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TIS ROMA 2019

INTERNATIONAL CONGRESS ON TRANSPORT INFRASTRUCTURE AND SYSTEMS IN A CHANGING WORLD

Road Geometric Design

Crest Vertical Curvature Safety Assessment through Variable Grade Stopping Sight Distance Control

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Stopping Sight Distance (SSD)

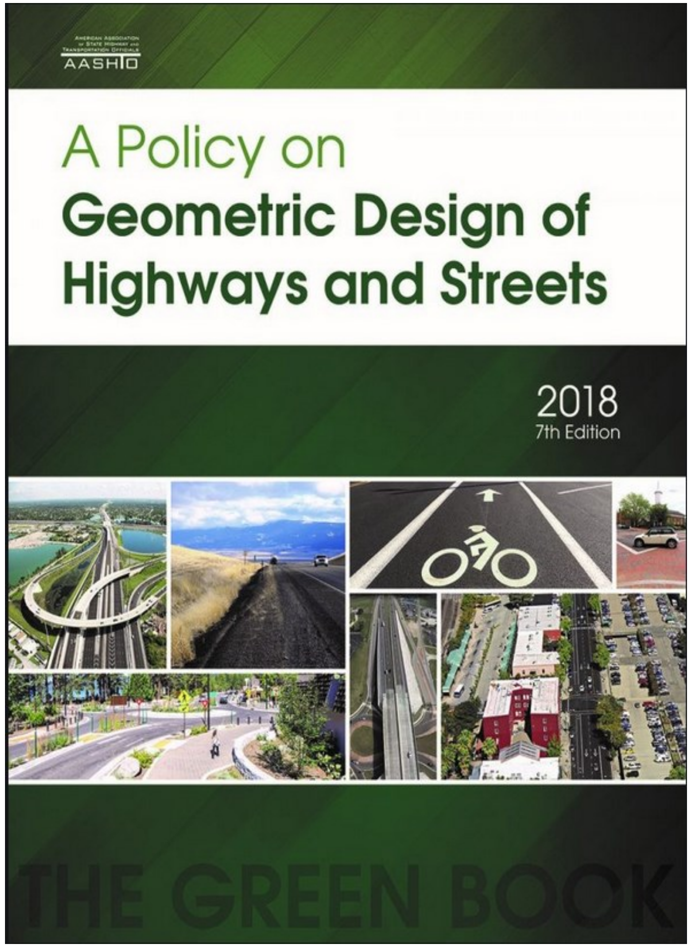
Highway Geometric Design Element
of Fundamental Importance

- Must be provided at every point along the road surface
- Affects critical road design parameters (e.g. vertical curvature)
  - imposes economic considerations on new road designs and road improvement projects

Grade Impact in SSD Calculation

Based on AASHTO's Design Guide (Green Book)

- Significant difference in SSD between upgrades and downgrades
- Regarding vertical curves, the grade effect is somewhat balanced
  - no need to adjust SSD due to grade
- Moreover (Green Book):
  ...minimum lengths of crest vertical curves,
  based on sight distance criteria,
  generally are satisfactory from the standpoint
  of safety, comfort and appearance



⟶ *vertical curvature rate is adequately determined through the suggested control values*

Research Objective

Investigate the Sufficiency of the Suggested Crest Vertical Curvature Rates (CVCR) from the Grade Control Point of View

- 3 assessed road design guidelines
  - AASHTO (2018)
  - OMOE-X (2001)
  - DM n.6792 (2001)

Current SSD Determination

$$SSD = \frac{V_o t_{pr}}{3.6} + \frac{1}{3.6^2 g}\int_{V_o}^{0} \frac{V}{\frac{s}{100} + f_T + \frac{A_d}{mg}} dV$$

