MODELING STOPPING SIGHT DISTANCE ON LEFT-TURN CURVES OF FREEWAYS OVERLAPPED WITH CREST VERTICAL CURVES

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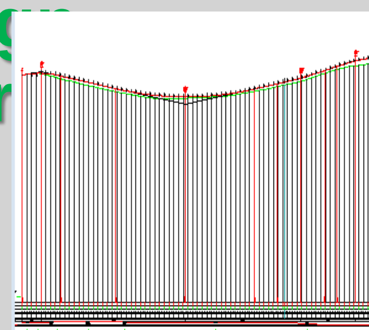
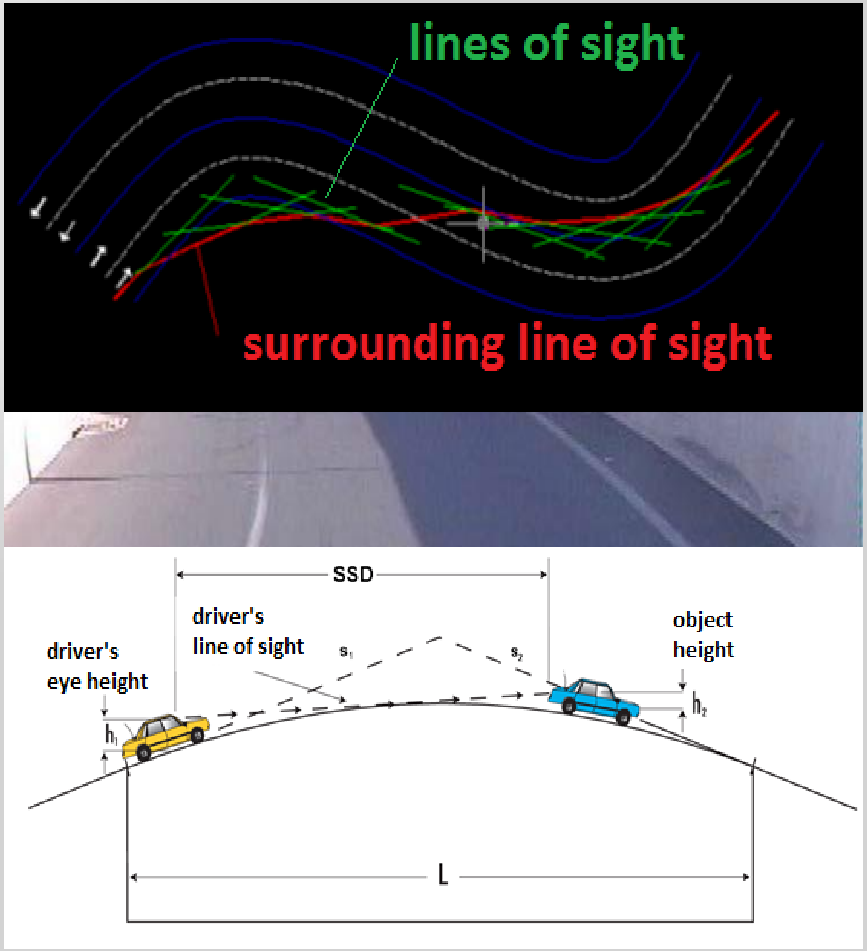
3D Highway Geometry

- 2 Independent and Mostly Uncorrelated 2D Stages
  - horizontal alignment
  - vertical alignment
- 2D Approach Associated with Design Misconceptions that Influence Desig Performance Adver
  - typical case: SSD



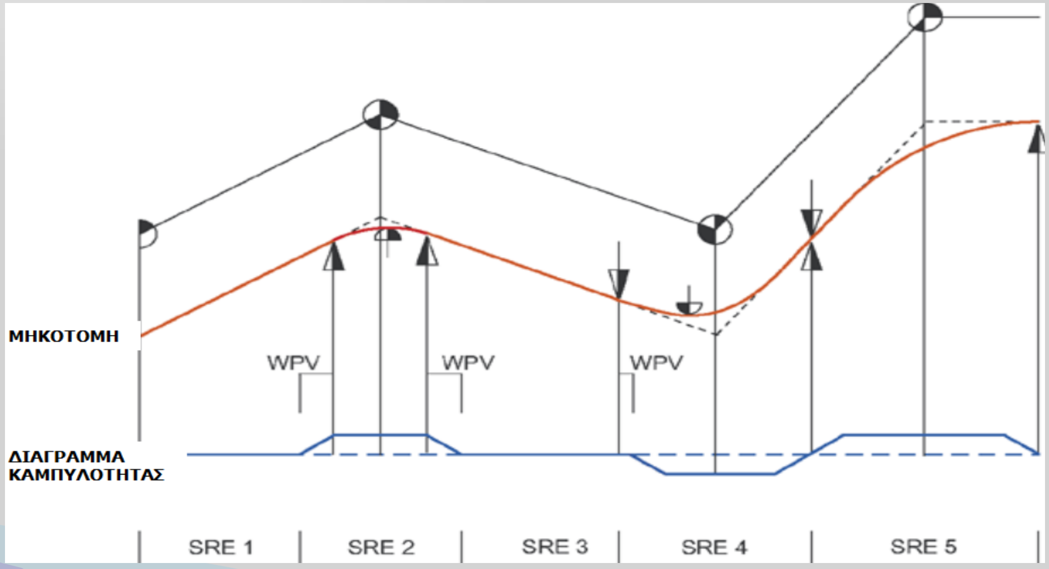
2D SSD Calculation

- Inexact
- Fragmentary
- May Produce Design Deficiencies
- May be Detrimental to Cost, Performance and/or Safety of Divided Highways



Current Practice

- 2D Approach
  - efforts to overcome this incorrect SSD determination
    - ✓ establishing some coordination between the horizontal and vertical curve positioning
  - not all design cases are addressed

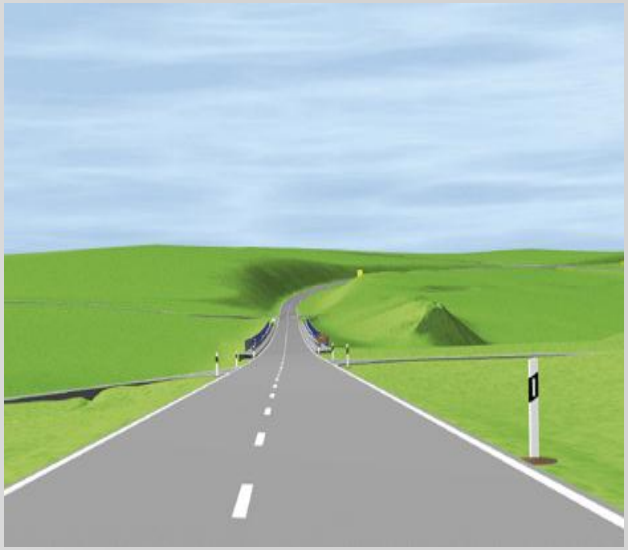


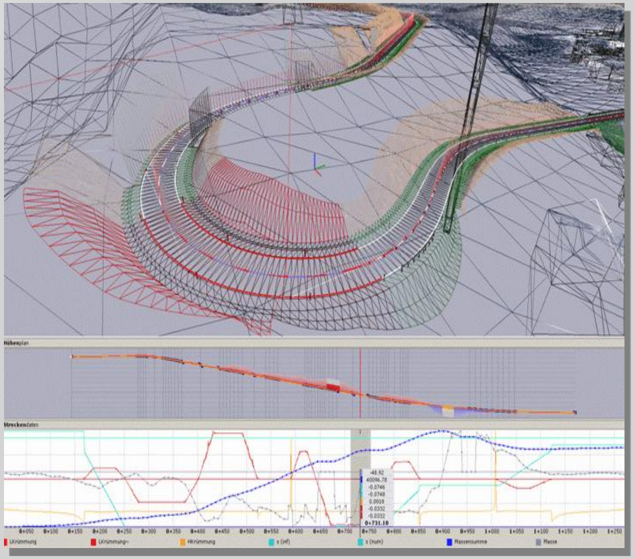
Current Practice on Left Curved Divided Highways

