Bridging the Gaps in the Emerald Necklace:

Route 9 to Brookline Avenue

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Route 9 to Brookline Avenue

Presented to:

Peter Furth, Senior Design Project Professor

April 2008

From:

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Preface

The City of Boston and the Town of Brookline are interested in developing continuous networks of paths to make travel easier and safer for cyclists and pedestrians. This desire is evident in many recent publications written by organizations, citizens, and government agencies from both cities, including the Boston Bicycle Plan (1) and the Brookline Parks, Open Space and Recreation Strategic Master Plan (2). Such a connected network of paths would provide better service to users who would in turn increase their use of the network. This would result in more people walking or using bikes to commute, exercise, and travel to and from places that are farther away within the city.

The positive effects of a connected bicycle network are in agreement with many other initiatives already in place in Boston and Brookline. By increasing the number of people who walk or ride bikes, public health will also improve. Also when people commute to work by bike or on foot, it helps to reduce congestion and pollution caused by vehicles. By connecting existing trail infrastructure in these cities, people will be more connected to different sections of the city, improving and encouraging their mobility.

Currently there are four major bikeways around the Boston area: the Esplanade along the Charles River, the Jamaicaway paths in the Emerald Necklace, the Southwest Corridor Bikepath, and the Harbor Walk, which are shown in Figure 0.1.

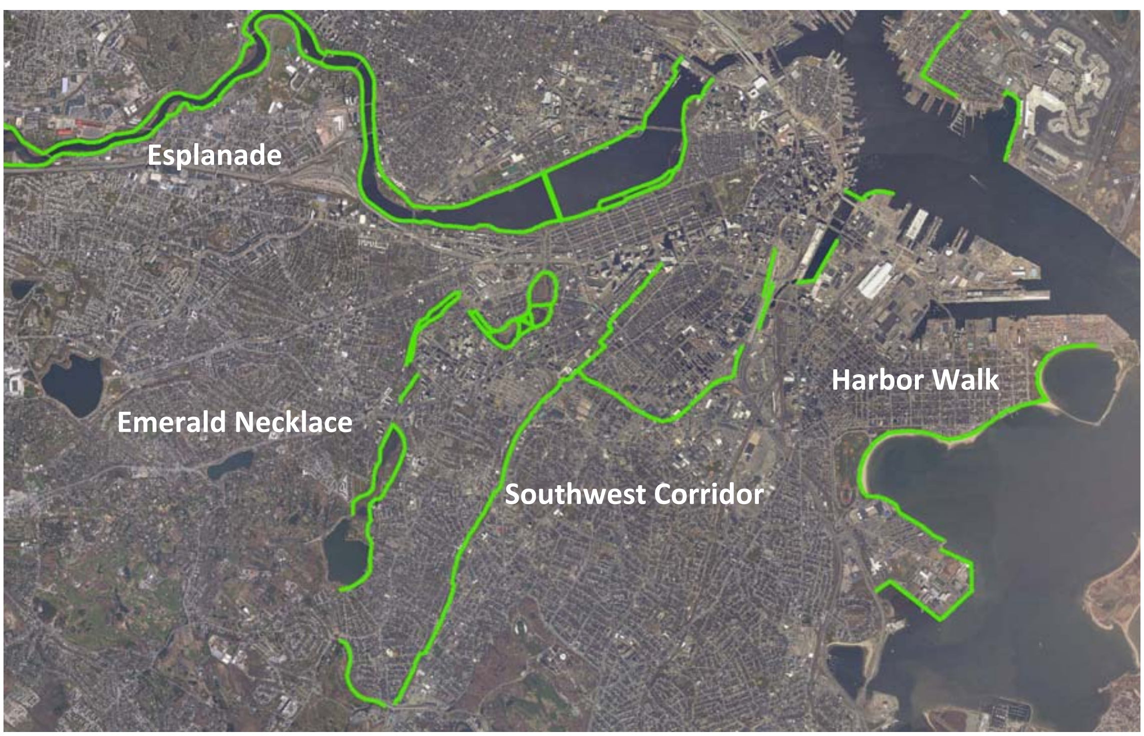


Figure 0.1 – Major bike paths in Boston

These segmented paths carry a multitude of users who use the paths for both recreation and travel between several major population centers and attractions throughout the Boston area. Many of these paths traverse parts of the city's parkland which provides users with peaceful scenic surroundings as opposed to the congestion of city streets. This makes the existing paths ideal for recreational use, and provides important access to many of the historic and passive parklands in these cities.

While the current trails do provide some recreation and commuter use, they do not provide a clear route for those trying to travel across the city. Disjointed paths make it difficult for bicyclists to safely and effectively reach their destinations, and discourage many people from using them altogether. These paths would serve a more prominent role if they were continuous and safe in order to encourage more people to walk or ride bicycles instead of driving to their destinations.

The challenge is to incorporate these paths into a densely populated city with physical limitations, historic landmarks, and a wide variety of users. It is possible to make the necessary connections and provide these cities with a world class path system without having a negative impact on the current traffic conditions. The focus of these types of projects is to complete them in a way that improves the level of service for all users, and improves the environment of the specific site.

Figure 0.2 – Existing paths along Riverway.

1. Introduction

The Emerald Necklace is the oldest linear greenway in the country and was designed by the famed landscape architect Frederick Law Olmsted, Sr. as a means for recreation and flood control for the Muddy River. Located on the border between Brookline and Boston, the parks have played a significant role in the development of both of these cities and have been listed on the National and State Register of Historic Places.

Olmsted's original design from the late 1800's was for a linear park along the banks of the Muddy River that stretched from the Charles River to Jamaica Pond and then south to include the Arnold Arboretum and Franklin Park. His vision was to create a natural haven for park users to retreat to as an escape from the busy life of the city. Three paths ran through these parks: a carriage path, a bridle path, and a walking path which provided access to all users of his time. As time progressed and the surrounding area developed, the parks have retained much of their shape and landscape. The parks were restored in 1929 and again in the 1980's as part of the Massachusetts Olmsted Historic Landscape Preservation Program.

Although a great deal has been done to preserve the original character of these parks, things inevitably change. Carriages and horses have given way to cars and bicycles and some significant changes have occurred in these parks. Though Olmsted's paths can still be seen, the carriage paths have become paved roads and a paved multiuse path has improved the bridle path in many areas. The continuity of these linear parks has been disrupted at several locations by roads carrying heavy volumes of traffic. These "breaks" in the Emerald Necklace mean that a user today cannot travel the length of the path from north to south without coming into many conflicts with traffic. Figure 1.1 shows the existing paths in green and the breaks in red.

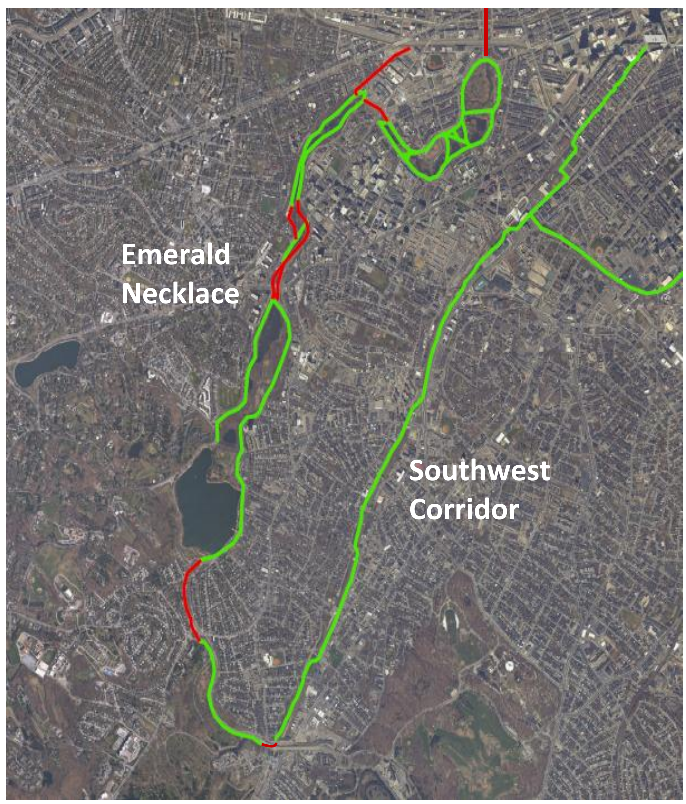


Figure 1.1 – Breaks in the Emerald Necklace

These paths originate to the south in the Jamaica Plain area and move north by Mission Hill, through Brookline, the Longwood Medical area, by the Landmark Center and finally end in the Back Bay Fens. There is also a proposed "Charlesgate Connection" (3) which would tie these paths in the Back Bay Fens all the way to those along the Esplanade. It is no question that the Emerald Necklace paths provide a vital connection to many densely populated areas in Boston and Brookline.

This project focuses on an important central section of the Emerald Necklace paths which has disappeared. The area between Route 9 and Netherlands Road, including Brookline Avenue, is heavily traveled by cyclists and pedestrians without a continuous safe route for them to use. Although some paths exist in these parks, they are interrupted by several major roadways where pedestrians and cyclists are forced to cross heavy vehicle traffic with no planned crossings or means of protection. This creates conditions which are not only difficult, but dangerous and discouraging to many potential users including walkers, cyclists, and the handicapped. A total of four critical crossings which need to be addressed were identified. These crossings are shown below in Figure 1.2.

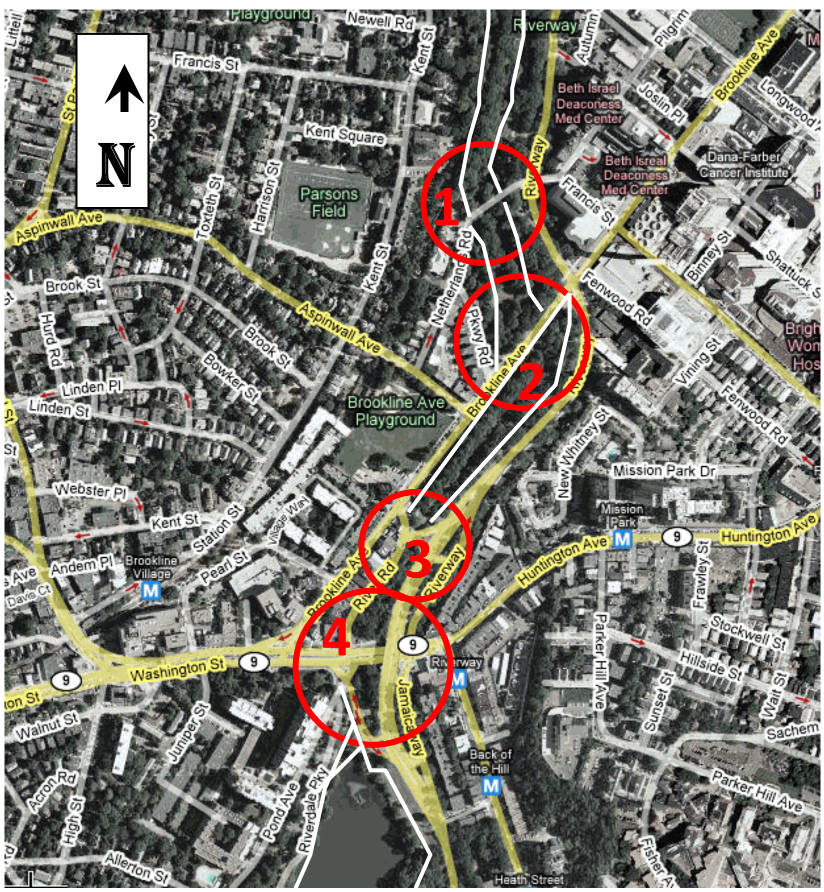


Figure 1.2 – Site map of major intersections

By bridging the gaps between Netherlands Road in the north and the major bicycle paths along Jamaicaway in the south, this connection can be re-established. Our proposal, a continuation of the 2007 study by Northeastern Students, creates a route for bicyclists and pedestrians to get from one part of the Emerald Necklace path to the other with as little interruption as possible. This plan also improves access to two stretches of parkland along the Riverway which have been isolated by these roadways as well. A major part of this project is the crossing at Route 9, which when completed will be a big step towards making Boston and Brookline more accessible on foot and by bike.

The idea of an improved pedestrian and cyclist crossing at Route 9 is something that is important to the residents of this area. In fact, Brookline Representative Barney Frank secured funding for improvements at the crossing of Route 9 as part of the National "Safe Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users", signed into law on August 10, 2005. According to this Act, $600,000 of funding is available to "design and construct signal crossing and other safety improvements to Emerald Necklace Greenway Bicycle Trail, (in the) Town of Brookline." To date, no commitments have been made to implement these much needed improvements.

The following chapters will detail the route alternatives and specific designs developed by this study. The chosen designs have been selected with consideration given to the need for improvement in conditions of path users, level of service to vehicular traffic in the area, and the preservation or improvement of conditions in these historic parks.

2. Route Alternatives

In order to make a continuous connection along the Emerald Necklace paths from the Longwood Medical Area to the Leverett Pond in the south, there are four major areas which need to be improved. At each of these locations multiple alternatives were considered. Some routes were found to be impractical because of specific restraints, while those that were feasible were analyzed in order to see their impact on both vehicular traffic as well as pedestrian and cyclist movements.

2.1 Netherlands Road

Two paved multi-use paths come from Landmark Center in the north along the Muddy River. After these paths cross Netherlands Road, the single paved path disappears and is replaced by two dirt paths. These two unpaved paths are remnants of what were formerly Olmsted's bridle path and walking path. These paths have not been well maintained and have been damaged by erosion which discourages people from using them.

On the Brookline side of the Muddy River, a single established gravel path runs through the park connecting Brookline Avenue to the paths coming from the north of Netherlands Road. This existing path travels over a historic Olmsted bridge with a staircase which does not allow for handicap or bicycle use.

In order to accommodate all users and increase use of this underdeveloped parkland, four routes were considered for this location. The four routes are shown in Figure 2.1. For the most part they coincide with those proposed by the Northeastern study of 2007.

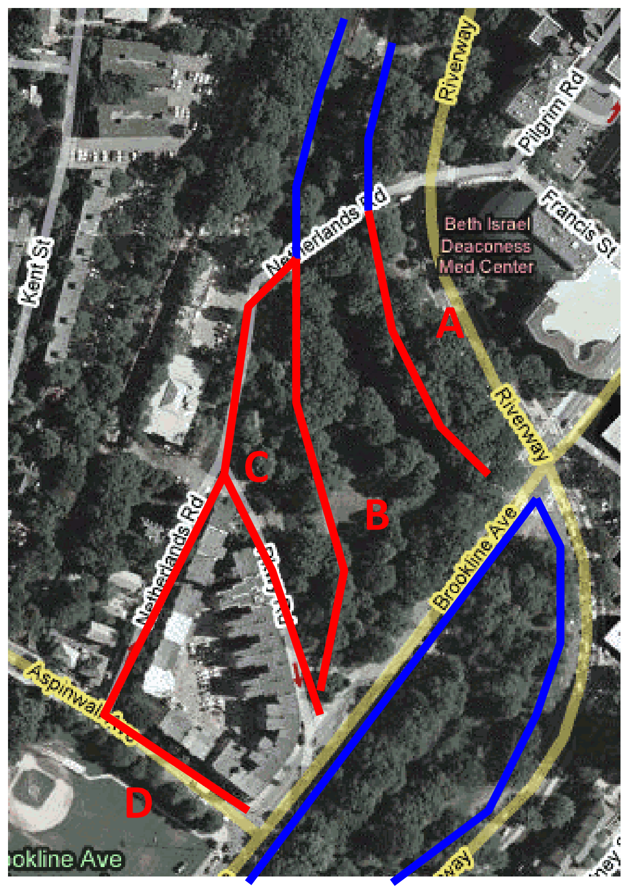


Figure 2.1 – Route Alternatives for Netherlands Road Crossing

On the Boston side of the river, route A is a hybrid of the two existing paths. A single paved path will invite more pedestrians into this open area of parkland while accommodating bicyclists and the handicapped and eliminating the current erosion problems.

Figure 2.2 – Olmsted's historic staircase

On the Brookline side there are several possibilities. Route B is the existing gravel path running through the park which is accessible for some pedestrians but is not feasible for people with bicycles, wheelchairs, or strollers because of the existing staircase (Figure 2.2). Since it is part of Olmsted's design, the staircase cannot be altered which requires an alternate route to accommodate these path users.

The third route, Route C, involves widening the sidewalks along Netherlands Road to carry cyclists to Parkway Road where bike lanes have been added. These two bike lanes, one running north and one running south, carry cyclists from Netherlands Road to Brookline Avenue. A traffic study was performed on Netherlands Road which determined that during the peak hours, the majority of southbound traffic is cutting through to avoid the lines at the intersection of Brookline Avenue and The Riverway. In order to calm traffic through this area and eliminate much of this cut through, Route C involves changing Netherlands Road to a one way northbound road from Riverway to the Brookline Water and Sewer Commission. A right turn lane would then be added to The Riverway so as not to decrease the level of service at the intersection with Brookline Avenue.

Route D, the fourth alternative, follows Netherlands Road and turns onto Aspinwall Avenue where riders can continue until reaching Brookline Avenue. Alternative D was ruled out because it requires riders to travel farther out of their way, and this would result in noncompliance by cyclists. The final design uses Routes A, B (for walking path users only), and C, in conjunction with each other in order to provide service to all types of users. The analysis for this area can be found in Chapter 3.

2.2 Brookline Avenue

The next major interruption to these paths to contend with is the crossing of Brookline Avenue. Brookline Avenue has existing sidewalks on the west and a multi-use path on the east which is set back 22 feet from the road and elevated 2 feet from street level. Currently there are two crosswalks on Brookline Avenue, one at the intersection of Riverway and one at the intersection of Aspinwall Avenue. Both of these crosswalks connect to the bike path on the east side of Brookline Avenue.

Three possible locations for crossing Brookline Avenue were considered. The first crossing is at the existing crosswalk at the intersection of Riverway and Brookline Avenue. This crossing is ideal for linking the paths on the Boston side of the Muddy River because it already has established crosswalks and a pedestrian walk-phase. A crossing here will become especially important if these paths are paved for increased use as discussed in the previous section and Chapters 3 and 4. This alternative connects segments A and E (Olmsted's bridle and walking paths) shown in Figure 2.3.

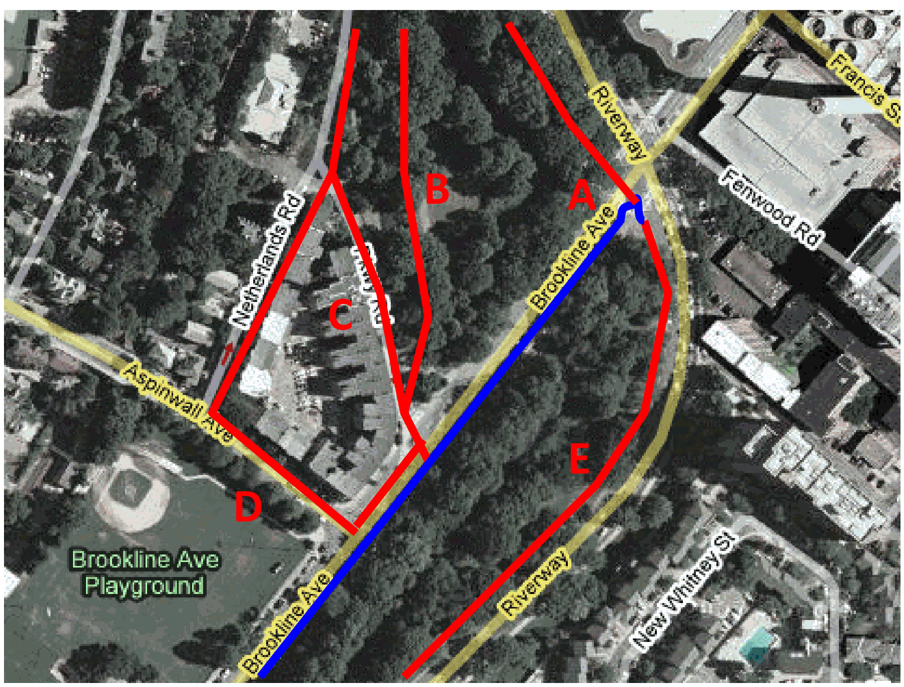


Figure 2.3 – Alternatives for crossing Brookline Avenue

The next possibility would be ideal for use in conjunction with Route D shown in Figure 2.3. This crossing uses the existing crosswalk at the intersection of Aspinwall and Brookline Avenue. There is currently a signalized intersection which connects Route D to the bike lane (shown in blue) in Figure 2.3. However this route would require that there be a bike lane following Netherlands Road which would continue on Aspinwall Avenue (see previous section).

