Lessons Learned Designing California's First Turbo Roundabout

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Abstract

The junction of Routes 25 and 156 near Hollister, California was identified to be converted from a traffic signal to a roundabout as an interim measure until a grade-separated interchange could be built. Traffic demands pointed to the need for a 2x2 roundabout with future need for a 3x3 roundabout. New to the United States, the Dutch Turbo Roundabout design allows for better safety and operation for multi-lane roundabouts and uses raised lane dividers between lanes throughout the roundabout to control lane usage and prevent lane changes in the middle of the roundabout. When translating a thoroughly tested Dutch design to the American context, several design challenges arose and were tackled ranging from heavy vehicle accommodation to signing and striping to the configuration of lane dividers. Due to traffic demand characteristics, the largest Turbo Roundabout design was selected, the Turbo Rotor with three entry lanes and two exiting lanes for every approach to the four-leg intersection. While the Turbo design was initially considered for improving capacity, use of the Dutch traffic model and additional VISSIM models indicated that the increase in capacity over conventional roundabout designs may not be significant, and the Dutch model's assumptions about drivers are thought to be unrealistic in the American context. Ultimately, it was the Turbo roundabout's superior safety characteristics and key design features such as the use of raised lane dividers to prevent lane changes in the roundabout that allowed the design to adequately mitigate for the intersection skew angle that made the Turbo roundabout the preferred alternative.

Keywords: Turbo Roundabout, Intersection Design, Safety, Roundabouts

Introduction

Being among the first to build a new geometric design presents its challenges, even if the concept has already been thoroughly vetted elsewhere in the world. Nevertheless, sometimes a design can clearly fit the needs of situation, making it worthwhile to pursue the application of a new idea, even if there are many unknowns that will need to be ironed out over time. When presented with the challenge of fitting a roundabout to the junction of Routes 25 and 156, it became clear that heavy traffic demand and challenging geometrics would require finding an intricate balance between competing objectives to ensure long-term success. The decision to build California's first Turbo Roundabout came about not as a lofty dream to achieve something new but rather as a pragmatic solution to a complex situation to ensure safe and effective operation.

Roundabouts have proven to be a highly effective means of improving safety and mobility at intersections, however, higher volumes require multiple lanes, something that has proven to be challenging for drivers to negotiate and often results in higher frequency of minor crashes (*1*). Accommodating multiple lanes on entry and measures to reduce crash rates make adequate control of entry speeds (a key metric for roundabout safety) difficult to achieve (*2*). Based on international experience, especially in the Netherlands, the Turbo Roundabout design offers the potential to improve operations and capacity while also improving safety by introducing measures such as raised dividers between lanes that force drivers to comply with lane usage (*3*). An example of an existing Turbo Roundabout can be seen in Figure 1 with raised lane dividers visible between lanes at the entry, circulatory roadway, and exit.

Figure 1. Example of a Turbo Roundabout in Amersfoort, NL (*1*)

Research and observations of multi-lane roundabouts in operation have shown that multi-lane roundabouts are challenging for drivers to negotiate and are also difficult to design and plan for effective operation as the design needs to take steps to anticipate and design in ways that support good driver behaviors (*2*). The data from Europe indicates that Turbo Roundabouts have proven to be effective both in terms of safety and capacity in operation. The design elements of a Turbo channelize drivers into fixed lanes through the roundabout that significantly reduces the occurrence of unsafe lane change and path overlap conflicts endemic to modern multi-lane roundabout designs. This allows a Turbo Roundabout to more readily support larger multi-lane roundabouts (i.e. 2x2 or larger configurations) to accommodate higher traffic demands. On the other hand, the spiral lane design and raised lane dividers can potentially be advantageous for ensuring a higher degree of safety and efficiency for multi-lane roundabouts in general (*3*).

