Capacity for Rail

Effect of very High Speed on track and bridges

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Systra

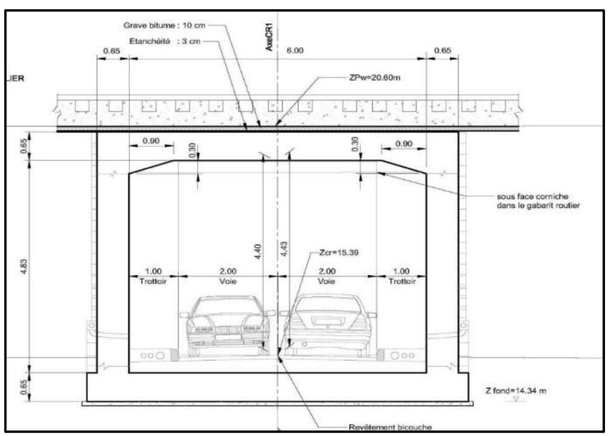
SEVENTH FRAMEWORK PROGRAMME

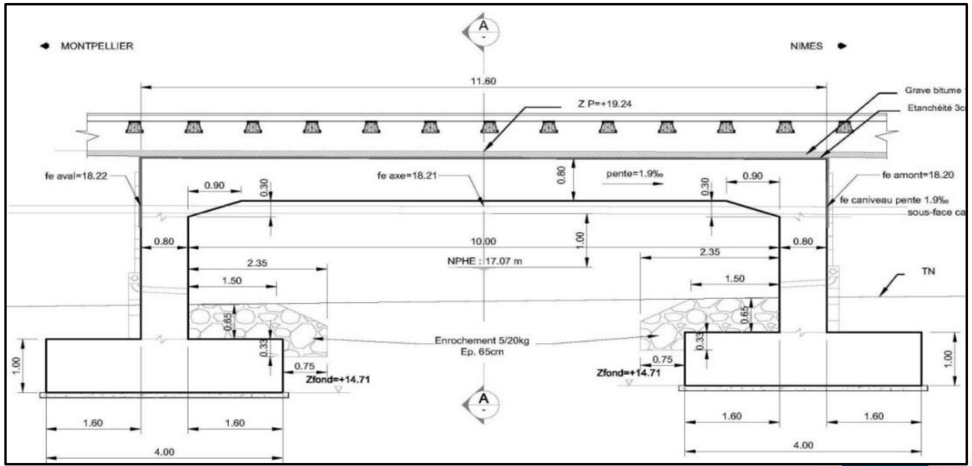
- **Dynamic behaviour of short span bridges for very high speed line**
  - **Selected Portal Frame Bridges and Characteristics for Dynamic Analysis**
  - **2D Model**
  - **Results Dynamic Analysis (10 HSLM Trains)**
- **Comfort Analysis of short span bridges for very high speed line**
  - **Characteristics for Comfort Analysis**
  - **2D Model**
  - **Results (French TGV and ICE2 2D Model)**
  - **3D Model**
  - **Results (French TGV 3D Model)**
- **Particular effects of track irregularities**
  - **Track irregularities**
  - **Results**

Selected portal Frame Bridges and Characteristics for Dynamic Analysis

- Calculation models are being created
- Bridge responses to passing HSLM trains are studied
- Speeds up to 480 km/h
- Following bridge types are found important to focus on

Type	Span Length [m]	Height of side wall [m]
Reinforced concrete open frame	10	5
Reinforced concrete open frame	15	5
Reinforced concrete closed frame	5	5
Reinforced concrete closed frame	10	5





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Selected portal Frame Bridges and Characteristics for Dynamic Analysis

Type	Span Length [m]	Height of side wall [m]	Side wall thickness [m]	Deck thickness [m]	Width [m]	Foundation	Footing thickness [m]	Footing width [m]	Span Length/Deck thickness
Reinforced concrete open frame	10	5	0.85	0.85	12.9	Footing	1	5.3	12
Reinforced concrete open frame	15	5	1.2	1.2	12.9	Footing	1.1	5.3	13

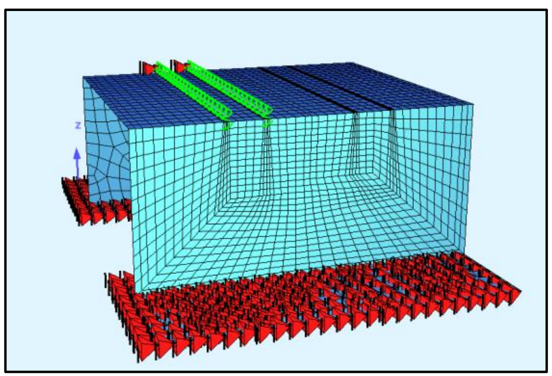
Selected portal Frame Bridges and Characteristics for Dynamic Analysis

Type	Span Length [m]	Height of side wall [m]	Side wall thickness [m]	Deck thickness [m]	Width [m]	Foundation	Footing thickness [m]	Footing width [m]	Span Length/Deck thickness
Reinforced concrete closed frame	10	5	1	1	12.9	Footing	1	-	10
Reinforced concrete closed frame	5	5	0.6	0.6	12.9	Footing	0.6	-	8

2D Model

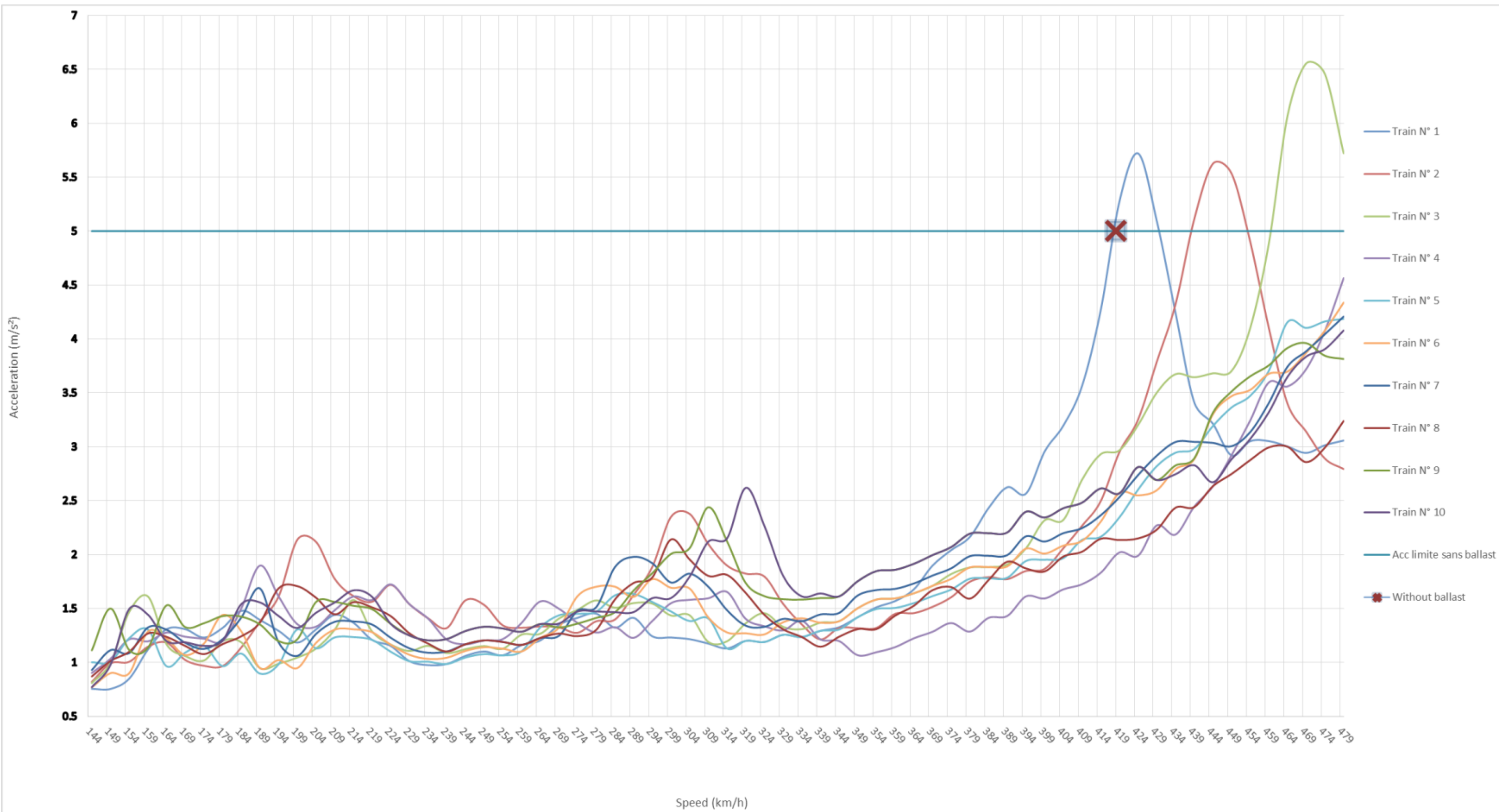
- Perfect contact between train and bridge, two loaded lane are considered with and without Ballast
- Ballast is modelled between rail and bridge. Ballast is modelled between rail and bridge. Two tracks are modelled, the ballast has a vertical stiffness equal to 25000 KN/lm
- 10 HSLM trains are considered.
- Wilson – Theta integration Method
- Time step 0.003s
- Speed step 5 Km/h

