
# Full Vehicle Durability Simulation

## Load prediction of a complete durability schedule

**FGA – RESEARCH & DEVELOPMENT**

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**Virtual Analysis Manager**

Stuttgart, 13.06.2012

# Agenda

- **Introduction**
- **Durability Schedule : Europe & US**
- **Durability Process & Simulation**
- **Load prediction : Random road, Driven road, Misuse/Single event**
- **Complete Durability Schedule Simulation & correlation**
- **Tracks comparison**
- **Summary & Conclusions**

# Introduction

- The accurate Loads prediction is one of the main key factors to dimension components. From the beginning of the process development, it strongly impacts on weights reduction and avoids late structural failures

- Simulation of a durability program is used to predict loads acting on chassis and body. MBody simulation and Fatigue Life prediction are used to simulate a complete durability cycle before to build mules and prototypes

- Combining simulation and measurements is also possible to compare different durability programs

**GOALS :**

- **Load prediction & correlation of a complete European durability program**
- **Comparison & correlation between European & North American durability programs**

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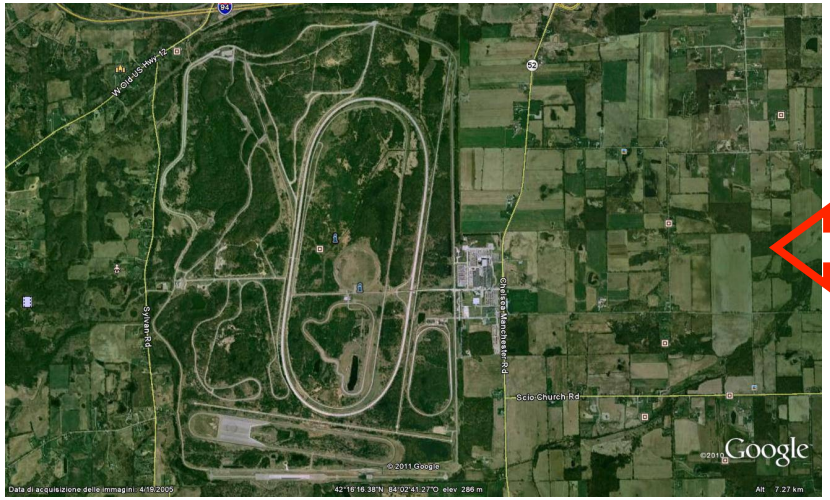
# Durability Schedule : Europe , US , China, Brasil

## CHELSEA PROVING GROUND (Michigan – US)



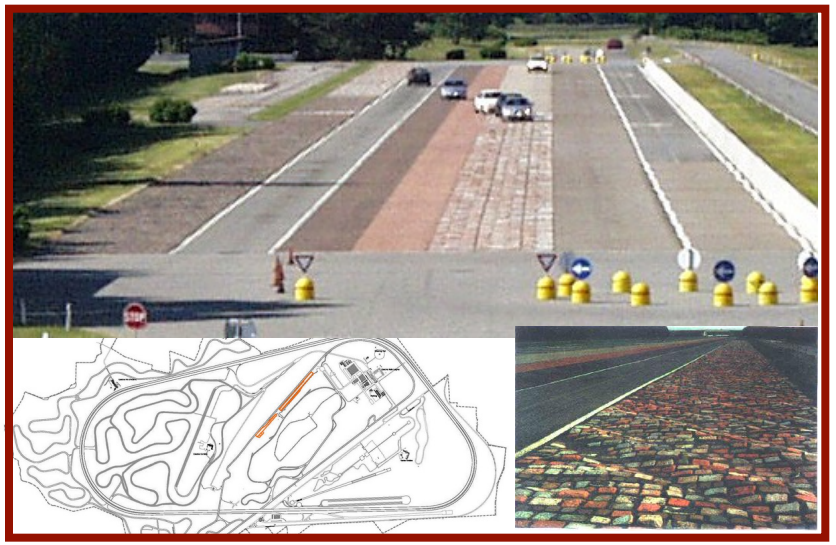

## BALOCCO PROVING GROUND (Balocco – IT)

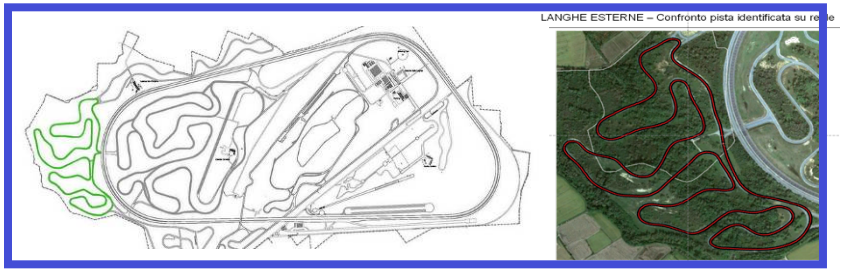
## CATARC (China)


## Under costruction (Nordeste – BR)

# Durability Schedule : Europe

| TRACKS | Speed [km/h] | Length (m.) |
|---|---|---|
| Pavé Pesante Balocco (PABA) | 25-30 | 400 |
| Porfido Rosso/Grigio (PORF) | 60 | 400 |
| Procaccini (PROC) | 50 | 200 |
| Pavè Pesante Mandria (PAMA) | 25-30 | 900 |
| Acciottolato Pesante Russo (APES) | 20-25 | 450 |
| Sterrato (STERR) | 50 | 1570 |
| Cisa (MCISA) | **Max** | **4170** |
| Pavimentazioni Speciali Langhe (PLX) | 50 | 6700 |
| Mistino (3MI) | **Max** | **7200** |
| Anello Esterno Alfa (ALFA) | Max | 5100 |
| Langhe Esterne (2LES) | Max | 10600 |
| Langhe Interne (2LIN) | Max | 13400 |
| Anello Veloce (3AV) | Max | 22700 |
| Nidi di Gallina (NGALL) | 20 | 290 |
| Rampe Basse 13% (RBA) | 15-20 | 240 |
| Rampe Alte 16% (RAL) | 15-20 | 240 |
| Pot Holes (POT) | 40 (25-30) | 180 |






**BALOCCO DURABILITY PROGRAM : total 35000 kms**

**random road - driven road - misuse**

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# Durability Process Development

**SIMULATION – VIRTUAL PREDICTION OF LOADS**

- Full virtual simulation of all tracks & tracks combination
- Model validation with measurements on Mules (all tracks & overall)
- FInal check with prototypes measurements


**TESTING – LOAD DATA ACQUISITION (Mules & Prototypes)**

- Road load data acquisition (forces, acceleration, strain)