SSD (m): stopping sight distance
V_o (km/h): vehicle initial speed
t_{pr} (sec): driver's perception – reaction time [2.5sec (AASHTO), 2.0sec (OMOE-X), 2.8-0.01V_o (DM, n.6792)]
f_T : upper limit of longitudinal friction engaged for braking
A_d (N): vehicle drag resistance
m (kgr): vehicle mass
s (%): road grade [(+) upgrades, (-) downgrades]
g (m/sec^2): gravitational constant [9.81m/sec^2]

Current SSD Determination

AASHTO (2018)

$$SSD = \frac{V_o t_{pr}}{3.6} + \frac{1}{3.6^2 g}\int_{V_o}^{0} \frac{V}{\frac{s}{100} + \boxed{f_T + \frac{A_d}{mg}}} dV$$

$$SSD = \frac{V_o t_{pr}}{3.6} + \frac{V_o{}^2}{2\ 3.6^2 g(\frac{s}{100} + \boxed{\frac{a_{average}}{g}})}$$

$a_{average}$ (m/sec^2): average vehicle deceleration rate [$3.4m/sec^2 = 0.35g$]

Current SSD Determination

OMOE-X (2001) and DM, n.6792 (2001)

$$SSD = \frac{V_o t_{pr}}{3.6} + \frac{1}{3.6^2 g}\int_{V_o}^{0} \frac{V}{\frac{s}{100} + \boxed{f_T + \frac{A_d}{mg}}} dV$$

Design Guideline	A_d / mg (Formula)	A_d / mg			$a_{average}$ (m/sec^2)		
		80km/h	100km/h	120km/h	80km/h	100km/h	120km/h
OMOE-X (2001) Motorways & Rural Arterials	$2.52\ 10^{-6}\ V_o^2$ (V_o: km/h)	0.02	0.03	0.04	0.39g	0.35g	0.32g
DM, n.6792 (2001) Motorways	$2.66\ 10^{-6}\ V_o^2$ (V_o: km/h)	0.02	0.03	0.04	0.51g	0.49g	0.46g
DM, n.6792 (2001) Rural Arterials					0.39g	0.34g	0.31g

Current CVCR Determination

$$L = \frac{(s_2 - s_1)SSD^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$ SSD≤L

$$L = 2SSD - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{s_2 - s_1}$$ SSD>L

$$H_K = \frac{100L}{s_2 - s_1}$$

$$\mathbf{H_K = \frac{SSD^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}}$$

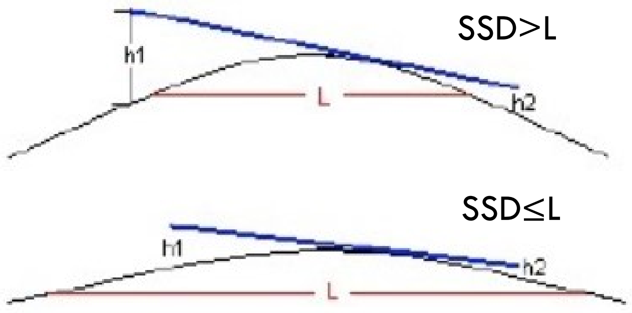
H_K (m): crest vertical curvature rate

L (m): length of vertical curve

h_1 (m): driver eye height [1.08m (AASHTO), 1.06m (OMOE-X), 1.10m (DM, n.6792)]

h_2 (m): object height (m) [0.60m (AASHTO), SSD tan[(5/60)°] (OMOE-X), 0.10m (DM, n.6792)]

s_1, s_2 (%): grade values



Design Control Values for SSD and CVCR

Design Guideline	SSD (m)			H_K (m)		
	80km/h	100km/h	120km/h	80km/h	100km/h	120km/h
AASHTO (2018) Motorway & Rural Arterial	130	185	250	2600	5200	9500
OMOE-X (2001) Motorway	170	245	290	6200	11000	15000
OMOE-X (2001) Rural Arterial	140	205	-	4500	8500	-
DM, n.6792 (2001) Motorway	95	135	180	2500	4900	8700
DM, n.6792 (2001) Rural Arterial	110	170	240	3300	7800	15500

