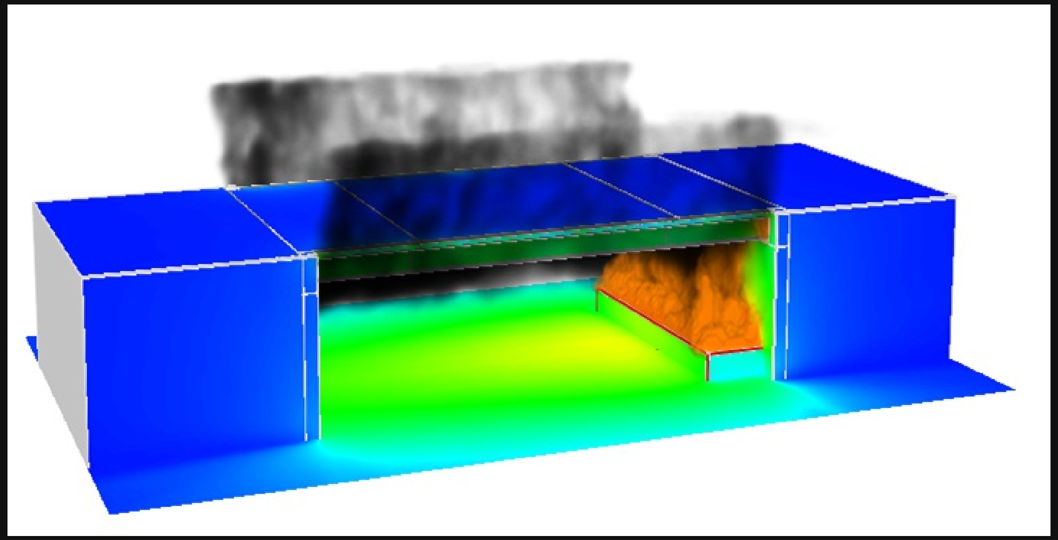
# STUDY OF PARAMETERS THAT INFLUENCE I-GIRDER BRIDGE BEHAVIOR DURING FIRE EVENTS



G. Peris-Sayol, I. Payá-Zaforteza
Euroestudios S.L
Universidad Politécnica de Valencia

# Bridge fires

# MacArthur Maze Collapse, USA, 2007


22 min until collapse
1 month closed
Repair Cost: 9 million USD
Indirect Cost: 180 million USD (6M USD/day)

# 9 mile, Detroit, USA, 2009

Bridge near Hazel Park
Detroit, USA - July 15th, 2009

# Standards

## Eurocode 1: Actions on Structures

**Eurocode 1 : Actions on structures –**

***Part 1-2 : General actions – Actions on structures exposed to fire***

**Links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products**

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works[4]. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes shall clearly mention which Nationally Determined Parameters have been taken into account.

**Additional information specific to EN 1991-1-2**

EN 1991-1-2 describes the thermal and mechanical actions for the structural design of buildings exposed to fire, including the following aspects:

*Safety requirements*

EN 1991-1-2 is intended for clients (e.g. for the formulation of their specific requirements), designers, contractors and relevant authorities.

The general objectives of fire protection are to limit risks with respect to the individual and society, neighbouring property, and where required, environment or directly exposed property, in the case of fire.

Construction Products Directive 89/106/EEC gives the following essential requirement for the limitation of fire risks:

# Standards

## NFPA 502: Road Tunnels, Bridges and Other Limited Access Highway

**6.2* Application.** For the purpose of this standard, bridge or elevated highway length shall dictate the minimum fire protection requirements.

**6.2.1** For bridges or elevated highways less than 300 m (1000 ft) in length, the provisions of this standard shall not apply.

**6.3 Protection of Structural Elements.**

**6.3.1** Regardless of bridge or elevated highway length, all primary structural elements shall be protected in accordance with this standard in order to:

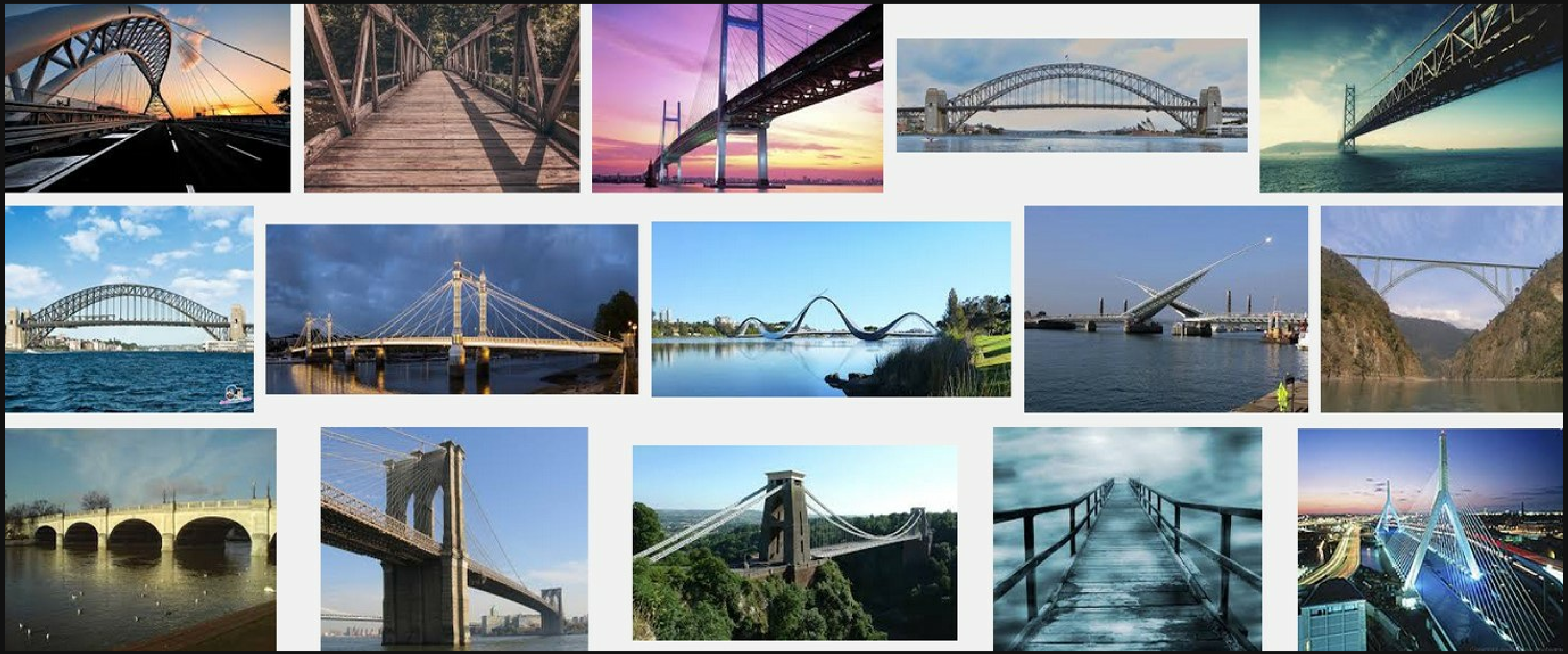
(1) Maintain life safety
(2) Mitigate structural damage and prevent progressive structural collapse
(3) Minimize economic impact

**6.3.2** Critical structural members shall be protected from collision and high-temperature exposure that can result in dangerous weakening or complete collapse of the bridge or elevated highway.

**6.3.3** For through truss and suspension bridges or elevated highways, an engineering analysis shall be prepared to determine acceptable risk, including possible collapse scenarios.