	Open frame 10m	Open frame 15m	Closed frame 5m	Closed frame 10m
Masses [tons]	1104	1702	505	1238
ξ [%]	2.141	1.766	2.508	2.13
Δξ [%]	0.387	0.628	0.128	0.398
Total damping [%]	2.528	2.394	2.636	2.528
f1 (First Vertical Frequency) [Hz]	6.541	5.268	8.722	7.025
f2 (F max) [Hz]	30.000	30	30	30
Rayleigh Mass proportional damping A	1.706	1.348	2.238	1.808
Rayleigh Stiffness proportional damping B	0.000220	0.000216	0.000217	0.000217



C4R Capacity for Rail

Results: Acceleration at mid span (tracks without Ballast), 10 HSLM Trains for Open Frame 10m



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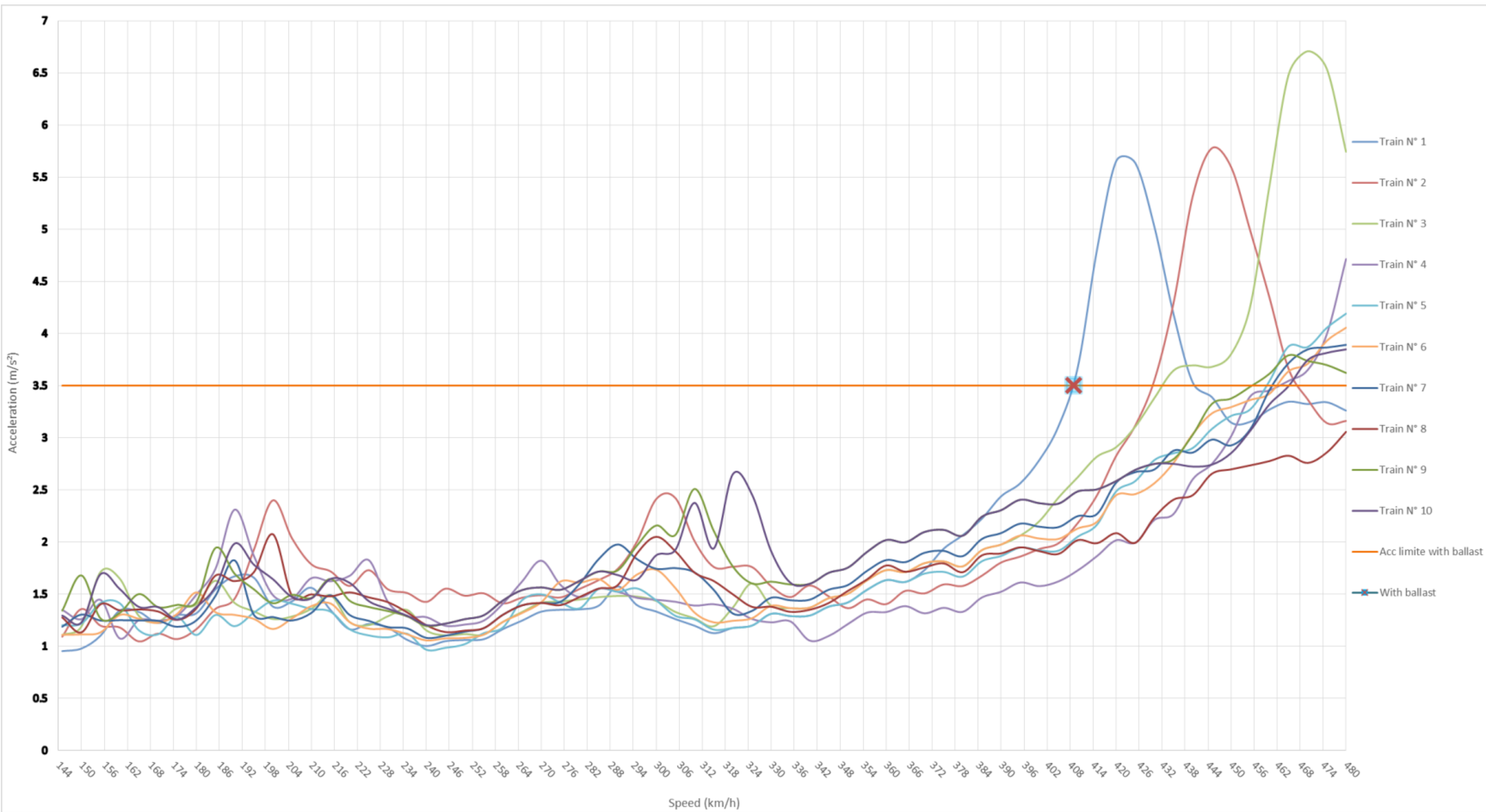
Results: Acceleration at mid span (tracks with Ballast), 10 HSLM Trains for Open Frame 10m



Results:

Type	Open Frame 10m		Open Frame 15m		Closed Frame 5m		Closed Frame 10m	
	With Ballast	Without Ballast	With Ballast	Without Ballast	With Ballast	Without Ballast	With Ballast	Without Ballast
	acc=3.5m/s²	acc=5 m/s²	acc=3.5m/s²	acc=5 m/s²	acc=3.5m/s²	acc=5 m/s²	acc=3.5m/s²	acc=5 m/s²
Speed max (km/h)	**406**	**415**	**430**	**480**	**252**	**310**	**438**	**448**

Conclusions:

- For closed frame bridges, lower is the spans length, higher is the resonance risk for high speed. The vertical acceleration at mid span for 5m closed frame bridge is higher than acceleration for 10m closed Frame Bridge.

- For open frame bridges, lower is the spans length, higher is the resonance risk for high speed. The vertical acceleration at mid span for 10m open frame bridge is higher than acceleration for 15m open Frame Bridge.

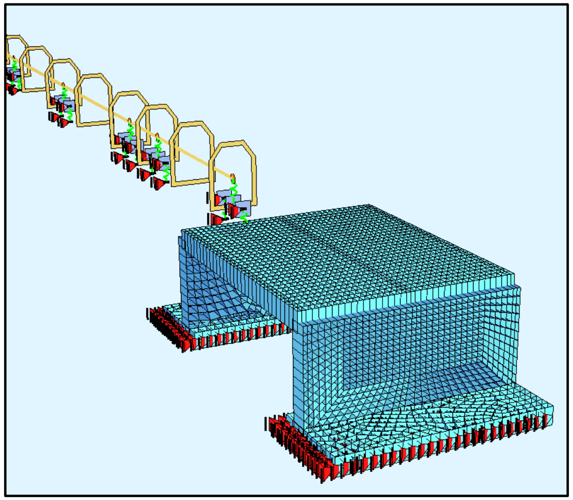
- The results of studied bridges are higher than limit of 3.5 m/s^2 for ballasted track or 5 m/s^2 for track without ballast. To respect these limitations we have redesigned the thickness of deck and increased the value as below:

Open frame 10m: from 0.85m to 1.00m
Open frame 15m: from 1.20m to 1.30m
Closed frame 5m: from 0.60m to 0.85m
Closed frame 10m: from 1.00m to 1.15m

