ESTABLISHING THE MINIMUM GROUND CLEARANCES FOR THE TAC DESIGN VEHICLES BASED ON THE DESIRABLE GRADES AND THE MAXIMUM GRADE CHANGES

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ABSTRACT

The TAC Geometric Design Guide for Canadian Roads (GDGCD) 1999 describes the turning characteristics of design vehicles using turning templates. Vehicle turning templates play an integral role in controlling the horizontal aspects of the geometric design of intersections. As to the vertical aspect of a design, design vehicles are ignored primarily because no information is provided on the vehicle's ground clearances nor the pitch and roll limitations at the vehicle's articulating points. Hence, vertical profiles are not typically evaluated against the standard design vehicles in practice, but instead it is assumed that the maximum recommended grades and grade changes for the vertical alignments presented in the design guideline will accommodate the vehicles. With ground clearance values implied, designers cannot easily perform checks to ensure the vertical profiles that deviate from the guidelines will accommodate the design vehicles. This may lead to potential vehicle hang-up conflicts at driveways, rail crossings, and roundabout truck aprons. This study is focused on establishing the ground clearances for the GDGCD design vehicles so that they can be incorporated into future guidelines. The ground clearance for 8 of the design vehicles is calculated as a function of the recommended grades in the GDGCD and verified against 3D vehicle simulation software. A more comprehensive study involving surveying the existing vehicle inventory in Canada to establish these ground clearance values is recommended but is not covered in the scope of this study.

LITERATURE REVIEW

Design vehicles presented in the GDGRC (1) are intended to represent most of the vehicles within its class, and are updated periodically in order to respond to changes in trends by the vehicle manufacturers. However, when it comes to the ground clearances for these vehicles, no information is published; instead, maximum desirable grades and grade changes are recommended for specific roadway components. An example of this are the maximum desirable grades and grade changes for residential, commercial and industrial driveways stated in the guideline.

Due to the grades and grade changes, driveways represent one of the most challenging scenarios when it comes to ground clearance analysis. The GDGCR (1) also considers the driveway as an important element for the performance of the road systems. The desirable maximum grade changes, between the roadway cross-slop and the driveway grade, also varies with the road type. For instance, if it is a higher classification road, it is desirable to lower the grade change at the roadway edge. By doing so, deceleration is reduced and high speed turns are encouraged, minimizing the interference with the major road.

There are several variables of a design vehicle that could influence the driveway grades. These variables include the front, wheelbase and rear lengths and their corresponding clearances – the front overhang, wheelbase ground clearances and rear overhang. All of these factors could potentially influence the design grades. Figure 1 illustrates these variables on a standard passenger car. Additionally, the maximum desired grades are also influenced by the specific overhangs. For example, the front and rear overhang clearances influence the max desirable grade when the vehicle is going uphill, while the wheelbase clearances influence the maximum desirable grade when the vehicle is going downhill.

The GDGCR (1) provides the maximum desirable grade changes based off of implied ground clearance values. This makes it difficult for designers to perform checks to ensure that the vertical profiles that deviate from the guidelines will accommodate the design vehicles. Deviations may be at the front or rear overhang or at the wheelbase ground clearance.