Braking Calculation On Variable Grades

Suggested Approach

$$V_{i+1} = V_i - g\left(\frac{a_{average}}{g} + s_i\right)t$$

$$SSD = V_o t_{pr} + \sum BD_{k-1}$$

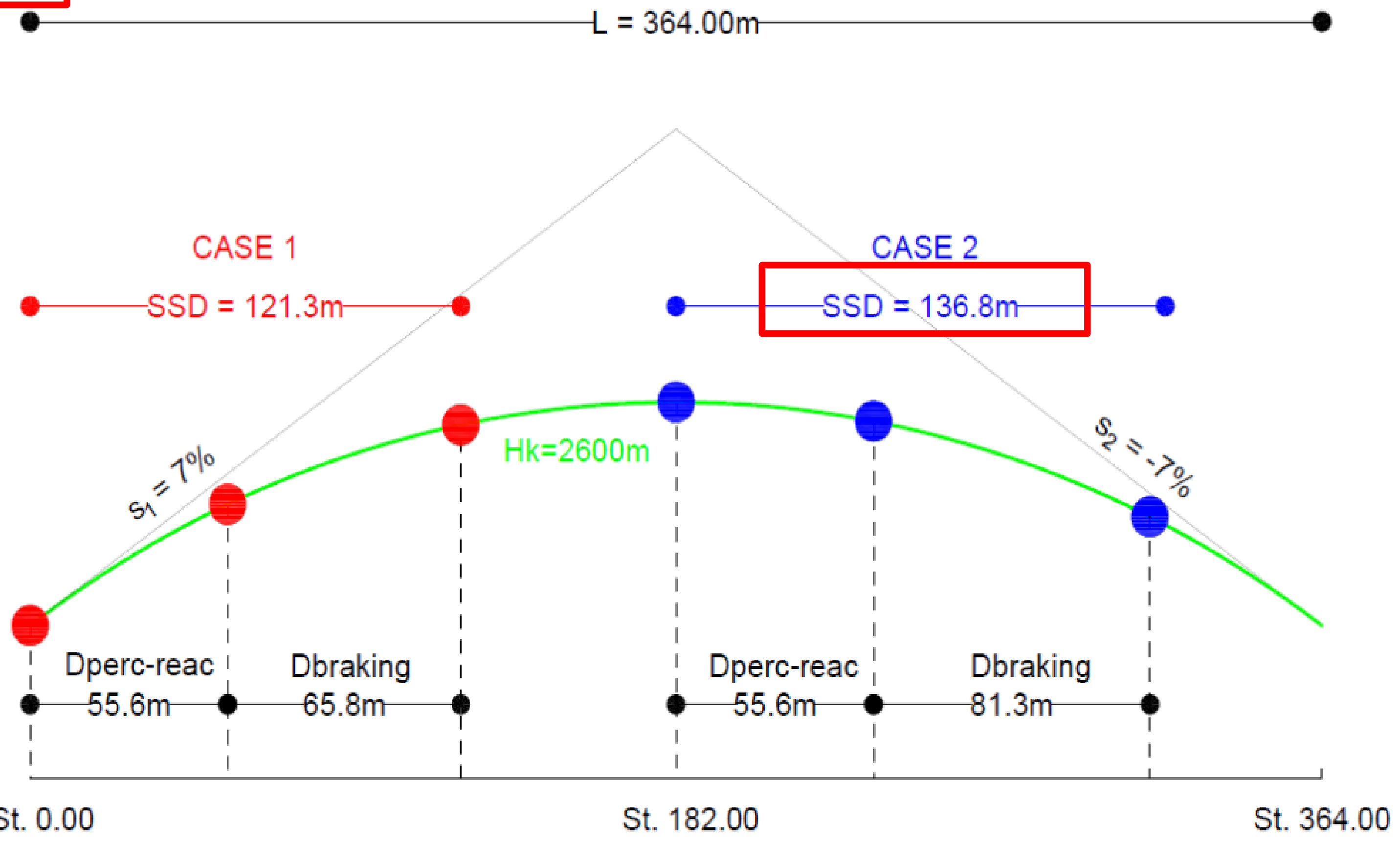
$$BD_i = V_i t - \frac{1}{2} g\left(\frac{a_{average}}{g} + s_i\right)t^2$$

