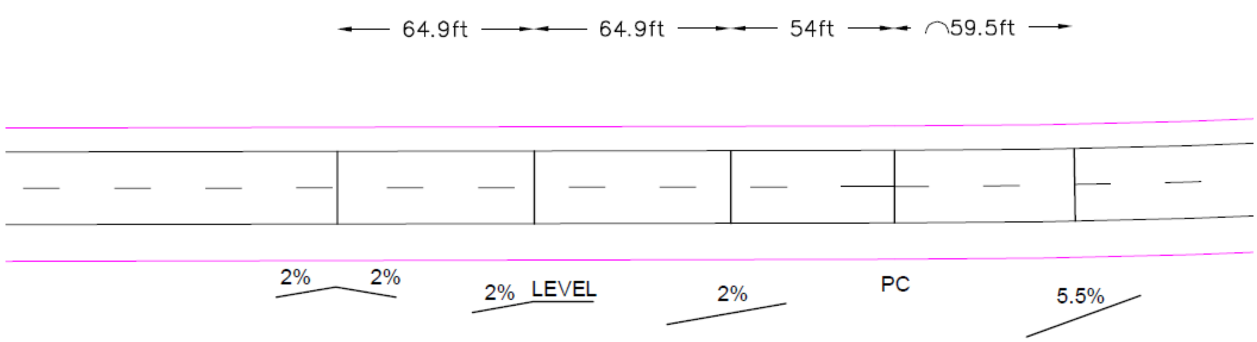
I-69 EB CURVE 1: PC



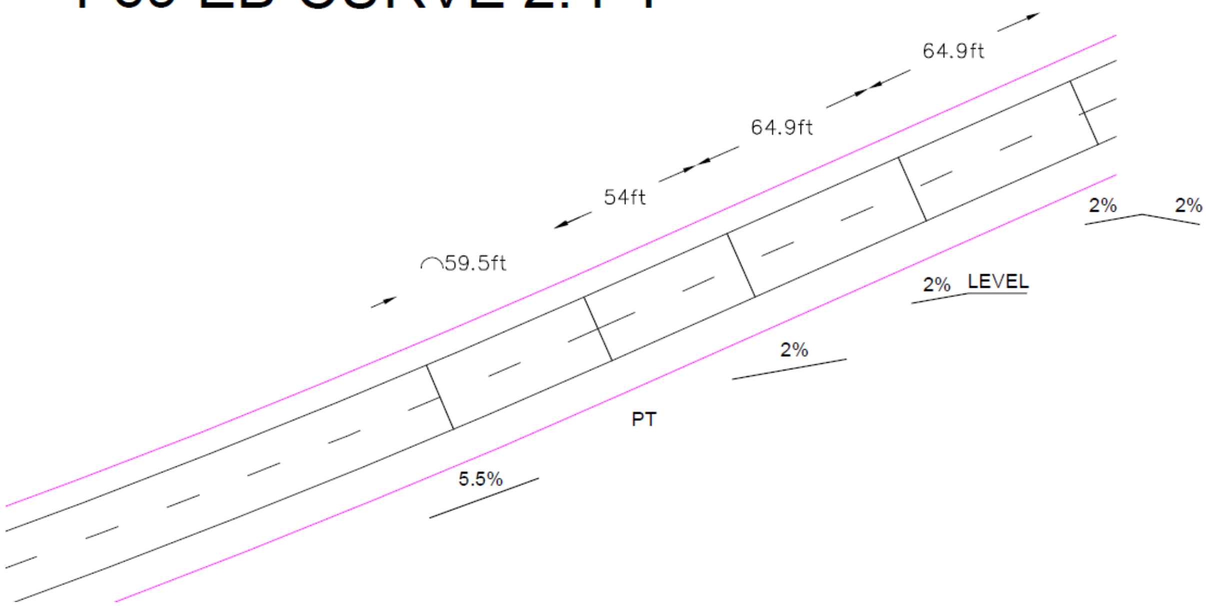
I-69 EB CURVE 1: PT



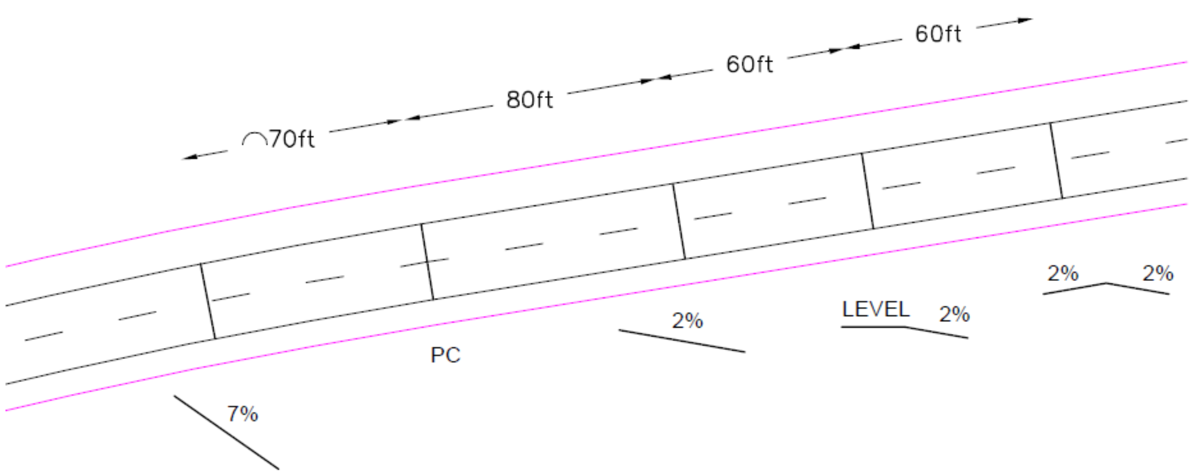
