ADVICE NOTE 3 - Geometric Standards

1. Introduction

The Design Manual for Urban Roads and Streets was published in March 2013. It sets out an integrated, holistic and multi-disciplinary approach to road and street design in cities, towns and villages. One of the core aims of the manual is to create self-regulating streets and it contains a range of measures that practitioners can apply to achieve this aim. DMURS introduces a set of geometric standards that will result in significantly more compact street geometry than the road design standards that have traditionally been applied to when designing urban streets. This paper documents the background research and considerations used in the development of the DMURS geometric standards.

Designers are provided with the flexibility to adapt to the multitude of circumstances that they may encounter when designing urban streets. The standards set out in the DMURS are less prescriptive than those contained in previous documents, and DMURS does not purport to comprehensively cover all aspects of geometric road and street design – on the contrary it offers guidance based on only some of the most fundamental aspects of street geometry.

Designers should be aware that strict adherence to geometric standards alone will not be sufficient to ensure compliance with DMURS. The creation of self-regulating streets and the holistic application of the principles, approaches and standards of the manual, will also be required. Practitioners should draw on their professional expertise and judgment to a greater extent when implementing the DMURS standards. It is imperative that designers apply their academic qualifications, knowledge and experience in street design, and that they exercise a duty of care when applying the geometric standards of the manual.

The DMURS geometric standards are primarily intended to be applied to new streets; however it is also recommended that they be applied on existing streets where practicable. However many existing streets consist of horizontal or vertical alignments that are below the standards included in the DMURS, but have operated for some time without undue difficulty. It is not intended that the DMURS would trigger a requirement to realign such streets. Furthermore, strict application within historical contexts may not be desirable where they would have a damaging effect on the established street character.

Conversely, there are existing streets with unsuitable geometry where the application of the DMURS standards would enhance the operation of the street and help to achieve the self-regulating street environment envisaged in the DMURS. When developing urban transport projects on such streets planners and designers must have regard to the scale of the proposed project; it would not be reasonable for small scale projects or maintenance works to include amendments to the geometry of a street for example. However, on larger projects which may include full reconfiguration of a street between boundary or building lines, there is likely to be more scope to apply the DMURS standards.

DMURS provides a toolkit to enable designers to innovate and to apply flexibility based on sound first principles. Above all, by basing design decisions on DMURS, designers can rely on that approach in any defence of their decisions.

2. Design Speed

The Design Speed for rural and urban roads has traditionally been based on the advice contained in the *NRA Design Manual for Roads and Bridges Document NRA TD 9/12*[1] *Road Link Design,* which in turn is based on the equivalent UK DMRB document.

The stated approach within this document to the adoption of a design speed for a particular section of road is such that the Design Speed *'shall be consistent with the anticipated vehicle speeds on the road.'*[2]

For roads in rural areas, the Design Speed is related to 3 factors: Alignment Constraint, Layout Constraint and Mandatory Speed Limits.

Alignment Constraint, Ac: a measure of the degree of constraint imparted by the road alignment, and:

Layout Constraint, Lc: a measure of the degree of constraint imparted by the road cross section, verge width and frequency of junctions and accesses.

Mandatory Speed Limits: Mandatory Speed Limits can restrict vehicle speeds to below those speeds that would be achievable in the absence of such restriction, and may act as a further constraint on speed to that indicated by the layout constraint.

NRA TD9/12 recognises that roads in urban areas differ from those in rural areas, and that lower limits on speed are appropriate. It advises that Design Speeds for roads in urban areas be selected with reference to speed limits, with an allowance made for speeds in excess of the Mandatory Speed Limit.[3] For example, a 50 kph speed limit in an urban area would attract a Design Speed of 60 kph (from tables 1/2 and 11/1 of NRA TD9/12).

1 *Now replaced by DN-GEO-03031, Rural Road Link Design, TII, April 2017.*
2 *NRA TD9/12 Paragraph 1.1*

3 *NRA TD9/12 Paragraph 1.8*

The approach of the Design Manual for Urban Roads and Streets with regard to Design Speed differs from that of NRA TD9/12 in that the aim of the DMURS is to encourage the design of streets such that the resultant vehicle speeds are appropriate to both the Function and Context of the street, rather than to cater or make allowance for higher vehicular speeds. Research carried out in preparation of Manual for Streets in the UK found that more generous geometry, particularly in terms of forward visibility and carriageway width, tends to encourage higher vehicular speeds.[4] Higher design speeds would result in the provision of more generous street geometry and the inclusion of a margin to allow for vehicle speeds in excess of the Mandatory Speed Limit is therefore not considered appropriate.

2.1 New Streets

The matrix illustrated in *Figure 1: Design Speed* Selection Matrix should be used to determine the appropriate design speed for new urban streets, based on the intended Function and Context of the street.

2.2 Existing Streets

For existing streets, where the Function and Context are often well established, *Figure 1* should also be used.