Basics of Turbo Roundabouts

The Turbo Roundabout design was first developed in the Netherlands by Bertus Fortuijin with the goal of improving the safety and operation of multi-lane roundabouts (*1*). The Turbo Roundabout improves lane keeping throughout the roundabout through the use of raised lane dividers that are typically mountable concrete curbs. These lane dividers start in advance of the entry to the roundabout and continue through to the respective exits from the roundabout with short gaps along the circulatory roadway to allow for side street access. The lanes are laid out in a spiral pattern with each lane starting at one entry and then spiraling outward to exit at a downstream leg (*1*, *3*, *4*). There are a wide variety of Turbo Roundabout layouts referred to as Turbo Blocks which are configured based on traffic patterns such that a new spiral lane is added at entries with high entering volumes with variations on how many spiral lanes are present and where the spiral lanes exit (*3*). A basic Turbo Block can be seen in Figure 3 where the spiral lane configuration is achieved by using concentric curves of varying radii offset about a translation axis. It should be noted that the larger Turbo Roundabout designs often do not allow for U-turn maneuvers due to the spiral lane configuration. The configuration of the lanes with raised lane dividers at Turbo Roundabouts also allow for simplified fastest path speed control as the raised lane dividers would prevent drivers from cutting across lanes through the roundabout (*2*, *3*). Contrary to typical modern roundabout design concepts in America, Dutch Turbo Roundabouts place the entries at right angles to the circulatory roadway with engineers from the Netherlands noting that this design concept improves yielding behaviors by allowing for excellent view angles. The improved view angles with the radial entries in turn make it easier for drivers to see oncoming traffic and find a gap which engineers also note may help to increase the capacity of the roundabout (*1*, *3*). The key design elements of a Turbo Roundabout are presented in **Figure 2** with callouts to relevant features. Additionally, extensive signage is used to alert drivers to the roundabout as well as additional guide signage to assist drivers in selecting the appropriate lane at the entry. Correct lane choice in advance of the roundabout is crucial as drivers are not able to change lanes in the roundabout due to the presence of raised lane dividers (*1*).

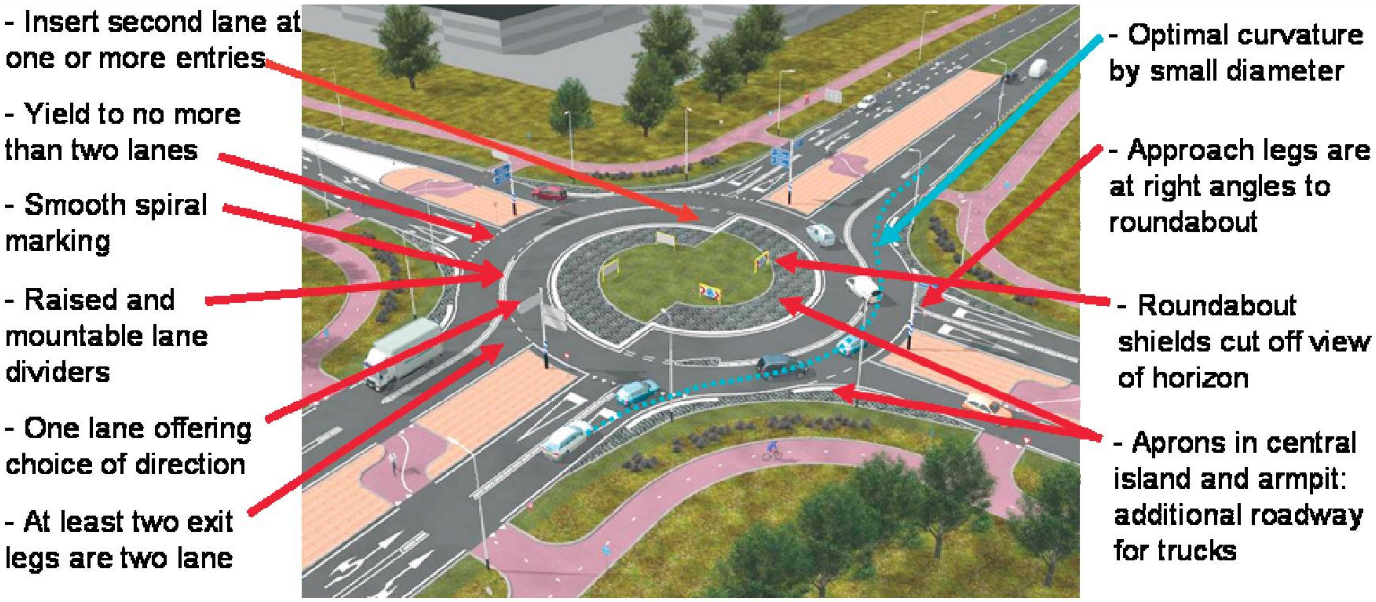

Figure 2. Basic features of a Turbo Roundabout (*3*)

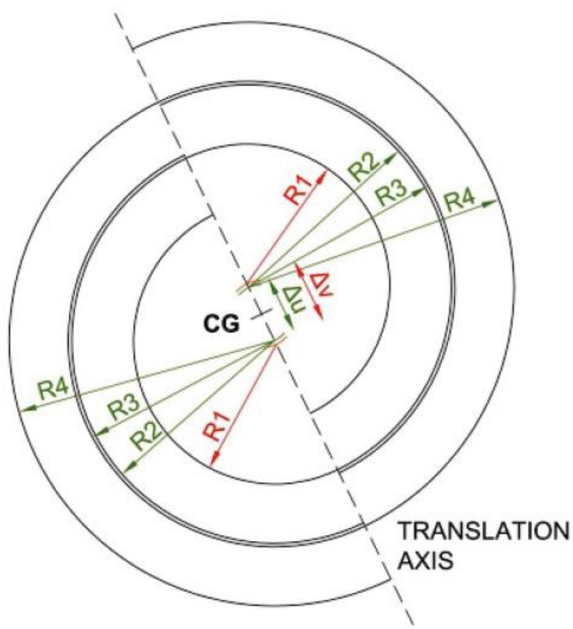

Figure 3. Example of a Turbo Block (*4*)