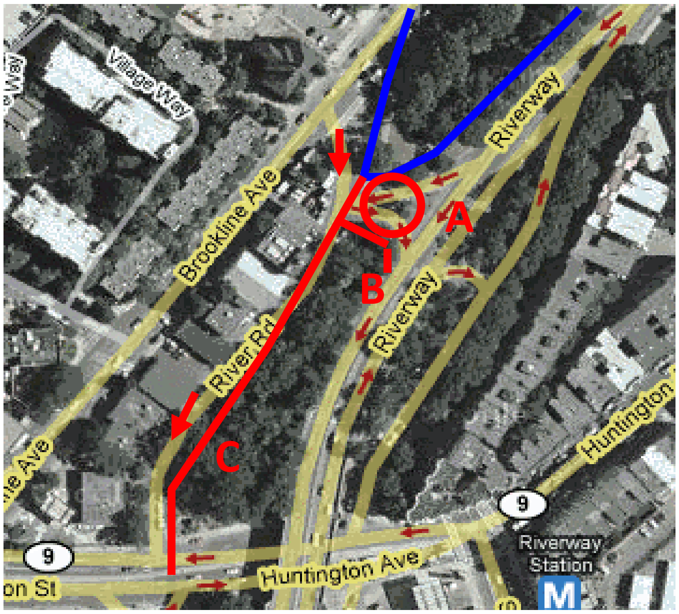
The final possibility would put the crossing at the intersection Brookline Avenue at Parkway Road, intersection shown in Figure 2.4. This alternative works best for pedestrians and cyclists using Routes B and C as proposed in the previous section for Netherlands Road. This alternative involves adding a crosswalk and bike crossing across Brookline Avenue at the Parkway Road intersection where Route B and C merge (Figure 2.3). This would involve the addition of a pedestrian signal. To minimize the impact on traffic, a signal could be timed in sync with the existing signals at the nearby Aspinwall intersection. Although this alternative requires the most work, it would be the best location for the crossing so that the pedestrians and cyclists can cross immediately instead of traveling farther to the Aspinwall crossing as they are likely to do anyways. The analysis for this section can be found in Chapter 4.

Figure 2.4 – Intersection of Parkway Road and Brookline Avenue

2.3 River Road

The existing paths along the Muddy River between Brookline Avenue and the Riverway merge north of the Riverway on/off ramps at River Road. At this fork, the Emerald Necklace paths disappear entirely until after the crossing at Route 9.

Two options were assessed for improving these ramps for the Riverway at this location. The first option was to add a rotary to the on and off ramps, as shown in Figure 2.5 (Route A). While a rotary was considered as a replacement for the current on/off ramp, this alternative was eventually rejected. A rotary would not sufficiently decrease the speed of traffic coming off The Riverway to allow for a safe crossing. This meant that a circle did little to improve the current condition and it provided a lower level of service and safety to pedestrians and cyclists.



The second alternative, shown as Route B in Figure 2.5, is to close the off ramp from Riverway onto River Road and redirect the current on ramp to reduce the speed of traffic. The existing ramps are shown in the picture in Figure 2.6. Through traffic studies, it was determined that the volume of traffic exiting the Riverway is minimal. If this off ramp is closed, motorists would simply have to exit at the previous Brookline Avenue intersection. By re-shaping this intersection to slow traffic, the safety of both cars and path users will be increased.

Figure 2.5 – Route Alternatives for River Road

In conjunction with both of the above alternatives, a considerable redesign of River Road was found to be necessary. Currently there is only a small dirt path which is insufficient for many path users. In order to continue the Emerald Necklace paths, River Road can be made a one-way southbound road shown by Route C in Figure 2.5. This allows for the removal of a lane, and a multiuse path can then be added to the park along the Muddy River. Of these possibilities, the safest alternative for cyclists and pedestrians is to use both Route B and Route C. The analysis for this section can be found in Chapter 5.

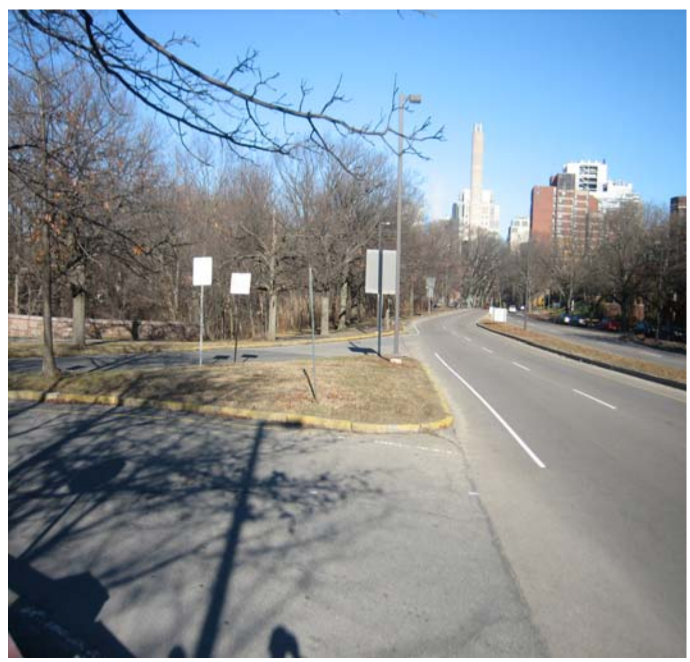


Figure 2.6 – Riverway on/off ramps

2.4 Route 9

The crossing at Route 9 is the final major element required to fill these gaps in the Emerald Necklace paths. It is also the most difficult and unsafe intersection for pedestrians and cyclists to cross because it is an extremely busy road with a high volume of traffic. The only existing measure to help pedestrians cross at this location is a three foot wide curb cut in the median. The existing paths, shown in blue in Figure 2.7, run on either side of Leverett Pond and meet just south of Route 9.

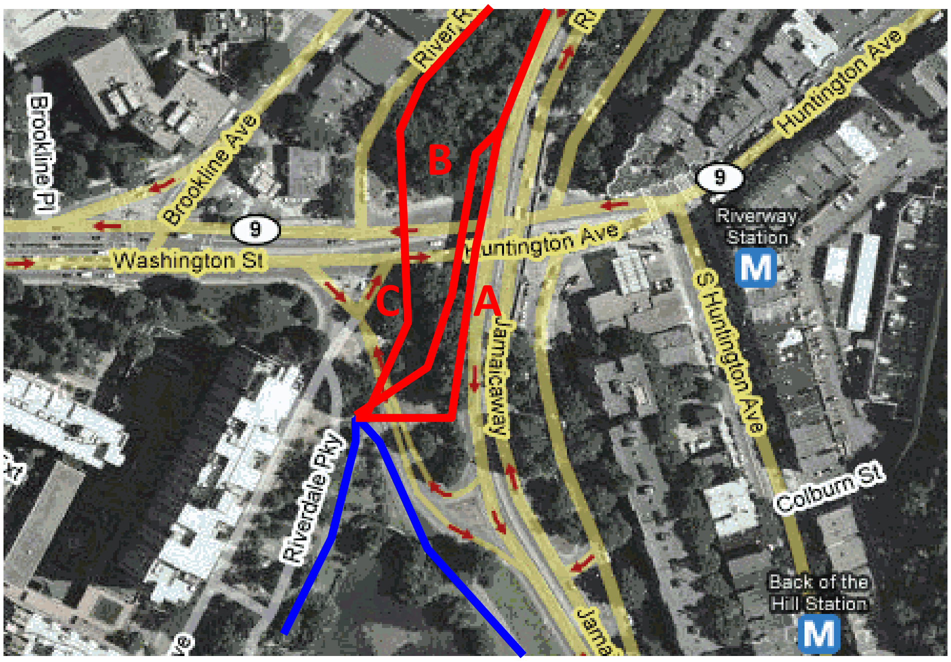


Figure 2.7 - Route 9 Alternatives

At this location, Route 9 is about 85 feet wide, with a narrow three and a half foot median in the center. This narrow median is not large enough for a bicyclist or a pedestrian with a baby carriage to wait on. During most of the day there is also a high volume of traffic on this road as well.

The most important change needed at this location is an improved at-grade crossing, shown by Route C in Figure 2.7. The proposed redesign of Route 9 would actually be more organized for traffic and pedestrians alike. This is the only part of Route 9 which is this wide; both to the east and west of this area the road narrows to two lanes in each direction. Changes at this location would need to include a widened median and a reduction in the width of the road in this area to two eastbound lanes and two westbound travel lanes with an extra lane to maintain the bus stop currently located under the Curley Overpass. By implementing these changes, pedestrians would have a much safer at grade crossing at this location because they can cross two lanes of traffic then have a refuge at the new median. After consideration, it would be better if this crossing remained unsignalized because a cycle time at this location would need to be greater than most pedestrians and cyclists would wait for due to the nearby signalized intersections to the east and west.

Figure 2.8 – Existing crossing of Route 9

While an at-grade crossing would provide a great improvement to this crossing, an elevated crossing is needed to provide cyclists and pedestrians with truly uninterrupted service through this busy area. Two alternatives for the elevated path were considered. One option is to create a separate footbridge to the west of the Curley Overpass over Route 9, shown as Route B in Figure 2.7. This route would involve a single footbridge spanning the road in conjunction with a boardwalk to the north which follows the embankment of The Riverway between the Muddy River and the roadway as well as a major re-grading of the south embankment of The Riverway. Though this does provide path users with uninterrupted service over the highway, it is quite costly in construction with added cost for maintenance. Additionally there is a question about whether residents would want a footbridge at this location because it would impede the view of the historic Curley Overpass.

Another option is to use the existing Curley Overpass to provide a grade-separated crossing for bicyclists and pedestrians. Shown as Route A in Figure 2.7, this alternative is much more economical and less disruptive to the environment. By redesigning the lane configuration on the bridge deck, a 13 foot space can be provided for pedestrians and cyclists. This can be achieved while maintaining the flow of traffic and keeping both vehicles and path users safe.

The intent is that one of the grade-separated crossing alternatives would be implemented along with the at-grade route to provide path users with a safe and direct means of crossing Route 9 while not negatively impacting traffic at this important location. The analysis for this area can be found in Chapter 6

3. Netherlands Road

After assessing the alternatives for the Netherlands Road area, a three route system (Figure 3.1 below) in conjunction with a one-way restriction on Netherlands Road through Riverway Park was found to be the most beneficial solution. On the Boston side of the Muddy River, a paved path will be added where Olmsted's walking and bridle paths run currently, similar to other sections of the Emerald Necklace. This is shown as Route A and it allows cyclists and the handicapped a route to pass through this section of park between Netherlands Road and Brookline. The second path, Route B, is the existing route which travels over Olmsted's bridge on the Brookline side of the Muddy River. While the stairs on this path do not allow access to cyclists or the handicapped, it is ideal for enjoying this section of park by foot and is true to Olmsted's original design. Finally, the most significant improvement to this area is the addition Route C, which consists of two side by side bike lanes running north and south along the length of Parkway Road.

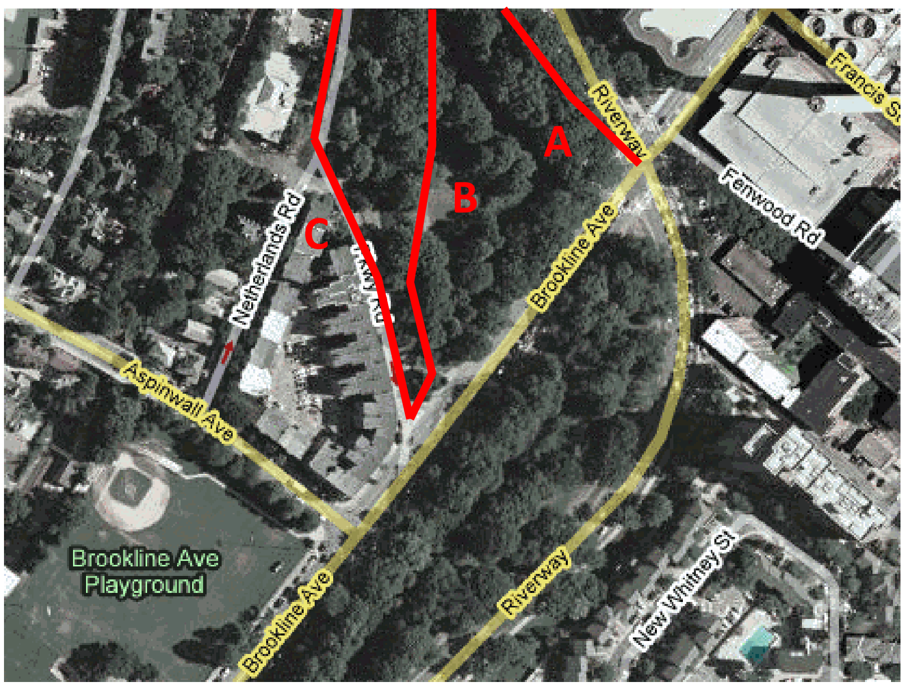


Figure 3.1 – Netherlands Road Final Design

Observation of Netherlands Road revealed that virtually all southbound traffic was cutting through to avoid the light at the intersection of Brookline Avenue and The Riverway. In order to make all routes safer for path users, Netherlands Road should be made a one way northbound street. There is a significant amount of northbound traffic; also it is important to keep this open for both trucks accessing the Brookline Water and Sewer Commission on Netherlands Road and emergency vehicles accessing the nearby hospitals to the north. Traffic on this road will then be reduced to predominantly residents. The low speed and volume of vehicles in this area due to the redesign of Netherlands Road allows for the addition of two side-by-side bike lanes on Parkway Road which will follow the east curb of this street.

3.1 Traffic and Route Analysis

Three alternatives were considered to make this section of Netherlands Road safer: making it one-way northbound towards the Longwood Medical Area, closing it, and making it one-way southbound towards Brookline Avenue. The last two options were ruled out because this is an important route for emergency vehicles traveling north to hospitals in the Longwood Medical Area. Traffic analysis was performed to determine what effects changing Netherlands Road to one-way, northbound would have on traffic at the intersection of The Riverway and Brookline Avenue.

The existing conditions were compared at this location to the one-way option. From this analysis, it was determined that forcing the current traffic that cuts through Netherlands Road to continue south on Riverway and turn at right Brookline Avenue, would negatively affect this southbound movement. In the AM peak hour, v/c experiences a minor increase from .53 to .67, but the larger more concerning increase in v/c ratio occurs in the PM peak hour, with v/c increasing from .99 to 1.34 (Figure 3.2).

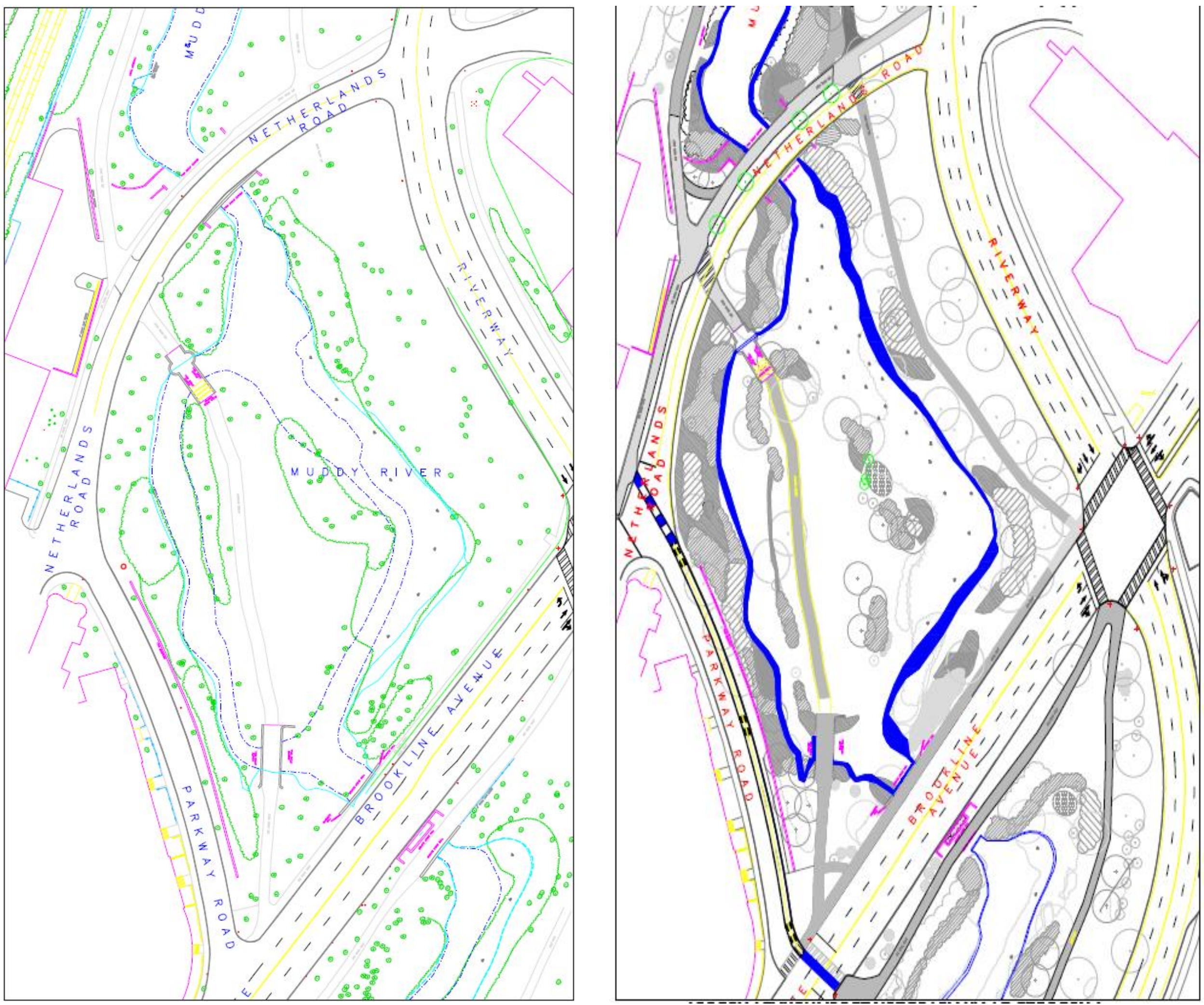
Intersection	Location	Existing			One-way			One-way w/ RTL		
		v/c	Delay	LOS	v/c	Delay	LOS	v/c	Delay	LOS
AM Riverway at Brookline Avenue	SB (Thru/Right)	0.53	28.1	C	**0.67**	**30.8**	C	**0.47**	**27.1**	C
	SB (Right)	n/a	n/a	n/a	n/a	n/a	n/a	**0.44**	**27.9**	**C**
PM Riverway at Brookline Avenue	SB (Thru/Right)	0.99	65.6	E	**1.34**	**199.4**	**F**	**0.95**	**57.6**	E
	SB (Right)	n/a	n/a	n/a	n/a	n/a	n/a	**0.85**	**54.1**	**D**

Figure 3.2 – AM and PM Peak Signalized Intersections

Based on this information, another analysis was done to determine if adding an exclusive right-turn lane added to the southbound movement on Riverway would improve these conditions. In order to achieve the necessary storage capacity in this lane, it would need to stretch 400 feet which is approximately the length of the park between Netherlands Road and Brookline Avenue along The Riverway, shown in Figure 3.3. The results shown in Figure 3.2 indicate that the v/c ratio and delay will improve slightly during both peak hours with the addition of this right turn lane. A difference of .20 in volume to capacity ratio, between the one-way and one-way with a right turn lane, demonstrates that this added lane would mitigate the additional traffic impact of making Netherlands Road one-way. In order to maintain the current level of service to vehicles in this area while improving the quality of the paths, this right turn lane will need to be added.

3.2 Design of the Boston Side Path

A comparison of the existing conditions and the proposed design for the Netherlands Road area is shown below in Figure 3.3. This design incorporates the roadway changes discussed above for the area between Netherlands Road and Brookline Avenue.



Existing Conditions **Proposed Design**

Figure 3.3 – Existing Conditions and Proposed Design for Netherlands Road

The proposed right-turn lane is shown in the drawing above on The Riverway at the intersection of Brookline Avenue. This southbound lane would alleviate the traffic that would have turned onto Netherlands Road. The existing path on the Boston side of the Muddy River coming from the north will continue across Netherlands Road to the new path shown above. The route this path follows is a hybrid of the current bridle and walking paths which gives users a single, clearly defined, paved path. The 8 foot wide path will start to follow the walking path after crossing Netherlands where it is closer to the river and merge into the bridle path in order to reach the current crosswalk at The Riverway and Brookline Avenue. This improved connection between Netherlands Road and Brookline Avenue will be more accessible to all users and aesthetically pleasing than the existing paths. The design for the Netherlands Road crossing on the Boston side is shown in Figure 3.4.