V_i (m/sec): vehicle speed at a specific station i
V_{i+1} (m/sec): vehicle speed reduced by the deceleration rate for t = 0.01sec
t (sec): time fragment (t = 0.01sec)
s_i (%/100) : road grade in i position [(+) upgrades, (-) downgrades]
BD_i (m): pure braking distance
$\sum BD_{k-1}$ (m): total vehicle pure braking distance for the initial value of vehicle speed

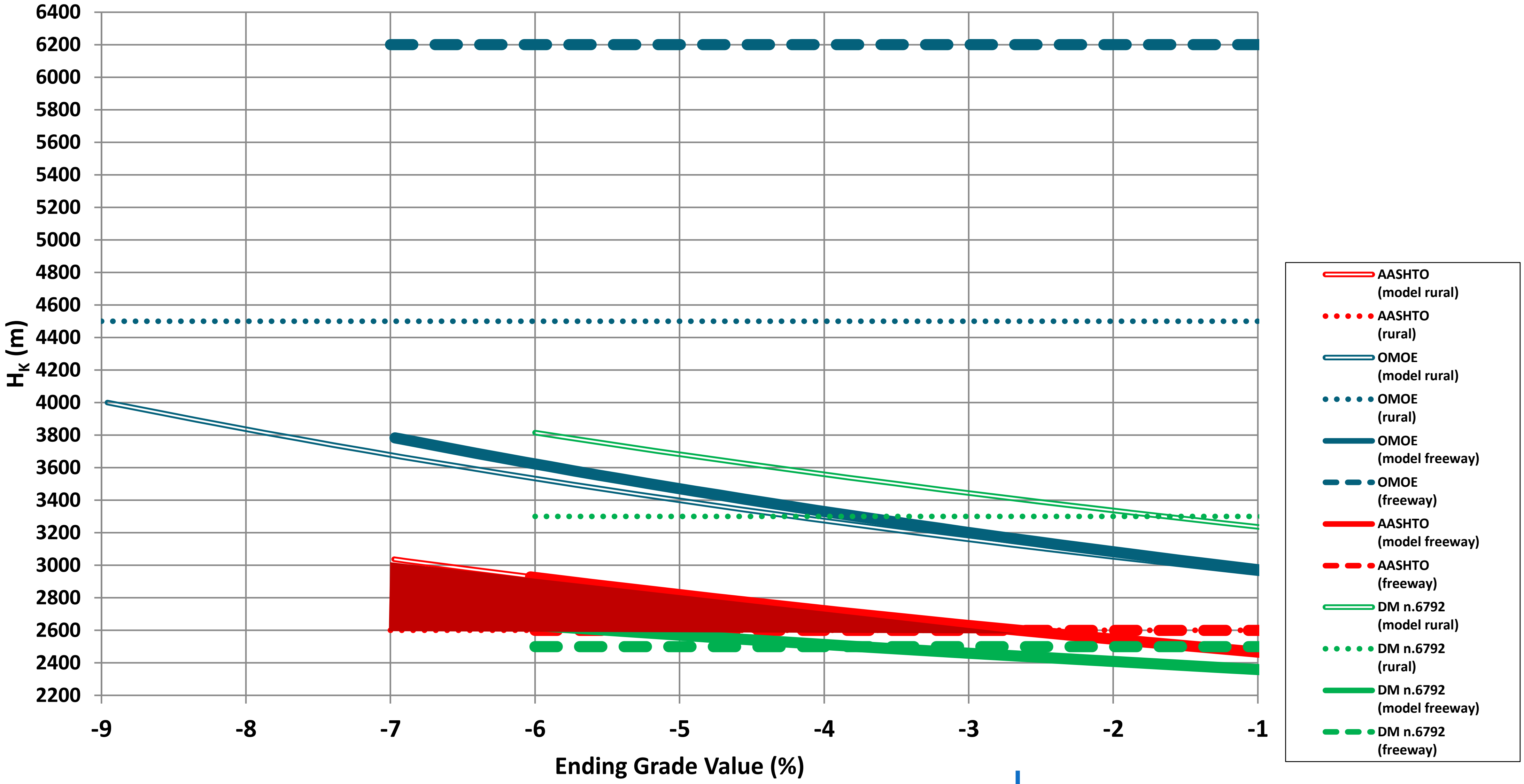