- **Necessity for SSD Adequacy Emphasized**
- **No Explicit Process Provided**
  - $SSD_{AVAILABLE}$ defined by lateral clearance and curve radius
    - ✓ valid for circular curves longer than the sight distance assuming both driver and obstacle positioned on circular curve
    - ✓ no assurance whether barrier height and/or the presence of vertical curve do not obstruct driver’s line of sight

SSD Modeling

- **3D Models**
  - capable of simulating accurately compound road environments (3D)
  - allow the definition of actual vision field to driver (3D)
  - focused in optimizing the available SSD introducing
    - ✓ new algorithms
    - ✓ design parameter combinations





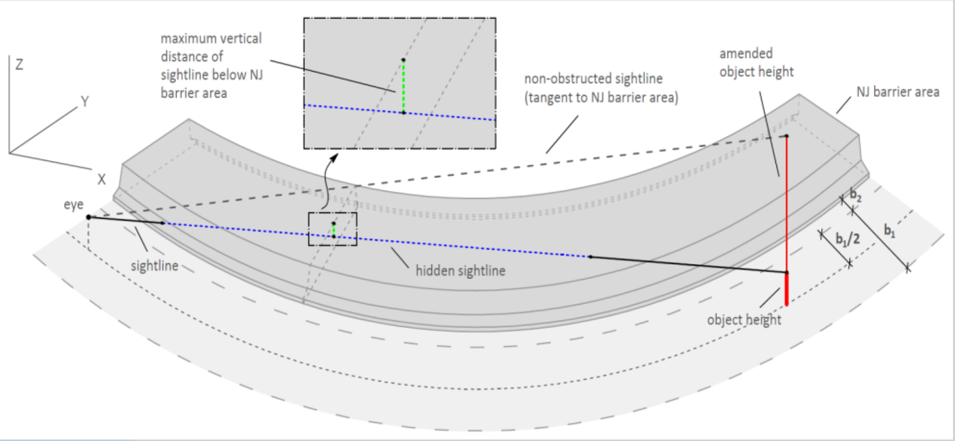
Objectives

- Deliver Reliable Tool for Researchers and Practitioners in terms of SSD Assessments
- Quantify the Safety Impact During Emergency Braking Conditions in Such 3D Roadway Environments
  - identify areas of interrupted vision lines between driver and object
  - examine the interaction of the utilized design parameters
  - estimate the probability of SSD inadequacy
  - predict the additional object height in order to grant SSD adequacy