# OBJECTIVE

# To improve bridge resilience against fires



# Tanker truck

# I-Girder Bridges


I-Girder bridge construction https://erkrishneelram.wordpress.com

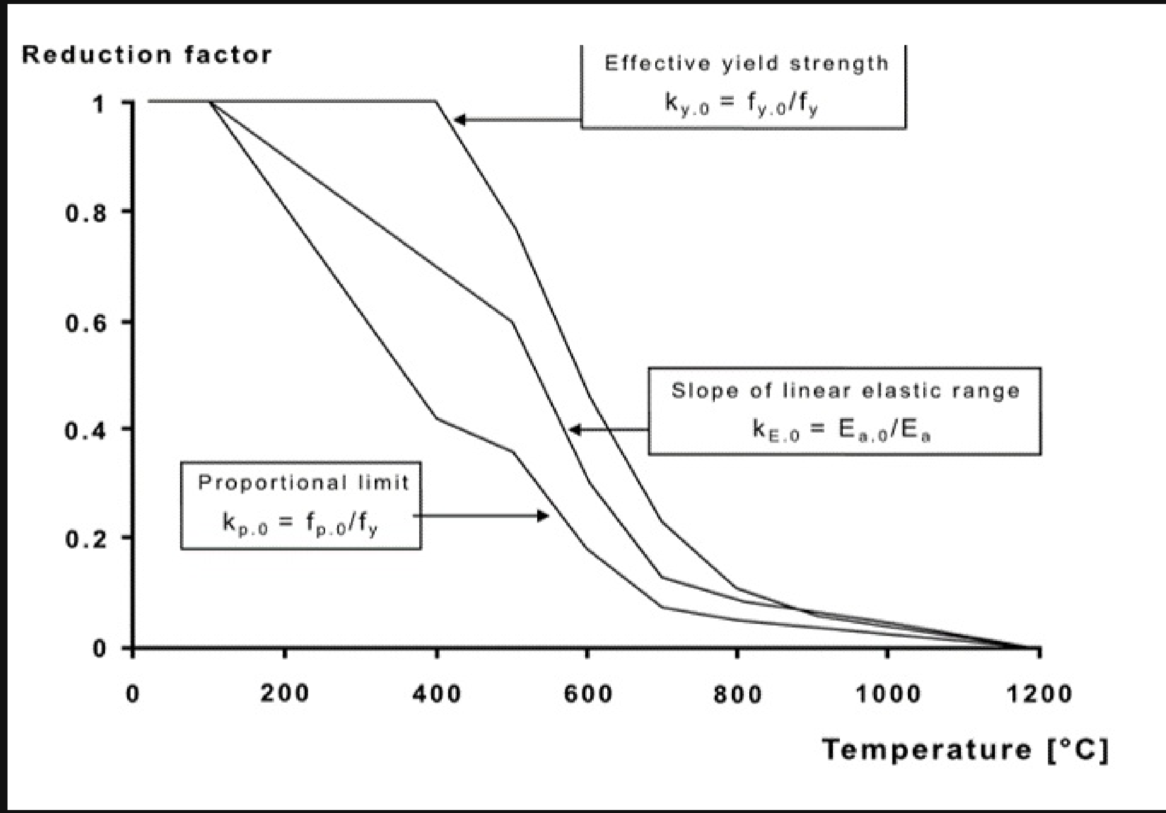
# Very Common Type of Bridge

Approaches to Port Authority Bus Station, NYC

# Very vulnerable structural system

Peris-Sayol et al. 2016, Garlock et al., 2012

# Importance of several parameters on the maximum gas temperatures





Four Geometric Parameters
Two Fire Scenario Parameters

# PARAMETERS

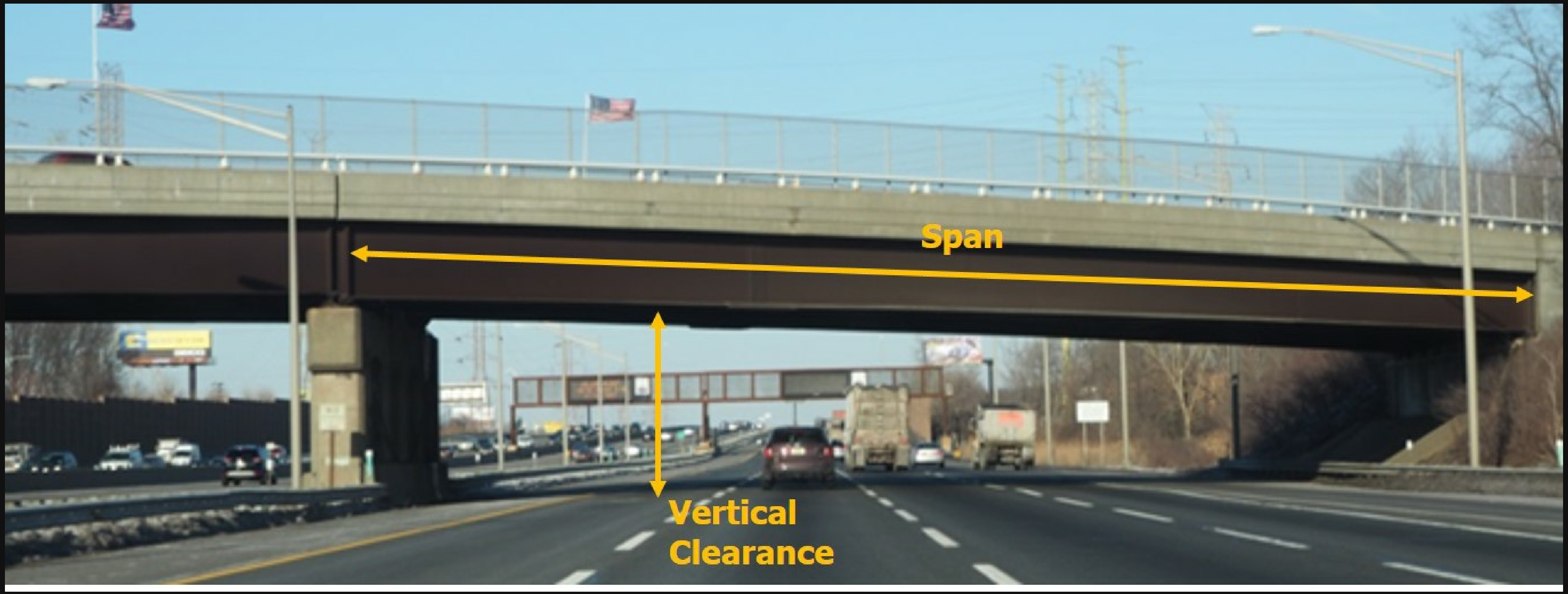

New York
Washington
STRAIGHT AHEAD
SPEED LIMIT 25
2
NO STOPPING

# Geometric Parameters


Vertical Clearance (6 and 9 meters)

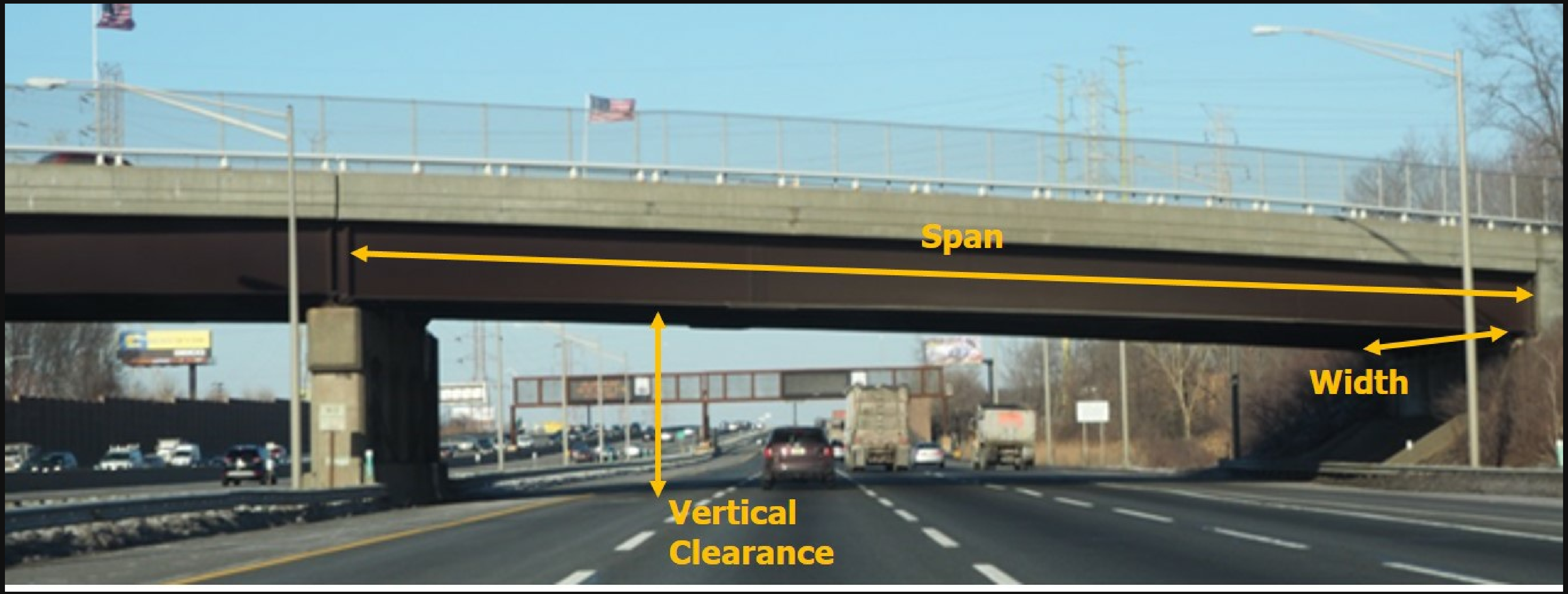
# Geometric Parameters

Span (16 and 24 meters)



# Geometric Parameters

Width (13 and 23.4 meters)



# Geometric Parameters

Bridge Substructure (Piers or Abutments)

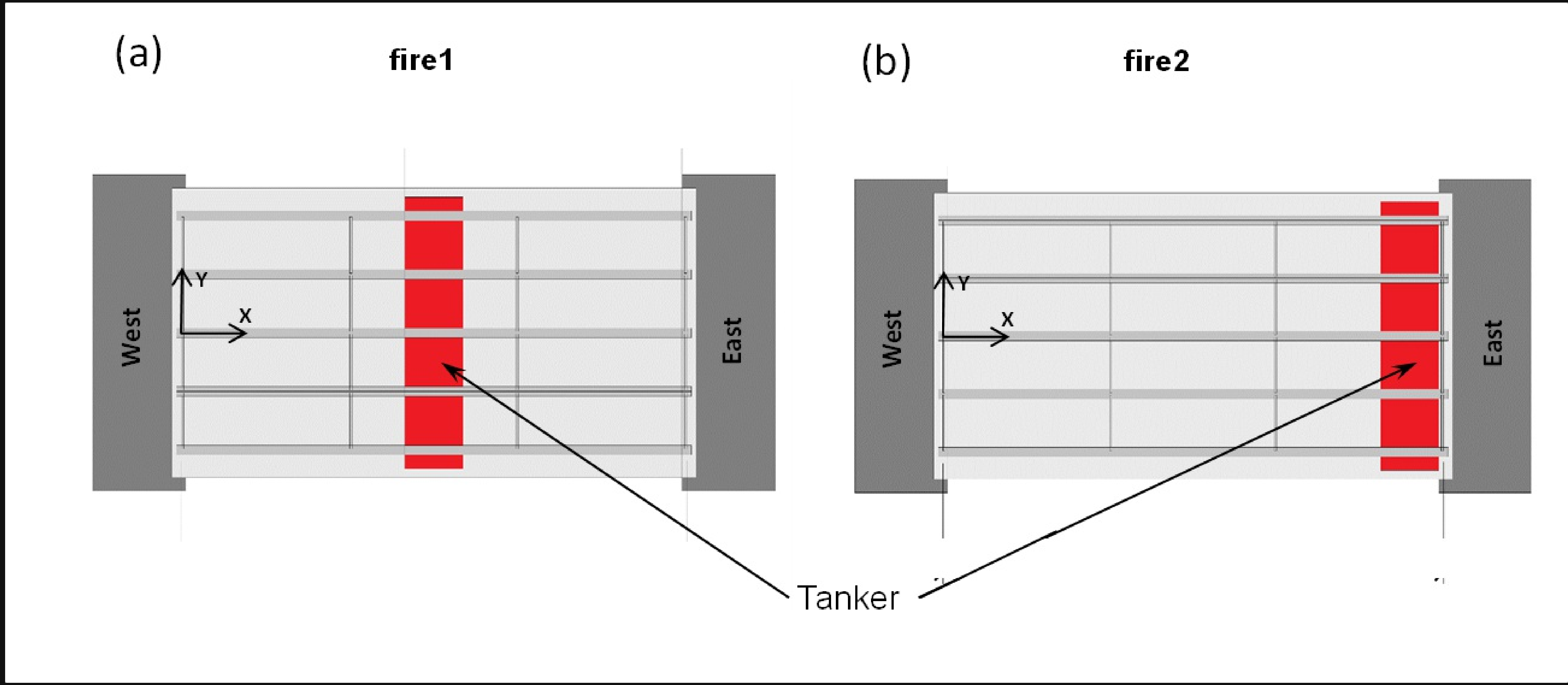
# Geometric Parameters

Bridge Substructure (Piers or Abutments)

# Fire Scenario Parameters

**Position of the Fuel Load**
(2 Positions, Center and close to the Abutment)

**Heat Release Rate**
(Type of Fuel)



# Fire Scenario Parameters

| Vertical Clearance | Substructure Bridge Configuration | Span | Heat Release Rate | Position | Width |
|---|---|---|---|---|---|
| 6 m | Piers | 16 m | 1800 kW/m2 (diesel) | Mid-span | 13 m |
| 9 m | Abutment | 24 m | 2400 kW/m2 (gasoline) | Abutment or Pier | 23.4 m |

