Technical Note 181

Guidelines for Design of Innovative Intersections 'Diverging Diamond Interchange'

December 2021

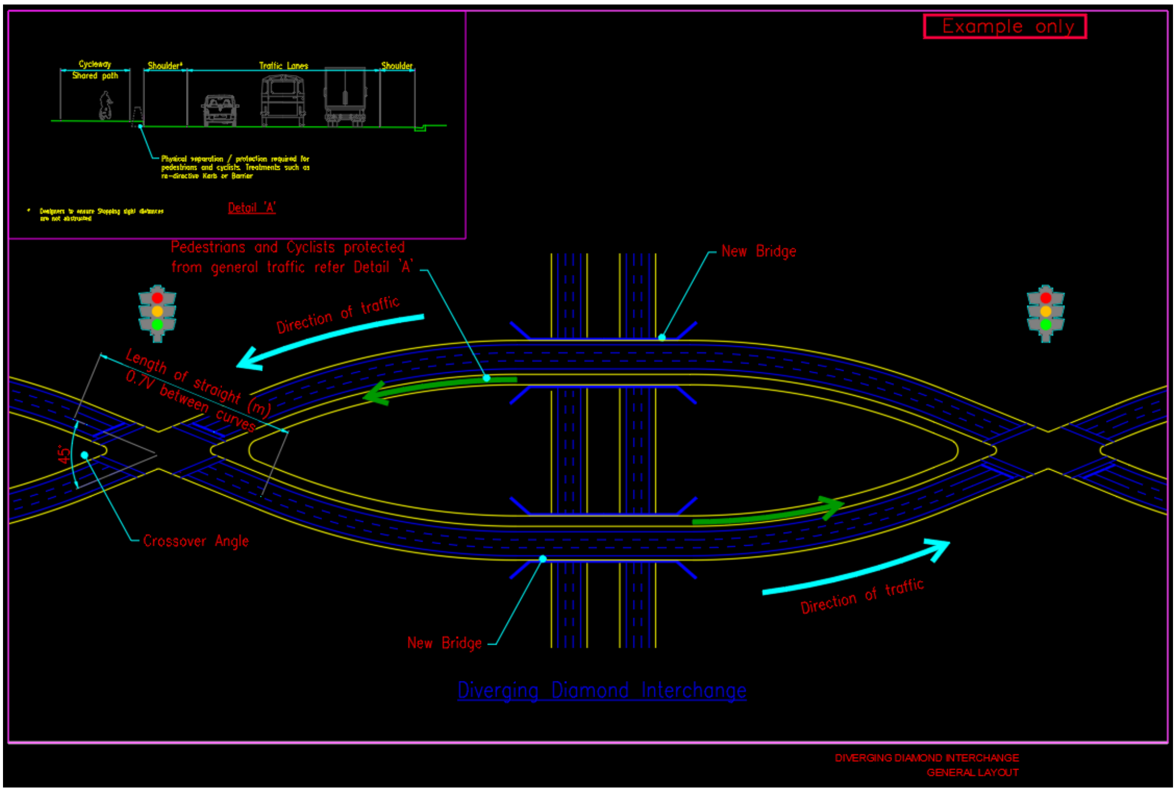
Queensland Government

1 Purpose and scope

This technical note provides interim advice on the geometric design methodology for Diverging Diamond Interchange (DDI) Intersection treatments on the Queensland State Controlled road network. The scope of this advice focuses on the geometric characteristics for the DDI aligned with the department's *Road Planning and Design Manual* (RPDM) and *Road Safety Policy* (RSP).

Figure 1(a) – DDI General layout

Figure 1(b) – DDI General arrangement layout



Comments and suggestions for improvements to this technical note based on experience with its use should be forwarded to the Director (Road Design) so that any adjustments can be considered and implemented where appropriate in subsequent revisions.

This technical note is intended to be eventually incorporated into the *Road Planning and Design Manual*.

2 Background information

A Diverging Diamond Interchange (DDI), also called a Double Crossover Diamond Interchange (DCD), is a type of diamond interchange in which the two directions of traffic on the non-major arterial road cross to the opposite side on both sides of the bridge at the major arterial. It is unusual in that it requires traffic on the non-major arterial road overpass (or underpass) to briefly drive on the opposite side of the road from what is customary (that is opposing vehicles pass on the left-side). The crossover of traffic is usually catered for at signalised intersections.