The right-turn lane on Riverway will take 5,400 square feet away from the parks but this will be reclaimed in different locations throughout the project. The removal of a lane on Netherlands Road alone will add 2,400 square feet of parkland back to the parks. Although there is a loss of 3,000 square feet of parks in this area, it is also important to remember that this new design stays true to Olmsted's original vision that the parks are a place to escape from the noise of the city. Currently, Netherlands Road disrupts the peace of this section of park. The redesigned road makes the area much quieter and less traveled by motorists.

Figure 3.4 – Chosen design for Netherlands Road

3.3 Design of the Parkway Road Bike Paths

On the Brookline side there will be two paths. One is the existing Olmsted path which remains unaltered. In addition to this, a 3.5 foot southbound bike lane will run alongside a 4 foot northbound bike lane which runs next to the east curb line on Parkway Road. The existing sidewalk on the west of Netherlands Road will be widened to 10 feet to accommodate users from the Boston side path crossing to Parkway Road. Path users can then travel along these sidewalks on the west side of Netherlands Road. This path and dual lane system will connect to the existing path coming from the north along the Muddy River to the paths on the south side of Brookline Avenue.

Netherlands Road will remain two-way from the Brookline Water and Sewer Commission to the intersection of Parkway Road in order for vehicles to have access to this facility. A 7 ½ foot combined northbound and southbound striped bicycle path will cross over to the east side of Netherlands Road at the intersection with Parkway Road and continue along Parkway Road until reaching Brookline Avenue.

In order to maintain safety at the junction of Netherlands Road and Parkway Road, Netherlands Road northbound will have a stop sign at Parkway Road as well as one on the southbound side where the path crosses over. The design for the Brookline side path is shown in Figure 3.5.

Figure 3.5 – Side-by-side bike paths on Parkway Road

3.4 Cost Estimate for Netherlands Area

The total estimated cost for the entire Netherlands Road area, specifically from the north side of Netherlands Road to the sidewalk on Brookline Avenue, is $150,153. For the purposes of cost estimation, the area is broken into the majority of Netherlands Road, Parkway Road, the path on the Boston side of the Muddy River, and the added right turn lane on The Riverway. These sections have been broken out in this manner because each segment can be completed separately. The cost estimate for this section is shown in Figure 3.6.

There are several variable costs in this price. One example is the trees that are listed to be installed; red maple was selected because it is a native tree but another could easily be used. Also, if the curb is removed and not salvaged, a new curb would need to be installed. However, if the curb is salvaged, this will erase the cost of new curb but will increase the cost of removal because it requires more delicate work. All storm drains are assumed to be capped in the estimate, not removed, and new ones will be installed along with vitrified clay pipe to tie them into the existing system. A five mile haul for the roadway and path excavation was assumed because the excess material will need to be removed from site.

Item	Quantity		Unit Cost From ENR (3)	Total w/ metro area multiplier
Netherlands Road				
Tree removal to 24" dia.	3	EA.	480	$1,699
Tree loading and trucking	3	EA.	370	$1,310
Tree - Red Maple	4	EA.	170	$802
Tree installation	4	EA.	850	$4,012
Remove and stack granite curb	324	L.F.	20	$7,646
Roadway excavation - 5 mile haul	44	C.Y.	5.25	$275
Path excavation - 5 mile haul	68	C.Y.	6.50	$523
Base - pavement path - crushed stone 3" thick	88	S.Y.	3.2	$332
Cap storm drain	3	EA.	385	$1,363
Replace storm drain	3	EA.	1300	$4,602
Install 6" dia. vitrified clay pipe for storm drain	96	L.F.	13	$1,473
Install ADA ramps	12	S.Y.	70	$991
Base - pavement path - crushed stone 3" thick	1017	S.Y.	3.2	$3,840
Install pavement - 10' path with bulb outs	1017	S.Y.	15	$17,999
Replace granite curb	324	L.F.	31	$11,852
Striping - solid yellow	1066	L.F.	1	$1,258
Striping - stop line	71	L.F.	3	$251
Striping - crosswalk	747	S.F.	2	$1,763
			Subtotal	**$61,993**
Parkway Road				
Striping - solid white	628	L.F.	1	$741
Striping - solid yellow	400	L.F.	1	$472
Striping - bike symbols and arrows	60	S.F.	2	$142
			Subtotal	**$1,355**

Item	Quantity		Unit Cost From ENR (3)	Total w/ metro area multiplier
Boston Side Path				
Install pavement - 8' path	420	S.F.	15	$7,434
Install ADA ramps	8	EA.	70	$661
Fine grading	420	S.F.	3	$1,487
			Subtotal	**$9,582**
Right Turn Lane on Riverway				
Tree removal - To 24" dia.	3	EA.	480	$1,699
Tree loading and trucking	3	EA.	370	$1,310
Remove and stack curb	473	L.F.	20	$11,163
Cap storm drain	2	EA.	385	$909
Light pole - remove and reset	1	EA.	3000	$3,540
Excavate soil - small dozer - small area	600	S.Y.	2.5	$1,770
Replace curb	460	L.F.	31	$16,827
Replace storm drain	2	EA.	1300	$3,068
Base - pavement path - crushed stone 3" thick	600	S.Y.	3.2	$2,266
Install pavement - 12' roadway	600	S.Y.	15	$10,620
Install ADA ramps	8	S.Y.	70	$661
Fine grading	5400	S.F.	3	$19,116
Striping - white dashed	380	L.F.	0.33	$148
Striping - solid yellow	415	L.F.	1	$490
Striping - right turn arrow	16	S.F.	2	$38
Striping - crosswalk	1514	S.F.	2	$3,573
Striping - stop line	12	L.F.	2	$28
			Subtotal	**$77,224**
			Total	**$150,153**

Figure 3.6 – Cost Estimate Chart for Netherlands Road Area Construction

4. Crossing Brookline Avenue

With the path design for the Netherlands Road area completed, the optimal location for crossing Brookline Avenue becomes much clearer (see Chapter 3 for an explanation of the design of the Netherlands Road Paths). The path on the Boston side of Muddy River coming from Netherlands Road approaches Brookline Avenue at the intersection of Riverway. There is already an existing pedestrian crossing at this location with crosswalks and an exclusive pedestrian phase in the timing, so no changes were needed at this location. The other path which travels through the park and the proposed bike lanes on Parkway Road which come from Netherlands Road both meet Brookline Avenue at Parkway Road. In order to provide path users with the highest level of service, the most efficient location for a crossing is at the intersection of Parkway Road and Brookline Avenue. At this location, a signalized pedestrian crossing has been recommended to provide pedestrians with a safe, efficient means of crossing Brookline Avenue while at the same time having virtually no negative effect on traffic at this location. The proposed crossings for Brookline Avenue are shown in Figure 4.1.

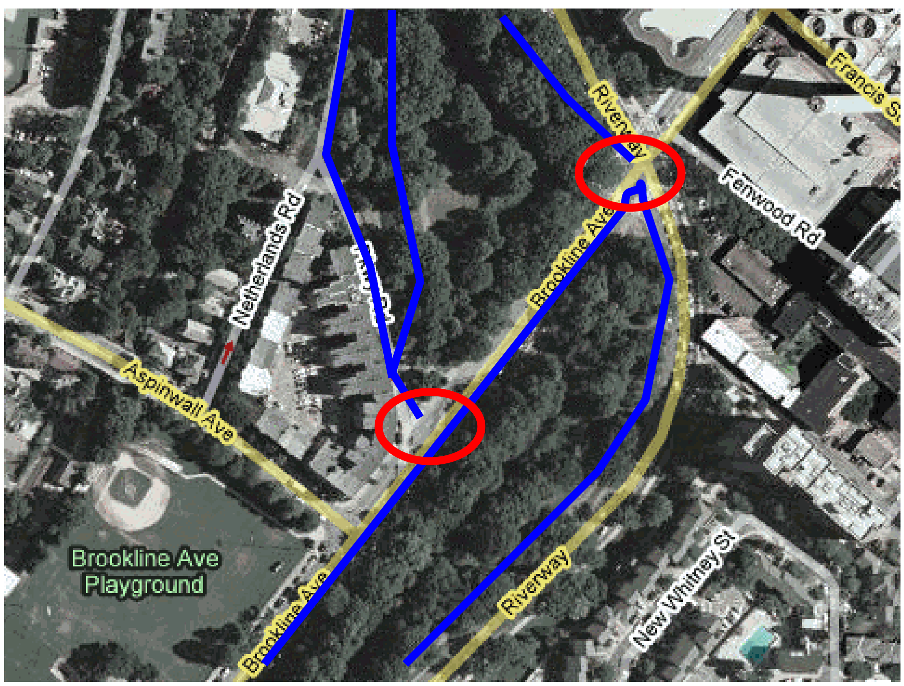


Figure 4.1 – Proposed Crossing for Brookline Avenue

4.1 Traffic Analysis

By rerouting the cut through traffic from Netherlands Road to the new right turn lane on The Riverway, the volume of traffic on Brookline Avenue is unchanged. These rerouted cars simply originate from one intersection further upstream than before which has no effect on the intersection at Aspinwall Avenue and Brookline Avenue. The volume of traffic turning out of

Parkway Road will decrease from 405 vehicles to only 25 vehicles in the PM peak hour as a result of this shift. This re-routed traffic will be required to go through the signalized intersection at Brookline Avenue at Riverway instead. With the addition of the exclusive right turn lane on The Riverway, any added delay from the 380 vehicles/hour shifted to this intersection will be minimal.

The addition of another stop light over Brookline Avenue is something which was originally rejected because of its effect on the already busy vehicular traffic at this location. Many attempts were made to tie the pedestrian traffic at Parkway Road in with the already signalized intersection located just one block down at Aspinwall Avenue. Though these improvements were determined to be more cost effective, any attempts to route path users to this location proved futile. Users would continue to cross at the most direct point, therefore using the Aspinwall Avenue intersection was not a valid solution. It was determined that a crossing for pedestrians was needed at the intersection of Parkway Road and Brookline Avenue.

The addition of a pedestrian signal is an ideal solution for this location. First, the curb at the opening of Parkway Road on Brookline Avenue was narrowed to make this intersection meet more like a "T" intersection. The pedestrian and cyclist crosswalks are installed perpendicular to the curb at this intersection with a stop light on either side as shown in Figure 4.2. These lights are tied into the same controller as the lights at the intersection of Aspinwall Avenue. This means that these lights will be timed the same as those at the Aspinwall intersection, and will operate with the same cycle. There are a few seconds of delay from one light to the other which allows a vehicle to get through both intersections and not get trapped in the space between them. This is shown in the timing diagram in Figure 4.3 and the time space diagram in Figure 4.5 below. If the button is pushed at the pedestrian crossing, the pedestrian phase in Aspinwall's existing cycle is activated and allows pedestrians at both locations to cross Brookline Avenue safely. Cars turning left out of Aspinwall Avenue cue up at the pedestrian light to the south of the Parkway Road crosswalk.

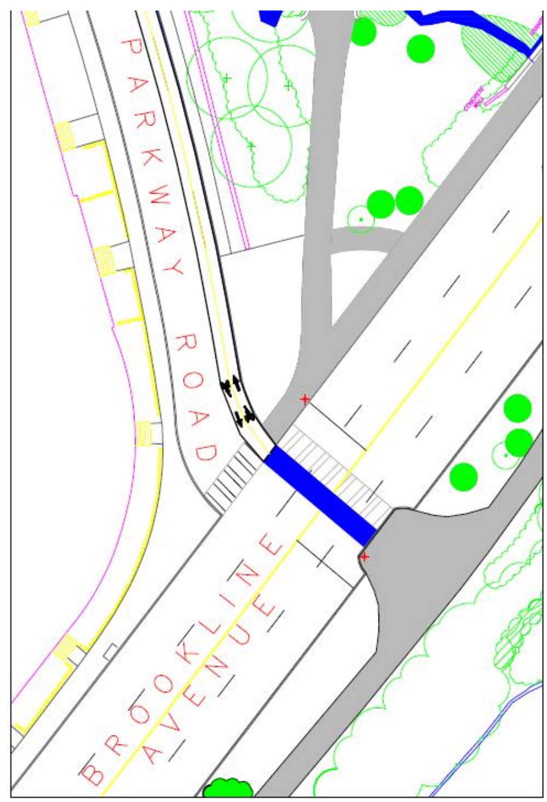


Figure 4.2 – Improved Crossing at Brookline Avenue

Traffic exiting from Parkway Road is controlled by the signal to the south of the crosswalks. The green light for Parkway Road will run concurrently with the pedestrian phase at Parkway Road as well as the green light and pedestrian phase of Aspinwall Avenue. The timings for these lights are shown in Figure 4.3. It is also important to remember that the volume of traffic exiting at this location has been minimized because of the lane closure on Netherlands Road. Figure 4.4 shows the stages for the light changes on Brookline Avenue at Parkway Road and Aspinwall Avenue.

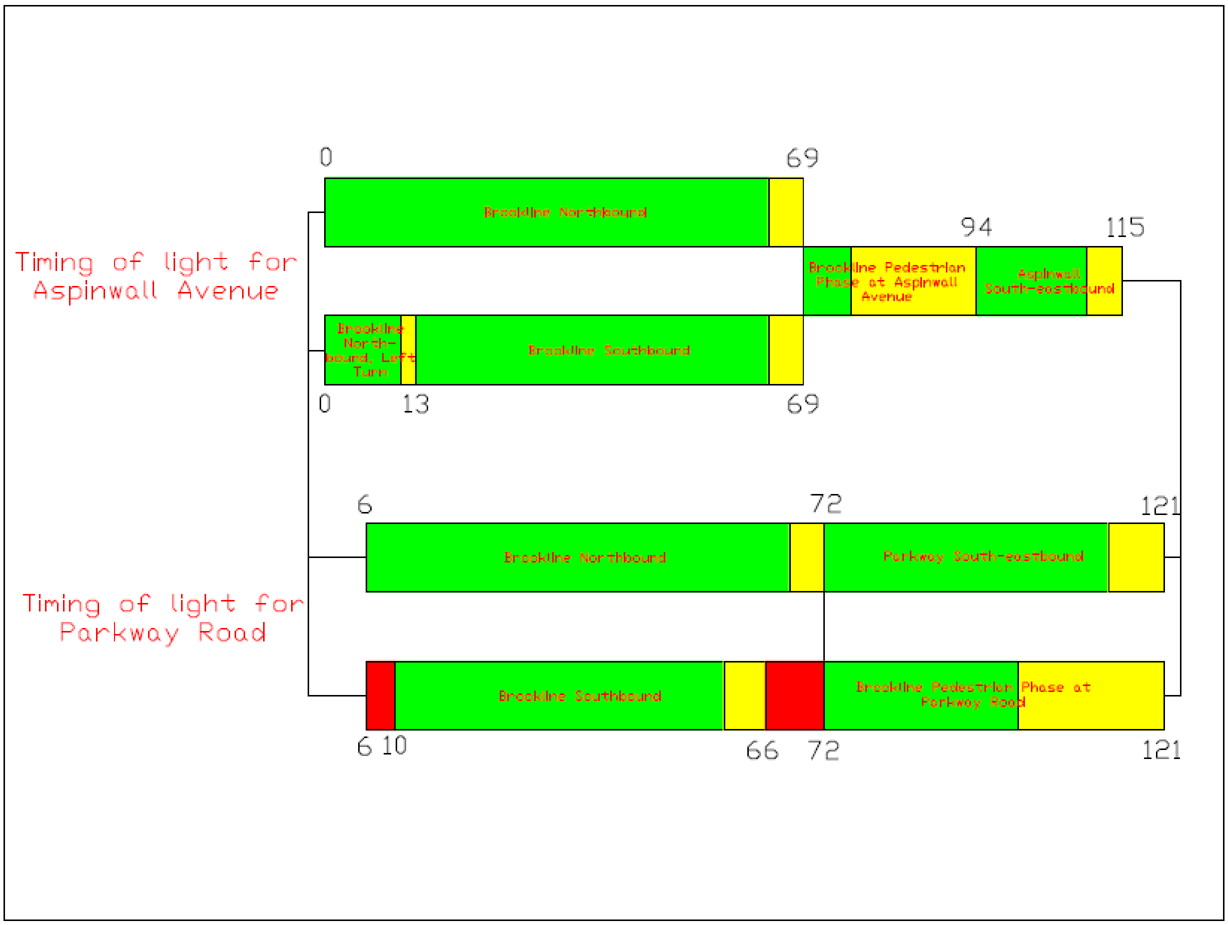


Figure 4.3 – Light Timing for Aspinwall Avenue and Parkway Road

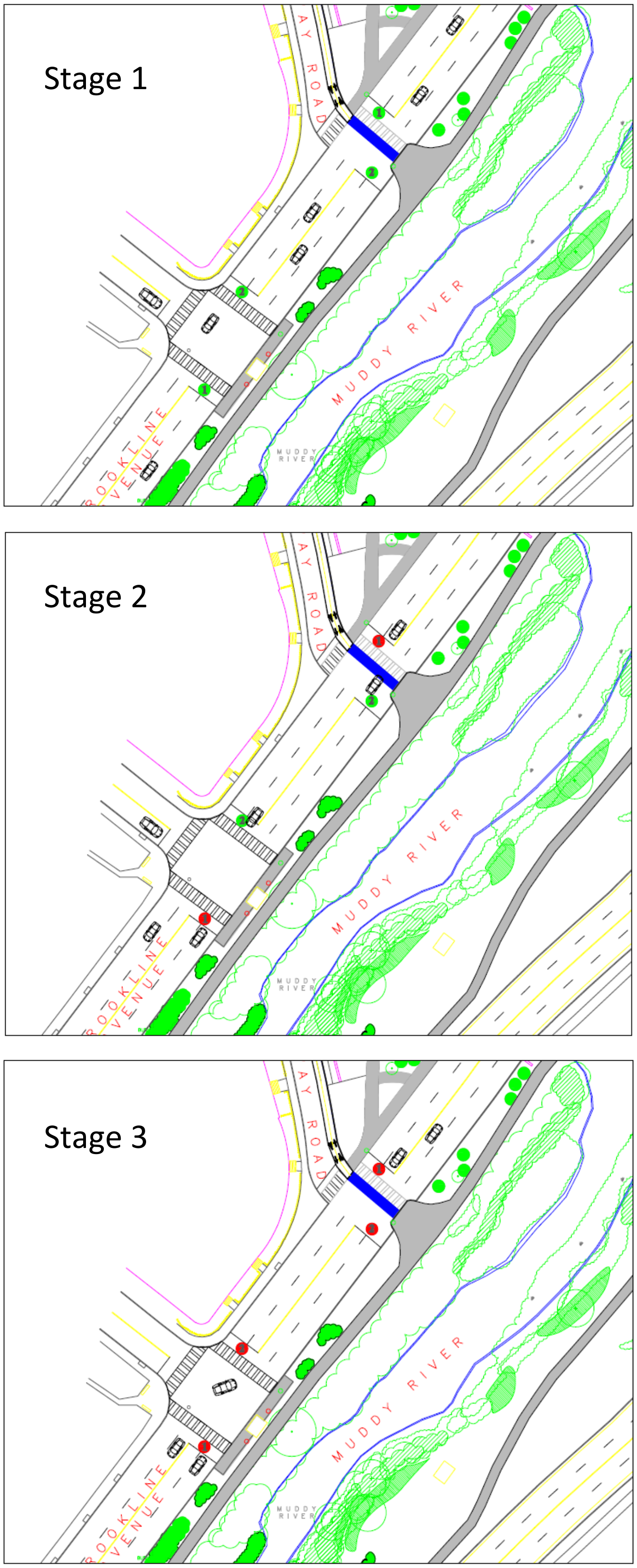


Figure 4.4 – Light Stages for Brookline Avenue, Parkway Road, and Aspinwall Road

This means that a signalized pedestrian crossing on Brookline Avenue at Parkway Road will not add any delay or affect traffic at this location. The time-space diagram (Figure 4.5) shows that the new signal will be timed so that no vehicles will be caught between these traffic lights because one will have an additional 6 seconds of green time at the beginning and the end of the Aspinwall Road southbound movement. By adding the signal, pedestrian and cyclist crossing safety is improved without adversely affecting vehicular traffic.

