Rehabilitation of the Armdale Rotary

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1. ABSTRACT

Prior to improvements constructed in 2007, the Armdale Rotary was a non-conforming traffic circle, located in the Armdale district of Halifax, Nova Scotia. The intersection receives vehicles from five different directions including traffic from the Halifax Peninsula, the Chebucto Peninsula, and along the isthmus of the Halifax Peninsula. It currently handles approximately 60,000 vehicles on weekdays. The historic intersection predates modern automobile traffic but was designed as the Armdale Rotary during the post-war period to handle 5,000-20,000 vehicles.

In 2004, Halifax Regional Municipality (HRM) commenced a series of operational reviews aimed at improving safety and efficiency with modern roundabout operating characteristics. This paper documents the history of the operational changes leading up to the 2007 reconstruction; and, the study of deficiencies arising from ineffective geometry and incorrect lane configurations, particularly for a multi-lane and multi-leg roundabout. Methods used to resolve safety and capacity deficiencies represent an application of design principles that are rooted in U.K. practice, but transcend the current guidelines and analysis tools. Innovative overhead lane designation signs were also applied with success.

The main accomplishment of this work, in terms of advancing roundabout design practice, is that the in-service improvements demonstrate the subtleties of the geometry/safety/capacity/marking relationships that were applied in the design development. After changes to priority rules and implementation of improvements in 2007, previous conflict patterns have virtually disappeared and queues have reduced substantially. Lane discipline and congestion relief is noticeable at the roundabout with the P.M. peak hour exhibiting the largest reduction in conflicts and congestion.

2. INTRODUCTION

This paper documents the in-service safety review of the Armdale Rotary and the unique methods used to resolve safety deficiencies arising from geometric deficiencies and incorrect lane use, particularly for multi-lane and multi-leg roundabout configurations. The study methodology that led to the development of geometric design, signing and marking improvements for these sites is similar and has been consolidated in this paper.

The non-conforming rotary was a source of irritation and controversy to its users due to the unusual operation rules. Prior to 2005 all vehicles had to "yield and proceed" while entering and while in the circle. This caused confusion to many visitors (and locals) to the City, and the roads leading up to the traffic circle were often congested for several hundred metres. For many years, the City assigned a Commissionaire to assist in traffic direction.

In October 2005, municipal and provincial traffic laws were amended in regard to the rules for entering and traversing the traffic circle, making them consistent with world-wide standards for modern roundabouts. This measure removed congestion from the circulating roadway but approaches controlled by traffic signals still had excessive queues. It wasn't until the improvements made in 2007 that the real benefits of modern roundabouts became evident at this location.

In the after condition, three years since the Armdale Rotary was reopened as a modern roundabout, previous conflict patterns have disappeared. Collision data has not been received from the Province since the improvements in 2007; however, HRM staff report a visible improvement in safety and congestion relief.

Congestion relief is noticeable at the roundabout with the P.M. peak hour exhibiting the greatest change. Morning rush hour traffic now exits the roundabout with greater efficiency to the extent that network problems at downstream traffic signals and lane reversal improvements were required to prevent blocking back from downstream intersections. One entry, Quinpool Road, having three lanes, is experiencing problems with left turning drivers not choosing the correct entry lane. One reason is that a correct entry lane choice exits the roundabout into a reversible lane downstream of the roundabout. Drivers prefer not to use the reversible lane, which translates upstream to the Quinpool Road entry.

The voluminous technical appendices detailing the data collected and the operational analysis underlying this study are not attached to this report but may be obtained from the road authority.

2.1 PREVIOUS RELATED STUDIES

Modern roundabout technology is still relatively new in North American. Most designs have not been tested by their design year traffic flows and therefore represent designs waiting to be proven. Several prominent, high volume, rotaries and several roundabouts that were formerly called rotaries or traffic circles are now undergoing or have undergone improvements to their operational performance. Applying the U.K. empirical design principles that recovered the Clearwater Gateway Roundabout in 2002 (1), other non-conforming roundabouts are being rehabilitated or modified for the first time to achieve improved safety and operations. The promising aspect of rehabilitating weak or failing circular intersections is that the results are instantaneous when the correct set of improvements is implemented.

In addition to the Clearwater Gateway Roundabout other high volume roundabouts have been rehabilitated. Among them are, the Long Beach Roundabout, Long Beach, California c. 1992 (2) and the Cony Rotary, Augusta, Maine c. 2008. In these projects a holistic application of U.K. roundabout design principles led the resolution of the capacity and safety deficiencies. Capacity improvements to the Long Beach Roundabout have been observed for 15 years; however capacity was traded-off for a less than acceptable safety performance. It still provides Level of Service ‘A’ (unsignalized control) with 5,300 cars per hour combined entering traffic but Caltrans has asked for improvements to safety. Again, using the U.K. empirical design relationships between safety and geometry a set of geometry, marking and way-finding changes are in process. The need for further improvements at the Long Beach Roundabout will involve trading off some of the capacity benefits for improved safety.

2.2 PROJECT BACKGROUND

Perhaps partly attributable to the Armdale Rotary, the Province of Nova Scotia, Canada changed the section of the Motor Vehicle Act pertaining to vehicles entering and driving in a rotary or roundabout in 2004. Prior to initiating yield at entry in 2004 and regulatory enforcement initiatives in 2006, the Armdale Rotary operated with mixed priority rules of: first in, one-on-one and priority reversal along with partial traffic signal control. Traffic signals controlled the approaches of three entries but none of the circulating roadway. This perpetuated congestion and lock-up of the circulatory roadway and led to excessive backups, greater than 50 vehicles on two lane entries, for two of five approaches during peak periods. The traffic signals were left in place until major improvements were undertaken in 2007.

In June 2004, the Halifax Regional Municipality (HRM) investigated the feasibility of converting the Armdale Rotary to a modern roundabout. A study concluded that the Armdale Rotary could be successfully converted to operate as a modern roundabout with priority to circulating traffic. In 2005, HRM developed a microsimulation model of the Armdale Rotary to assess operations using existing traffic data; and, to test alternative geometric changes. The modeling of the proposed layout in the P.M. peak suggested that congestion downstream of the rotary would back up into the Rotary and cause it to fail. The report recommended that before any changes were made to the Rotary, interactions with nearby intersections needed to be fully assessed. HRM chose to investigate the microscopic operation of the rotary to better understand what would reduce conflicts and improve its efficiency.

Operation of the rotary changed significantly following the changes in driver response to the yield at entry priority rule enacted in 2004 that were later enforced with yield at entry in 2006. In the subject study two assessments of operations and alternative improvements were developed and evaluated. The first was early in 2006 prior to enforcement of yield at entry, and a second set of observations undertaken after the rules of priority were well established. What became apparent from a second set of field observations was that problems with geometry and lane configuration previously masked by the faulty priority rules were unmasked when circulating traffic began to flow freely. This triggered further evaluation of alternative deficiencies not evident under the previous priority rules.

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The study area with the rotary at the center of the image is shown above. The traffic circle receives vehicles from five different directions: Chebucto Road and Quinpool Road on the Halifax Peninsula, Herring Cove Road and St. Margaret's Bay Road on the Chebucto Peninsula, and Joseph Howe Drive, which runs along the isthmus of the Halifax Peninsula. It currently handles approximately 60,000 vehicles on weekdays. Historically, the intersection predates modern automobile traffic, but was designed as the Armdale Rotary during the post-war period to handle 5,000-20,000 vehicles.

The previous study work determined that the rotary is affected by the adjacent intersections, i.e. upstream and downstream conditions. In addition, the interaction of entering and circulating traffic under signal metering control masked the problems that deficient geometry was contributing to. The fact that entries were saturated represented the opportunity to demonstrate that that roundabout capacity is very sensitive to geometry.