The DDI allows for two-phase operation at all signalised intersections within the interchange. This is a significant improvement in safety, since no long turns (e.g. right turns) must clear opposing traffic and all movements are discrete, with most controlled by traffic signals.

Additionally, the design can improve the efficiency of an interchange, as the lost time for various phases in the cycle can be redistributed as green time. There are only two clearance intervals (the time for traffic signals to change from green to yellow to red) instead of the six or more found in other interchange designs.

A diverging diamond can be constructed for limited cost, at an existing straight-line bridge, by building cross-over intersections outside the bridge ramps to switch traffic lanes before entering the bridge.

Some additional advantages include:

- two-phase signals with short cycle lengths, significantly reducing delay
- increases the capacity of turning movements to and from the ramps
- potentially reduces the number of lanes on the crossroad, minimising space requirements
- reduces the number of conflict points, thus theoretically improving safety, and
- increases the capacity of an existing overpass or underpass, by removing the need for multiple right-turn lanes.

Some disadvantages include:

- drivers may not be familiar with configuration, particularly regarding to merging manoeuvres along the opposite side of the roadway or the crossover flow of traffic
- incorporating safe operation for Vulnerable Road Users is a challenge, and
- free-flowing traffic in both directions on the non-motorway road is impossible, as the signals cannot be green at both intersections for both directions simultaneously.

Diverging diamond roads have been used in France since the 1970's, however their popularity really began to grow after their introduction into the USA (Missouri 2009). There are now 135 DDI's throughout nine countries worldwide (the most being the USA with 123).

Industry and departmental practitioners are encouraged to consider this type of treatment at appropriate locations as a legitimate design solution.

3 Design considerations

Until such time as more formal guidance is given within the Austroads suite of technical publications, interim design guidance shall be via the following publication from the USA Federal Highway Administration (FHWA) *Diverging Diamond Interchange Informational Guide*, except where Queensland specific guidance has been stipulated in Section 4 of this technical note. This guide can be accessed via Crossover Intersections | Intersection Safety - Safety | Federal Highway Administration (dot.gov).

Whilst this technical note provides guidance on the specific geometric characteristics for the DDI, designers, engineers and planners must also consider the traffic operational performance, driver expectation, public transport, road lighting, egress, environmental and future land use impacts with any proposal to including the DDI as a solution. Furthermore, the accessibility and safety to vulnerable road users must also be considered.

4 Design guidance

Road design specifics for the DDI will utilise current Australian design and specification practice and will include the department's *Road Planning and Design Manual* and Austroads guidelines. The following items will be included and therefore take precedence / overwrite sections within the primary design guide Federal Highway Administration (FHWA) *Diverging Diamond Interchange Informational Guide.*

Table 4 – DDI Function Geometrics

Crossover Angle (absolute min – desirable min)	Posted Speed (max) km/h Design Speed km/h	Number of traffic lanes (Max)	Infrastructure Type	Examples of Usage
22° – 30°	40 ***Truck 43 km/h*** ***Car 50 km/h***	4 lane / 2 way	Brownfield	Retrofit onto existing single interchange bridge
31° – 44°	50 ***Truck 52 km/h*** ***Car 60 km/h***	4 lane / 2 way	Brownfield / Greenfield	Alternative option for: • service Interchange • at grade intersection
45° – 50°	60 ***Truck 60 km/h*** ***Car 70 km/h***	6 lane / 2 way	Greenfield	

To enhance the functional operation of the DDI with respect to driver behaviour and traffic performance, the following design elements **shall** be given priority (refer Figures 1(a) and 1(b), and Figure 4.3 for location details).

1. **Long straight tangent through the cross-over** (this allows far superior self-navigation guidance through the DDI. It may also negate the need for more costly overhead gantry secondary lane direction signals. It also allows for a less complex road surface crossfall and rotation between the reverse curve horizontal alignment).
2. In accordance with the department's *Road Safety Policy*, **pedestrian crossings on all legs of signalised intersections should be signalised**.
3. Right-turn lane exits through the DDI **should be developed as a right-turn auxiliary lane** commencing before the first signalised cross-over intersection.