It may also be appropriate to equate the Design Speed for existing streets to the measured 85th percentile speeds on the street. In this case, the designer should consider if the 85th percentile speeds are appropriate to the Function and Context of the street. The adoption of a lower Design Speed will be required where 85th percentile speeds are considered to be too high. For the purpose of determining an appropriate design speed it is recommended that 85th percentile speeds on existing streets are measured outside of peak traffic hours in order to mitigate the impact of congestion on traffic speeds.

4 *Refer to TRL Report 661 for a full description of the findings*

Alternatively, the Mandatory Speed Limit in place on the street may be used, however care should be taken to ensure that it is appropriate for the established Function and Context of the street in order to avoid excessive vehicle speeds. For example, many town centres have a Mandatory Speed Limit of 50 kph, however it is often undesirable for vehicle speeds to reach that level due to the higher place value of town centres. Where there is a significant difference between the existing Mandatory Speed Limit and the appropriate design speed as determined from *Figure 1*, consideration should be given to reducing the Mandatory Speed Limit to avoid the perception that higher speeds are acceptable or achievable.

3. Visibility

3.1 Stopping Sight Distance

The stopping sight distance can be defined as the minimum distance a driver must be able to see ahead and be able to stop the vehicle within for a given speed.

Stopping sight distances have 3 constituent parts:

- *Perception Distance:* The distance travelled before the driver perceives a hazard.
- *Reaction Distance:* The distance travelled following the perception of a hazard until the driver applies the brakes.
- *Braking Distance:* The distance travelled until the vehicle decelerates to a halt.

The perception and reaction distances are generally taken as a single parameter based on a combined perception and reaction time.

The basic formula for the calculation of Stopping Sight Distance is:

Equation 1: $SSD = vt + v^2/2d$

Where:

v = vehicle speed (m/s)
t = driver perception-reaction time (s)
d = deceleration rate (m/s^2)

PEDESTRIAN PRIORITY — VEHICLE PRIORITY

FUNCTION	CENTRE	N'HOOD	SUBURBAN	BUSINESS/ INDUSTRIAL	RURAL FRINGE
ARTERIAL	30-40 KM/H	40-50 KM/H	40-50 KM/H	50-60 KM/H	60-80 KM/H
LINK	30 KM/H	30-50 KM/H	30-50 KM/H	50-60 KM/H	60-80 KM/H
LOCAL	10-30 KM/H	10-30 KM/H	10-30 KM/H	30-50 KM/H	60 KM/H

CONTEXT

Figure 1: Design Speed Selection Matrix

The Desirable Minimum Stopping Sight Distances recommended in NRA TD 9/12 are derived using a perception reaction time of 2 seconds, and a deceleration rate of 0.25g, or 2.45 m/s^2.

Research carried out in the preparation of the UK *Manual for Streets* found that these values are conservative.[5] Based on this research, a driver perception-reaction time of 1.5 seconds, and a deceleration rate of 0.45g, or 4.41 m/s, were applied for areas with design speeds of 60 kph and below within *Manual for Streets,* and this is approach is replicated in the DMURS. Recommended SSD values based on these parameters are presented in *Table 1: Stopping Sight Distances.*

SSD's are based on the position of the driver, not the front of the vehicle. Typically in light vehicles the driver is located approximately 2.4 metres from the front of the vehicle, which is a significant proportion of shorter SSD's. The distances presented below in *Table 1* have therefore been adjusted to allow for bonnet length by adding 2.4 metres to the values calculated using the SSD formula.

3.2 Visibility Requirements

Visibility is generally checked both along the street and at junctions, in both the horizontal and vertical planes.

Visibility in the horizontal plane can be checked using plan views of the street layout. In the vertical plane, visibility is checked to ensure that sight distances are not compromised by the presence of crests or dips in the street.

3.2.1 Forward Visibility

The minimum forward visibility required along a street corresponds to the minimum SSD appropriate to the Design Speed. Forward visibility is checked at horizontal curves by measuring between points on the curve along the centreline of the inner lane, as illustrated in *Figure 2: Forward Visibility at Horizontal Curves.*

The required envelope of visibility in the vertical plane is illustrated in *Figure* 3: *Visibility Envelope in the Vertical Plane*. The envelope shall encompass the area between a driver eye height in the range of 1.05 metres to 2.00 metres, and an object height in the range of 0.6 metres to 2.00 metres.

3.2.2 Visibility at Junctions

Visibility splays at junctions are provided to ensure that there is an adequate level of intervisibility between the major and minor arms of junctions. Junction visibility splays are composed of 2 elements; the X and Y distances. The procedure for checking visibility at junctions is illustrated in *Figure 4: Visibility Splays at Junctions.*

In addition to checking the visibility splay at a junction, designers must also check that there is sufficient forward visibility, in line with paragraph 3.2.1, along the major arm towards the junction for approaching drivers to observe a vehicle stopped and waiting to turn right into the minor arm, and equally that the driver of a right turning vehicle has sufficient forward visibility to observe vehicles approaching in the opposite direction in time to accept a gap in traffic.