**Table 1.** Table of Scenario Parameters

$2^6$=64 different cases → $2^{6-1}$ = 32 cases

↑

Taguchi design of experiments technique

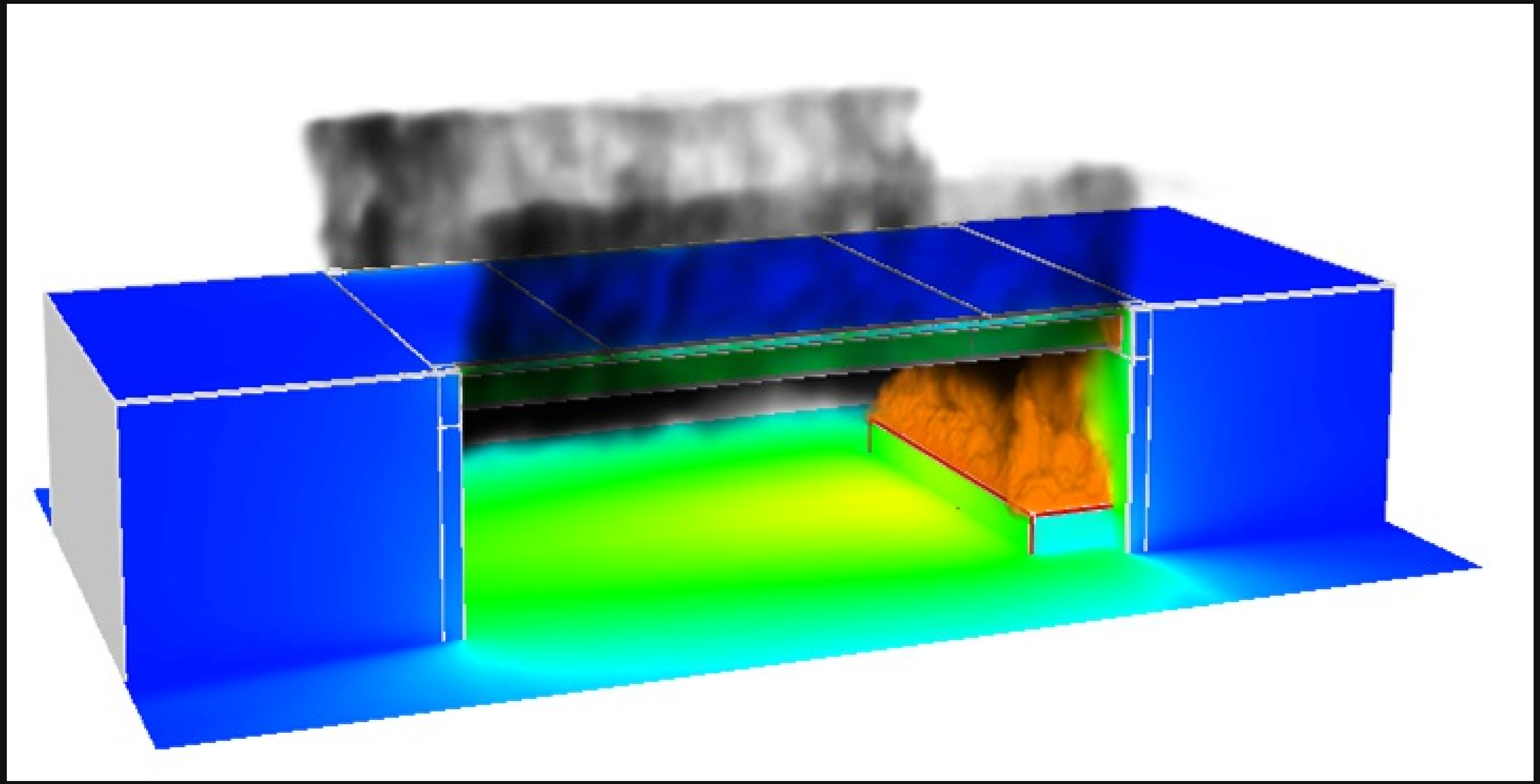
# Design of Experiments

| N° Simulation | Vertical Clearance 9m/6m | Abutment Configuration Abutment/Span | Span 16m / 24m | Heat Release rate 1800-2400 kW/m2 | Position Central/Abutment | Width 13m / 23.4m |
|---|---|---|---|---|---|---|
| | Factors | | | | | |
| 1 | 9m | Piers | 24m | 2400 kW/m2 | Abutment | 23.4m |
| 2 | 6m | Piers | 24m | 2400 kW/m2 | Abutment | 13m |
| 3 | 9m | Abutment | 24m | 2400 kW/m2 | Abutment | 13m |
| 4 | 6m | Abutment | 24m | 2400 kW/m2 | Abutment | 23.4m |
| 5 | 9m | Piers | 16m | 2400 kW/m2 | Abutment | 13m |
| 6 | 6m | Piers | 16m | 2400 kW/m2 | Abutment | 23.4m |
| 7 | 9m | Abutment | 16m | 2400 kW/m2 | Abutment | 23.4m |
| 8 | 6m | Abutment | 16m | 2400 kW/m2 | Abutment | 13m |
| 9 | 9m | Piers | 24m | 1800 kW/m2 | Abutment | 13m |
| 10 | 6m | Piers | 24m | 1800 kW/m2 | Abutment | 23.4m |
| 11 | 9m | Abutment | 24m | 1800 kW/m2 | Abutment | 23.4m |
| 12 | 6m | Abutment | 24m | 1800 kW/m2 | Abutment | 13m |
| 13 | 9m | Piers | 16m | 1800 kW/m2 | Abutment | 23.4m |
| 14 | 6m | Piers | 16m | 1800 kW/m2 | Abutment | 13m |
| 15 | 9m | Abutment | 16m | 1800 kW/m2 | Abutment | 13m |
| 16 | 6m | Abutment | 16m | 1800 kW/m2 | Abutment | 23.4m |
| 17 | 9m | Piers | 24m | 2400 kW/m2 | Center-Span | 13m |
| 18 | 6m | Piers | 24m | 2400 kW/m2 | Center-Span | 23.4m |
| 19 | 9m | Abutment | 24m | 2400 kW/m2 | Center-Span | 23.4m |
| 20 | 6m | Abutment | 24m | 2400 kW/m2 | Center-Span | 13m |
| 21 | 9m | Piers | 16m | 2400 kW/m2 | Center-Span | 23.4m |
| 22 | 6m | Piers | 16m | 2400 kW/m2 | Center-Span | 13m |
| 23 | 9m | Abutment | 16m | 2400 kW/m2 | Center-Span | 13m |
| 24 | 6m | Abutment | 16m | 2400 kW/m2 | Center-Span | 23.4m |
| 25 | 9m | Piers | 24m | 1800 kW/m2 | Center-Span | 23.4m |
| 26 | 6m | Piers | 24m | 1800 kW/m2 | Center-Span | 13m |
| 27 | 9m | Abutment | 24m | 1800 kW/m2 | Center-Span | 13m |
| 28 | 6m | Abutment | 24m | 1800 kW/m2 | Center-Span | 23.4m |
| 29 | 9m | Piers | 16m | 1800 kW/m2 | Center-Span | 13m |
| 30 | 6m | Piers | 16m | 1800 kW/m2 | Center-Span | 23.4m |
| 31 | 9m | Abutment | 16m | 1800 kW/m2 | Center-Span | 23.4m |
| 32 | 6m | Abutment | 16m | 1800 kW/m2 | Center-Span | 13m |

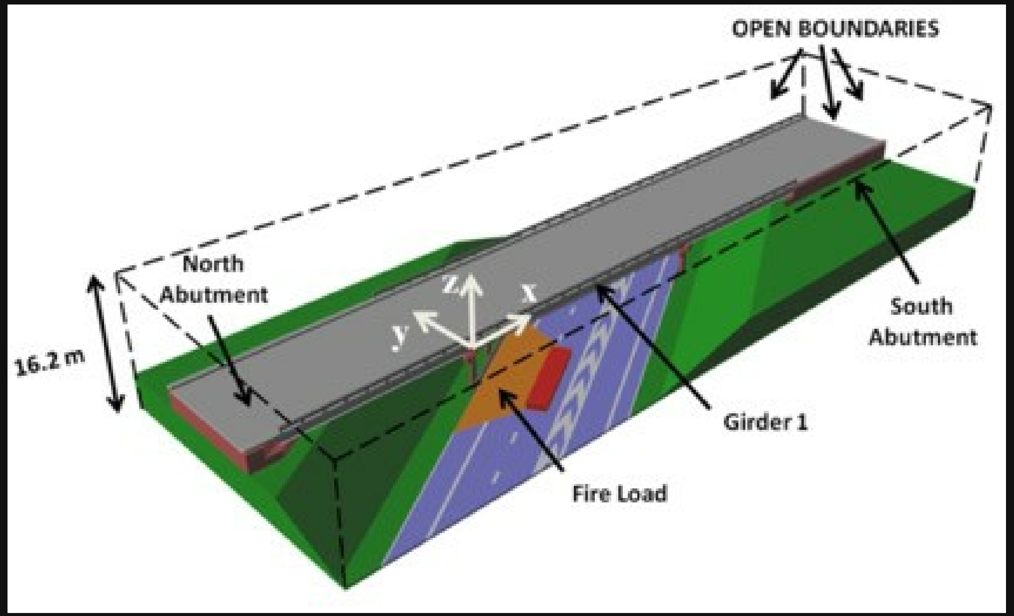
Temperatures?

