CASE STUDY: DESIGN OF THE HIGHWAY 406 TERMINATION ROUNDABOUT

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1.0 ABSTRACT

A multi-lane roundabout is currently under construction at the south end of Highway 406, the main highway connecting the cities of St. Catharines and Welland in southern Ontario. The southern section of Highway 406 is being expanded to a four-lane divided highway with grade-separated interchanges, and the roundabout will facilitate its termination at East Main Street in Welland. The use of roundabouts at highway terminations is common in countries where roundabout use is widespread, but rare in the United States and Canada. This paper describes development of the horizontal geometry of the roundabout, and some issues associated with the advance signing.

During the conceptual design process decisions were made about the lane configuration of the roundabout, whether to shift the roundabout to avoid a nearby parking lot, whether to implement a southbound "semi" right-turn bypass ending in a yield condition or a fully-channelized bypass, and whether to construct an interim design for the roundabout or implement the ultimate design at the outset.

During the preliminary design process decisions were made about the methodology by which large trucks would be accommodated, and the type, size and location of the advance signage associated with the roundabout.

Overpass work along the two-lane section of Highway 406 commenced in 2010, and the widening of the highway commenced in 2011. Construction of the multi-lane roundabout began in late 2012. Completion of the entire project, under the jurisdiction of the Ministry of Transportation Ontario (MTO), is expected in the fall of 2013.

2.0 BACKGROUND AND INTRODUCTION

Highway 406 extends south and west of the Queen Elizabeth Way (QEW) in the Niagara peninsula of southern Ontario. The southern section of Highway 406 is currently being expanded to a four-lane divided highway with grade-separated interchanges, and its terminus at East Main Street in Welland will be converted from a signalized intersection to a roundabout. The intersection location is shown in Figure 2.1.