5 *Refer to TRL Report 332 for full findings.*

SSD STANDARDS

Design Speed (km/h)	SSD Standard (metres)
10	7
20	14
30	23
40	33
50	45
60	59

Forward Visibility

Design Speed (km/h)	SSD Standard (metres)
10	8
20	15
30	24
40	36
50	49
60	65

Forward Visibility on Bus Routes

Table 1: Stopping Sight Distances

X Distance is the distance to the point back along the minor arm from which visibility is measured. It is normally measured from the continuation of the line of the nearside edge of the major arm, including all hard strips or shoulders. In urban areas this is likely to correspond to a kerb or outside edge of a footway. On streets that include a raised cycle track adjacent to the roadway, the x distance should be measured from the nearside edge of the cycle track. For simplicity, it is normally measured along the centreline of the minor arm.

A minimum x distance of 2.4 metres should be used on new streets, and where practicable on existing streets, in urban areas. In difficult circumstances this may be reduced to 2.0 metres where vehicle speeds are slow and flows on the minor arm are low. However, the use of a 2.0 metre x distance will result in some vehicles slightly protruding into the major arm carriageway, and may result in drivers tending to nose out cautiously into traffic. Care should be taken to ensure that cyclists and drivers can observe this overhang from a reasonable distance and manoeuvre to avoid it without undue difficulty.

The use of x distances longer than 2.4 metres is not generally recommended in urban areas. Longer x distances allow drivers to observe traffic on the major arm and to identify gaps more readily, and possibly before their vehicle comes to a stop, allowing increased vehicle speeds through junctions. Alternatively, a longer x distance may allow more than one vehicle to accept the same gap where it is not ideal that they do so.

Neither circumstance is desirable in urban areas where the attention of a driver should not solely be focussed on approaching vehicles and the acceptance of gaps, but also on the presence of vulnerable road users. In situations where longer x-distances are unavoidable, such as on streets with a footway greater than 2.4 metres wide, junctions should be carefully designed to ensure that the speed of exiting vehicles is not excessive. The application of measures such as reduced corner radii, raised entry treatments and/or the use of different materials and finishes at the junction may be helpful in this regard.

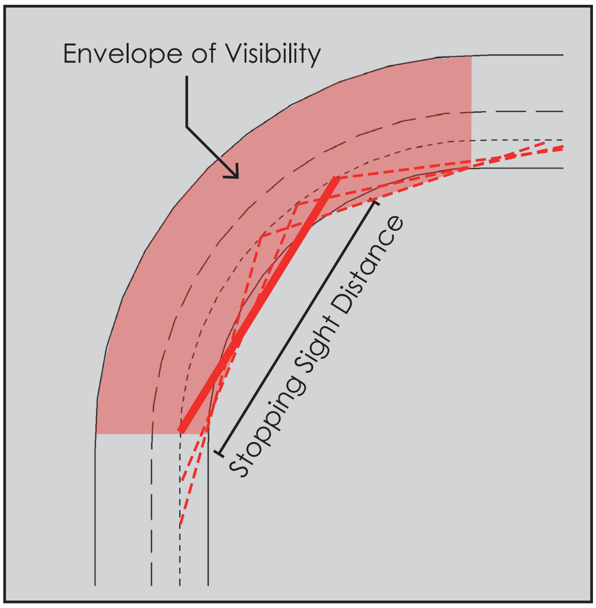

Figure 2: Forward Visibility at Horizontal Curves

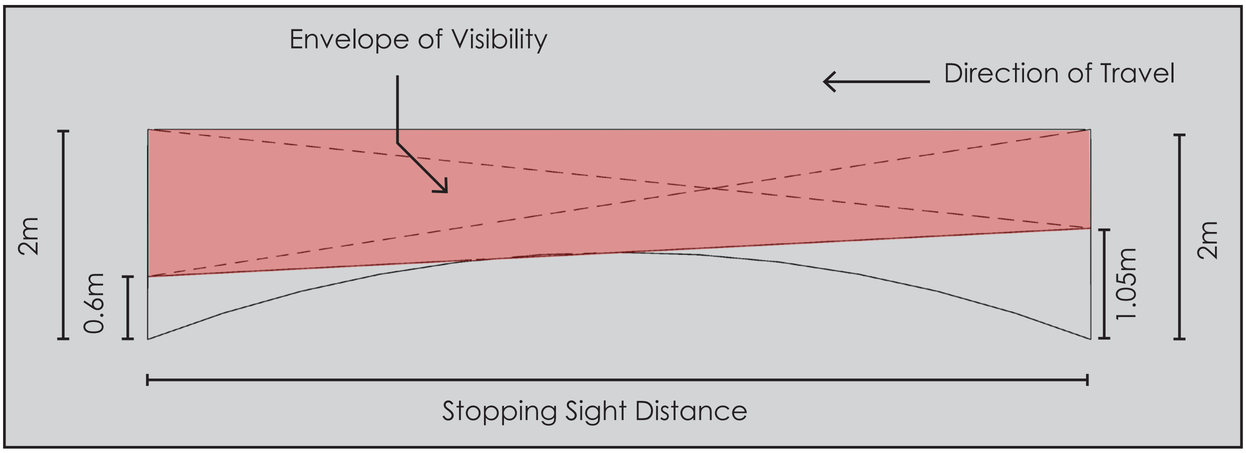

Figure 3: Visibility Envelope in the Vertical Plane

Y Distance is the distance a driver exiting from the minor road can see to the left and right along the major arm. It is normally measured from the nearside edge of the roadway. In urban areas this is likely to correspond to a kerb or the outside edge of a footway. On streets that include a raised cycle track adjacent to the roadway , the y-distance should be measured from the nearside edge of the cycle track. Where the minor arm joins a major arm on the outside of a bend, an additional check is made by drawing an additional sight line tangential to the kerb, or edge of roadway, to ensure that an approaching vehicle is visible over the entire Y distance.