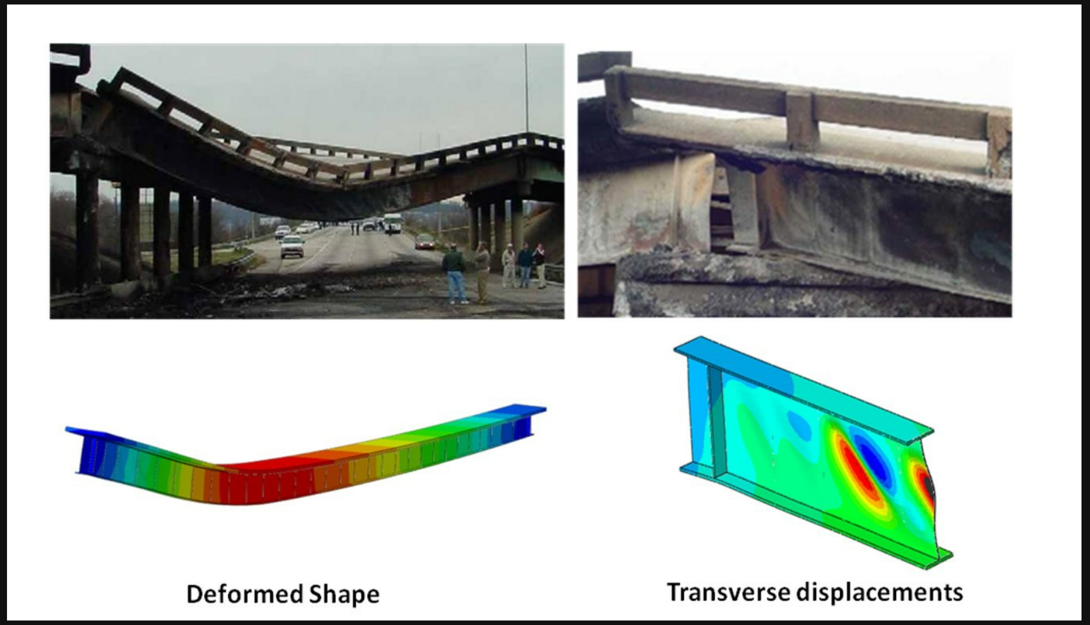
# CFD Simulations

Fire Model using FDS



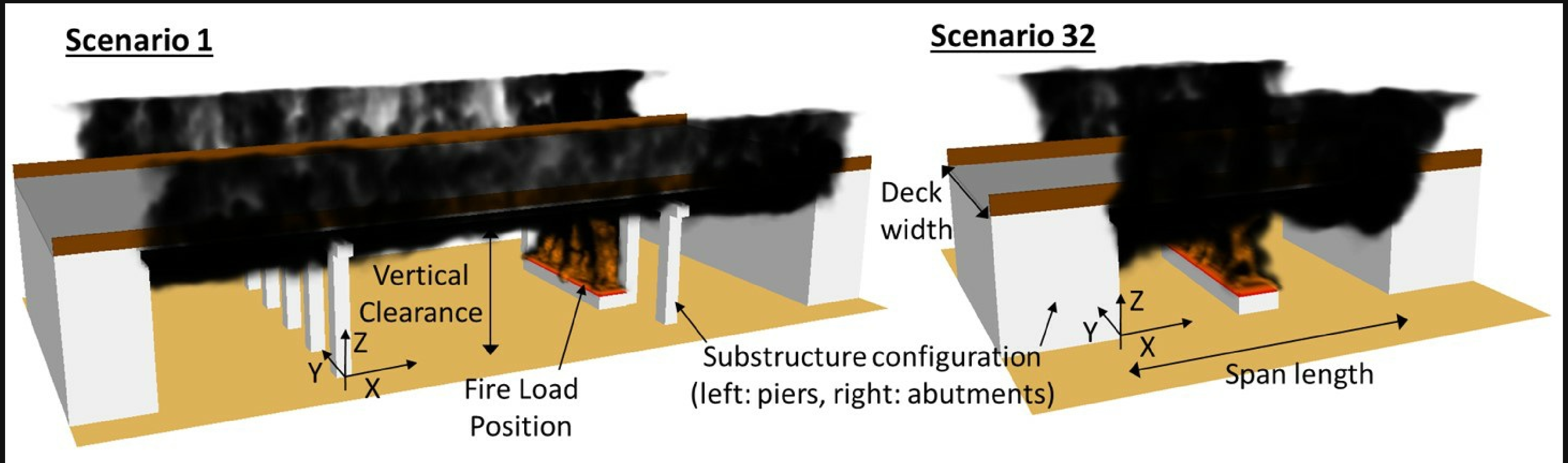
# CFD Simulations




Alós Moya et Al. "Analysis of a Bridge Failure due to fire using Computational Fluid Dynamics and Finite Element Models." Engineering Structures, 68, pp 96-110, 2014.

# CFD Simulations



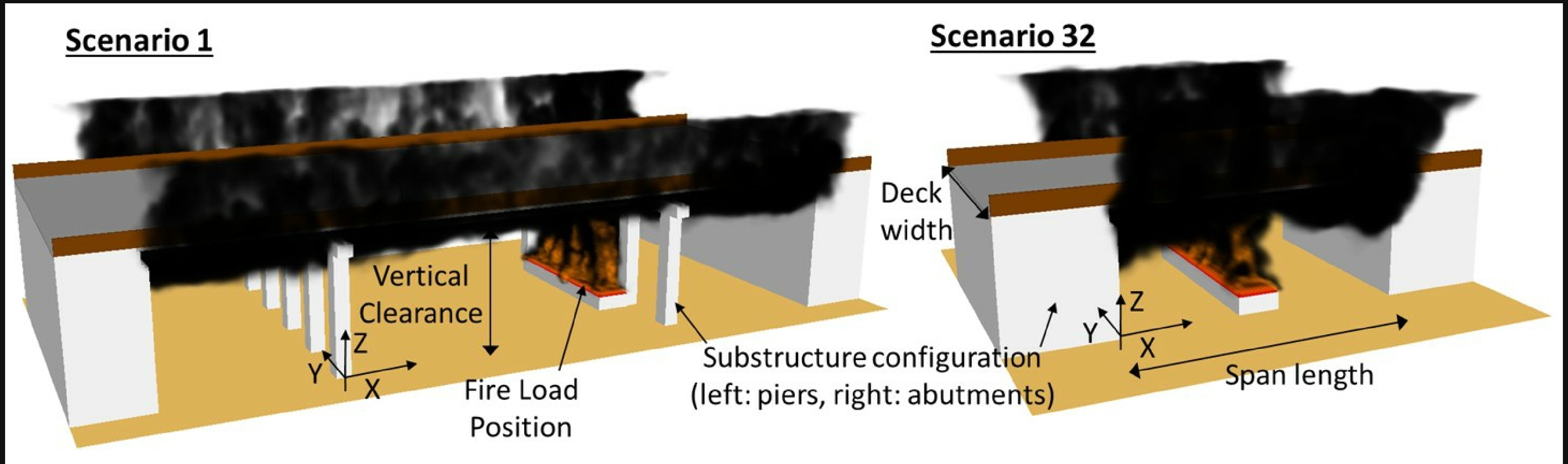

Control Volume: Varies according to the scenario.

- X-direction: 28 to 58 m
- Y-direction: 27 to 30 m
- Z-direction: 12 to 15 m

Mesh: 0.20 x 0.20 x 0.20 m.

- Total amount of cells: 1,134,000 to 3,262,500 cells

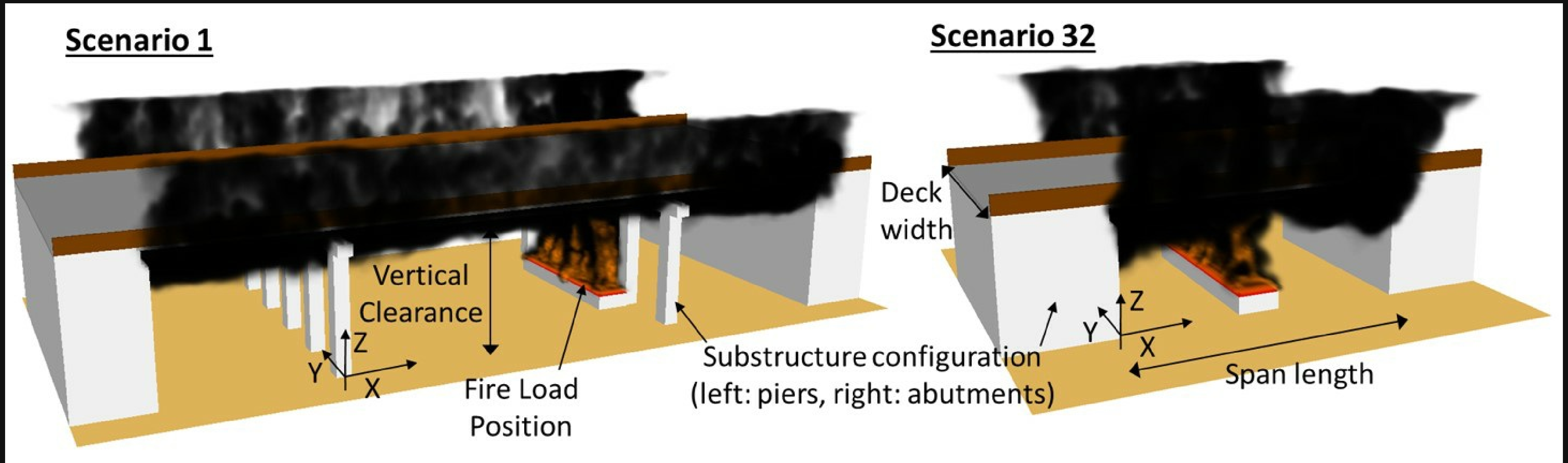
# CFD Simulations




Fire Load:

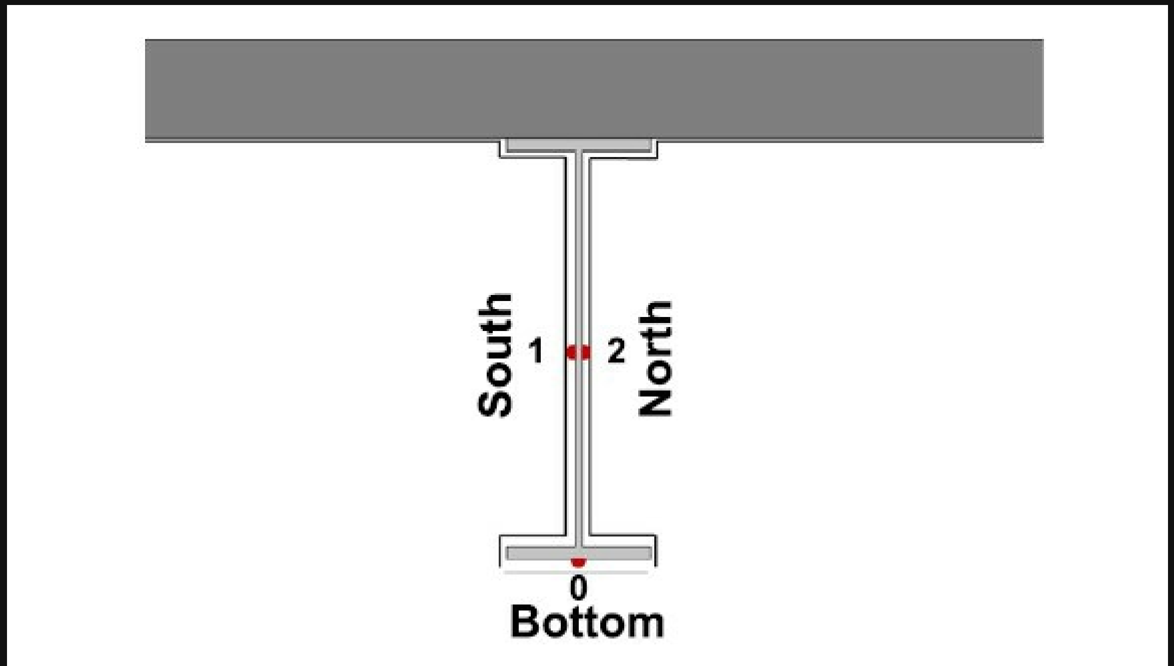
- Tanker truck: 30 m2 (12 x 2.5 m) at one meter above road level.
- HRR is a parameter
- CO yield and Soot Yield according to SFPE Handbook
- CO yield = 0.019 g/g
- Soot yield = 0.059 g/g