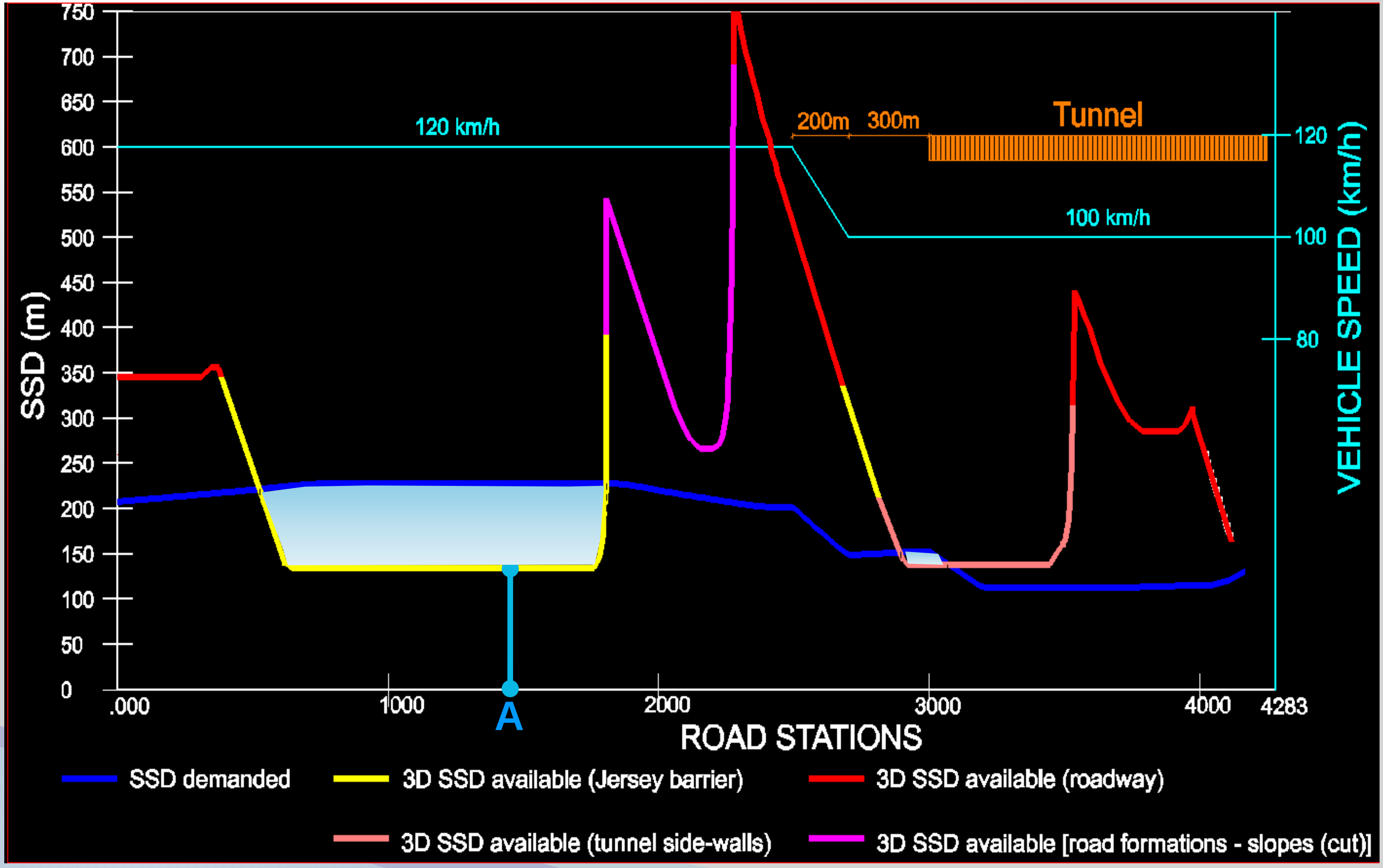
SSD Modeling Proposal

$$SSD_{DEMANDED} \leq SSD_{AVAILABLE}$$

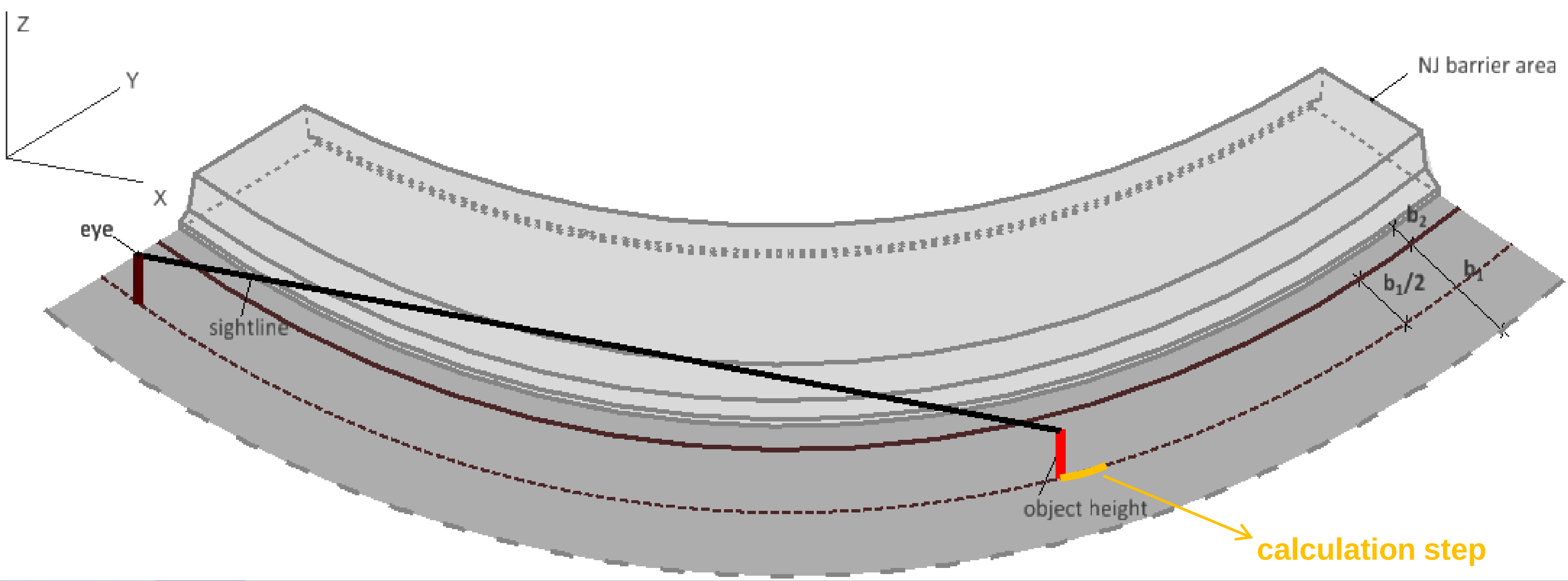
- $SSD_{DEMANDED}$
  - enriched point mass model
    - ✓ actual values of grade (vertical curves)
    - ✓ friction variation (vehicle cornering)
- $SSD_{AVAILABLE}$
  - driver's line of sight towards object height
    - ✓ at certain axis offset
    - ✓ 3D roadway environment



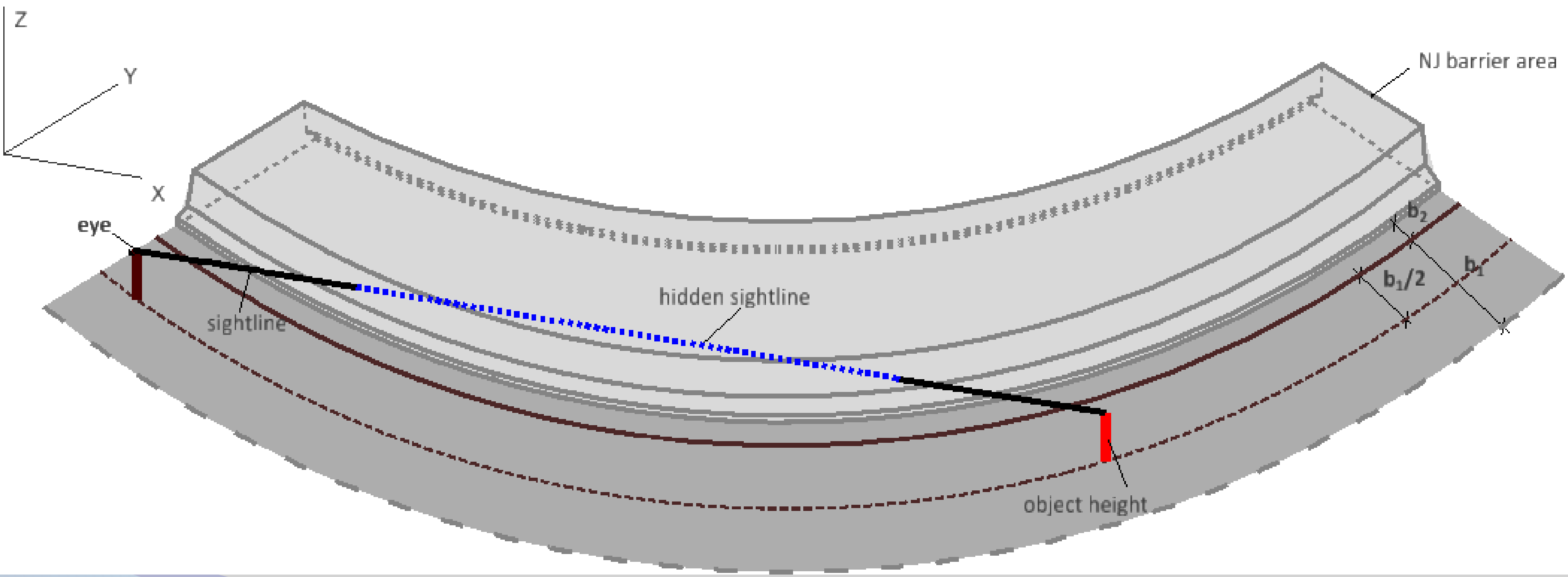
SSD Assessment (existing approach)