I-69 EB CURVE 2: PC



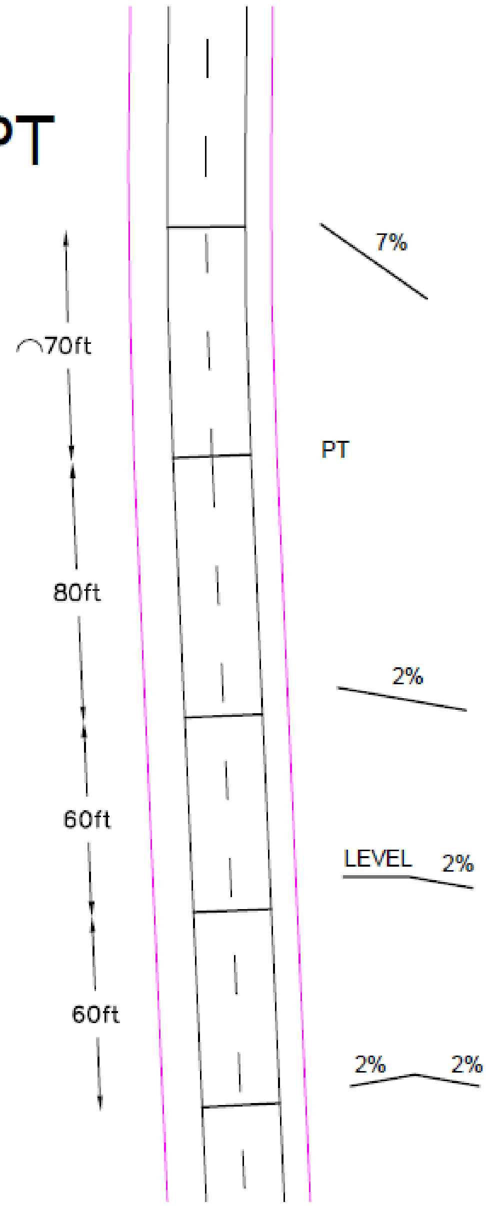
I-69 EB CURVE 2: PT



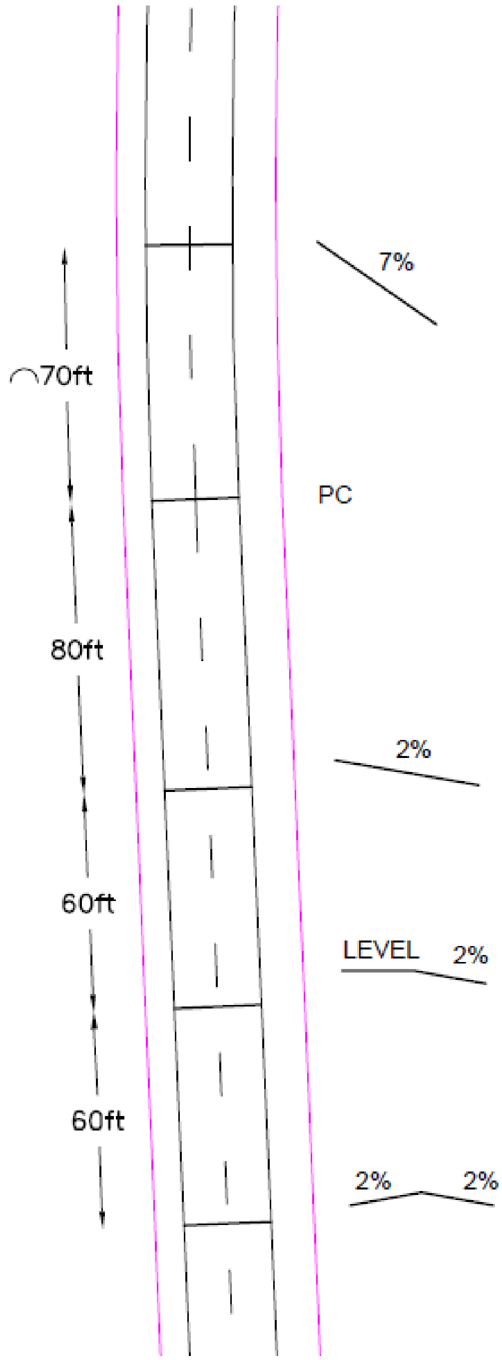
I-94 WB: PC



I-94 WB: PT



I-94 EB: PC