Earlier studies of the Armdale Rotary accounted for the U.K. geometry capacity and safety relationships, but their approach did not account for the importance of by-lane modeling and the ineffectiveness of the geometry when not coupled with correct lane designation. Failing to make the connection between existing lane use and ineffective geometry would have resulted in non-complimentary lane assignments with the proposed geometry. This and other related factors were at the root of deriving effective geometric improvements for 2007 and those which could be implemented to reinforce circle priority, lane balance, lane discipline and improved entry capacity.

3. RESEARCH ON HIGH CAPACITY MULTI-LEG ROUNDABOUTS

The purpose in bringing in a portion of the technical fundamentals concerning modern roundabouts is to demonstrate the principles upon which this study and the ensuing design work were based. Since guidance for would-be roundabout designers is still developing, the background rationale and basis for the recommended improvements needed to be made explicit. The combination of science and deep experience, regarding how best to resolve problematic roundabouts, is emphasized in this case study.

The importance of research and its usefulness in studies of this kind cannot be overemphasized. Already in 1975 experiments were carried out by Transport and Road Research Laboratory, U.K. (TRRL) on public roads to determine ways of improving the capacity of large roundabouts without degrading safety (3). This early work preceded the majority of research of the effects of geometry on the capacity of roundabouts (5).

The research by Blackmore and Marlow (3) indicated that reducing the size of the central island to increase entry widths and circulating widths increased capacity of large roundabouts by up to 35%, but it was later discovered that the added capacity sacrificed safety performance because special care was not taken to deflect and slow vehicle paths at roundabout entries.

Through this research and the years of empirical application of its principles, high capacity roundabout design was refined and applied at many sites. The following principles emerged from this extensive experience.

1. Maximize the effectiveness of width for entries and circulating road for all movements, particularly at the point of entry where average speed is lowest.

2. Provide adequate deflection to control entry speed to a safe level mainly for through traffic movements. Blackmore identified that a suitable arrangement of curbs and splitter islands should limit the radius of curvature of the entry path to approximately 100m (300ft). to prevent the speed of vehicles crossing roundabouts from exceeding 50 km/hr (30mph) Although this work was done in 1975, this principle is still applied today and was reinforced by the Safety Research conducted by TRRL in 1984 (4).

3. Provide an uncluttered view of what is important, which imposes sight restrictions on curbs, street furniture and signs (7, 8).

The report by Blackmore and Marlow concluded that the most useful principle to observe is to increase the discharge capacity from large roundabouts by changes in markings within the same horizontal geometry and flaring of entries including curbs and splitter islands. The Long Beach Roundabout was an early North American application of these principles. The use of curbed or pavement marked ‘vane’ islands was also found to be a practical measure in limiting the entry path speeds of straight through movements.

The principle of improving discharge capacity developed more recently into principles of spiral markings to guide drivers to make a correct lane choice, at entry, so that through the roundabout lane change lanes are eliminated. The Clearwater Gateway Roundabout in Florida benefited from spiral markings, c. 2001 (1). North American roundabout specialists are beginning to apply the principles of lane designation and improved discharge capacities to reinforce the principles of how modern roundabouts should operate – slow in, but unimpeded circulation and exits.

4. ROUNDABOUT STUDY PHASE

A circular intersection has been in use at Armdale for approximately 50 years. The intersection is the confluence of five regional arterial roadways servicing the Halifax area. This study methodology followed traditional in-service safety reviews for the intersection specific changes, but also examined the network impacts of relieving congestion at this major intersection. The tasks undertaken were as follows:

1. Model and assess the operation of the Armdale Rotary and its five approaches, for a distance of at least 500m (1500ft.) using a traffic simulation model capable of modeling roundabouts. The model was to be developed, calibrated and tested using field collected traffic data to reflect existing conditions. Delphi-MRC, a local transportation engineering company, developed a simulation model to account for the effects of traffic upstream and downstream of the rotary.

2. Model and assess the traffic impact of left turning vehicles, pedestrians, and other factors which interfere with free flow on St. Margaret's Bay Road and Chebucto Road. Determine if this had an impact on traffic flow within the Armdale Rotary.

3. Prepare functional design alternatives for the conversion of the Armdale Rotary to a modern roundabout. Two alternatives were prepared, one that employs a three lane circulating roadway with three lane entries on Quinpool Road and Chebucto Road and a second option that constrains Quinpool Road to a two lane entry and the circulatory roadway to two lanes.

4. Model and assess the operation of the Armdale Rotary and its five approaches under proposed conditions. This effort involved testing the effectiveness of each alternative for residual capacity, ease of use and predictability for drivers.

4.1 COLLISION HISTORY

HRM provided a raw data file of five years of collision history for the rotary. The raw data was not in a state suitable to develop a collision diagram. The records indicate elevated incidence of exit type collisions and entry circulating collisions characteristic of large non-conforming traffic circles. Additional emphasis was placed on field observations of conflicts to examine whether patterns typical of roundabouts without stripes and fast entries were evident here. The overall collision frequency and some indications of severity are as follows:

- 238 reported collisions; 48 collisions per year; 2.60 collisions per million vehicles per year based on the daily volume of 50,000 vehicles.
- 38 injury related (16%); 7.6 injury collisions per year.

The injury rate of 7.6 was higher than average rates (3 to 6) for 4 leg British roundabouts having similarly high traffic volumes. This suggested that with proper geometry and educated drivers, the higher collision incidence could be mitigated.

4.2 DATA COLLECTION, JUNE 5 AND 6, 2006

The field visit involved assessing driver interactions with the existing geometry and lane designations, observing conflicts, queuing, congestion in the circle and operations with other users, e.g. transit, bicyclists and pedestrians.

HRM conducted tube counts on all five approaches as part of this study, which in turn were converted to turning counts for use in the roundabout study phase. HRM provided the topographic survey of the rotary and each approach. The peak hour counts were assigned lane-by-lane according to the desired exit path. This effort facilitated identifying lane balance issues that could be verified by field observation and using the Arcady/RODEL software.

HRM did not provide any future traffic estimates. The design modifications were based on the assumption that the Armdale Rotary will not be expanded in the future, but was to provide extra capacity if feasible through the conversion of the rotary to a modern roundabout.

A video file of the rotary in operation during two peak periods was obtained for both morning and evening peak hours. This information was used in an attempt to calibrate the capacity analysis of the rotary using Paramics and Arcady/RODEL. A tedious and time-consuming reduction of the video 'footage' was undertaken to accumulate a data set of queues and capacity for each entry to the rotary. The data set was to represent at-capacity conditions for each entry as defined by a minimum queue of five vehicles in each lane, simultaneously. Because the rotary was operating with mixed priority rules during the survey, it was difficult to assess entry and circulating flows representing true at-capacity conditions. This coupled with partial traffic signal control proved to be overly problematic for modeling the existing conditions.

Two of the roundabout approaches, Quinpool Road and Chebucto Road are fed by upstream development and a road pattern that permits alternate travel choice to the Armdale Rotary. The fact that traffic can and will move between the two links, depending on congestion levels, present both challenge and opportunity. On the one hand, traffic demand could be managed by constraining an entry capacity; on the other hand, it could be allowed to gravitate to where delay is least. Both options were considered in developing geometric design solutions.

4.3 DATA COLLECTION NOVEMBER 21 AND 22, 2006

The circulatory roadway became uncongested after changes in rules of priority. Based on observations of higher operating speeds in and around the rotary, additional field observations of entry and circulating traffic interactions were recommended. During an additional two days of field visits, the peak and off-peak periods were observed and select video recording of the changes that had taken place were collected. The functional design alternatives were compared and contrasted with the newly established rules of priority to circulating traffic.

A follow-up field investigation involving approximately eight hours of observations was undertaken November 21st and 22nd, 2006. A recount of the combinations of entering and circulating flows with saturated entries was not undertaken. Emphasis was placed on refining the preliminary design to address the safety and capacity needs of the rotary and to minimize changes to the existing curb locations to minimize reconstruction costs.

