Tech Brief

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Hot Mix Asphalt Pavement (HMAP) Roundabouts

U.S. Department of Transportation
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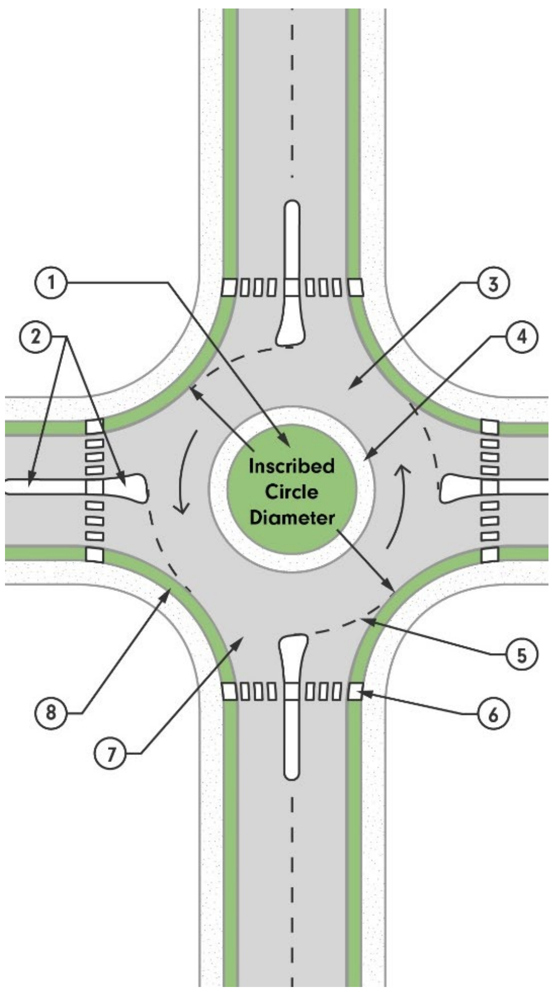
Introduction

General Background on Roundabouts

A roundabout is a form of circular intersection in which traffic travels counterclockwise (in the United States and other right-hand traffic countries) around a central island and in which entering traffic yields to circulating traffic (Rodegerdts et al. 2010). Compared with signalized and stop-controlled intersections, modern roundabouts provide better overall safety performance, shorter delays and shorter queues, better management of speed, and lower management and operation costs while also adding aesthetic value (FHWA 2010). Figure 1 presents a general schematic of a roundabout, along with a brief description of some of the key design features.



1. **Central Island** – Raised area around which the traffic circulates.
2. **Splitter Island** – Raised or painted area on the approach used to separate entering and exiting traffic, control entering traffic, and accommodate pedestrians crossing the roadway.
3. **Circulatory Roadway** – Curved path used by vehicles to travel around the central island in a counterclockwise direction.
4. **Truck Apron** – Part of central island that facilitates wheel tracking of large vehicles.
5. **Entrance / Yield Line** – Marks the point of entry to the circulatory roadway. Also functions as a yield line in the absence of a separate yield line.
6. **Accessible Pedestrian Crossings** – Provided before the entrance / yield line; splitter island is cut to allow access for pedestrian, wheelchairs, strollers, and bicycles in accordance with ADA requirements.
7. **Exit** – Marks the point of exit from the circulating roadway.
8. **Landscape Buffer** – Separates vehicular and pedestrian traffic and guides pedestrians to designated crossing locations.

Figure 1. Key roundabout design features.

Roundabouts are typically classified into three basic categories: mini, single lane, and multilane (FHWA 2010). Most roundabouts constructed in the United States are single lane (roughly 70 percent) and multilane (28 percent) (Rodegerdts 2017). As shown in figure 2, a cross slope of 2 percent away from the central island is typical for the circulatory roadway on single-lane roundabouts (WSDOT 2019). This not only helps in surface drainage, but also promotes safety by raising the height of the central island and improving its visibility, encourages lower circulating speeds, and minimizes breaks in the cross slopes of the entrance and exit lanes (FHWA 2010).

Various pavement types can be used in the construction of roundabouts, including hot-mix asphalt pavement (HMAP), jointed concrete pavement (JCP), continuously reinforced concrete pavement (CRCP), and precast concrete pavement (PCP). This Tech Brief describes the application, design, and construction aspects of HMAP roundabouts.