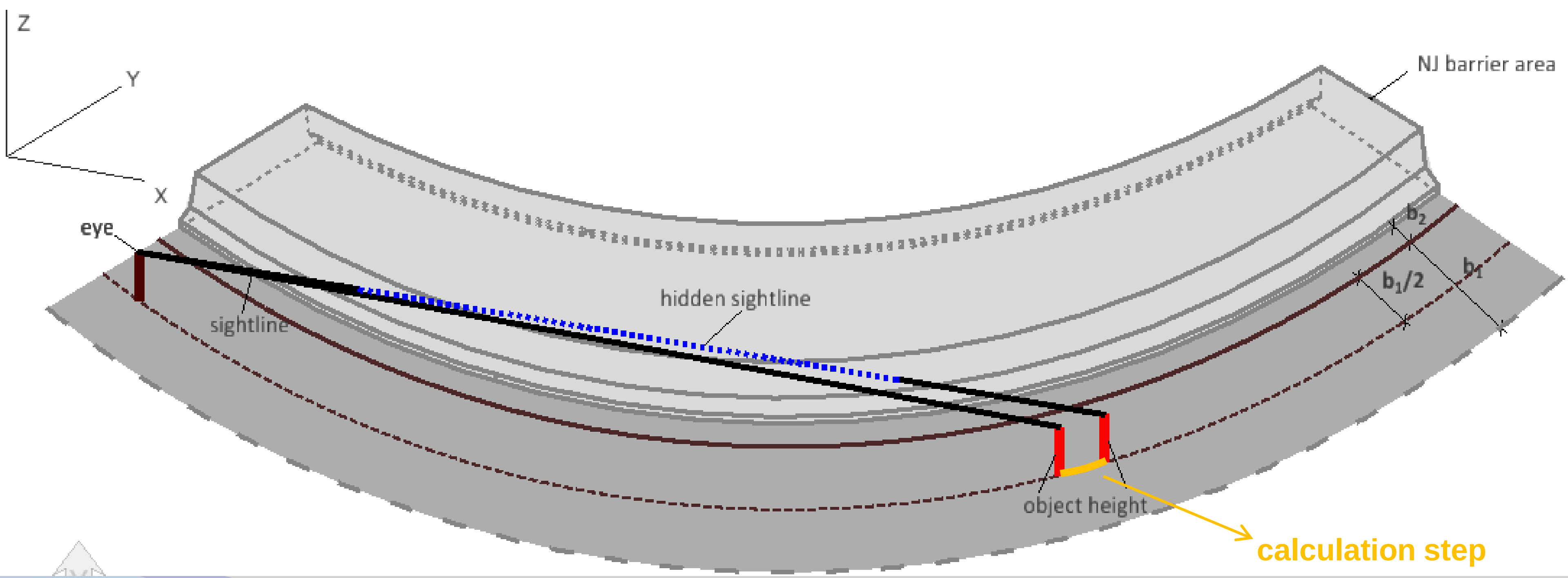
$SSD_{AVAILABLE}$ (Station A)



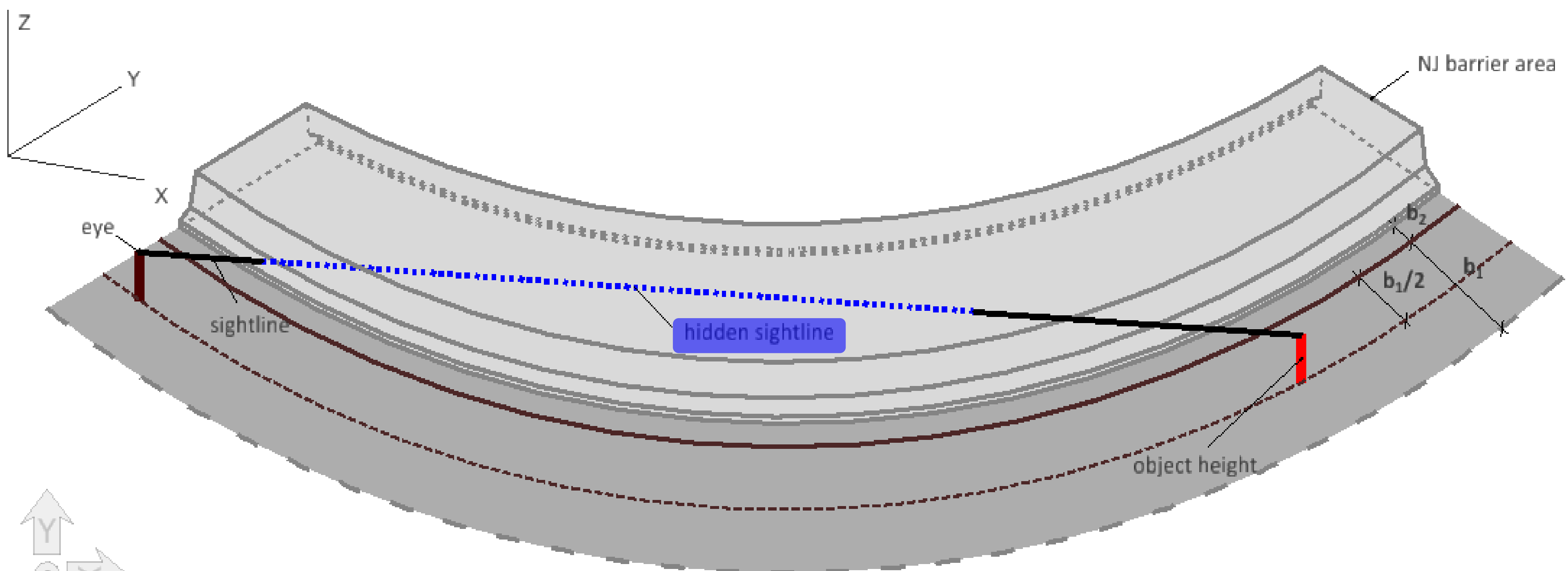
$SSD_{AVAILABLE}$ (Station A)



$SSD_{AVAILABLE}$ (Station A)

