4th International Conference on Road Safety and Simulation RSS 2013

23rd-25th October 2013
Rome, Italy

Analytical Method for Three-Dimensional Stopping Sight Distance Adequacy Investigation

Fotis Mertzanis
Rural and Surveying Eng. MSc, PhD Candidate

Antonis Boutsakis
Civil Eng. Research Associate

Ikaros Kaparakis
Civil Eng. Research Associate

Stergios Mavromatis
Assistant Professor
Technological Educational Institute of Athens

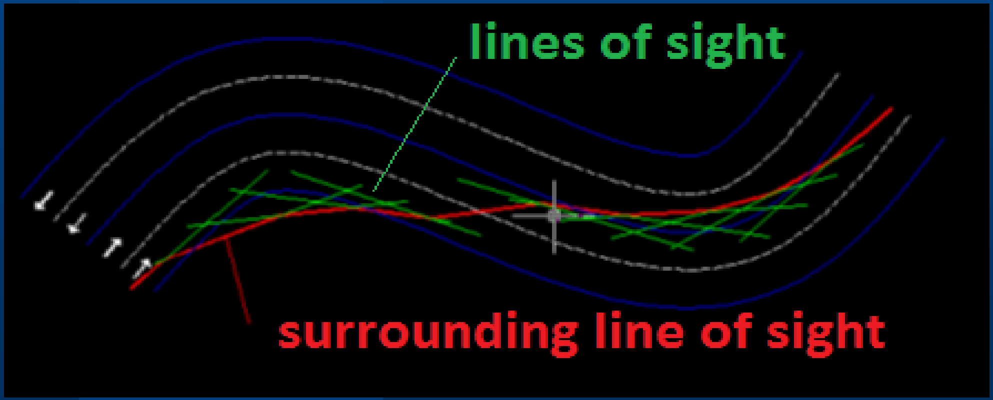
Basil Psarianos
Professor
National Technical University of Athens

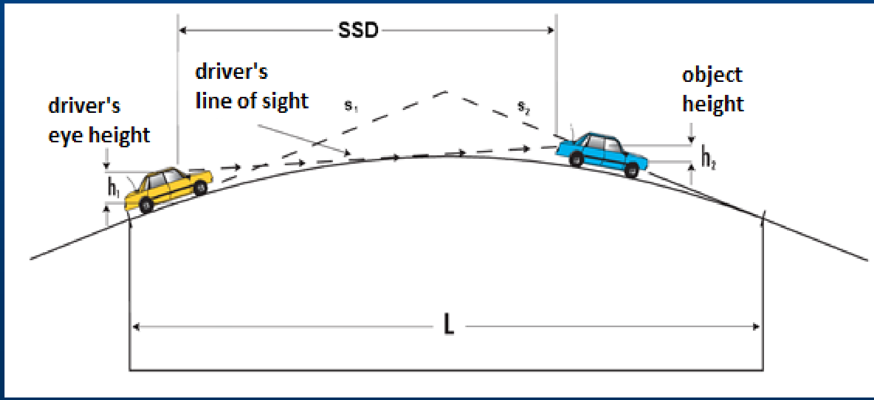
Stopping Sight Distance (SSD) Approach

- 2D
  - inexact – fragmentary
  - negative impact
    - cost
      (excessive overdesign suggestions)
    - design consistency
      (unnecessary posted speed areas)
- 3D
  - integrated

Current Practice

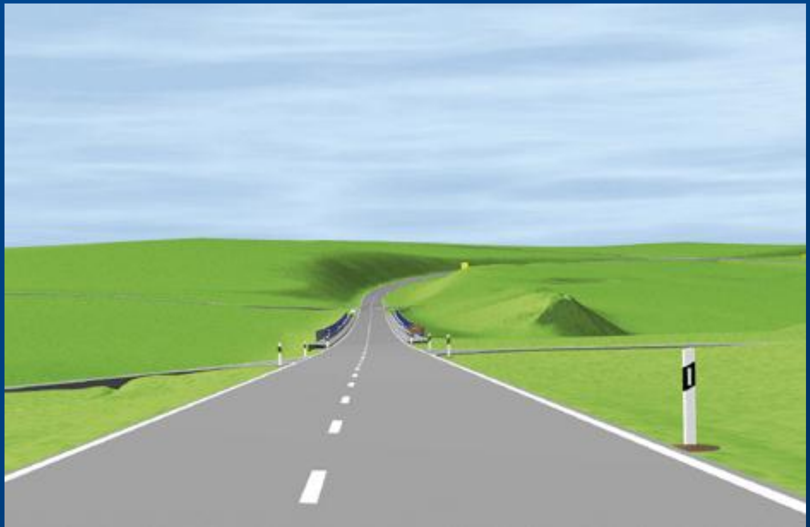
- **2D approach**
  - **efforts to overcome this incorrect SSD determination**
    - **establishing some coordination between the horizontal and vertical curve positioning**
      - **e.g. vertical transition curve should be entirely designed inside the horizontal curve [Green Book (2011)]**
    - **not all design cases are addressed**

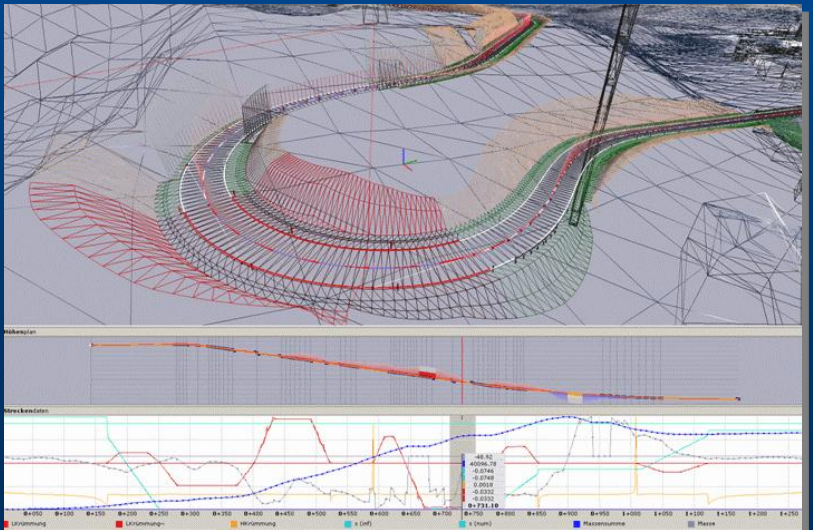




SSD Modeling

- **2D and 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

- simulate from a 3-D perspective concurrently
  - alignment design
  - vehicle dynamics on the road surface during emergency braking conditions
- point out design elements responsible for SSD inadequacies
  - providing precious guidance to the designer for further alignment improvement

Methodology

- $SSD_{demanded}$ calculation
  - 3D road environment
  - vehicle dynamics

- $SSD_{available}$ calculation
  - 3D road environment
  - define areas where line of sight intersects roadway or cross sectional elements

SSD$_{demanded}$ Calculation

$$SSD = V_o t + \frac{V_o^{\,2}}{2g\left(\frac{a}{g} + s\right)}$$

where :
V_o (m/sec) : vehicle initial speed
t (sec) : driver's perception – reaction time
g (m/sec^2) : gravitational constant
a (m/sec^2) : vehicle deceleration rate
s (%/100) : road grade [(+) upgrades, (-) downgrades]

SSDdemanded Calculation (2/5)

$$SSD = V_o t + \frac{{V_o}^2}{2g\left(\frac{a}{g} + \boxed{s}\right)}$$

where :
V_o (m/sec) : vehicle initial speed
t (sec) : driver's perception – reaction time
g (m/sec^2) : gravitational constant
a (m/sec^2) : vehicle deceleration rate
s (%/100) : road grade [(+) upgrades, (-) downgrades]

$SSD_{demanded}$ Calculation (3/5)

- **enriched model of SSD determination**
  - **actual friction in the longitudinal direction**

$$f_T = \sqrt{\left(\frac{a}{g}\right)^2 - \left(\frac{V^2}{gR} - e\right)^2}$$

where :
f_T : friction demand in the longitudinal direction of travel
V (m/sec) : vehicle (design) speed
a (m/sec^2) : vehicle deceleration rate
g (m/sec^2) : gravitational constant
R (m) : horizontal radius
e (%/100) : road cross – slope

$SSD_{demanded}$ Calculation

- enriched model of SSD determination
  - grade effect on vertical curves

$$V_{i+1} = V_i - g(f_T + s)t$$

$$BD_i = V_i t - \frac{1}{2} g(f_T + s)t^2$$

where :

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 (%/100) : road grade in i position [(+) upgrades, (-) downgrades]

f_T : friction demand in the longitudinal direction of travel

BD_i (m) : pure braking distance

g (m/sec^2) : gravitational constant

$SSD_{demanded}$ Calculation (5/5)

- enriched model of SSD determination
  - actual friction in the longitudinal direction
  - grade effect on vertical curves

$$SSD_{demanded} = V_o t + \sum BD_i$$

where :