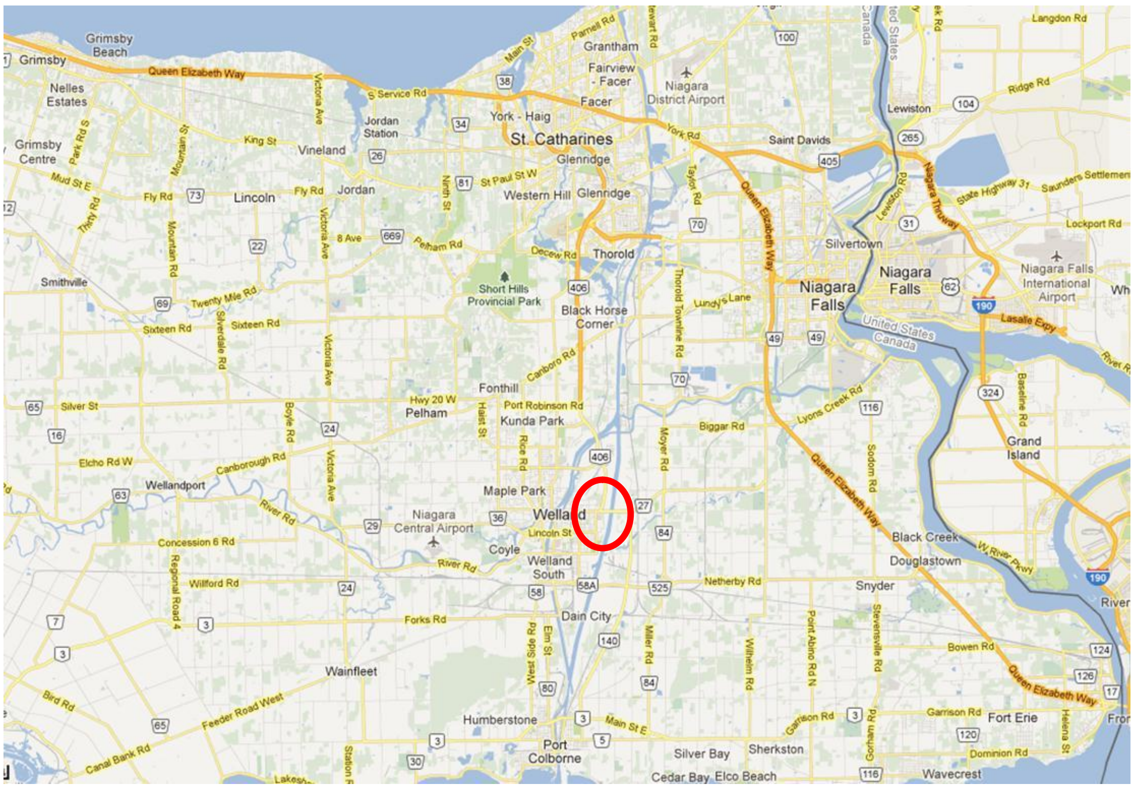

Figure 2.1 Intersection Location. The intersection is south of St. Catharines and southwest of Niagara Falls, at the termination of Highway 406 at Welland.

The use of roundabouts at major highway terminations is common in countries where roundabout use is widespread, but rare in the United States and Canada. The decision to implement a roundabout was made through a transportation study that predicted a multi-lane roundabout would exhibit better safety and operational performance than a signalized intersection. The safety performance of roundabouts in general is well-documented, most recently in the United States.[1] At this location a roundabout was also predicted to result in less motorist delay because of forecast high left-turn demand southbound and eastbound, conditions under which signal control is not particularly efficient.

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1 National Cooperative Highway Research Program (NCHRP) Report 572, *Roundabouts in the United States*. The report shows an overall decrease in injury collisions of 76% with conversion to a roundabout. The before condition was a mix of stop and signal control in urban and rural locations, and the after condition was either a single-lane or a multi-lane roundabout.

A roundabout at this location was not without its challenges. The site context is shown in Figure 2.2. In addition to the high-speed approach from Highway 406 southbound, there is a closely-spaced intersection some 220 metres to the west (Wellington Street), and a tunnel under the Welland Canal to the east which had the potential to make sightlines approaching the roundabout problematic.

Figure 2.2 Site Context. Highway 406 terminates at East Main Street. To the west is downtown Welland, and to the east is a tunnel under the Welland Canal.

Highway 406 and the intersection are under the jurisdiction of the Ministry of Transportation Ontario (MTO). Design of the roundabout commenced in 2009 and construction is being undertaken with the widening of Highway 406. All work is expected to be completed by the fall of 2013.

Ourston Roundabout Engineering (formerly a Member of The Sernas Group Inc. but now part of GHD Inc.) developed the horizontal geometry of the roundabout and provided assistance with the sign design.

3.0 THE DESIGN PROCESS

3.1 CONCEPTUAL DESIGN

3.1.1 Determining the Lane Configuration

During the initial design process traffic forecasts for a 2031 horizon year were run through the computer program RODEL to determine the most appropriate lane configuration for the roundabout.[2] The analysis predicted that the roundabout would result in low motorist delay if it had a two-lane entry plus right-turn bypass southbound on Highway 406, and two-lane entries eastbound and westbound on East Main Street. However since RODEL (and its sister program ARCADY) only indicate the number of entry lanes needed, a more detailed lane-by-lane analysis was undertaken to confirm the lane configuration because of forecast high left-turn demand southbound and eastbound.

The lane-by-lane analyses revealed that two left-turn lanes would be needed at the southbound and eastbound entries to accommodate the high left-turn volumes. In the southbound direction this would be both entry lanes (since there would be a bypass for the right turns). In the eastbound direction this meant that the left lane would need to be a left-turn only lane and the right lane would be a shared left/through lane. However with consecutive double-left turns and a two-lane circulatory road eastbound, drivers in the right entry lane would end up in the outside lane in the circulatory road and have to make a lane change in order to exit the roundabout to the north. Roundabouts should not require mandatory lane changes in the circulatory road. The solution was to provide a section with a third lane that would "spiral out" southbound drivers, as illustrated in Figure 3.1. With three circulating lanes it made sense from a traffic capacity perspective to have a three-lane entry eastbound.