Turbo Roundabout Design Challenges

While in some ways it may seem that the Turbo Roundabout is the solution to the multi-lane roundabout's challenges, there are some valid reasons for being skeptical about applying the Turbo roundabout in the American context (*1*). While the radial layout of the entries and the inclusion of lane divider curbs seems highly unusual, in reality, the most significant challenge to designing a Turbo roundabout in the American context will actually be design vehicle accommodation. Dutch Turbo Roundabouts are designed so that the largest applicable design vehicle, typically an 80+ foot long tractor-trailer truck, is fully accommodated within each lane of the roundabout except when adjacent to the central island (*3*). European design vehicles are generally smaller and lighter and are designed to sweep a much smaller path than American vehicles—this means that Dutch Turbo Roundabouts are able to accommodate large trucks within a lane without necessitating wide lanes (*5*). An example of one of the largest design vehicles in the Netherlands staying within a lane while negotiating a Turbo Roundabout can be seen in Figure 4. On the other hand, American design vehicles require significantly more roadway width to negotiate a turn—easily requiring a 22-foot wide or wider lane. While it is conceptually possible to design a Turbo Roundabout assuming that trucks would off-track into adjacent lanes, this would pose a significant challenge for drivers as it would negate the value of installing the lane dividers and would be both confusing and challenging for drivers to negotiate, not to mention the increased maintenance requirements for the divider curbs.

Figure 4. Still images of largest design vehicle in the Netherlands making a left turn at a Turbo Roundabout (*6*)

When designing the 25/156 Turbo Roundabout, it was challenging to limit the footprint of the Turbo Block as using the tighter inside radius typical of Dutch Turbo Roundabouts meant that the lanes needed to be very wide (22+ feet wide) to accommodate the design vehicles. Based on experience with modern roundabouts, lanes greater than 20 feet wide tend to introduce operational challenges as some drivers may be inclined to treat the roadway as being two lanes wide (*2*). Increasing the radius of the roundabout allows for narrower lanes but also allows for higher circulating speeds, especially for the outside lanes of the roundabout. Higher circulating speeds makes it more challenging for drivers entering the roundabout to safely find gaps and may negatively affect the capacity of the roundabout (*3, 7, 8*). The ultimate Turbo Block chosen for the project balanced the competing objectives of needing to limit the lane width versus limiting the circulatory roadway speed. For Turbo Blocks with inside radii less than 70 feet, increasing the inside radius does not significantly increase the footprint of the roundabout as the larger inside radius allows for narrower lanes, limiting the increase in footprint. Another issue related to design vehicles was the layout and placement of the “frogs” or the nose of the raised lane divider within the circulatory roadway when a new lane is added. The “frog” is used to provide a more traversable curbed area to extend the raised lane divider within the swept path of a tractor-trailer semi-truck, with the goal of improving lane path assignment and to prevent errant lane change maneuvers (*1, 5*). American design vehicles require a much wider swept path, and thus the placement of the “frogs” required special consideration to ensure that medium-sized design vehicles like a bus would not hit the curbing while still ensuring that the “frog” prevents errant movements at the entry such as a vehicle from the middle lane crossing over into the inside lane.

The layout and approach angle of the entries does depart significantly from traditional modern roundabout design; however, this ultimately may not be of much concern as some researchers have indicated that reducing the phi angle and “squaring up” the entries at modern roundabouts can improve driver compliance and yielding behavior (*9, 10*). As highlighted by researchers from the Netherlands, the effectively 90-degree angle approach to a Turbo Roundabout would afford drivers an excellent view of oncoming traffic, so it is anticipated that driver yielding behavior would likely be improved relative to a typical modern roundabout (*3*). Approaching an intersection at a right angle is a customary practice for most drivers therefore approaching a Turbo Roundabout may not be that foreign of an experience for most drivers, although time will tell if there will be an increase in wrong-way maneuvers from drivers making an errant left turn at the entry, especially during off-peak periods. It should be noted that such errant maneuvers have still been observed by the author at modern roundabouts despite the significant deflection at the entry to modern roundabouts.