5. INVESTIGATION RESULTS

5.1 MAJOR DEFICIENCIES BEFORE CHANGES TO PRIORITY

Figure 1 illustrates the existing conditions of geometry and pavement markings as recorded by survey and field verified in June 2006. The pavement marking plan supplied was updated during the field visit and is reflected on Figure 1. Figure 2 illustrates the condition diagram showing deficiencies in geometry, markings, conflicts, pedestrian crossing treatments and transit stop concerns. This documentation was based on observations to determine if patterns exist and to assist in drawing conclusions as to the cause of entry and exit collisions and impediments to efficiency.

5.2 DEFICIENCIES OBSERVED AFTER CHANGES TO PRIORITY

Following the changes in priority rules to yield at entry and priority to circulating traffic, contrasting operations were noted on November 21st and 22nd, 2006 as follows:

- The circulatory roadway no longer congested although occasionally a driver stops to let traffic enter.
- Previously drivers were either not conscious of the conflicts in the circulatory roadway caused by incorrect lane designation or they tolerated the conflicts because they were predictable and at low speed only a nuisance. Without the circulatory roadway being congested, drivers had adjusted their lane choice to compensate for the circulatory roadway conflicts that because of higher circulating speeds were of greater consequence and were being avoided by unbalanced lane use on two approaches: Quinpool Road and Chebucto Road.
- The Chebucto entry had unbalanced lane use and constrained entry capacity owing to the poor sight lines looking upstream toward Quinpool Road. There was visual clutter looking toward Quinpool Road, e.g. parked cars to the right of the entry mixing with sight of entering vehicles. The flaws of the faster entry geometry were evident when the entry became unconstrained by circulating traffic.

- The queues on Quinpool Road, Chebucto Road and St. Margaret's Bay Road were longer in the after condition mostly because signal timings had not been adjusted to coincide with demand. Although signal timing was a major factor in the queues, the poor geometry was still allowing traffic to enter faster, affecting the ability of downstream traffic to enter safely. Drivers were moving to the left-most lane at entries to compete for the best sight lines knowing gaps were few and upstream entry speeds were high.
- On Joseph Howe Drive the queues tended to fluctuate more and occasionally reached over 25 vehicles from the entry point. Previously the right hand lane was more heavily used than the left hand lane. This changed to a more even lane distribution after priority rules changed.
- The traffic signals were starving then over-feeding the circulatory roadway inefficiently. This was a classic condition that could be overcome with improved, effective entry geometry. At the meeting on November 22 it was recommended to leave the traffic signals in place until geometry was improved, but in the interim, to add 10 to 20 seconds of green for Quinpool Road and St. Margaret's Bay Road.
- The geometry of the Joseph Howe and St. Margaret's Bay Road exits, overlapping entries of Chebucto and Joseph Howe respectively were causing turbulence resulting in poor lane use for upstream entries feeding those exits. There was more entry capacity on Quinpool and Chebucto but it was unrealized because of this exit turbulence.
- A two lane exit to Quinpool Road was thought to be required based on observations of St. Margaret's Bay Road entry demand and directional distribution of traffic. There appeared to be compelling evidence to maintain a second exit lane that tapers downstream.
- The response of drivers to the existing geometry had changed since earlier observations mainly due to relief in the circulatory roadway when yielding at entries began to take place. Drivers had adjusted to the circulatory conflicts but this resulted in longer entry queues and unbalanced lane use. Entry speeds were also contributing to reduced gap acceptance on downstream entries; hence, metering traffic signals were left in place as long as the geometry was unaltered.
- Cursory observations indicate there was ample circulatory roadway capacity. Accordingly, there was excess unrealized entry capacity for several entries. This was partly attributed to the traffic signals controlling two entries in the P.M. peak period. At times the signals were red but there was no circulatory traffic passing the stopped entry. During these frequent occurrences 100% of the available entry capacity was unrealized which represented a significant portion of the peak hour capacity. The change in priority to circulating traffic was contributing to improved efficiency but the use of traffic signals starved then over-fed entries. It is well understood however that removing the traffic signals could not occur until the geometry was made effective, otherwise traffic conflicts and the ensuing failure in priority rules would further degrade operations.

5.3 ROTARY CAPACITY REVIEW

Using the U.K. method (Arcady/RODEL) to model the existing traffic on the existing rotary, but with sensitivity to lane balance, the results, not surprisingly, indicated that there was sufficient entry capacity in an idealized geometric layout of the existing rotary. Neither Arcady nor RODEL accounted for the breakdown in priority to entering traffic that prevailed during the earlier period of observations, in June 2006. The capacity analysis assumptions account for effective geometry only as defined by the six geometric design parameters being effectively incorporated into the overall layout (5, 7). The U.K. model assumes effective geometry when calculating entry capacities. Therefore, the results exhibited what would be possible when the rotary would be brought into conformance with modern roundabout design parameters.

There was no value in attempting to model existing conditions by calibrating it to any known capacity simulation model as long as rules of priority were not in place. After yield at entry was imposed the circulatory roadway was no longer congested however signals still remained in place to meter two entries, Quinpool Road and St. Margaret Bay Road. The signal timings were penalizing those entries to the extent that their queues were longer than any other entry.

The existing geometric layout was modeled assuming effective geometry to demonstrate how the rotary would perform if it conformed to a modern roundabout, both in geometry and rules of priority. The A.M. peak period results as displayed on Table 1 exhibit the unrealized capacity of a modern roundabout in place of the existing conditions. Analysis of the evening peak period was consistent with this finding, which indicated favourable levels of service were achievable with improved geometry. Three entries, Quinpool Road and Chebucto Road would be minimally capacity constrained, but to a much lesser degree with more effective geometry, markings and signs.

Table 1- U.K. Model Output for Existing Geometry Made Effective (AM Peak Period)

Measure	Units	Chebucto Road	Joseph Howe Drive	Bay Road	Herring Cove Road	Quinpool Road	Overall Measure	Overall Values
Flow	Veh.	388	347	1298	682	436	Average Delay secs./veh.	12.6
Capacity	Veh.	2279	1966	1881	1412	1898	LOS Sig.	B
Ave Delay	Mins./Veh.	0.16	0.17	0.24	0.22	0.17	LOS Unsig	B
Max Delay	Mins./Veh.	0.17	0.18	0.30	0.26	0.19		
Ave Queue	Veh.	0	0	2	1	0		
Max Queue	Veh.	0	0	3	1	0		

Note: results represent ideal geometry operating under modern roundabout rules of priority.

6. DESIGN CONCEPT ALTERNATIVES

A functional plan was prepared from the capacity modeling based on existing volumes and patterns as of June 2006. A follow-up exercise involved evaluating the change in operation that occurred while enforcement and education initiatives were completed. The functional plan considered lane designations approaching and within the roundabout.

Figures 3 and 4 represent alternatives to resolve the existing geometric design and operational deficiencies. These alternatives were analyzed for capacity performance using the U.K. model at the 50th percentile capacity prediction and the 85th percentile capacity prediction. The capacity analysis results showed favourable levels of service for both peak periods. The lane configurations employed in the model reflected the origin and destination patterns identified by the earlier traffic count, accounting for off-peak periods (6).

The design concepts shown on Figures 3 and 4 produce multiple benefits over the existing layout with the following highlights:

- Improved entry path deflection for all entries to reduce the highest possible entry speeds to less than 50km/h (30mph) (R1's < 80m (250ft.) (ref. 4 and 7);
- Elimination of weaving sections and exit path conflicts by elimination of lane changes and improved exit paths removing reverse curves that create path overlap;
- Rational lane configurations that correspond to the capacity requirements of entries, (Level of Service ranging between B and C (unsignalized control level of service);
- Rational lane configurations and spiral markings that correspond between entry, circulating and exit lane demands – lane continuity and lane balance;
- A slightly more compact circle with reduced circulating speeds;
- Additional entry capacity on Chebucto Road;
- Single lane exits on Joseph Howe Drive and one or two lane exits on Quinpool Road (Figure 3 or 4).