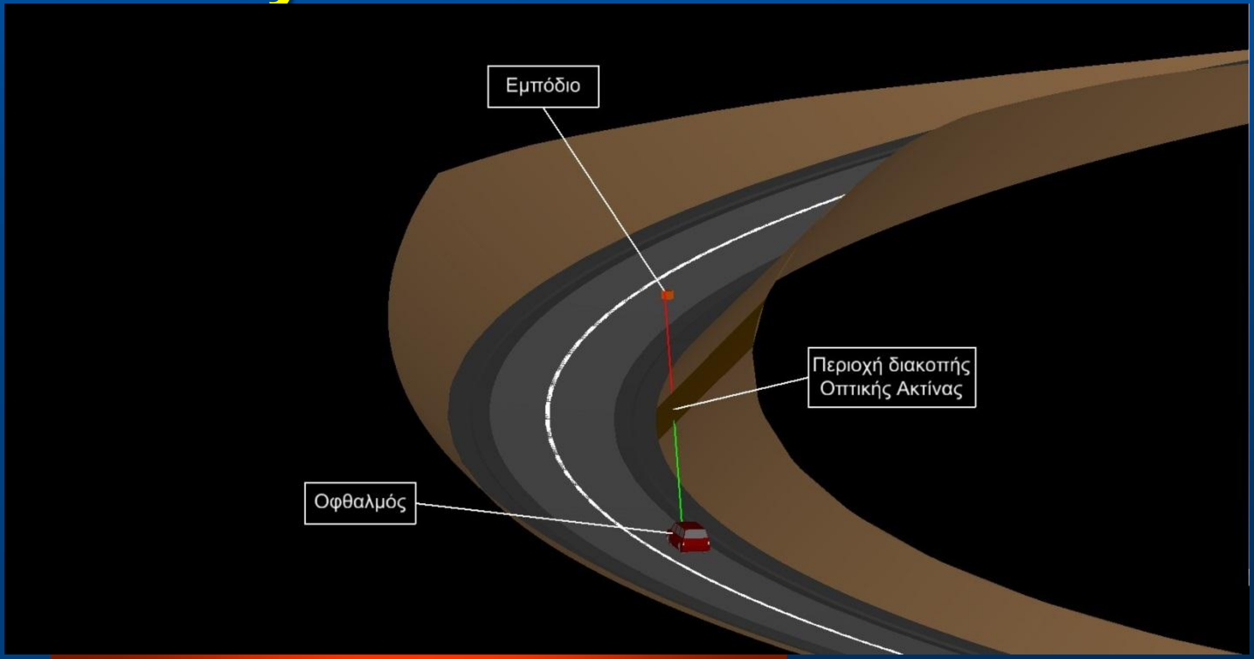
V_o (m/sec) : vehicle initial speed

t (sec) : driver's perception – reaction time

$\sum BD_i$ (m): total vehicle pure braking distance for the initial vehicle speed

SSD$_{available}$ Calculation

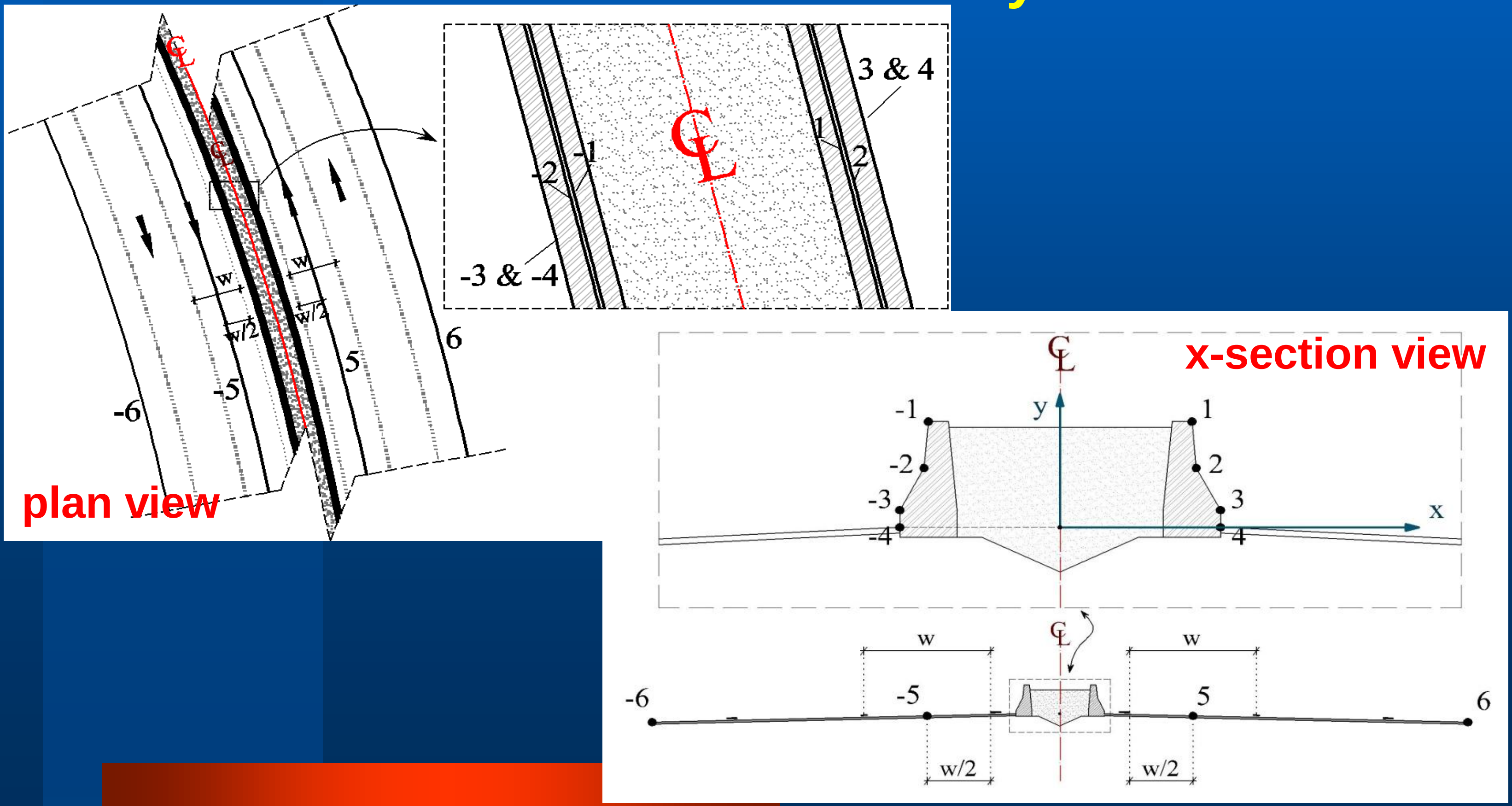
- line of sight between driver – obstacle positioned at any desired offset and any predefined heights
- identify areas where line of sight intersects roadway or cross sectional elements



SSD$_{available}$ Calculation (2/6)

roadlines

- lines running longitudinally across the roadway that split the road into areas of uniform or linearly varied transverse slope