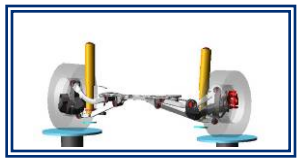
**TESTING – BENCH TEST 4DoF (suspension system) & 6 DoF (full vehicle)**

- 4Dof test on suspension system in pre-mules phase
- 4Dof test on suspension system in mules phase
- 6Dof test on full vehicle in prototypes phase

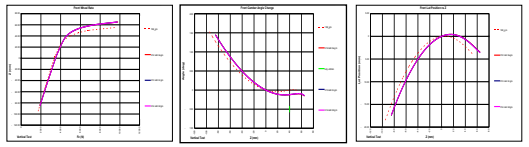
**TESTING – ROAD TEST (complete vehicle)**

- Road test with prototypes and pre-series vehicles

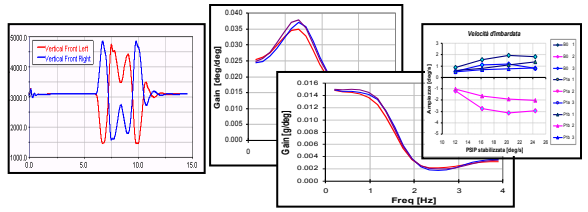
# Simulation process

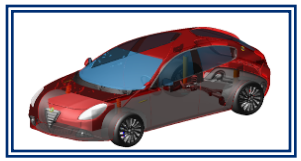


**K&C Front & Rear Suspension**

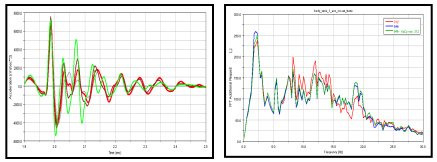


**HANDLING PERFORMANCES**

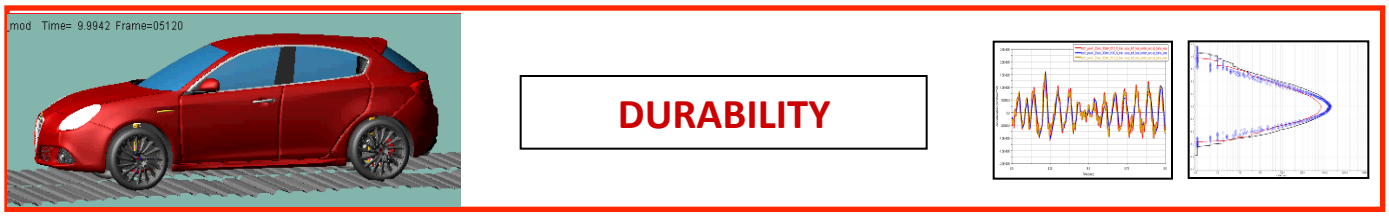


**RIDE-COMFORT PERFORMANCES**



- **HANDLING & RIDE C. PERFORMANCES ACHIEVEMENT STRONGLY INFLUENCES THE LOADS**
- **DURABILITY MODEL STARTS FROM ACCURATE K&C , HANDLING , RIDE COMFORT MODELS**

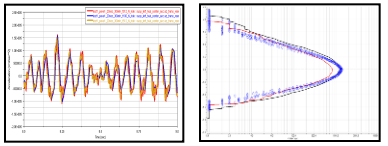



**DURABILITY**

**DURABILTY MUST BE INCLUDED FROM THE BEGINNING AND LINKED TO THE DEVELOPMENT OF HANDLING & COMFORT PERFORMANCES**

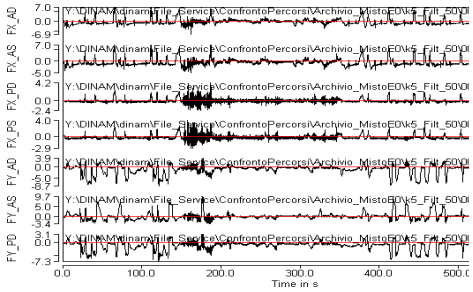
# Simulation : Load generation for ε-N or σ-N fatigue

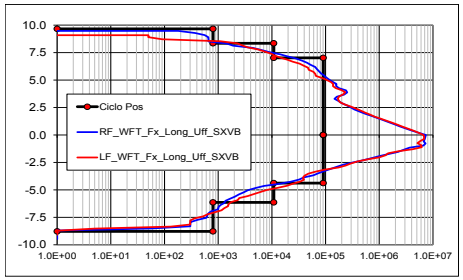

**DURABILITY**



**LOADS GENERATION**

- Wheel center
- All components



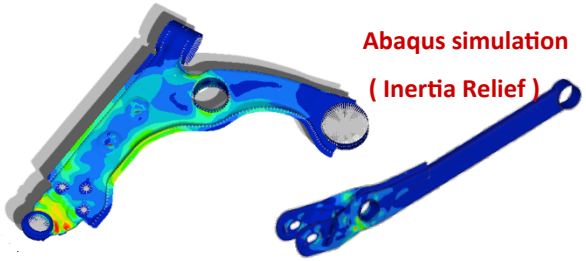




**LOADS GENERATION**

- Wheel center

**STRAIN LIFE APPROACH (ε-N)**

**Fatigue Life prediction using t.h. of loads applied at each single components**

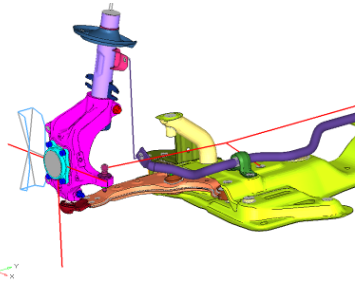


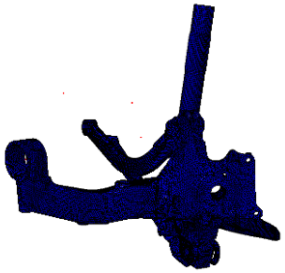
**Abaqus simulation**

**( Inertia Relief )**

**STRESS LIFE APPROACH (σ-N)**

**Fatigue Life prediction using levelcrossing of loads applied at wheel center of a complete suspension subsystem**



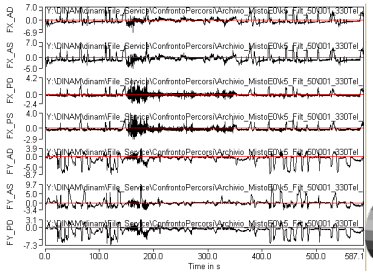


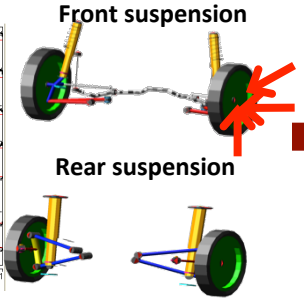
# Simulation : Load prediction with strain life approach