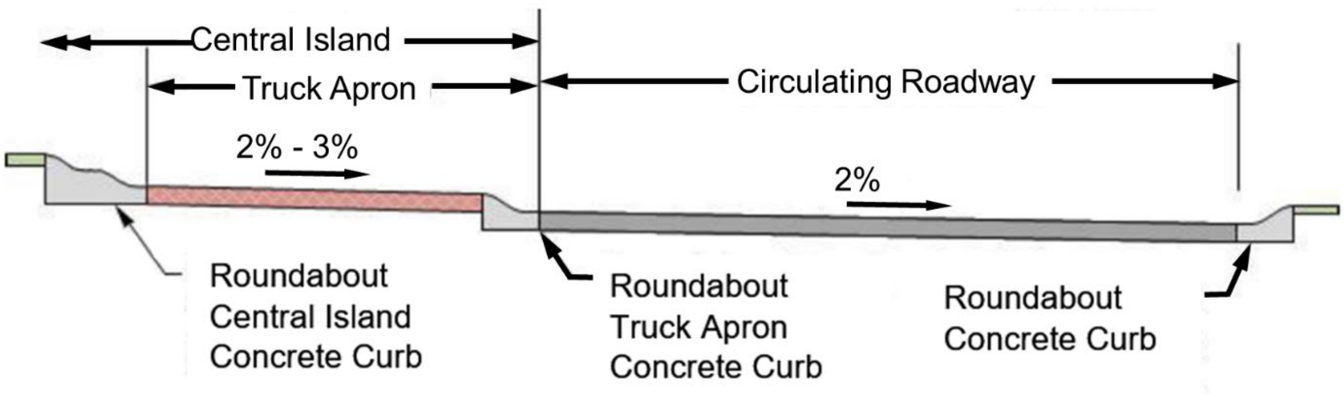


Figure 2. Typical circulatory roadway section with truck apron.

Background on HMAP Roundabouts

Like the majority of paved streets and highways, most roundabouts nationally and internationally are paved with hot-mix asphalt (HMA) (KDOT 2003). Photos of typical HMA roundabouts are shown in figures 3 and 4.

Figure 3. Aerial view of HMAP roundabout.

As a viscoelastic material, however, the use of HMA in a roundabout application could pose some performance issues. For example, vehicles negotiating the circular pattern produce outward (shear) forces in the pavement surface; similarly, braking forces in the approach portions of the roundabout could create excessive shear stresses. The result of these shear stresses is shoving of the asphalt and potentially cracking or tearing of the surface layer. In addition, a high percentage of heavy trucks moving at somewhat slower speeds because of the roundabout geometry could lead to permanent deformation (see figure 5). These potential performance problems can be addressed through the selection of materials and an effective HMA mixture design.

Figure 4. Typical roundabout paved with HMA.

Figure 5. HMA roundabout exhibiting rutting and shoving in wheelpaths.

Applications and Effectiveness

Typical Applications

HMA has been used in all three major roundabout types (single lane, multilane, and mini) and under a range of traffic loading conditions. If the characteristics of the roundabout are considered in both the structural design and the mixture design stages, HMA can be used in any roundabout application. In multilane roundabouts, the use of HMA is sometimes preferred because the contrast of pavement marking for lane lines and directional arrows promotes safe operations (GDOT 2019); another agency prefers HMA to differentiate it from the concrete truck apron (VDOT 2014).

The decision to use an HMAP for a roundabout will depend on local preferences and often on the pavement type of the approach roadways (KDOT 2003). Like conventional applications, the primary factors that make HMAP attractive for use in roundabouts include (Rodegerdts et al. 2010):

- Low initial cost. HMAP generally has a low initial construction cost.
- Qualified contractors. Qualified contractors knowledgeable and experienced in HMAP construction are present throughout the United States.
- Ease of construction and rehabilitation. The curvature of a roundabout does not create any significant issues in the construction of the HMAP, with only a few minor deviations from the construction of tangent sections. HMAPs can also be readily constructed under active traffic and are easily and rapidly rehabilitated through conventional mill-and-fill operations.
- Satisfactory performance. HMAP provides a durable and smooth riding pavement surface.