Characteristics for Comfort Analysis 2D Model

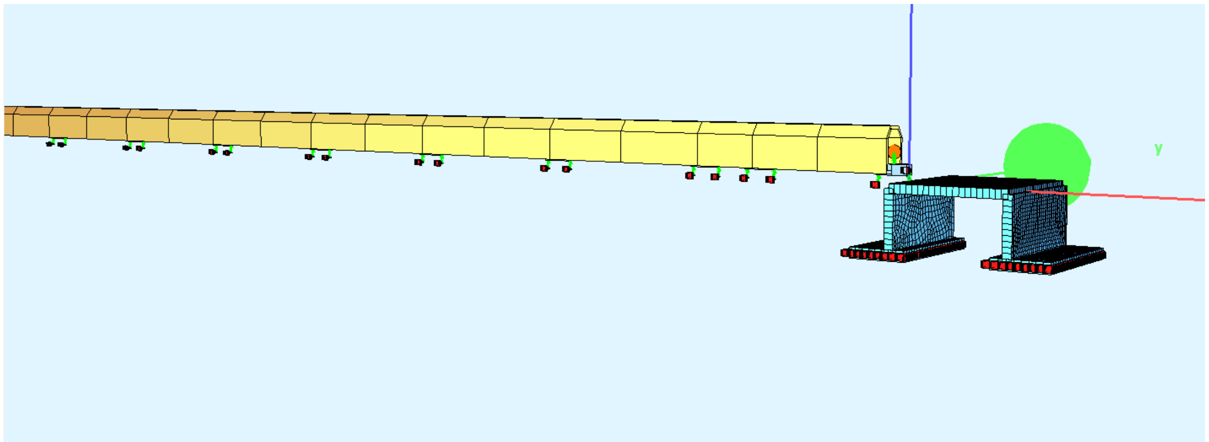
- Perfect contact between train and bridge, only one loaded lane is considered
- 2D models for French TGV and ICE2
- No track is modelled
- No track irregularities are considered
- Speed from 144 Km/h to 400 Km/h with a step of speed equal to 5 Km/h
- Time step is 0.003s

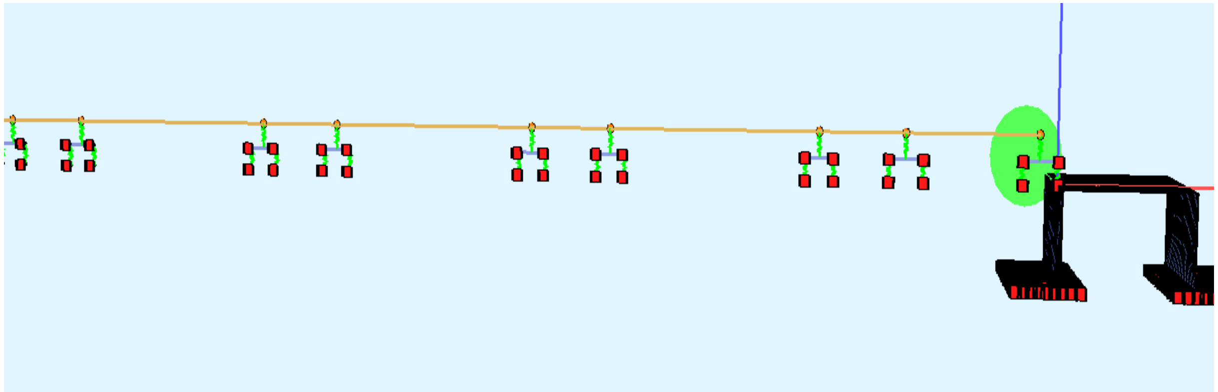
	Open frame 10m	Open frame 15m	Closed frame 5m	Closed frame 10m
Masses [tons]	1104	1702	505	1238
ξ %	2.141	1.766	2.508	2.13
f1 (First Vertical Frequency) [Hz]	6.541	5.268	8.722	7.025
f2 (F max) [Hz]	30.000	30	30	30
Rayleigh Mass proportional damping A	1.445	0.994	2.130	1.524
Rayleigh Stiffness proportional damping B	0.000187	0.000159	0.000206	0.000183



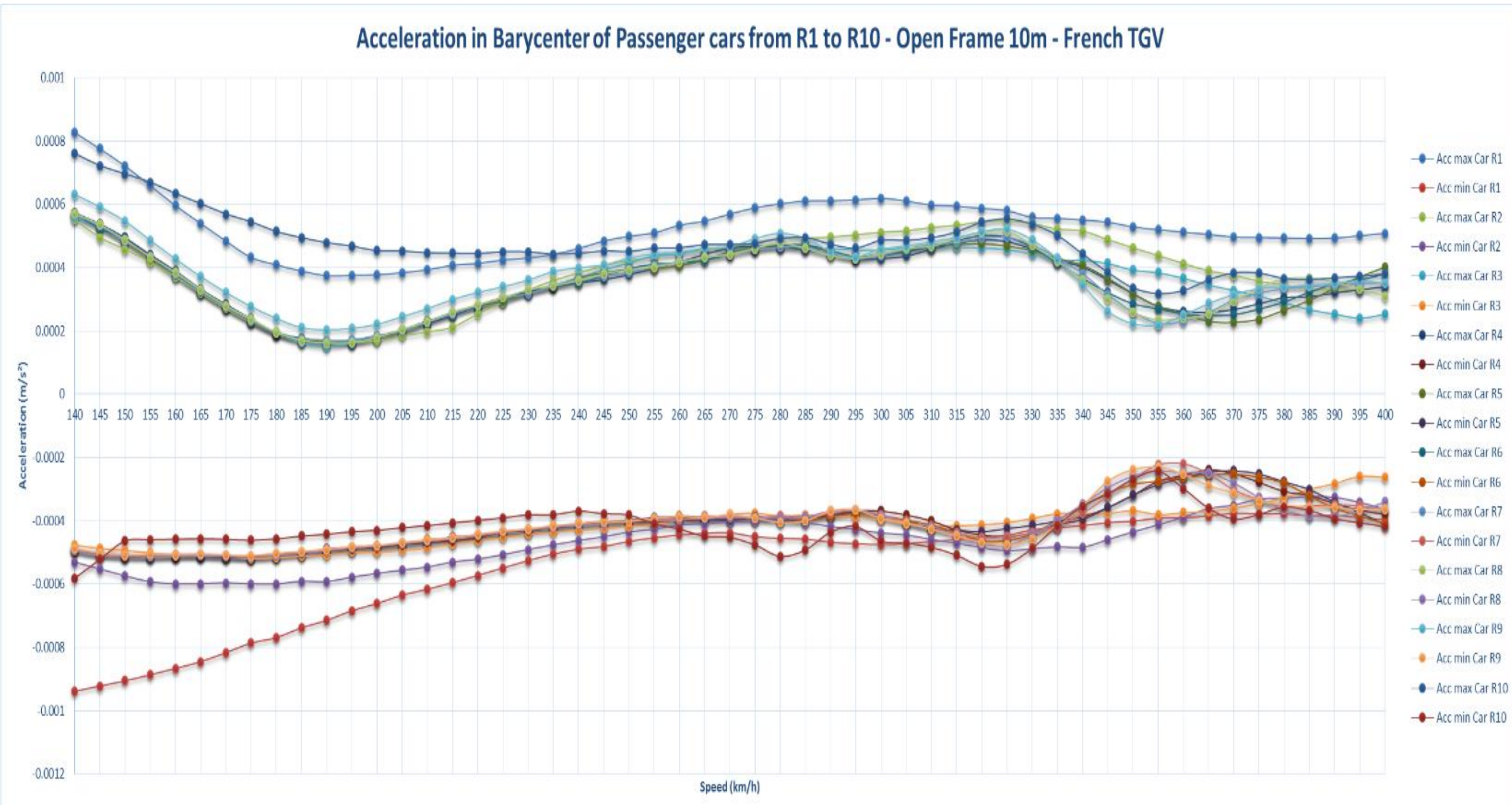
Characteristics for Comfort Analysis 2D Model