4.1 Posted speed / Design speed

It is possible for the posted speed at a signalised intersection on an arterial road throughout the Transport and Main Road's network to be up to 80 km/h. As a direct application / consequence of the department's road safety initiative into the reduction of Fatal and Serious Injuries (FSI) on state roads, all departmental projects **shall** adhere to cross-over angles-vs-speed values within Table 4, unless approved by the Director (Road Design).[2][3][8]

Speed reductions caused by geometric elements (e.g. ramp exits and entries off the main through DDI carriageway) should be limited to **Cars and Trucks = 5 km/h** (*absolute maximum*).

The posted speeds and estimated design speeds are shown in Table 4. Posted speed throughout the DDI will remain constant and the minimum length of the speed zone will be in accordance with the department's Queensland *Manual of Uniform Traffic Control Devices*. Posted speed signs are to be placed equidistant from both cross-over intersections.

4.2 Positioning and design of the crossover intersections

Diverging Diamond Interchange Informational Guide recommends the spacing between the main cross-over intersections range from 600 feet to 750 feet (185 m to 230 m). A function of the DDI is to coordinate the signals at the crossovers, thus the spacing between these two intersections will have an impact on the signal phasing strategy. A much more robust traffic modelling investigation is needed to achieve the optimal performance for the network. Local site constraints and other factors (e.g. Greenfield or Brownfield site) may also need to be factored in considering the spacing of the crossover intersections.

The geometric design of the cross-overs are quite complex and need to match several competing demands at the same location for example; horizontal and vertical alignments, surface drainage, signal phasing and location of signal infrastructure, traffic lanes, design vehicle movements, Vulnerable Road Users, land space availability and so on.

With regards the cross-over angle, competing road reserve widths influence this design choice quite substantially, be it either a constrained Brownfield site or more generous Greenfield site.

As recommended from the *Diverging Diamond Interchange Informational Guide*, a 45° – 52° cross-over angle appears to be a desirable angle for most situations. The smaller angles shown in Table 4 represent an opportunity to expand the DDI functionality into highly restricted / constrained brownfield sites, such as retrofitting a DDI layout onto a single bridge interchange to improve traffic 'Level of Service'. This retrofit has the potential to increase the interchange functional life up to 25% - 40%, thus extensive cost savings.

As noted in Section 4.1, if design speeds are kept within the cross-over angles noted in Table 4, safety should not be compromised.

Other key elements to the geometric design at the crossover include:

- A minimum length of straight of 0.7V (*that is: V = vehicle speed in km/h*) between the approach curve and the departure curve. This length will obviously be longer if for example the 22° cross-over angle is used.
- Pavement marking of stop-lines to be staggered (perpendicular to lane lines), and
- The use of common tangent point reverse horizontal curves along with compound curves are considered undesirable as both heavy vehicle and motorcyclist operations are problematic.