The Y distance should correspond to the recommended SSD for the Design Speed of the major arm.

4. Horizontal Alignment

The horizontal alignment of a street is essentially composed of a series of horizontal curves that facilitate the smooth transition between straight sections. It is the design of these curves that is the main focus of preparing an appropriate horizontal alignment. This is related to the Design Speed of the street, and is based on the need to counteract the centrifugal force acting on a vehicle travelling around a curve to ensure that the vehicle does not leave the carriageway.

This centrifugal force is balanced by 2 factors: friction between the tyres and the road surface, and the superelevation of the carriageway. The relationship between Design Speed, superelevation, friction and curvature can be expressed by the following equation:[6]

Equation 2: $S + F = v^2/127R$

Where:

S = Superelevation (expressed as a decimal)
F = Side Friction Factor
V = Velocity (km/h)
R = Radius of Curvature

6 *M. Rogers, Highway Engineering, Blackwell Publishing, 2003, p. 168-169*

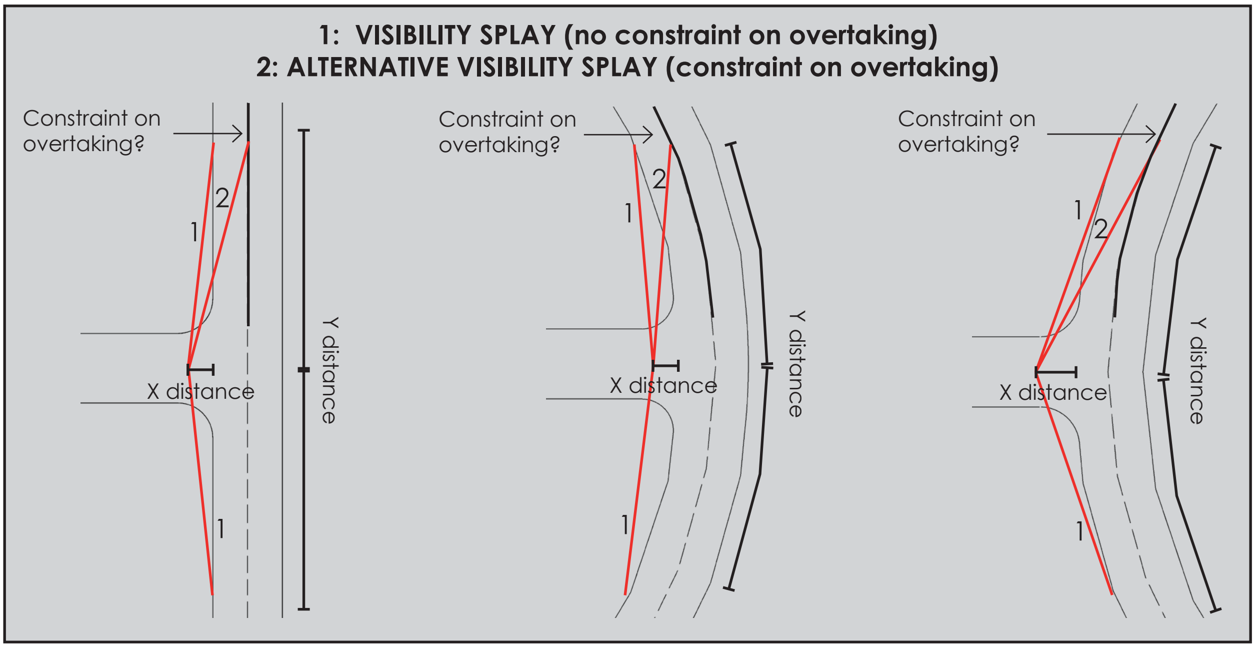

Figure 4: Visibility Splays at Junctions

For the purposes of the DMRB it is assumed that 55% of the centrifugal force is balanced by friction, with the remaining 45% balanced by the superelevation of the carriageway. By expressing S as a percentage, the equation can then be simplified to:[5]

Equation 3: $S = 0.354V^2/R$

which is the equation used to derive the radii recommended in NRA TD9/12.

However, the recommended radii and associated superelevation rates in the DMRB have been designed to ensure that a vehicle can travel around a bend without reducing speed or without causing significant discomfort to the occupants of the vehicle.

The use of sharper turning radii can be an effective tool to assist in controlling vehicular speeds, however it is generally not desirable to provide excessive levels of superelevation in urban areas. Consequently, there is a need to provide sharper horizontal curves that do not have the benefit of high levels of superelevation to counteract the centrifugal force.