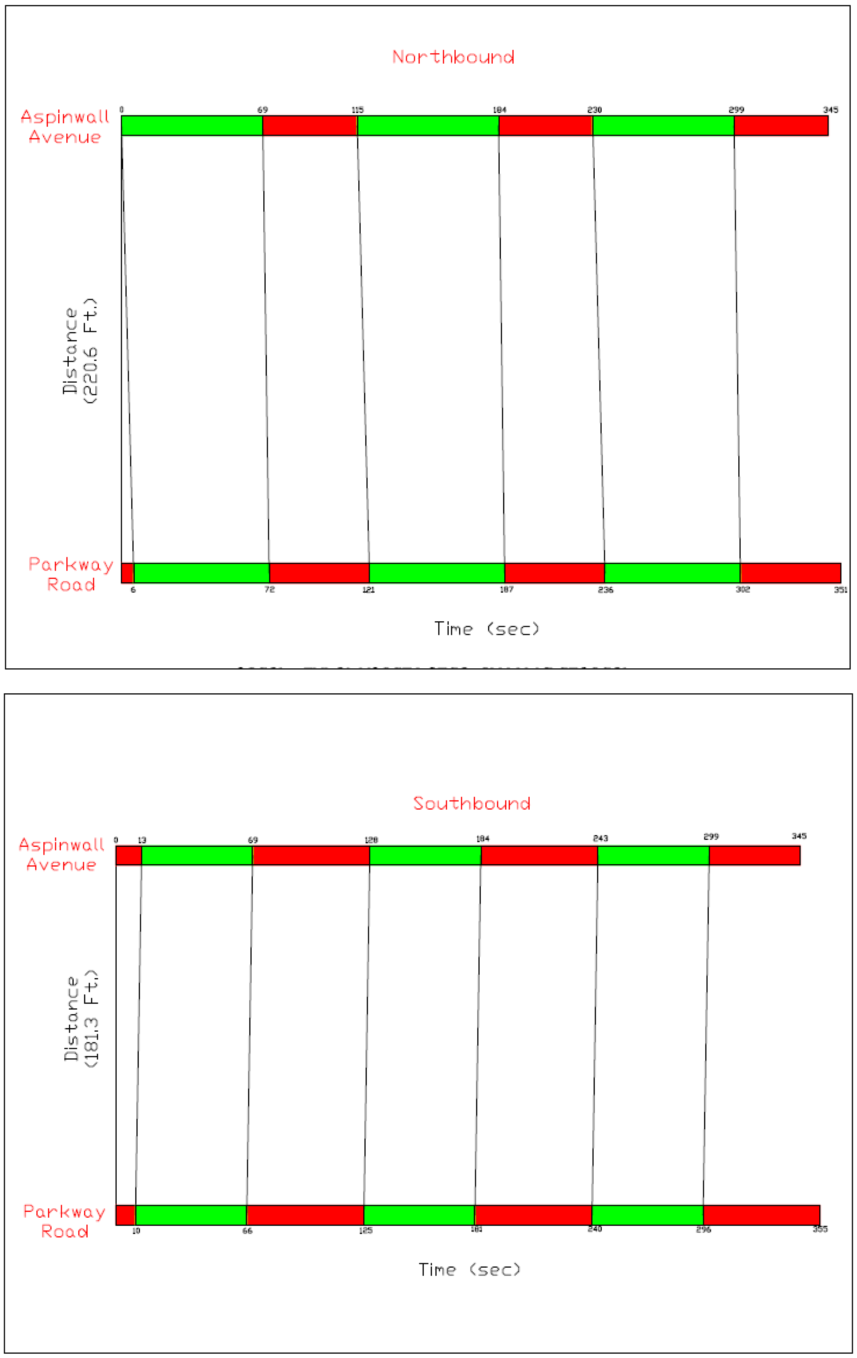


Figure 4.5 – Time-space Diagram for Brookline Avenue: Northbound and Southbound

4.2 Design of Boston Side path

The existing crossing on the Boston side of the path at the intersection of Brookline Avenue and The Riverway will remain mostly unchanged. The crosswalks on Brookline Avenue will be shifted slightly because of the added right turn lane on Riverway. These will need to be repainted and the existing signal will need to be moved to a new location. Once path users have crossed Brookline Avenue, there is an existing 8 foot multiuse path which runs along Brookline Avenue all the way to River Road. Currently there are also remnants of Olmsted's original bridle and walking paths running through the park located between the Muddy River and The Riverway. This entire half of the park is underused because there is no established path to walk on. In order to provide access to this part of the park to all users, Olmsted's walking path will be paved to create a defined path. The path will be paved in order to accommodate all users and to alleviate erosion problems which have left the dirt paths on this side in disrepair. The final design for the Boston side path is shown in Figure 4.6.

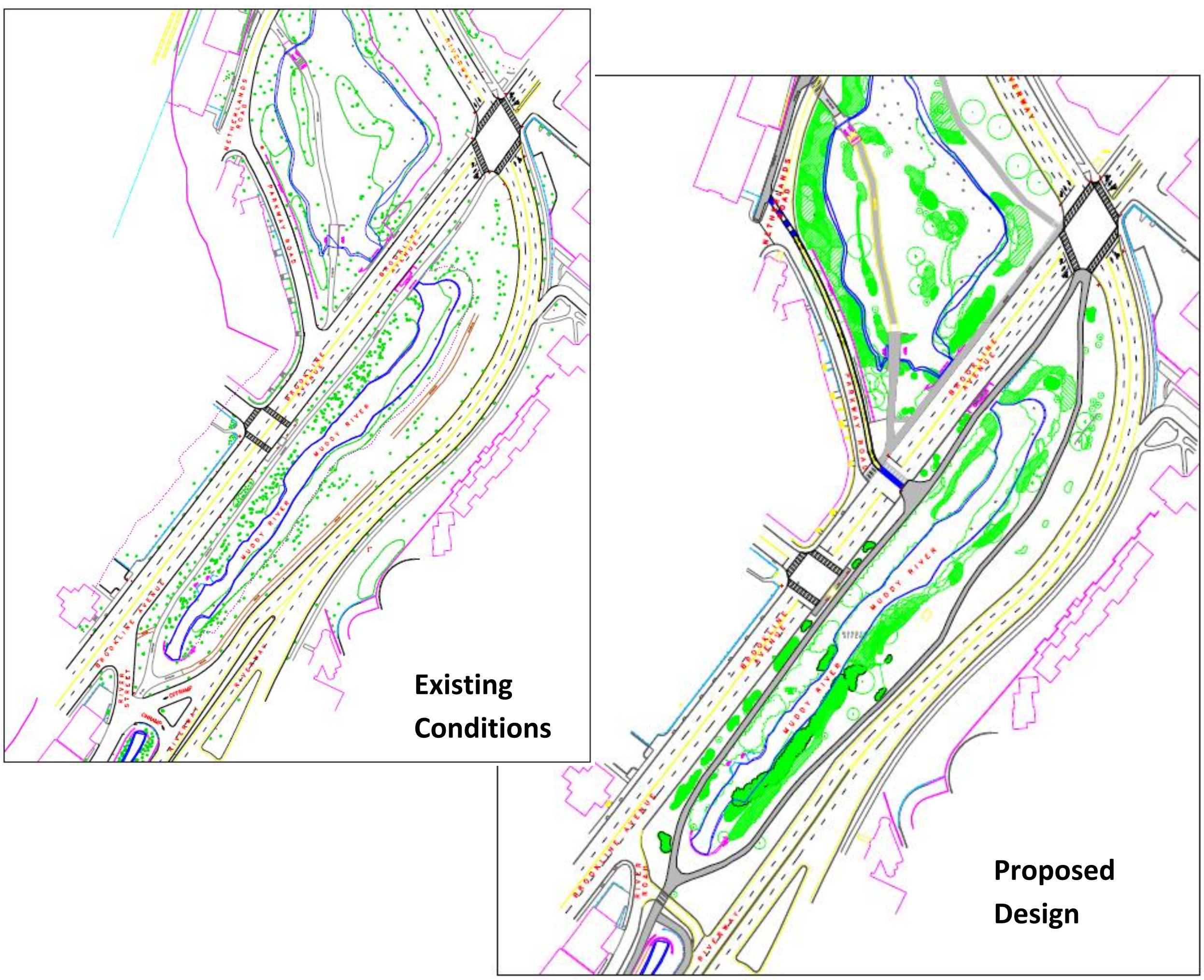


Figure 4.6 – Final design for the Brookline Avenue crossings

4.3 Design of Brookline Side path

On the Brookline side of the Muddy River, a crossing will be added to Brookline Avenue at Parkway Road. The width of Parkway Road at Brookline Avenue is decreased to 37 feet to slow traffic exiting from Parkway Road. A new crosswalk and a 7 ½ foot wide blue bike path will run from Parkway Road to a bulb-out on the east side of Brookline Avenue. The bulb-out will extend 6 feet into the 8 foot parking lane on Brookline Avenue. This bulb-out will necessitate the removal of three parking spaces in order to connect the path with the existing bike path on the east side of the street, but greatly improves the visibility of crossing path users. This route will then connect to the existing bike path on the east side of Brookline Avenue which continues south until it reaches River Road. The design for the Brookline Avenue crossing is shown above in Figure 4.6.

4.4 Cost Estimate for Brookline Avenue

The total estimated cost for all of the elements discussed in this chapter is $242,998. The cost is broken out into the Brookline Avenue crossing at Parkway Road and the path on the Boston side of the Muddy River, because they can be completely separately. This estimate is shown below in Figure 4.7. The estimated cost for all of the work required for the new crossing at Parkway Road will be $67,001. The cost for the Boston path covers the work required to pave the path between Brookline Avenue and River Road.

Item	Quantity		Unit Cost From ENR (3)	Total w/ metro area multiplier
Brookline Avenue crossing				
Tree removal	2	EA.	480	$1,133
Tree loading and trucking	2	EA.	370	$873
Remove and stack curb	172	L.F.	20	$4,059
Roadway excavation - 5 mile haul	8	C.Y.	5.25	$49
Parking meter removal	3	EA.	400	$1,416
Remove and reset sign	2	EA.	400	$944
Signal pole	2	EA.	500	$1,180
10' signal post and base	3	EA.	750	$2,655
25' mast arm	2	EA.	3500	$8,260
Signal pole foundation	3	EA.	500	$1,770
Mast arm foundation	2	EA.	2500	$5,900
Pedestrian LED housing	3	EA.	1000	$3,540
12" vehicle - 1 way - 3 section housing	2	EA.	600	$1,416
Pedestrian push button	3	EA.	175	$620
3" NM Plastic UL (Item # 804.3) conduit	285	L.F.	55	$18,497
Interconnect cable	150	L.F.	2	$354
Replace curb	187	L.F.	31	$6,840
Base - concrete sidewalk - crushed stone 3" thick	6	S.Y.	15	$106
Install concrete - sidewalk 4" thick cast in place with wire mesh, base not incl.	430	S.F.	2.4	$1,218
Install paved sidewalk	119	S.F.	15	$2,104
Install ADA ramps	16	S.Y.	70	$1,322
Striping - stop lines	56	L.F.	2	$132
Striping - crosswalk	740	S.F.	2	$1,746
Striping - blue	367	S.F.	2	$866
			Subtotal	**$67,001**
Boston path				
Tree removal	5	EA.	480	$2,832
Tree loading and trucking	5	EA.	370	$2,183
Install paved sidewalk	9660	S.F.	15	$170,982
			Subtotal	**$175,997**
			Total	**$242,998**

Figure 4.7 – Chart for cost estimate for Brookline Area Construction

5. River Road On/Off Ramp

The multiuse paths on the east and west sides of the Muddy River, between Brookline Avenue and River Road, meet at the Riverway on and off ramps. The current Riverway on/off ramps pose a difficult crossing for cyclists and pedestrians because of the road configuration. In addition to this, only a narrow dirt trail exists along River Road to Route 9 on the other side of this on/off ramp.

Two designs were considered to improve the safety of pedestrians and cyclists at the on/off ramp for The Riverway. The first option was to install a small rotary to replace the existing on/off ramps and the second option was to remove the off ramp entirely. As mentioned in the route alternatives section of these findings, a traffic circle did little to improve the current condition and it provided a lower level of service and safety to pedestrians and cyclists. In order to maximize the pedestrians' level of service at this location and take the opportunity to convert some unnecessary pavement to parkland, the second alternative was selected. Both of these plans were considered in tandem with removing a lane on River Road. By making River Road a one-way, southbound street (Figure 5.1), the width of the road is reduced and this space can then be added to the adjacent parklands and used to accommodate a multiuse pedestrian path.

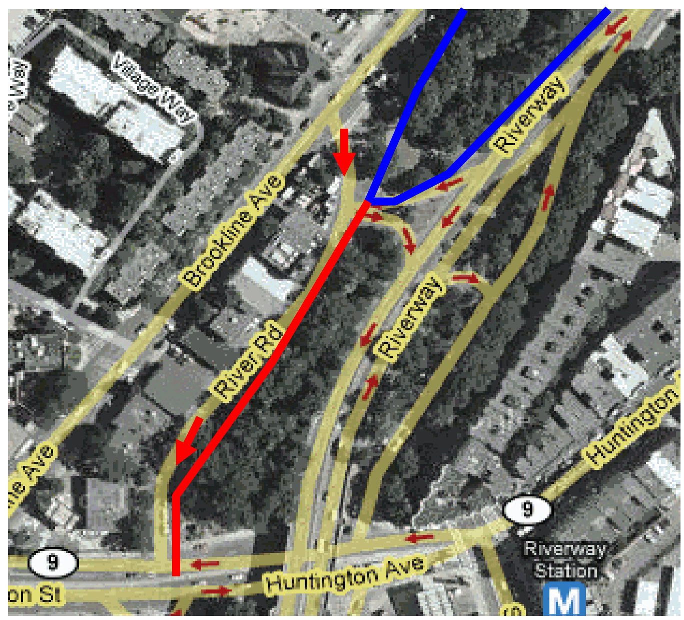


Figure 5.1 – Proposed Path location

5.1 Traffic Analysis

Currently most traffic on River Road falls in two categories: traffic accessing the local businesses on this street, and traffic cutting through to get onto either Brookline Avenue or The Riverway. By changing River Road to a one-way southbound road, it will redirect traffic currently turning right on to River Road from Route 9 to turn right at Brookline Avenue. This traffic can then travel up Brookline Avenue or take a right to access either the businesses on River Road or The Riverway. This adversely affects the westbound Route 9 movement at the intersection of Brookline Avenue by changing the v/c ratio from .83 to 1.06 in the AM peak hour (Figure 5.2) and from .74 to .81 in the PM peak hour (Figure 5.3). Designating the right lane as an exclusive right turn lane was considered but the volume of through traffic is too high for the other two lanes to accommodate it.

Because of the increase in v/c and delay, two alternative signal timings were evaluated for this intersection at the AM peak hour as well as another modified timing for the PM peak hour. One option for the AM peak hour is to alter the phase timings by shortening the Brookline southbound movement and adding it to the Route 9 westbound movement. In this scenario the new conditions for Route 9 westbound are comparable to the existing conditions although there is an increase in v/c for all Brookline southbound movements. The second alternative for the AM peak hour is to increase the cycle length at this intersection from 80 seconds to 90 seconds. This maintains existing conditions for the Route 9 westbound lanes while improving the Route 9 eastbound movement and not adversely affecting the Brookline southbound movement as much as the first alternative. This alternative is the best solution for the intersection of Route 9 and Brookline Avenue and will make up for any increase in traffic at this location for the AM hours.

Route 9 at Brookline Avenue												
Location	**Existing**			**River Road One-Way SB**			**Alternative 1 Phase timing changes for WB and SB approaches**			**Alternative 2 Increase cycle length to 90 seconds**		
	v/c	**Delay**	**LOS**	**v/c**	**Delay**	**LOS**	**v/c**	**Delay**	**LOS**	**v/c**	**Delay**	**LOS**
Route 9 EB (Left)	0.92	39.6	D	0.92	39.6	D	0.92	39.6	D	**0.82**	**31.7**	**C**
Route 9 EB (Thru)	0.75	28.6	C	0.75	28.6	C	0.75	28.6	D	**0.67**	**26.6**	C
Route 9 WB	0.83	36.5	D	**1.06**	**74.4**	**E**	**0.87**	**34.7**	**C**	**0.89**	**40.8**	D
Apartment NB	0.40	41.6	D	0.40	41.6	D	0.40	41.6	D	**0.44**	**49.3**	D
Brookline SB (Left)	0.34	33.1	C	0.34	33.1	C	**0.5**	**42.3**	**D**	**0.50**	**46.9**	**D**
Brookline SB (Thru)	0.36	33.4	C	0.36	33.4	C	**0.52**	**43.2**	**D**	**0.53**	**47.8**	**D**
Brookline SB (Right)	0.47	11.3	B	0.47	11.3	B	**0.5**	**14.1**	B	**0.49**	**13.8**	B

Figure 5.2 – AM Peak Signalized Intersections for River Road

The cycle length cannot be lengthened for the PM peak hour because it is already 120 seconds; therefore a dual ring timing plan was analyzed as an alternative. This timing plan improves conditions for the Route 9 eastbound and westbound movement from what is currently in place, and does not affect the Brookline Avenue southbound movement. This new timing makes up for any increase in traffic in this location for the PM hours.

Route 9 at Brookline Avenue									
Location	Existing			River Road One-Way SB			Dual ring timing plan		
	v/c	Delay	LOS	v/c	Delay	LOS	v/c	Delay	LOS
Route 9 EB (Left)	0.52	35.3	D	0.52	35.3	D	**0.60**	**39.3**	**D**
Route 9 EB (Thru)	1.15	120.7	F	1.15	120.7	F	**0.57**	**19.3**	**B**
Route 9 WB	0.74	34.1	C	**0.81**	**36.0**	**D**	**0.68**	**29.7**	**E**
Route 9 WB (Left)	-	-	-	**-**	**-**	**-**	**0.55**	**61.4**	**C**
Apartment NB	0.41	54.0	D	0.41	54.0	D	**0.41**	**54.0**	**D**
Brookline SB (Left)	0.76	50.4	D	0.76	50.4	D	**0.80**	**54.6**	**D**
Brookline SB (Thru)	0.79	52.5	D	0.79	52.5	D	**0.83**	**57.3**	**E**
Brookline SB (Right)	0.63	19.7	B	0.63	19.7	B	**0.92**	**46.8**	**D**

Figure 5.3 – PM Peak Signalized Intersections for River Road

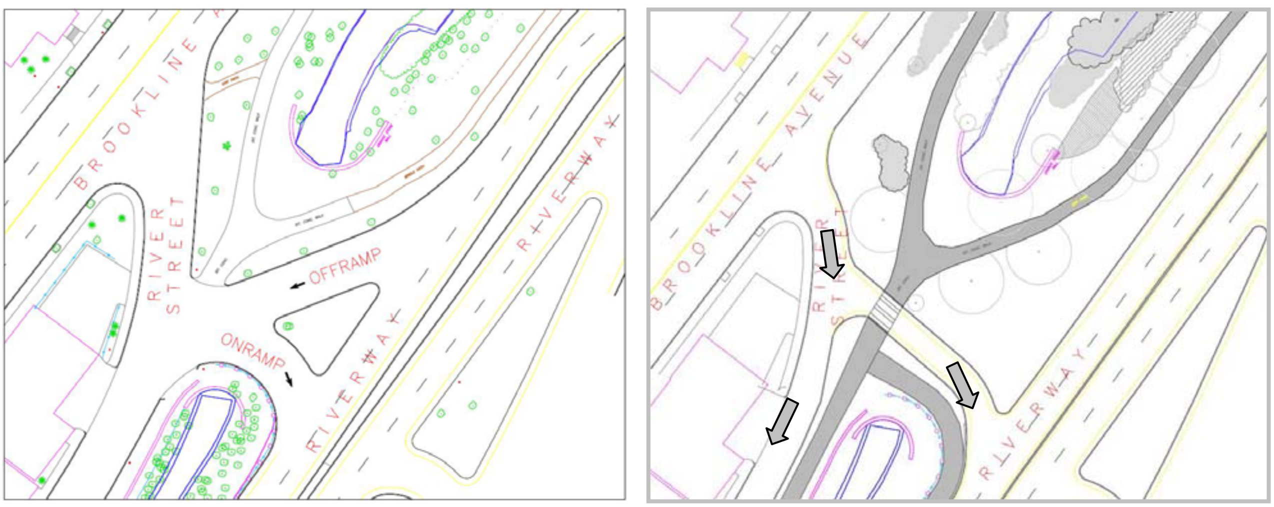
After performing a study of the traffic on the ramps for the Riverway, it was determined that the volume of traffic that uses the off ramp is minimal. In the AM peak hour only 21 vehicles used this ramp which is low enough to facilitate the closure of this ramp. It is important to note that most of the cars exiting at this point can easily exit at the new right turn lane added at the intersection of The Riverway and Brookline Avenue (see Chapter 3) just upstream of this off ramp. The on ramp carries significant traffic volumes of 250 vehicles during the PM peak hour. Closing this on ramp would force traffic to seek another point to access The Riverway. This traffic would have to access the Riverway at either the intersection with Brookline Avenue or on the south side of Route 9. Getting to the other on ramp south of Route 9 would require too much rerouting of traffic, and the Brookline Avenue intersection does not have any additional capacity, so the Riverway on ramp will be left open.

5.2 Design of River Road Path

Since analysis proved that there were no significant negative effects to traffic in the surrounding area, the preferred alternative for the River Road crossing is to close the Riverway off ramp and make River Road a one-way southbound. In addition to closing the Riverway off ramp, the on ramp will be moved and narrowed to slow traffic coming from off of Brookline Avenue. The new crossing will be narrowed from 52 feet across to 18 feet across, shown in Figure 5.4, and striped to make it more visible and safe. The section of River Road between Brookline Avenue and the Riverway ramps will be re-aligned with a sharper curve in order to slow vehicles down and provide a better view of the path crossing.