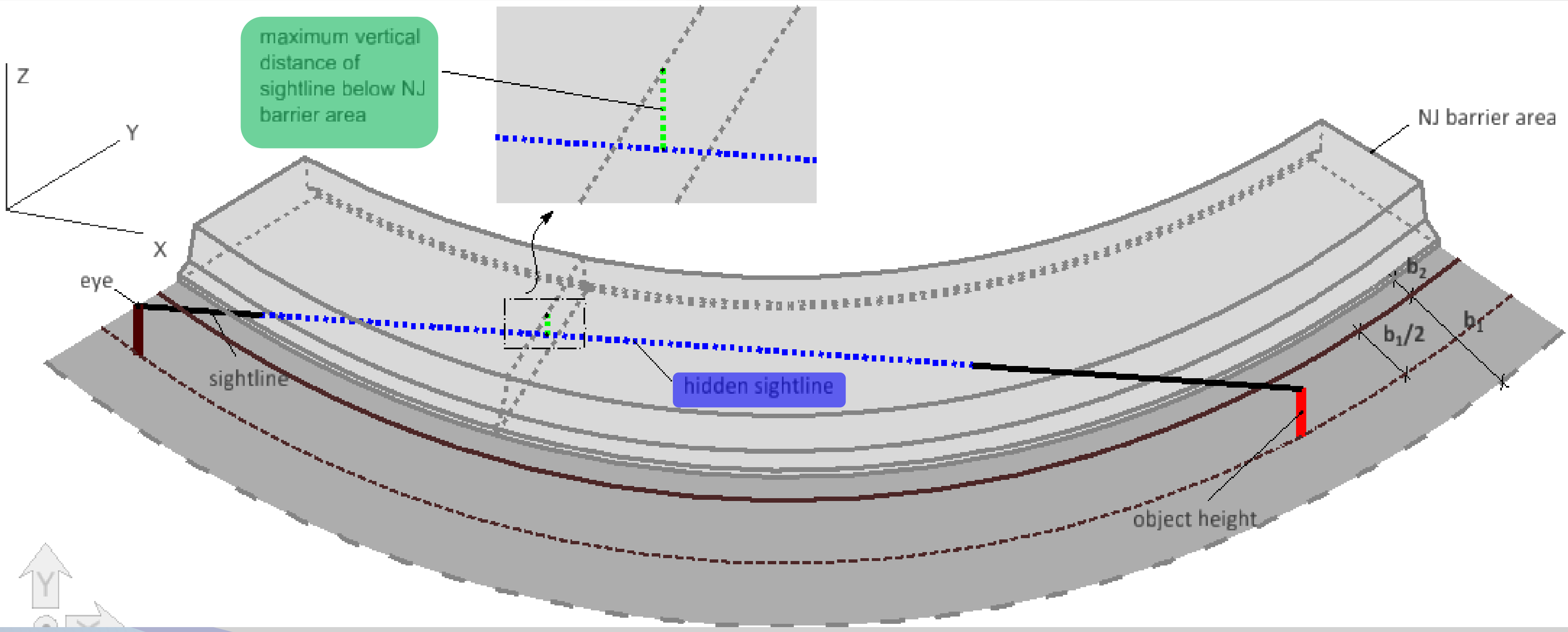


SSD Modeling Proposal (1/3)