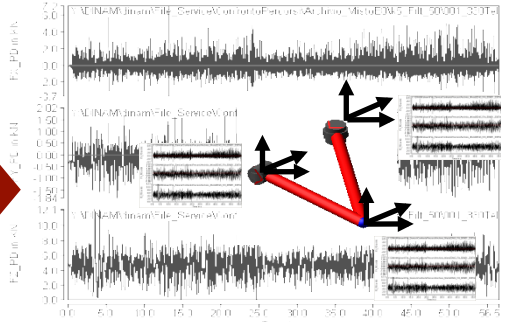
**Subsystem Force and moment at WC**

**Full vehicle Road profile simulation**

Experimental or simulated





*Fx, Fy, Fz, Mx, My, Mz*


**Loads (6 components) at each interface point**

***Stress Calculation***

*Unit loads on interface point*

(k = 1..n)

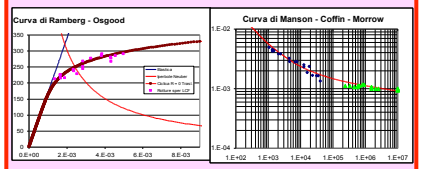

***Load superposition***

**Fatigue Life Prediction code**

**LMS/VirtualLab**

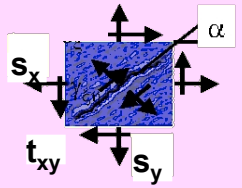
$$\sigma_{ij}(x,t) = \sum_{k=1}^{n} \sigma_{ij,k}(x)\, P_k(t)$$

***Material Data***




Damage criterion

(critical plane)

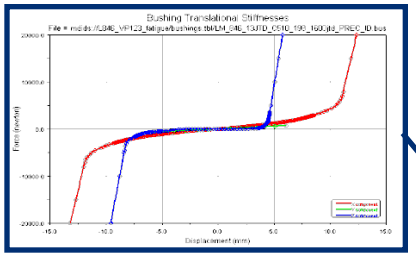



**Fatigue Life Prediction**

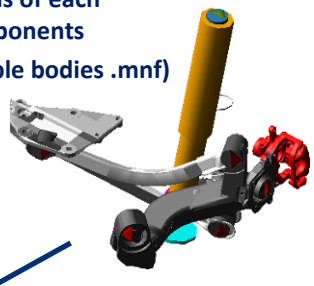
# Simulation : Durability Model - MBSHARC (Adams Car)

MB-SHARC

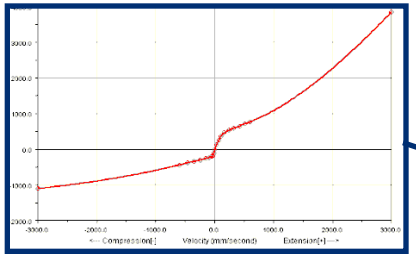
Non linear 6 dof Bushing characteristics (dynamic stiffness, loss angle)



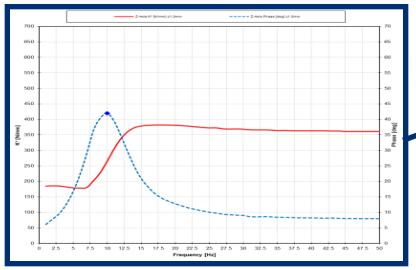
Masses & Inertias of each suspension components (optionally flexible bodies .mnf)

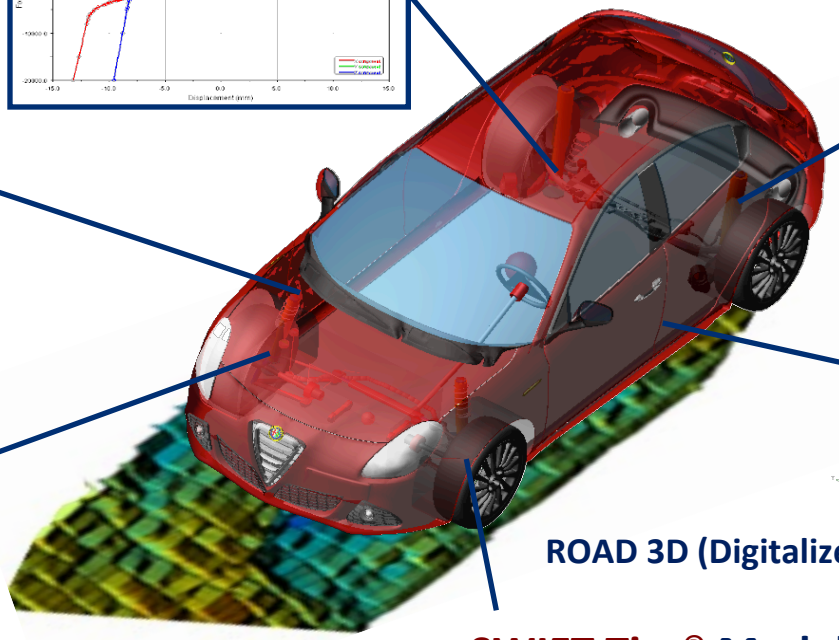


Shock-absorber characteristics up to > 2.5m/s (displacement & velocity map)



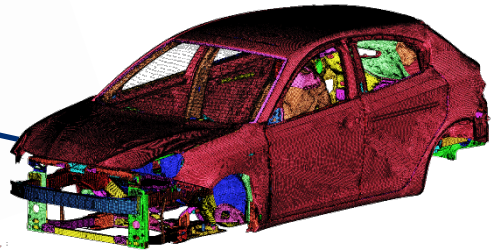
MB hydraulic mount (TFSISO)



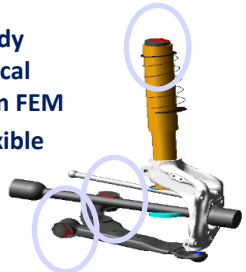


ROAD 3D (Digitalized)

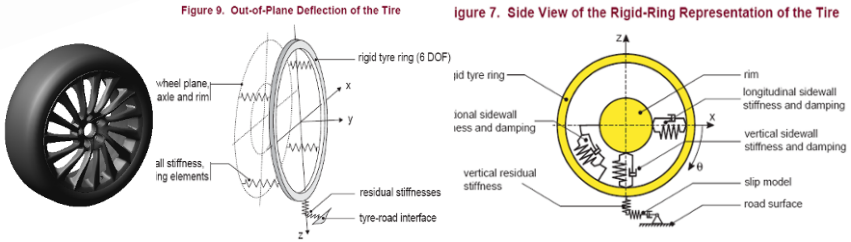
Flexible Body (.mnf) / optionally body attachment stiffnesses