Limitations

One key consideration on the use of HMA in roundabout applications is the increased potential for permanent deformation and cracking/shoving in the HMA because of the level of heavy vehicle loadings and vehicle braking/navigation forces. This could lead to significantly reduced service lives and ongoing maintenance and rehabilitation demands if not adequately addressed during the mixture design stage.

Pavement Design Considerations

Asphalt Materials and Mixture Design

Asphalt materials and mixture design procedures are largely the same for roundabouts as for any conventional HMA roadway. The overall objective of the asphalt mixture design process is to determine the combination of asphalt cement and aggregate that will provide a durable and long-lasting pavement structure for the project-specific climatic and traffic loading conditions. This is most commonly achieved using the Superpave system of asphalt mixture design that was developed in the 1990s and significantly evolved over the ensuing years (NAS 2012). However, a few local roadway agencies still use either the Marshall method or the Hveem mix procedure (AI 2014; Von Quintus and Hughes 2019).

For the HMAP roundabout, State and local highway agencies typically follow their mixture design procedures for intersections and heavy-duty pavements. However, the special loading conditions may merit some additional considerations. Von Quintus and Hughes (2019) identify several notable asphalt facility types and conditions where "heavy-duty" asphalt mixtures are often appropriate in the pavement structure to resist severe loading conditions and high stresses. Among the various examples are roadways carrying heavy, slow-moving, channelized traffic and areas subject to severe braking or lateral stresses or areas deserving special attention, which would include many roundabout facilities. Key characteristics of heavy-duty mixtures suggested for these locations include a dense gradation featuring the use of aggregates that meets the State or local highway agency's criteria for soundness, hardness, durability, abrasion resistance, and number of fractured faces. Crushed and angular aggregates provide better resistance to rutting and shoving than round aggregates (Von Quintus and Hughes 2019).

In addition to the standard Superpave mixture design process, other laboratory performance-based tests can be carried out to evaluate the rutting resistance of HMA mixtures if there are concerns about excessive loading (AAT 2011). One such test is the dynamic modulus (E*), which evaluates the effect of temperature and traffic speeds on the mixture stiffness. To assess the rutting resistance on an HMA mixture, pavement design software can be used to obtain the minimum E* that the mixture should have to limit rutting to the specified level (based on HMA layer thicknesses, design traffic level, design traffic speed, environmental conditions, and the allowable rut depth in the HMA layers). Another test is the flow number, which is the number of load cycles corresponding to the minimum rate of change of permanent axial strain (the point at which the tertiary flow of a mixture starts). High flow numbers provide increased resistance to rutting.

If laboratory testing indicates that the loading conditions in a given roundabout may be problematic, key mixture design changes that could be considered include (AI 2014; Von Quintus and Hughes 2019):

- "Bumping" the grade of binder to be used in the mixture to a stiffer one to better accommodate the slow-moving, heavy truck traffic.
- Using a polymer-modified binder to increase mixture stiffness at high temperatures to resist permanent deformation.
- Using a gap-graded mixture that features a stone-on-stone aggregate skeleton, such as in a stone matrix asphalt (SMA) mixture, which exhibits increased resistance to rutting.

The mixture enhancements to improve resistance to rutting and shoving are typically used only in the top lift of the HMAP, as this is where the state of stress is highest in the top 2 inches of the pavement structure (Witczak et al. 2002).

Structural Thickness Design

The structural thickness design for HMAP roundabouts typically follows that used in conventional tangent-section HMA street or highway pavements. In simple terms, the primary goal of HMA pavement structural design is to determine a pavement cross section (i.e., combination of layer types and thicknesses) that: 1) protects the natural (subgrade) soil from overstress (i.e., level of vertical stress that can cause permanent deformation), and 2) minimizes the level of tensile strain in the HMA layer. There are many procedures available to develop structural designs for HMA pavements, and the State or local highway agency's usual procedure should be followed.

Mechanistic-based design procedures typically are more capable of addressing the high-stress/high-wheel load conditions associated with a roundabout (Von Quintus and Hughes 2019). These procedures also have an improved capability to consider traffic load spectra data, meaning that they can account for the impacts of specific truck loadings and axle configurations.