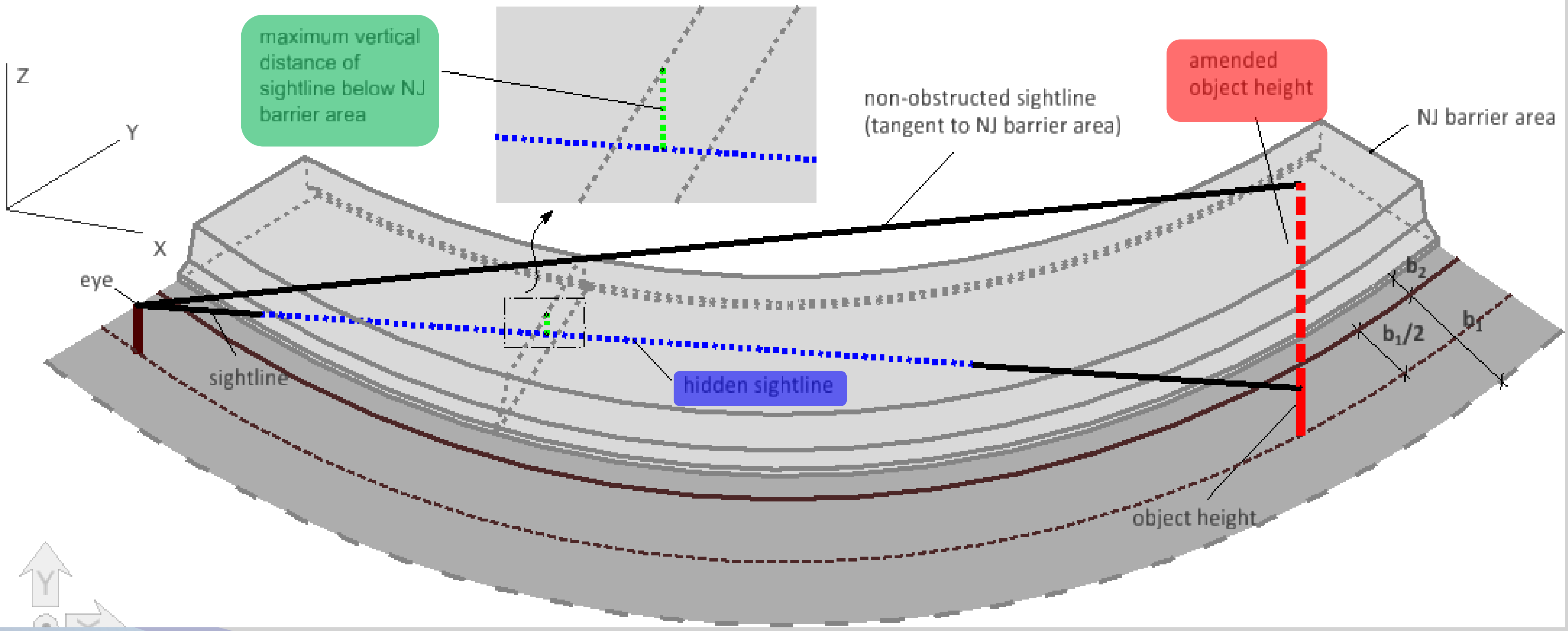
$$SSD_{DEMANDED} = SSD_{AVAILABLE}$$

SSD Modeling Proposal



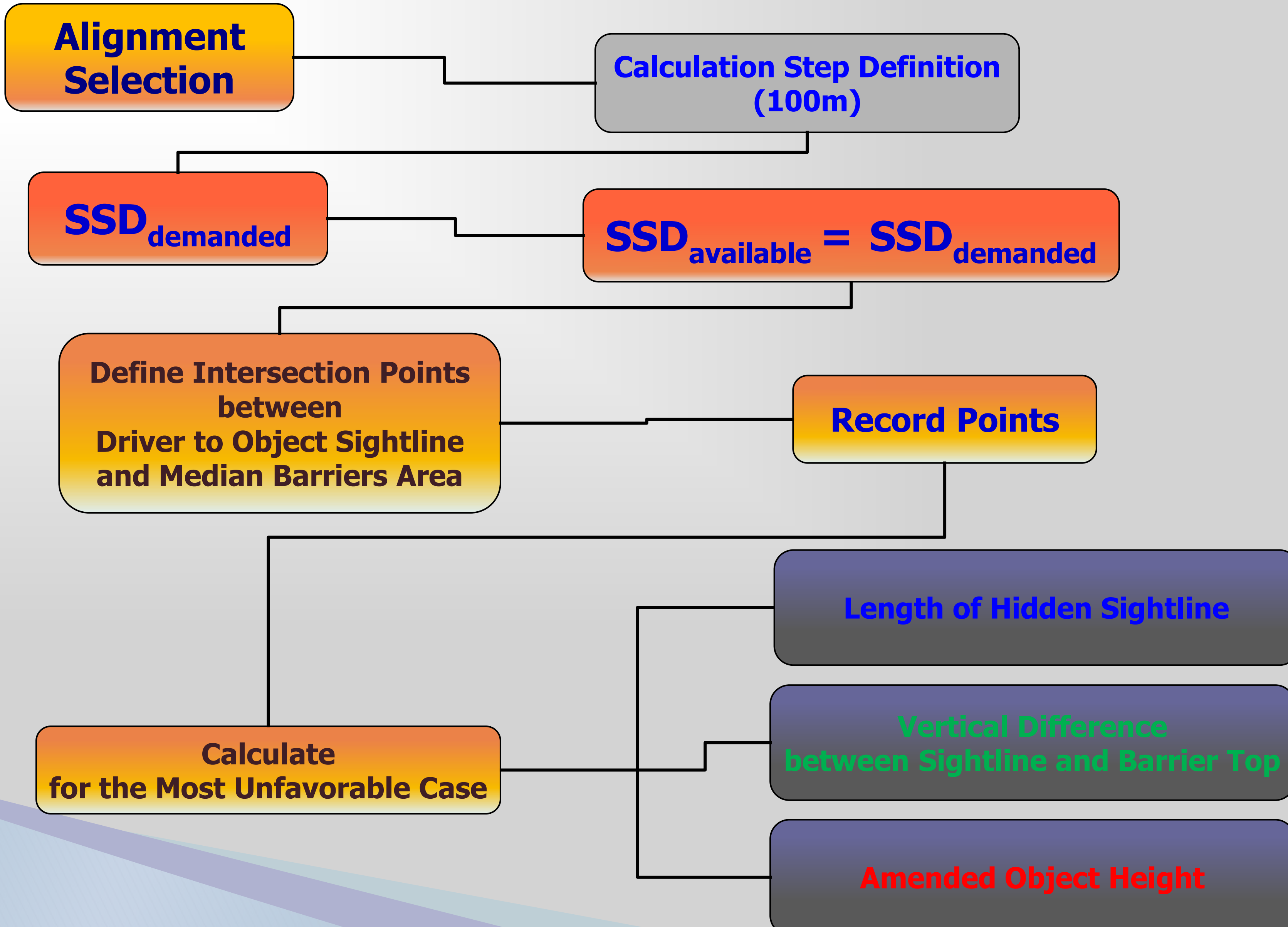
$SSD_{DEMANDED} = SSD_{AVAILABLE}$

SSD Modeling Proposal



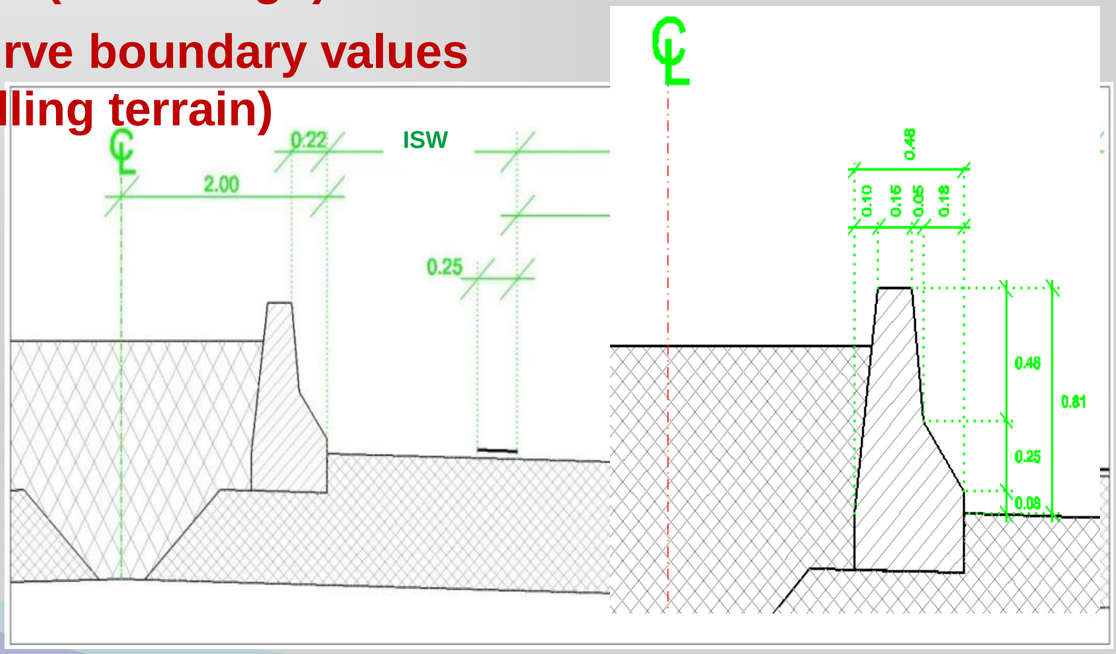
$SSD_{DEMANDED} = SSD_{AVAILABLE}$

SSD Adequacy Investigation

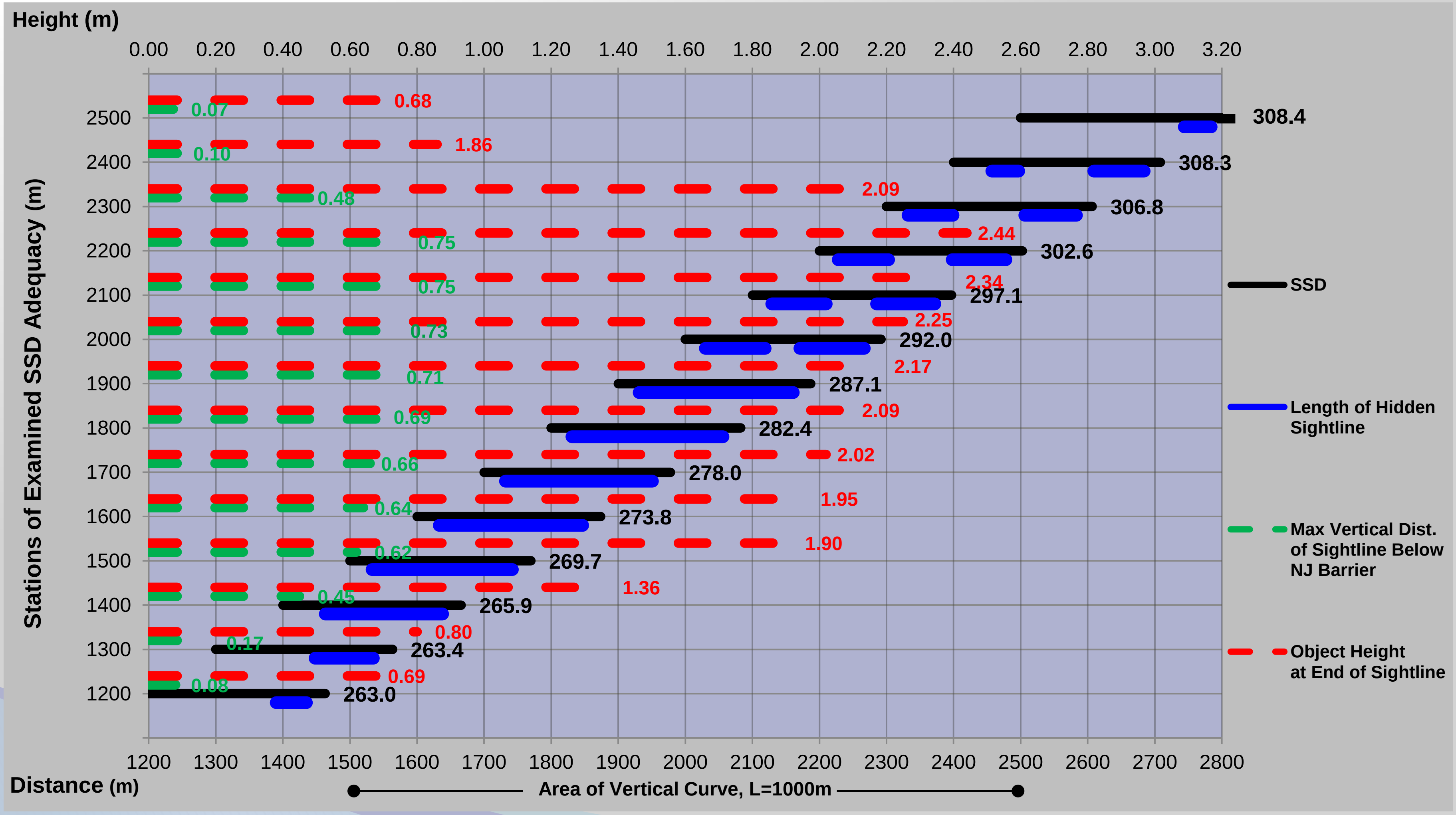


3D SSD Adequacy Investigation on Left Curved Divided Highways

- AASHTO 2011 Design Guidelines
  - V_{design} =130km/h
  - variety of horizontal – vertical parameters
    - ✓ passing lane 3.60m
    - ✓ NJ curvature at top increases by 0.22m
    - ✓ NJ median barrier (0.90m high)