- 2D models for French TGV and ICE2





Results (French TGV and ICE2 2D Model) for Open Frame Bridge 10m



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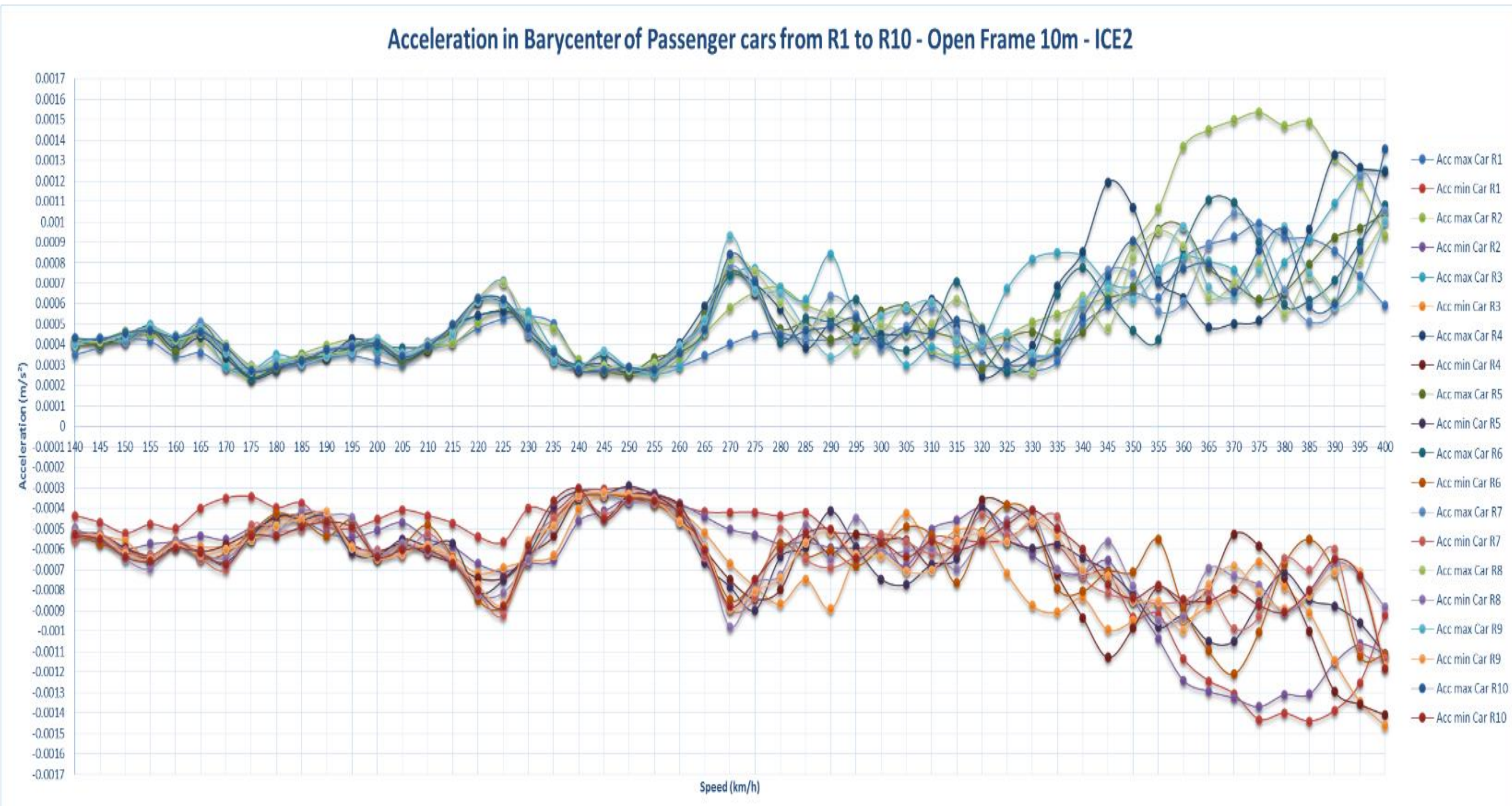
Results (French TGV and ICE2 2D Model) for Open Frame Bridge 10m



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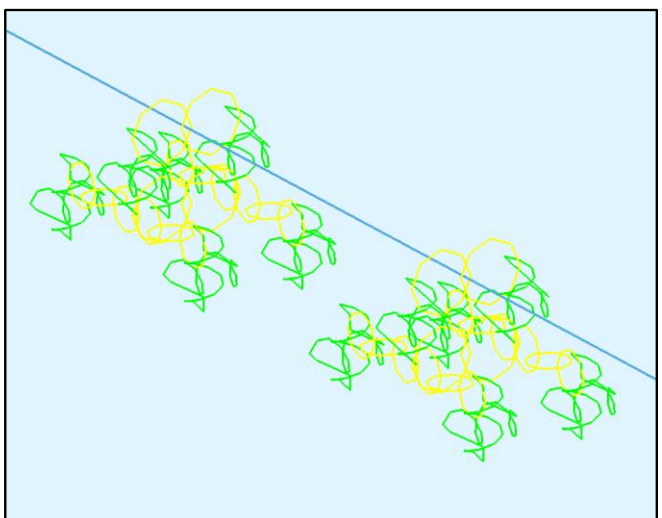
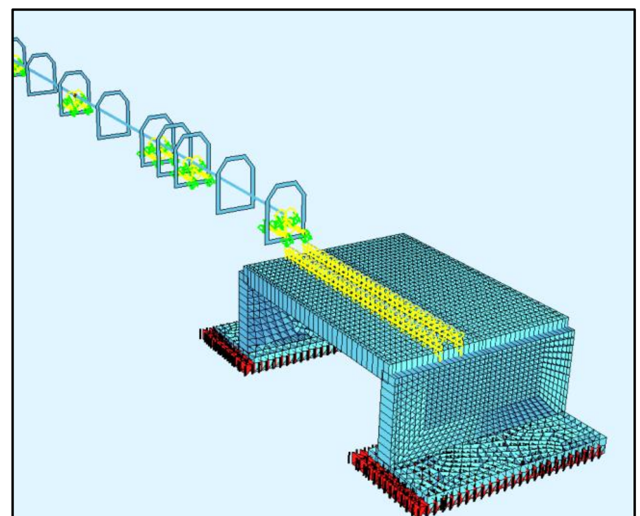
Conclusion (French TGV and ICE2 2D Model)

- The barycenter of power cars of French TGV and ICE2 have the most important accelerations.
- The first bogie of power car of French TGV and ICE2 presents the most important acceleration.
- For French TGV the passenger acceleration decreases when speed of train increases. This phenomena is not shown for the ICE2.
- The passenger acceleration decreases if the span length decreases.
- The passenger acceleration is lower than 1 m/s^2 (good comfort following Eurocode 0 Annex A2 (High speed line train).

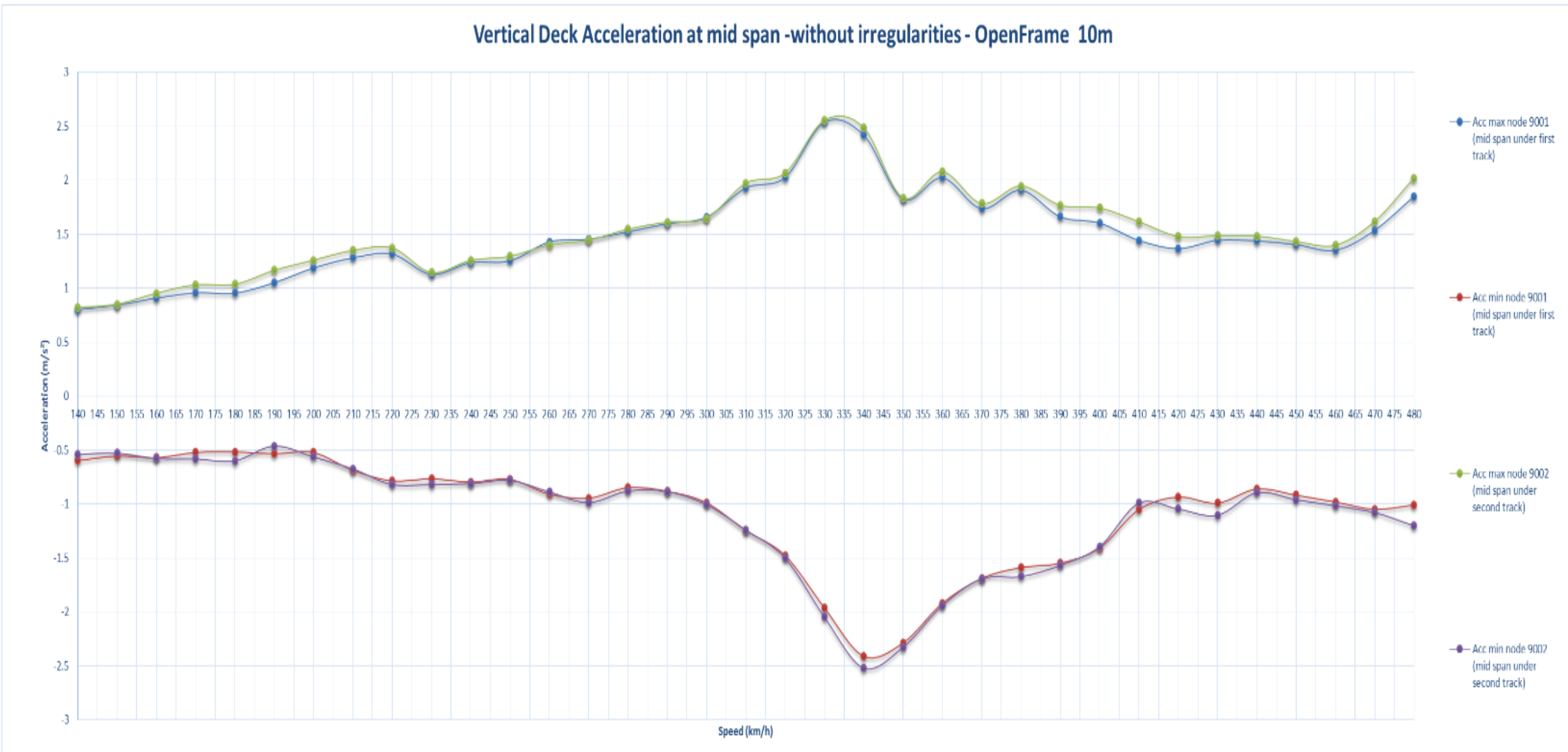
Characteristics for Comfort Analysis 3D Model