The American Association of State Highway and Transportation Officials guidance document '*A Policy on Geometric Design of Highways and Streets*' (the 'Green Book') recommends that, on low speed urban streets, where drivers have developed a higher threshold for discomfort through conditioning, the centrifugal force should be balanced by the side friction factor so long as this value is less than the maximum allowable for the Design Speed and the curvature of the alignment.[7]

7 *A Policy on Geometric Design of Highways and Streets, 4th Edition, AASHTO, 2001, p. 193*

The Green Book also offers a means of determining values for the maximum allowable side friction factor, F, for low speed urban streets that are based on a tolerable level of discomfort and a reasonable margin of safety against skidding under normal driving conditions. Values of F taken from Exhibit 3-39 of the Green Book[8] are used in conjunction with Equation 1 to derive the recommended minimum curve radii provided in *Table 2: Recommended Minimum Curve Radii* below. The minimum curve radii provided in the DMURS cater for 2 sets of circumstances. The first is where the provision of a drainage crossfall results in adverse camber. In this case the minimum radii are determined by substituting the rate of crossfall as a negative value for S in *Equation 1*. The curve radii in Table 2 are based on a crossfall rate of 2.5%.

The second circumstance catered for is where the introduction of radii less than those for '*minimum radius with adverse camber of 2.5%*' is unavoidable. In this case a reasonable level of superelevation may be introduced to eliminate adverse camber and introduce a favourable crossfall. Minimum curve radii for a superelevation rate of 2.5% are also presented in *Table 2*, and may be used in such circumstances.

8 *A Policy on Geometric Design of Highways and Streets, 4th Edition, AASHTO, 2001, Exhibit 3-39*

Horizontal Curves

Design Speed (km/h)	10	20	30	40	50	60
Side Friction Factor (F)	0.300	0.300	0.300	0.25	0.214	0.184
Min. radius with adverse camber of 2.5%	3	11	26	56	104	178
Min. radius with superelevation of 2.5%	3	11	22	46	82	136

Table 2: Recommended Minimum Curve Radii

The curve radii presented in *Table 2* relate to the longitudinal horizontal alignment of a street. Where a designer chooses to introduce sharp changes in direction or horizontal deflections as speed control measures, the radii set out in *Table 2* may not be appropriate. In such circumstances, the proposed features should be designed such that appropriate visibility envelopes are achieved, and the swept paths of vehicles likely to travel through the feature are accommodated.

5. Vertical Alignment

A vertical alignment consists of a series of straight-line gradients that are connected by curves, usually parabolic curves. At changes in gradient along an alignment, vertical curves are introduced such that the appropriate stopping sight distances are achieved, and an adequate level of driver comfort is provided.

Vertical curves can either be in the form of Crest Curves, which occur at the summit of rises, or Sag Curves, which occur at the bottom of dips.

Ordinarily in urban areas where it can be expected that vehicle speeds will reduce in response to changes in alignment, it will be sufficient to design vertical curves such that the minimum Stopping Sight Distance is provided.

5.1 Vertical Crest Curve Design:

At crest curves visibility between a driver and an object can be obstructed by the road surface itself. Crest curves should be designed such that the curvature is sufficient to maintain an adequate stopping sight distance for a driver. As vertical curves are parabolic, and the height of the curve is determined by the tangential gradients connected to it, the length of the curve, L, is the critical parameter for design.

There are 2 possible scenarios to consider when estimating the minimum length, L_m, of a crest curve. The first is where the required sight distance is contained within the curve length. The second is where the required sight distance extends into the tangents to either side of the crest curve.

The formulae to determine the minimum length of a crest curve for each of these scenarios are:[9]

Equation 4: $L_m = AS^2/(\sqrt{2H_1} + \sqrt{2H_2})^2$ (Where $S \leq L$)

And

Equation 5: $L_m = 2S - 2(\sqrt{H_1} + \sqrt{H_2})^2/A^2$ (Where $S > L$)

9 *M. Rogers, Highway Engineering, Blackwell Publishing, 2003, p. 184*

Where:

L_m= Minimum Curve Length (m)
S = Stopping Sight Distance (m)
A = The algebraic change in gradient
H_1 = Driver eye height (m)
H_2 = Object height (m)

The first crest curve equation above results in a linear relationship between the length of a curve, L, and the algebraic change in gradient, A. This linear relationship allows the computation of curve lengths to be simplified by introducing a constant of curvature, K, where:

Equation 6: $K = L/A$

Therefore the length of a curve is given by:

Equation 7: $L = KA$

However, due to the reduced Stopping Sight Distances and Design Speeds provided in the DMURS, most circumstances will require curve length to be computed using the second equation. This results in a non-linear relationship between curve length and difference in gradient, as illustrated in *Figure 5: Vertical Crest Curve Lengths*.

A single constant of curvature, K, suitable for all values of A for a given design speed step is therefore not readily identifiable. However, using the equations above to determine a curve length from first principles for each vertical curve a designer might encounter would be a cumbersome exercise, therefore the process to determine an appropriate curve length has been simplified.