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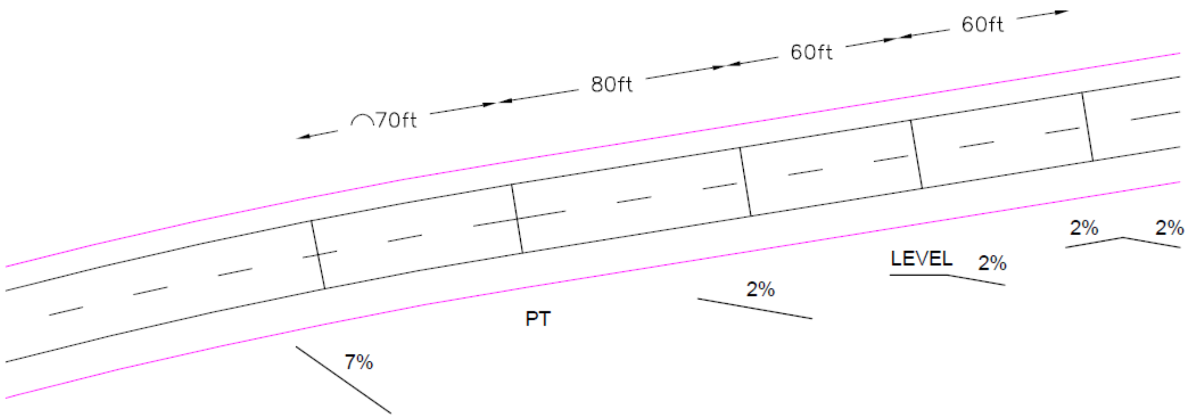
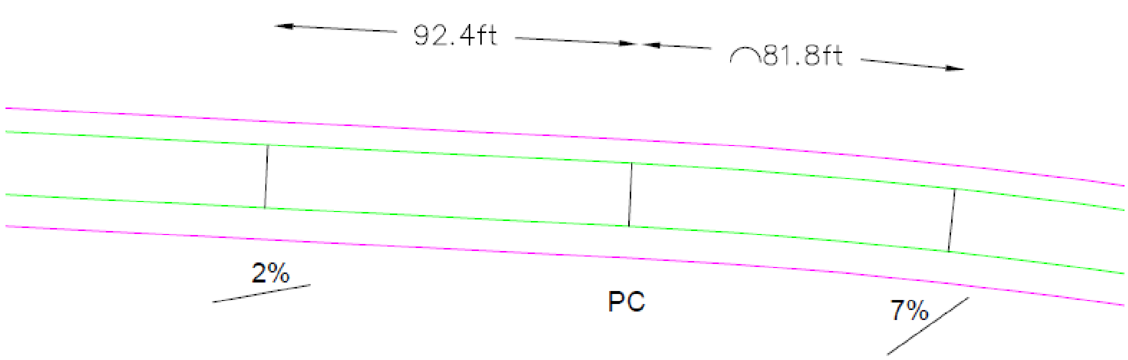
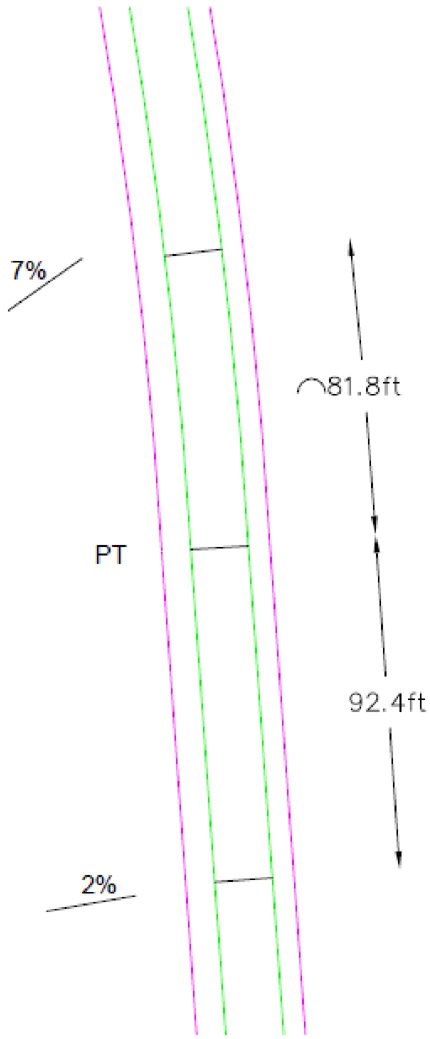