Suspension-Body attachments local stiffnesses from FEM (0-25Hz) or flexible body (0-50Hz)



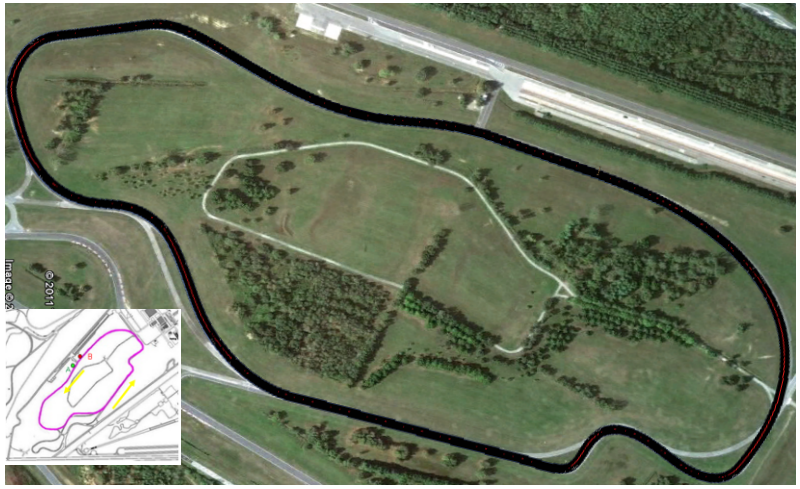
SWIFT Tire® Model

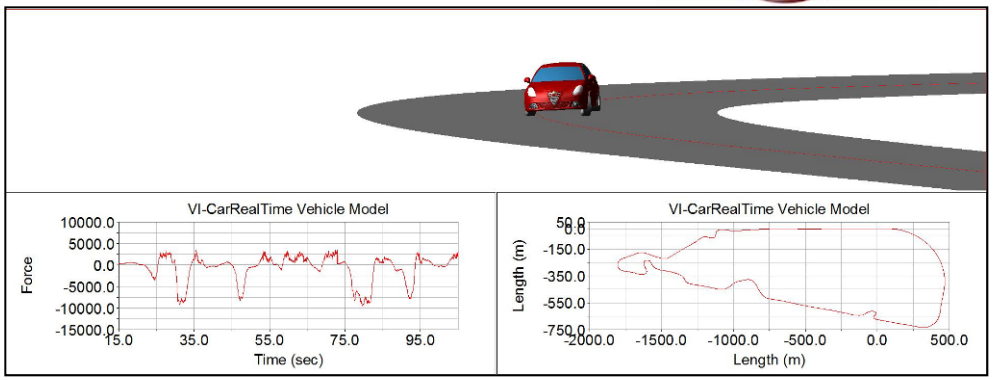


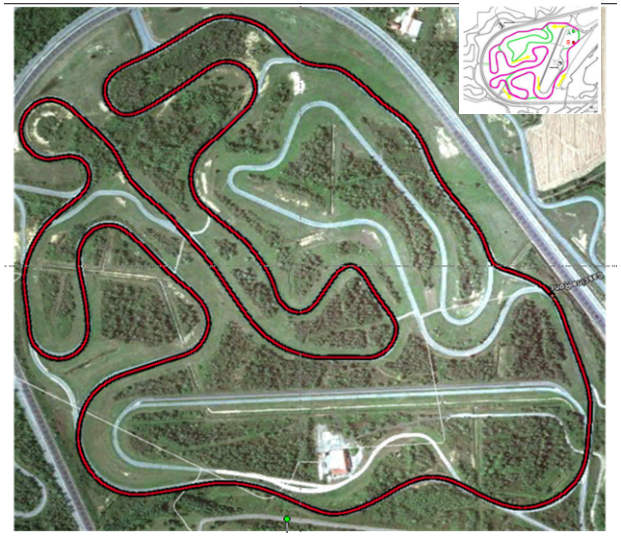

+ STEERING SYSTEM
+ PT MOUNT SYSTEM
+ BRAKE SYSTEM
+ ACTIVE SYSTEMS (opt.)

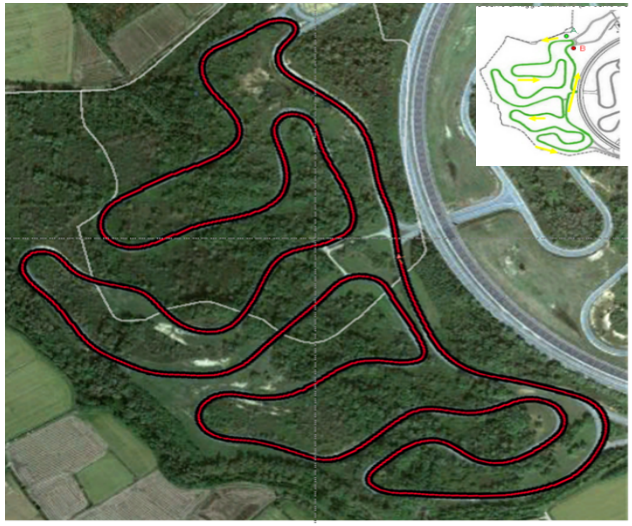
# Simulation : Durability Model for driven tracks