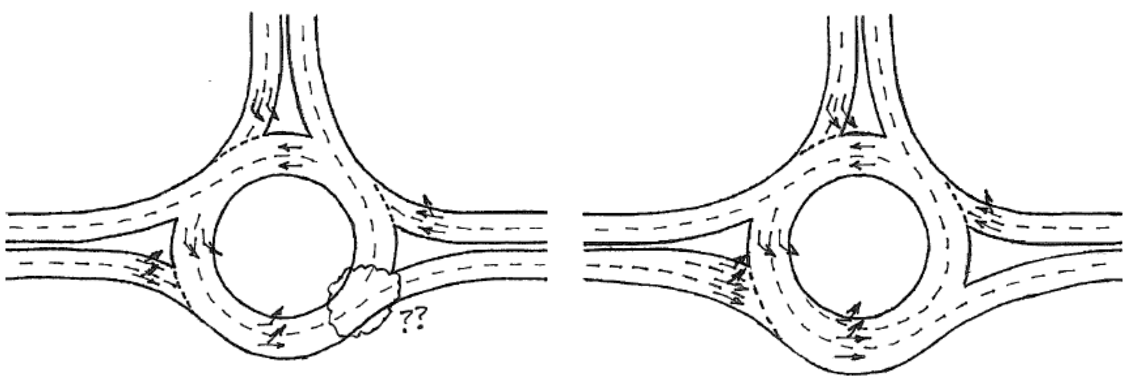

Figure 3.1 Implications of Not Providing a Third Circulating Lane. In the figure on the right, eastbound drivers in the right lane would need to make a lane change to exit the roundabout to the north. This was resolved by adding a third circulating lane (the figure on the left).

[2] RODEL and ARCADY are roundabout capacity analysis programs that utilize empirical equations relating capacity to entry geometry as developed by the Transport Research Laboratory in the U.K.

An interim lane configuration based on 2021 traffic forecasts was also developed. The difference between it and the ultimate 2031 lane configuration was the elimination of the three-lane entry eastbound on East Main Street by serving the eastbound left-turn movement with one lane rather than two. The RODEL analysis predicted that this one lane would function at PM peak hour LOS 'D' at the 50th percentile confidence level (CL). An analysis at the 85th percentile CL shows there would be little residual capacity, with LOS 'F'.[3]

An alternative to eliminating the eastbound left-turn lane would have been to eliminate the through lane instead and provide a single-lane exit on the east leg. This would have worked well according to the capacity analysis, but with little to gain because the southbound double-left turn would have still required a two-lane exit eastbound.

3.1.2 Initial Conceptual Design

The initial conceptual design, based on the 2031 peak hour capacity analysis, is shown in Figure 3.2. An extension of the truck apron was developed to initiate the spiral in the circulatory road, since experience has shown that motorists will drive over circulatory road markings otherwise, as seen in Figure 3.3.