# CFD Simulations



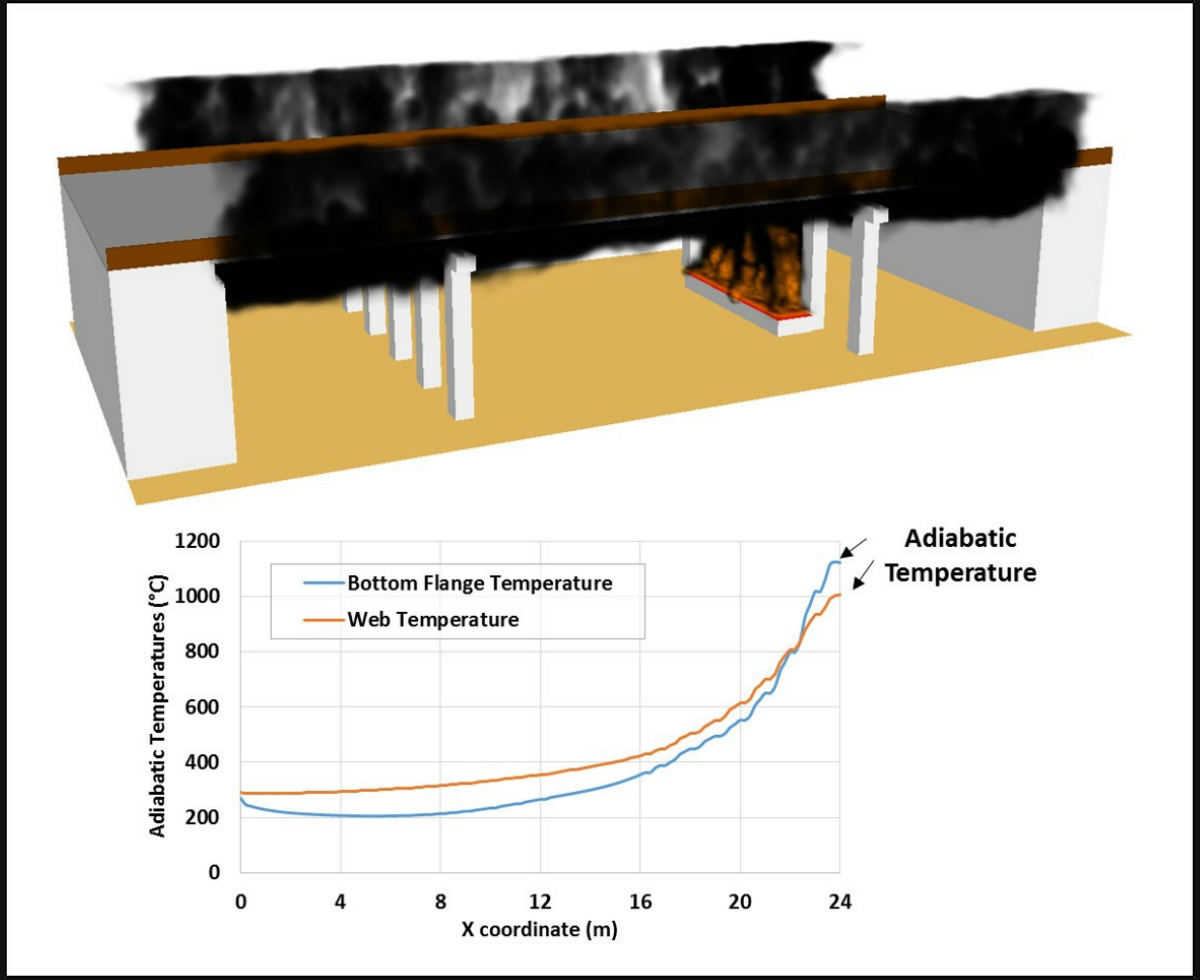

Adiabatic Temperatures

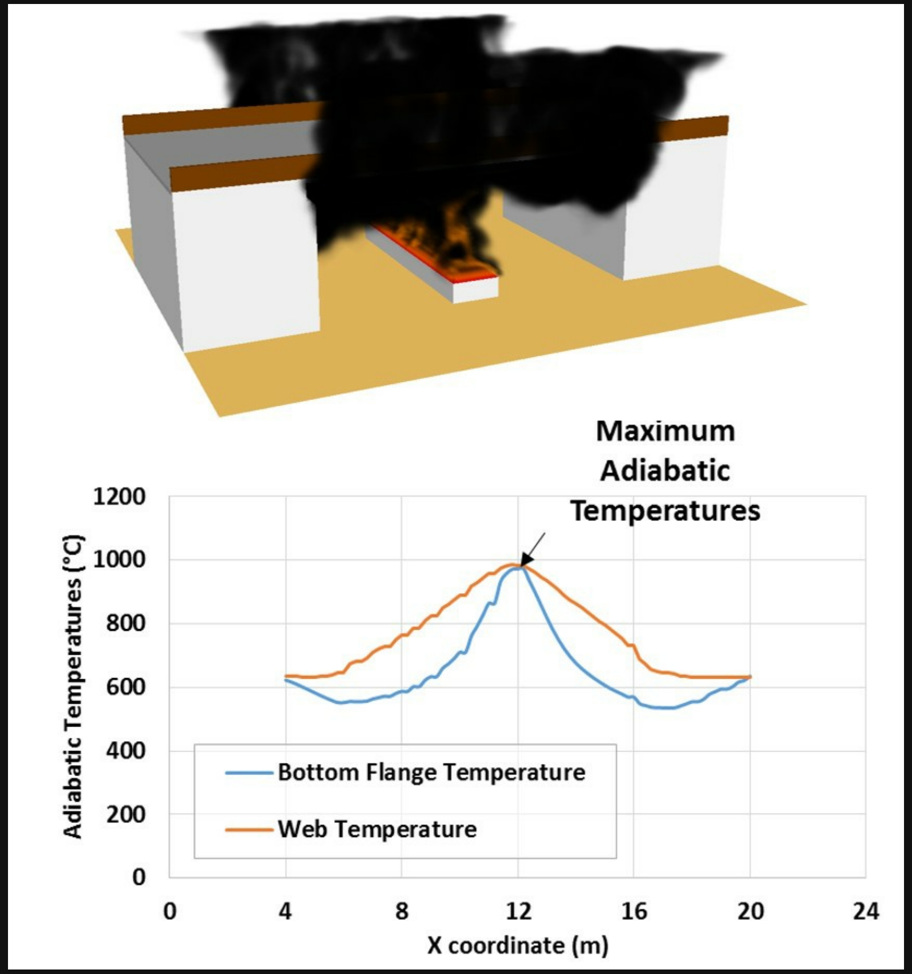
- Sensors every 20 cm
- 3 sensors per section
- Most exposed girder



# CFD Simulations

Adiabatic temperatures along the most exposed girder



# ANOVA ANALYSIS

Maximum Adiabatic Temperatures

| Maximum Temperatures | | | Maximum Temperatures | | | Maximum Temperatures | | |
|---|---|---|---|---|---|---|---|---|
| **Case** | **Flange** | **Web** | **Case** | **Flange** | **Web** | **Case** | **Flange** | **Web** |
| **1** | 1126 | 1014 | **12** | 1114 | 1160 | **23** | 909 | 886 |
| **2** | 1323 | 1294 | **13** | 990 | 820 | **24** | 1073 | 1166 |
| **3** | 1301 | 1340 | **14** | 1253 | 1157 | **25** | 694 | 629 |
| **4** | 1248 | 1312 | **15** | 1178 | 1215 | **26** | 1043 | 1038 |
| **5** | 1170 | 1064 | **16** | 1225 | 1290 | **27** | 711 | 650 |
| **6** | 1288 | 1278 | **17** | 905 | 877 | **28** | 1022 | 1028 |
| **7** | 1170 | 1226 | **18** | 1162 | 1208 | **29** | 702 | 646 |
| **8** | 1081 | 1133 | **19** | 902 | 871 | **30** | 1037 | 1044 |
| **9** | 990 | 821 | **20** | 1158 | 1208 | **31** | 696 | 641 |
| **10** | 1246 | 1173 | **21** | 704 | 646 | **32** | 973 | 1000 |
| **11** | 1188 | 1216 | **22** | 1157 | 1204 | | | |

What parameters are responsible for these values?