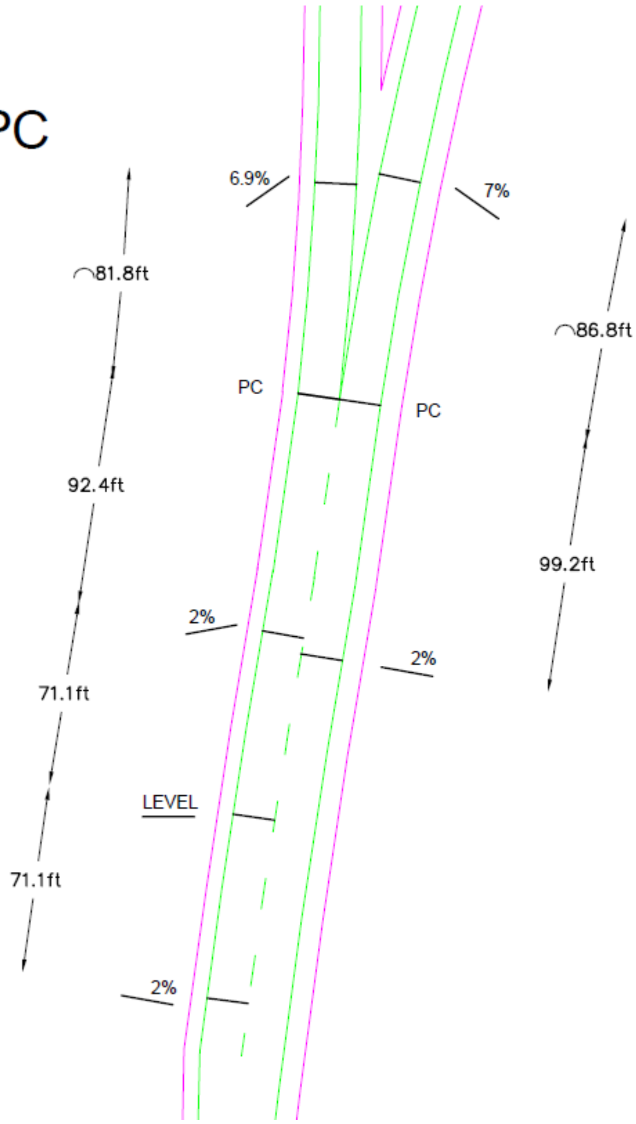
RAMP A: PC



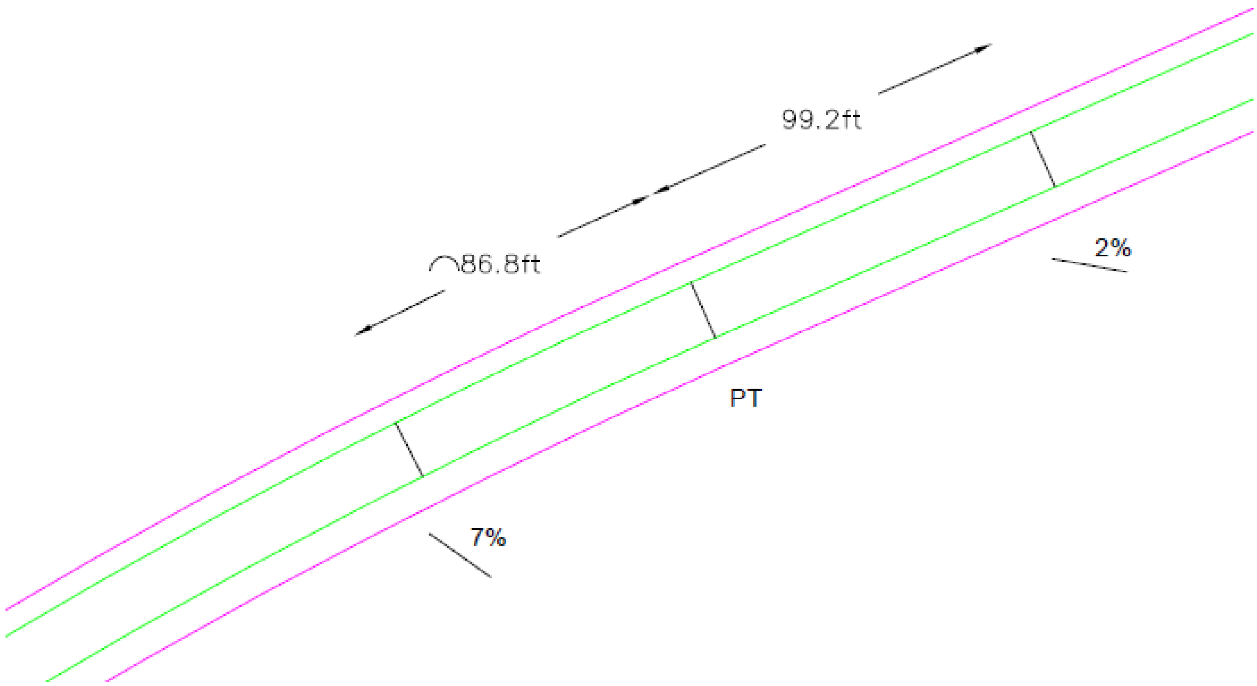


RAMP A: PT

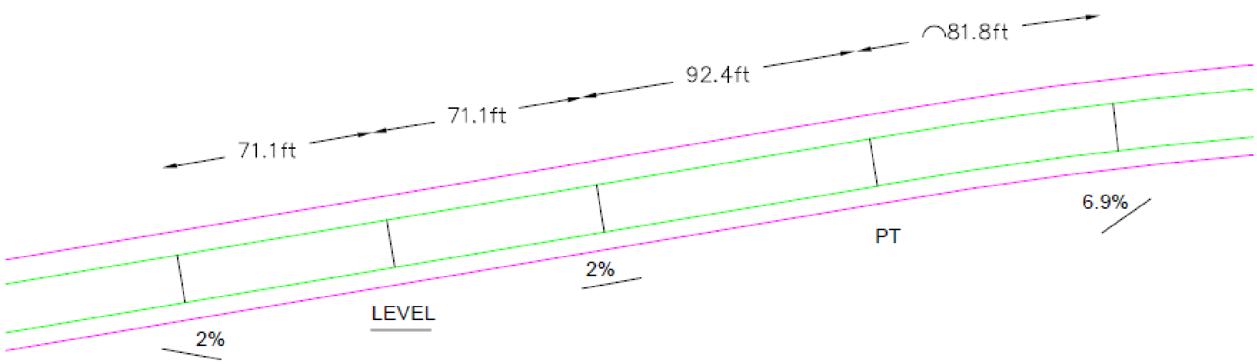
RAMPS B AND D: PC



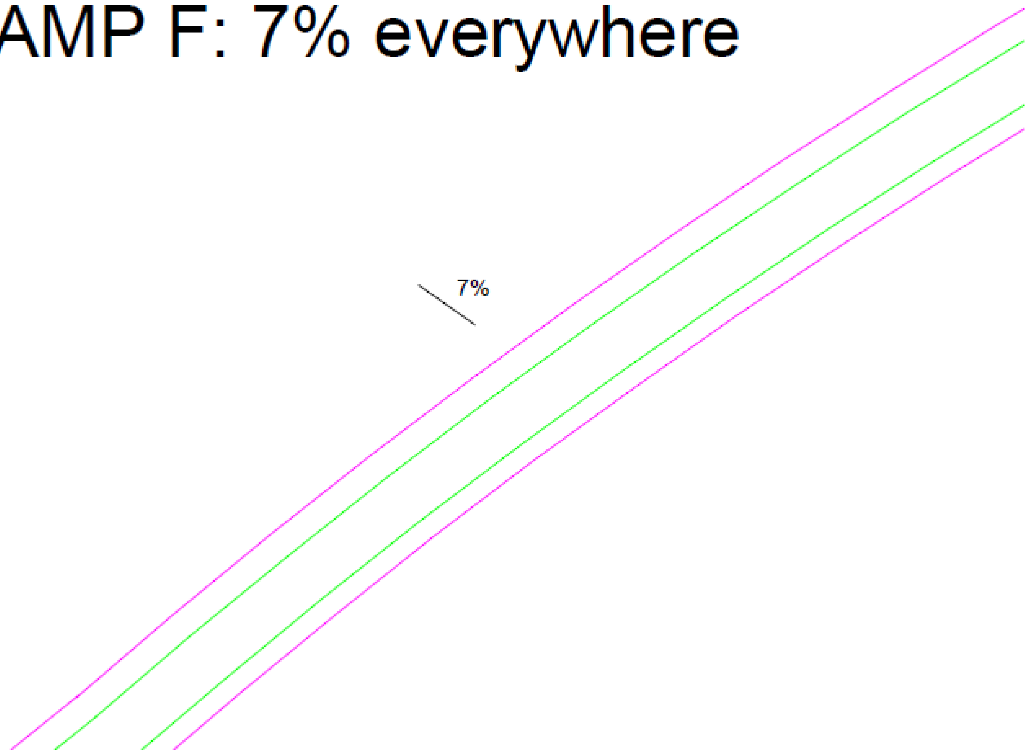
RAMP B: PT



RAMP D: PT



RAMP F: 7% everywhere



Appendix B: Vertical Alignment Profiles

Appendix C: Earthwork Calculations

WB I-94				
	ELEVATION (Feet)			
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)
0+00	646.9675	646.7933	520.3608408	0
1+00	644.7676	644.6833	498.4849521	0
2+00	642.3391	642.5733	422.909542	0
3+00	640.1208	640.4633	397.8963066	0
4+00	637.7071	638.3533	329.6066995	0
5+00	635.1946	636.2433	243.3120909	0
6+00	632.7711	634.1333	179.4241968	0
7+00	630.6345	632.0233	174.1374304	0
8+00	628.5719	629.9136	183.5128889	0
9+00	627.0607	628.0457	256.6494239	0
10+00	625.8492	626.6323	299.7171366	0
11+00	624.8549	625.6734	292.0785683	0
12+00	624.2246	625.1691	265.1917239	0
13+00	623.6332	625.0980	159.1479035	0
14+00	623.2466	625.1362	78.51603858	0
15+00	623.0710	625.1743	39.97479508	0
16+00	622.8590	625.2125	0	3.441827572
17+00	623.2783	625.2506	63.44042076	0
18+00	623.3574	625.2888	70.87087019	0
19+00	623.3915	625.3269	70.1419892	0
20+00	623.5065	625.3651	84.21933439	0
21+00	623.6223	625.4032	98.63949513	0
22+00	623.7364	625.4414	112.8983128	0
23+00	623.8037	625.4795	118.429384	0
24+00	623.8945	625.5177	128.4566324	0
25+00	624.0055	625.5558	142.4892524	0
26+00	623.9728	625.5940	128.8395143	0
27+00	624.1152	625.6321	148.9710625	0
28+00	624.1984	625.6703	157.756307	0
29+00	624.1618	625.6860	147.5515568	0
30+00	624.0291	625.5404	150.0610687	0
31+00	623.9236	625.2096	194.6850436	0
32+00	623.7069	624.6976	255.4510756	0
33+00	623.5024	624.1276	334.2407825	0
34+00	623.2965	623.5576	416.6642122	0
35+00	623.0079	622.9876	483.0573808	0
36+00	622.6787	622.4176	541.7343356	0
37+00	622.3475	621.8476	601.6206586	0