Figure 3 presented a two lane entry on Quinpool Road; and, Figure 4 a three lane entry on both Quinpool Road and Chebucto Road. The plans were dimensioned with default values according to the number of lanes and the space requirements for trucks and cars simultaneously.

A two lane concept, Figure 3 was expected to perform well as exhibited by the RODEL analysis with existing traffic. The predicted average delays in the P.M. peak period range from a low of 0.2 minutes per vehicle to 0.34 minutes per vehicle. At Level of Service 'B' (unsignalized control LOS) overall, the two lane alternative would perform reasonably well for the existing traffic with modest residual capacity for traffic growth. The two lane concept simplified the entry lane and circulatory roadway configurations. HRM requested that improvements provide as much capacity as possible without expanding the circle size or increasing the number of entry lanes above three.

Figure 4 geometry maintained the third lane entry on Quinpool Road, similar to existing conditions while a third lane could be added to Chebucto Road. The three lane concept, Figure 4, was expected to perform very well for the existing traffic flows and showed residual capacity beyond the existing traffic flows. Select approaches such as Joseph Howe Drive and Herring Cove Road were expected to continue to exhibit queues in the peak periods as upstream entries became unconstrained.

The major difference between the performances of these two alternatives was the simplicity of the two lane design for ease of driver task load and for ease of comprehension of signs and markings. The two lane entry represented an opportunity to balance flows between Chebucto Road and Quinpool Road. It also created reduced driver demand to respond to additional lane choices on high demand approaches. Conversely, the restriction to two lanes on Quinpool Road established a permanent capacity constraint that could force a shift in demand to the Chebucto Road entry where lane reversal would be required to add more link capacity. Providing residual capacity to both Quinpool and Chebucto entries was of interest for the P.M. peak hour. It is counterintuitive to improve the rotary's capacity, i.e. to reduce congestion by removing an approach lane. However, like traffic signal timing, geometric alterations can achieve a balance of delay among roundabout entries.

Although the capacity analysis predicted that this was possible it was decided by HRM to add capacity in conjunction with formalizing the rotary geometry, particularly given the expense of doing so and not wanting to revisit it. It was also evident from the follow-up review that drivers were demonstrating their ability to accommodate the existing three lane entries on Quinpool Road since the circulatory roadway had become nearly congestion-free after the yield rule was implemented.

Supplemental field review indicated drivers were adapting to the complexities of a deficient layout; hence, the elimination of congestion in the circulatory roadway. Previous conflicts in the circle were reduced by drivers adjusting their lane of approach. This supported the choice to maximize the rotary capacity, including three lane entries on Chebucto Road and Quinpool Road.

The three lane concept, Figure 4 was preferred in order to maximize overall roundabout capacity. The follow-up field investigation in 2006 led to further evaluation and identification of additional alternative lane configurations primarily to address lane choice issues. Figure 5 illustrates the design that was optimized for capacity and safety and constructed in 2007 with extensive signing and marking modifications.

7. AFTER CONDITIONS

7.1 CASUAL OBSERVATION OF THE IMPLEMENTED DESIGN

In the after condition, since the rotary was reopened as a modern roundabout, previous conflict patterns have virtually disappeared. Congestion relief is noticeable at the roundabout with the P.M. peak hour exhibiting the greatest change. Morning peak hour traffic now exits the roundabout with greater efficiency to the extent that network problems at downstream traffic signals were initially backing up to the roundabout, as predicted. HRM anticipated this and planned for a lane reversal to be implemented on Chebucto Road and other intersection improvements in the downstream road network.

One entry, Quinpool Road, having three lanes is experiencing problems with drivers still not choosing the correct entry lane for a left turn. One reason is that a correct entry lane choice exits to a reversing lane downstream of the roundabout. Lane reversal existed before these modifications and HRM did not wish to remove it. Drivers prefer not to use the reversible lane at the roundabout exit which translates upstream to the left lane of the Quinpool Road entry.

Joseph Howe Drive entry continues to experience high P.M. peak hour delay as the higher demand Quinpool and Chebucto Road entries operate with newly improved efficiency. St. Margaret's Bay Road entry continues to impact the downstream Herring Cove Road entry. The St. Margaret's Bay Road entry capacity was maximized, resulting in a greater impediment to the Herring Cove Road entry. Reducing this impact is possible but best done with geometry subject to a detailed assessment of capacities of both entries to seek an overall balance. Reduced entry speed for the 'Bay Road' by virtue of the entry geometry will facilitate improved gap finding for Herring Cove Road.

Adjusting the flare length on St. Margaret's Bay Road is a simple and sure method of creating more capacity for the downstream entry, Herring Cove Road. Entry capacity is extremely sensitive to flare length as the author demonstrated in the field in the opening days by experimenting with flare length on St. Margaret's Bay Road.

The current levels of service are a significant improvement compared to the previous conditions in the P.M. peak hour. Predicted delay for any one entry was less than one half minute per vehicle. It was difficult to imagine the Armdale Rotary without congestion as it is in the P.M. peak hour today. Drivers have demonstrated lane discipline but speeds in the circle have increased, somewhat regrettably for some motorists formerly accustomed to the previous locked-up conditions.

7.2 ADDITIONAL OBSERVED BENEFITS OF THE IMPLEMENTED DESIGN

Figure 5 illustrates the design that was optimized for capacity and safety and constructed in 2007 with extensive signing and marking modifications. The in-service performance of the design has not been fully assessed with a sufficiently long after period, however readily evident benefits have been observed in the field since the re-opening in October 2007.

- Adjustments to intersection sight to the left, of upstream entries resulted from improved separation distance between Quinpool Road and Chebucto Road. This improved the capacity of the Chebucto Road entry.

- A two lane exit for the Quinpool Road leg serves the higher exit demands observed in 2006. There is a higher percentage of Quinpool Road traffic from St. Margaret's Bay Road versus left turns to Chebucto Road. A recount of that exit flow prior to final design was necessary and helped to build confidence that this solution was robust for the predictable range of traffic flows.

- Flared entries for the three lane entries; a left lane flare for Chebucto with or without a lane reversal; and, a right lane flare on Quinpool recognized the heavy left turn lane demand in the P.M. If the design flow changes, the lane configuration can be revisited by adjusting the length of the flare. The approach roadways have two lanes feeding three lane entries, providing logical lane designations for left turns and through movements. This is essential from a driver's perspective given the challenging driving task of navigation and lane choice at any intersection approach. Approach lanes upstream of the entries were assigned no more than 750 vehicles per hour unless the lane splits into a two lane flared entry configuration.

- Entry paths were checked and adjustments made to the final design to reduce the entry paths to less than 45 km/h (22mph). The lane configurations were balanced and entry flares favour high demand lanes on approaches.

- The original circle did not change significantly in size or location, but entries have been completely revised to impose deflection criteria, geometrically significant capacity improvements and sight requirements. The lower speeds of entry traffic are self-evident.

- Markings were adjusted and finalized for the preliminary design layout. The use of 1.8m (6ft.) skip white was recommended for the circulatory roadway in conjunction with specialized lane assignment arrows. Approach markings were standard 3m/9m (10ft./30ft.) skip white as shown on Figure 5.

- Accommodations of pedestrians by setting back crosswalks one vehicle length behind the ICD on approaches and exits was challenged but reaffirmed during construction. The sidewalk locations and tie-in points maximize observed desire lines and existing patterns and minimal walking distances. Pedestrian traffic is low and mostly associated with transit use.