From Figure 5 it can be seen that there are a significant number of negative results for curve length. This suggests that, due to the reduced Stopping Sight Distances used in the DMURS, forward visibility for a driver will not be obstructed by the road surface at certain values of A for each Design Speed, and these data points can be eliminated from further consideration. Furthermore, excessive changes in gradient tend to be uncommon in urban areas, and it is reasonable to restrict the data to cover the majority of circumstances that designers are likely to encounter, and values for the algebraic change in gradient, A, above 12% have therefore also been eliminated, resulting in the plot shown in *Figure 6: Vertical Crest Curve Lengths - Reduced Dataset.*

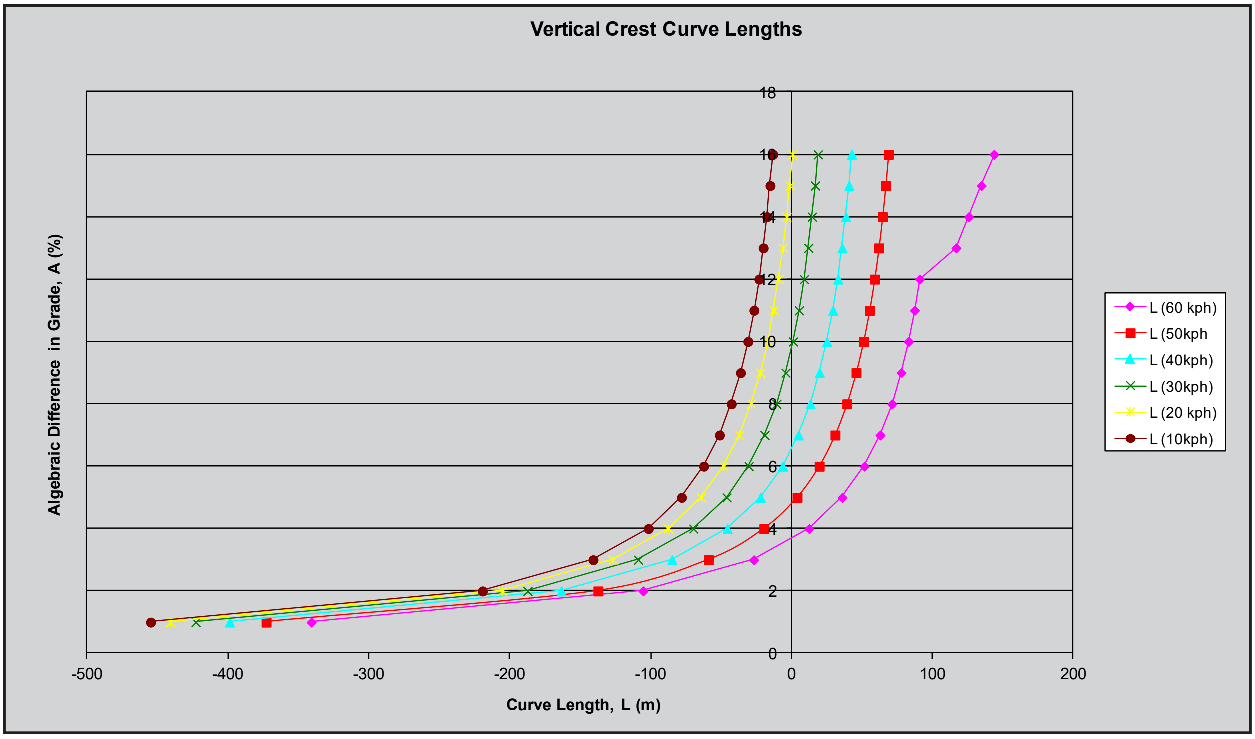

Figure 5: Vertical Crest Curve Lengths

Curve lengths for the 30 kph design speed have been disregarded in *Figure* 6 as they are so short as to be impractical and do not require a specific design.

Plots of the best-fit lines through both the origin and the remaining data points in the reduced dataset illustrated in Figure 6 represent reasonable approximations of the value of the relationship between curve length, L, and change in gradient, A, for each design speed step. Where the lines diverge from the data points at lower values of A they err conservatively in that a larger value of L would be returned for a given value of A.

A set of K-values can be determined from the slope of the best-fit line for each design speed step, and these K-values are presented in Table 3. These values can be substituted into Equation 7 to compute appropriate curve lengths.

5.2 Vertical Sag Curve Design:

When designing vertical sag curves, there are 3 potential design parameters that need to be considered:

- Driver Comfort
- Clearance from Structures
- Night-time Conditions

The minimum sag curve length is therefore the longest of the curve lengths required to satisfy each of these parameters, where they are applicable. However, most urban streets tend to be lit, and structures that could obstruct forward visibility in the vertical plane tend to be uncommon in urban areas, therefore the vertical sag curve K-values presented in the DMURS are derived based on the driver comfort criterion.