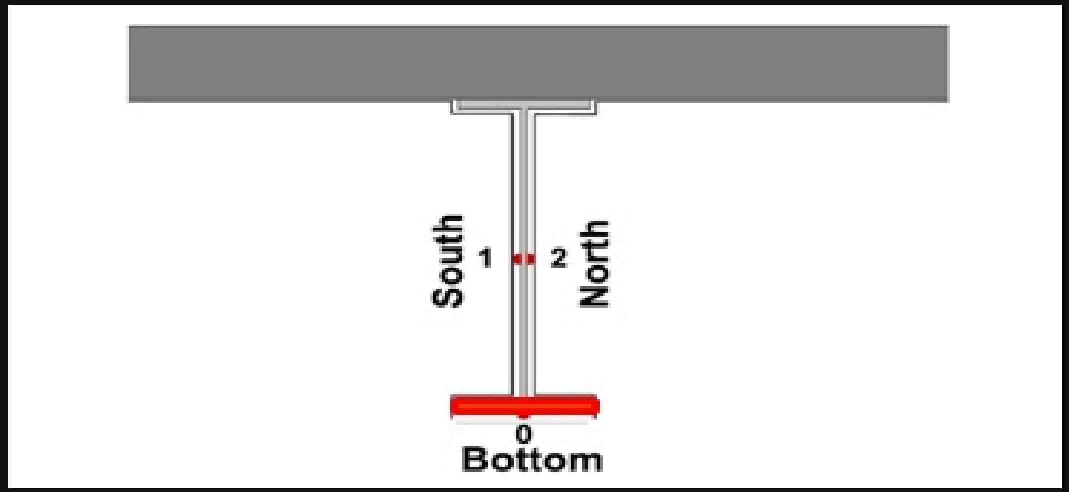
⬇

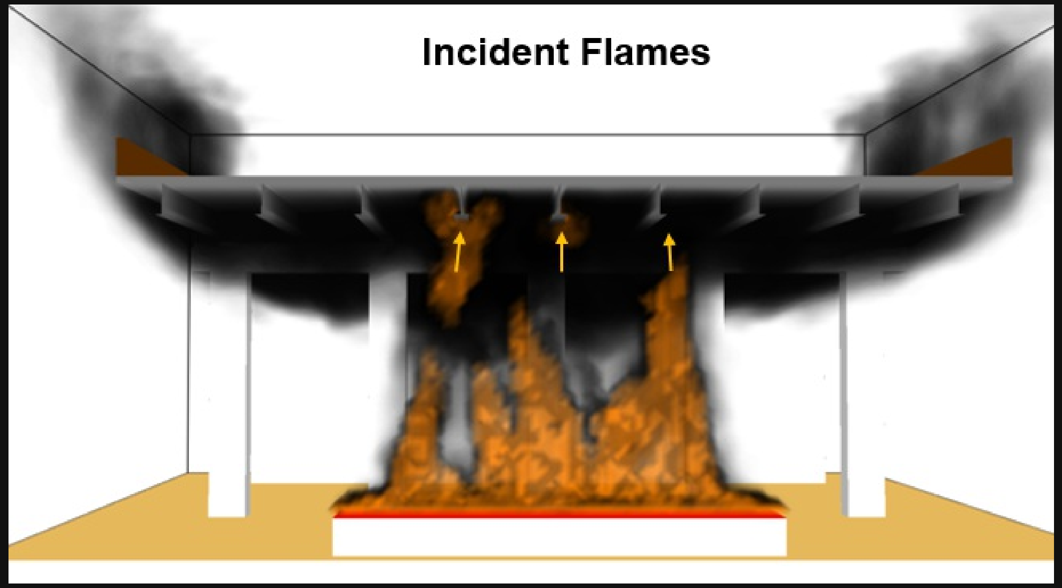
ANOVA
(Analysis of Variance)

# ANOVA ANALYSIS

## Bottom Flange Temperatures

| Flange Temperatures | p-value |
|---|---|
| Principal Effects | |
| A: Vertical Clearance | 0,0000 |
| B: Bridge Substructure | 0,6042 |
| C: Span Length | 0,1039 |
| D: Heat Release Rate | 0,0003 |
| E: Position of the Fire Load | 0,0000 |
| F: Bridge Width | 0,5201 |
| Interactions | |
| AB: Clearance-Bridge Sub. | 0,0008 |
| AC | 0,8223 |
| AD | 0,1503 |
| AE: Clearance-Position | 0,0002 |
| AF | 0,0721 |
| BC | 0,6180 |
| BD | 0,6349 |
| BE | 0,7954 |
| BF | 0,2116 |
| CD | 0,0630 |
| CE | 0,5878 |
| CF | 0,3627 |
| DE | 0,0843 |
| DF | 0,1482 |
| EF | 0,2784 |
| Residuals | |
| Total | |



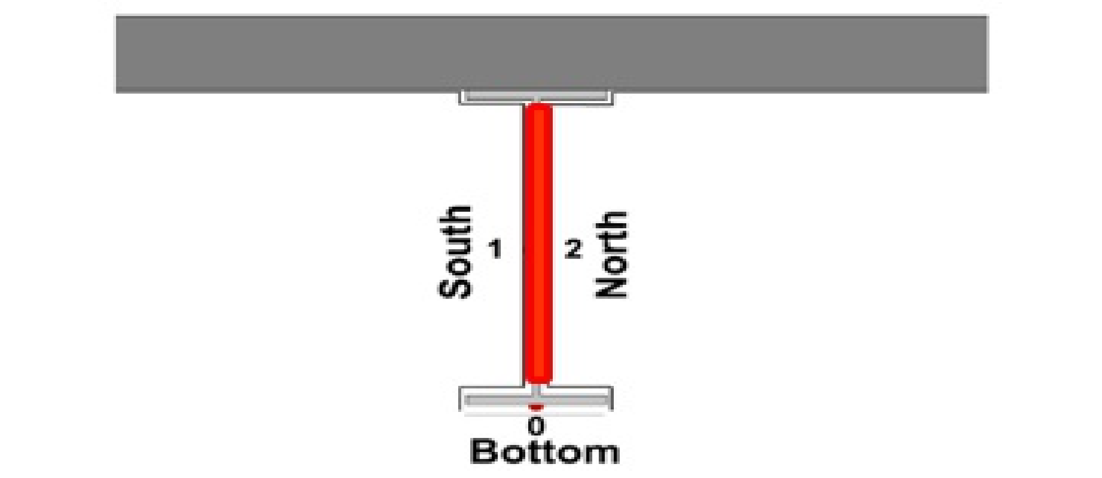



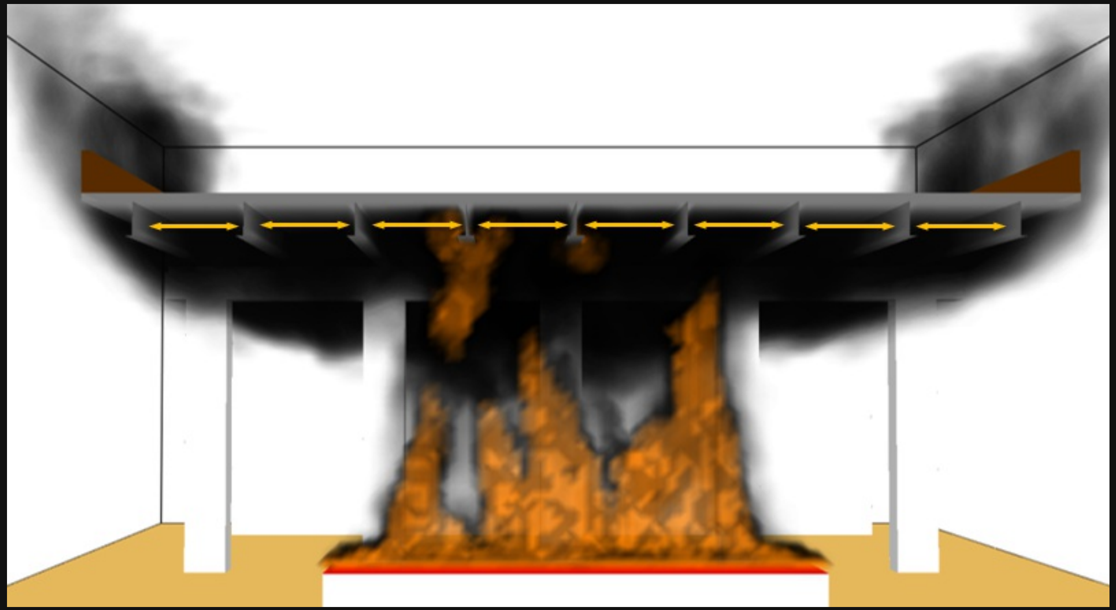

p-values below 0.05 indicate significance influence

# ANOVA ANALYSIS

## Web Temperatures

| Web Temperatures | p-value |
|---|---|
| **Principal Effects** | |
| A: Vertical Clearance | 0,0000 |
| B: Bridge Substructure | 0,0074 |
| C: Span Length | 0,3479 |
| D: Heat Release Rate | 0,0004 |
| E: Position of the Fire Load | 0,0000 |
| F: Bridge Width | 0,7659 |
| **Interactions** | |
| AB: Clearance-Bridge Sub. | 0,0034 |
| AC | 0,7708 |
| AD | 0,4047 |
| AE: Clearance-Position | 0,0010 |
| AF | 0,1131 |
| BC | 0,9404 |
| BD | 0,4782 |
| BE: Bridge Sub.-Position | 0,0261 |
| BF | 0,3195 |
| CD | 0,1761 |
| CE | 0,7679 |
| CF | 0,5592 |
| DE | 0,2030 |
| DF | 0,3271 |
| EF | 0,3480 |
| **Residuals** | |
| **Total** | |



p-values below 0.05 indicate significance influence

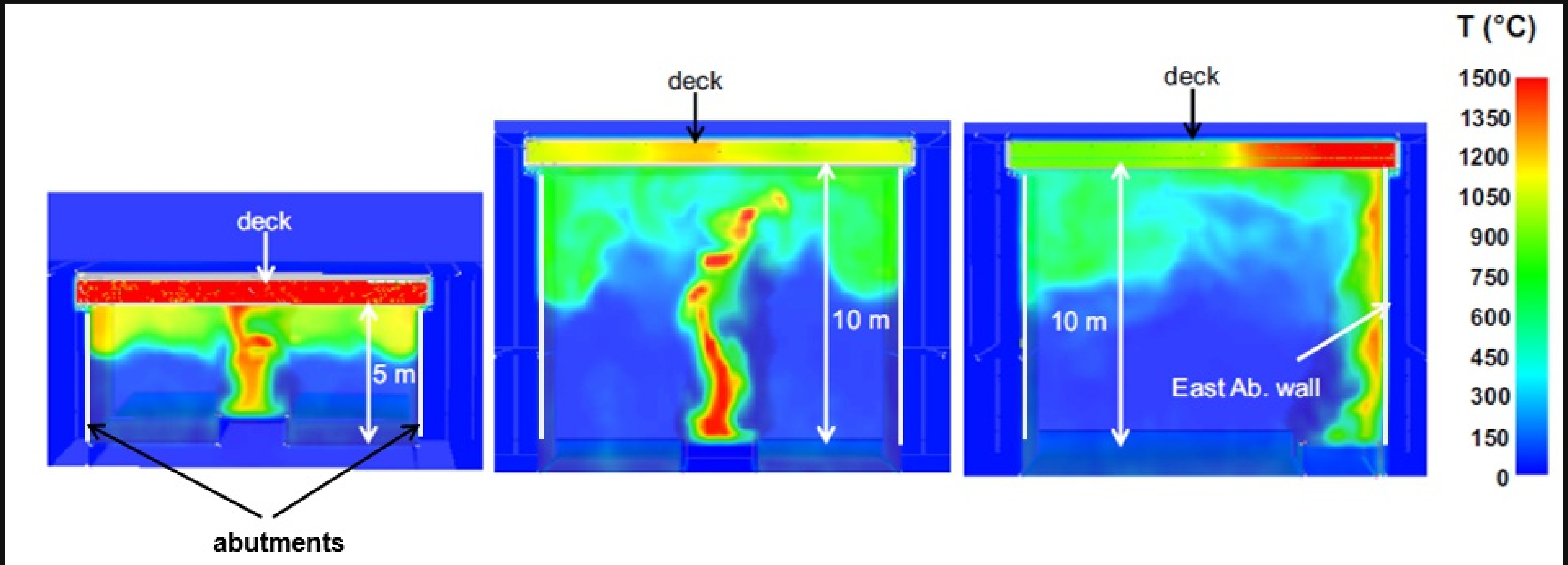
# ANOVA ANALYSIS

## Web Temperatures


# ANOVA ANALYSIS

Interactions (synergies)

clearance - position - bridge substructure




Coandâ Effect

# STRUCTURAL ANALYSIS

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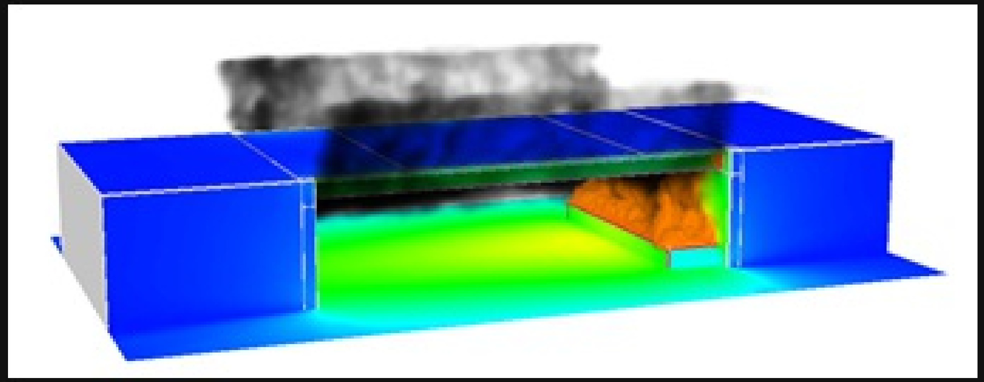
**Fire Model (FDS)** →