Available data for the traffic operations modelling of Turbo roundabouts is very limited, with the primary model being based on Dutch research which uses assumptions about drivers that likely do not directly correlate to American drivers and vehicles. The Dutch model, known officially as “Multilane Roundabout Explorer” or “Meerstrooksrotondeverkenner” in Dutch, was developed based on the Bovy capacity model with adjustment factors for pseudo-conflicts and basic geometry aspects related to pseudo-conflicts such as the width of the splitter islands (*1, 8*). A significant factor in the analysis of Turbo Roundabouts noted by researchers in the Netherlands was the concept and issues relating to pseudo-conflicts or the occasions when a driver waits unnecessarily for a gap in traffic thinking that a vehicle is conflicting when in reality the vehicle is exiting the roundabout at the adjacent upstream exit (*7*). Pseudo-conflicts can be present at all roundabouts since it is challenging for drivers to anticipate if circulating traffic is conflicting or exiting, although the issue is likely much more prevalent at Turbo Roundabouts due to having a much shorter separation between the entry and adjacent upstream exit compared to typical modern roundabouts with large deflection angles at the entry and exit. Increasing the width of the splitter island at an entry increases the separation between the entry and adjacent upstream exit thereby reducing the occurrence of pseudo-conflicts and can increase the capacity of that approach. The Dutch model is still useful as a means of scoping out the necessary intersection configuration based on traffic demands as specific Turbo Roundabout configurations are better suited to different traffic demands. The "Multilane Roundabout Explorer" tool considers a wide range of different Turbo Roundabout configurations and suggests which configurations are most viable which, in the case of the study intersection, was the Turbo Rotor design as can be seen in Figure 5 (*8*). Further research and especially data collection at Turbo Roundabouts in America will be essential for better understanding how drivers will negotiate Turbo Roundabouts and what the capacity will be (*1*).

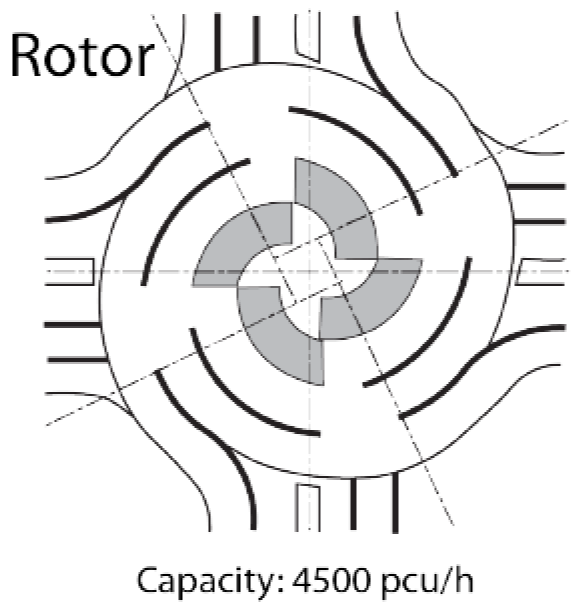

Figure 5. Concept image of a Turbo Rotor Roundabout design (*1*)

Site Specific Challenges

The project location at the Junction of Routes 25 and 156 near Hollister, California was identified for conversion to a roundabout to improve operations and safety at the intersection. Initial traffic studies identified the intersection would need a minimum of a 2x2 roundabout design with potential future need for a 3x3 roundabout, which lead the traffic operations team to initially consider a Turbo Roundabout design as a means of increasing the future capacity.

However, preliminary studies indicated that even the Turbo Rotor roundabout design would not provide sufficient capacity to meet the 20-year forecasted traffic volumes based on the indicated thresholds from research (*7*, *8*). The insufficient very-long term capacity of a Turbo Roundabout coupled with the anticipated added complexity of a turbo design and the uncertainty of support for the design from project stakeholders led to the concept initially being rejected. The Turbo Rotor design returned to the fore after the design team identified that speed control and path overlaps would be challenging for drivers due to the significant skew of the existing intersection. The existing intersection was built with a 50-degree skew angle, which would have required significant right-of-way acquisition to adequately realign the approaching roadways to reduce the skew angle. The design team realized that the Turbo Roundabout provided an effective means of controlling speeds and lane utilization while also preventing path overlap concerns all while limiting the right-of-way acquisition needed for the project.