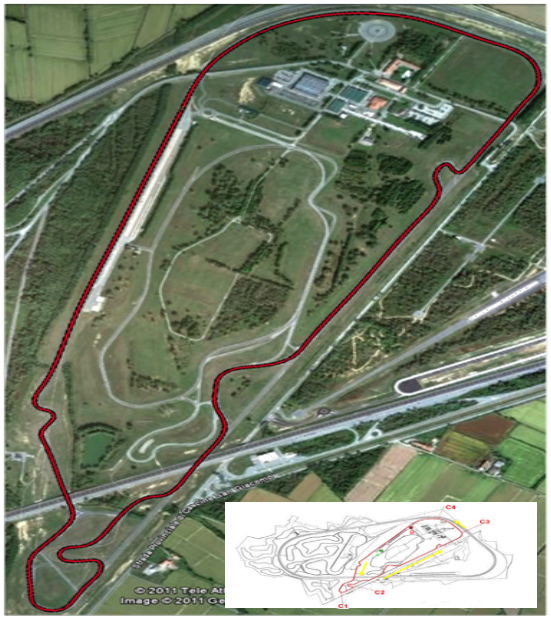
## VI CRT & VI sports car driver model









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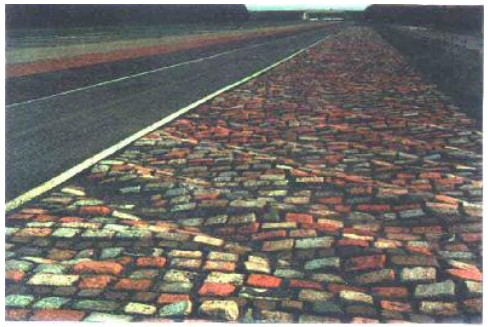
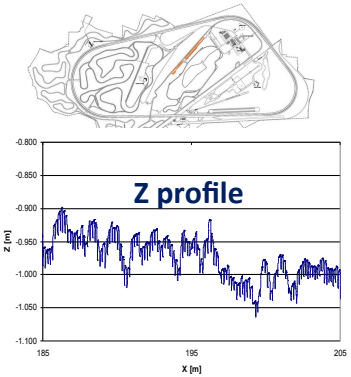
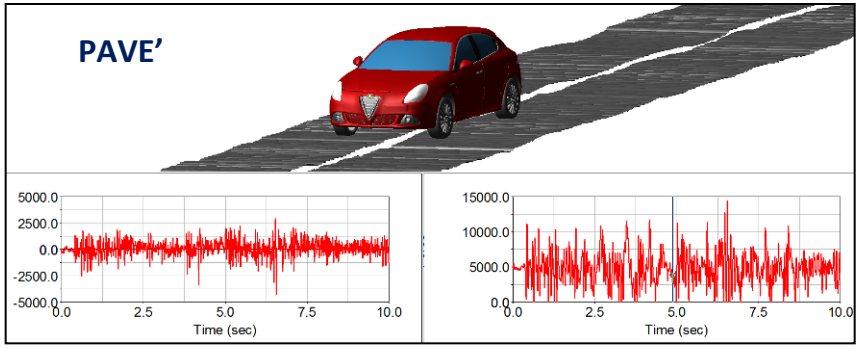
# E0 program : Random Road (Pavè) durability track

## INPUT SIMULATION

- Road digitalized profile left & right
  Z vs. X = f (wheel track, tire size))
- Time-history vehicle Speed / steering angle

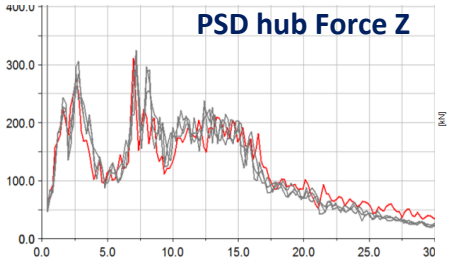


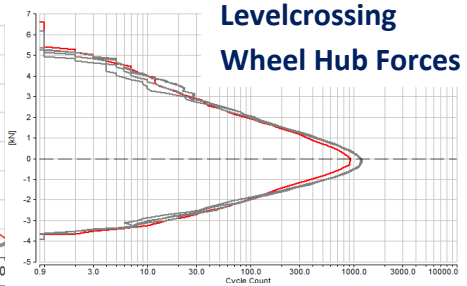


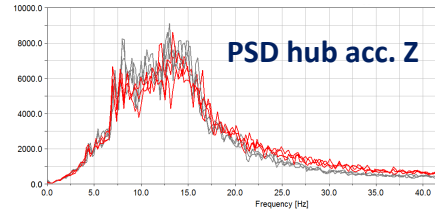



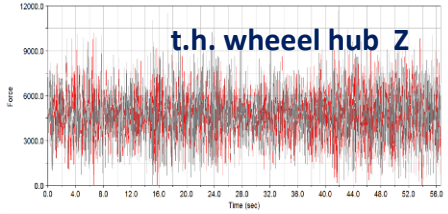

## OUTPUT SIMULATION

- Levelcrossing wheel hub forces,
  t.h. of loads at each components
- PSD wheel hub forces and accelerations




**PAVE' ROAD**

Road profile amplitude >= +/-15mm

vehicle speed = 35km/h – 25km/h

Length = approx. 400m / 60sec

Simulation time = 20min

N.Repetition in bench = 2x(600)