38+00	621.9493	621.2776	645.749758	0
39+00	621.3721	620.7076	643.8827856	0
		Total =	10,080.77	3.44

LANE WIDTH (ft) =	24	
SHOULDER (ft) =	22	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	4	: 1

EB I-94				
	ELEVATION (Feet)			
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)
0+00	646.9457	644.5451	1138.523824	0
1+00	644.8541	642.1951	1219.781118	0
2+00	642.4486	639.8451	1202.161581	0
3+00	640.0603	637.4951	1190.055736	0
4+00	637.5638	635.1451	1144.151172	0
5+00	635.1363	632.7951	1120.124374	0
6+00	632.7619	630.4451	1112.596642	0
7+00	630.4704	628.1156	1124.327815	0
8+00	628.6076	626.1924	1143.062254	0
9+00	627.0000	624.8216	1070.232163	0
10+00	625.4200	624.0033	847.231605	0
11+00	624.1245	623.7375	573.0969893	0
12+00	623.0599	623.7541	319.0635766	0
13+00	622.3005	623.7707	158.0893701	0
14+00	621.8578	623.7874	71.1990213	0
15+00	621.7427	623.8040	47.44274767	0
16+00	621.6598	623.8206	29.83557162	0
17+00	621.9123	623.8373	72.03806584	0
18+00	622.0017	623.8539	85.40033508	0
19+00	622.1351	623.8706	107.1479708	0
20+00	622.2676	623.8872	129.1459053	0
21+00	622.3318	623.9038	138.29573	0
22+00	622.4136	623.9205	150.9181539	0
23+00	622.4575	623.9371	156.2487991	0
24+00	622.4932	623.9537	159.9914276	0
25+00	622.4991	623.7884	194.0205768	0
26+00	622.6033	623.4184	292.8106043	0
27+00	622.4317	623.0484	336.1201975	0
28+00	622.5680	622.6784	451.9283843	0
29+00	622.5332	622.3084	532.7789553	0
30+00	622.4050	621.9384	593.1682964	0
31+00	622.2506	621.5684	648.4751795	0
32+00	622.0597	621.1984	695.4661551	0
33+00	621.7299	620.8284	706.1441486	0
34+00	621.5228	620.4584	749.9040761	0
35+00	621.1108	620.0884	738.5463635	0
36+00	620.7475	619.7184	740.3546853	0
37+00	620.4152	619.3484	750.5546669	0
38+00	620.0788	618.9784	759.6808583	0
		Total =	22,700.12	-

LANE WIDTH (ft) =	24	
SHOULDER (ft) =	22	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	4	: 1