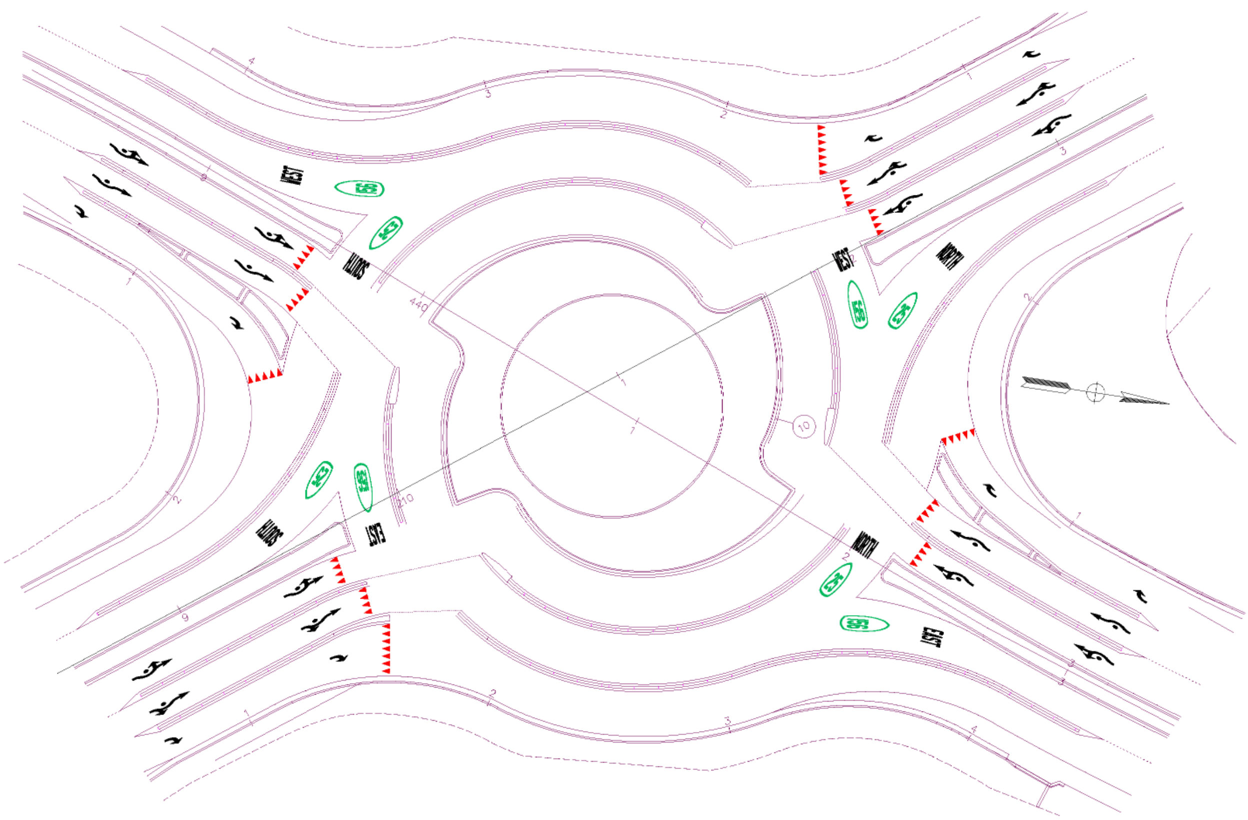

Figure 6. Proposed Turbo Rotor Roundabout for the junction of Routes 25 and 156

Due to the very high traffic demands, which are fairly balanced across all approaches between the morning and afternoon peak periods as can be seen in Table 1, the largest Turbo Roundabout design was selected, the Turbo Rotor, which initiates a new spiral lane for each approach. Using the Dutch design principles and experience as the basis, the design was fleshed out to include raised lane dividers based on Dutch designs, the Turbo Rotor uses three lanes on each approach (1-through-left, 1-through-right, 1-right), with a configuration similar to a 2x2 roundabout with right-turn-bypass lanes on every approach as can be seen in Figure 6 (*1*, *3*). Unfortunately, since about 80% of the traffic volumes on each approach pass straight through the intersection, the two through lanes on each approach with the Turbo Rotor likely will not be sufficient to accommodate long-term traffic growth. While the Turbo Roundabout concept is very versatile and allows for a wide range of configurations, a limitation of Turbo Roundabout concept is that the spiral lane design makes it not possible to build a true 3x3 roundabout design.

Table 1. Design opening year and forecast turning movement volumes (veh/h).

Design Year		SB 25			NB 25			EB 156			WB 156		
		SBL	SBT	SBR	NBL	NBT	NBR	EBL	EBT	EBR	WBL	WBT	WBR
Opening Year	AM Peak	12	338	67	23	1104	6	236	133	43	6	270	19
	PM Peak	29	1042	215	64	528	5	106	270	18	5	292	11
20-Year Horizon (forecast)	AM Peak	72	857	65	45	1056	2	238	496	41	3	691	20
	PM Peak	7	953	151	38	787	3	89	824	40	2	617	112

The final roundabout design configuration has the inside radius, or the outside edge of the central island/truck apron, vary between 55 feet at the entry when a new lane is added and 78 feet at the lane spiral transition where the inside lane transitions to the middle lane. The inscribed circle diameter is 272 feet with 22-foot-wide inner and middle circulating lanes and 19-foot-wide outer circulating lanes. Lane widths are typically 14 feet between curbs/raised lane dividers at the entries and exits although the right turn lanes are flared slightly to accommodate design vehicles.