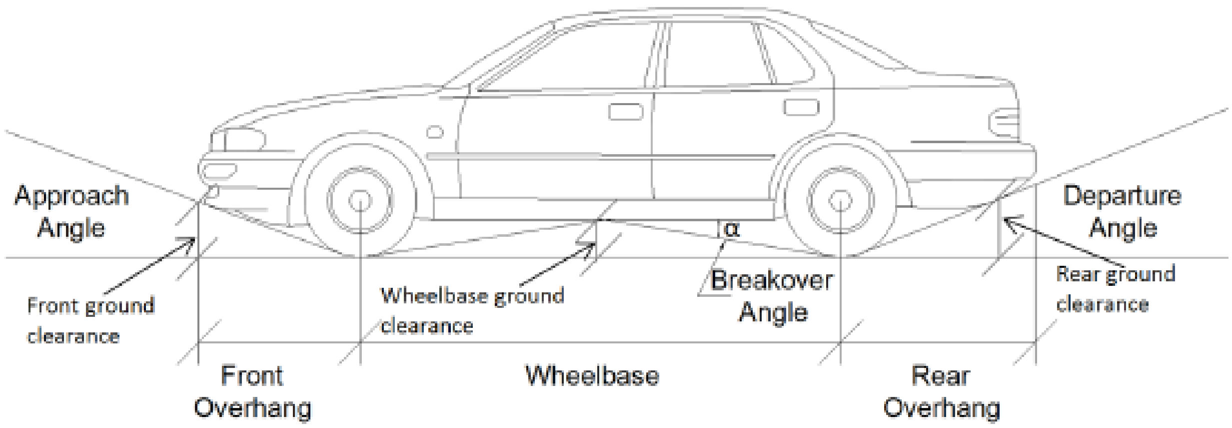

Figure 1. Vehicle profile example – Ground clearances, angles and lengths

In the United States, many studies have been performed (2, 3, 4, 5, 6, 7, 8, 9) with the purpose of improving the adjacent roadway performance by analyzing driveway geometry. In NCHRP Report 659 (10), ground clearance values are presented for a series of low clearance vehicles, including garbage trucks, fire trucks, mini-buses, etc. Even though these vehicles are not part of the design vehicles in the GDGCR (1), they are often used in a design to ensure access of the driveway for emergency and operational reasons.

Overall, the studies suggest enhancements to the current guidelines. These changes include showcasing the minimum front, wheelbase and rear ground clearances that will pass the current maximum desirable grades.

In the case of the vertical profile analysis, previous studies conducted by the authors, identified minimum ground clearances for some of the GDGCR (1) based on the maximum grades for residential driveways. However, not all the design vehicles were tested, as some of them are not really applicable for such scenario. Most of the minimum ground clearance values identified as valid, for the case of vertical profile analysis, highlighted issues when evaluated on the 3D model based off the same vertical profile geometry.

METHODOLOGY

This study focuses on finding the lowest acceptable front, wheelbase and rear ground clearance values for eight of the major GDGCR (1) vehicles for both residential and industrial driveways. To perform this analysis, tools including Autodesk AutoCAD (12), NEXUS Intersection® (10) and AutoTURN PRO 3D® (11) were used to serve as the CAD platform, intersection modelling tool, and 3D vehicle simulation tool respectively.
The vehicles that were chosen for this study included the passenger car (P), light single unit truck (LSU), medium single unit truck (MSU), heavy single unit truck (HSU), standard bus (B-12), standard bus (I-BUS), semitrailer (WB-19) and semitrailer (WB-20). Figure 2 depicts the various vehicles and their dimensions.

To test the ground clearances for both residential and industrial driveways, the vehicles that were applicable for the scenarios were determined. In the case of the residential driveway, P, LSU, MSU, HSU, I-BUS and B-12 were used. For the industrial driveway, larger vehicles were used including MSU, I-BUS, WB -19 and WB-20.