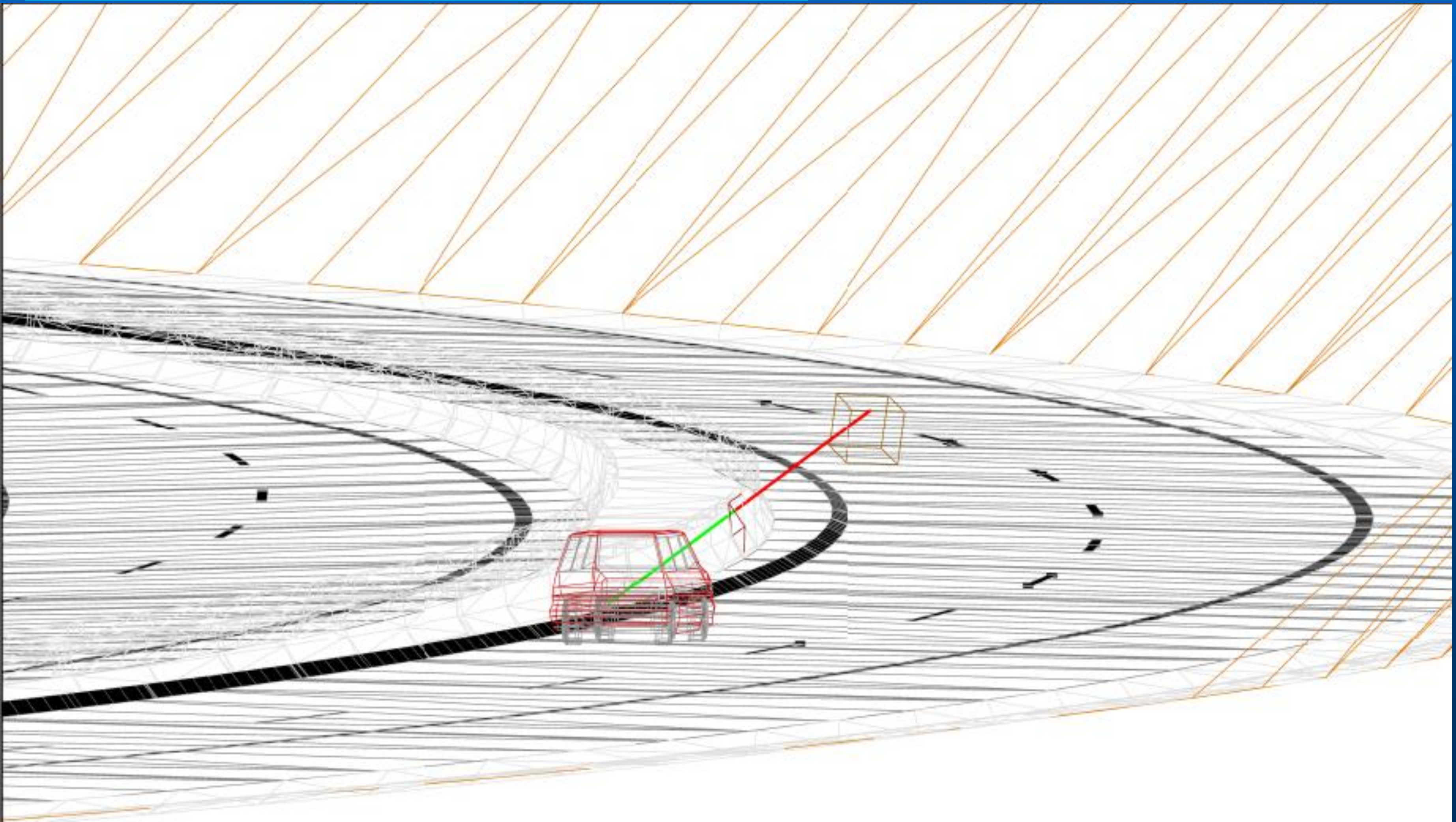
SSD$_{available}$ Calculation

- **roadline calculation step is user-specified and delivers a number *n* of cross-sections**
  - ***n* is defined as the total roadway length divided by the selected calculation step**
- **roadline coordination performed on every cross-section**
- **a network of triangles representing the roadway surface as well as other distinctive parts is created**
  - **connecting a point on one roadline with two relative points on an adjacent roadline**

SSD$_{available}$ Calculation

(4/6)

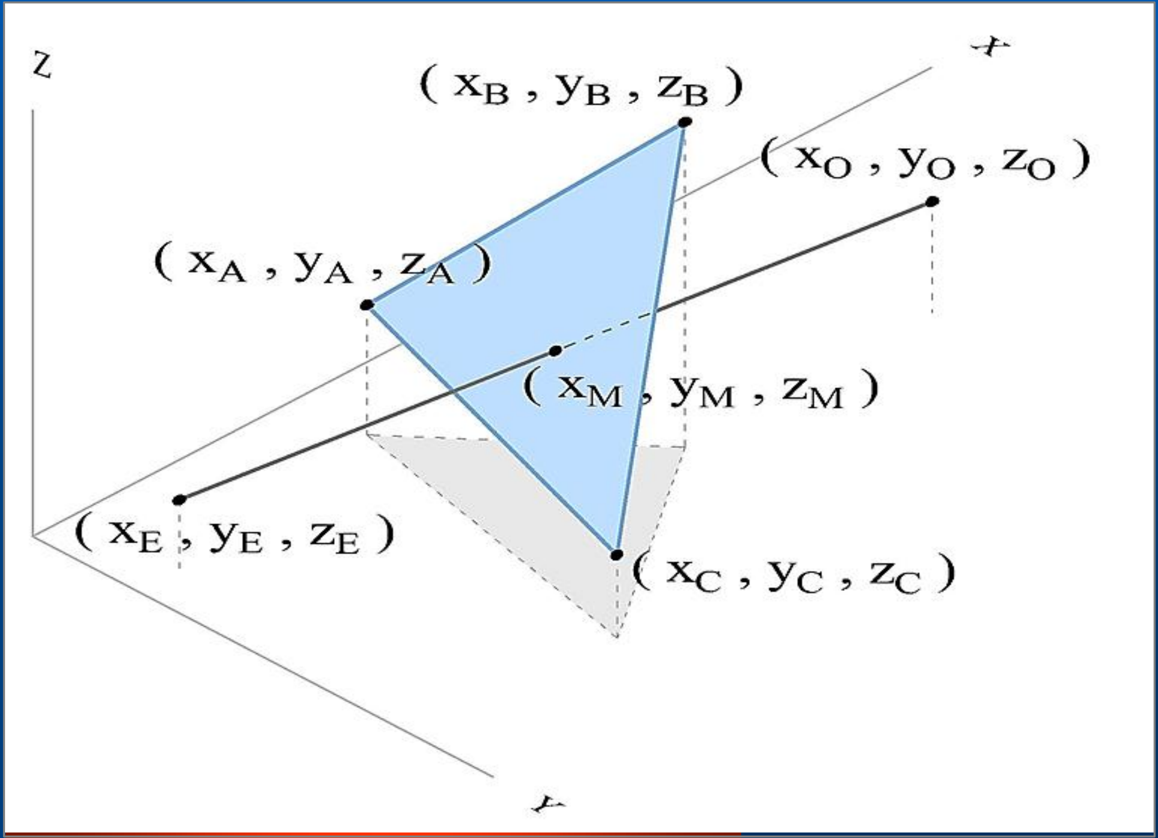
SSD$_{available}$ Calculation (5/6)



SSDavailable Calculation (6/6)