Use of the Dutch models indicate that the Turbo Rotor design will work effectively for the near-term, but operations will likely break down prior to the 20-year horizon design year. As Table 1 shows, the traffic demands are heavy, especially since both corridors regularly see heavy volumes of truck traffic with trucks currently accounting for about 14% of traffic on Route 156 and 8% of traffic on Route 25. It should be noted that there are valid reasons for assuming that the actual observed capacity will likely be lower than the Dutch models predict due to variations in driver behaviors and design differences necessary for accommodating American design vehicles (*1*). The local Metropolitan Planning Organization (MPO) already has plans for widening the Route 25 corridor to a 4-lane expressway and these plans include constructing a grade separation at the junction of Routes 25 and 156. The long-term plan is to have Route 156 cross over Route 25 and to slightly modify the configuration of the Turbo Roundabout to serve as the single point interstation for the grade-separated interchange. Currently the MPO plans to build the expressway in about 7-8 years which will allow the proposed grade separation to handle future traffic growth. Constructing a much larger signalized Turbo Roundabout in the future is not currently under consideration at this time as such a design would require considerably more right-of-way and would introduce added complexity to the intersection design.

Truck accommodation was a key issue, as both routes see heavy interstate truck traffic. After reviewing available Dutch guidance on design and operation for heavy vehicles, it was found that the lane dividers needed to be placed outside of the design vehicle's swept path to reduce the maintenance needs for the raised lane dividers and to improve safety in operation (*3, 5*). This made it challenging to limit the overall footprint of the intersection, but the impacts were significantly smaller overall than if the highways were realigned to significantly reduce the skew angle as would have been necessary for a traditional multi-lane roundabout. It is expected with the presence of raised lane dividers as shown in Figure 7 that truck drivers will typically avoid striking curbs whenever possible and attempt to stay within their lane. Having trucks stay within their own lane will improve the capacity and overall performance of the roundabout, especially compared to more traditional roundabout designs that would assume trucks would encroach on adjacent lanes (*2*).

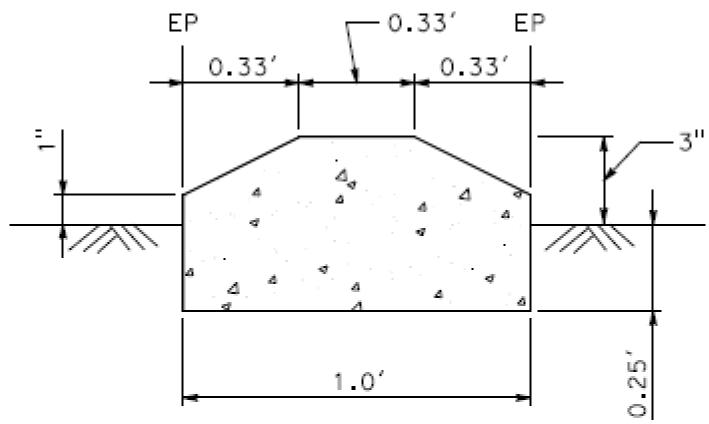

Figure 7. Proposed raised lane divider for the 25/156 Turbo Roundabout.

Another significant concern was improving guide signage for the intersection as the inclusion of raised lane dividers make it essential for drivers to correctly choose the appropriate lane when approaching the roundabout as changing lanes is not possible within the intersection. Both highways approaching the intersection carry a large proportion of regional and inter-regional traffic with both freight and tourist traffic and therefore there will be a persistent element of driver unfamiliarity with the intersection, especially for the Route 156 approaches. Past experiences with traditional multi-lane roundabouts in California have highlighted the importance of adequate guide signage to reduce driver confusion at roundabouts. When combined with Dutch guidance stressing the value of overhead lane assignment signs, the design team chose to include overhead guide signs on each approach to help improve the visibility of lane assignments at the intersection as can be seen in Figure 9 (*1, 3*). Incorporating overhead signs significantly increased the cost and complexity of the project but will likely pay dividends over the life of the project by minimizing driver confusion.