    - ✓ crest vertical curve boundary values +4% and -4% (rolling terrain)

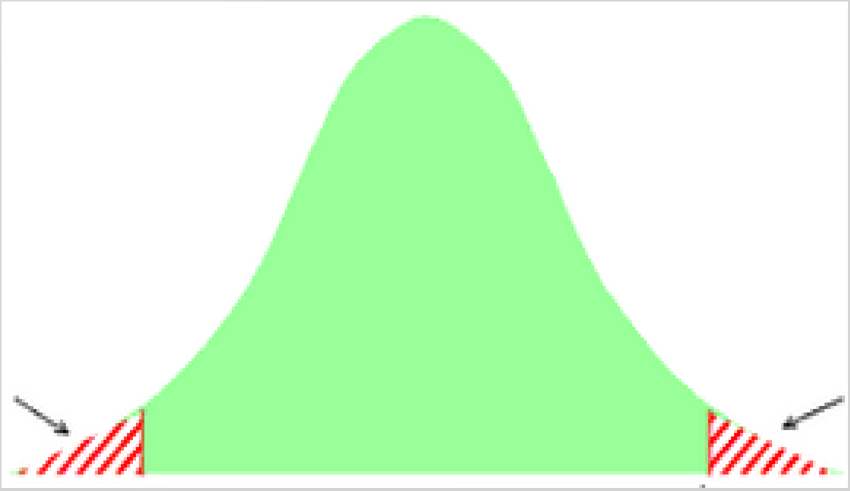


Output Data (R=950m, K=125m, ISW=1.20m)



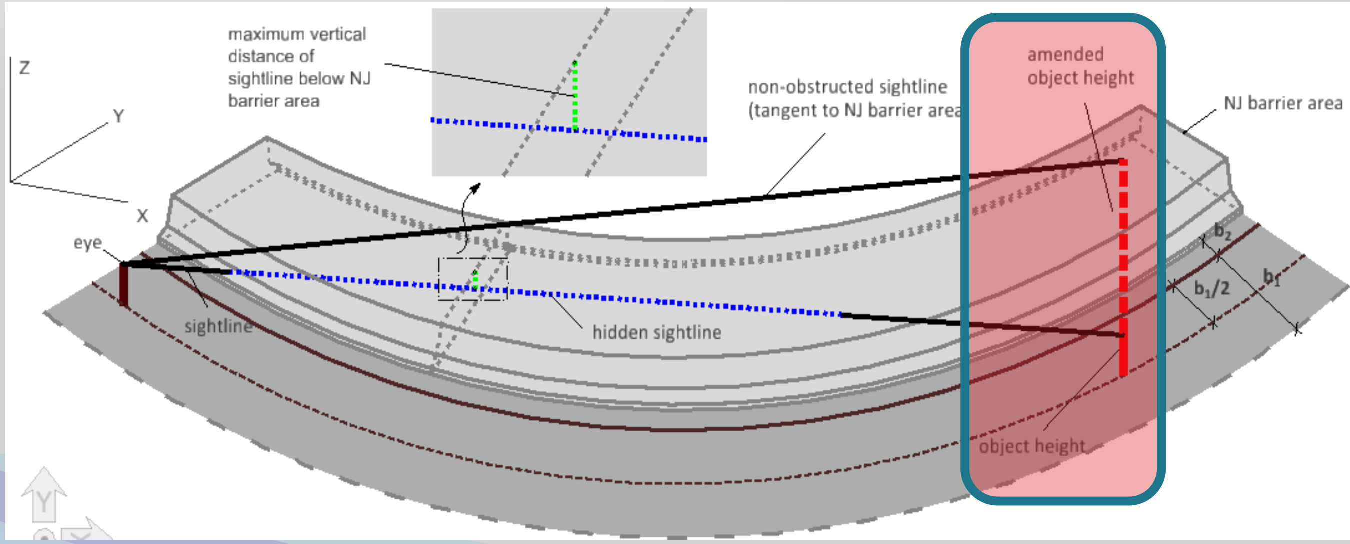
Models Development

- In-depth Analysis
  - individual variables effects
  - interactions
- Identify Statistically Significant Effects
  - model parameters with p-values<0.05



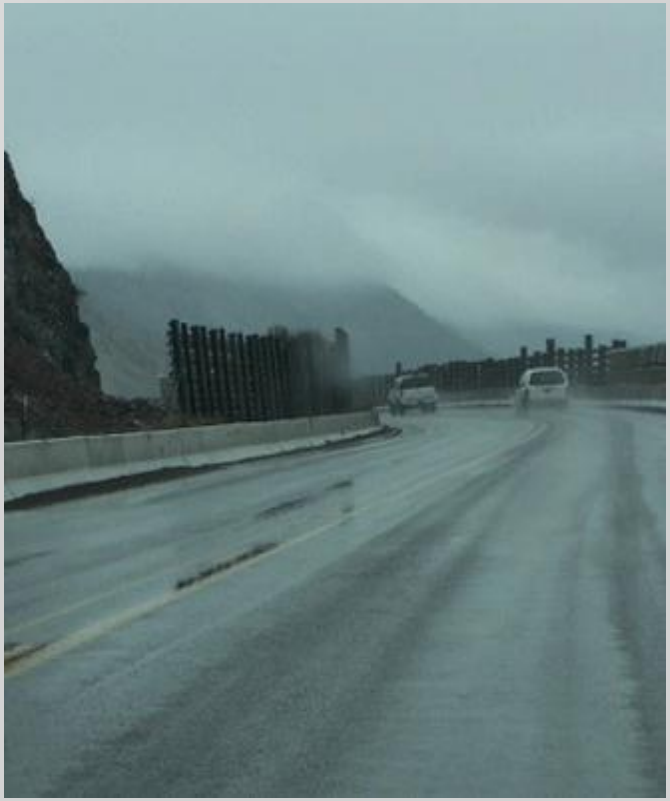
Models Development

- **Probability of SSD Inadequacy**
  - **logistic regression model**
    - ✓ **estimate probability $SSD_{DEMANDED} > SSD_{AVAILABLE}$**
- **Amended Object Height Prediction**
  - **lognormal regression model**