- 3D Structure Geometry of bridge
- Two loaded lines are considered
- No Ballast is modelled between rail and bridge.
- 3D models for French TGV
- Without Track irregularities.
- Speed from 144 Km/h to 400 Km/h with a step of speed equal to 5 Km/h
- Time step is 0.002s



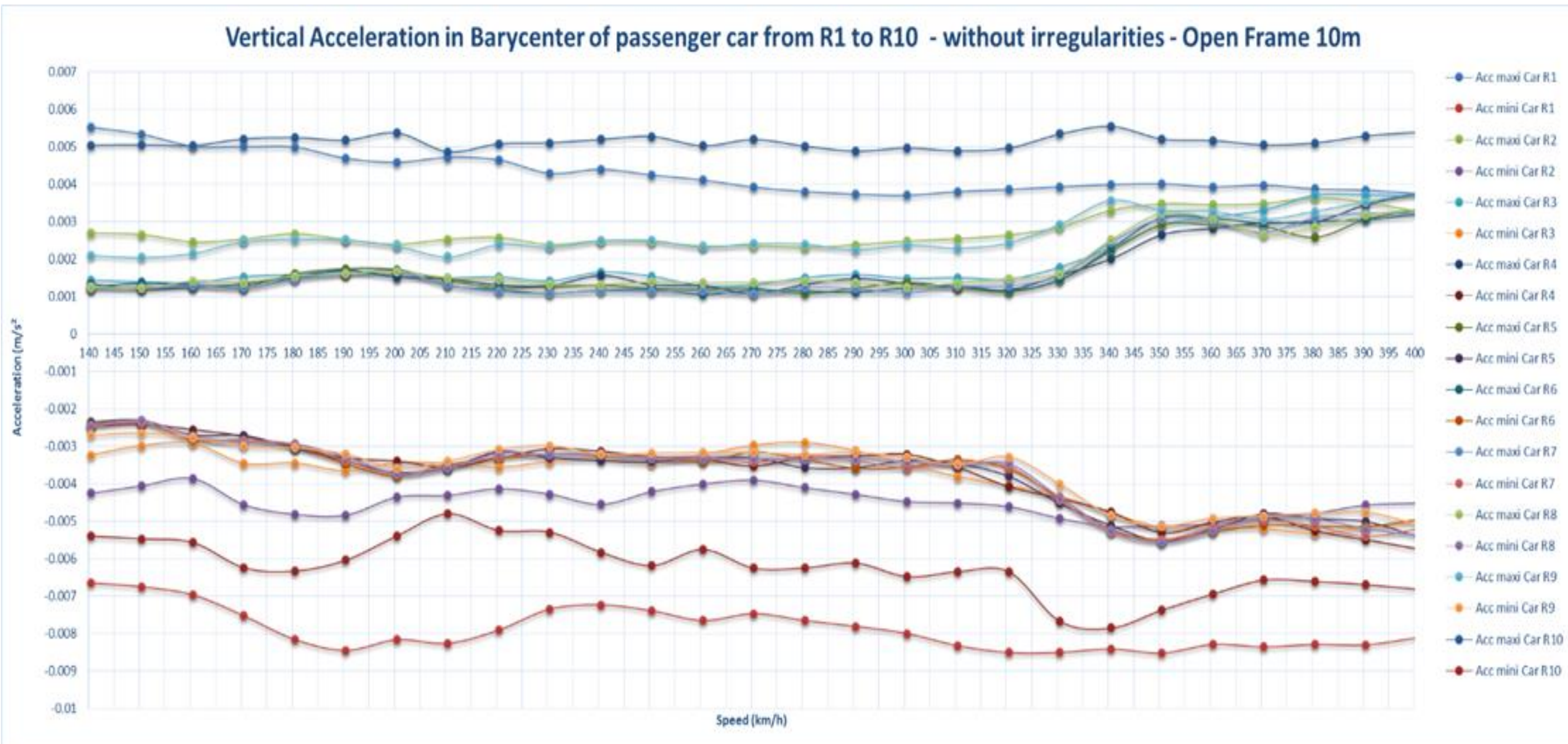


Results (French TGV 3D Model) for Open Frame Bridge 10m
Vertical deck acceleration at mid span