Truck Apron

As shown in figure 1, the truck apron is the area between the circulating roadway and center island whose purpose is to provide a paved surface for wheel tracking of trailer axles as long trucks pass through the roundabout. Colored or stamped concrete or block pavers are among the options used to differentiate the appearance of the truck apron from the circulatory roadway, but in some cases, these may discourage truck drivers from using the apron (ITE 2008). The truck apron is typically placed with a gutter pan that the HMAP can be constructed against. Figure 6 shows a truck encroaching upon the truck apron on a HMAP roundabout.

The truck apron itself may be CRCP, JCP, or in some cases block pavers, with an expansion joint used to isolate it from the back of curb of the circulatory pavement. If the truck apron is JCP, some standard detail drawings (e.g., SDD 13C18-e, WisDOT 2018) show the truck-apron transverse joints without dowels, which may satisfy most design situations. State or local highway agencies may choose not to place dowels in the truck apron if it is assumed that few if any trucks could traverse the transverse joints. Alternatively, dowels could be used along the full length of transverse joints in the truck apron, especially for smaller-diameter roundabouts, if it is assumed that a significant number of trucks could traverse them. Similarly, a logical design detail for transverse joints in the truck apron could also show dowels along the outer half of the transverse joint if this is assumed to be the portion of the transverse joint that could be subjected to a significant volume of truck traffic.

Figure 6. Truck traversing apron in HMAP roundabout.

Pavement Construction

For some of the key factors related to HMAP construction, there may be no practical differences between the construction practices used for roundabouts and those used in conventional (tangent) HMA facilities. Some general items are highlighted in the following sections, with more detailed information available elsewhere (USACE 2000; Brown et al. 2009; AI 2020).

Traffic Staging

Three general traffic management strategies may be employed during the construction of roundabouts: (1) all traffic is routed around the construction zone, (2) some traffic is diverted away from the construction area, and (3) full traffic is maintained during construction (Rodegerdts et al. 2010). For projects in its jurisdiction, the Georgia Department of Transportation provides detailed guidance on the following construction phasing scenarios (GDOT 2019):

- Closure of the intersection with a traffic detour for part or most of construction duration.
- Partial detour by closing the crossroad or one leg of roundabout.
- Short-term closure of the intersection with a traffic detour.
- Construction of the roundabout under traffic for undivided 2-lane roadway.
- Construction of the roundabout under traffic for divided 4-lane roadway.
- Construction of a roundabout off alignment.

Subgrade Preparation

For new roundabout construction at an existing intersection, the first step is the preparation of the subgrade. As with conventional HMAP construction, the subgrade should be stable and capable of providing good support to the overlying pavement layers. Any problem soils, such as those that are expansive or are susceptible to frost heave, should be either removed and replaced or addressed through stabilization.

In the case of a rehabilitation of an existing HMAP roundabout, it is likely that the subgrade will not have to be reworked.

Base and Subbase Preparation

The type and thickness of the base and subbase layers typically are determined as part of the structural pavement design process. These layers can be placed, trimmed, and compacted using the same basic practices as is used in conventional tangent HMAP sections. Other than impacting the rate of progress, the circular geometry of the roundabout has no effect on the construction.

In the case of a rehabilitation of an existing HMAP roundabout, the base and subbase materials should be inspected for damage and assessed for their ability to provide structural support to the HMAP.

Utilities

The presence of utilities in the HMAP roundabout typically are handled in the same way as on conventional tangent HMAP sections. Some handwork may be needed in these areas.

HMA Placement

General HMA placement considerations for HMAP roundabout construction are like conventional construction, but several key considerations are highlighted below.

Segregation

Segregation is a potential issue for any HMAP, including roundabout pavements. Segregation is the separation of the coarsest aggregate particles from the rest of the asphalt mixture and can lead to a more open structure that is less durable and may exhibit reduced performance (Van Quintus and Hughes 2019). Like conventional paving, it is important that standard practices to minimize segregation be observed throughout the entire paving process, from the HMA production to the HMA loading and delivery and to the final laydown. More detailed information on ways of minimizing segregation potential for heavy-duty mixtures is presented by Von Quintus and Hughes (2019).