Line of Sight – Obstacle Intersection

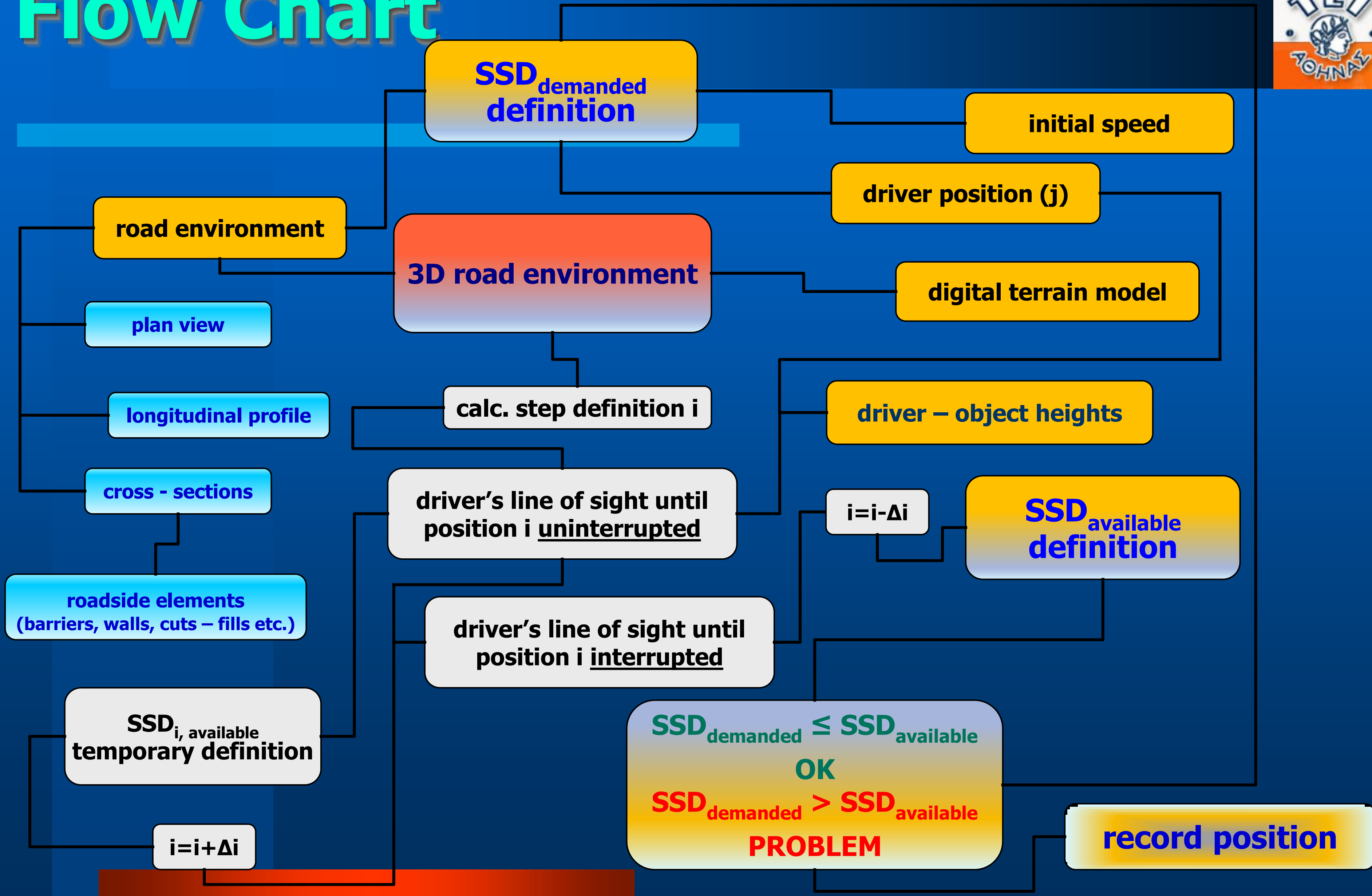
- analytical geometry



SSD Adequacy

$$SSD_{demanded} \leq SSD_{available}$$

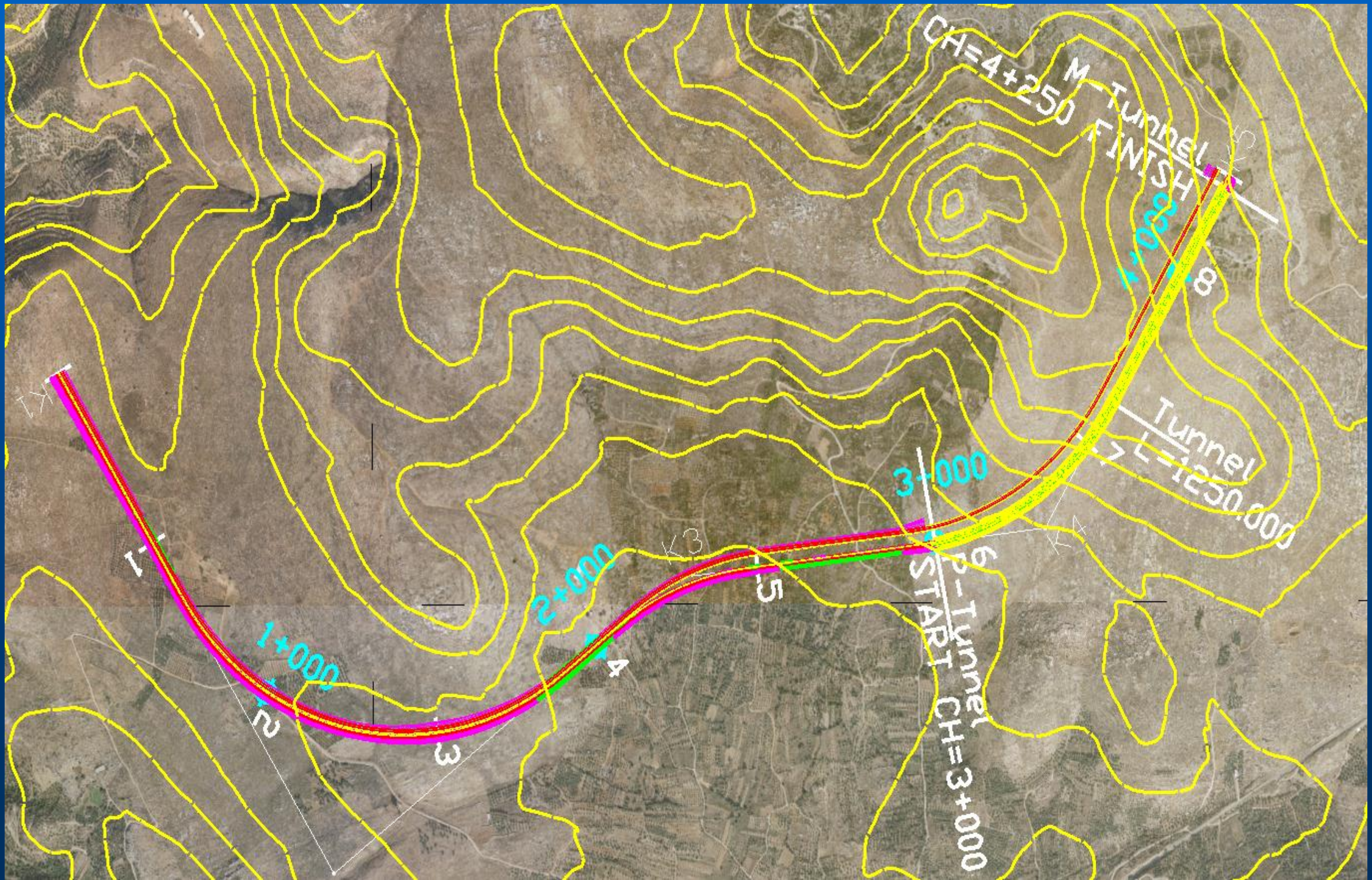
SSD Adequacy Investigation Flow Chart



Case Study

divided highway

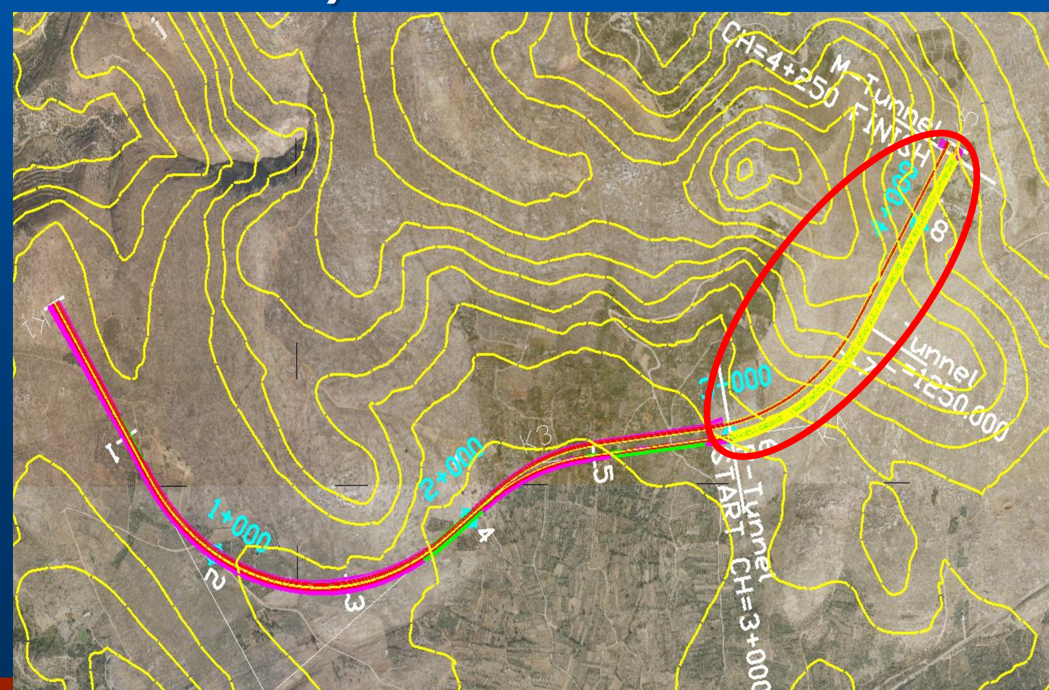
- **right branch section (L=4.3km)**



Case Study

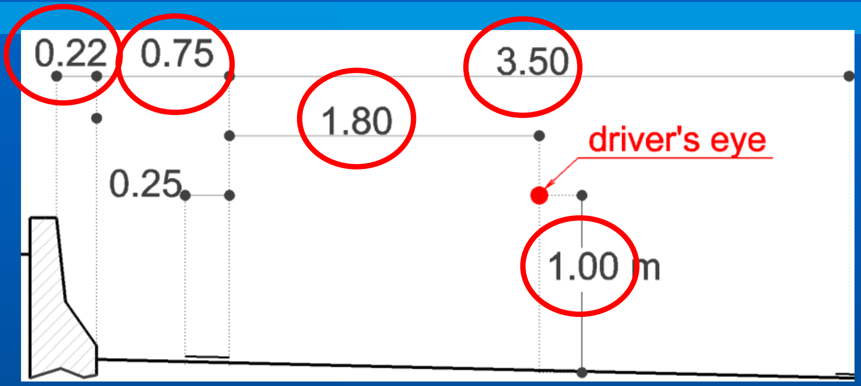
divided highway

- right branch section (L=4.3km)
- V_{design} = 120km/h
- open roadway
- tunnel
  - ► L_{tunnel} = 1,250m (St.3+000 – St.4+250)
- passing lane