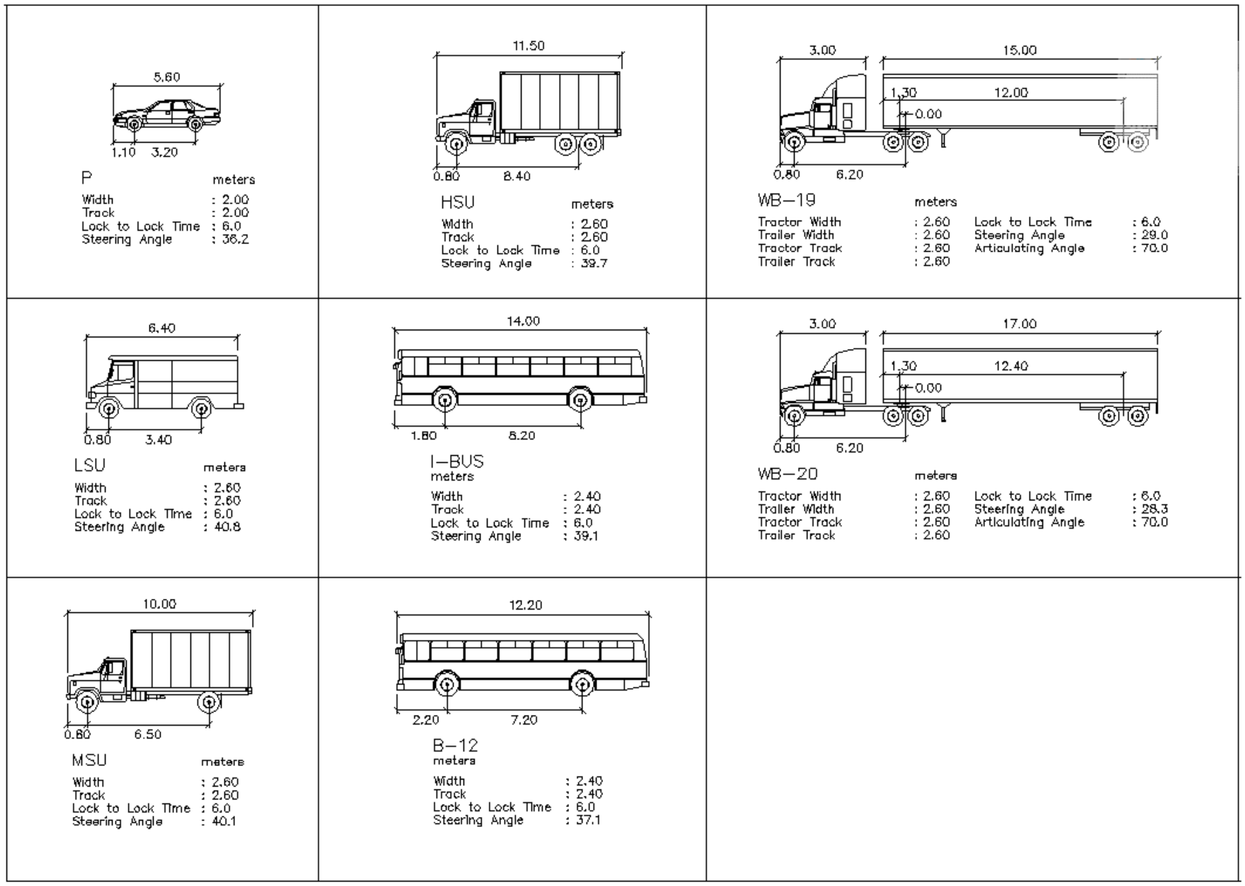

Figure 2. TAC vehicles selected for the evaluation of the driveway model

In order to perform this analysis, the residential and industrial driveways were modelled in AutoCAD with the assistance of NEXUS Intersections in 3D. Both the uphill and downhill scenarios were created using the recommended driveway grades provided in the GDGCR (1). Figure 3 shows the difference grades that were used for the residential and commercial driveway's design The horizontal driveway geometry was also taken from the GDGCR guidelines for residential and commercial entrances. As for the vertical profile design, the maximum desired grades were taken from the GDGCR and drafted in AutoCAD.