Both Routes 25 and 156 are fairly high-speed facilities with posted speed limits of 55 mph in the vicinity of the intersection. The design team opted to follow Dutch design guidance and the

Turbo Roundabout design incorporates the radial entry design typical of Dutch Turbo Roundabouts to maximize the safety and operational benefits of the design (*3*). Chicanes were considered for the approaches to the roundabout, but right-of-way constraints made it impractical to incorporate chicanes into the design. The project team acknowledged the value of incorporating speed control features to the roundabout's approaches, however the new Turbo Roundabout design will make the intersection drastically more conspicuous than the existing traffic signal with increased signage, raised lane dividers, and increased illumination at night. The roundabout will also create a break in sight lines and paths of travel through the intersection as traffic would be forced to merge with the circulatory roadway at the entry.

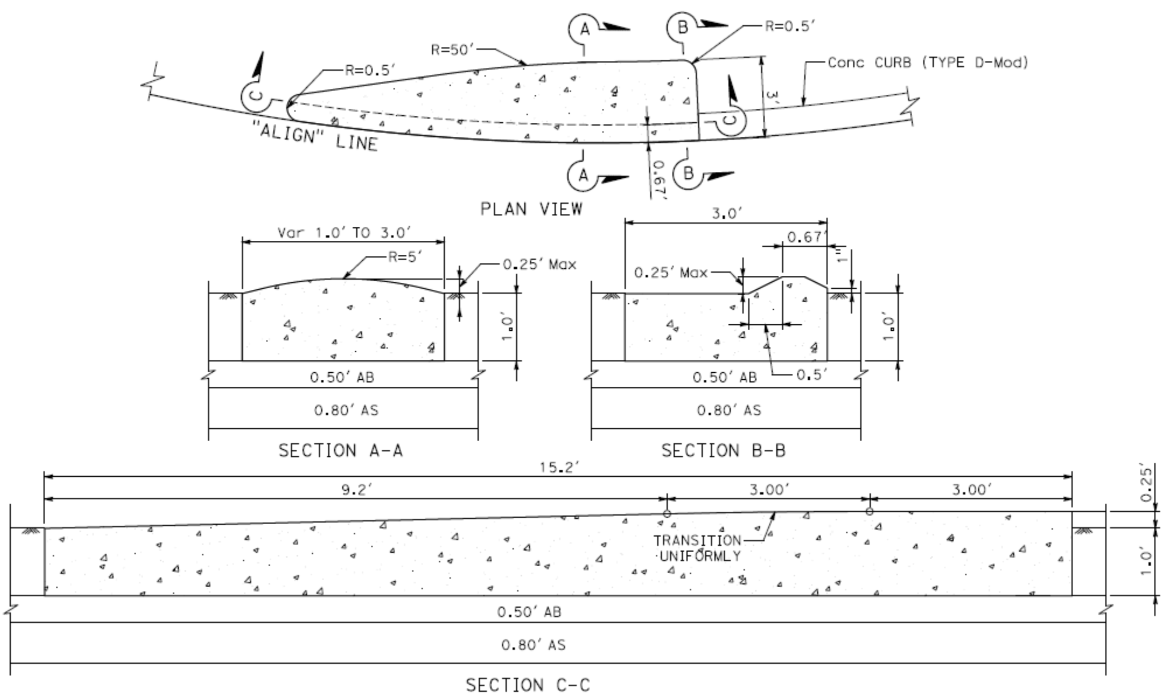

Figure 8. "Frog" or raised lane divider nose used for the 25/156 Turbo Roundabout.

Additionally, the combination of the radial entry and raised lane dividers at the roundabout helps with reducing the fastest path speeds at the entry to the roundabout with entry fastest path speeds of about 20-23 mph or 25 mph if drivers cross over the "frog" curb nose at the entry. Note that the nose of the "frog" is easily traversable as shown in Figure 8 making it possible that more aggressive drivers may cross over the "frog" when entering the roundabout. Circulating fastest path speeds are limited to 19-20 mph while the exiting speeds are limited to 25 mph with the aid of the raised lane dividers. Right turn speeds vary depending on entry due to the skew angle of the approaching roadways and the resulting variance in separation distance between legs but are typically limited to 19-23 mph near the entry and 19-25 mph when exiting. Pedestrian facilities were not included in the intersection design as the intersection is fairly remote with no development nearby to generate pedestrian or bicycle traffic.