Braking Calculation On Variable Grades

Suggested Approach

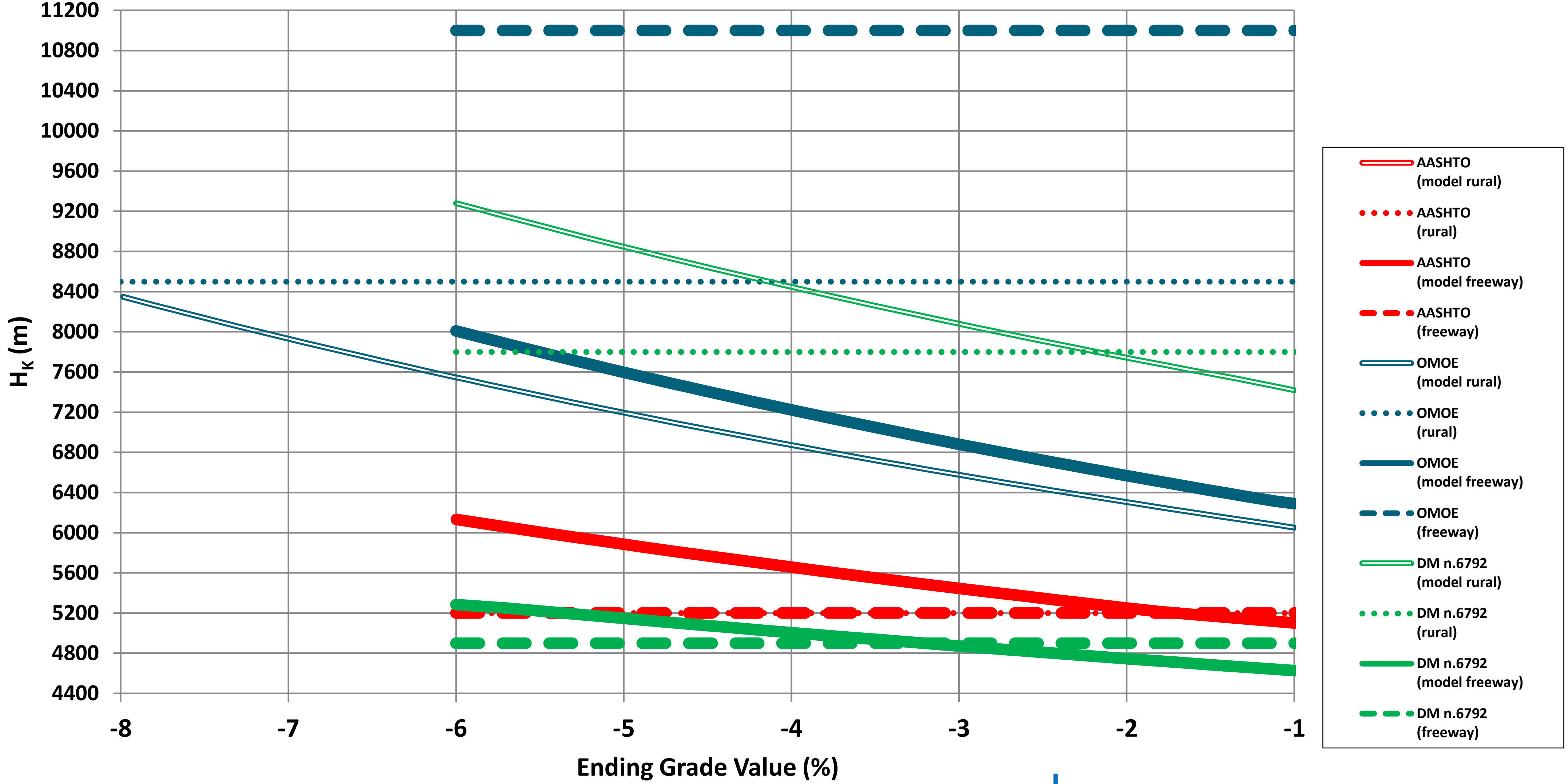
- V=80km/h, SSD=130m, H_K=2600m



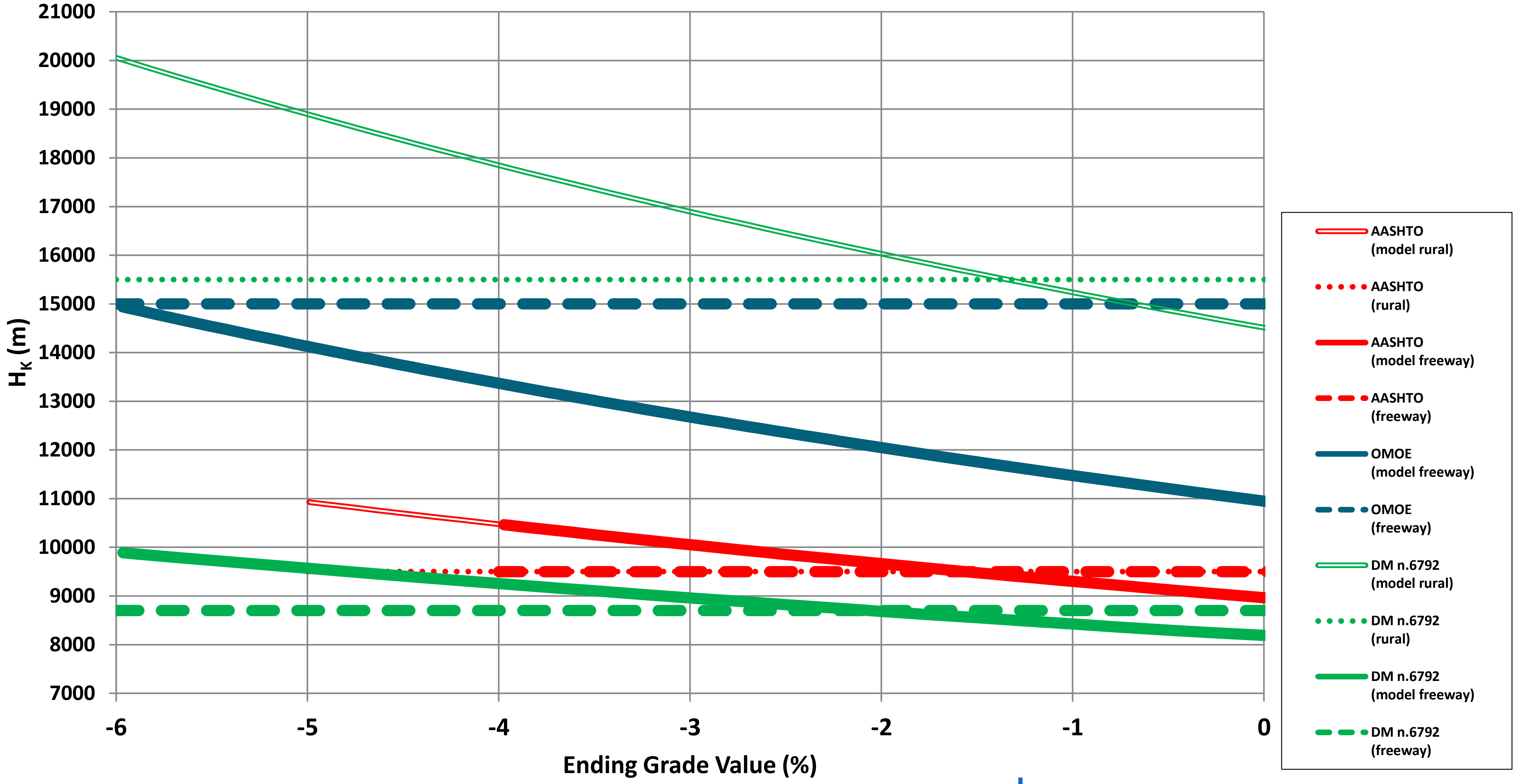
Overall Crest Vertical Curvature Rates (V=80km/h)