With the improved visibility and slower curve in the road, vehicles and cyclist will be able to see each other more easily. The distance from River Road to the crosswalk on the new on ramp was increased to ensure that cars were going as slow as possible while exiting the “S” curve and would not hit crossing path users. Although this road was redesigned with the safety of pedestrians and cyclists in mind, vehicles will still have the right-of-way. When bicycles arrive at this point they will have to yield to traffic on the on ramp. The improved path and roadway will provide better visibility for both vehicles and path users, but people on foot or bicycle are still in a better position to see traffic than the reverse. The path will split again after crossing over the ramps in order to allow for both a path on River Road heading towards Route 9, as well as a possible raised crossing over Route 9.

By making River Road one-way southbound, a lane can be removed which decreases the required width from 32 to 22 feet. This allows for a 12 foot travel lane and an 8 foot parking lane while providing space for a new 10 foot path to run along River Road which removes bicyclists from the street. With the removal of the off ramp from Riverway and the lane removal from River Road, 15,390 square feet of park land will be given back to the parklands in this area. The design of this area can be seen in Figure 5.4.



Existing Conditions **Proposed Design**

Figure 5.4 – AutoCAD or picture of River Road area

5.3 Cost Estimate for River Road area

The estimated total cost for the River Road section is $119,024. The cost for this area is contingent on whether improvements are made for a raised crossing of Route 9, see next chapter for details. Depending on which of the proposed options is selected the curb lines on the Riverway will be moved accordingly which will have an effect on the amount of pavement and curb line required.

Item	Quantity		Unit Cost From ENR (3)	Total w/ metro area multiplier
River Road				
Remove and stack curb	1429	L.F.	20	$33,724
Roadway excavation - 5 mile haul	201	C.Y.	5.25	$1,245
Remove and reset sign poles	12	EA.	400	$5,664
Excavate soil - small dozer - small area	200	C.Y.	2.5	$590
Base - pavement sidewalk - crushed stone 3" thick	53	C.Y.	15	$931
Wall formwork up to 8' high	249	S.F.	7.5	$2,204
Install concrete wall 2' x 4' by pump	30	C.Y.	150	$5,376
Install ADA ramps	8	EA.	70	$661
Install pavement - path	631	S.Y.	15	$11,173
Install pavement - roadway	328	S.Y.	15	$5,802
Install new curb	1369	L.F.	31	$50,078
Seeding by hand, 10 lb per 100 S.Y.	293	S.Y.	0.79	$273
Striping - solid yellow	518	L.F.	1	$611
Striping - stop line	20	L.F.	2	$47
Striping - crosswalk	274	S.F.	2	$647
			Total	**$119,024**

Figure 5.5 – Chart of estimated cost for River Road area construction

6. Route 9

Perhaps the worst crossing which pedestrians and cyclists come across on this section of the Emerald Necklace paths is the crossing at Route 9. Five very wide lanes of traffic with a narrow three and a half foot median make crossing this busy road very challenging for pedestrians and cyclists. The most important improvement at this location is to redesign the road's cross section to make the at-grade crossing safer for pedestrians and more structured for cars. In addition to this improved at-grade crossing, a grade-separated path would provide path users with a much higher level of service at this location. The alternatives for a grade-separated path are either a footbridge for pedestrians and cyclists or a designated path on the Curley Overpass. By making these improvements, this section of Route 9 can provide a critical link for pedestrians and cyclists traveling along these paths.

6.1 Design of At-Grade Path

Currently on this section of road are three wide westbound lanes for a total width of 40 feet, with the outside lane operating as a combined bus stop and vehicle lane. In the eastbound direction, the lines have faded and only one twelve foot lane exists close to the median with a 24.5 foot double wide lane next to it for a total width of 36.5 feet. This means that currently a pedestrian has to cross about 80 feet with only a narrow median to stop at. The excessive lane widths on this section of Route 9 make vehicular traffic unstructured and difficult to predict making it impossible for pedestrians to cross safely and uninterrupted.

Currently traffic turning onto River Road from Route 9 and busses stopping under the Curley Overpass reduce the capacity of the northern most westbound lane so that it does not carry any significant volumes of through traffic. Further westbound, right turning traffic at the intersection Route 9 at Brookline Avenue can still use this third lane for turning while through traffic can continue in the other two lanes. Also this lane is currently 17 feet-wide and can be reduced to eleven feet and still support the bus and vehicle traffic it currently holds. In order to maintain the consistency of lane widths in this section of Route 9 with those on the rest of the road, all of the lane widths on both the east and westbound sides will be stripped at 11 feet wide. This consistency will make the vehicular traffic in this area operate more safely and predictably without adversely affecting how this traffic operates. By changing the widths on the westbound side of the road to two 11 foot through lanes with a 13 foot bus and turning lane, the width of this section is reduced from 40 feet to 36 feet. In order to do this the curb lines will be moved to create a more defined boundary for traffic in this area.

At the intersection of Route 9 and Brookline Avenue the eastbound side of Route 9 has three existing lanes, but only two are currently utilized because the inside lane acts as a de facto left turn lane. After the light at Brookline Avenue, two through lanes discharge into three receiving lanes. This third lane is not needed to maintain traffic volumes and creates confusion for motorists who spread out and are forced to bottleneck back to two lanes just upstream. Our design reduces this section of road to only two receiving lanes which will not have an adverse impact on traffic because only two of the three lanes are currently utilized. This will also reduce the width of this roadway from 36.5 feet to 26 feet, making this a much shorter distance for pedestrians to cross. In order to do this the curb lines will be moved to create a more defined boundary for traffic in this area.

Improving the existing at-grade crossing on Route 9 for pedestrians also requires a redesign of the median in the center of the road. The median will remain in the same location as the existing median but will be expanded in both directions to accommodate all users (Figure 6.1). The existing 3 ½ foot median is not long enough for a single bicyclist or person with a baby-stroller to stand and wait in heavy traffic. This median will be expanded to 8 feet wide from curb to curb with a one foot buffer on either side designated by a solid yellow line. Also, the curb cut in the median is only wide enough for one cyclist to utilize at a time; the new design calls for a 10 foot wide curb cut to allow for more users. A bollard will be installed in the center of the median in order to stop vehicles from using it as a cut-through.

A painted crosswalk on the road will clearly identify the path for pedestrians and cyclists to follow, which also serves as an alert to drivers. With the lane width reductions in both directions, the pedestrian and cyclist crossing is shortened from 80 feet to 70 feet with the 8 foot median in the center. This makes the new at-grade crossing much safer for pedestrians and cyclists without the need to add a signal which would aversely affect the through traffic at this location. This design also reclaims 6,087 square feet of parklands.

Existing Conditions **Proposed Design**

Figure 6.1 – AutoCAD of final design for the at Grade Path

6.2 Traffic Analysis for At Grade Path

No signalized intersection will be added at this section, which makes analysis of this crossing difficult. With this aside, the effect of straightening out the lanes and making them a uniform width would not adversely affect traffic in this area, because the new 11 foot widths are equivalent to the effective widths in the existing conditions. The proposed changes will organize this confusing section of roadway which will help alleviate congestion in this location. The effects of making River Road a one way southbound street were analyzed and the results are shown in Chapter 5, but they do not indicate that either of the proposed changes would adversely affect traffic in this location.

6.3 Design of Footbridge over Route 9

The first alternative for the raised crossing is an independent system that includes construction of a boardwalk and pedestrian footbridge that runs along the west side of The Riverway. The idea of this proposed boardwalk and footbridge is that a path user could travel over Route 9 unimpeded by traffic. The boardwalk will begin after crossing the River Road on-ramp to Riverway and connect to the footbridge across Route 9 and eventually land on the existing embankment of the Curley Overpass to the south. This proposed route is shown in Figure 6.2.

The section of the bridge system on the north side of Route 9 consists of five pre-fabricated 80-foot steel spans, designed by BIG R Manufacturing LLC out of Greeley, Colorado, (Appendix B). The design for the footbridge is a steel H-truss with vertical diagonals along the sides and diagonal bracing below the floor beams. The interior width of the boardwalk is 12 feet with vertical picket rails and a rub rail along the entire length for rider safety. The riding surface will be a wood plank deck that will lie on stringers. Each of these spans will be delivered in two sections and assembled on site. The design conforms to the service load requirements of the "AASHTO Guide Specifications for Pedestrian Bridges".

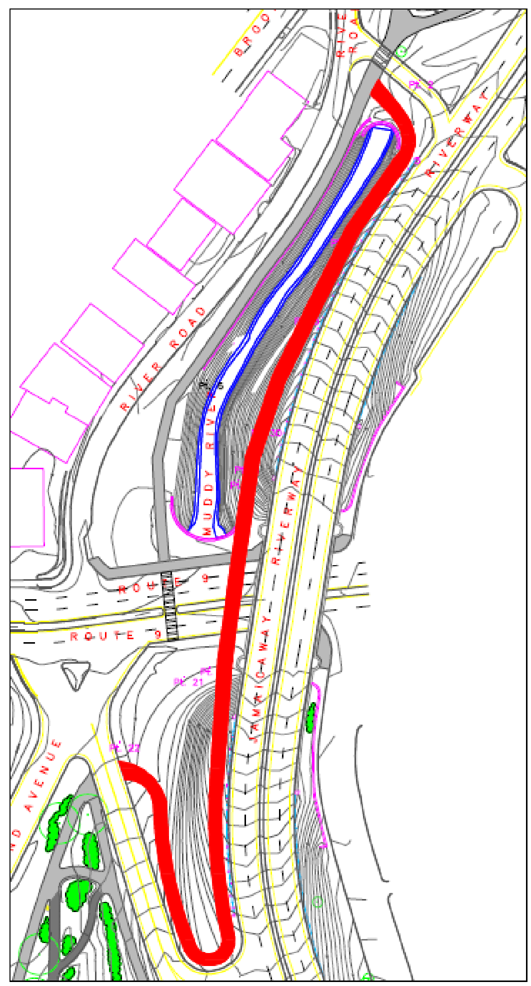


Figure 6.2 – Location of footbridge over Route 9

The boardwalk is located along Riverway on a steep embankment with a grade that increases from The Muddy River at the lower side to the Riverway at the high side. Because the conditions under the boardwalk change so drastically from one landing to the next, a separate but joined foundation system was designed. See a typical cross section in Figure 6.6. Where the individual spans meet, they will sit on a 16 X 6 X 1.5 foot connector slab of concrete that the anchor plates for each span will attach to. Based on the grade elevation beneath the proposed foundation location, the connector slab sits on either a 3-foot diameter reinforced concrete column that connects to a shallow foundation, or the connector slab will sit directly on the 5 X 5 X 5 foot shallow foundation itself. These shallow foundations were designed with a factor of safety of 3. Refer to the load calculations in Figure 6.3 below.

Shallow Foundation Design	
Foundation Dimensions	
Length (ft)	5
Base (ft)	5
Depth (ft)	5
Factor of Safety	3
L/B < 5	1
Soil	
Friction Angle	30
Unit weight (lb/ft^3)	120
Bearing Capacities	
N unit	19.13
N q	22.46
Allowable Load	
q (lb/ft2)	600.00
q_u (lb/ft2)	18,067.20
q_{all} (lb/ft2)	6,022.40
$q_{allowable}$ (kip/ft^2)	6.02
Q_u (lb)	150,560.00
Q_u (kips)	150.56

Figure 6.3 – Shallow Foundation Design for Footbridge

Shallow foundations were selected for the boardwalk because of the simplicity of construction and for cost efficiency. It was determined that the soil this bridge was being built on is designated as select fill. Thus, the soil is of good quality and not typical construction type fill that would have cinder blocks, bricks, scrap wood, or other debris from construction imbedded in it. It was determined that because the Curley Overpass was built in 1935, select fill would have been the probable soil type used for back fill and retaining walls. If this design is to be implemented, a more in-depth geotechnical study of the soil parameters in the area will have to be done to determine if the assumptions made in this study are correct. In order to meet code, the base of these foundations will be a minimum of four feet from the surface of the soil which accounts for freeze-thaw. There will be a pair of these shallow block foundations at the connection of each span excluding the two back spans that are attached to the main 117 foot span across Route 9. Once the preliminary foundation was designed assuming some basic soil conditions, a calculation was done to determine if the loads that will be applied to the foundation system could be supported by these foundations. Figure 6.4 shows the connector load figured in with the typical resulting load of two spans which rest on any of these foundations along the boardwalk.

Load on Foundation (minus Columns)	
P of Spans (kips)	87.75
Connector Dimensions	
Width (ft)	6.0
Thickness (ft)	1.5
Length (ft)	16.0
Volume of Concrete (ft^3)	144.0
P of Connectors (kips)	21.6
P total (kips)	98.6

Figure 6.4 – Load Calculations for Foundations

The boardwalk and bridge system was broken into eight sections. Section 1 is the foundation system for the back span of the south side approach of the bridge coming from Leverett Pond. Sections 2 and 3 are the pile foundation systems designed for the main span. The remaining five sections start with the landing of the first short span and extend the 400 plus feet down to the existing grade at the River Road on-ramp to the Riverway. In Figure 6.5 below, the necessary column heights are shown for all of the shallow foundations at each respective cross section excluding the main span systems. The columns are designed with a diameter of 3 feet which allows the axial loading from the bridge spans and the connector slab to be supported sufficiently and not rest directly on the shallow foundations themselves. The total loading for each individual shallow foundation system along the boardwalk, including the back span connection to the main span across Route 9, are also shown in Figure 6.5. These calculations include the loads each specific shallow foundation will be carrying from the prefab steel spans, the connector slab, and the column required by that respective foundation. Reactions and cad profiles of a typical 80-foot span and cross sections can be found in Appendix-B.

Section	Column Height (ft)	Column Area (ft^2)	Column Volume (ft^3)	P Columns (kips)	P Connector (kips)	P from Spans (kips)	P Total (kips)	Q applied (kip/ft^2)	Q allowable (kip/ft^2)
Section 1									
Right	0	0	0	0	0	43.88	43.88	1.76	6.02
Left	0	0	0	0	0	43.88	43.88	1.76	6.02
Section 4									
Right	0.00	7.07	0.00	0.00	10.80	87.75	98.55	3.94	6.02
Left	7.60	7.07	53.72	8.06	10.80	87.75	106.61	4.26	6.02
Section 5									
Right	0.00	7.07	0.00	0.00	10.80	87.75	98.55	3.94	6.02
Left	6.50	7.07	45.95	6.89	10.80	87.75	105.44	4.22	6.02
Section 6									
Right	1.50	7.07	10.60	1.59	10.80	87.75	100.14	4.01	6.02
Left	10.20	7.07	72.10	10.81	10.80	87.75	109.36	4.37	6.02
Section 7									
Right	2.10	7.07	14.84	2.23	10.80	87.75	100.78	4.03	6.02
Left	12.20	7.07	86.24	12.94	10.80	87.75	111.49	4.46	6.02
Section 8									
Right	0.00	7.07	0.00	0.00	10.80	87.75	98.55	3.94	6.02
Left	6.40	7.07	45.24	6.79	10.80	87.75	105.34	4.21	6.02

Figure 6.5 – Loading for each shallow foundation

After the calculations above were completed it was determined that the design for the shallow foundations could support an allowable load of approximately 6 kips which is more than sufficient to support the chosen foot bridge structure.

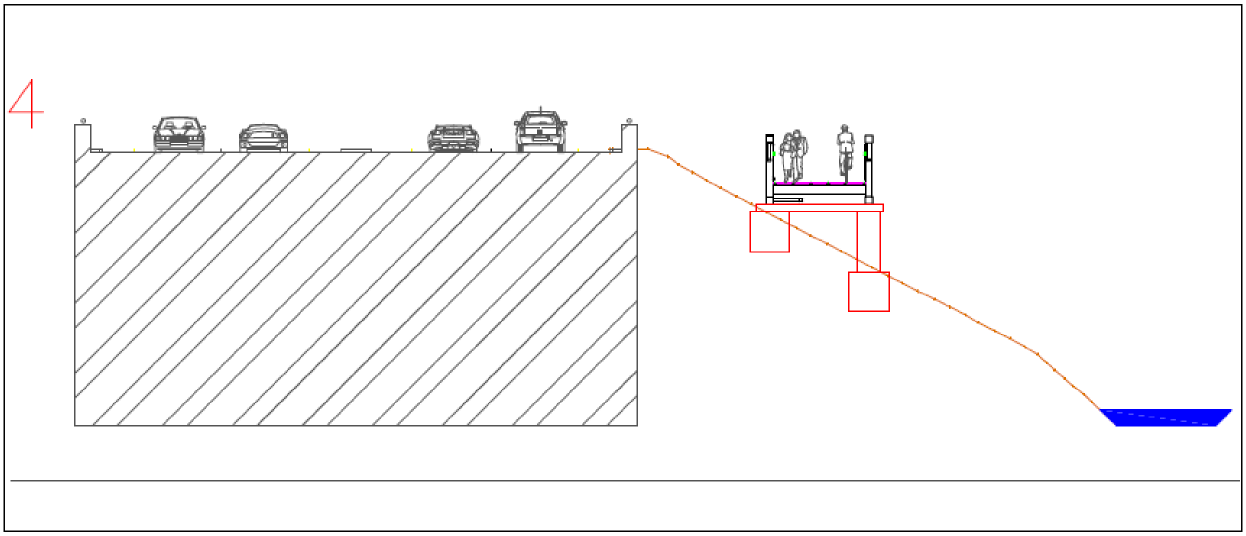


Figure 6.6 – Cross section of typical shallow foundation

The main span consists of a 117 ft single span and will be delivered in two sections to be connected and installed onsite. The AutoCAD profile of the cross section and span with resulting reactions used for calculations can be found in Appendix B. This main span requires a foundation system capable of supporting the larger loads generated by the 117 ft span as well as half the load of each back span. Therefore, a stronger foundation system than that used for the boardwalk had to be designed. Using soil borings from the 1935 construction plan of the Curley Overpass, soil parameters and SPT values were estimated for the foundation design. This soil information was based on the historic information shown in Appendix C. The resulting calculations for the connector and pier design are located in Figure 6.8. These resulting loads were then used to calculate the main span pile foundation system. The results of these calculations can be found in the "Bridge Foundation and Pier Design Calculation Sheet" located in Appendix B. For both sides of the bridge it was decided that a pile cap foundation system consisting of six H-piles with a designation size of 14 (in) x 102 (lb/ft) would have to be implemented to withstand the larger loads at each landing of the bridge. A typical pile and pile cap system is detailed in plan view in Figure 6.7 below. This configuration can not only account for the axial loading but also the horizontal forces and moment loading that the main span will experience.

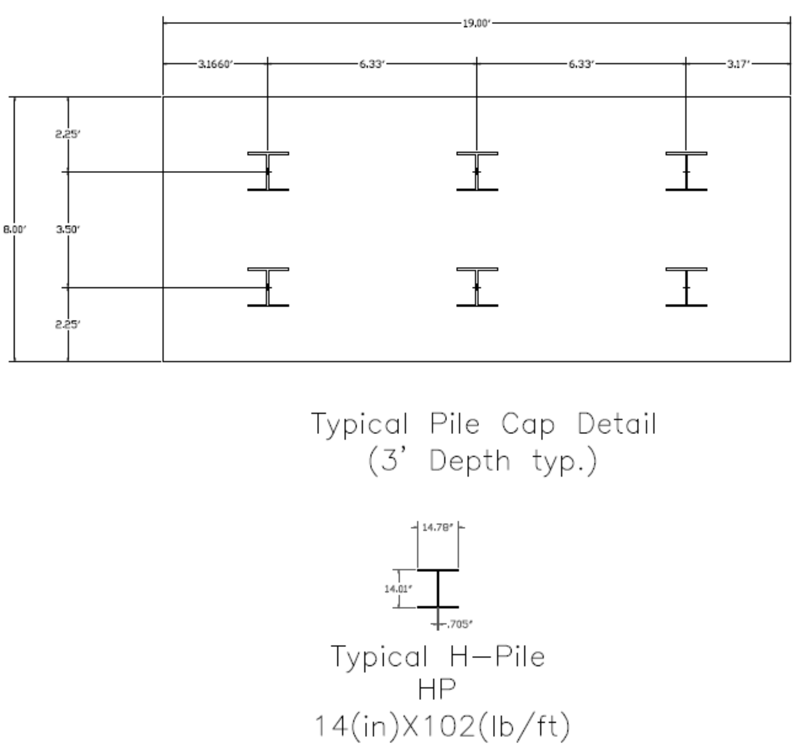


Figure 6.7 – H-pile cross-section

Column Design			
Area of column base (ft^2)	Volume of Column (ft^3)	P of Column (lbs)	P in Kips
7.07	98.96	14844.03	14.84
Concrete Connectors			
Volume of Connector (ft^3)	P (lbs)	P (kips per Column)	
99.00	14850.00	7.43	

Figure 6.8 – Column Design and Connectors

The piles for the northern landing by River Road have to be driven to a depth of 41 feet from surface elevation and 63 feet from surface elevation for the southern landing. The ultimate capacity of these pile foundations were three times higher than their respective allowable loads of 58.13 kips for the north side and 46.34 kips for the south side to allow a factor of safety of three. The ultimate load which each side can handle is greater than the 41.93 kip load per pile that each pile has to carry.