The following formula is used to determine the required sag curve length where comfort is taken as the primary design criterion:[10]

Equation 8: $L = V^2A/3.9$

10 *M. Rogers, Highway Engineering, Blackwell Publishing, 2003, p. 189*

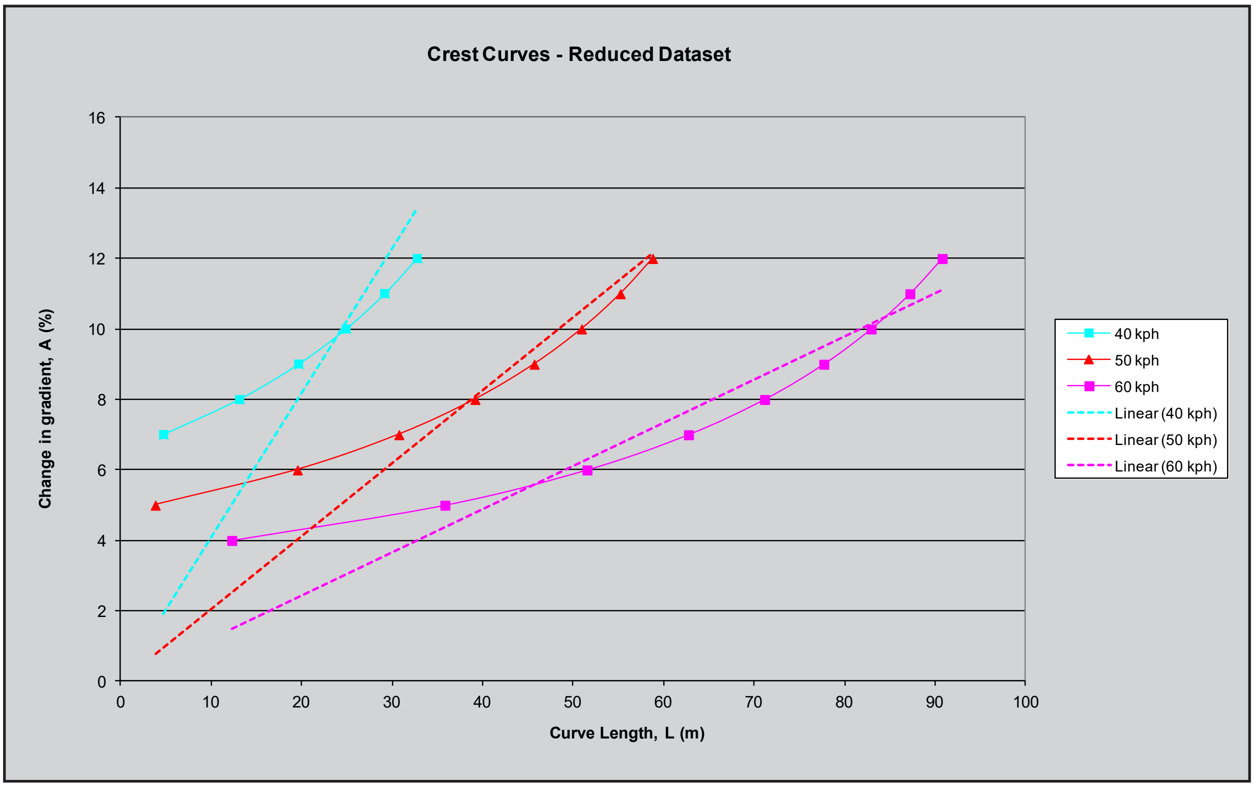

Figure 6: Vertical Crest Curve Lengths - Reduced Dataset

Where:

L = Required sag curve length (m)
V = Vehicle speed (km/h)
A = the algebraic change in gradient expressed as a percentage.

Passengers are more sensitive to changes in vertical direction at sag curves than crest curves as the centripetal force experienced by passengers acts in the opposite direction to gravity. It is generally accepted that comfort is not unduly affected when vertical radial acceleration does not exceed 0.3 m/s^2,[11] and this values is assumed in *Equation 8*. This VRA is also used to determine sag curve values for '*1 Design Speed step below Desirable Minimum*' within the DMRB,[12] so sag curves based on this parameter will not be unfamiliar to drivers and passengers.

This formula in *Equation 8* represents a linear relationship between algebraic difference in gradient, A, and the curve length, L, as illustrated in *Figure 7: Sag Crest Curves.*

As with crest curves, the slopes of these lines represent the relationship between the algebraic difference in gradient, A, and curve length, and are used to determine an appropriate K-value for each design speed step, which can then be used in *Equation 7* to determine the length of a sag curve. Sag curve K-values are presented in *Table 3*.

5.3 Maximum and Minimum Gradients:

In urban areas, it is likely that the comfort of vulnerable road users will be the determining factor for desirable maximum longitudinal gradients on streets. Part M of the building regulations advises that access routes with a gradient of 1:20 or less are preferred. Therefore, in general, streets should be designed to have a maximum gradient of 5%

Where the topography, or other circumstances make this difficult to achieve, a gradient of 8.3% should be considered as a practical maximum (unless alternative measures are implemented). This corresponds to the maximum gradient that most wheelchair users can negotiate.