Overall Crest Vertical Curvature Rates (V=100km/h)



Overall Crest Vertical Curvature Rates (V=120km/h)



Discussion

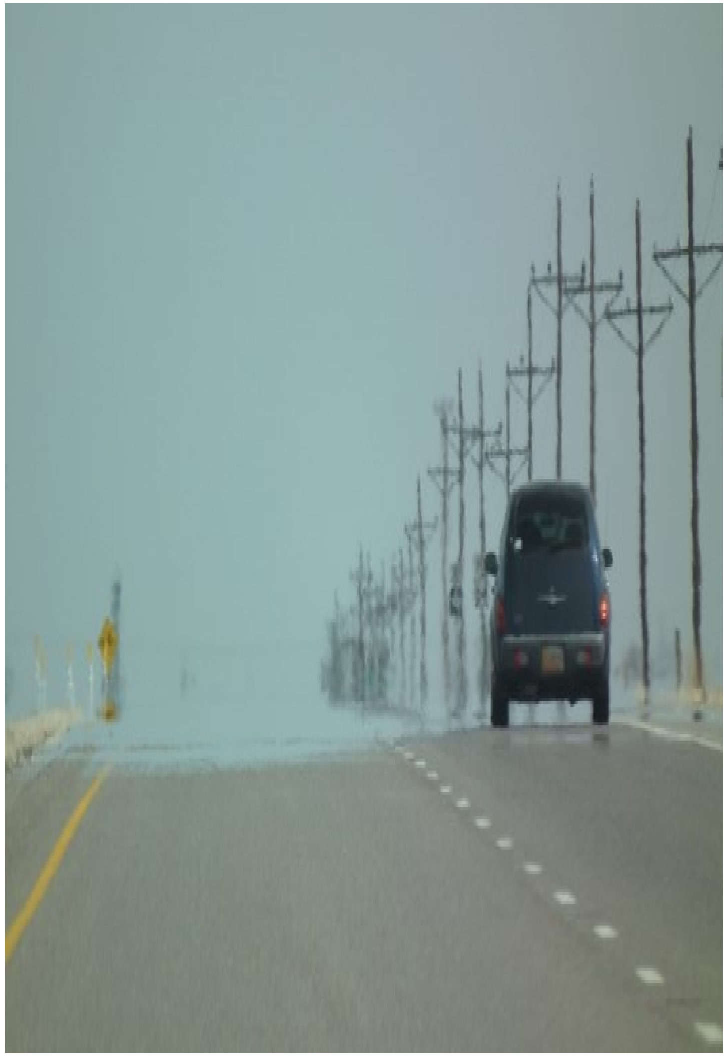
- CVCR safety assessment through variable grade SSD control
  - 3 design guidelines
    - AASHTO (2018)
    - DM, n.6792 (2001)
    - OMOE-X (2001)
  - 3 (high) speed values arterials, freeways)
    - 80km/h
    - 100km/h
    - 120km/h
  - Point mass model
  - Laws of mechanics
  - 2D approach

Conclusions (1/2)

- Greek OMOE-X (2001)
  - Costly overdesigned CVCR adopted

- DM, n.6792 (2001), AASHTO (2018)
  - CVCR inadequacy
    on the downgrade area with s<-2%