This H-pile system relies solely on frictional resistance to hold the loading of the main span. The reason for the deeper driving on the southern side is because of the thick layer of Boston blue clay located here while the north landing is located on a coarse sand and coarse gravel mix. The pile does not carry any point load because the cross sectional area of the pile is 30 in^2. Each pile in a group will connect into a 3 X 8 X 19 foot pile cap as seen in Figure 6.7.

The top surface of these pile caps will rest at 1 foot below grade. It is also necessary to ensure that the base of the pile cap is a minimum of 4 feet below grade to account for freeze thaw. This design ensures that each H-pile is the minimum distance required away from any other pile in the cap. Each pile also has more than the required amount of concrete coverage to the outside face of the cap.

On top of each pile cap, two 3 foot diameter, 14 foot tall reinforced concrete columns rise to support the bridge deck. Each pair of columns meet and tie into a rectangular reinforced concrete connector slab with a dimension of 16.5 X 1.5 X 4 feet. This slab is located at the connection of the main span and back span. These dimensions provide extra space in the length and width to ensure enough area to connect the bridge and back spans. With the columns and the connector, the lowest clearance that the bridge creates is 14.5 feet at the ends. Like the boardwalk, a detailed geotechnical report would be necessary to ensure the design with the assumed soil conditions is truly capable of carrying these loads.

6.4 Design of Re-Alignment of Curley Overpass

The second design for an above grade crossing of Route 9 uses the existing Curley Overpass bridge deck. The Curley Overpass is currently wide enough to add a mixed-use path without removing any lanes of traffic. This path will be separated from the roadway by a granite curb and short concrete wall. The proposed path for this option starts in the same location as the boardwalk proposed in the previous section. South of the crossing of the newly designed Riverway on-ramp from River Road, this path would be graded up to the existing road bed and continue along the west side of the Riverway. This design is shown in Figure 6.9.

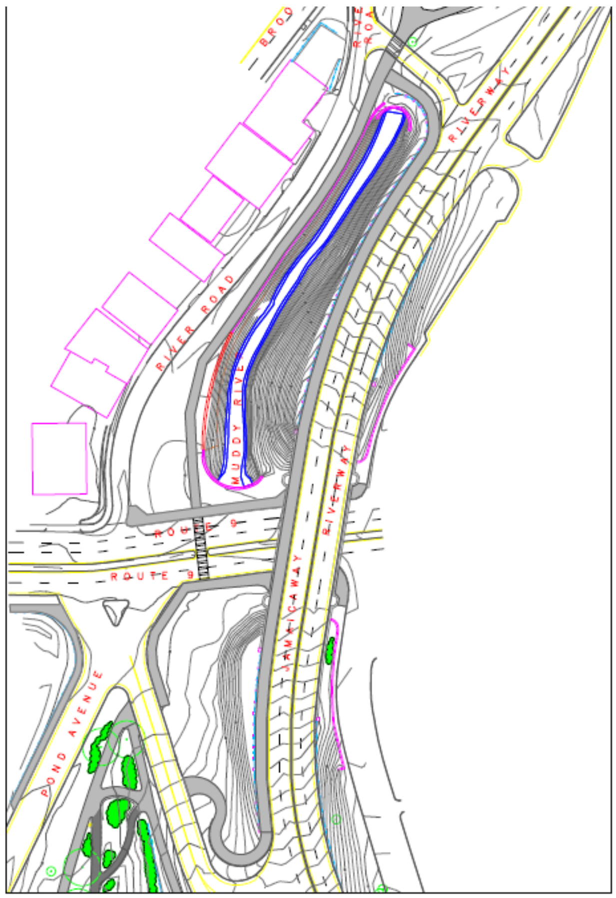


Figure 6.9 – Redesign of Curley Overpass

In order to add a raised path on the overpass, the existing cross section of the overpass will have to be altered. Currently the median on the Curley Overpass consists of a 4 foot median with paint lines spaced at 5 feet to the west of the median and 4 feet to the east of the median. This means that there are a combined 13 feet of lost space on the bridge deck due to the current median. This design reduces this median to 4 feet with a 1 foot wide by 3 foot tall concrete barrier taking the place of the current median, with only 1.5 feet of paint lines on either side. A comparison of the existing and modified conditions is shown below in Figure 6.10. Although no other section of the Riverway besides the Curley Overpass has a median, our group felt it was an added safety benefit to maintain one in this location. Because this is a bridge deck, there is potential for icing in the winter which presents an added danger.

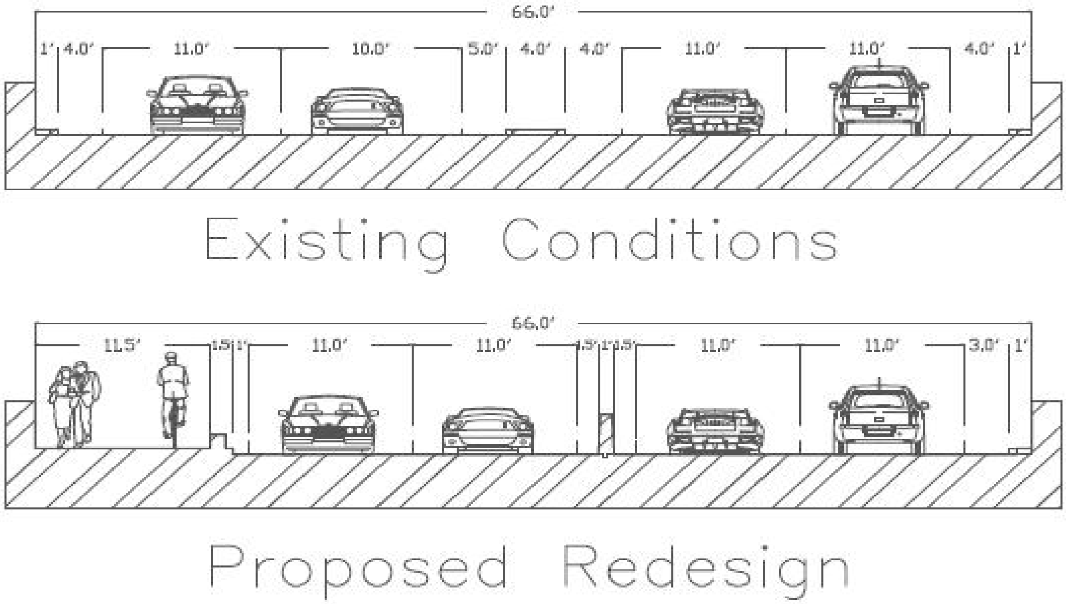


Figure 6.10 – Cross Section of Redesigned Curley Overpass

The breakdown lane on the northbound side of Riverway will be reduced to three feet, and the breakdown lane on the southbound side is reduced to one foot. Going northbound, there will be two 11-foot lanes, which are the same width as the existing lanes in this direction. Then the redesigned median will split northbound and southbound traffic. Two 11 foot lanes will carry southbound traffic, which are also the same width as the existing lanes in this direction. This leaves 14 feet of unused roadway. In order to provide pedestrians and cyclists with the highest quality crossing at this location, a separated bike lane was designed to carry them safely across the Curley Overpass.

Along the western wall on the existing overpass, an 11.5 foot multiuse path will sit separated 6 inches above the road elevation. On the east side of this path, a 1 foot by 1 foot concrete barrier with a 6 inch diameter round guard rail running across the top will protect path users from automobiles. This type of barricade is similar to the one that exists on the Massachusetts Avenue Bridge shown in Figure 6.11. The new bridge alignment can be seen in the cross section in Figure 6.10.

Figure 6.11 – Massachusetts Avenue pedestrian barrier

6.5 Traffic Analysis for Elevated Paths

The grade separated paths have little to no affect on traffic. The idea behind the footbridge and the Curley Overpass designs are to keep path users out of the way of traffic. The footbridge carries pedestrians and cyclists over Route 9, and therefore it will not affect any of the existing conditions. The Curley Overpass has a larger overall width than needed for the current number of lanes. The bridge can be reconfigured to have a narrower median and less dead space with the addition of a grade separated path for pedestrians and cyclists. The lane widths will not need to be altered and the median is not removed, so it should not affect the flow of traffic on the bridge.

6.6 Cost Estimate for At Grade crossing

The cost estimate for the at-grade crossing is shown in Figure 6.12. The total estimated cost for this section is $185,142.

Item	Quantity		Unit Cost From ENR (3)	Total w/ metro area multiplier
At-grade Crossing				
Roadway excavation - 5 mile haul	126	C.Y.	5.25	$781
Remove concrete - sidewalk	780	S.Y.	6.5	$5,983
Remove and stack curb - median	1172	L.F.	20	$27,659
Remove concrete - median	195	S.F.	6.5	$1,498
Add fill	76	C.Y.	28.5	$2,556
Replace curb - median	1180	L.F.	31	$43,164
Place imported top soil by loader 4" deep	404	S.Y.	1.05	$501
Install steel bollard	1	EA.	900	$1,062
Install concrete - median	4102	S.F.	15	$72,605
Install ADA ramps	8	S.Y.	70	$661
Install concrete - sidewalk 4" thick cast in place with wire mesh, base not incl.	8455	S.F.	2.4	$23,945
Seeding by hand, 10 lb per 100 S.Y.	404	S.Y.	0.79	$377
Striping - dotted white	1758	L.F.	0.33	$691
Striping - solid yellow	1758	L.F.	1	$2,074
Striping - crosswalk	671	S.F.	2	$1,584
			Subtotal	**$185,142**

Figure 6.12 – Cost estimate chart for At Grade crossing

6.7 Cost Estimate for Footbridge

The cost estimate for the proposed footbridge is shown in Figure 6.13. The total estimated cost is $1,030,702 for the footbridge and boardwalk to cross from River Road to the south side of Route 9. The cost estimate for this above grade alternative includes several key costs. The cost of the spans includes the fabrication and freight of the span sections to the location in Boston, MA. However, each span comes in two sections and needs to be unloaded, assembled, and put in place. This will require at least one crane, staging, and laborers and engineers on site during assembly and placement. All cost figures for the concrete work on this alternative are calculated by the amount of concrete necessary for each section of the bridge system.

Item	Quantity		Unit Cost	Total
Footbridge			From ENR (3)	w/ metro area multiplier
Clear and grub - trees	0.03	ACRE	4900	$172
Add fill	1914	C.Y.	28.5	$64,368
Bridge System Spans (not from ENR)				
117' Mainspan	1	EA.	150386	$150,386
80' Backspan	6	EA.	108792	$652,752
Mainspan Foundation System				
Concrete Columns	4	EA.	586.43	$2,768
Concrete Connector Slab	2	EA.	480	$1,133
Concrete Pile Cap	2	EA.	2702.22	$6,377
Piles	624	L.F.	160	$117,811
Formwork Columns	4	EA.	588	$2,775
Formwork Connector Slab	1	EA.	1517.74	$1,791
Formwork Pile Cap	1	EA.	3619.5	$4,271
Backspan Foundation System				
Concrete Foundation Connectors	5	EA.	853.33	$5,035
Concrete Shallow Foundation	12	EA.	740.74	$10,489
Concrete Columns: 3 foot dia. by Height (ft)				
7.6	1	EA.	318.41	$376
6.5	1	EA.	272.33	$321
1.5	1	EA.	62.84	$74
10.2	1	EA.	427.34	$504
2.1	1	EA.	87.98	$104
12.2	1	EA.	511.13	$603
6.4	1	EA.	268.14	$316
Formwork Connector Slabs	1	EA.	1944	$2,294
Formwork Shallow Foundation Block	2	EA.	585.94	$1,383
Formwork Connector Slabs	1	EA.	1944	$2,294
Column Formwork : 3 foot dia. by Height (ft)				
7.6	1	EA.	319.2	$377
6.5	1	EA.	273	$322
1.5	1	EA.	63	$74
10.2	1	EA.	428.4	$506
2.1	1	EA.	88.2	$104
12.2	1	EA.	512.4	$605
6.4	1	EA.	268.8	$317
			Total Cost	**$1,030,702**

Figure 6.13 – Cost estimate chart for Route 9 area

6.8 Cost Estimate for Re-Alignment of Curley Overpass

The cost estimate for the re-alignment of the Curley Overpass is shown in Figure 6.14. The total estimated cost for this construction is $214,868. This includes the removal and relocation of the center median on the Riverway. It also includes the cost of the new path and barrier for the pedestrian and cyclist path on the west side of the bridge.

Item	Quantity		Unit Cost From ENR (3)	Total w/ metro area multiplier
Path on Curley Overpass				
Tree removal	2	EA.	480	$1,133
Tree loading and trucking	2	EA.	370	$873
Remove, relocate, reset curb - before bridge	66	L.F.	25	$1,947
Remove, relocate, reset curb - road on bridge	960	L.F.	25	$28,320
Remove, relocate, reset curb - median	3005	L.F.	25	$88,648
Add fill - No. 21 crusher run stone	230	C.Y.	28.5	$7,750
Install concrete - sidewalk 4" thick cast in place with wire mesh, base not incl.	12444	S.F.	2.4	$35,241
Install pavement - roadway	1383	S.Y.	15	$24,473
Install barrier - concrete to 4' by chute	34	C.Y.	100	$4,064
Install jersey barrier	167	C.Y.	100	$19,699
Striping - dotted white	1728	L.F.	0.33	$680
Striping - solid yellow	1728	L.F.	1	$2,039
			Subtotal	**$214,868**

Figure 6.14 – Cost estimate chart for Route 9 area

6.9 Cost Comparison for Route Alternatives

The costs for the individual sections are shown above. The alternatives for this section are to build only an at-grade path, an at-grade path along with the separate footbridge over Route 9, and an at-grade with the re-alignment of the Curley Overpass. These three options are shown in Figure 6.15 below in order to compare the costs of the alternatives. The footbridge is the most costly option of all by a large margin. The at-grade crossing and the path on the Curley Overpass are both reasonable priced.

Location	Cost
Route 9 Alternative 1 (at-grade only)	$185,142
Route 9 Alternative 2 (at-grade and footbridge)	$1,215,844
Route 9 Alternative 3 (at-grade and path on Curley Overpass)	$400,009

Figure 6.15 – Cost Comparison Chart

7. Summary

The goal of this project was to establish a solid connection for pedestrians which bridged the gaps from Netherlands Road to Route 9. In order for this missing connection in the Emerald Necklace paths to be the most successful project possible all aspects of the above mentioned design should be undertaken. Without one of the four sections discussed above, gaps would still exist in this path system. Although all of these areas need attention, it is important to stress the flexibility of this design. Although Netherlands Road, Brookline Avenue, River Road, and Route 9 all need these improvements, some improvement is better than no improvement at all. By reestablishing these individual connections, pedestrians, cyclists, and persons with disabilities can be accommodated throughout.

With two paths, one on the Boston side and one on the Brookline side of the Muddy River, a larger group of people will be able to access the parks for recreational use and commuting. If taken as a whole, this design re-established Olmsted's dual path system from Netherlands Road to south of Route 9. In order to do this, paths were developed on separate sides of the Muddy River. We felt that this optimized the paths and provided the most access to these historic parks.

Our design enhances the paths along the Muddy River in order to make Olmsted's original paths more usable by those traveling on them today. The bridle and walking paths give a good base for the location of these paths and provide a historic element that is hard to find anywhere else. As a whole, the proposed design adds 11,000 square feet of parkland and provides access to previously underdeveloped regions of these parks.

The cost for this project was broken out into the four sections. Because of the option between a footbridge and using the Curley Overpass, the cost is not fixed. There are a few alternatives that are available that we considered. We looked at the total cost of the project with each of the three alternatives for the Route 9 crossing, as discussed in Chapter 6. The total cost comparisons are shown in Figure 7.1.

Location	Cost
Netherlands Road	$150,153
Brookline Avenue	$242,998
River Road	$119,024
Route 9 Alternative 1 (at-grade only)	$185,142
Route 9 Alternative 2 (at-grade and bridge)	$1,215,844
Route 9 Alternative 3 (at-grade and path on Curley Overpass)	$400,009
Total Project Cost Alternative 1	**$697,317**
Total Project Cost Alternative 2	**$1,728,019**
Total Project Cost Alternative 3	**$912,184**

Figure 7.1 – Chart of Combined Total Cost

As shown by the chart above, the footbridge over Route 9 is the most costly approach for this area. The alternative with only an at-grade crossing is the least expensive option but it does not give the maximum safety and fluidity that an above grade path can provide although there is a strong need for it. Alternative 2 is the best option since it is not as costly as the footbridge and also gives the best service for pedestrians, cyclists, and vehicles. The total costs may seem high but there is a large scope of work that is greatly needed.

The costs presented in this report are estimates and need to be viewed as such. There are several costs that have not been accounted for including mobilization, ranging from $200 for a backhoe to $400 for a bulldozer, another $1100 and $1600 per week, respectively, to rent the machinery, and another added cost to have someone run the machinery. Also, temporary barricades will be needed especially on Riverway which are $14 per linear foot. These costs also do not take into account overhead, profit, professional fees, field staff, surveying, testing concrete, construction signs and labor.

This design has taken a step by step approach from north to south along this large gap in the Emerald necklace path. Along the way, different alternatives were considered and the routes which best kept to the goal of providing a better level of service to path users were selected. Although the optimal solution would be to incorporate all of these designs to make a path with excellent service to its users, each element of this design can be considered individually as well. By improving one or more of these sections, an overall benefit to path users can be achieved.

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Acknowledgements

GR8 Engineers would like to formally recognize the contributions of several groups or people, without whom we would not have been able to complete this project. First of all, we would like to thank last year's capstone group, Muddy River Design Group, Inc. Many of our designs were developed based off of their work last year. Secondly, we would like to thank the engineers at BIG R Manufacturing LLC for lending their time and expertise in helping to develop our bridge design. A special thanks is also due to Professor Yegian for his guidance in the design process. Finally, we would like to thank our capstone advisor, Professor Furth, for guiding us through this project from start to finish.