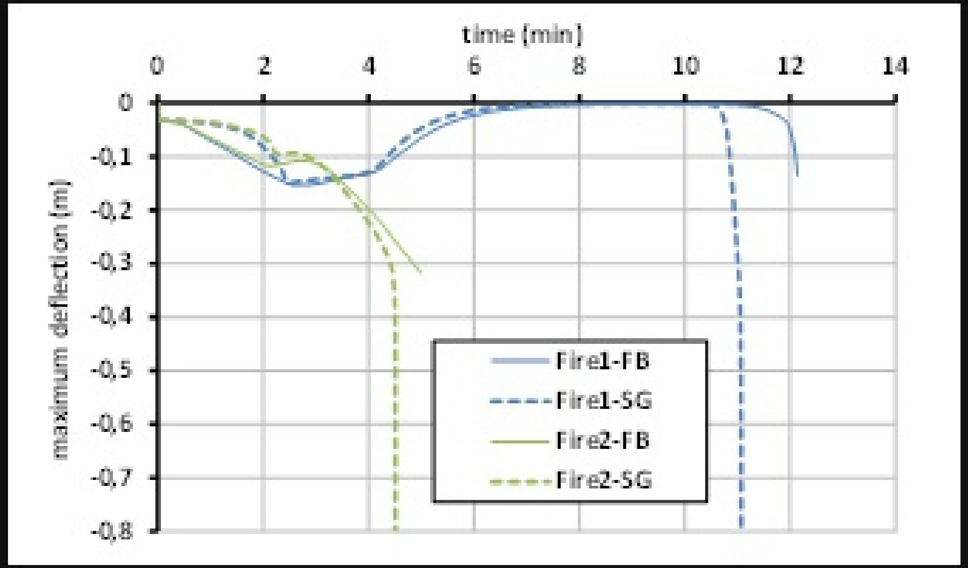


**gas temperatures**

**Heat transfer model (Abaqus)** →

**Temperatures in steel and concrete**

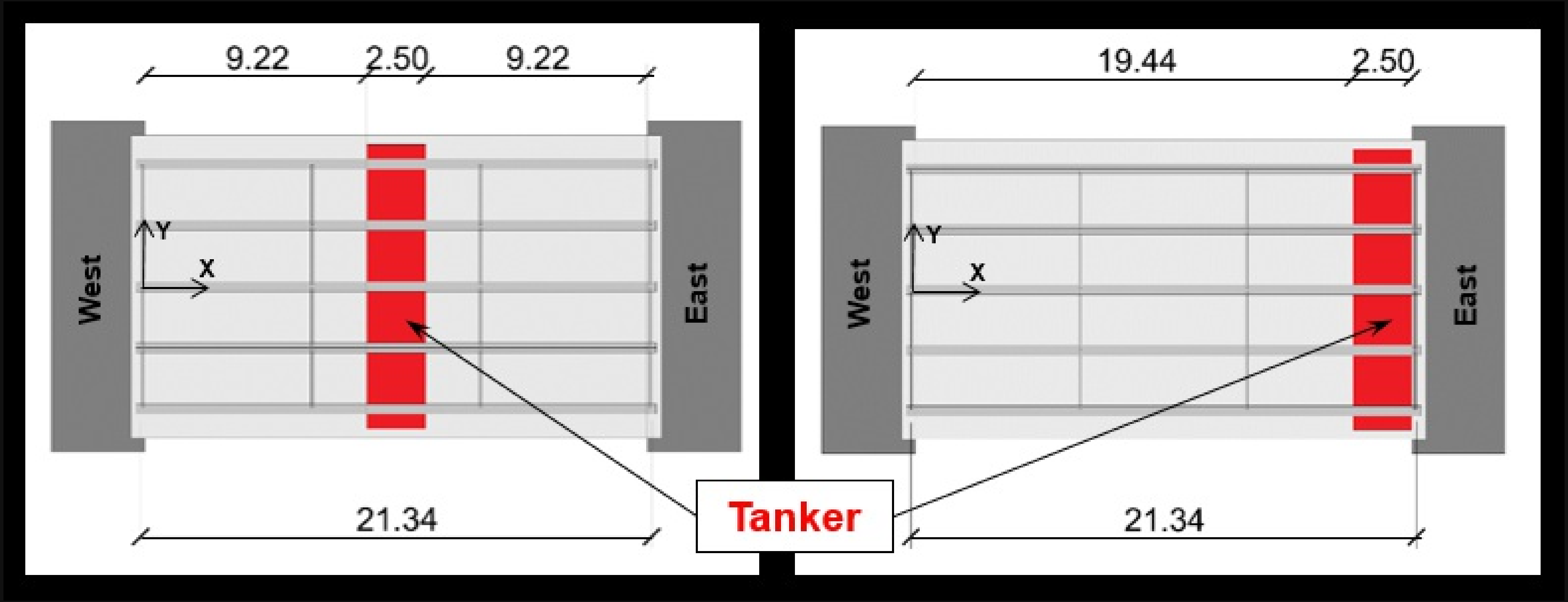
**Structural model (Abaqus)** →




**Mechanical response**

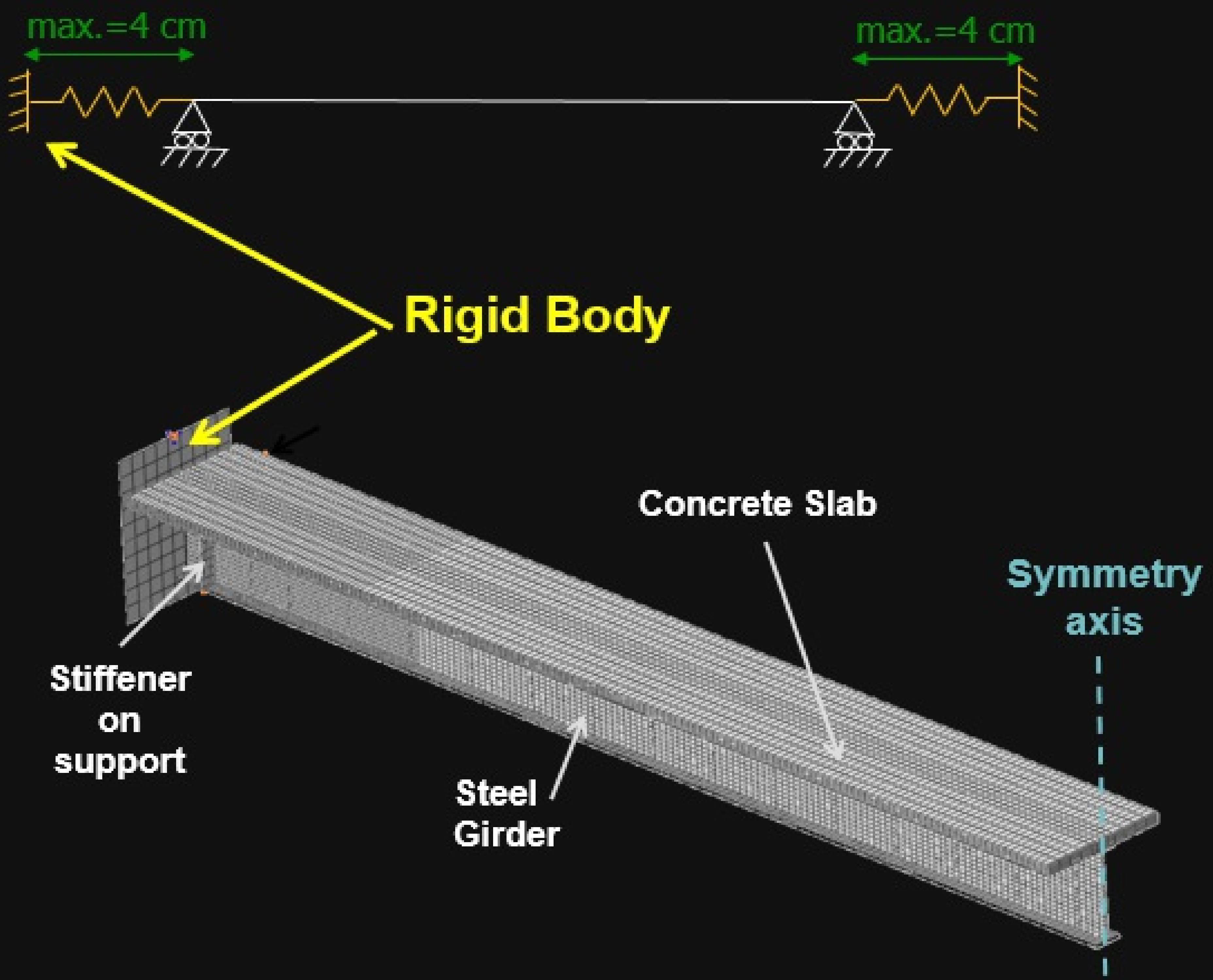
non-linear mechanical
non-linear geometrical
temperature dependent material properties
time dependent