- Adjustment of the transit stop on the Chebucto Road exit eliminated the sight deficiency and the conflict with right turning traffic from the Quinpool Road right turn by-pass lane. The separation of conflicts and establishment of good sight lines favoured moving the transit stop to just downstream of the exit from the rotary.

- The Quinpool Road exit transit stop was better protected by enlarging the separation area and by providing a pavement hatch marking or visible restriction to incorrect paths for passenger cars exiting to Quinpool Road.

- The Herring Cove Road entry was marked to accommodate the lane reversal for outbound traffic with higher efficiency. During low flows the right lane feeds the by-pass and the through/left lane at the entry. During high flows, the extra lane upstream feeds the extra lane at the yield line. Although the Chebucto Road lane reversal had questionable status at the time it was reaffirmed recently.

- Provision of a truck apron for over-tracking requirements of a WB-20 truck using the innermost lane was removed from the final design at the request of HRM. Trucks are generally over-tracking at entries and downstream, which is acceptable; however, occasionally a passenger car driver will possess a lane and crowd a truck or risk being run into.

- On the Armdale Rotary, overhead signs were originally to be added only to the three lane entries: Quinpool Road and Chebucto Road. In the final design overhead signs were added to the other three entries.

7.3 FUTURE USE OF TRAFFIC SIGNALS TO METER ENTRY FLOW

Signalizing a roundabout should be a last resort when geometric and marking changes have first been tried and found ineffective. Because of the way geometry can regulate capacity it is rare that signals would represent a superior choice to improve operations.

It is not recommended that traffic signals be considered for the upgraded rotary, now a modern roundabout, unless a thorough study demonstrates that delay for lower demand entries becomes excessive, i.e. greater than 1.0 minute per vehicle. The risk is that a metered high volume entry will develop a higher total approach delay resulting in an unbalanced apportionment of capacity to the intersection. Nevertheless, underground cable has been installed upstream of four entries in the event that improved entry capacity proves to be too efficient for downstream entries such as Joseph Howe Drive. If ramp metering traffic signals are used they must be traffic responsive and arranged with vehicle detection upstream of the problem entry, likely Joseph Howe Drive.

Where the use of traffic signals has been thought to be helpful at roundabouts it has rarely been preceded by an exploration of geometric improvements. In some cases, the roundabout fitted with traffic signals is simply over capacity and there is no space for further improvements or additional entry capacity. But, in most cases, improved geometry can resolve the congestion and improve safety as shown many times in the U.K. and at several locations more recently in North America.

8. CONCLUSION

In the after condition, since the rotary was reopened in 2007 as a modern roundabout, previous conflict patterns have virtually disappeared. Congestion relief is even more noticeable at the roundabout with the P.M. peak hour exhibiting the greatest change. Morning rush hour traffic now exits the roundabout with greater efficiency to the extent that network problems at downstream traffic signals were impacted, as predicted. HRM anticipated this and implemented network improvements including a lane reversal on Chebucto Road.

The main accomplishments of this work, in terms of advancing roundabout design practice, are that the in-service improvements immediately demonstrate the subtleties of the geometry/safety/capacity relationships established in the U.K by extensive research in the 1980's.

Recent changes in rules of priority at the Armdale have demonstrated that drivers can adapt to the new condition. This has been proven many times over through application of research into roundabout operations in the U.K. Geometry, signs and markings are instructive and educative to drivers, particularly for multilane entries.

A follow-up evaluation of the effectiveness of the roundabout improvements should include:

- Counts of each entry turning movement using video data collection;
- Calibration of the U.K. capacity model to local conditions to test the original predictions and to determine if minor geometric modifications or metering signals are necessary;
- Observations of lane use;
- Collision history with a before and after comparison. At the time of writing, the Province has not released the last three years of collision data; and,
- Observations for conflict patterns that may require lane designation changes, particularly the Quinpool Road entry.

This information will, among other benefits, help determine the redistribution of traffic from Quinpool Road to Chebucto Road and potential future traffic growth on either link. In the meantime, it is recommended to preserve the existing three lane entry for Quinpool Road while providing a three lane entry on Chebucto Road approach.

Signalization of approaches for metering traffic may be a practical solution to improve any entry impacted by high circulating flows; however, it should not be the first choice solution before less costly and more subtle geometric design modifications are explored. The above noted data collection and analysis is essential before an attempt is made to balance the capacity needs of this complex roundabout.

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2. Leif Ourston, Nonconforming Traffic Circle Becomes Modern Roundabout, Presented to ITE 64th Annual Meeting, in Dallas, TX, October, 1994.

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6. Armdale Rotary Traffic Modeling Project – Proposed Traffic Data Collection Program & Collision History Request, Delphi MRC, May 25th, 2006