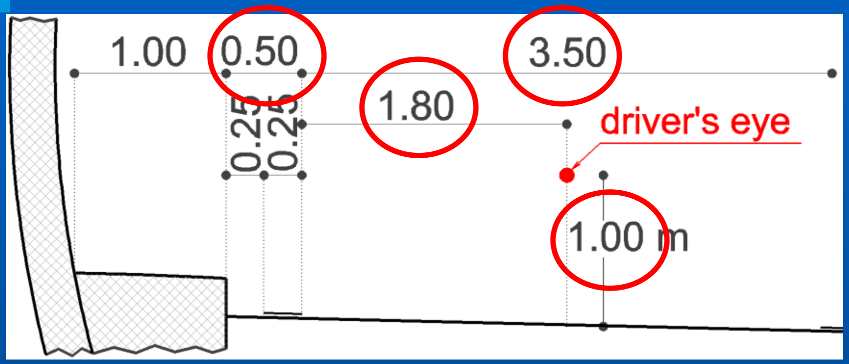


Case Study

assumptions



open roadway x-section

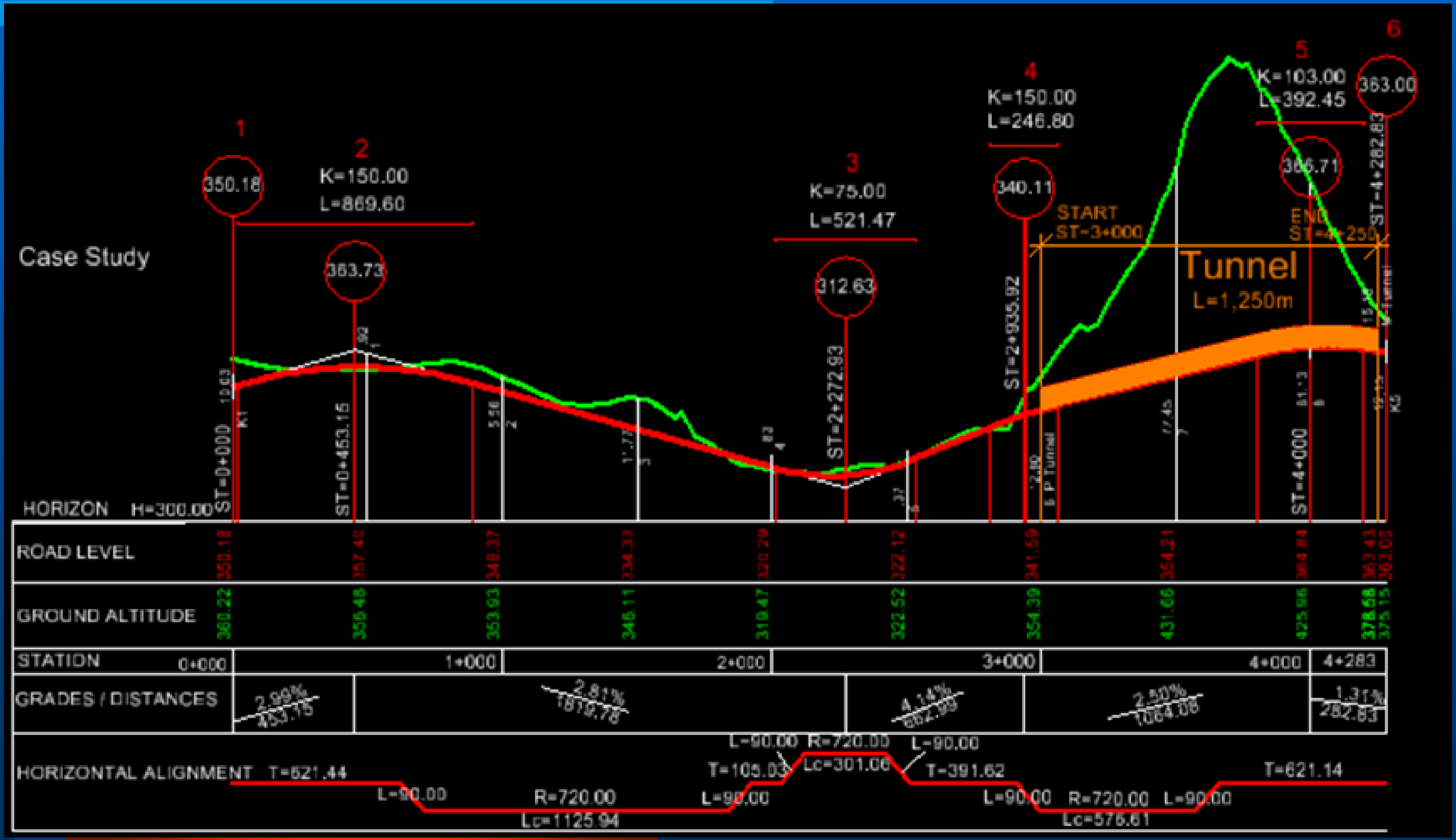


tunnel x-section

- **tunnel advisory speed = 100km/h**
- **tunnel effective length**
  - 300m in advance of the entering portal
  - extra 200m segment transition zone ahead $V_{vehicle}$=120km/h → $V_{vehicle}$=100km/h
- **f_{wet} = 0.38 (decelaration$_{wet}$ = 0.38 x g m/sec^2)**
- **f_{dry} = 0.65 (decelaration$_{dry}$ = 0.65 x g m/sec^2)**