Appendix A – Synchro Analysis

Synchro Analysis for Brookline Avenue at Riverway and Route 9 at Brookline Avenue

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations		↰↑↱			↰↑↱		↰	↑↱		↰	↑↱	
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	10	10	10	9	11	11	9	10	11
Total Lost time (s)		4.0			4.0		4.0	4.0		4.0	4.0	
Lane Util. Factor		0.95			0.95		1.00	0.95		1.00	0.95	
Frt		0.94			0.98		1.00	1.00		1.00	0.99	
Flt Protected		1.00			1.00		0.95	1.00		0.95	1.00	
Satd. Flow (prot)		3900			3900		1608	3200		1593	3283	
Flt Permitted		0.95			1.00		0.13	1.00		0.24	1.00	
Satd. Flow (perm)		3900			3900		218	3200		410	3283	
Volume (vph)	5	815	580	0	590	75	225	615	5	230	365	15
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	5	858	611	0	621	79	237	647	5	242	384	16
Lane Group Flow (vph)	0	1474	0	0	700	0	237	652	0	242	400	0
Heavy Vehicles (%)	2%	2%	2%	1%	1%	1%	1%	9%	0%	2%	2%	2%
Turn Type	Perm			Perm			Perm			D.P+P		
Protected Phases		3			3			1		4	1 4	
Permitted Phases	3			3			1			1		
Actuated Green, G (s)		32.0			32.0		29.0	29.0		34.0	37.0	
Effective Green, g (s)		34.0			34.0		31.0	31.0		35.0	39.0	
Actuated g/C Ratio		0.34			0.34		0.31	0.31		0.35	0.39	
Clearance Time (s)		6.0			6.0		6.0	6.0		3.0		
Vehicle Extension (s)		3.0			3.0		3.0	3.0		3.0		
Lane Grp Cap (vph)		1326			1326		68	992		191	1280	
v/s Ratio Prot					0.18			0.20		c0.05	0.12	
v/s Ratio Perm		0.38					c1.08			0.39		
v/c Ratio		1.11			0.53		3.49	0.66		1.27	0.31	
Uniform Delay, d1		33.0			26.5		34.5	29.9		32.8	21.2	
Progression Factor		1.00			1.00		1.00	1.00		1.00	1.00	
Incremental Delay, d2		61.3			1.5		1154.3	3.4		154.9	0.6	
Delay (s)		94.3			28.1		1188.8	33.3		187.6	21.8	
Level of Service		F			C		F	C		F	C	
Approach Delay (s)		94.3			28.1			341.4			84.3	
Approach LOS		F			C			F			F	

Intersection Summary			
HCM Average Control Delay	139.3	HCM Level of Service	F
HCM Volume to Capacity ratio	2.20		
Actuated Cycle Length (s)	100.0	Sum of lost time (s)	31.0
Intersection Capacity Utilization	86.8%	ICU Level of Service	D
c Critical Lane Group			

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	10	10	10	9	11	11	9	10	11
Total Lost time (s)		4.0			4.0		4.0	4.0		4.0	4.0	
Lane Util. Factor		0.95			0.95		1.00	0.95		1.00	0.95	
Frt		0.94			0.96		1.00	1.00		1.00	0.99	
Flt Protected		1.00			1.00		0.95	1.00		0.95	1.00	
Satd. Flow (prot)		3900			3900		1608	3200		1593	3283	
Flt Permitted		0.95			1.00		0.13	1.00		0.24	1.00	
Satd. Flow (perm)		3900			3900		218	3200		410	3283	
Volume (vph)	5	815	580	0	590	250	225	615	5	230	365	15
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	5	858	611	0	621	263	237	647	5	242	384	16
Lane Group Flow (vph)	0	1474	0	0	884	0	237	652	0	242	400	0
Heavy Vehicles (%)	2%	2%	2%	1%	1%	1%	1%	9%	0%	2%	2%	2%
Turn Type	Perm			Perm			Perm			D.P+P		
Protected Phases		3			3			1		4	1 4	
Permitted Phases	3			3			1			1		
Actuated Green, G (s)		32.0			32.0		29.0	29.0		34.0	37.0	
Effective Green, g (s)		34.0			34.0		31.0	31.0		35.0	39.0	
Actuated g/C Ratio		0.34			0.34		0.31	0.31		0.35	0.39	
Clearance Time (s)		6.0			6.0		6.0	6.0		3.0		
Vehicle Extension (s)		3.0			3.0		3.0	3.0		3.0		
Lane Grp Cap (vph)		1326			1326		68	992		191	1280	
v/s Ratio Prot					0.23			0.20		c0.05	0.12	
v/s Ratio Perm		0.38					c1.08			0.39		
v/c Ratio		1.11			0.67		3.49	0.66		1.27	0.31	
Uniform Delay, d1		33.0			28.2		34.5	29.9		32.8	21.2	
Progression Factor		1.00			1.00		1.00	1.00		1.00	1.00	
Incremental Delay, d2		61.3			2.7		1154.3	3.4		154.9	0.6	
Delay (s)		94.3			30.8		1188.8	33.3		187.6	21.8	
Level of Service		F			C		F	C		F	C	
Approach Delay (s)		94.3			30.8			341.4			84.3	
Approach LOS		F			C			F			F	

Intersection Summary			
HCM Average Control Delay	134.7	HCM Level of Service	F
HCM Volume to Capacity ratio	2.20		
Actuated Cycle Length (s)	100.0	Sum of lost time (s)	31.0
Intersection Capacity Utilization	86.8%	ICU Level of Service	D
c Critical Lane Group			

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1950	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	10	10	10	9	11	11	9	10	11
Total Lost time (s)		4.0			4.0	4.0	4.0	4.0		4.0	4.0	
Lane Util. Factor		0.95			0.95	1.00	1.00	0.95		1.00	0.95	
Frt		0.94			1.00	0.98	1.00	1.00		1.00	0.99	
Flt Protected		1.00			1.00	1.00	0.95	1.00		0.95	1.00	
Satd. Flow (prot)		3900			3900	1766	1608	3200		1593	3283	
Flt Permitted		0.95			1.00	1.00	0.13	1.00		0.24	1.00	
Satd. Flow (perm)		3900			3900	1766	218	3200		410	3283	
Volume (vph)	5	815	580	0	590	250	225	615	5	230	365	15
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	5	858	611	0	621	263	237	647	5	242	384	16
Lane Group Flow (vph)	0	1474	0	0	621	263	237	652	0	242	400	0
Heavy Vehicles (%)	2%	2%	2%	1%	1%	1%	1%	9%	0%	2%	2%	2%
Turn Type	Perm			Perm		Perm	Perm			D.P+P		
Protected Phases		3			3			1		4	1 4	
Permitted Phases	3			3		3	1			1		
Actuated Green, G (s)		32.0			32.0	32.0	29.0	29.0		34.0	37.0	
Effective Green, g (s)		34.0			34.0	34.0	31.0	31.0		35.0	39.0	
Actuated g/C Ratio		0.34			0.34	0.34	0.31	0.31		0.35	0.39	
Clearance Time (s)		6.0			6.0	6.0	6.0	6.0		3.0		
Vehicle Extension (s)		3.0			3.0	3.0	3.0	3.0		3.0		
Lane Grp Cap (vph)		1326			1326	600	68	992		191	1280	
v/s Ratio Prot					0.16			0.20		c0.05	0.12	
v/s Ratio Perm		0.38				0.15	c1.08			0.39		
v/c Ratio		1.11			0.47	0.44	3.49	0.66		1.27	0.31	
Uniform Delay, d1		33.0			25.9	25.6	34.5	29.9		32.8	21.2	
Progression Factor		1.00			1.00	1.00	1.00	1.00		1.00	1.00	
Incremental Delay, d2		61.3			1.2	2.3	1154.3	3.4		154.9	0.6	
Delay (s)		94.3			27.1	27.9	1188.8	33.3		187.6	21.8	
Level of Service		F			C	C	F	C		F	C	
Approach Delay (s)		94.3			27.3			341.4			84.3	
Approach LOS		F			C			F			F	

Intersection Summary			
HCM Average Control Delay	133.9	HCM Level of Service	F
HCM Volume to Capacity ratio	2.20		
Actuated Cycle Length (s)	100.0	Sum of lost time (s)	31.0
Intersection Capacity Utilization	86.8%	ICU Level of Service	D
c Critical Lane Group			

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	10	10	10	9	11	11	9	10	11
Total Lost time (s)		4.0			4.0		4.0	4.0		4.0	4.0	
Lane Util. Factor		0.95			*1.00		1.00	0.95		1.00	0.95	
Frt		0.95			1.00		1.00	1.00		1.00	0.99	
Flt Protected		1.00			1.00		0.95	1.00		0.95	1.00	
Satd. Flow (prot)		3900			3900		1593	3412		1593	3285	
Flt Permitted		0.67			1.00		0.15	1.00		0.23	1.00	
Satd. Flow (perm)		3900			3900		248	3412		391	3285	
Volume (vph)	15	645	355	0	1090	45	160	495	10	435	660	25
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	16	679	374	0	1147	47	168	521	11	458	695	26
Lane Group Flow (vph)	0	1069	0	0	1194	0	168	532	0	458	721	0
Heavy Vehicles (%)	0%	0%	0%	0%	0%	0%	2%	2%	0%	2%	2%	2%
Turn Type	Perm			Perm			Perm			D.P+P		
Protected Phases		3			3			1		4	1 4	
Permitted Phases	3			3			1			1		
Actuated Green, G (s)		35.0			35.0		25.0	25.0		42.0	45.0	
Effective Green, g (s)		37.0			37.0		27.0	27.0		43.0	47.0	
Actuated g/C Ratio		0.31			0.31		0.22	0.22		0.36	0.39	
Clearance Time (s)		6.0			6.0		6.0	6.0		3.0		
Vehicle Extension (s)		3.0			3.0		3.0	3.0		3.0		
Lane Grp Cap (vph)		1203			1203		56	768		300	1287	
v/s Ratio Prot					c0.31			0.16		c0.20	0.22	
v/s Ratio Perm		0.27					c0.68			0.34		
v/c Ratio		0.89			0.99		3.00	0.69		1.53	0.56	
Uniform Delay, d1		39.5			41.4		46.5	42.7		33.2	28.4	
Progression Factor		1.00			1.00		1.00	1.00		1.00	1.00	
Incremental Delay, d2		10.0			24.2		945.9	5.1		253.3	1.8	
Delay (s)		49.5			65.6		992.4	47.8		286.5	30.2	
Level of Service		D			E		F	D		F	C	
Approach Delay (s)		49.5			65.6			274.5			129.8	
Approach LOS		D			E			F			F	

Intersection Summary			
HCM Average Control Delay	115.0	HCM Level of Service	F
HCM Volume to Capacity ratio	1.78		
Actuated Cycle Length (s)	120.0	Sum of lost time (s)	40.0
Intersection Capacity Utilization	85.5%	ICU Level of Service	D
c Critical Lane Group			

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations		↰↑↑↱			↰↑↑↱		↰	↑↑↱		↰	↑↑↱	
Ideal Flow (vphpl)	1900	1900	1900	1950	1950	1950	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	10	10	10	9	11	11	9	10	11
Total Lost time (s)		4.0			4.0		4.0	4.0		4.0	4.0	
Lane Util. Factor		0.95			0.95		1.00	0.95		1.00	0.95	
Frt		0.95			0.96		1.00	1.00		1.00	0.99	
Flt Protected		1.00			1.00		0.95	1.00		0.95	1.00	
Satd. Flow (prot)		3900			3900		1593	3412		1593	3285	
Flt Permitted		0.67			1.00		0.15	1.00		0.23	1.00	
Satd. Flow (perm)		3900			3900		248	3412		391	3285	
Volume (vph)	15	645	355	0	1090	440	160	495	10	435	660	25
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	16	679	374	0	1147	463	168	521	11	458	695	26
Lane Group Flow (vph)	0	1069	0	0	1610	0	168	532	0	458	721	0
Heavy Vehicles (%)	2%	2%	2%	1%	1%	1%	2%	2%	0%	2%	2%	2%
Turn Type	Perm			Perm			Perm			D.P+P		
Protected Phases		3			3			1		4	1 4	
Permitted Phases	3			3			1			1		
Actuated Green, G (s)		35.0			35.0		25.0	25.0		42.0	45.0	
Effective Green, g (s)		37.0			37.0		27.0	27.0		43.0	47.0	
Actuated g/C Ratio		0.31			0.31		0.22	0.22		0.36	0.39	
Clearance Time (s)		6.0			6.0		6.0	6.0		3.0		
Vehicle Extension (s)		3.0			3.0		3.0	3.0		3.0		
Lane Grp Cap (vph)		1203			1203		56	768		300	1287	
v/s Ratio Prot					c0.41			0.16		c0.20	0.22	
v/s Ratio Perm		0.27					c0.68			0.34		
v/c Ratio		0.89			1.34		3.00	0.69		1.53	0.56	
Uniform Delay, d1		39.5			41.5		46.5	42.7		33.2	28.4	
Progression Factor		1.00			1.00		1.00	1.00		1.00	1.00	
Incremental Delay, d2		10.0			157.9		945.9	5.1		253.3	1.8	
Delay (s)		49.5			199.4		992.4	47.8		286.5	30.2	
Level of Service		D			F		F	D		F	C	
Approach Delay (s)		49.5			199.4			274.5			129.8	
Approach LOS		D			F			F			F	

Intersection Summary			
HCM Average Control Delay	157.8	HCM Level of Service	F
HCM Volume to Capacity ratio	1.94		
Actuated Cycle Length (s)	120.0	Sum of lost time (s)	40.0
Intersection Capacity Utilization	95.4%	ICU Level of Service	E
c Critical Lane Group			

Movement	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations		↰↑↱			↰↑↑	↱	↰	↑↑↱		↰	↑↑↱	
Ideal Flow (vphpl)	1900	1900	1900	1950	1950	1950	1900	1900	1900	1900	1900	1900
Lane Width	10	10	10	10	10	10	9	11	11	9	10	11
Total Lost time (s)		4.0			4.0	4.0	4.0	4.0		4.0	4.0	
Lane Util. Factor		0.95			0.95	1.00	1.00	0.95		1.00	0.95	
Frt		0.95			1.00	0.98	1.00	1.00		1.00	0.99	
Flt Protected		1.00			1.00	1.00	0.95	1.00		0.95	1.00	
Satd. Flow (prot)		3900			3900	1766	1593	3412		1593	3285	
Flt Permitted		0.67			1.00	1.00	0.15	1.00		0.23	1.00	
Satd. Flow (perm)		3900			3900	1766	248	3412		391	3285	
Volume (vph)	15	645	355	0	1090	440	160	495	10	435	660	25
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	16	679	374	0	1147	463	168	521	11	458	695	26
Lane Group Flow (vph)	0	1069	0	0	1147	463	168	532	0	458	721	0
Heavy Vehicles (%)	2%	2%	2%	1%	1%	1%	2%	2%	0%	2%	2%	2%
Turn Type	Perm			Perm		Perm	Perm			D.P+P		
Protected Phases		3			3			1		4	1 4	
Permitted Phases	3			3		3	1			1		
Actuated Green, G (s)		35.0			35.0	35.0	25.0	25.0		42.0	45.0	
Effective Green, g (s)		37.0			37.0	37.0	27.0	27.0		43.0	47.0	
Actuated g/C Ratio		0.31			0.31	0.31	0.22	0.22		0.36	0.39	
Clearance Time (s)		6.0			6.0	6.0	6.0	6.0		3.0		
Vehicle Extension (s)		3.0			3.0	3.0	3.0	3.0		3.0		
Lane Grp Cap (vph)		1203			1203	545	56	768		300	1287	
v/s Ratio Prot					c0.29			0.16		c0.20	0.22	
v/s Ratio Perm		0.27				0.26	c0.68			0.34		
v/c Ratio		0.89			0.95	0.85	3.00	0.69		1.53	0.56	
Uniform Delay, d1		39.5			40.7	38.9	46.5	42.7		33.2	28.4	
Progression Factor		1.00			1.00	1.00	1.00	1.00		1.00	1.00	
Incremental Delay, d2		10.0			16.9	15.2	945.9	5.1		253.3	1.8	
Delay (s)		49.5			57.6	54.1	992.4	47.8		286.5	30.2	
Level of Service		D			E	D	F	D		F	C	
Approach Delay (s)		49.5			56.6			274.5			129.8	
Approach LOS		D			E			F			F	

Intersection Summary			
HCM Average Control Delay	107.3	HCM Level of Service	F
HCM Volume to Capacity ratio	1.76		
Actuated Cycle Length (s)	120.0	Sum of lost time (s)	40.0
Intersection Capacity Utilization	89.2%	ICU Level of Service	D
c Critical Lane Group			

Movement	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBL	NBT	NBR	SBL
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)		4.0	4.0				4.0			4.0		4.0
Lane Util. Factor		0.97	0.95				*1.00			1.00		0.95
Frt		1.00	1.00				0.99			0.99		1.00
Flt Protected		0.95	1.00				1.00			0.98		0.95
Satd. Flow (prot)		3467	3563				5586			1848		1698
Flt Permitted		0.95	1.00				1.00			0.98		0.95
Satd. Flow (perm)		3467	3563				5586			1848		1698
Volume (vph)	44	943	809	17	19	2	826	54	27	31	3	178
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	46	993	852	18	20	2	869	57	28	33	3	187
Lane Group Flow (vph)	0	1039	870	0	0	0	948	0	0	64	0	95
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turn Type	Split	Split			Split	Split			Split			Split
Protected Phases	1	1	1		4	4	4		3	3		2
Permitted Phases												
Actuated Green, G (s)		25.0	25.0				17.0			7.0		12.0
Effective Green, g (s)		26.0	26.0				18.0			7.0		13.0
Actuated g/C Ratio		0.32	0.32				0.22			0.09		0.16
Clearance Time (s)		5.0	5.0				5.0			4.0		5.0
Lane Grp Cap (vph)		1127	1158				1257			162		276
v/s Ratio Prot		c0.30	0.24				c0.17			0.03		0.06
v/s Ratio Perm												
v/c Ratio		0.92	0.75				0.75			0.40		0.34
Uniform Delay, d1		26.0	24.1				28.9			34.5		29.7
Progression Factor		1.00	1.00				1.00			1.00		1.00
Incremental Delay, d2		13.6	4.5				4.2			7.1		3.4
Delay (s)		39.6	28.6				33.2			41.6		33.1
Level of Service		D	C				C			D		C
Approach Delay (s)			34.6				33.2			41.6		
Approach LOS			C				C			D		

Intersection Summary			
HCM Average Control Delay	31.0	HCM Level of Service	C
HCM Volume to Capacity ratio	0.69		
Actuated Cycle Length (s)	80.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	96.1%	ICU Level of Service	E
c Critical Lane Group			

HCM Signalized Intersection Capacity Analysis
2: Route 9 & Brookline Avenue 4/14/2008

Movement	SBT	SBR
Lane Configurations		
Ideal Flow (vphpl)	1900	1900
Total Lost time (s)	4.0	4.0
Lane Util. Factor	0.95	1.00
Frt	1.00	0.85
Flt Protected	0.96	1.00
Satd. Flow (prot)	1709	1599
Flt Permitted	0.96	1.00
Satd. Flow (perm)	1709	1599
Volume (vph)	8	477
Peak-hour factor, PHF	0.95	0.95
Adj. Flow (vph)	8	502
Lane Group Flow (vph)	100	502
Heavy Vehicles (%)	1%	1%
Turn Type		custom
Protected Phases	2	2
Permitted Phases		1 3
Actuated Green, G (s)	12.0	44.0
Effective Green, g (s)	13.0	46.0
Actuated g/C Ratio	0.16	0.58
Clearance Time (s)	5.0	5.0
Lane Grp Cap (vph)	278	1079
v/s Ratio Prot	0.06	c0.08
v/s Ratio Perm		0.24
v/c Ratio	0.36	0.47
Uniform Delay, d1	29.8	9.9
Progression Factor	1.00	1.00
Incremental Delay, d2	3.6	1.4
Delay (s)	33.4	11.3
Level of Service	C	B
Approach Delay (s)	17.4	
Approach LOS	B	

Intersection Summary

Movement	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBL	NBT	NBR	SBL
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)		4.0	4.0				4.0			4.0		4.0
Lane Util. Factor		0.97	0.95				*1.00			1.00		0.95
Frt		1.00	1.00				0.95			0.99		1.00
Flt Protected		0.95	1.00				1.00			0.98		0.95
Satd. Flow (prot)		3467	3563				5380			1848		1698
Flt Permitted		0.95	1.00				1.00			0.98		0.95
Satd. Flow (perm)		3467	3563				5380			1848		1698
Volume (vph)	44	943	809	17	19	2	826	373	27	31	3	178
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	46	993	852	18	20	2	869	393	28	33	3	187
Lane Group Flow (vph)	0	1039	870	0	0	0	1284	0	0	64	0	95
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turn Type	Split	Split			Split	Split			Split			Split
Protected Phases	1	1	1		4	4	4		3	3		2
Permitted Phases												
Actuated Green, G (s)		25.0	25.0				17.0			7.0		12.0
Effective Green, g (s)		26.0	26.0				18.0			7.0		13.0
Actuated g/C Ratio		0.32	0.32				0.22			0.09		0.16
Clearance Time (s)		5.0	5.0				5.0			4.0		5.0
Lane Grp Cap (vph)		1127	1158				1211			162		276
v/s Ratio Prot		c0.30	0.24				c0.24			0.03		0.06
v/s Ratio Perm												
v/c Ratio		0.92	0.75				1.06			0.40		0.34
Uniform Delay, d1		26.0	24.1				31.0			34.5		29.7
Progression Factor		1.00	1.00				1.00			1.00		1.00
Incremental Delay, d2		13.6	4.5				43.4			7.1		3.4
Delay (s)		39.6	28.6				74.4			41.6		33.1
Level of Service		D	C				E			D		C
Approach Delay (s)			34.6				74.4			41.6		
Approach LOS			C				E			D		

Intersection Summary			
HCM Average Control Delay	44.6	HCM Level of Service	D
HCM Volume to Capacity ratio	0.77		
Actuated Cycle Length (s)	80.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	103.6%	ICU Level of Service	F
c Critical Lane Group			

Movement	SBT	SBR
Lane Configurations		
Ideal Flow (vphpl)	1900	1900
Total Lost time (s)	4.0	4.0
Lane Util. Factor	0.95	1.00
Frt	1.00	0.85
Flt Protected	0.96	1.00
Satd. Flow (prot)	1709	1599
Flt Permitted	0.96	1.00
Satd. Flow (perm)	1709	1599
Volume (vph)	8	477
Peak-hour factor, PHF	0.95	0.95
Adj. Flow (vph)	8	502
Lane Group Flow (vph)	100	502
Heavy Vehicles (%)	1%	1%
Turn Type		custom
Protected Phases	2	2
Permitted Phases		1 3
Actuated Green, G (s)	12.0	44.0
Effective Green, g (s)	13.0	46.0
Actuated g/C Ratio	0.16	0.58
Clearance Time (s)	5.0	5.0
Lane Grp Cap (vph)	278	1079
v/s Ratio Prot	0.06	c0.08
v/s Ratio Perm		0.24
v/c Ratio	0.36	0.47
Uniform Delay, d1	29.8	9.9
Progression Factor	1.00	1.00
Incremental Delay, d2	3.6	1.4
Delay (s)	33.4	11.3
Level of Service	C	B
Approach Delay (s)	17.4	
Approach LOS	B	