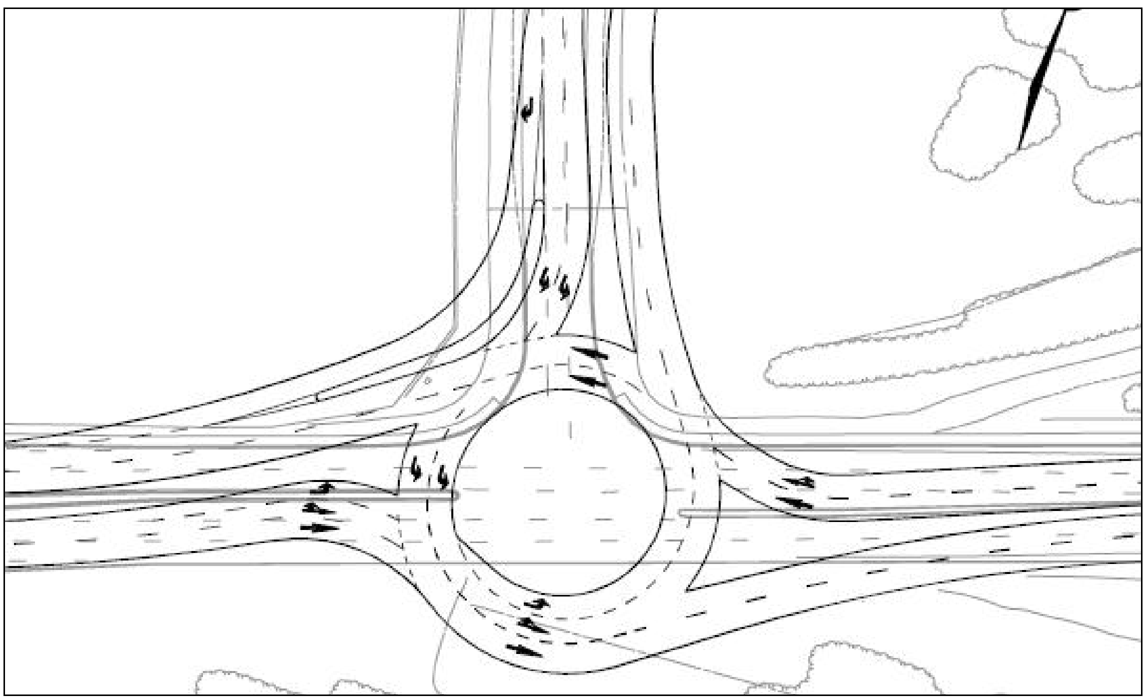

Figure 3.2 Roundabout Conceptual Design. Note the use of the truck apron to initiate the spiral in the circulatory road.

3 The 50th percentile CL corresponds to the most likely prediction of capacity. Testing at a higher CL, such as the 85th, is unique to RODEL and allows a designer to test the robustness of a design in response to driver unfamiliarity with roundabouts or other factors. This feature is similar to the use of a y-intercept adjustment of the capacity prediction in more recent versions of ARCADY.

Figure 3.3 Example of Ineffective Circulatory Road Markings. Drivers can run over the markings and end up in the incorrect circulating lane.

3.1.3 Additional Issues

Three additional issues came up during the conceptual design process:

- Whether to shift the roundabout to avoid a parking lot on the northwest corner of the intersection, or leave it in its current location.
- Whether to implement a “semi” bypass ending in a yield condition for southbound right turns, or a fully-channelized bypass.
- Whether to implement an interim design for the roundabout, to be staged to the ultimate design when warranted by traffic growth, or implement the ultimate design at the outset.

Determine Roundabout Location

A business owner on the northwest corner of the intersection had requested that the roundabout be relocated to avoid a parking lot. This could have been accomplished by shifting the roundabout to the east and/or south, however it would have resulted in a number of other impacts.

Shifting the roundabout approximately 60 metres to the east to avoid the parking lot would have meant:

- The roundabout would be closer to the Welland Canal tunnel, resulting in less distance over which to install advance signing, and requiring a steeper uphill grade westbound to the roundabout (making achieving minimum stopping sight distance more difficult).
- The Highway 406 southbound approach would need to be realigned to achieve sufficient speed control into the roundabout from the north.

Shifting the roundabout approximately 10 metres to the south would have meant:

- Additional impacts to properties on the south side of East Main Street.
- A longer distance to tie back to existing on the east leg, resulting in a higher construction cost. Further, the east leg would have needed to be significantly realigned to achieve sufficient speed control into the roundabout from the east.

It was therefore recommended that the roundabout remain in its initial location.

Decide on Southbound Right-Turn Bypass

Rather than a fully-channelized bypass ending in a merge condition, a semi bypass (or “smart” channel) ending in a yield condition could have been designed to accommodate southbound right-turn flows. This design treatment is often used in the United Kingdom and Australia and is seeing some application at signalized intersections and roundabouts in the United States and Canada.

The two southbound right-turn options are shown in Figure 3.4.