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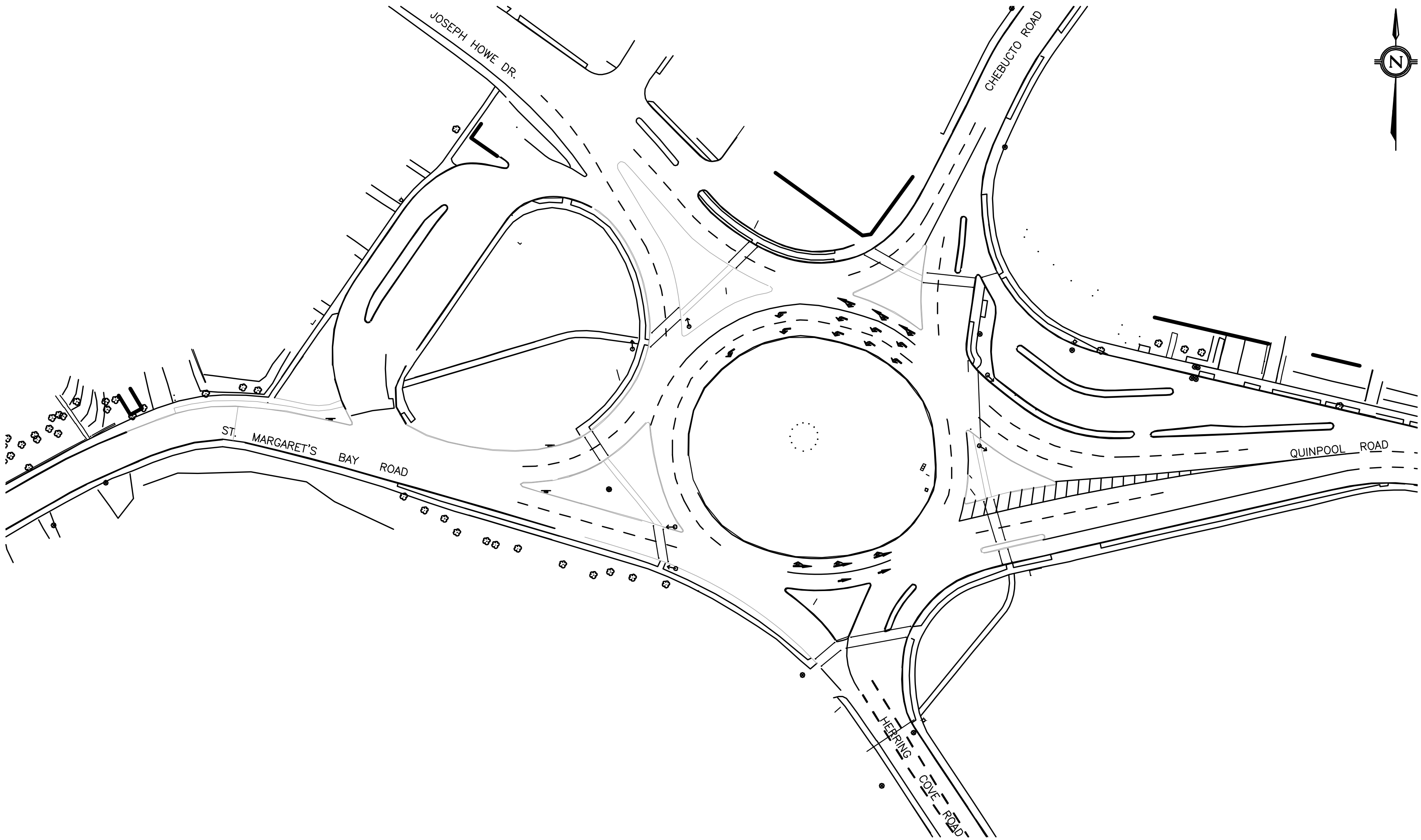
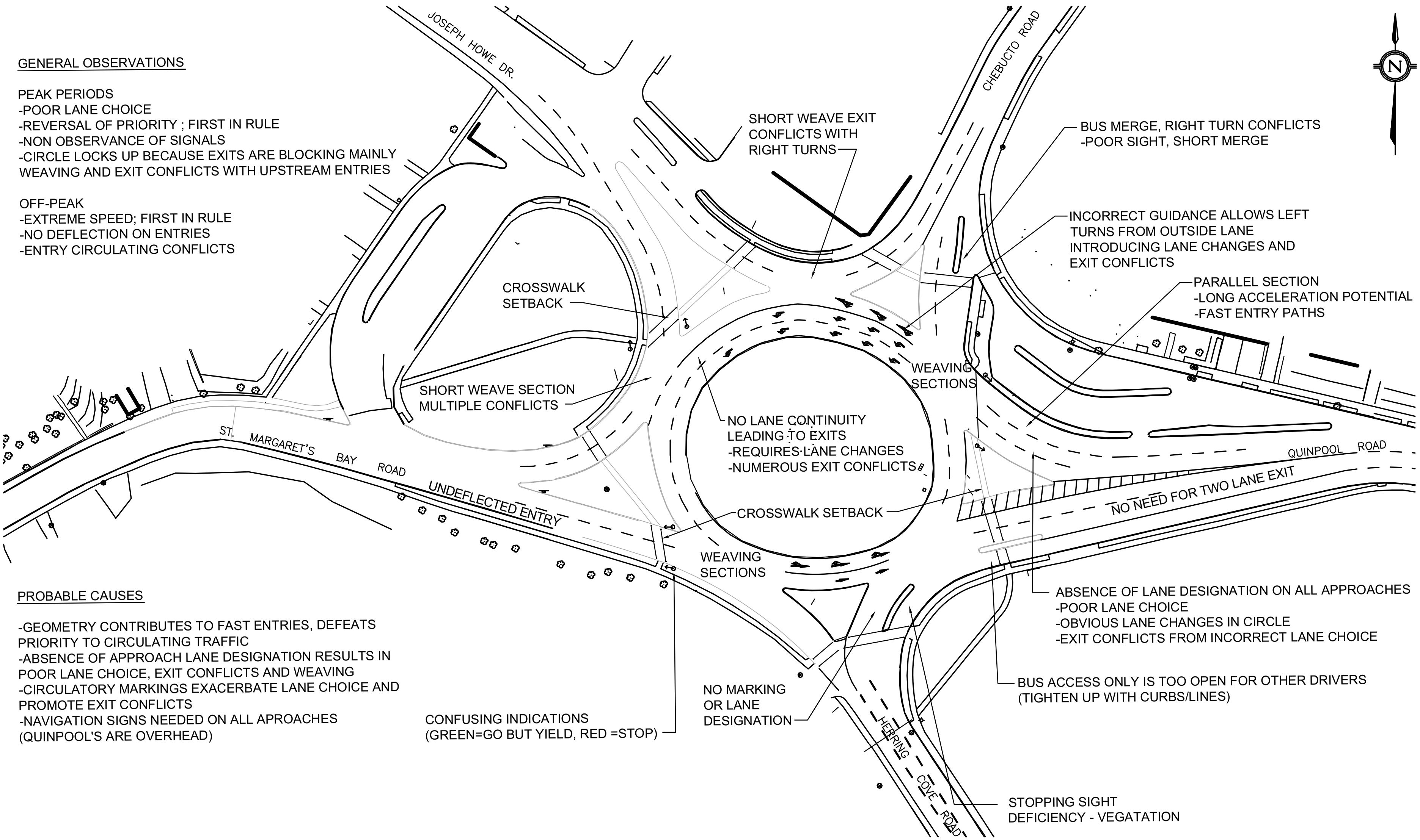


ARMDALE ROTARY EXISTING CONDITONS HALIFAX, NOVA SCOTIA	Ourston Roundabouts Canada *A Member of The Sernas Group Inc.*	DATE SEPT., 2006	PROJECT No. 06244
		SCALE 1:1000	FIGURE No. 1



GENERAL OBSERVATIONS

PEAK PERIODS
-POOR LANE CHOICE
-REVERSAL OF PRIORITY ; FIRST IN RULE
-NON OBSERVANCE OF SIGNALS
-CIRCLE LOCKS UP BECAUSE EXITS ARE BLOCKING MAINLY WEAVING AND EXIT CONFLICTS WITH UPSTREAM ENTRIES