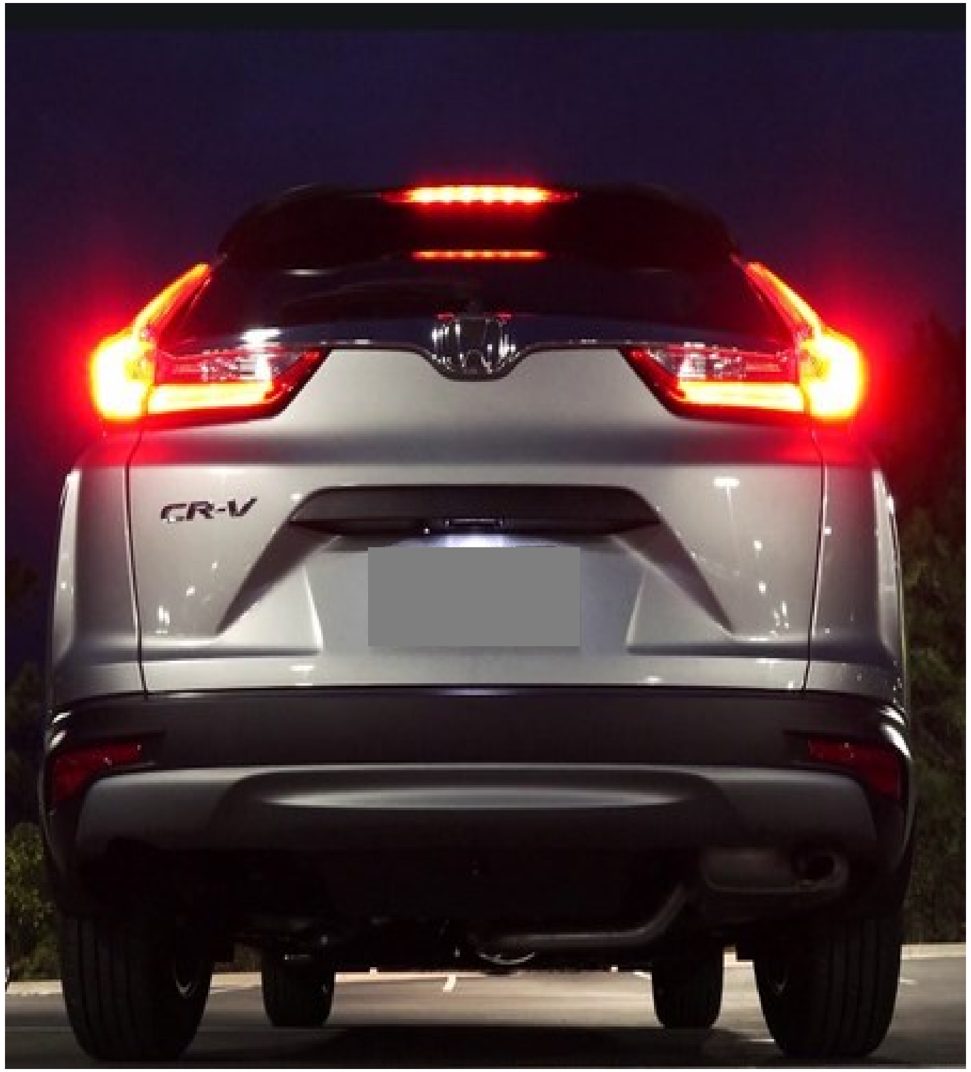
- Amended CVCR,
  in order to grant SSD adequacy
  throughout the braking process
  - Provide designers
    with ready-to-use values



Conclusions

(2/2)

- DM, n.6792 (2001)
  - Increase object height 0.10m → 0.50m
  - Current CVCR adequate for s>-6%



Further Research

- Assess the impact of combined horizontal – vertical alignment
- Additional qualitative research in current vehicle dynamics trends
  - Evaluate parameters of SSD
    - braking on curves
    - ABS braking
    - friction coefficient etc.
- Additional restrictions from human factors

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