# E0 program : Random Road (Pavè) durability track

**Red = numerical**

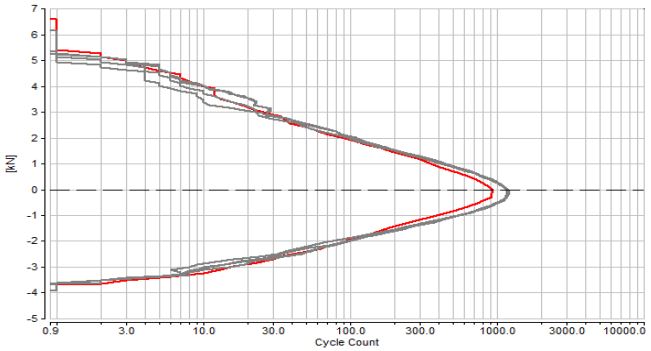
**Grey = experimental**

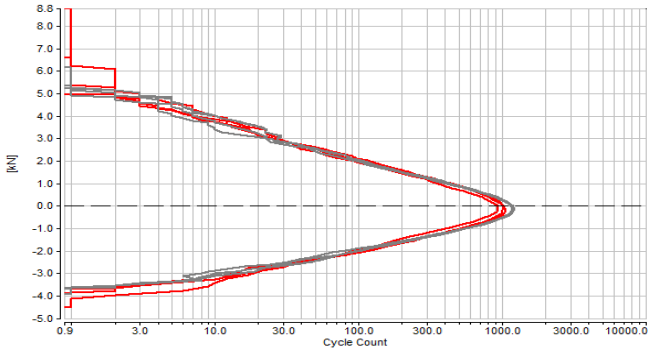
## Simulation vs testing

**1 sim. – 3 exp.**

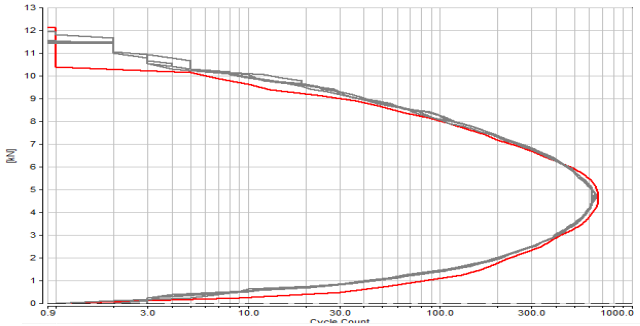
**3 sim. – 3 exp.**

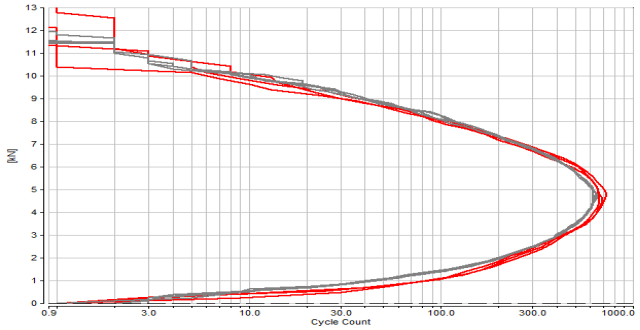
**Fx @WC front left**



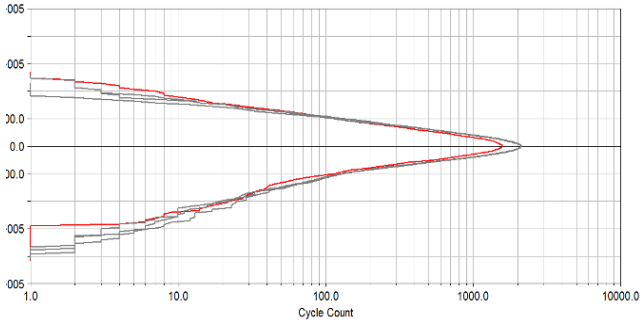



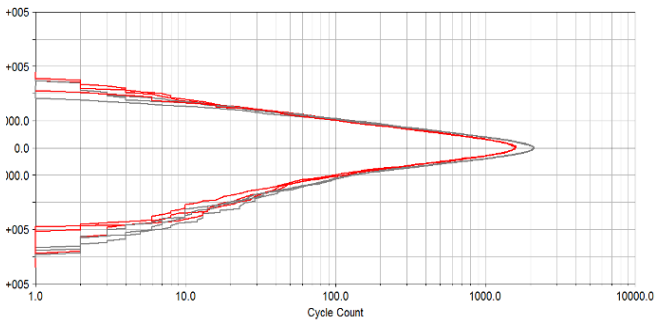

**Fz @WC front left**




**Ax @WC front left**



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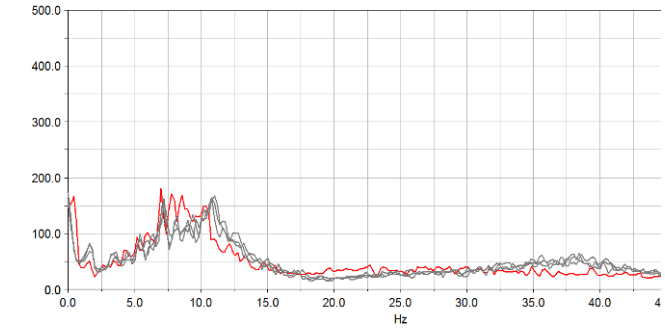
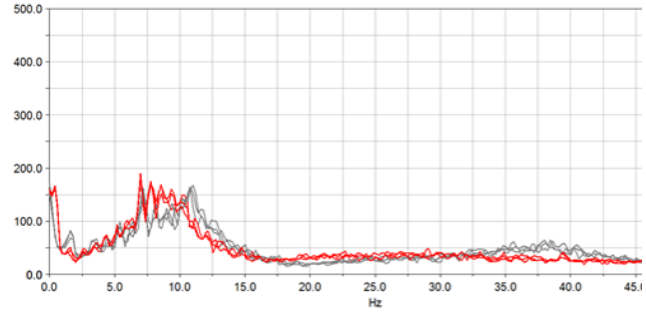
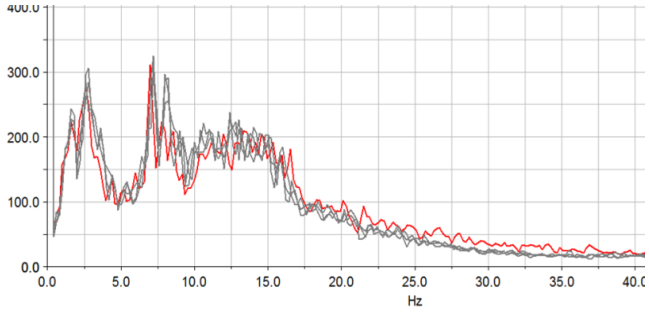
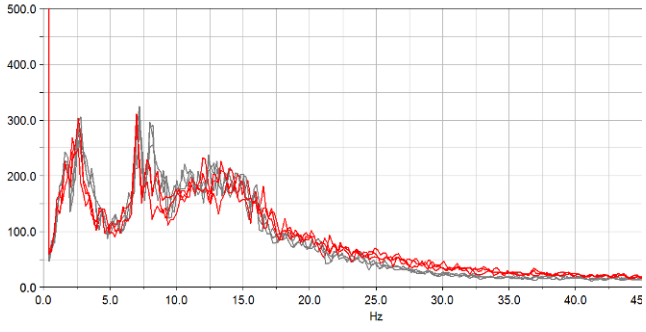
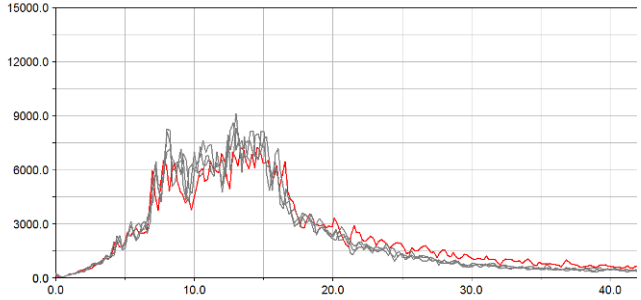
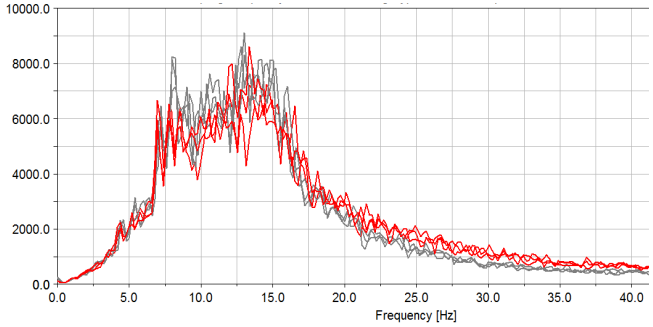
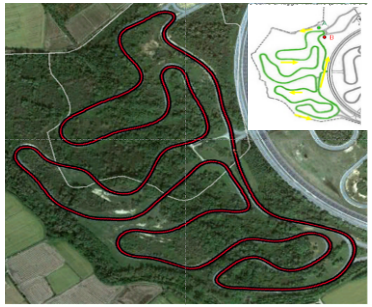
## Simulation vs testing

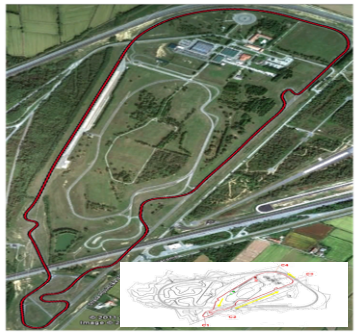
| | 1 sim. – 3 exp. | 3 sim. – 3 exp. |
|---|---|---|
| **PSD(Fx@WC) front left** |  |  |
| **PSD(Fz@WC) front left** |  |  |
| **PSD(Acc Z@WC) front left** |  |  |

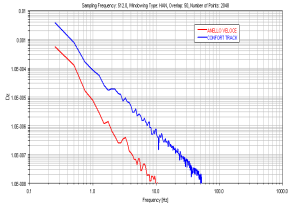
# E0 program : Driving Road (Langhe ext.)