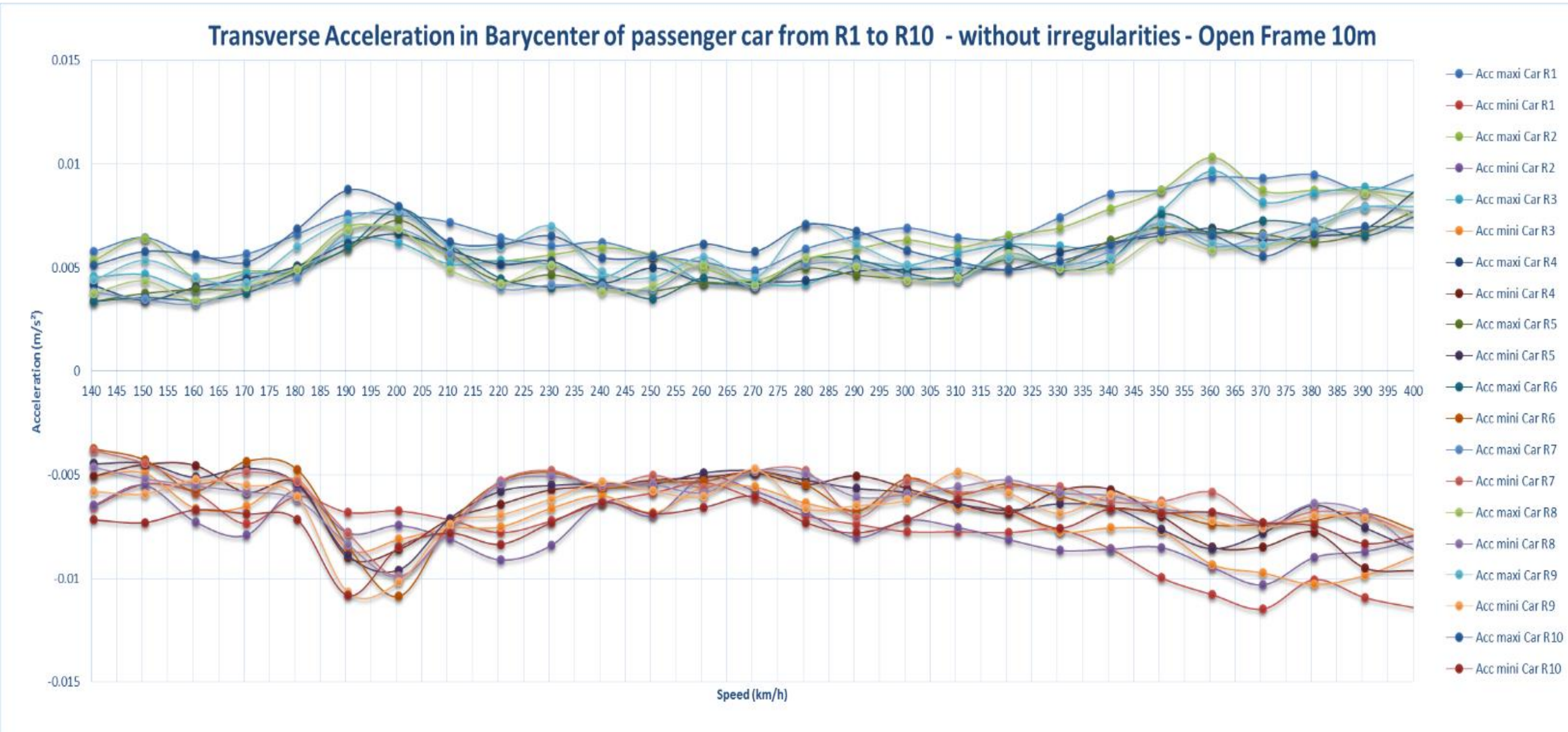


Results (French TGV 3D Model) for Open Frame Bridge 10m

Vertical acceleration in barycenter of passenger car from R1 to R10



Results (French TGV 3D Model) for Open Frame Bridge 10m
Transverse acceleration in barycenter of passenger car from R1 to R10



Conclusion (French TGV 3D Model)

Vertical deck acceleration at mid span

	Acc MAX [m/s2]	Speed [KM/h]	Acc MIN [m/s2]	Speed [KM/h]
Open Frame 10m	2.54	330	-2.52	340
Open Frame 15m	1.6	290	-1.6	290
Closed Frame 5m	4.5	480	-4.5	480
Closed Frame 10m	1.75	340	-1.15	380

Vertical acceleration in barycenter of passenger car from R1 to R10

Open Frame 10m= 0.009 m/s^2

Open Frame 15m= 0.015m/s^2

Closed Frame 5m= 0.005 m/s^2

Closed Frame 10m= 0.008 m/s^2

Transverse acceleration in barycenter of passenger car from R1 to R10

Open Frame 10m= 0.012 m/s^2

Open Frame 15m= 0.025m/s^2

Closed Frame 5m= 0.015 m/s^2

Closed Frame 10m= 0.008 m/s^2

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Conclusion (French TGV 3D Model)

- The results of comfort analysis show that for the studied bridge, the values of acceleration are lower than the limit given by the Eurocode for good level of Comfort equal to 1 m/s^2. Therefore for little span bridges comfort analysis is not critical

- The results of dynamic analysis of bridge for French TGV show that for Closed Frame Bridge (5m), the vertical acceleration at mid span of the deck is higher than 3,5 m/s^2 given in the Eurocode. Therefore the vertical acceleration in the deck increases when the span length decreases.

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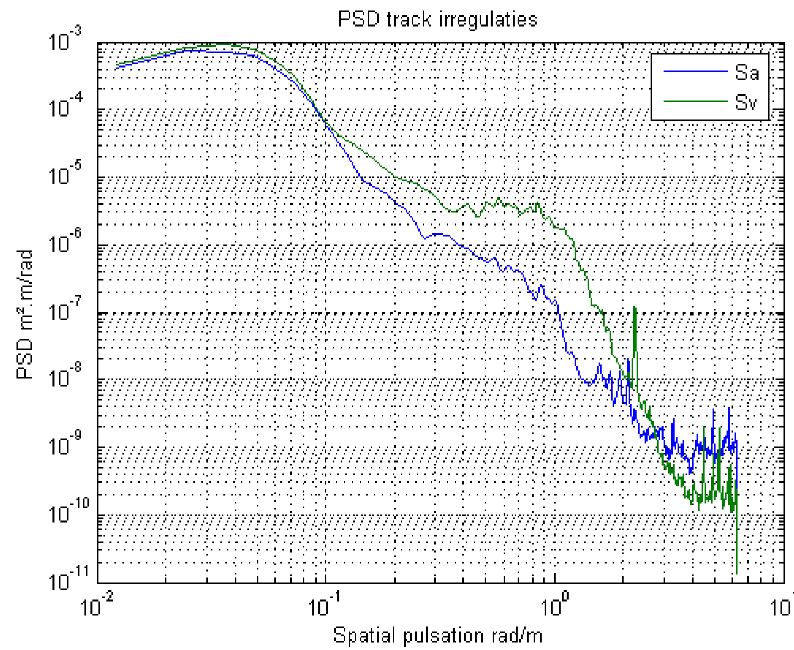
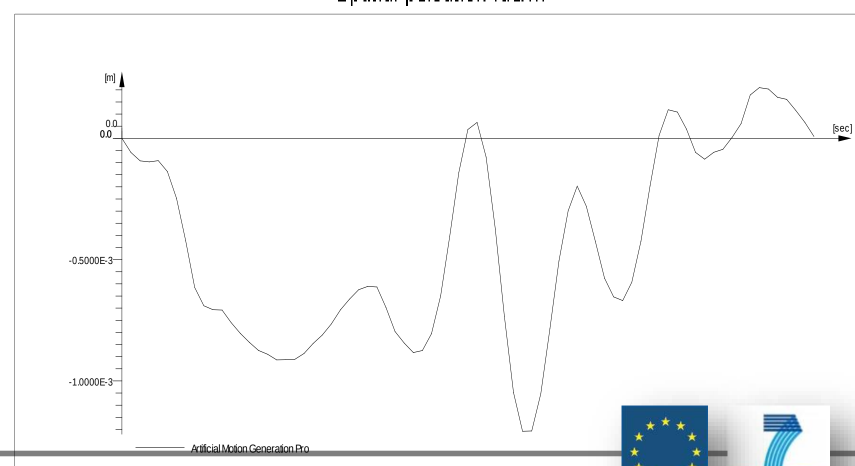
C4R Capacity for Rail

Track irregularities

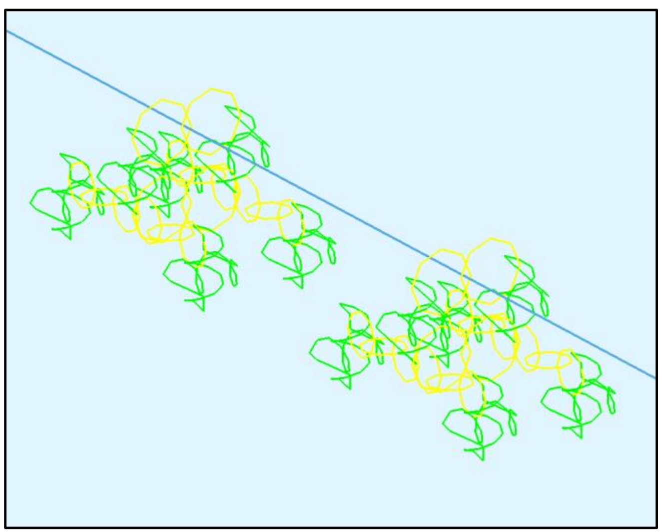
- The track irregularities are generated through the power spectra density (PSD) Track irregularity for TGV train, issued from measures on TGV French North line
- The effects of track irregularities in vertical and in horizontal.