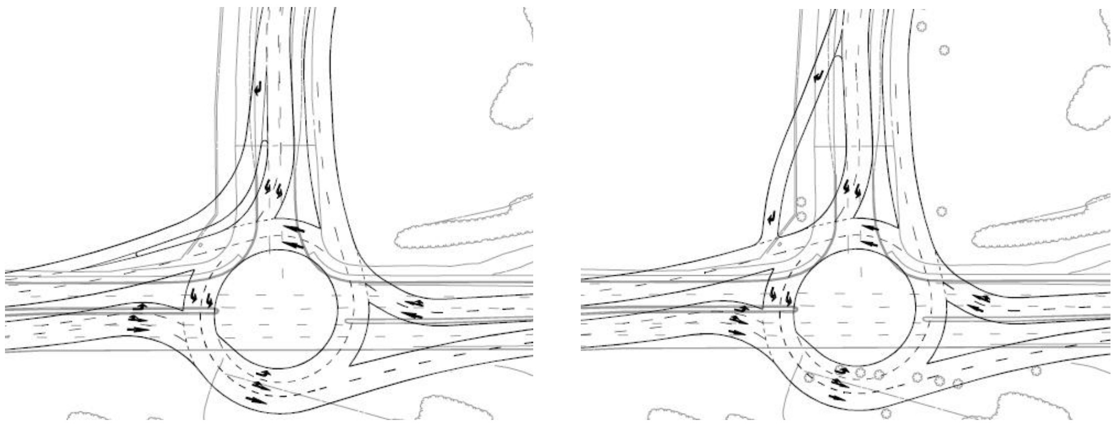

Figure 3.4 Fully-Channelized (left) and Semi (right) Right-Turn Bypasses. The semi bypass ends in a yield condition, requiring drivers to look to their left. Therefore it is important that it not intersect the mainline at too low an angle.

Advantages of a semi bypass design include one less lane change required downstream for a left-turn movement at the next intersection to the west (Wellington Street), and lower vehicle speeds and potentially better sightlines should a pedestrian crossing be installed on the north leg of the roundabout.

The main disadvantage of a semi bypass design in this case was less vehicle capacity. Although right-turn treatments are difficult to model accurately, it was predicted using RODEL that the movement would operate at 2031 PM peak hour LOS ‘D’ to ‘E’.[4]

Although both right-turn treatments were viable options, in the interests of providing higher southbound capacity it was recommended that a fully-channelized bypass ending in a merge condition be implemented.

4 RODEL1 capacity analysis at the 50th percentile CL.

Construct Interim or Ultimate Design

An interim design for the roundabout could have been implemented initially, and then converted to the ultimate design when warranted by traffic growth. The interim design would eliminate the three-lane entry eastbound on East Main Street by serving the eastbound left-turn movement with one lane rather than two. The spiral circulatory road markings needed to accommodate consecutive double-left turns in the ultimate design would not be necessary until the ultimate design was implemented.

The interim and ultimate conceptual designs are shown in Figure 3.5.

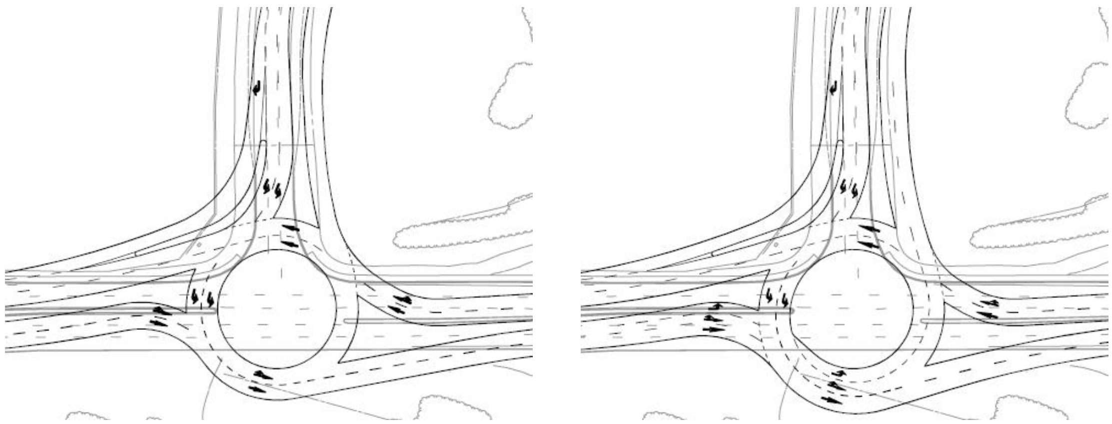

Figure 3.5 Interim (left) and Ultimate (right) Roundabout Conceptual Designs. The interim design has only a two-lane entry eastbound.

Advantages of implementing an interim design initially included:

- Slightly higher motorist safety due to one less entry and circulating lane.
- Slightly lower construction cost initially.
- The interim period could be long (or even permanent) if the 2031 traffic forecasts are not realized.
- The roundabout would be simpler for drivers to deal with on opening day.