11 *A Policy on Geometric Design of Highways and Streets, 4th Edition, AASHTO, 2001, p. 279*
12 *NRA TD 9/12, Paragraph 4.7*

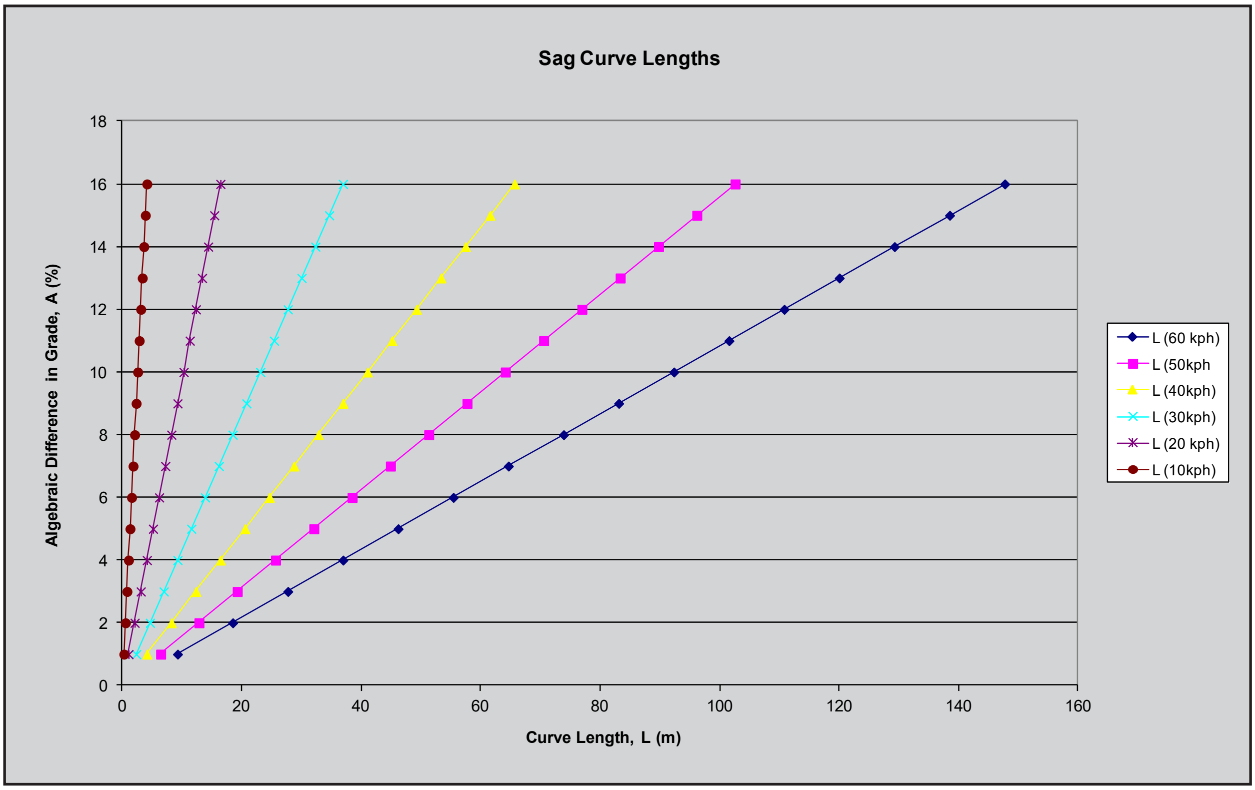

Figure 7: Sag Crest Curves

In these circumstances, the designer may need to consider including mitigation measures, such as intermediate landings, to ensure that pedestrian routes are accessible.

A minimum longitudinal gradient of 0.5% is desirable to maintain effective drainage on streets. Care needs to be taken at vertical curves, and in particular at sag curves, to ensure that there is provision at level points of curves to allow surface water to run off the carriageway.

VERTICAL CURVATURE						
Design Speed (km/h)	**10**	**20**	**30**	**40**	**50**	**60**
Crest Curve K Value	N/A	N/A	N/A	2.6	4.7	8.2
Sag Curve K Value	N/A	N/A	2.3	4.1	6.4	9.2

Table 3: Vertical Curve K-Values

6. References

1. Rogers, M., *Highway Engineering,* Blackwell Publishing, 2001.

2. *A Policy on Geometric Design of Highways and Streets*, 4th Edition, American Association of State Highways and Transportation Officials, 2001.

3. NRA TD 9/12 (NRA DMRB 6.1.1) – Road Link Design, National Roads Authority, 2012

4. Department for Transport (UK), *Manual for Streets,* Thomas Telford Publishing, 2007.

5. *Manual for Streets 2 – Wider Application of the Principles*, The Chartered Institution of Highways and Transportation, 2010.

6. York, I. et al, *TRL Report 661 – The Manual for Streets: evidence and research*, Transport Research Laboratory, 2007.

7. Maycock, G., PJ Brockelbank and RD Hall, *TRL Report 332 – Road layout design standards and driver behaviour*, Transport Research Laboratory, 1998.

8. Building Regulations 2010, Technical Guidance Document M, *Access and Use*, The Stationary Office, 2010.