Models Development

- Road Geometry Design Elements Interaction in 3D
- Calculation Step
  - 100m
- Explanatory Variables
  - horizontal curvature (R)
    - ✓ 950m, 1500, 2000m, 2500m, 3000m, 3500m
  - vertical curvature (K)
    - ✓ 125m, 200m, 250m, 300m, 350m, 400m
  - starting (s1) and ending (s2) grade values of braking process
    - ✓ $-4\% \leq s_i \leq +4\%$
  - grade difference ($Ds=s_2-s_1$)
  - inner shoulder width (ISW)
    - ✓ 1.20m, 1.80m, 2.40m
- Every Possible Arrangement Examined
  - 2,772 different alignment cases



Probability of SSD Inadequacy

Logistic Regression Model

$$\mathrm{Logit}(\pi_{ij}) = \mathrm{Log}\left(\frac{\pi_{ij}}{1-\pi_{ij}}\right) = \sum \beta i X i + \varepsilon i$$

where:

π_{ij} : probability of SSD inadequacy

X_i : explanatory variables

β_i : parameters to be estimated

ε_i : logistically distributed ~[0, μ] error term

Probability of SSD Inadequacy

- Parameter Estimates and Goodness-of-Fit Measures

Parameter	B	S.E.	Wald test	p-value	Exp(B)	Elasticity
K	,01813703	,00295862	37,580	<0,001	1,018	3,404
R	,00875999	,00064639	183,663	<0,001	1,009	1,516
s1	-,16167454	,05077569	10,138	,001	,851	-0,009
Ds	-11,56791068	1,42435424	65,959	<0,001	,000	0,617
ISW	-5,15025730	,31647009	264,845	<0,001	0,006	-0,680
10^{-3} R^2	-,00232342	,00020009	134,829	<0,001	0,998	-1,006
K * Ds	-,00765764	,00269050	8,101	,004	,992	0,115
R * Ds	,00375407	,00048204	60,651	<0,001	1,004	-0,513
K * R	-,00000705	,00000127	30,590	<0,001	1,000	-3,250
Ds * s1	,78238421	,08736706	80,195	<0,001	2,187	-0,036
Null Log-likelihood (LL0)		-1864,85				
Final Log-likelihood (LL)		-392,825				
Likelihood Ratio test		2944,05				
df		10				
pseudo R-squared		0,79				

Probability of SSD Inadequacy

- Classification of Cases of the Model Predictions

SSD inadequacy		Predicted		Correct (%)
		0	1	
Calculated	0	1032	75	93,2
	1	80	1585	95,2
Total				94,4

Amended Object Height Prediction

- **Lognormal Regression Modelling of AOH**

$$\text{Log}(AOH_i) = \sum \beta i X i + \varepsilon i$$

where:

X_i : explanatory variables

β_i : parameters to be estimated

ε_i : normally distributed ~[0, σ^2] error term

Amended Object Height Prediction

Parameter Estimates and Goodness-of-Fit

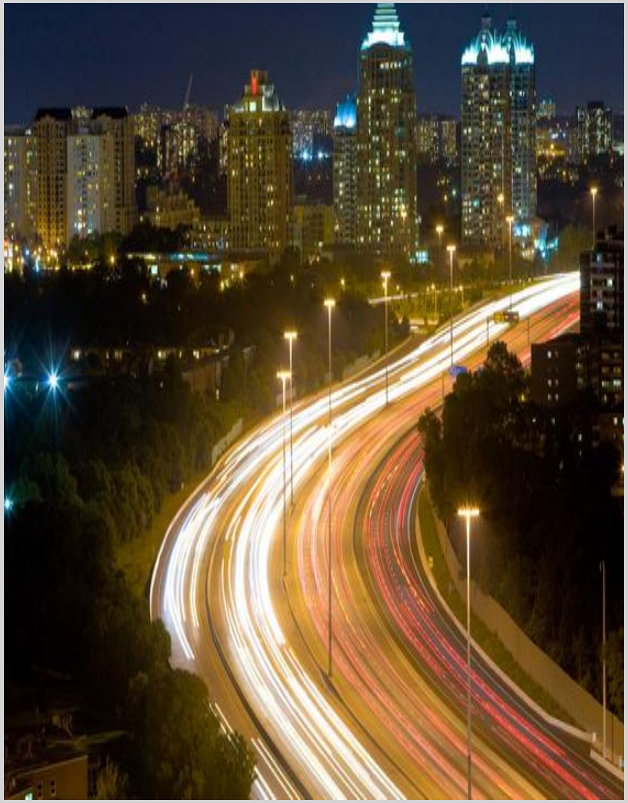
Parameter	B	Std. Error	Wald Chi-Square	p-value
(Intercept)	1,1172864	,2487440	20,175	<0,001
K	-,0024194	,0003363	51,754	<0,001
R	-,0029807	,0001715	301,972	<0,001
ISW	-,7683734	,0546478	197,697	<0,001
Ds	-,7717293	,0748511	106,300	<0,001
Kx R	,0000008	,0000002	23,110	<0,001
K * Ds	-,0053688	,0002712	391,984	<0,001
R * Ds	-,0002012	,0000362	30,832	<0,001
R * ISW	,0002100	,0000310	45,802	<0,001
[s14=,00] * R	-2,4985374	,2694198	153,768	<0,001
[s14=1,00] * R	0		.	.
[s14=,00]	,0022574	,0001820	86,003	<0,001
[s14=1,00]	0		.	.
(Scale)	,1259748	,0043661		
Null Log-likelihood		-2198,8		
Final Log-likelihood		-637,8		
Likelihood Ratio test		3122		
df		10		
pseudo R-squared		0,71		

Conclusions

- SSD Adequacy Investigation
  - passing lane of freeways
  - left-turn curves overlapped with crest vertical alignments
- Potential Safety Violation for AASHTO 2011
  - V_{design} =130km/h
  - $SSD_{DEMANDED} \leq SSD_{AVAILABLE}$

Conclusions

- Extensive SSD Shortage Areas for Control Horizontal and Vertical Design Values
- SSD Sufficiency Evaluation
  - probability of SSD inadequacy
    - ✓ logistic regression model
  - prediction of the amended object height
    - ✓ lognormal regression model



Conclusions

- Analytical Model is Computationally Demanding (Although Accurate)
- Proposed Modelling Approach
  - emphasis in identifying interacting road design elements
  - quantification of these effects (elasticities)
  - very useful tool for practitioners and researchers

Conclusions

- **Probability Modelling Approach**
  - efficient, suitable for researchers to correctly assess SSD in such 3D road alignments
- **Logarithmic Modelling Approach**
  - somewhat less accurate in AOH prediction
    - ✓ further analysis required to investigate non-linear relationships between the examined variables

Conclusions

- **Additional Work**
  - models validation
  - examine more speed values
  - optimize in terms of SSD provision, the influence of additional parameters involved
    - median barrier type for certain cases (e.g. bridge - tunnel areas, etc.)
    - issues associated to human factors
    - more realistic deceleration values
    - night time driving

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