# CASE STUDY



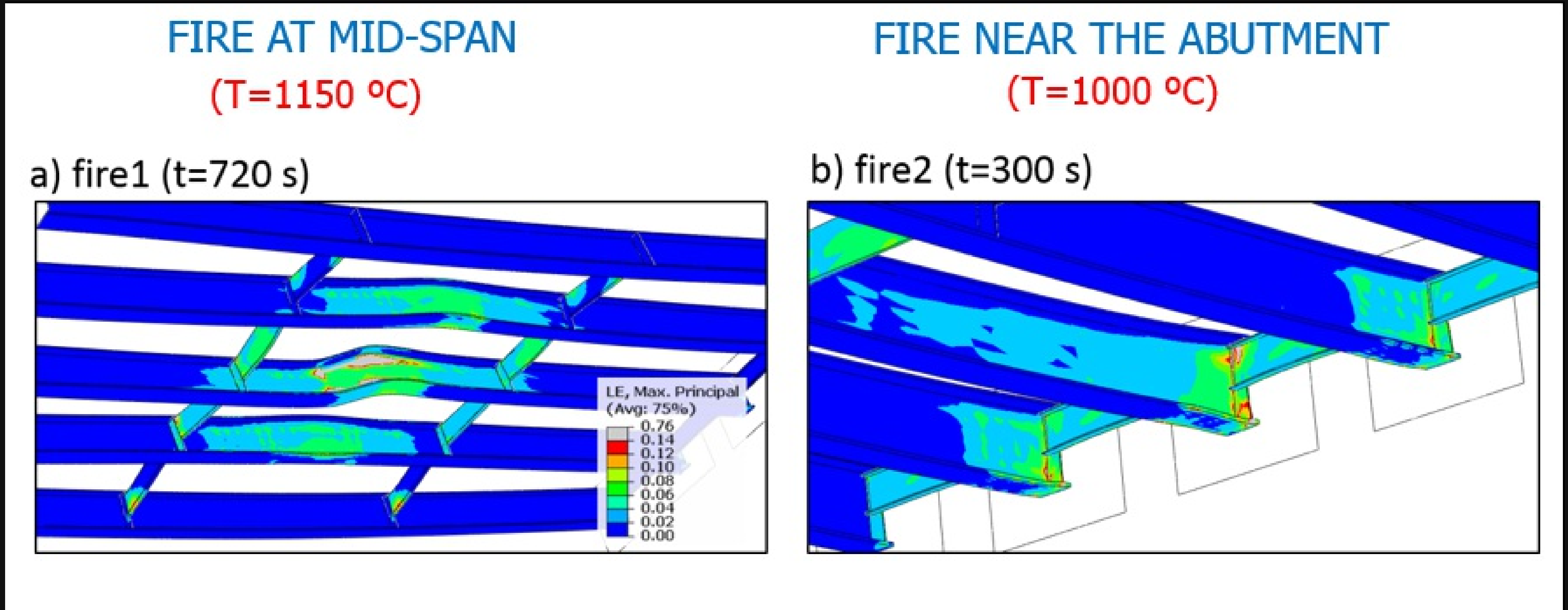

- 21 meters span
- 5 girders
- 2 fire scenarios

# BOUNDARIES


max.=4 cm
max.=4 cm
Rigid Body
Concrete Slab
Symmetry axis
Stiffener on support
Steel Girder

# RESULTS AND CONCLUSIONS

Bridges fail by yielding of the steel girder when steel reaches its ultimate strain

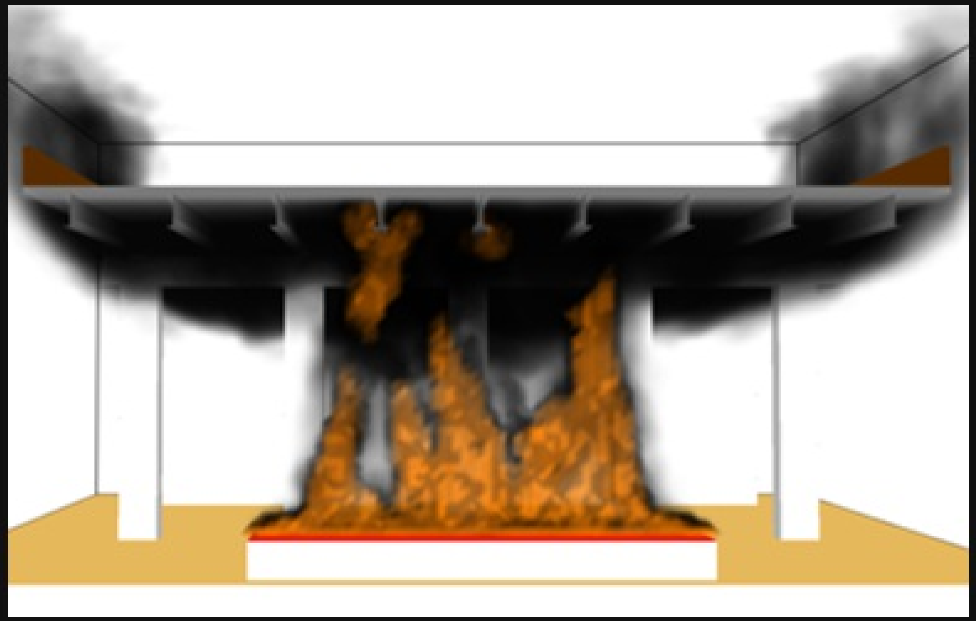



Different times and modes of failure

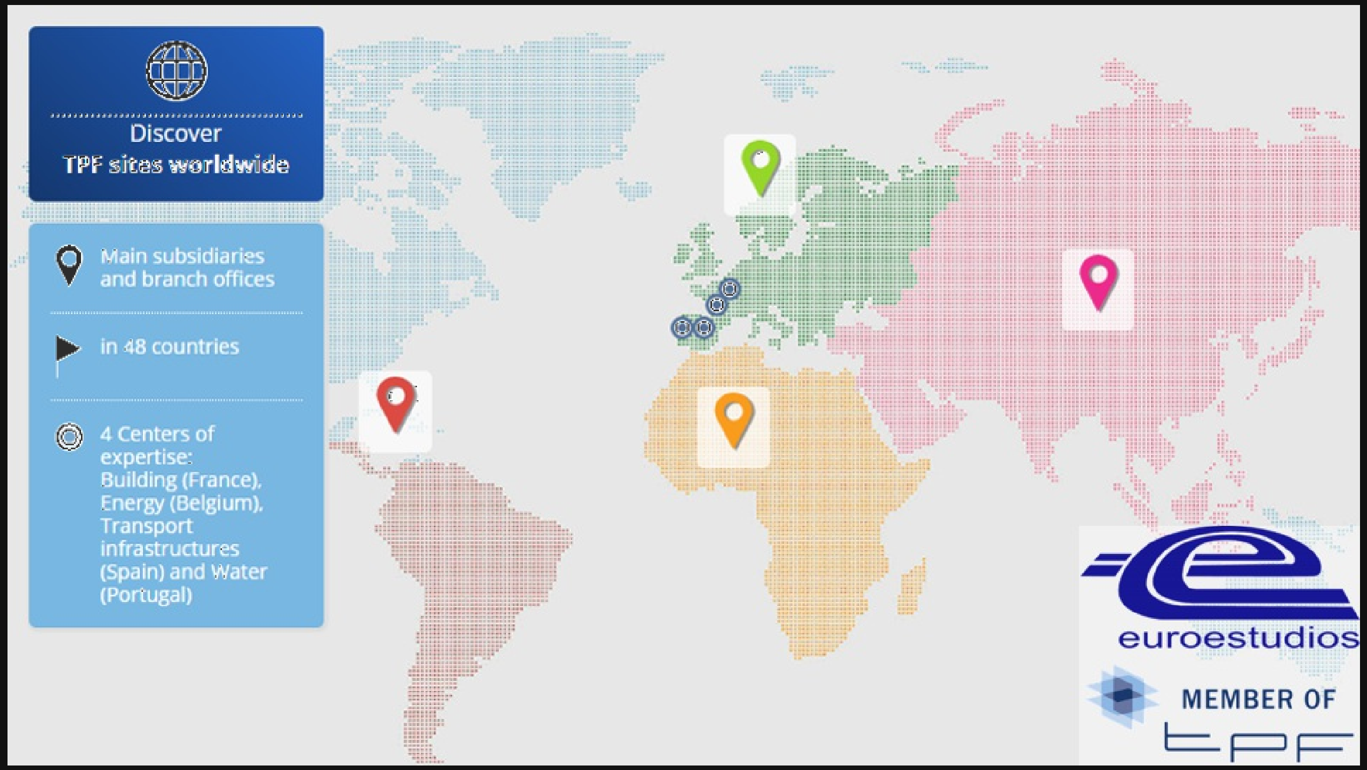
# CONCLUSIONS AND FUTURE WORK

1. Vertical Clearance, HRR and fire position have an influence in flange temperatures
2. Web temperatures are also influenced by the bridge substructure configuration
3. Interactions have to be taken into account (Coandâ Effect)
4. Position of the fire load also influence the structural behavior

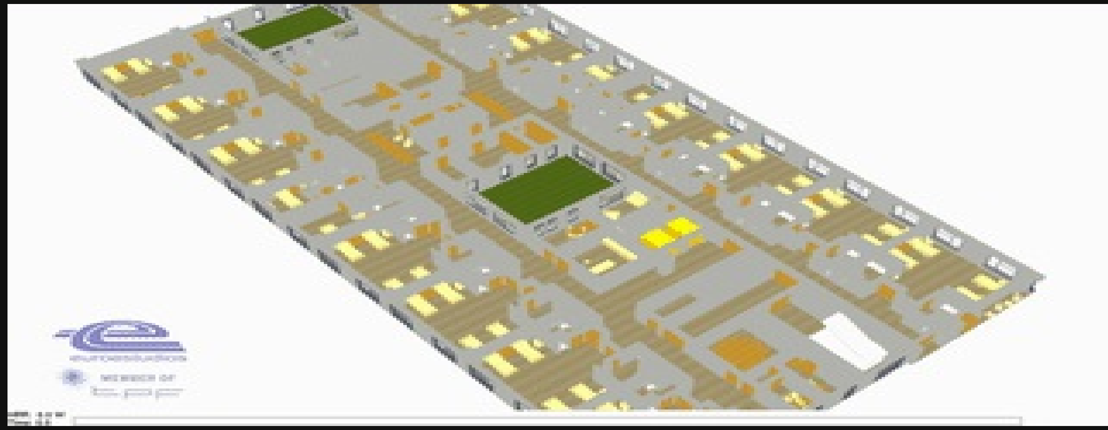
THESE CONCLUSIONS SHOULD BE CONSIDERED IN FUTURE PROPOSALS OF FIRE CURVES SPECIFIC FOR BRIDGES



# EUROESTUDIOS




- Madrid (Spain)
- Part of TPF Group
- Civil Engineering and Building Development Consulting Company
- Strong Focus on New Technologies - BIM and Computer Simulations



Thanks for looking :-)