Disadvantages of implementing an interim design initially included:

- The eastbound left turn was predicted to operate at 2021 PM peak hour LOS ‘D’ at the 50th percentile CL, and LOS ‘F’ at the 85th percentile CL.
- Slightly higher construction cost overall because of the need to reconstruct portions of the initial roundabout (although the roundabout could have been designed to minimize the cost of converting from interim to ultimate layout).
- The interim period could be short if traffic forecasts are higher than anticipated, or if the roundabout is constructed later than scheduled.
- The roundabout would require some degree of public education later with the change in lane configuration.
- It may be perceived that roundabout was not designed with sufficient capacity if interim period is short.

It was difficult to make a recommendation whether to implement an interim design because of the uncertainties inherent in traffic forecasting. If the traffic forecasts are accurate, then in the interests of capacity, cost and public perception it would make the most sense to implement the ultimate design of the roundabout at the outset. However, if for whatever reason the 2031 traffic forecasts are not realized then it would be better to implement an interim design on the chance the ultimate design is never required.

Based on discussions with the MTO project team it was decided to implement the ultimate design at the outset.

3.2 PRELIMINARY DESIGN

3.2.1 Truck Accommodation Methodology

A key consideration at this stage of developing the horizontal geometry of the roundabout was the manner in which large trucks would be accommodated. There are three basic truck accommodation methodologies at multi-lane roundabouts:

- Allow large trucks to track across adjacent lanes as they enter, circulate and exit the roundabout. Such roundabouts may be called Case 1 designs.
- Enable large trucks to maintain their own lane through the entry, but not as they circulate and exit. These may be called Case 2 designs.
- Enable large trucks to maintain their own lane as they enter, circulate and exit. These may be called Case 3 designs.

Case 1 roundabout designs are analogous to other types of intersections where trucks will track across adjacent lanes as they make left or right turns, except that at the roundabout the truck will need to do this for through movements as well. An obvious disadvantage is that this may lead to side-swipe collisions between light vehicles and trucks through the roundabout entry. This can be mitigated by training truck drivers to straddle the entry lanes so that other drivers cannot drive beside them. Not as obvious is that there are several advantages to Case 1 designs. They will likely be smaller than roundabouts where trucks can maintain their lane, with narrower entries and exits. These features will act to increase overall safety potential through more speed control. Also, since Case 1 roundabouts are smaller they will occupy somewhat less land area and may be less expensive to construct than Case 2 or Case 3 designs.

Given the relatively high truck percentages that may be found on provincial highways, it was recommended that the two-lane entries be Case 2 designs. This was accomplished via wider entries southbound and westbound, with a gore striping treatment to keep trucks from encroaching into the adjacent lane. Introducing gore striping on a three-lane entry was considered impractical, so this entry was maintained as a Case 1 design.

A Case 3 design was not considered at this location. However the circulatory road is wide enough such that if a passenger car ends up beside a large truck, there should still be enough space to maintain a minimum clearance between it and the truck without either overrunning an adjacent curb.

3.2.2 Finalizing the Horizontal Geometry

The final horizontal geometry of the roundabout is shown in Figure 3.6. In addition to the gore striping, several adjustments were made from the conceptual design in order to optimize the geometry in terms of capacity, safety and cost.