Lessons Learned

Turbo Roundabouts are not a new idea by any means, having been thoroughly tested throughout Europe over the past 20 years with great success (*1*). However, applying the concept in the American context still comes with its challenges with the foremost being design vehicle accommodation. American design vehicles require significantly more room to maneuver than any European design vehicle and this created limitations on how small the roundabout could be and resulted in a significantly larger roundabout that would typically be seen in Europe (*3*, *5*). The project team has plans to observe how truck traffic negotiates the roundabout to ascertain the validity of the team's assumptions of truck driver's behaviors. This leads into the second major concern about intersection capacity and driver behaviors. Currently there is a huge lack of knowledge about how American drivers will approach driving through a Turbo Roundabout and to what degree driver confusion and unfamiliarity may limit operational capacity. Additionally, the larger footprint necessary to accommodate American design vehicles allows for higher circulating speeds which may negatively affect intersection capacity. The project team used existing models from the Netherlands recognizing the caveat that the actual capacity observed in the future may potentially be significantly lower than what was predicted by the model. Finally, planning for a Turbo Roundabout requires additional effort in planning effective guide signage, especially for larger and more complex configurations such as the Turbo Rotor design used for the project. This ultimately increased the construction costs as four overhead sign structures (Figure 9) were ultimately deemed necessary for the intersection to ensure adequate guide signage for the approaches to the intersection.

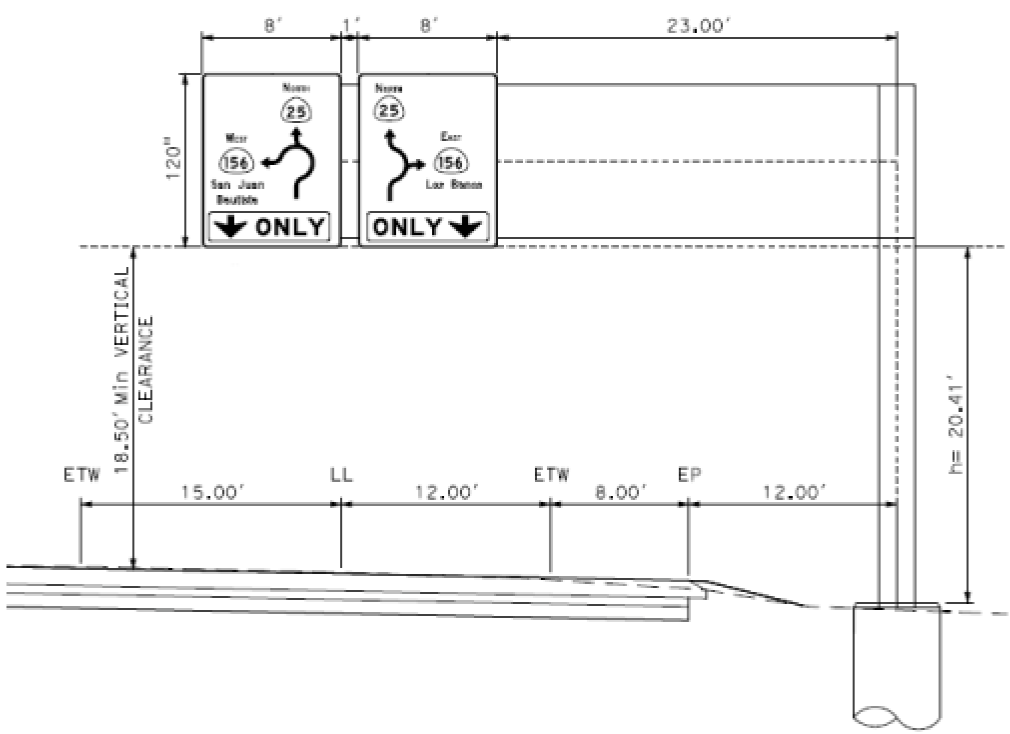

Figure 9. Proposed overhead signs for the 25/156 Turbo Roundabout.

The design team found that existing design elements could easily be used for the Turbo Roundabout with the only unique design details being related to the raised lane dividers (Figure 7 andFigure 8). MUTCD compliant signs and striping were used for the roundabout. In addition to the overhead signs, additional route shield pavement markings will be placed at key decision points in the roundabout to further assist drivers in selecting the correct lane assignment for their desired path of travel.

Conclusion

The Turbo Roundabout design offers significant advantages over more traditional multilane roundabout designs and can be adapted for use in America. The raised lane dividers and spiral lane configuration of Turbo Roundabouts can be used to better control vehicle paths and speeds through a multilane roundabout, especially for intersections with significant skew angles. Future analysis will be necessary to ascertain what the intersection capacity will be in operation as well as how drivers will negotiate the intersection (*1*). Designing a Turbo Roundabout that accommodates American design vehicles requires a larger overall footprint than typically necessary for European design vehicles. The resulting increased roundabout diameter allows for higher circulating traffic speeds relative to Dutch Turbo Roundabouts which may negatively affect intersection capacity (*3*, *5*). While existing signage and striping can readily be used for Turbo Roundabout designs, designers will need to account for additional guide signage especially for larger Turbo Roundabout designs such as a Turbo Rotor where overhead guide signage may be necessary for each approach to the roundabout to assist drivers in selecting the correct lane prior to entry as the raised lane dividers prevent lane changes inside the roundabout.

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