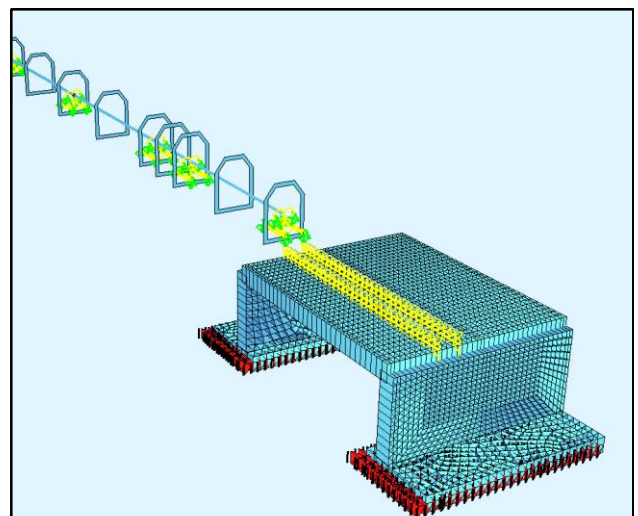




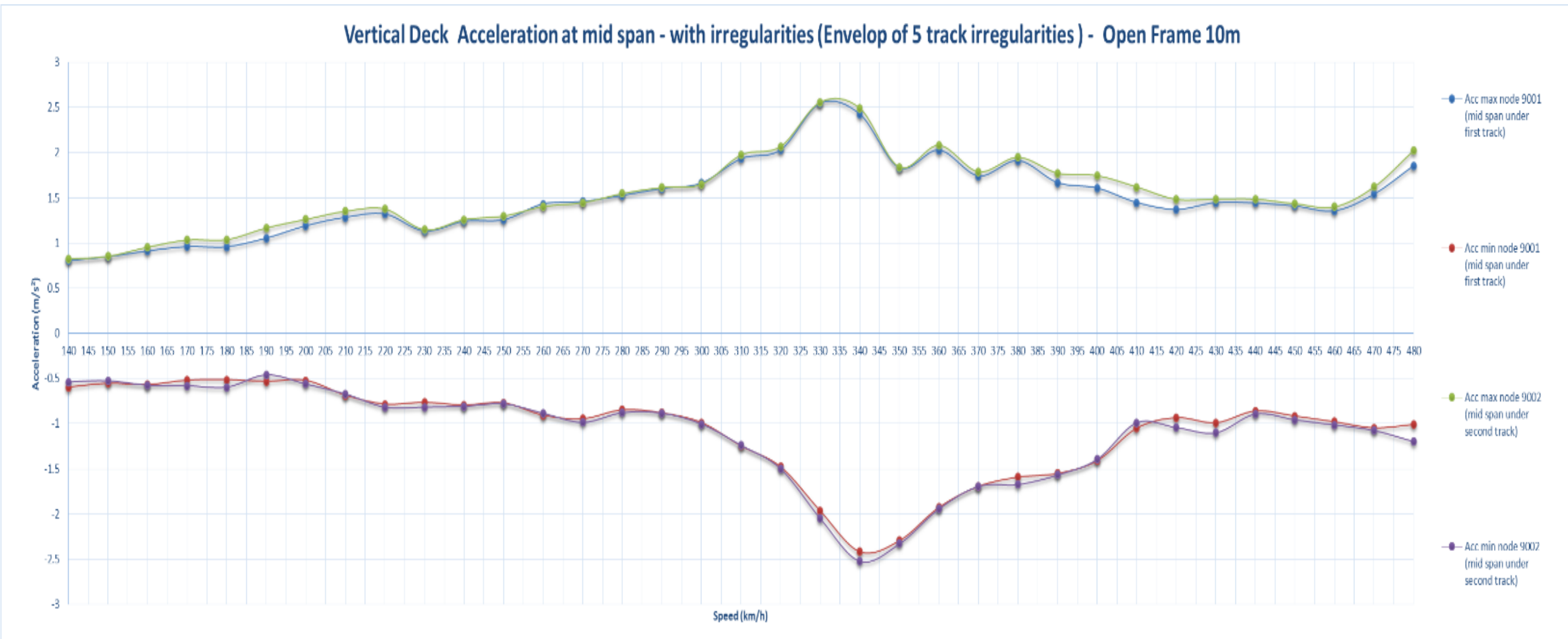
Characteristics for Comfort Analysis 3D Model+ Track irregularities

- 3D Structure Geometry of bridge
- Two loaded lines are considered
- No Ballast is modelled between rail and bridge
- 3D models for French TGV
- Track irregularities (5 track profiles are generated)
- Speed from 144 Km/h to 400 Km/h with a step of speed equal to 5 Km/h
- Time step is 0.002s





Results (French TGV 3D Model) for Open Frame Bridge 10m with track irregularities
Vertical deck acceleration at mid span



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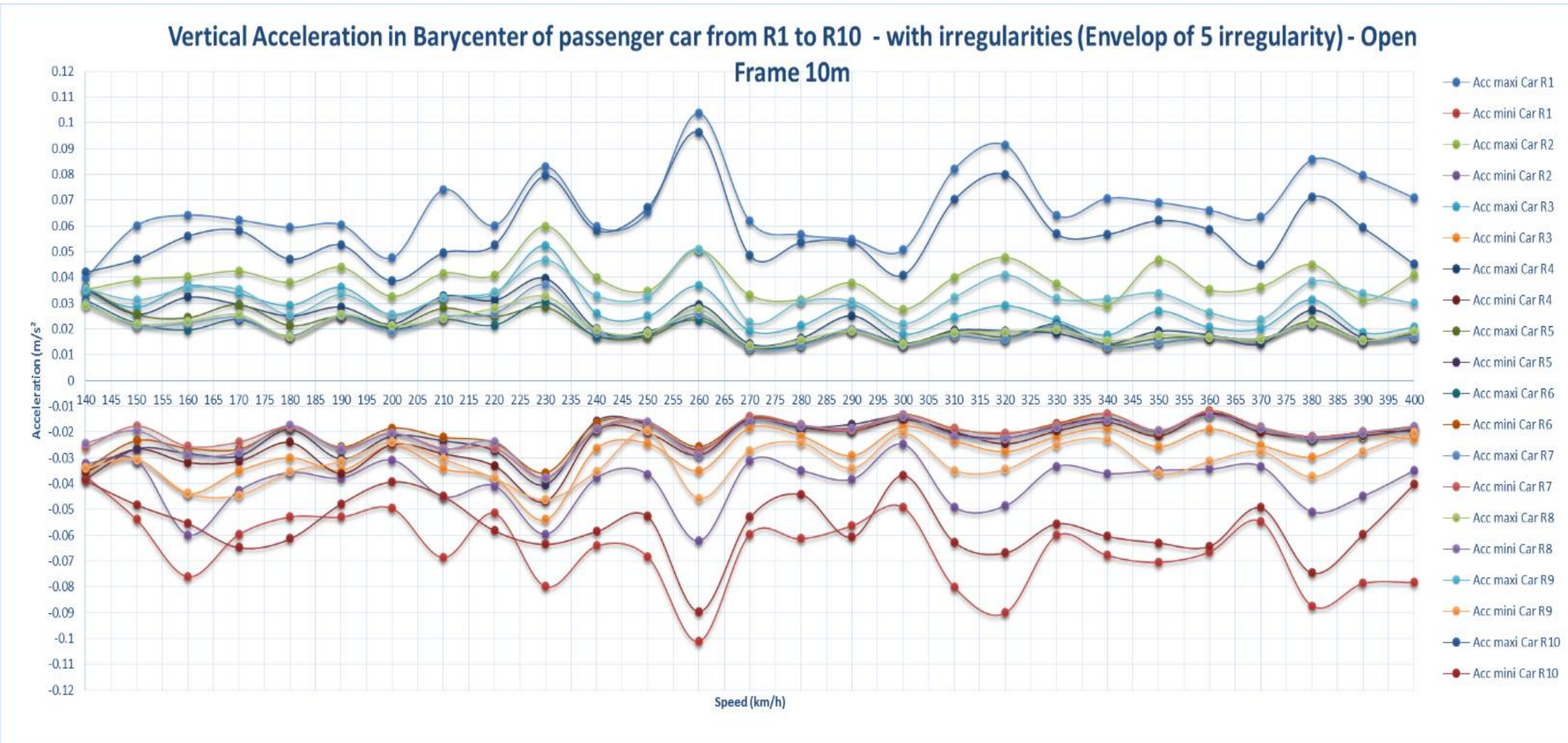
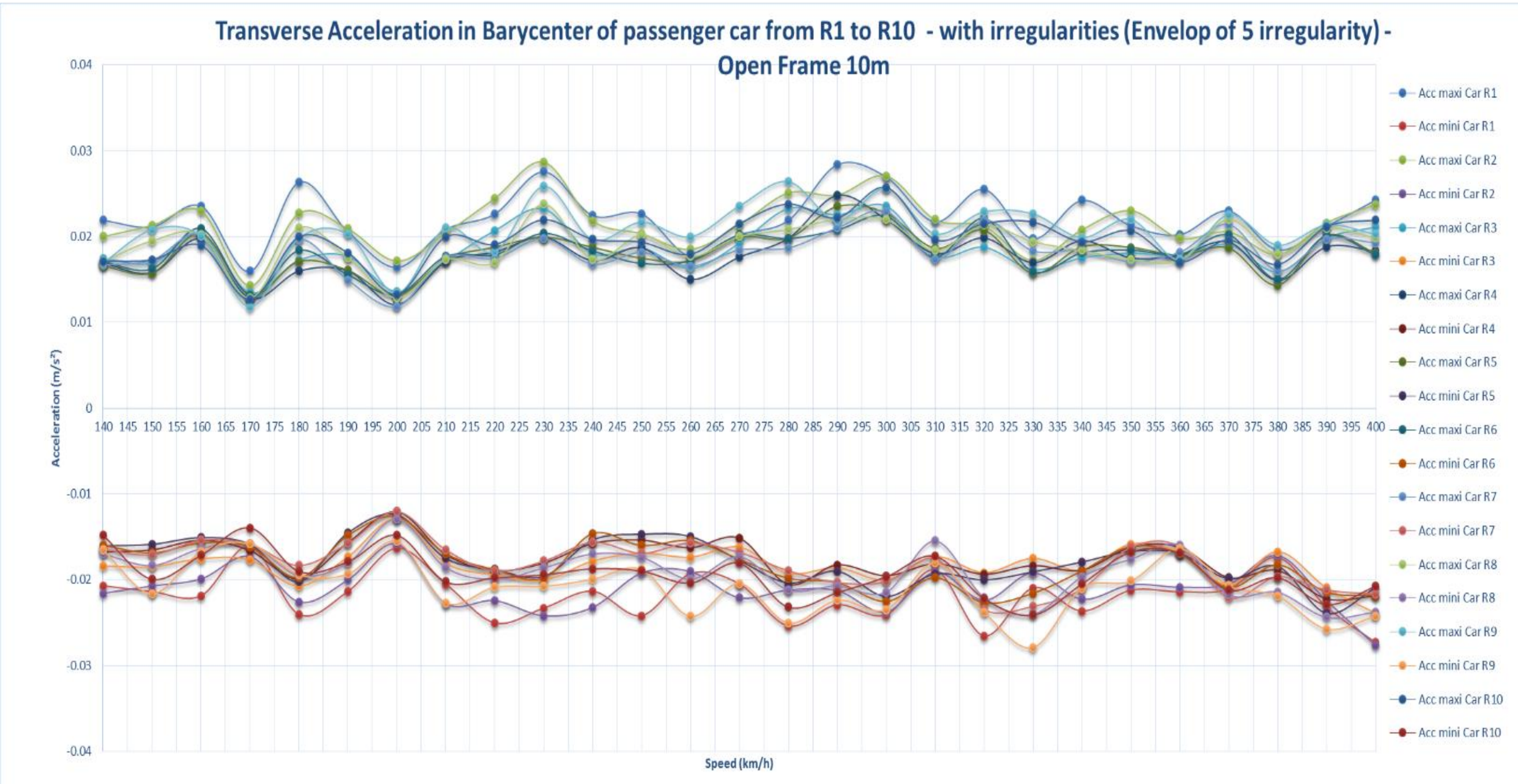
Results (French TGV 3D Model) for Open Frame Bridge 10m with track irregularities