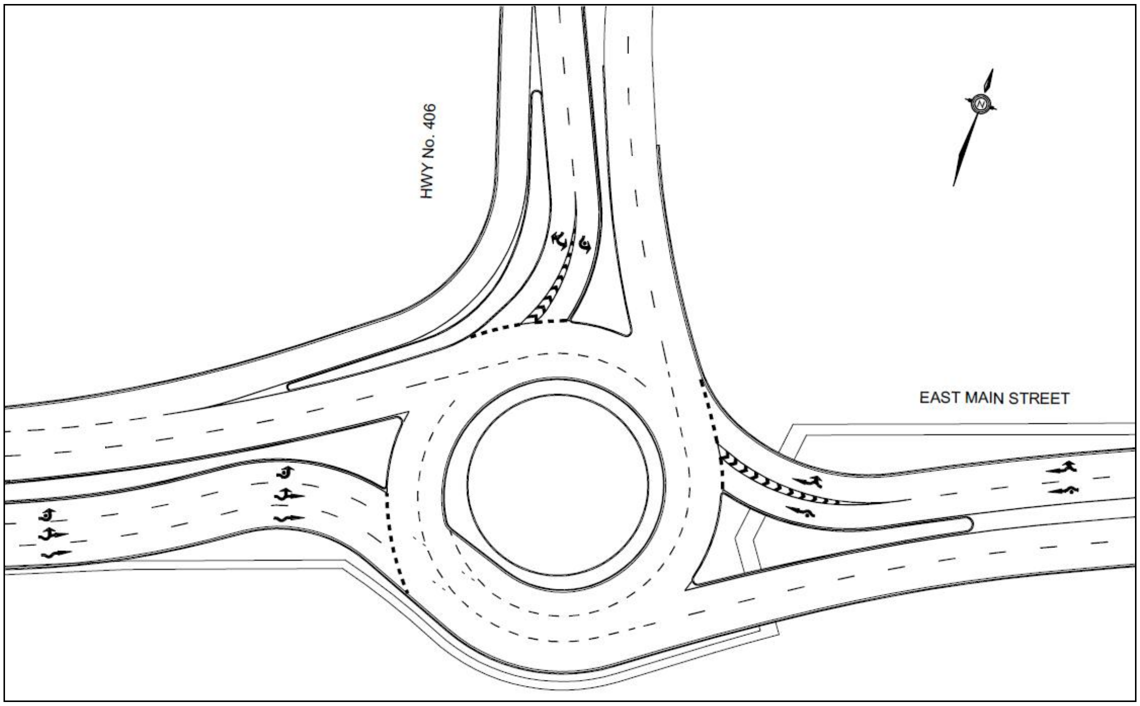

Figure 3.6 Roundabout Preliminary Design. Note the truck gore striping on the north and east legs.

A pedestrian crossing was added to the east leg of the roundabout to connect a trail running along the south side of East Main Street and a sidewalk running along the north side of the tunnel under the Welland Canal.

3.3 SIGN LAYOUT AND DESIGN

3.3.1 The Advance Guide Signs

Several signing plans were developed for the roundabout. The main difference between them was in the number and layout of the advance guide signs. Based on discussions with the MTO project team it was decided to proceed with two ground-mounted diagrammatic and one overhead guide sign southbound, and one ground-mounted diagrammatic and one overhead guide sign eastbound and westbound. Initial versions of these signs are shown in Figure 3.7. The general layout of the signs is consistent with those in a forthcoming update to the Manual of Uniform Traffic Control Devices (MUTCD) for Canada, the study for which was being carried out concurrently with the design of this roundabout.