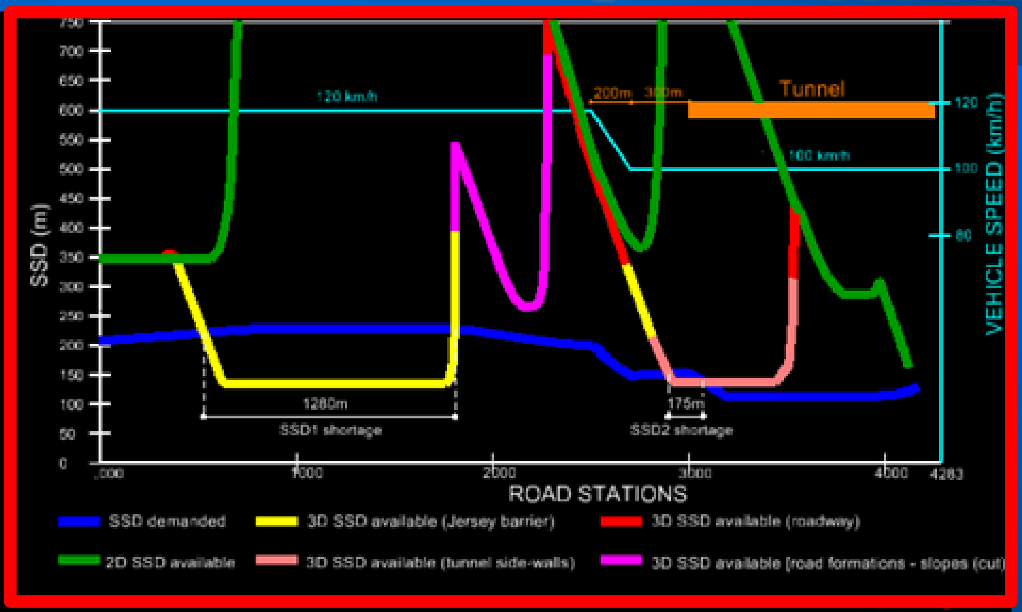
Case Study

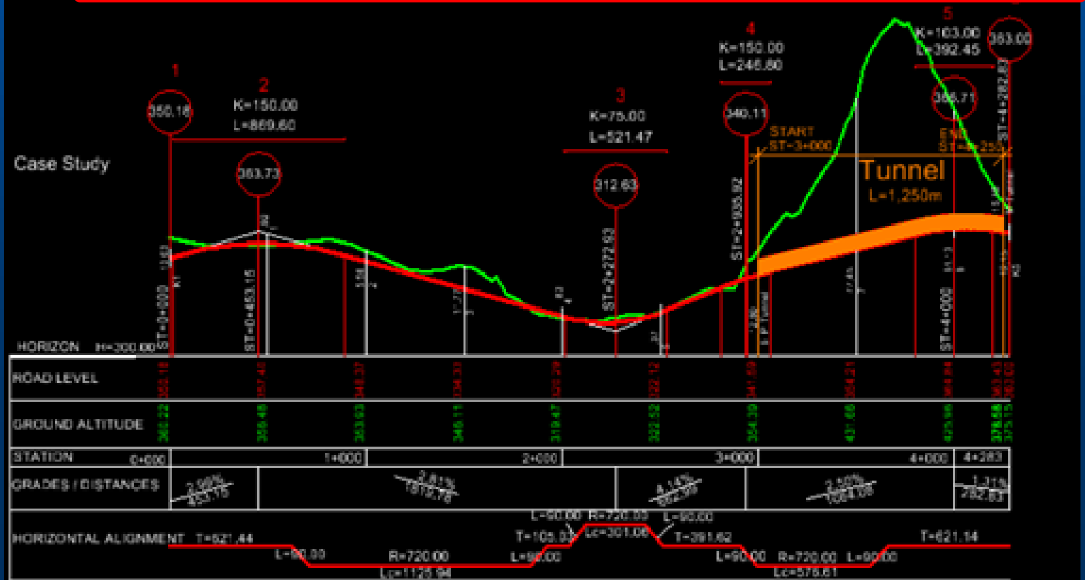
longitudinal profile



Case Study

SSD Adequacy Investigation

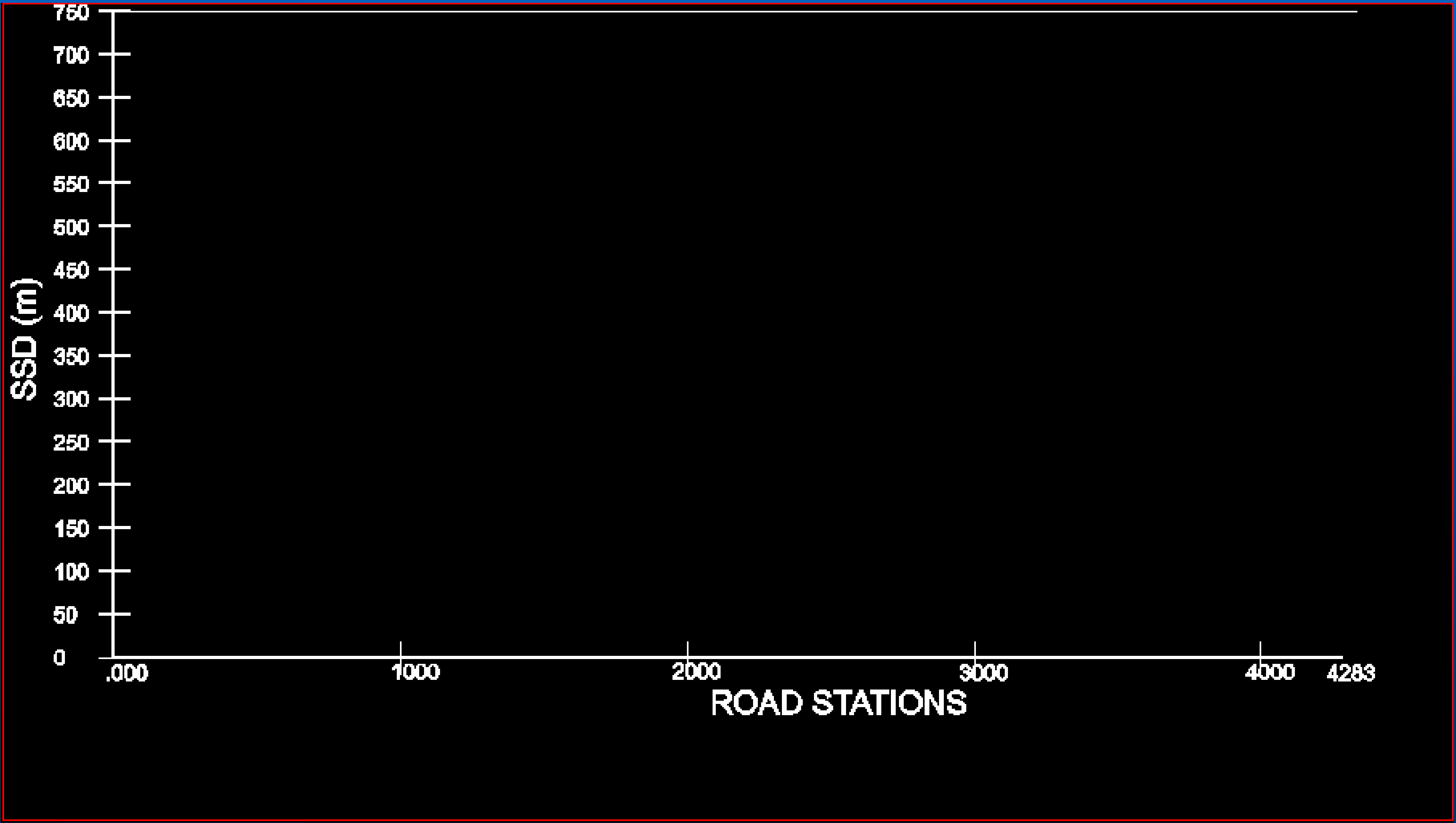




outputs

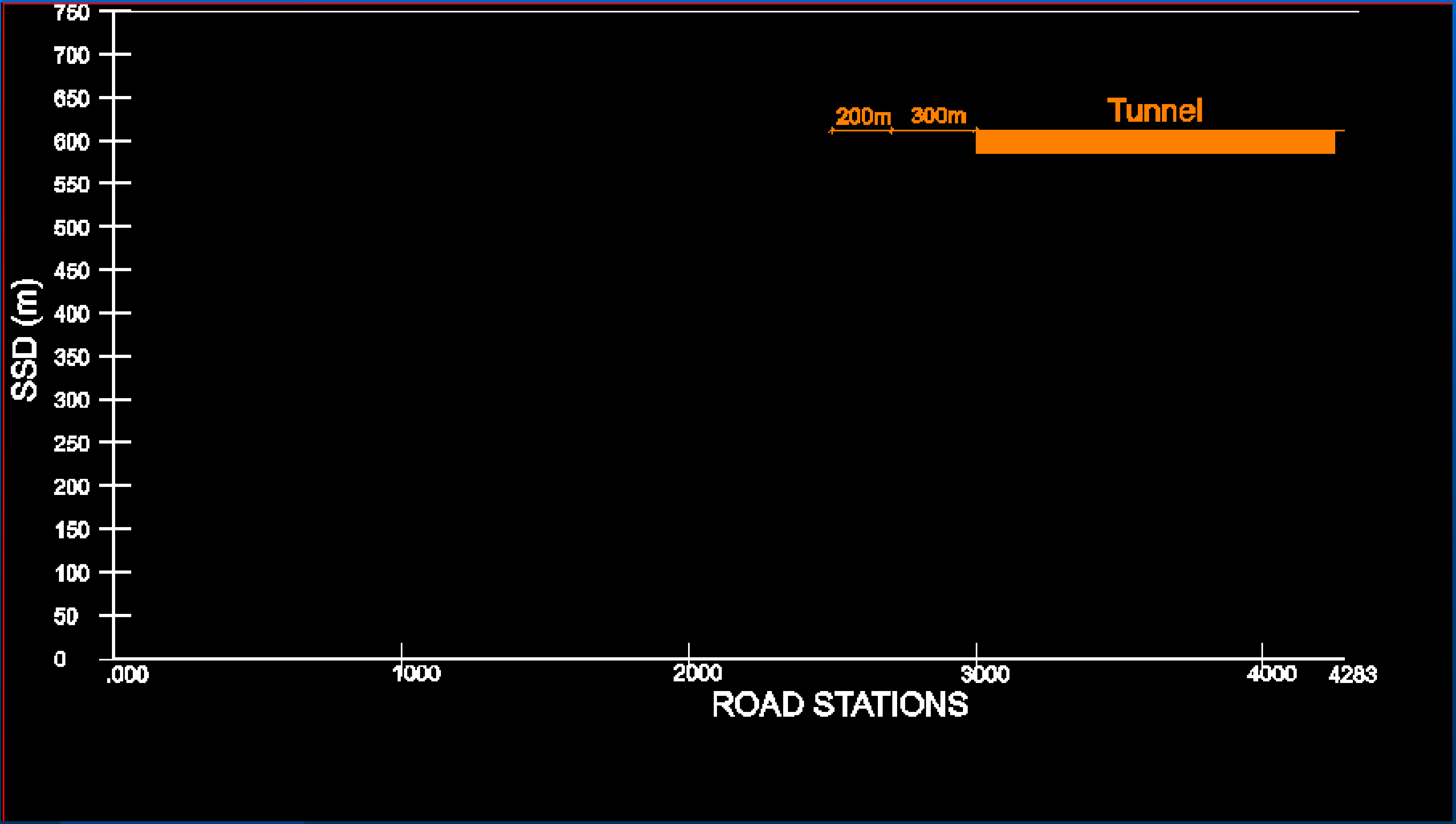
Case Study

SSD Adequacy Investigation



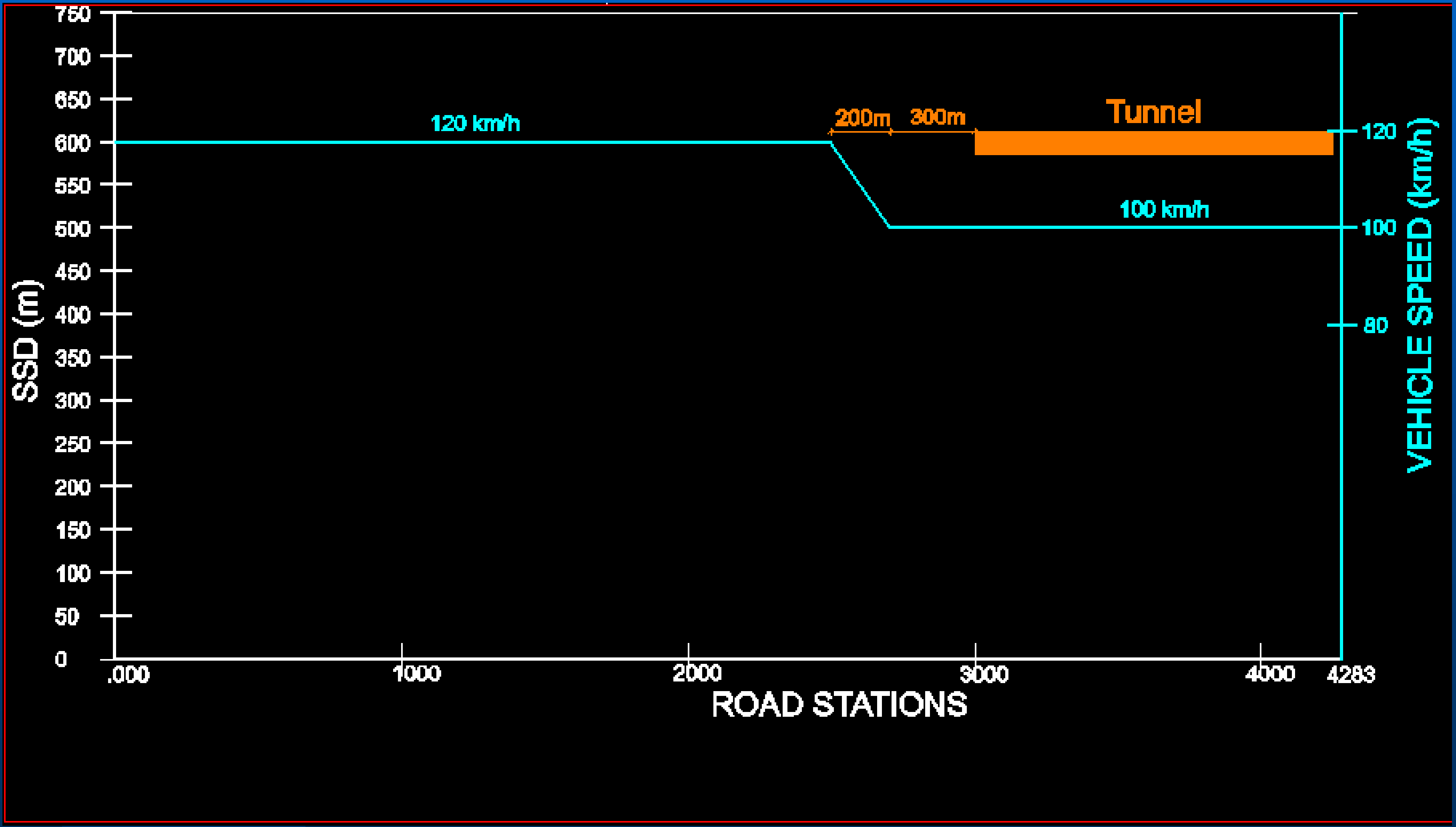
Case Study

SSD Adequacy Investigation