WB I-69

	ELEVATION (Feet)			
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)
0+00	632.7714	632.2730	601.2392149	0
1+00	631.9531	631.6128	561.4088672	0
2+00	631.6254	630.9525	646.0610694	0
3+00	631.3808	630.2923	756.4448399	0
4+00	631.0707	629.6320	853.4313896	0
5+00	630.8009	628.9718	965.8345865	0
6+00	630.5649	628.3115	1093.119348	0
7+00	629.9738	627.6513	1114.353591	0
8+00	629.4974	626.9910	1171.554845	0
9+00	629.0651	626.3308	1243.832458	0
10+00	628.8625	625.6706	1393.605729	0
11+00	628.6446	625.0727	1522.695764	0
12+00	628.5233	624.8779	1548.158305	0
13+00	628.1100	625.0452	1351.38336	0
14+00	627.6553	625.2423	1142.377977	0
15+00	627.4444	625.4394	1017.955103	0
16+00	626.9786	625.6364	826.3433869	0
17+00	626.8495	625.8335	736.8202535	0
18+00	626.5909	626.0306	617.0355141	0
19+00	626.2000	626.2277	471.5663467	0
20+00	625.9849	626.4247	375.7200269	0
21+00	626.0292	626.6218	341.4605314	0
22+00	626.2354	626.8189	343.4814819	0
23+00	626.5803	627.0159	376.6714835	0
24+00	627.4458	627.2130	534.7492388	0
25+00	628.2253	627.4101	683.2799331	0
26+00	629.1793	627.6072	891.331746	0
27+00	630.3318	627.8042	1178.213425	0
28+00	631.9497	628.0013	1654.8164	0
29+00	633.8388	628.1984	2300.420098	0
30+00	635.8985	628.3955	3109.204249	0
31+00	637.8327	628.5925	3956.182328	0
32+00	639.7855	628.7863	4904.897458	0
33+00	641.6538	628.8558	5969.8901	0
34+00	643.5068	628.7400	7245.423605	0
35+00	644.7711	628.4391	8341.422249	0
36+00	645.6115	627.9793	9307.054142	0
37+00	645.8723	627.4993	9879.630718	0
38+00	646.1920	627.0193	10515.98301	0
39+00	623.8711	626.5393	0	58.71262742
40+00	621.7893	626.0593	0	385.516214
41+00	625.8972	625.5793	555.825504	0
42+00	643.0224	625.0993	9529.956663	0
43+00	641.1781	624.6193	8506.255337	0
44+00	639.0242	624.1393	7325.588777	0
45+00	636.5430	623.6593	6023.022027	0
46+00	633.6470	623.1793	4608.567966	0
47+00	630.6293	622.6993	3309.101399	0
48+00	627.4214	622.2193	2125.040576	0
49+00	624.6360	621.7393	1296.27603	0
		Total =	134,824.69	444.23

LANE WIDTH (ft) =	24	
SHOULDER (ft) =	22	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	4	: 1

EB I-69				
	ELEVATION (Feet)			
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)
0+00	632.4649	632.4176	489.5510874	0
1+00	631.5683	631.9876	380.3689916	0
2+00	631.0969	631.5576	370.9931694	0
3+00	630.6842	631.1276	374.9049087	0
4+00	630.2393	630.6976	371.5353087	0
5+00	629.9937	630.2676	413.699985	0
6+00	629.8671	629.8376	485.2676251	0
7+00	629.5499	629.4076	512.5710183	0
8+00	629.2561	628.9776	546.0408399	0
9+00	628.9450	628.5476	575.7087092	0
10+00	628.7174	628.1176	627.1748813	0
11+00	628.3381	627.6876	640.2569584	0
12+00	627.8301	627.2576	620.1622325	0
13+00	625.8706	627.0377	218.8412373	0
14+00	624.0428	627.2720	0	164.5191667
15+00	623.4247	627.9608	0	447.1703356
16+00	622.5205	629.1042	0	787.1049383
17+00	621.3429	630.7021	0	1301.08642
18+00	618.4424	632.7546	0	2218.308642
19+00	617.7325	635.1828	0	2799.438272
20+00	619.4479	637.6495	0	2938.567901
21+00	621.1586	640.0697	0	3069.95679
22+00	621.1937	642.3125	0	3478.790123
23+00	620.7724	644.3701	0	3937.845679
24+00	620.1948	646.2425	0	4391.549383
25+00	619.7888	647.9297	0	4779.179012
26+00	619.5281	649.4318	0	5105.623457
27+00	618.8489	650.7487	0	5475.271605
28+00	618.9830	651.8804	0	5660.012346
29+00	618.3063	652.8269	0	5960.604938
30+00	618.0056	653.5882	0	6157.271605
31+00	617.9666	654.1643	0	6271.179012
32+00	618.2563	654.5553	0	6289.938272
33+00	618.4640	654.7610	0	6289.567901
34+00	618.5429	654.7816	0	6278.771605
35+00	618.6545	654.6170	0	6227.623457
36+00	633.8298	654.2672	0	3352.604938
37+00	663.7836	653.7322	0	0
38+00	637.0624	653.0121	0	0
39+00	616.9668	652.1067	0	0
40+00	617.1551	651.0162	0	0
41+00	616.9945	649.7405	0	0
42+00	617.3944	648.2796	0	10902.97795
43+00	617.1564	646.6335	0	10082.15335
44+00	617.6282	644.8022	0	8802.918917
45+00	616.4287	642.7858	0	4270.891852
46+00	616.0038	640.5841	0	3955.016296
47+00	616.5890	638.1973	0	3426.660741
48+00	618.0487	635.6253	0	2709.914074
49+00	619.9699	632.8681	0	1878.198519
50+00	620.1678	629.9290	0	1320.50963
51+00	619.9957	626.9290	0	817.7718519
52+00	619.7860	623.9290	0	321.7185185
53+00	619.4825	620.9290	156.9158521	0
		Total =	6,783.99	141,870.72