OFF-PEAK
-EXTREME SPEED; FIRST IN RULE
-NO DEFLECTION ON ENTRIES
-ENTRY CIRCULATING CONFLICTS

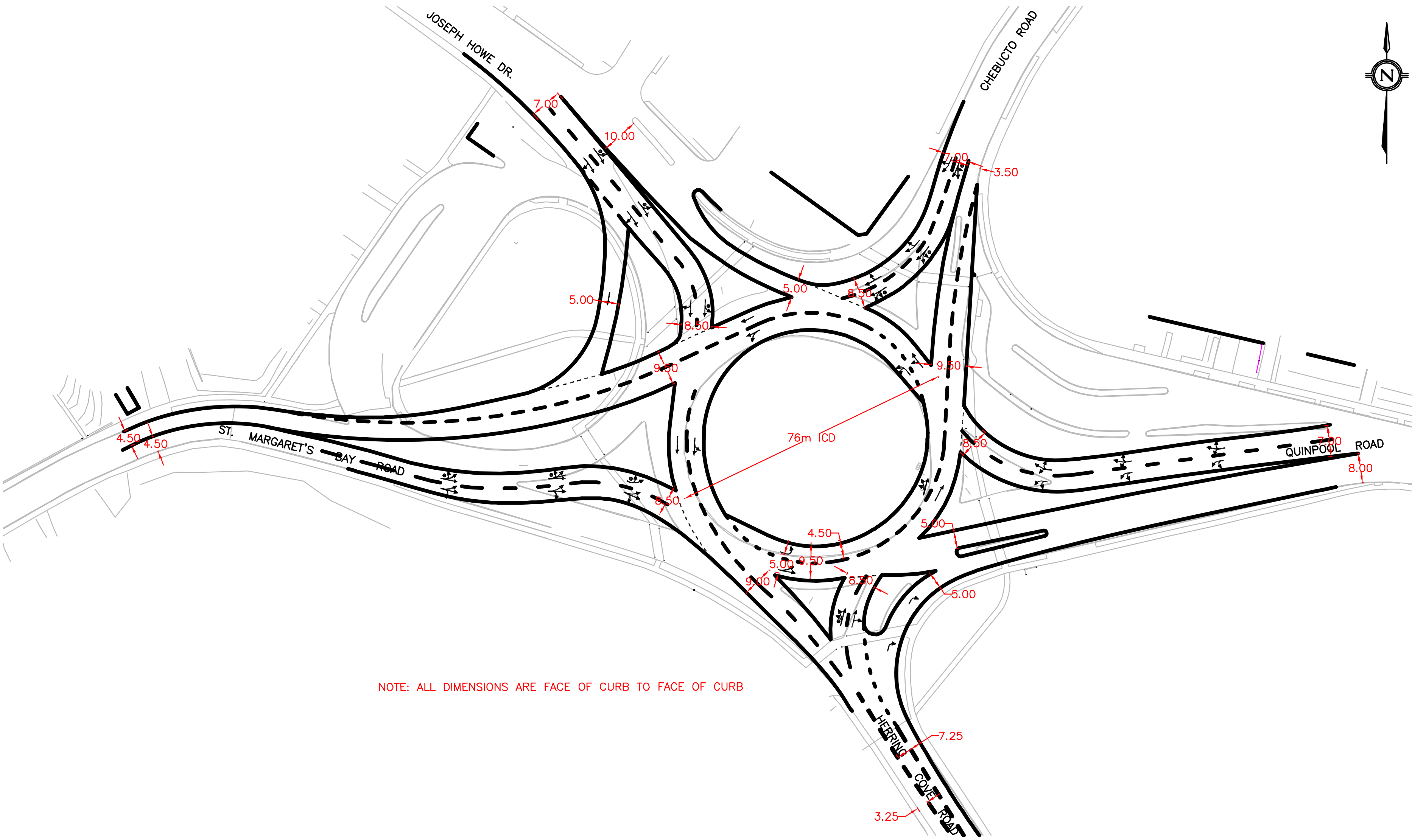
PROBABLE CAUSES

-GEOMETRY CONTRIBUTES TO FAST ENTRIES, DEFEATS PRIORITY TO CIRCULATING TRAFFIC
-ABSENCE OF APPROACH LANE DESIGNATION RESULTS IN POOR LANE CHOICE, EXIT CONFLICTS AND WEAVING
-CIRCULATORY MARKINGS EXACERBATE LANE CHOICE AND PROMOTE EXIT CONFLICTS
-NAVIGATION SIGNS NEEDED ON ALL APROACHES (QUINPOOL'S ARE OVERHEAD)

ARMDALE ROTARY
EXISITNG TRAFFIC OPERATIONS & DEFICIENCIES
HALIFAX, NOVA SCOTIA

Ourston Roundabouts Canada
A Member of The Sernas Group Inc.

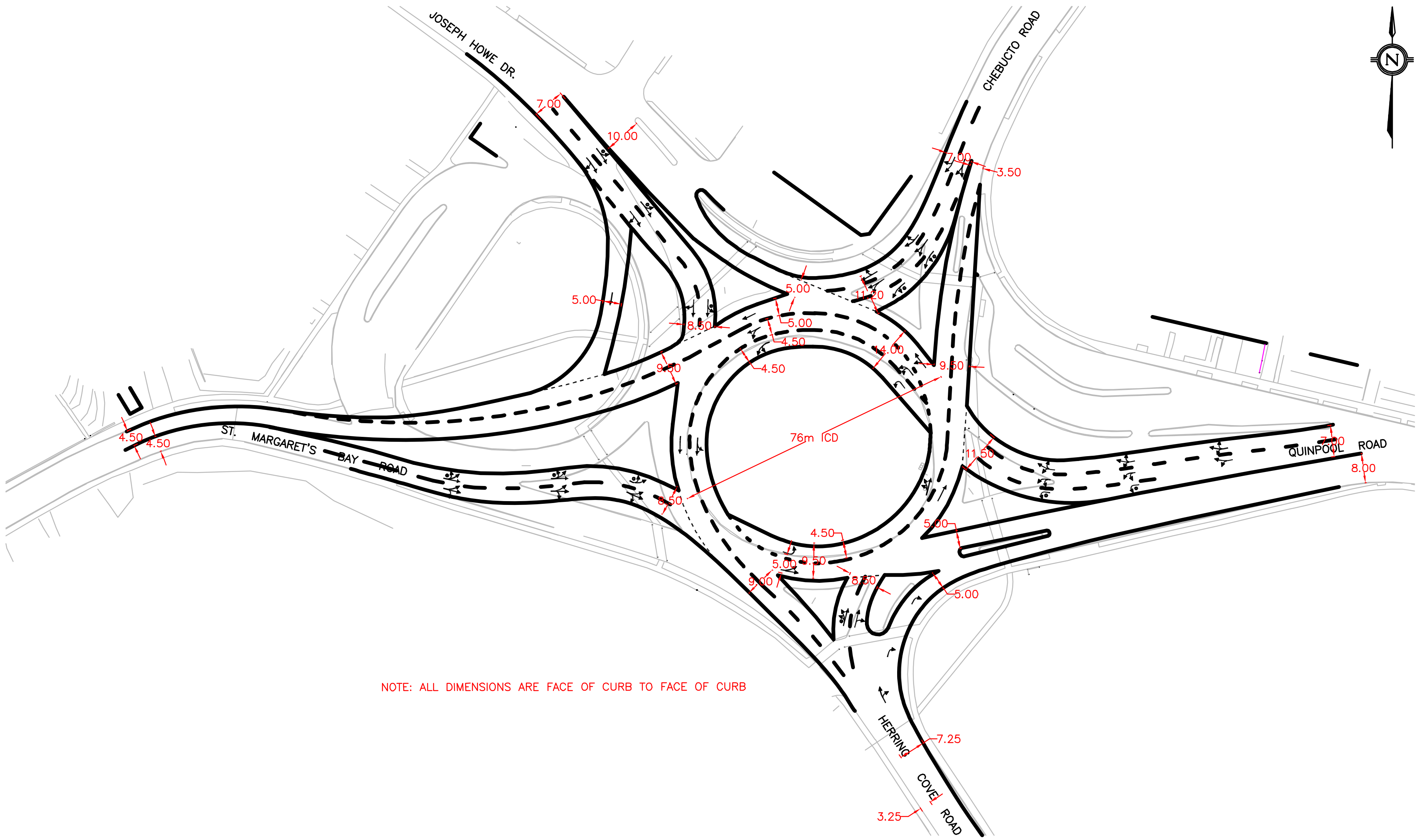
DATE	PROJECT No.
SEPT., 2006	06244
SCALE	FIGURE No.
1:1000	2



ARMDALE ROTARY
PROPOSED CONCEPTUAL 2 LANE ROUNDABOUT
HALIFAX, NOVA SCOTIA

Ourston Roundabouts Canada
A Member of The Sernas Group Inc.