Vertical acceleration in barycenter of passenger car from R1 to R10



Results (French TGV 3D Model) for Open Frame Bridge 10m with track irregularities
Transverse acceleration in barycenter of passenger car from R1 to R10



Results (French TGV 3D Model) for Open Frame Bridge 10m with track irregularities

Wheel unloading coefficient

	Speed / irregularities	ΔP maxi	Speed / irregularities	ΔP mini
Node n°1	230/5	2.99	230/5	-3.13
Node n°2	230/5	3.25	230/5	-3.12
Node n°3	230/5	3.09	230/5	-3.40
Node n°4	230/5	3.25	230/5	-3.38
Node n°5	200/5	4.04	225/4	-4.39
Node n°6	**200/5**	**4.24**	**225/4**	**-4.65**
Node n°7	200/5	3.94	200/5	-4.42
Node n°8	270/3	3.99	200/5	-4.61
Node n°9	265/5	2.86	265/5	-2.69
Node n°10	215/3	2.88	225/4	-2.69
Node n°11	265/5	3.96	260/3	-3.49
Node n°12	265/5	3.49	225/4	-3.47
Node n°13	260/5	3.10	265/2	-3.17
Node n°14	260/3	3.31	270/4	-3.05
Node n°15	260/2	3.46	215/3	-3.72
Node n°16	260/2	3.61	265/5	-3.85

ΔPmax=4.65 KN corresponds to a maximum irregularities equal to 4mm generated for speed= 225 Km/h

P=85 KN   ΔP/P=0.055 < 0.25   (Ma and Zhu, 1998)

Results (French TGV 3D Model) for Open Frame Bridge 10m with track irregularities

Derailment coefficient

	Speed / irregularities	ΔY maxi	Speed / irregularities	ΔY mini
Node n°1	265/4	1.04	270/2	-1.75
Node n°2	265/4	1.04	270/2	-1.74
Node n°3	265/4	1.04	270/2	-1.70
Node n°4	265/4	1.04	270/2	-1.78
Node n°5	270/4	1.56	**265/4**	**-2.95**
Node n°6	270/4	1.56	265/4	-2.93
Node n°7	270/4	1.56	265/4	-2.88
Node n°8	270/4	1.56	265/4	-3.00
Node n°9	**255/4**	**2.23**	185/4	-1.34
Node n°10	255/4	2.11	255/2	-1.39
Node n°11	255/4	2.18	185/4	-1.34
Node n°12	255/4	2.15	255/2	-1.37
Node n°13	185/2	2.27	245/5	-1.97
Node n°14	185/2	2.27	245/5	-1.95
Node n°15	185/2	2.27	185/4	-1.93
Node n°16	185/2	2.27	245/5	-2.00

ΔYmax=2.95 KN corresponds to a maximum irregularities equal to 4mm generated for speed= 265 Km/h

P=85 KN   Y/P=0.035 < 1.2   (Elkins and Carter, 1993)

Conclusion (French TGV 3D Model with irregularities)

Vertical deck acceleration at mid span

	Acc MAX [m/s2]	Speed [KM/h]	Acc MIN [m/s2]	Speed [KM/h]
Open Frame 10m	2.54	330	-2.52	340
Open Frame 15m	1.6	290	-1.6	290
Closed Frame 5m	4.5	480	-4.5	480
Closed Frame 10m	1.75	340	-1.15	380

Vertical acceleration in barycenter of passenger car from R1 to R10

Open Frame 10m= 0.1 m/s^2

Open Frame 15m= 0.1 m/s^2

Closed Frame 5m= 0.1 m/s^2

Closed Frame 10m= 0.1 m/s^2

Transverse acceleration in barycenter of passenger car from R1 to R10

Open Frame 10m= 0.028 m/s^2

Open Frame 15m= 0.035 m/s^2

Closed Frame 5m= 0.030m/s^2

Closed Frame 10m= 0.008 m/s^2

Conclusion (French TGV 3D Model)

Comparison with / without irregularities

Vertical deck acceleration at mid span

Track irregularities have no impact on the dynamic behavior for the studied Concrete Frame Bridges.

Vertical acceleration in barycenter of passenger car from R1 to R10

	Acc MAX [m/s2] without Track Irregularities	Acc MAX [m/s2] with Track Irregularities
Open Frame 10m	0.009	0.1
Open Frame 15m	0.015	0.1
Closed Frame 5m	0.005	0.1
Closed Frame 10m	0.008	0.1

The vertical acceleration due to track irregularities is governing.

Conclusion (French TGV 3D Model)
Comparison with / without irregularities

Transverse acceleration in barycenter of passenger car from R1 to R10

	Acc MAX [m/s2] without Track Irregularities	Acc MAX [m/s2] with Track Irregularities
Open Frame 10m	0.012	0.028
Open Frame 15m	0.025	0.035
Closed Frame 5m	0.015	0.030
Closed Frame 10m	0.008	0.008

The transverse acceleration due to track irregularities has the same order of magnitude than the transverse acceleration without track irregularities.

Conclusions

- The dynamic behaviour of bridge governs the design for small span and speed higher than 350 Km/h.
- The passengers comfort does not govern the design of the bridges for small span bridges
- Track irregularities create:
  - Large increase of vertical passenger acceleration
  - Small increase of transverse passenger acceleration

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Thank you for your kind attention

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SYSTRA

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