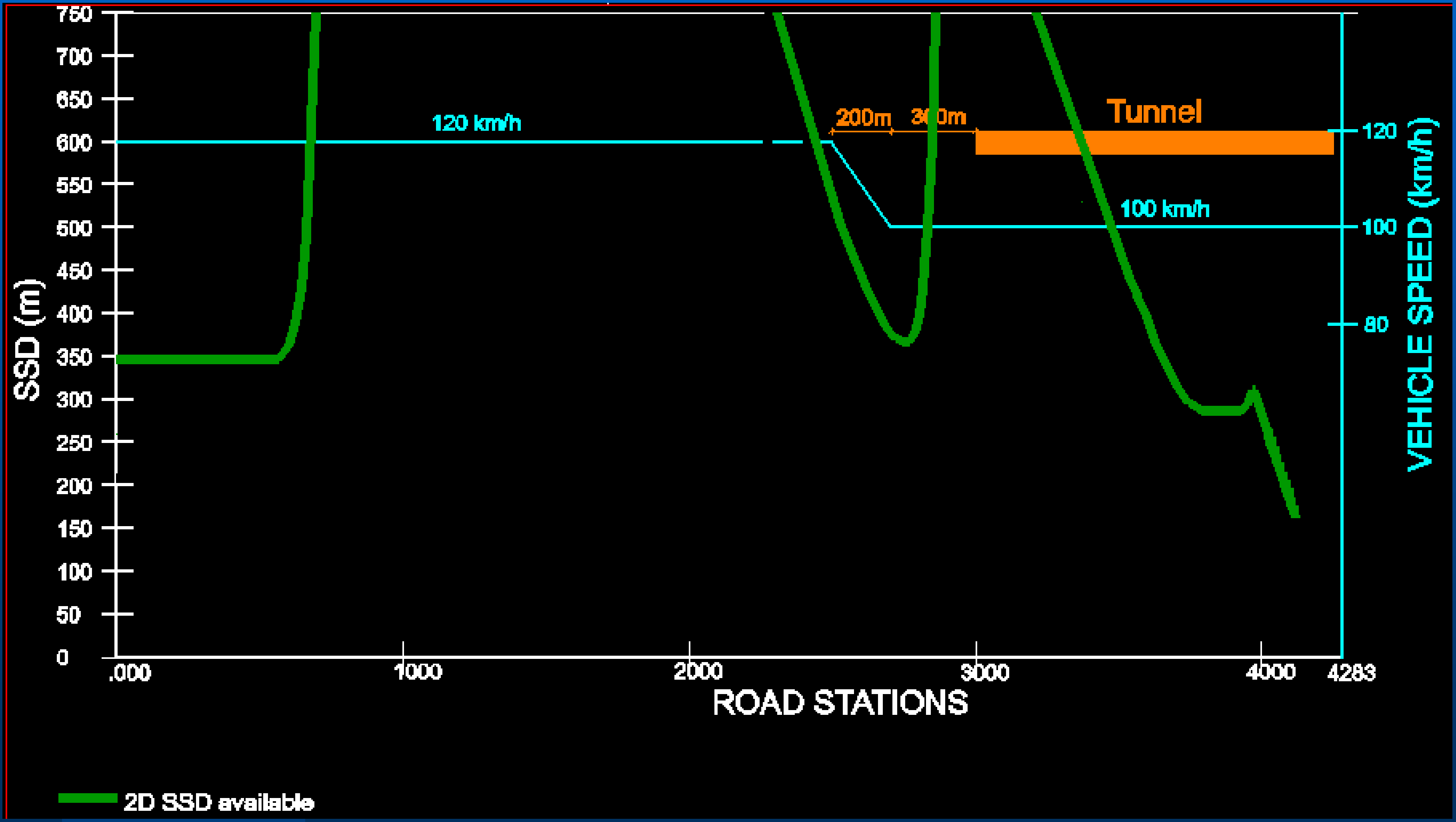
Case Study

SSD Adequacy Investigation



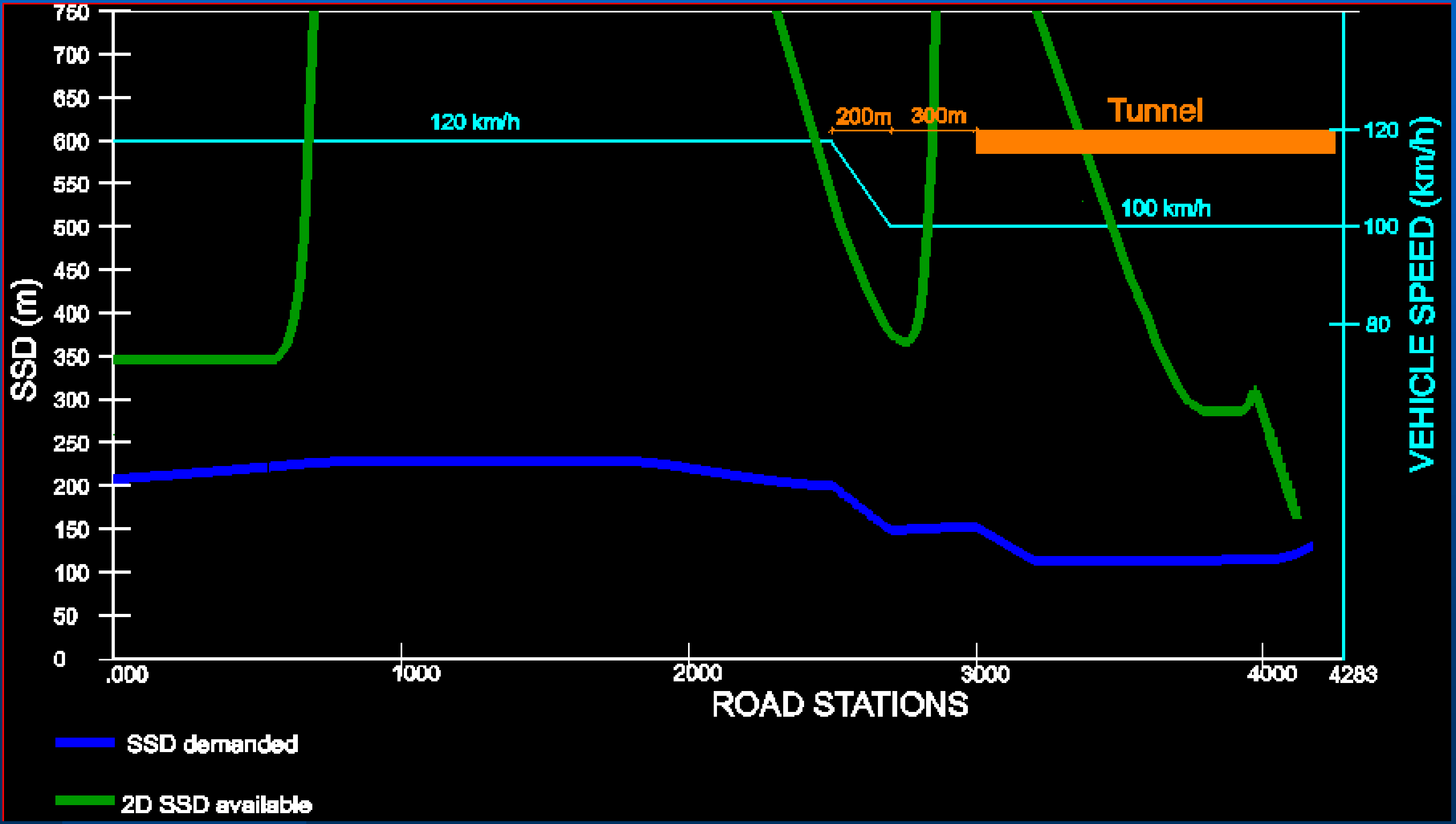
Case Study

SSD Adequacy Investigation



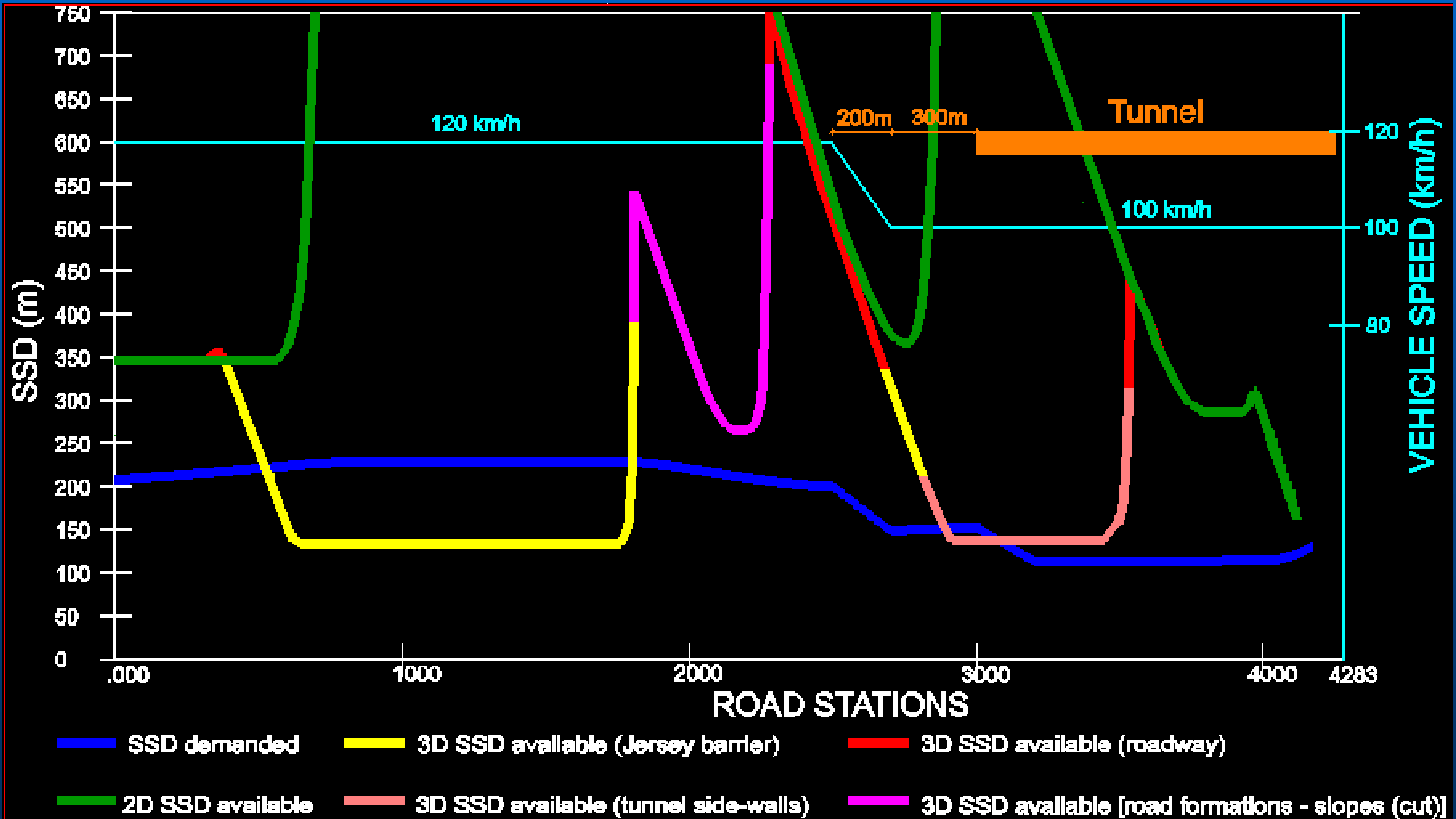
Case Study

SSD Adequacy Investigation



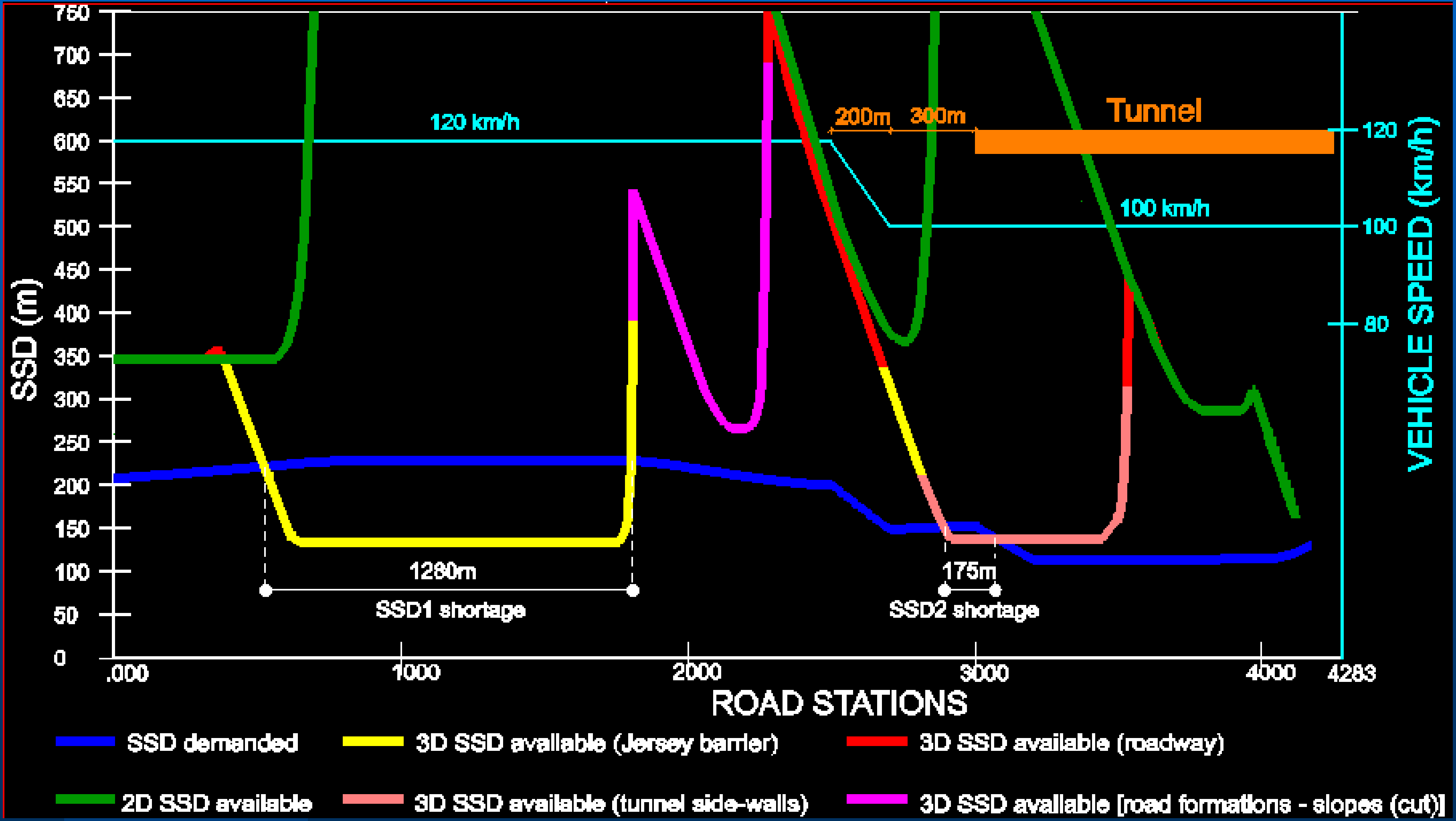
Case Study

SSD Adequacy Investigation



Case Study

SSD Adequacy Investigation



Conclusions

- accurate SSD adequacy investigation
  - based on the difference between $SSD_{available}$ - $SSD_{demanded}$
  - applied in any 3-D road environment
- flexibility among every road design and/or vehicle dynamic parameter inserted
- direct overview regarding design elements responsible for SSD inadequacies
- accurate aid to implement geometric design control criteria