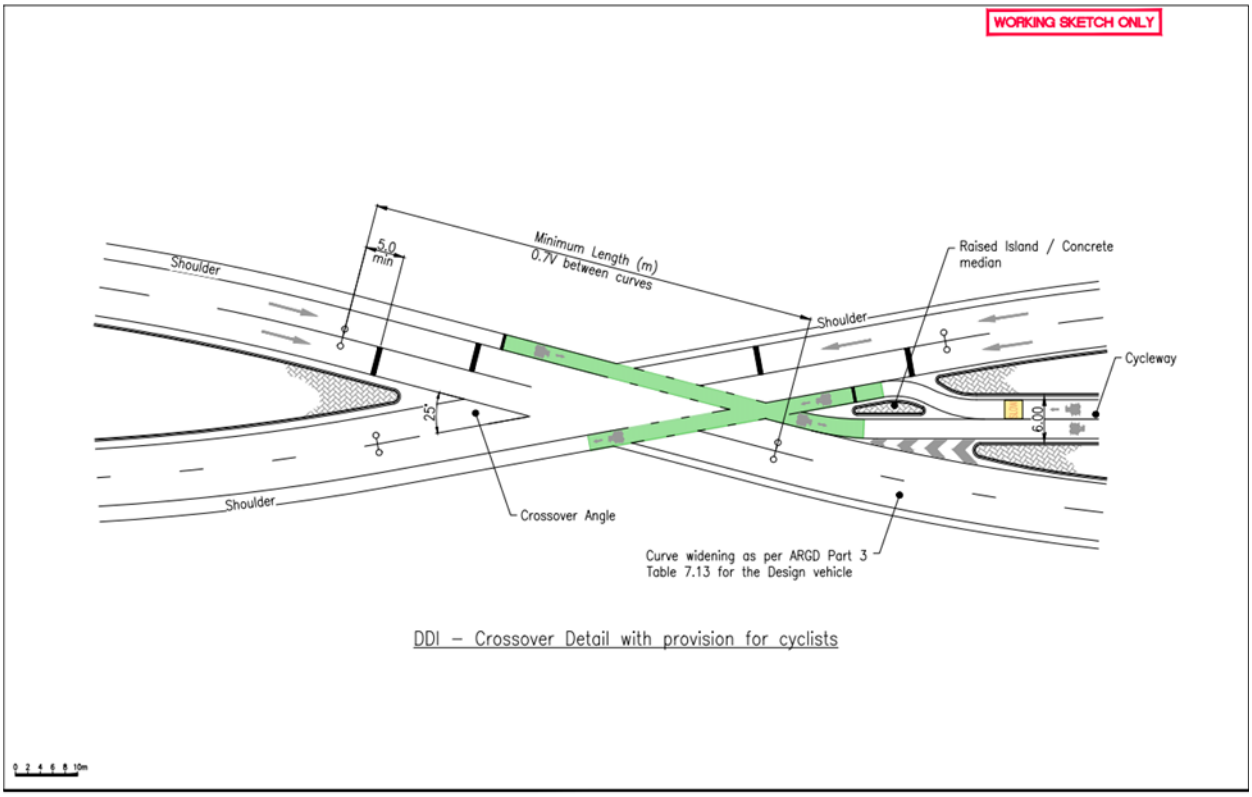
4.3 Provision for Vulnerable Road Users (VRU)

There are basically three different design approaches for the safe passage of VRU's:

- Duplication either side of the DDI for shared use.
- Duplication either side of the DDI for pedestrians with on-road cyclists adjacent to vehicular traffic, and
- Single combined shared-use corridor placed centrally between opposing traffic lanes. This can either be done on a single wide existing bridge or with an independent bridge structure.

Any of the above options are valid but need to be balanced against more precise traffic modelling (e.g. signal phasing delays), the safety risk to VRU's and the department's *Road safety Policy-2018*. See Figure 4.3 for a typical cross-over detail with provision for cyclists.

Figure 4.3 – Cycling option down centre of DDI



DIVERGING DIAMOND PROJECT
DDI CROSSOVER DETAIL WITH CYCLISTS

4.4 Pavement / tyre friction geometrics

The traffic approaching and passing through the signalised DDI will be treated as an intersection for its entire functional length.

Friction demand shall incorporate in combination both the lateral acceleration / side friction factors (as per *Austroads Guide to Road Design* (AGRD) *Part 3 Geometric Design* – Table 7.5) and longitudinal deceleration / braking friction (as per AGRD Part 3 – Table 5.3).

Note: With regard to the approach vertical grades in the direct braking zone to the signalised DDI cross-over intersections, the absolute maximum co-efficient of deceleration should be 0.4.

4.5 Cross fall / superelevation / grades / horizontal curvature

The desirable minimum crossfall through the DDI is 3% with an absolute minimum of 2.5% on the bridge deck. However, either a crowned crossfall or one-way crossfall should not exceed 3% through the cross-over intersections.

It is normally the department's preference for mid-block road sections to have superelevation applied to all horizontal curves. In the case of intersections adverse crossfall may be unavoidable to achieve a satisfactory surface profile in order that intersecting roads can adequately drain surface flows.

Due to the cross-over angles and slope that are inbuilt into many DDI's already in service, the use of adverse crossfall both on the approach and departure horizontal curvature and also through the DDI can be seen as an alternative geometric design outcome. This may be required for reasons of constructability, property access, comfort and efficient drainage to the finished road surface.

Adverse cross fall should not exceed -3%. As referenced in *Austroads Guide to Road Design Part 3* the use of adverse cross fall should consider carefully the following areas:

- on the approach to intersections with very high breaking demands
- locations subject to aquaplaning, ponding of water, and
- where longitudinal grades exceed 3% - 4%.