LANE WIDTH (ft) =	24	
SHOULDER (ft) =	22	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	4	: 1
EMBANK Ratio =	2	: 1

No fill needed for bridge over WB and EB I-94

RAMP A				
	ELEVATION (Feet)			
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)
0+00	626.8884	630.0000	0	95.44739266
1+00	626.5714	632.3841	0	565.9443319
2+00	626.3735	634.4574	0	1128.863215
3+00	626.1387	636.2081	0	1746.181148
4+00	626.1026	637.6363	0	2276.288841
5+00	626.1983	638.7418	0	2678.87042
6+00	623.7928	639.5248	0	4148.359533
7+00	620.9918	639.9852	0	5963.086242
8+00	619.3553	640.1231	0	7082.786093
9+00	617.8775	639.9383	0	7957.465794
10+00	617.4121	639.4310	0	7928.344963
11+00	617.8908	638.6010	0	7044.973755
12+00	617.1991	637.4653	0	6756.803065
13+00	617.0776	636.2554	0	6075.104552
14+00	617.0342	635.0455	0	5383.457612
15+00	616.7089	633.8357	0	4885.8912
16+00	616.2649	632.6258	0	4473.768542
17+00	616.5230	631.4159	0	3732.436516
18+00	615.1962	630.2061	0	3789.179147
19+00	616.7306	628.9962	0	2565.065498
20+00	618.5459	627.7863	0	1474.230666
21+00	618.9746	626.5764	0	996.5961632
22+00	621.4171	625.5156	0	242.2898276
23+00	623.7444	625.0497	129.8830005	0
24+00	624.7046	625.2089	252.7868583	0
25+00	625.6807	625.9931	285.0543932	0
26+00	627.1512	627.4023	295.5917875	0
27+00	628.9049	629.4364	248.3015313	0
		Total =	1,211.62	88,991.43

LANE WIDTH (ft) =	16	
SHOULDER (ft) =	14	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	4	: 1

RAMP B

	ELEVATION (Feet)			
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)
0+00	633.7151	645.0000	0	2181.737715
1+00	631.2743	642.6500	0	2216.031777
2+00	628.4745	640.3000	0	2389.518193
3+00	625.6652	637.9500	0	2572.854649
4+00	624.1323	635.6000	0	2251.028213
5+00	624.1743	633.4320	0	1479.697833
6+00	625.2545	631.8094	0	733.0870388
7+00	627.4010	630.7421	0	127.019906
8+00	630.1763	629.9317	384.8924485	0
9+00	633.0744	629.1217	1283.843927	0
10+00	633.5231	628.6107	1582.868912	0
11+00	635.7615	628.6552	2368.947074	0
12+00	641.4936	629.2553	4764.737007	0
13+00	646.9628	630.4109	7382.093156	0
14+00	650.8931	631.7586	9212.986934	0
15+00	648.9513	632.8594	7076.718124	0
16+00	636.1894	633.7102	877.844105	0
17+00	633.5503	634.3110	211.3766756	0
18+00	633.4818	634.6618	147.8544856	0
19+00	632.0807	634.7625	0	40.51746693
20+00	631.2677	634.6133	0	127.6545749
21+00	631.4925	634.2141	0	45.37408895
22+00	632.3135	633.5649	137.5567369	0
23+00	633.6791	632.6657	537.7944297	0
24+00	631.8914	631.5165	409.5744857	0
25+00	629.1268	630.1173	175.9177979	0
26+00	626.6478	628.4681	60.90301039	0
27+00	624.5637	626.5689	38.05439236	0
28+00	622.5780	624.4197	58.20671607	0
29+00	621.0059	622.0217	172.109542	0
		Total =	36,884.28	14,164.52

LANE WIDTH (ft) =	16	
SHOULDER (ft) =	14	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	4	: 1

RAMP D						
	ELEVATION (Feet)					
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)		
0+00	628.3693	632.0000	0	156.6197057		
1+00	627.2906	631.4049	0	221.3803131		
2+00	626.4588	631.1958	0	309.8712107		
3+00	625.7331	631.6118	0	487.0379615		
4+00	625.4792	632.6527	0	711.3312101		
5+00	624.8062	634.3186	0	1179.444431		
6+00	624.4093	636.6095	0	1817.467095		
7+00	624.2969	639.5254	0	2664.539432		
8+00	623.8912	642.7970	0	3875.804825		
9+00	623.3517	646.0701	0	5343.162541		
10+00	623.6085	649.3432	0	6656.625643		
11+00	623.2829	652.6163	0	8400.034074		
12+00	622.3922	655.8894	0	10656.62656		
13+00	622.1904	659.1626	0	12736.54877		
14+00	621.9120	662.4146	0	15032.82902		
15+00	622.0934	665.4099	0	16995.31444		
16+00	623.5526	668.0827	0	17877.91568		
17+00	625.4169	670.4328	0	18237.33331		
18+00	624.8039	672.4604	0	20252.12546		
19+00	630.6438	674.1654	0	4881.572346		
20+00	638.5693	675.5478	0	4106.093827		
21+00	628.3115	676.6077	0	5447.450864		
22+00	619.3696	677.3449	0	0		
23+00	617.9480	677.7596	0	0		
24+00	617.9480	677.8517	0	0	No fill needed for bridge	
25+00	636.3412	677.6212	0	0	over WB and EB I-69	
26+00	631.4561	677.0681	0	0		
27+00	618.4082	676.1924	0	28937.49344		
28+00	618.2529	674.9942	0	27972.93583		
29+00	617.0418	673.4734	0	27689.60338		
30+00	617.6215	671.6300	0	25521.85444		
31+00	618.3229	669.4640	0	0		
32+00	617.6772	666.9755	0	0		
33+00	622.4088	664.1643	0	0	No fill needed for bridge	
34+00	620.9494	661.0306	0	0	over WB and EB I-69	
35+00	620.0629	657.6609	0	0		
36+00	616.3503	654.2798	0	0		
37+00	616.7199	650.8986	0	11050.42873		
38+00	621.4482	647.5174	0	6810.587899		
39+00	626.9270	644.1362	0	3292.069697		
40+00	625.8852	641.0290	0	2639.000416		
41+00	624.8476	638.5456	0	2219.449248		
42+00	624.9220	636.6872	0	1706.948954		
43+00	626.2890	635.4538	0	1104.74768		
44+00	628.7941	634.8455	0	515.5186647		
45+00	631.4132	634.8420	0	130.6077572		
		Total =	-	297,638.37		