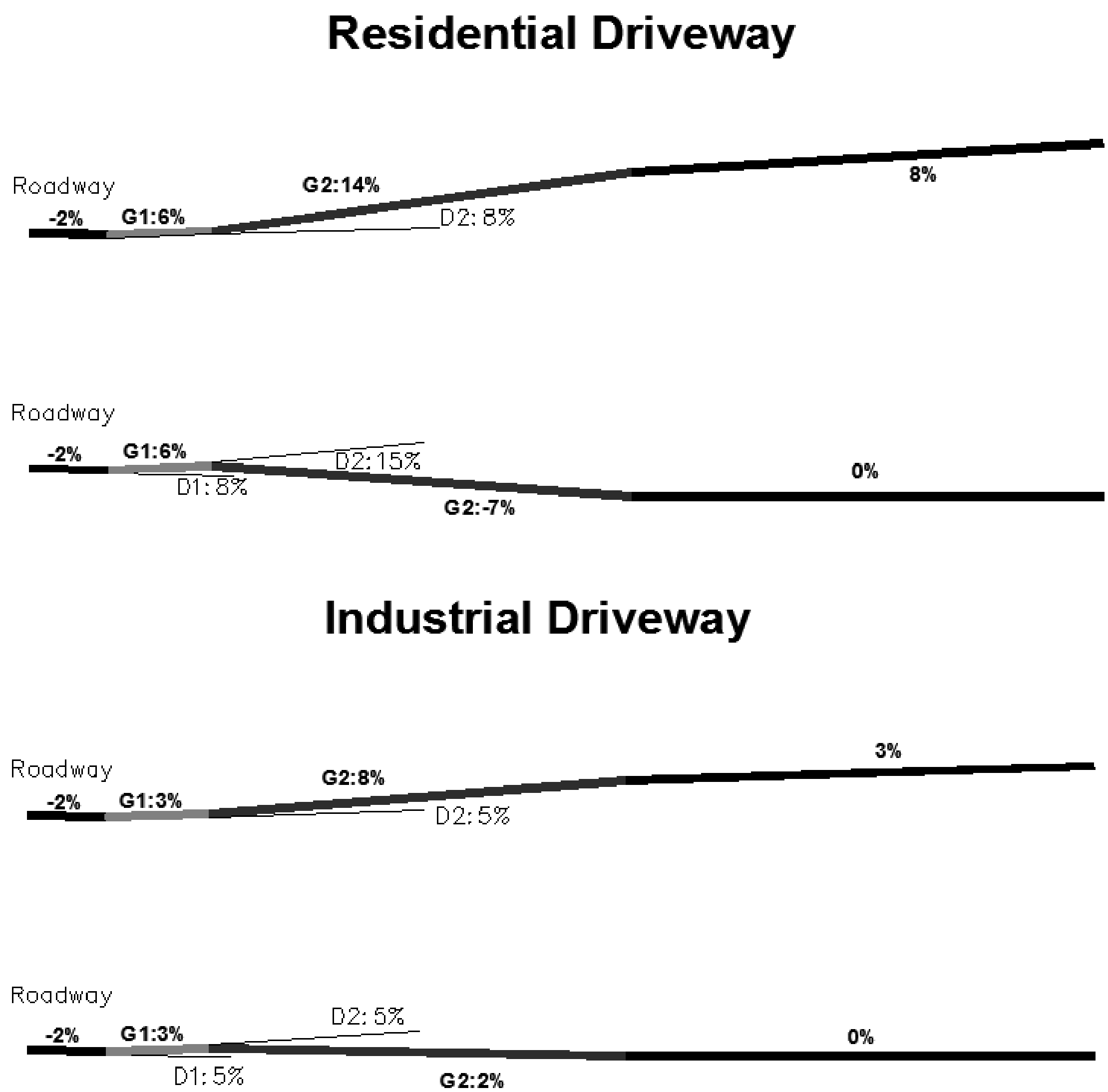

Figure 3. Uphill and downhill profiles for residential and industrial driveways based on thresholds grades recommended by GDGCR

In order to test the various ground clearances for each of the vehicles directly in 3D, AutoTURN Pro was used. In the 3D scenarios, two driveways were created for each vehicle (uphill and downhill). Then, the 2 possible turning maneuvers were evaluated for each vehicle, which resulted in the evaluation of the 4 possible scenarios per vehicle (downhill left turn, downhill right turn, uphill left turn and uphill right turn), as seen in Figure 4. Every scenario was considered to determine the minimal possible ground clearance values.