Horizontal curve design **shall not** exceed the Limiting Curve Speed at the 85th percentile operating speed for cars and trucks throughout the DDI. This design aspect is a total departure from that used in the USA and represents driver behaviour on Queensland roads.

Refer Table 4.5 for minimum horizontal curvature on DDI's.

Table 4.5 – Minimum horizontal curvature on DDI's with adverse crossfall

Design Speed (km/h)	Cars (radius m)	Trucks# (radius m)
43	**-**	**135**
50	**120**	**180**
60	**220**	**340**
70	**400**	**610**
80 +	Not recommended	Not recommended

For trucks, horizontal curves that use adverse cross fall shall be designed based on 2/3rds of the desirable side friction values for trucks published within *Austroads Guide to Road Design Part 3*.

As noted in *Austroads Guide to Road Design Part 4A Unsignalised and Signalised Intersections* Section 2.2.2, vertical approach grades to intersections should normally not exceed 3% - 5%. In highly constrained Brownfield sites, steep downgrades (that is grades greater than 3%) may be unavoidable therefore the modified usage of *Austroads Guide to Road Design Part 3*, Section 7.6.1 (Equation 7) will be necessary.

Note: The steep grade adjustment will also be applied to values in Table 4.5.

Ramp's positive superelevation to be 6% (maximum) as per *Austroads Guide to Road Design Part 4C Interchanges*.

4.6 Cross section

Lane widths through the DDI shall be as per the *Road Planning and Design Manual*, *Edition 2 Volume 3, Supplement to Austroads Guide to Road Design – Part 3 Geometric Design*, based on the designated design vehicle.

Due to traffic directional operations peculiar to that of a DDI, curve widening for the specific design vehicle shall be applied as per *Austroads Guide to Road Design Part 3* Table 7.13 for all lanes.

However, lane widths should not exceed 4.6 m. Where lane widths exceed 4.6 m based on the curve widening or using turn-path templates, designers should consider changing the proposed alignment.

Shoulder widths are per project team requirements or to be a minimum of 1.0 m as default.

4.7 Sight distance

All aspects of sight distance, approach sight distance, safe intersection sight distance, minimum gap sight distance to the entire DDI, including any property access, shall be in accordance with the current guidelines outlined within *Road Planning and Design Manual, Edition 2 Volume 3, Supplement to Austroads Guide to Road Design Part 3* and *4A*.

The combination of horizontal and vertical sight distance and resultant sight lines can have major geometric effects on resultant bridge superstructure design. Site layout conditions and constructability will determine the most optimum design.

Crossing Sight Distance (CSD) is required to all crossings as per *Austroads Guide to Road Design Part 4A*.

It is desirable to allow a minimum 5 secs observation / decision time of sight distance to lane line pavement marking throughout the DDI.

5 Mitigation and monitoring

DDI arrangements will be documented and approved as a design exception (pilot project).

References

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3. Jurewicz.G., Sobhani.A., Woolley.J., Dutschke.J., Corben.B. (2016). *Exploration of Vehicle Impact Speed – Injury Severity Relationships for Application in Safer Road Design*, 6th Transport Research Arena April 18-21, 2016
4. *Guide to Diverging Diamond Interchanges* (2014). Utah Department of Transport, USA
5. Austroads (2016). *Guide to Road Design Part 3 Geometric Design*, Austroads, Sydney Australia
6. Austroads (2016). *Guide to Road Design Part 4 Intersections and Crossings*, Austroads, Sydney Australia
7. Austroads (2016). *Guide to Road Design Part 4A Unsignalised and Signalised Intersections*, Austroads, Sydney Australia
8. Department of Transport and Main Roads (2018). *Road Safety Policy – Organisational Policy*, Queensland, Australia. https://www.tmr.qld.gov.au/Safety/Road-safety/Road-Safety-Policy
9. Department of Transport and Main Roads. Queensland *Manual of Uniform Traffic Control Devices Part 2 Traffic Control Devices for General Use* (Queensland MUTCD), Queensland Australia https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Manual-of-uniform-traffic-control-devices.aspx
10. Department of Transport and Main Roads *Road Planning and Design Manual, Volume 3 – Guide to Road Design*, https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition.aspx
11. Department of Transport and Main Roads *Traffic Control Standard Drawings*, Queensland Australia