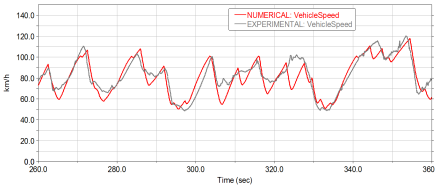
## INPUT SIMULATION :

- Road track (X,Y,Z)
- Path, Speed, Ax, Ay



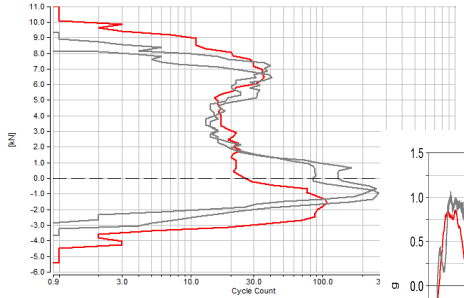


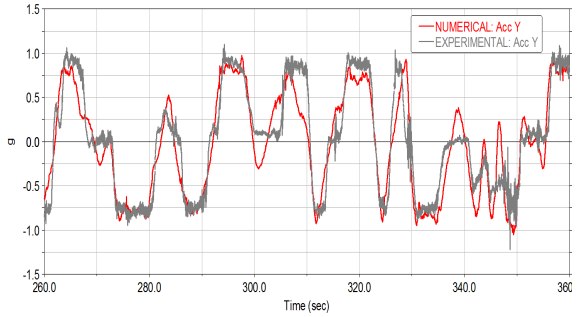


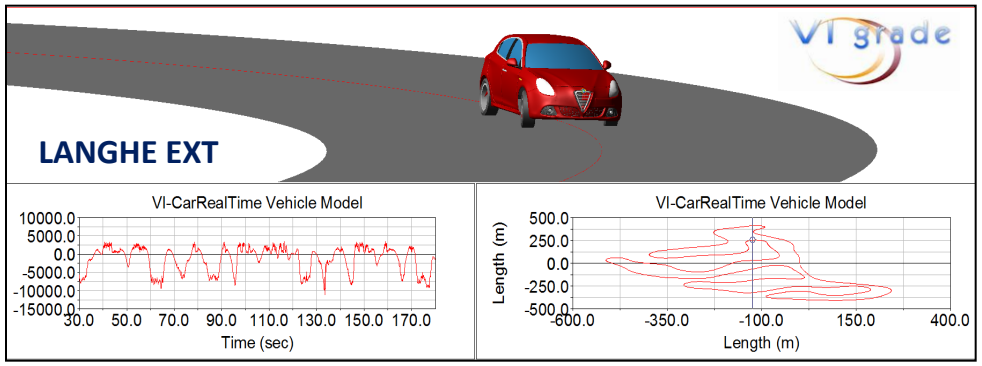



## OUTPUT SIMULATION

- Levelcrossing wheel hub forces, t.h. of loads at each components
- PSD wheel hub forces and accelerations
- Lateral and longitudinal acceleration




**LANGHE ALFA ROMEO TRACK**

**Road length = 5098 m (Les), 5544 m (Alfa)**

**Range vehicle speed = 30 – 130 km/h (car perform.)**

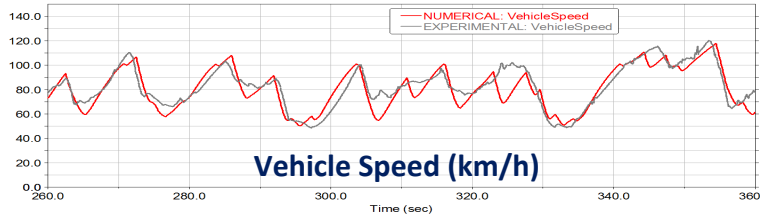
**Simulation time = <4 min (Les , Alfa)**

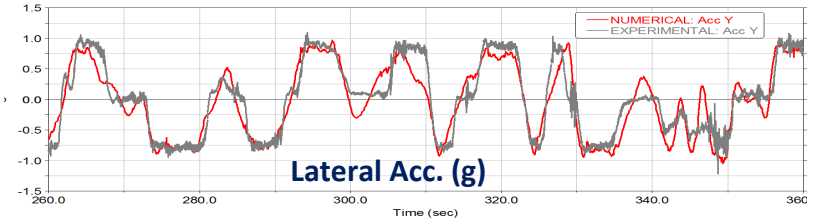
# E0 program : Driving Road (Langhe ext.)