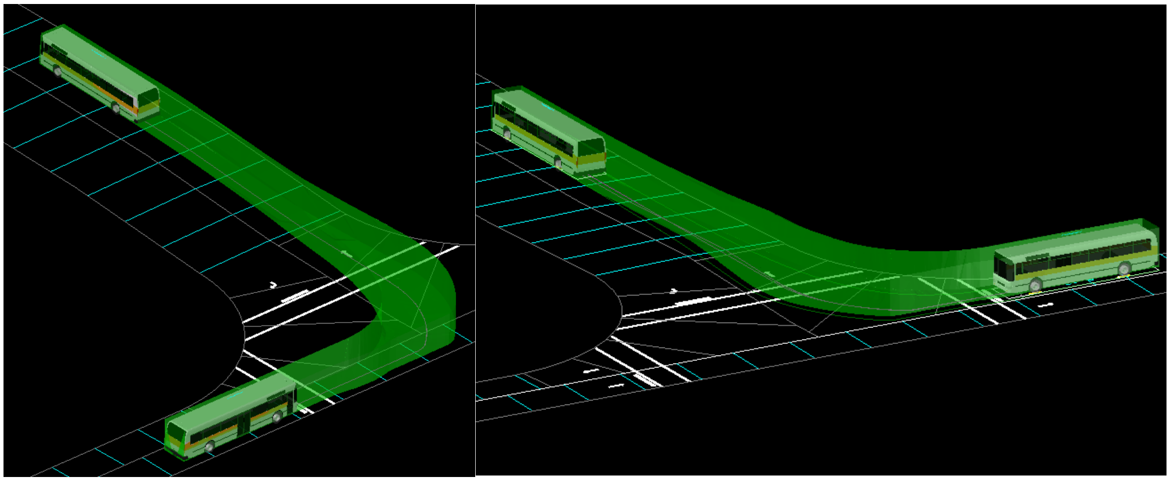

Figure 4. 3D driveway modeling and uphill and downhill right turn simulation for the I-BUS

In this study, the minimum ground clearance values for each vehicle were determined through trial and error. Each vehicle simulation analysis was conducted for the different scenarios. The ground clearance values for front, wheelbase and rear were varied iteratively until the minimum values for both vertical profile geometry and 3D model were established. The iterative process involved changing each of the front, wheelbase and rear ground clearances by 1cm increments. This process was conducted for each of the eight TAC vehicles on the four different scenarios (uphill-left, uphill-right, downhill-left, and downhill-right). By keeping the wheelbase and rear clearance at standard height (acceptable clearance limit) the front was continuously lowered until a conflict was observed. This was done for all four scenarios until the minimum acceptable clearance value was found (all four scenarios permitted the lowest clearance value). For each of incremental change, the 3D simulation analysis was performed to determine if the vehicle conflicted with the 3D terrain. The minimum value represents the limits given the 1cm interval. In practice, a clearance should be established for the safety buffer, possibly around an extra 15-20%.

FINDINGS

The findings in this study showcased the minimum ground clearances for all of the eight TAC design vehicles. The residential and industrial driveways were created for both uphill and downhill scenarios using the GDGCR (1) recommendations. In terms of the vehicles, the lengths of the vehicle's overhangs and wheelbase were kept constant and the ground clearances were varied until no conflicts were observed. Through an iterative process of trial and error, the ground clearance height was altered by 1cm increments until the front, wheelbase and rear minimum ground clearances were determined.

An example of the iterative, minimum ground clearance is shown in Appendix A for P car, LSU truck and B12 bus. As seen in the appendix, the vertical profile was modelled for uphill and downhill scenarios and the 3D model was done for the uphill-right, uphill-left, downhill-right and downhill-left scenario. The minimum ground clearance values were then taken from each of the possibilities for the front, wheelbase and rear. These minimum results are shown for each case below in Table 1.