DATE	PROJECT No.
SEPT., 2006	06244
SCALE	FIGURE No.
1:1000	3

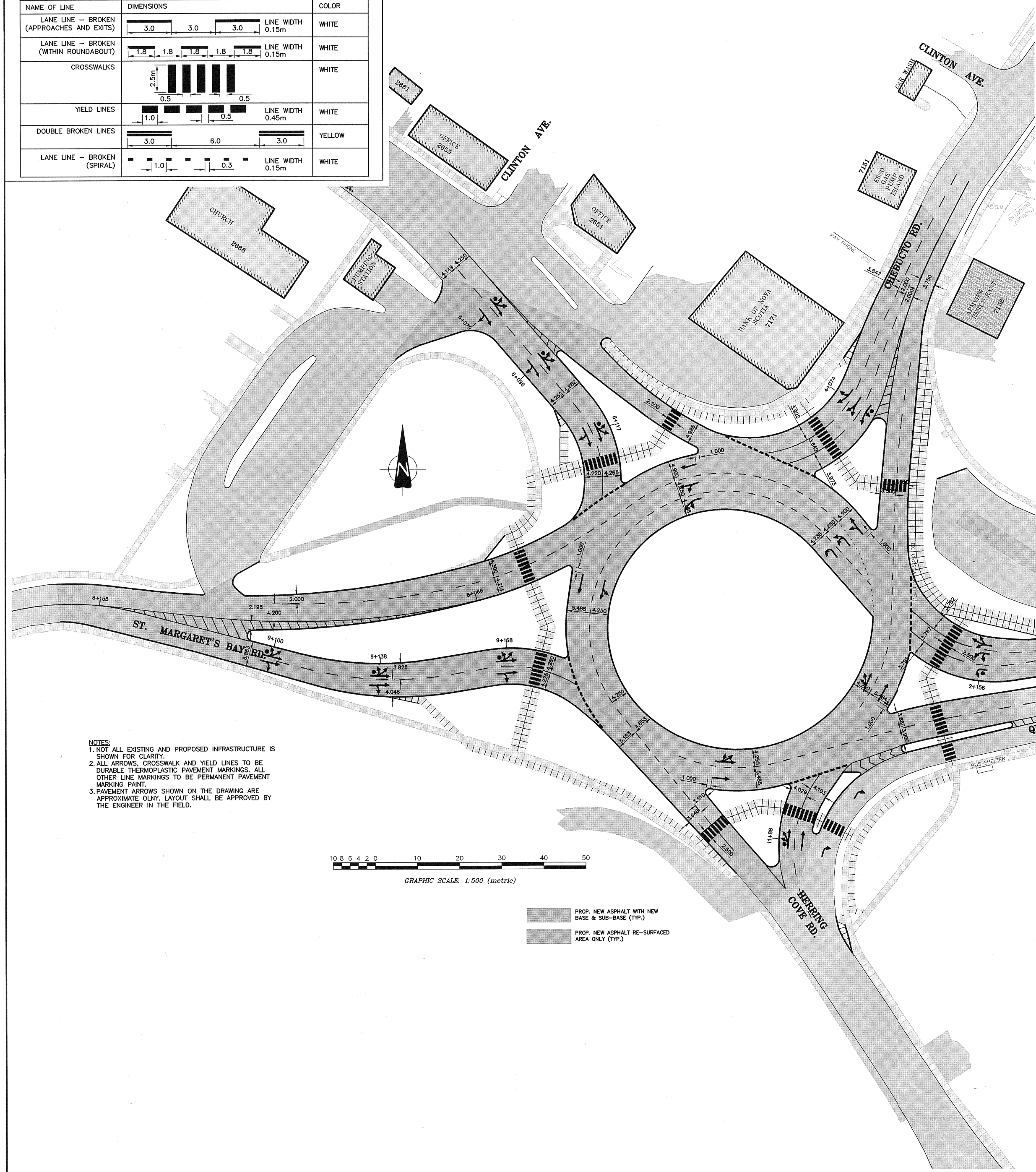
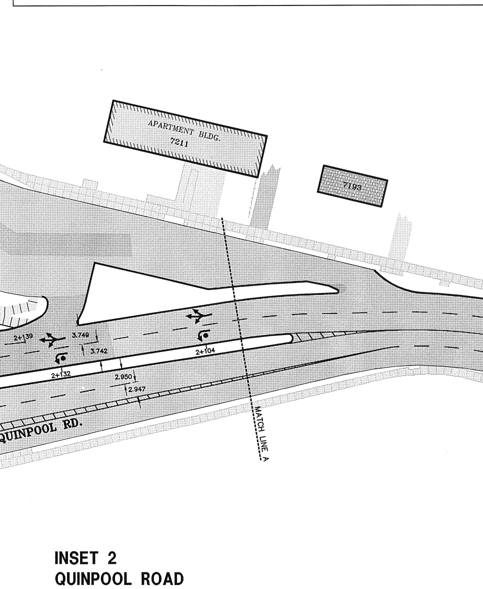


NOTE: ALL DIMENSIONS ARE FACE OF CURB TO FACE OF CURB

ARMDALE ROTARY PROPOSED CONCEPTUAL 3 LANE ROUNDABOUT HALIFAX, NOVA SCOTIA	Ourston Roundabouts Canada *A Member of The Sernas Group Inc.*	DATE SEPT., 2006	PROJECT No. 06244
		SCALE 1:1000	FIGURE No. 4

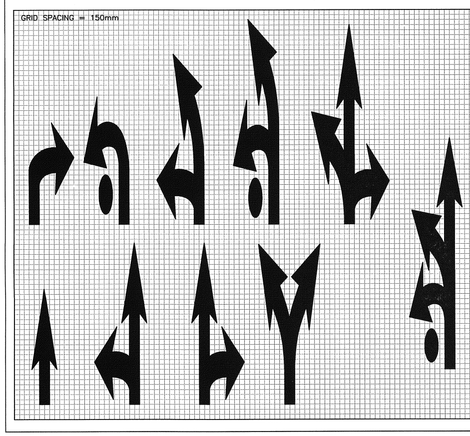
LINE PAINTING SCHEDULE

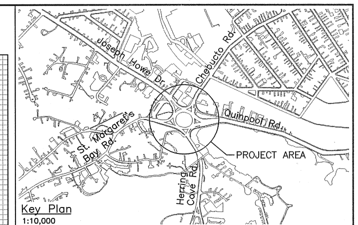
NAME OF LINE	DIMENSIONS	COLOR
LANE LINE – BROKEN (APPROACHES AND EXITS)	3.0 / 3.0 / 3.0 — LINE WIDTH 0.15m	WHITE
LANE LINE – BROKEN (WITHIN ROUNDABOUT)	1.8 / 1.8 / 1.8 / 1.8 / 1.8 — LINE WIDTH 0.15m	WHITE
CROSSWALKS	2.5m; 0.5 / 0.5	WHITE
YIELD LINES	1.0 / 0.5 — LINE WIDTH 0.45m	WHITE
DOUBLE BROKEN LINES	3.0 / 6.0 / 3.0	YELLOW
LANE LINE – BROKEN (SPIRAL)	1.0 / 0.3 — LINE WIDTH 0.15m	WHITE

NOTES:
1. NOT ALL EXISTING AND PROPOSED INFRASTRUCTURE IS SHOWN FOR CLARITY.
2. ALL ARROWS, CROSSWALK AND YIELD LINES TO BE DURABLE THERMOPLASTIC PAVEMENT MARKINGS. ALL OTHER LINE MARKINGS TO BE PERMANENT PAVEMENT MARKING PAINT.
3. PAVEMENT ARROWS SHOWN ON THE DRAWING ARE APPROXIMATE OLNY. LAYOUT SHALL BE APPROVED BY THE ENGINEER IN THE FIELD.

LANE ARROW SCHEDULE

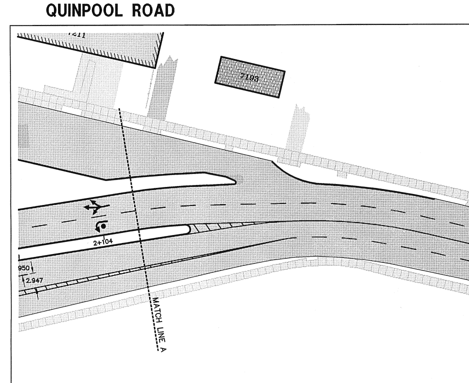




Key Plan
1:10,000

LEGEND:

INSET 2
QUINPOOL ROAD



No.	Date	Revision Description	Appr'd
C03	20-06-07	ISSUED FOR CONSTRUCTION	RNB

HALIFAX REGIONAL MUNICIPALITY

Association Of Professional Engineers Of N.S. 2007
Date: June 25, 2007
M.S. Lenters, P.Eng. 16047
License To Practice

Ourston Roundabouts Canada

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ARMDALE ROTARY
CONVERSION TO A MODERN ROUNDABOUT

PAVEMENT MARKINGS PLAN

Date	2 APR 07	Drawn	A. NOBLE	Project No.	07–247
Scale	1:500	Engineer	R. BOYCHUK	Plan No.	024
Reference		Approved	A. PERTUS	HRM No.	07015925
Surveyed		Sheet	25 OF 33		

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Figure 5