Placement

HMA pavers are maneuverable and are equipped with variable speed slat conveyors and mix augers (that can deliver more mix to one side of the paver than the other), extendable screeds (that can change the width of paving on demand), and profile and grade controls (that can help ensure that adequate smoothness and the proper cross slope are being achieved). Nevertheless, to avoid complications, the placement of the HMA on the roundabout typically is done one lane-at-a-time using standard paving equipment. If the design HMA thickness is greater than 4 inches, the HMA is constructed in multiple lifts, with no single lift being greater than 4 inches. The first lane is usually placed along the outer perimeter of the roundabout against an existing curb and gutter to help provide lateral confinement to the HMA layer.

Because of the curvature of a roundabout, there may be some physical restrictions to the haul trucks and techniques used to load the paver hopper. If belly dump trucks and windrow elevators are being used to place HMAP in the straightaway sections, more maneuverable end-dump trucks may be used to allow for unloading of the material directly into the paver hopper. Although all pavers can place HMA around a curve, the use of other forms of vertical referencing rather than skis may be suitable to achieve a smooth alignment. Figures 7 through 9 show some general construction photos of HMAP roundabouts.

Figure 7. Loading asphalt mixture into the paver hopper using a short end-dump truck.

Figure 8. Close-up of paver placing HMA along the outer perimeter of a roundabout.

Figure 9. Paver with screed extended to pave the entire 16-ft width of an entry lane.

Compaction

As with all HMA paving, effective compaction is critical to the long-term performance of the pavement. Effective compaction reduces the air voids in the mixture and increases aggregate interlock and interparticle friction, which ultimately increases resistance to fatigue, permanent deformation, moisture sensitivity, and oxidation (Von Quintus and Hughes 2019).

The same combination of vibratory steel wheel and rubber-tired rollers used for rolling HMA straightaway sections may be appropriate for use in compacting HMAP in roundabouts, and the State or local highway agency's typical compaction specifications should be followed. Roller operators should follow the established roller patterns to ensure uniform compaction, taking care to avoid making overly tight turns that could tear the mat.

Figure 10 shows the compaction effort on a portion of an HMAP roundabout project. Additional information on compaction is available from USACE 2000; Brown et al. 2009; and AI 2020.

Figure 10. Vibratory steel-wheel roller compacting the first lift of a new roundabout.

Longitudinal Joint Considerations

The construction of durable joints between HMA lanes is another important item contributing to the performance of a roundabout pavement. A durable joint minimizes the intrusion of water and air into the pavement system and prevents the development of raveling and joint deterioration that could present on-going maintenance issues (Buncher and Rosenberger 2012).

Typical State or local highway agency practices for longitudinal joint construction on conventional HMA paving should be followed for HMAP roundabout construction. Typical practices for longitudinal joint construction involve the use of either wedge or notched-wedge joint. Both joints improve the ability of the roller to achieve joint densities that approach those in the center of the lane. Some contractors may elect to use two pavers operating in echelon as a means of achieving maximum density.

Entry and Exit Transitions

If the design pavement cross section in the roundabout is significantly thicker than that of the standard cross section, then the thickness should be gradually transitioned to the cross section in the straightaway section. Usually, this kind of transition is accomplished in the HMAP surface layer over a 10- to 15-ft segment. This approach typically does not pose any significant problems with the performance of the pavement in the transition zone.

Acceptance

Acceptance tests (e.g., thickness, density) and thresholds should typically follow those used by State or local highway agencies in their conventional paving practices. Smoothness can be checked with a 10-ft straight edge to look for vertical deviations that fall within the agency-specified range (e.g., 0.12 to 0.25 inches).

Summary

HMAPs are the most common pavement type used in roundabout construction throughout the United States and worldwide, and have been used for single lane, multilane, and mini roundabout systems. The low initial costs, rapid construction, and ease of future maintenance often associated with HMAPs may make them attractive for many applications. In general, the mixture design, structural design, and construction are performed following the State or local highway agency's conventional HMA practices. Some special mixture design considerations may be appropriate for heavily loaded roundabout facilities to ensure resistance to permanent deformation and lateral shear forces.

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