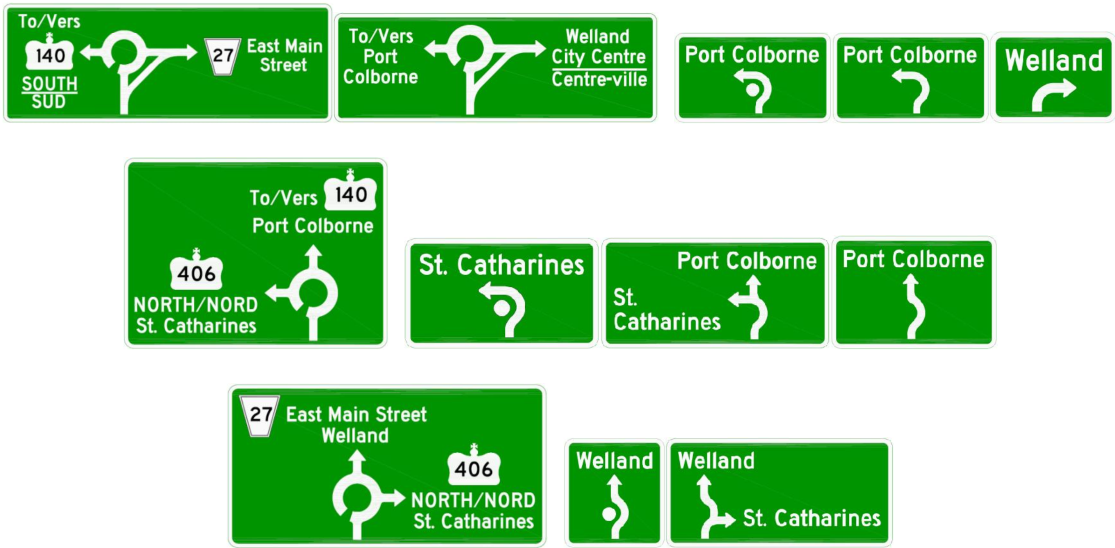

Figure 3.7 Southbound (top), Eastbound (middle), and Westbound (bottom) Advance Guide Signs. Final versions of these ground-mounted and overhead signs are still under development.

One issue faced with the guide signs was that of determining an appropriate letter height for the sign text. A unique opportunity presented itself when an overhead sign on a section of Highway 406 was scheduled to be replaced one evening during the summer of 2011 (along with a number of other signing upgrades along that section of highway). Staff from the MTO created mock-ups of one of the overhead signs for the roundabout in two different standard sign heights: 9 feet (2.7 metres) and 14 feet (4.2 metres). The resulting upper-case letter heights were 250 mm and 300 mm.

The sign mock-ups were installed over the existing sign as shown in Figure 3.8. With the section of highway closed to non-maintenance traffic the signs were approached by several test vehicles at speeds representative of a roundabout approach. From the tests it was determined that the larger sign offered approximately 2 more seconds of reading time than the smaller sign.

Figure 3.8 Comparison of Overhead Signs. Both signs are shown from a distance of 100 metres.

A drawback of the larger signs was that they would need to be supported on larger, non-standard gantries than the smaller signs. However MTO staff ultimately decided that in this case the additional reading time was an appropriate trade-off for the higher costs associated with the larger gantries.

3.3.2 The Other Signs

Another issue that arose had to do with the Roundabout Ahead sign. Typical practice at roundabouts is to install a Roundabout Ahead warning sign unless the presence of a diagrammatic guide sign is deemed sufficient to notify drivers they are approaching a roundabout. Often such a sign is accompanied by an advisory speed tab.

Practice varies among road agencies as to an appropriate advisory speed, and opinion varies as to whether the speed should apply at the sign or at the roundabout entry. Another factor is whether the advisory speed should be for a through movement or a turning movement at the roundabout, and whether it should be intended for passenger cars or for large trucks.

In this case an advisory speed tab of 20 km/h was initially proposed. On the southbound approach, given the other ground-mounted and overhead advance guide signs, the sign would need to be located some 500 metres from the roundabout to ensure sufficient reading time between signs. However between this location and East Main Street is an existing reverse curve on Highway 406 that is posted with an advisory speed of 40 km/h. Both sets of signs are shown in Figure 3.9.

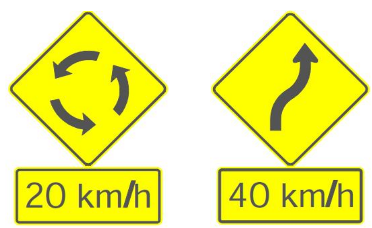

Figure 3.9 Roundabout Ahead and Reverse Curve Signs. The advisory speed tab for the Roundabout Ahead sign has since been replaced with a distance tab.

Since it seemed illogical to display a higher advisory speed closer to the roundabout, the practice of posting advisory speeds on Roundabout Ahead signs was investigated during the course of the study being carried out for the MUTCD for Canada. It was ultimately decided, both for this roundabout and in the forthcoming update, to show an optional distance tab rather than an advisory speed tab for Roundabout Ahead signs, as this is often done for intersection warning signs in general.

4.0 DETAILED DESIGN AND CONSTRUCTION

The foregoing describes development of the horizontal geometry of the roundabout at the termination of Highway 406 at East Main Street in Welland, and some issues associated with the advance signing.

Ourston Roundabout Engineering developed the horizontal geometry of the roundabout and provided assistance with the signage design. Detailed design of the roundabout, and the Highway 406 widening, was undertaken by Giffels/IBI Group. Overpass work along the two-lane section of Highway 406 commenced in 2010, and the widening of the highway commenced in 2011. Construction of the roundabout began in late 2012. Completion of the entire project is expected in the fall of 2013.