LANE WIDTH (ft) =	16	
SHOULDER (ft) =	14	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	2	: 1

RAMP F				
	ELEVATION (Feet)			
STATION	EXT	PROP	CUT (cyd)	FILL (cyd)
0+00	619.3361	619.3494	337.5230321	0
1+00	618.9365	619.8817	182.7839133	0
2+00	618.7625	620.4140	82.6466177	0
3+00	618.9690	620.9463	41.43718125	0
4+00	619.3065	621.4787	18.28835483	0
5+00	620.0456	622.0110	42.88703612	0
6+00	621.2069	622.5433	125.4944603	0
7+00	620.6568	623.0756	0	9.604511868
8+00	618.3390	623.6079	0	453.841506
9+00	617.1906	624.1402	0	828.6210065
10+00	618.0579	624.6725	0	747.2406559
11+00	617.8992	625.2048	0	918.7471971
12+00	620.0729	625.7245	0	531.820647
13+00	621.0181	625.9531	0	389.3506584
14+00	623.0472	625.7768	0	46.35595957
15+00	628.3275	625.3095	1018.841014	0
16+00	625.7777	624.8295	524.1475706	0
17+00	623.8707	624.3495	257.0117613	0
		Total =	2,631.06	3,925.58

LANE WIDTH (ft) =	16	
SHOULDER (ft) =	14	
PAV. THICKNESS (ft) =	2.33	
STATION INCREMENT (ft) =	100	
EMBANK Ratio =	4	: 1

Appendix D: Cost Estimate Tables

Pay Item Code	Item Description	Unit	Quantity	Unite Price	Ext. Amount
Removal and Construction					
2010001	Clearing	Acre	7.7	$ 7,875.00	$ 60,638
2020004	Tree, Rem, 6 inch to 18 inch	Ea	102	$ 231.00	$ 23,562
2040006	Curb and Gutter, Rem	Ft	0	$ 9.02	$ -
2040009	Fence, Rem	Ft	14142	$ 1.24	$ 17,522
2040011	Pavt, Rem	Syd	58155	$ 5.81	$ 337,676
2050016	Excavation, Earth	Cyd	215117	$ 3.57	$ 767,968
2050010	Embankment, CIP	Cyd	331922	$ 3.68	$ 1,219,813
3030020	Geotextile Separator	Syd	145994	$ 3.15	$ 459,881
3037011	Open-Graded Dr Cse, 16 inch, Modified	Syd	145994	$ 19.25	$ 2,810,385
3077011	Shoulder, Cl II, 11 inch	Syd	30304	$ 13.65	$ 413,650
4040113	Underdrain, Outlet Ending, 6 inch	Ea	8	$ 115.50	$ 924
4040043	Underdrain, Pipe, Open-Graded, 6 inch	Ft	1860	$ 4.20	$ 7,812
6020224	Shoulder, Nonreinf Conc, High Performance	Syd	30304	$ 35.00	$ 1,060,640
6027011	Conc Pavt, Nonreinf, 11 inch High Performance	Syd	71660	$ 27.50	$ 1,970,650
8080002	Fence, Woven Wire with Steel Post	Ft	14142	$ 2.73	$ 38,608
8167011	Turf Establishment, Performance	Syd	106972	$ 4.20	$ 449,282
8220001	Shoulder Corrugations, Ground or Cut, Conc	Ft	61770	$ 0.68	$ 42,158
					$ 9,681,168
Drainage					
	Culv, Rem	Ea	1	$903.00	$ 903
	Culv End, Rem	Ea	2	$247.00	$ 494
	Culv, Conc	Ft	50	$210.00	$ 10,500
	Culv, End Sect	Ea	2	$577.50	$ 1,155
					$ 13,052
Safety					
2040008	Guardrail, Rem	Ft	15000	$2.00	$ 30,000
8070002	Guardrail, Type T	Ft	16790.0	$20.00	$ 335,800
8070023	Guardrail Anch, Bridge Det T2	Ft	8	$1,500.00	$ 12,000
8070043	Guardrail Approach Terminal, Type T	Ea	4	$2,520.00	$ 10,080
8070051	Guardrail Departing Terminal, Type T	Ea	4	$638.10	$ 2,552
					$ 390,432
Total Estimate Cost					**$ 10,084,652**
1000001	Mobilization, Max.	LS	1	5%	$ 504,233
1040001	Contractor Staking	LS	1	2%	$ 201,693
2090001	Project Cleanup	LS	1	1%	$ 100,847
					$ 10,790,578

Roadway	
Total	**$10,790,578**
Structures	
S29 of 77111 - Ramp D over WB 69	**$2,977,000**
S23 of 77111 - Ramp D over I-94	**$5,286,000**
S15 of 77111 - EB I-69 over I-94	**$6,566,000**
Total	**$14,829,000**
Maintaining Traffic	
Assumption - 8% of	$25,619,578
Total	**$2,049,566**
Signing	
Assumption - 1% of	$25,619,578
Total	**$256,196**
Mobilization	
Assumption - 5% of	$25,619,578
Total	**$1,280,979**
Total Estimate Cost	
10% Contingency of	**$2,561,958**
Total	**$31,768,277**