Vehicle		Min. Front Overhang Clearance (m)	Min. Wheelbase Clearance (m)	Min. Rear Overhang Clearance (m)	Type of driveway: Residential (R) Industrial: (I)
1	P car	0.13	0.11	0.16	R
2	LSU	0.11	0.13	0.24	R
3	MSU	0.11	0.22	0.29	R,I
4	HSU	0.11	0.3	0.23	R,I
5	I-BUS	0.2	0.28	0.43	R,I
6	B-12	0.25	0.24	0.31	R,I
7	WB-19 Tractor	0.08	0.09	NA	I
	WB-19 Trailer	NA	0.18	0.12	I
8	WB-20 Tractor	0.08	0.09	NA	I
	WB-20 Trailer	NA	0.19	0.2	I

Table 1. Minimum driveway ground clearance results for the eight TAC vehicles used in study

The driveway scenario results showed the severity of the conflicts and the locations where the vehicle scrapped the surface depending on the type of turn (left or right turn). The uphill and downhill scenarios also pointed out that the conflicts were more prominent in the downhill, particularly in the downhill-left turn scenario.

The findings also shows that some of the industrial driveway vehicles were not necessary to duplicate after being done in residential. As seen in previously in Figure 4, the residential driveway was much steeper, therefore if the minimal ground clearance was found for a vehicle crossing a residential driveway then if could definitely cross a more level industrial driveway.

CONCLUSION

Based on the recommend grades presented in the GDGCR (1) for the driveway vertical profile, the minimum ground clearances were calculated for the eight TAC design vehicles. The worst-case or minimum vehicle ground clearance values for each of clearances at the front, wheelbase and rear were determined for both the uphill- downhill and left-right turning scenarios through 3D vehicle simulation models. From the observation, as the vehicle maneuvers a left or right turn into the driveway, each wheel is suspended at a different elevation on the 3D surface. This results in the base of the vehicle body orientating causing the ground clearances at the wheelbase and overhangs to differ. For example, in the scenario where the vehicle makes a right turn into an uphill driveway profile, the ground clearance at the front right corner bumper is closest to the ground. However, when in the scenario where the vehicle makes a left turn into the uphill driveway profile, the ground clearance at the center of the front bumper is closest to the ground.

In a left turn, the vehicle would have had the chance to straighten out parallel to the profile alignment.

RECOMMENDATIONS

The current GDGCR (1) contains minimal information in regards to vehicle ground clearances. This absence of information makes it difficult to evaluate roadway components, such as driveways and their vertical geometry. If this aspect is not checked or designed properly, it may lead to damages to the vehicles and roads. As a result, it is recommended that the existing design vehicles in the GDGCR should include information about their minimum ground clearances.

The information presented in this study describes one possible way to establish the ground clearance values. The minimum values with consideration of the appropriate safety buffer could be considered for the future editions of the GDGCR.

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APPENDIX A

P-Car	**Vertical profile**		
	Front (m)	Wheelbase (m)	Rear (m)
Uphill	**0.13**	0.11	**0.16**
Downhill	0.07	**0.11**	0.08

3D Model			
	Front (m)	Wheelbase (m)	Rear (m)
Uphill-Right	**0.13**	0.08	**0.16**
Uphill-Left	0.09	0.08	0.15
Downhill-Right	0.09	**0.11**	0.12
Downhil-Left	**0.13**	**0.11**	0.13

LSU Truck	**Vertical profile**		
	Front (m)	Wheelbase (m)	Rear (m)
Uphill	**0.10**	0.09	**0.24**
Downhill	0.06	**0.13**	0.16

3D Model			
	Front (m)	Wheelbase (m)	Rear (m)
Uphill-Right	0.10	0.09	0.23
Uphill-Left	**0.11**	0.09	**0.24**
Downhill-Right	0.06	**0.12**	0.18
Downhil-Left	**0.11**	**0.12**	0.20

B12	**Vertical profile**		
	Front (m)	Wheelbase (m)	Rear (m)
Uphill	**0.25**	0.18	**0.31**
Downhill	0.12	**0.21**	0.16

3D Model			
	Front (m)	Wheelbase (m)	Rear (m)
Uphill-Right	**0.22**	0.16	**0.28**
Uphill-Left	0.19	0.16	0.27
Downhill-Right	0.15	0.23	0.21
Downhil-Left	0.17	**0.24**	0.23