Intersection Summary

Movement	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBL	NBT	NBR	SBL
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)		4.0	4.0				4.0			4.0		4.0
Lane Util. Factor		0.97	0.95				*1.00			1.00		0.95
Frt		1.00	1.00				0.95			0.99		1.00
Flt Protected		0.95	1.00				1.00			0.98		0.95
Satd. Flow (prot)		3467	3563				5380			1848		1698
Flt Permitted		0.95	1.00				1.00			0.98		0.95
Satd. Flow (perm)		3467	3563				5380			1848		1698
Volume (vph)	44	943	809	17	19	2	826	373	27	31	3	178
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	46	993	852	18	20	2	869	393	28	33	3	187
Lane Group Flow (vph)	0	1039	870	0	0	0	1284	0	0	64	0	95
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turn Type	Split	Split			Split	Split			Split			Split
Protected Phases	1	1	1		4	4	4		3	3		2
Permitted Phases												
Actuated Green, G (s)		25.0	25.0				21.0			7.0		8.0
Effective Green, g (s)		26.0	26.0				22.0			7.0		9.0
Actuated g/C Ratio		0.32	0.32				0.28			0.09		0.11
Clearance Time (s)		5.0	5.0				5.0			4.0		5.0
Lane Grp Cap (vph)		1127	1158				1480			162		191
v/s Ratio Prot		c0.30	0.24				c0.24			0.03		0.06
v/s Ratio Perm												
v/c Ratio		0.92	0.75				0.87			0.40		0.50
Uniform Delay, d1		26.0	24.1				27.6			34.5		33.4
Progression Factor		1.00	1.00				1.00			1.00		1.00
Incremental Delay, d2		13.6	4.5				7.1			7.1		9.0
Delay (s)		39.6	28.6				34.7			41.6		42.3
Level of Service		D	C				C			D		D
Approach Delay (s)			34.6				34.7			41.6		
Approach LOS			C				C			D		

Intersection Summary			
HCM Average Control Delay	32.6	HCM Level of Service	C
HCM Volume to Capacity ratio	0.76		
Actuated Cycle Length (s)	80.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	103.6%	ICU Level of Service	F
c Critical Lane Group			

Movement	SBT	SBR
Lane Configurations		
Ideal Flow (vphpl)	1900	1900
Total Lost time (s)	4.0	4.0
Lane Util. Factor	0.95	1.00
Frt	1.00	0.85
Flt Protected	0.96	1.00
Satd. Flow (prot)	1709	1599
Flt Permitted	0.96	1.00
Satd. Flow (perm)	1709	1599
Volume (vph)	8	477
Peak-hour factor, PHF	0.95	0.95
Adj. Flow (vph)	8	502
Lane Group Flow (vph)	100	502
Heavy Vehicles (%)	1%	1%
Turn Type		custom
Protected Phases	2	2
Permitted Phases		1 3
Actuated Green, G (s)	8.0	40.0
Effective Green, g (s)	9.0	42.0
Actuated g/C Ratio	0.11	0.52
Clearance Time (s)	5.0	5.0
Lane Grp Cap (vph)	192	999
v/s Ratio Prot	0.06	c0.06
v/s Ratio Perm		0.26
v/c Ratio	0.52	0.50
Uniform Delay, d1	33.5	12.3
Progression Factor	1.00	1.00
Incremental Delay, d2	9.7	1.8
Delay (s)	43.2	14.1
Level of Service	D	B
Approach Delay (s)	22.1	
Approach LOS	C	

Intersection Summary

Movement	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBL	NBT	NBR	SBL
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)		4.0	4.0				4.0			4.0		4.0
Lane Util. Factor		0.97	0.95				*1.00			1.00		0.95
Frt		1.00	1.00				0.95			0.99		1.00
Flt Protected		0.95	1.00				1.00			0.98		0.95
Satd. Flow (prot)		3467	3563				5380			1848		1698
Flt Permitted		0.95	1.00				1.00			0.98		0.95
Satd. Flow (perm)		3467	3563				5380			1848		1698
Volume (vph)	44	943	809	17	19	2	826	373	27	31	3	178
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	46	993	852	18	20	2	869	393	28	33	3	187
Lane Group Flow (vph)	0	1039	870	0	0	0	1284	0	0	64	0	95
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turn Type	Split	Split			Split	Split			Split			Split
Protected Phases	1	1	1		4	4	4		3	3		2
Permitted Phases												
Actuated Green, G (s)		32.0	32.0				23.0			7.0		9.0
Effective Green, g (s)		33.0	33.0				24.0			7.0		10.0
Actuated g/C Ratio		0.37	0.37				0.27			0.08		0.11
Clearance Time (s)		5.0	5.0				5.0			4.0		5.0
Lane Grp Cap (vph)		1271	1306				1435			144		189
v/s Ratio Prot		c0.30	0.24				c0.24			0.03		0.06
v/s Ratio Perm												
v/c Ratio		0.82	0.67				0.89			0.44		0.50
Uniform Delay, d1		25.8	23.9				31.8			39.6		37.7
Progression Factor		1.00	1.00				1.00			1.00		1.00
Incremental Delay, d2		5.9	2.7				9.0			9.6		9.2
Delay (s)		31.7	26.6				40.8			49.3		46.9
Level of Service		C	C				D			D		D
Approach Delay (s)			29.4				40.8			49.3		
Approach LOS			C				D			D		

Intersection Summary			
HCM Average Control Delay	32.3	HCM Level of Service	C
HCM Volume to Capacity ratio	0.73		
Actuated Cycle Length (s)	90.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	103.6%	ICU Level of Service	F
c Critical Lane Group			

HCM Signalized Intersection Capacity Analysis
2: Route 9 & Brookline Avenue 4/14/2008

Movement	SBT	SBR
Lane Configurations		
Ideal Flow (vphpl)	1900	1900
Total Lost time (s)	4.0	4.0
Lane Util. Factor	0.95	1.00
Frt	1.00	0.85
Flt Protected	0.96	1.00
Satd. Flow (prot)	1709	1599
Flt Permitted	0.96	1.00
Satd. Flow (perm)	1709	1599
Volume (vph)	8	477
Peak-hour factor, PHF	0.95	0.95
Adj. Flow (vph)	8	502
Lane Group Flow (vph)	100	502
Heavy Vehicles (%)	1%	1%
Turn Type		custom
Protected Phases	2	2
Permitted Phases		1 3
Actuated Green, G (s)	9.0	48.0
Effective Green, g (s)	10.0	50.0
Actuated g/C Ratio	0.11	0.56
Clearance Time (s)	5.0	5.0
Lane Grp Cap (vph)	190	1030
v/s Ratio Prot	0.06	c0.05
v/s Ratio Perm		0.26
v/c Ratio	0.53	0.49
Uniform Delay, d1	37.8	12.2
Progression Factor	1.00	1.00
Incremental Delay, d2	10.1	1.6
Delay (s)	47.8	13.8
Level of Service	D	B
Approach Delay (s)	23.2	
Approach LOS	C	

Intersection Summary

Movement	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBL	NBT	NBR	SBL
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)		4.0	4.0				4.0			4.0		4.0
Lane Util. Factor		0.97	0.95				0.91			1.00		0.95
Frt		1.00	1.00				1.00			0.98		1.00
Flt Protected		0.95	1.00				1.00			0.98		0.95
Satd. Flow (prot)		3467	3563				5098			1815		1698
Flt Permitted		0.95	1.00				1.00			0.98		0.95
Satd. Flow (perm)		3467	3563				5098			1815		1698
Volume (vph)	11	401	918	20	62	4	1016	33	22	19	9	542
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	12	422	966	21	65	4	1069	35	23	20	9	571
Lane Group Flow (vph)	0	434	987	0	0	0	1173	0	0	52	0	286
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turn Type	Split	Split			Split	Split			Split			Split
Protected Phases	1	1	1		4	4	4		3	3		2
Permitted Phases												
Actuated Green, G (s)		23.0	23.0				30.0			7.0		21.0
Effective Green, g (s)		24.0	24.0				31.0			7.0		22.0
Actuated g/C Ratio		0.24	0.24				0.31			0.07		0.22
Clearance Time (s)		5.0	5.0				5.0			4.0		5.0
Lane Grp Cap (vph)		832	855				1580			127		374
v/s Ratio Prot		0.13	c0.28				c0.23			0.03		0.17
v/s Ratio Perm												
v/c Ratio		0.52	1.15				0.74			0.41		0.76
Uniform Delay, d1		33.0	38.0				30.9			44.5		36.6
Progression Factor		1.00	1.00				1.00			1.00		1.00
Incremental Delay, d2		2.3	82.7				3.2			9.5		13.8
Delay (s)		35.3	120.7				34.1			54.0		50.4
Level of Service		D	F				C			D		D
Approach Delay (s)			94.6				34.1			54.0		
Approach LOS			F				C			D		

Intersection Summary			
HCM Average Control Delay	57.1	HCM Level of Service	E
HCM Volume to Capacity ratio	0.84		
Actuated Cycle Length (s)	100.0	Sum of lost time (s)	12.0
Intersection Capacity Utilization	105.0%	ICU Level of Service	F
c Critical Lane Group			

HCM Signalized Intersection Capacity Analysis
2: Route 9 & Brookline Avenue 4/14/2008

Movement	SBT	SBR
Lane Configurations		
Ideal Flow (vphpl)	1900	1900
Total Lost time (s)	4.0	4.0
Lane Util. Factor	0.95	1.00
Frt	1.00	0.85
Flt Protected	0.95	1.00
Satd. Flow (prot)	1705	1599
Flt Permitted	0.95	1.00
Satd. Flow (perm)	1705	1599
Volume (vph)	11	585
Peak-hour factor, PHF	0.95	0.95
Adj. Flow (vph)	12	616
Lane Group Flow (vph)	297	616
Heavy Vehicles (%)	1%	1%
Turn Type		custom
Protected Phases	2	2
Permitted Phases		1 3
Actuated Green, G (s)	21.0	51.0
Effective Green, g (s)	22.0	53.0
Actuated g/C Ratio	0.22	0.53
Clearance Time (s)	5.0	5.0
Lane Grp Cap (vph)	375	975
v/s Ratio Prot	c0.17	c0.14
v/s Ratio Perm		0.25
v/c Ratio	0.79	0.63
Uniform Delay, d1	36.8	16.6
Progression Factor	1.00	1.00
Incremental Delay, d2	15.7	3.1
Delay (s)	52.5	19.7
Level of Service	D	B
Approach Delay (s)	35.2	
Approach LOS	D	

Intersection Summary

Movement	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBL	NBT	NBR	SBL
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)		4.0	4.0				4.0			4.0		4.0
Lane Util. Factor		0.97	0.95				*1.00			1.00		0.95
Frt		1.00	1.00				0.97			0.98		1.00
Flt Protected		0.95	1.00				1.00			0.98		0.95
Satd. Flow (prot)		3467	3563				5484			1815		1698
Flt Permitted		0.95	1.00				1.00			0.98		0.95
Satd. Flow (perm)		3467	3563				5484			1815		1698
Volume (vph)	11	401	918	20	62	4	1016	225	22	19	9	542
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	12	422	966	21	65	4	1069	237	23	20	9	571
Lane Group Flow (vph)	0	434	987	0	0	0	1375	0	0	52	0	286
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turn Type	Split	Split			Split	Split			Split			Split
Protected Phases	1	1	1		4	4	4		3	3		2
Permitted Phases												
Actuated Green, G (s)		23.0	23.0				30.0			7.0		21.0
Effective Green, g (s)		24.0	24.0				31.0			7.0		22.0
Actuated g/C Ratio		0.24	0.24				0.31			0.07		0.22
Clearance Time (s)		5.0	5.0				5.0			4.0		5.0
Lane Grp Cap (vph)		832	855				1700			127		374
v/s Ratio Prot		0.13	c0.28				c0.25			0.03		0.17
v/s Ratio Perm												
v/c Ratio		0.52	1.15				0.81			0.41		0.76
Uniform Delay, d1		33.0	38.0				31.8			44.5		36.6
Progression Factor		1.00	1.00				1.00			1.00		1.00
Incremental Delay, d2		2.3	82.7				4.3			9.5		13.8
Delay (s)		35.3	120.7				36.0			54.0		50.4
Level of Service		D	F				D			D		D
Approach Delay (s)			94.6				36.0			54.0		
Approach LOS			F				D			D		

Intersection Summary			
HCM Average Control Delay	56.6	HCM Level of Service	E
HCM Volume to Capacity ratio	0.87		
Actuated Cycle Length (s)	100.0	Sum of lost time (s)	12.0
Intersection Capacity Utilization	109.5%	ICU Level of Service	F
c Critical Lane Group			

Movement	SBT	SBR
Lane Configurations		
Ideal Flow (vphpl)	1900	1900
Total Lost time (s)	4.0	4.0
Lane Util. Factor	0.95	1.00
Frt	1.00	0.85
Flt Protected	0.95	1.00
Satd. Flow (prot)	1705	1599
Flt Permitted	0.95	1.00
Satd. Flow (perm)	1705	1599
Volume (vph)	11	585
Peak-hour factor, PHF	0.95	0.95
Adj. Flow (vph)	12	616
Lane Group Flow (vph)	297	616
Heavy Vehicles (%)	1%	1%
Turn Type		custom
Protected Phases	2	2
Permitted Phases		1 3
Actuated Green, G (s)	21.0	51.0
Effective Green, g (s)	22.0	53.0
Actuated g/C Ratio	0.22	0.53
Clearance Time (s)	5.0	5.0
Lane Grp Cap (vph)	375	975
v/s Ratio Prot	c0.17	c0.14
v/s Ratio Perm		0.25
v/c Ratio	0.79	0.63
Uniform Delay, d1	36.8	16.6
Progression Factor	1.00	1.00
Incremental Delay, d2	15.7	3.1
Delay (s)	52.5	19.7
Level of Service	D	B
Approach Delay (s)	35.2	
Approach LOS	D	

Intersection Summary

Movement	EBU	EBL	EBT	EBR	WBU	WBL	WBT	WBR	NBL	NBT	NBR	SBL
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost time (s)		4.0	4.0				4.0			4.0		4.0
Lane Util. Factor		0.97	0.95				*1.00			1.00		0.95
Frt		1.00	1.00				0.97			0.98		1.00
Flt Protected		0.95	1.00				1.00			0.98		0.95
Satd. Flow (prot)		3467	3563				5484			1815		1698
Flt Permitted		0.95	1.00				1.00			0.98		0.95
Satd. Flow (perm)		3467	3563				5484			1815		1698
Volume (vph)	11	401	918	20	62	4	1016	225	22	19	9	542
Peak-hour factor, PHF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Adj. Flow (vph)	12	422	966	21	65	4	1069	237	23	20	9	571
Lane Group Flow (vph)	0	434	987	0	0	0	1375	0	0	52	0	286
Heavy Vehicles (%)	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turn Type	Split	Split			Split	Split			Split			Split
Protected Phases	1	1	1		4	4	4		3	3		2
Permitted Phases												
Actuated Green, G (s)		35.0	35.0				36.0			7.0		23.0
Effective Green, g (s)		36.0	36.0				37.0			7.0		24.0
Actuated g/C Ratio		0.30	0.30				0.31			0.06		0.20
Clearance Time (s)		5.0	5.0				5.0			4.0		5.0
Lane Grp Cap (vph)		1040	1069				1691			106		340
v/s Ratio Prot		0.13	c0.28				c0.25			0.03		0.17
v/s Ratio Perm												
v/c Ratio		0.42	0.92				0.81			0.49		0.84
Uniform Delay, d1		33.6	40.7				38.3			54.8		46.2
Progression Factor		1.00	1.00				1.00			1.00		1.00
Incremental Delay, d2		1.2	14.3				4.4			15.3		21.5
Delay (s)		34.8	55.0				42.7			70.1		67.7
Level of Service		C	D				D			E		E
Approach Delay (s)			48.8				42.7			70.1		
Approach LOS			D				D			E		

Intersection Summary			
HCM Average Control Delay	45.7	HCM Level of Service	D
HCM Volume to Capacity ratio	0.83		
Actuated Cycle Length (s)	120.0	Sum of lost time (s)	12.0
Intersection Capacity Utilization	109.5%	ICU Level of Service	F
c Critical Lane Group			

HCM Signalized Intersection Capacity Analysis
2: Route 9 & Brookline Avenue 4/14/2008

Movement	SBT	SBR
Lane Configurations		
Ideal Flow (vphpl)	1900	1900
Total Lost time (s)	4.0	4.0
Lane Util. Factor	0.95	1.00
Frt	1.00	0.85
Flt Protected	0.95	1.00
Satd. Flow (prot)	1705	1599
Flt Permitted	0.95	1.00
Satd. Flow (perm)	1705	1599
Volume (vph)	11	585
Peak-hour factor, PHF	0.95	0.95
Adj. Flow (vph)	12	616
Lane Group Flow (vph)	297	616
Heavy Vehicles (%)	1%	1%
Turn Type		custom
Protected Phases	2	2
Permitted Phases		1 3
Actuated Green, G (s)	23.0	65.0
Effective Green, g (s)	24.0	67.0
Actuated g/C Ratio	0.20	0.56
Clearance Time (s)	5.0	5.0
Lane Grp Cap (vph)	341	999
v/s Ratio Prot	c0.17	c0.12
v/s Ratio Perm		0.26
v/c Ratio	0.87	0.62
Uniform Delay, d1	46.5	17.8
Progression Factor	1.00	1.00
Incremental Delay, d2	24.9	2.9
Delay (s)	71.4	20.7
Level of Service	E	C
Approach Delay (s)	44.5	
Approach LOS	D	

Intersection Summary

Appendix B – Footbridge

Footbridge Calculations and Design

Bridge Foundation and Pier Design Calculation Sheet

Properties

Average unit weight of soil and fill = 120
Average unit weight of clay= 115
Average SPT soil north side = 13
Water table = 3 ft below elevation 0
14 (in) X 102 (lb/ft) H piles
3 foot diameter concrete column for the abutment
Unit weight of concrete (includes structural rebar) = 150 pcf

North Side Bridge Piles

Layer	Feet
Fill	23
To stratum	10
Five ft in stratum	8
Total	41

Factors	Figures
1 Overburden Stress (lb/ft^2)	3451.20
2 Overburden Stress (lb/ft^2)	3681.60
Friction Angle	30.00
Interface friction angle	20.00
Bearing Capacity	
N_q	150.00
H-pile Dimensions	
Depth (in)	14.01
Flange Width (in)	14.78
Area pile (ft^2)	2.50
Perimeter (ft)	4.80
K	1.40
1 f	1758.59
2 f	1875.99
1 Q_s (lb/ft^2)	84382.85
2 Q_s (lb/ft^2)	90016.19
Q_u (lb/ft^2)	174399.04
Q_u (kips)	174.40
Load from Bridge	60.00
Load from Backspan	43.88
Load from Column	14.84
Load from Connector	7.43
Load bracing	1.00
Load pile has to carry (kips)	254.29
Load Per Pile (kips)	**42.38**
Ultimate Capacity (kips)	**174.40**
Allowable Load (kips)	**58.13**

South Side Bridge Piles

Layer	Feet
Fill	23
Clay	40
Total	63

Factors	Figures
1 Overburden Stress (lb/ft^2)	3023.00
2 Overburden Stress (lb/ft^2)	3549.00
3 Overburden Stress (lb/ft^2)	4075.00
4 Overburden Stress (lb/ft^2)	4601.00
H-pile Dimensions	
Depth (in)	14.01
Flange Width (in)	14.78
Area pile (ft^2)	2.50
Alpha	0.95
1 C_u (psf)	604.60
2 C_u (psf)	709.80
3 C_u (psf)	815.00
4 C_u (psf)	920.20
Perimeter (ft)	4.80
1 Q_s (lb/ft^2)	27560.19
2 Q_s (lb/ft^2)	32355.64
3 Q_s (lb/ft^2)	37151.10
4 Q_s (lb/ft^2)	41946.55
Q_u (lb/ft^2)	139013.47
Q_u (kips)	139.01
Load from bridge (kips)	60.00
Load from backspan (kips)	43.88
Load from Column (kips)	14.84
Load from Connector (kips)	7.43
Load bracing (kips)	1.00
Load pile cap has to carry (kips)	254.29
Load per pile (kips)	**42.38**
Ultimate capacity (kips)	**139.01**
Allowable load (kips)	**46.34**

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Appendix C – Curley Overpass

Curley Overpass

For full size Curley Overpass drawings, see attached roll and CD

Appendix D – Drawings

For drawings, see attached roll and CD