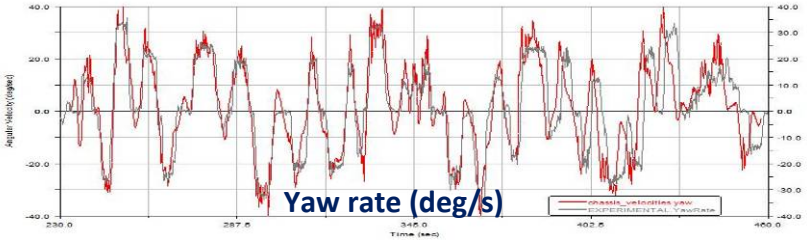
**Red = numerical**

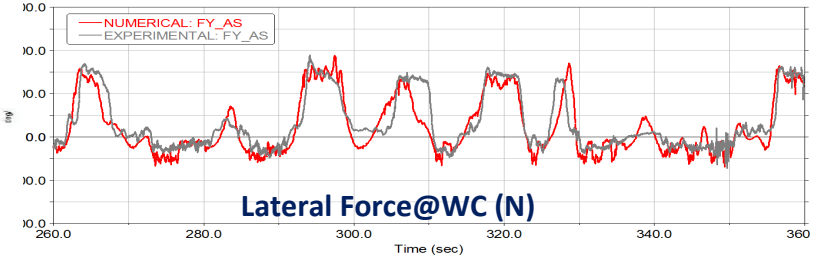
Grey = experimental

## Simulation vs testing : 1 complete track lap of "Langhe"

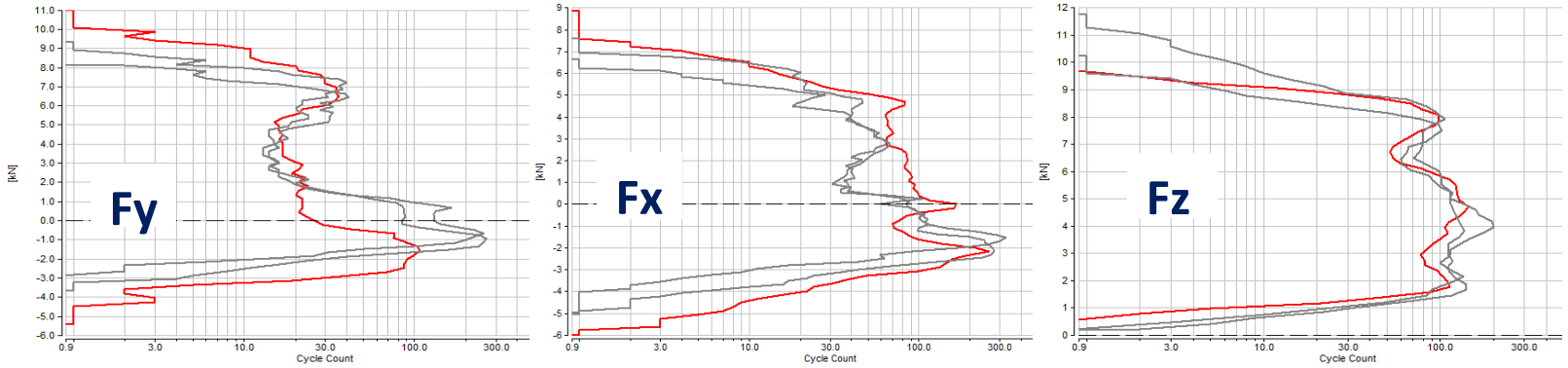


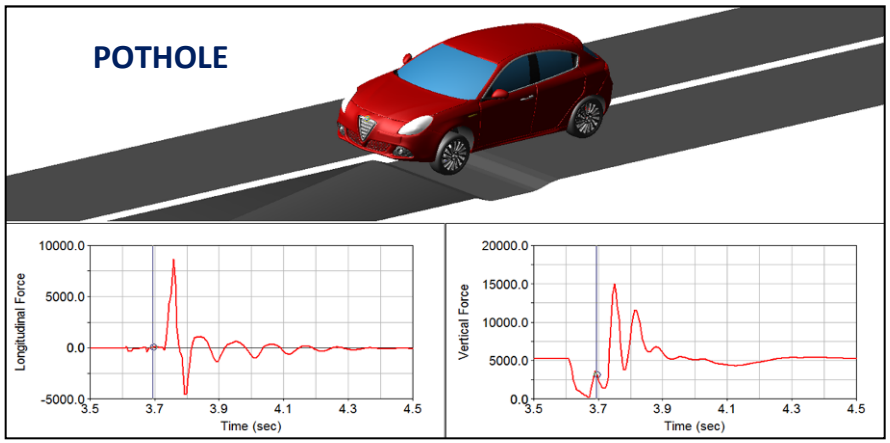

## Levelcrossing at WC : 1 simulated lap vs 2 measured laps



# E0 program : Pothole

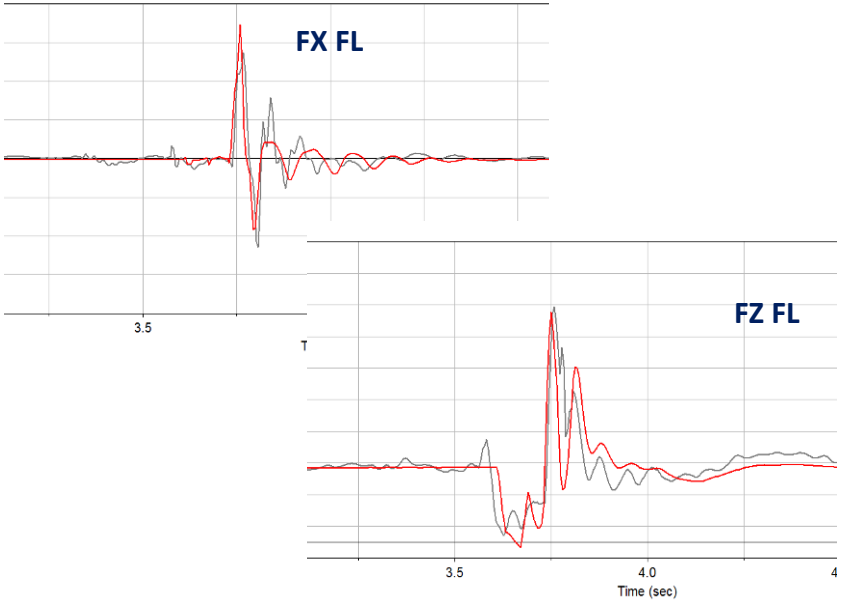
**INPUT SIMULATION :**

- Road profile left, right (Z vs. X) 4 Potholes
- vehicle Speed




**OUTPUT SIMULATION**

- t.h. of loads @ hub and each components
- PSD wheel hub forces and accelerations




**MISUSE - Pothole**

**Road profile amplitude = -127mm**

**Mean vehicle speed = 40km/h**

**Length single pothole = approx. 2m**

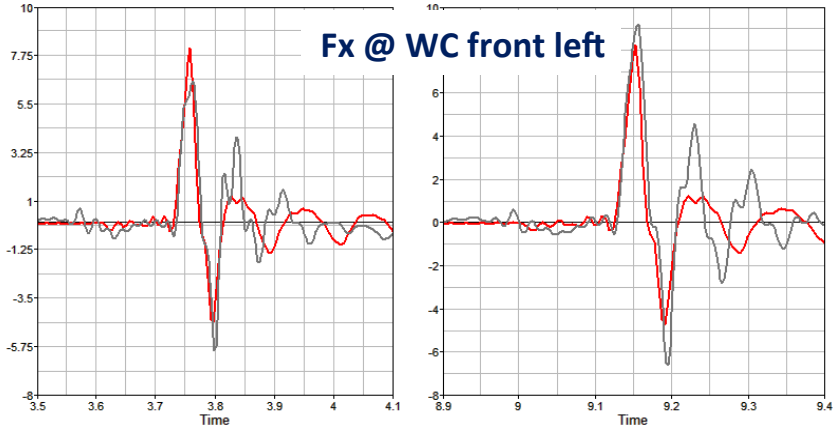
**Simulation time = 10-15min**

# E0 program : Pothole

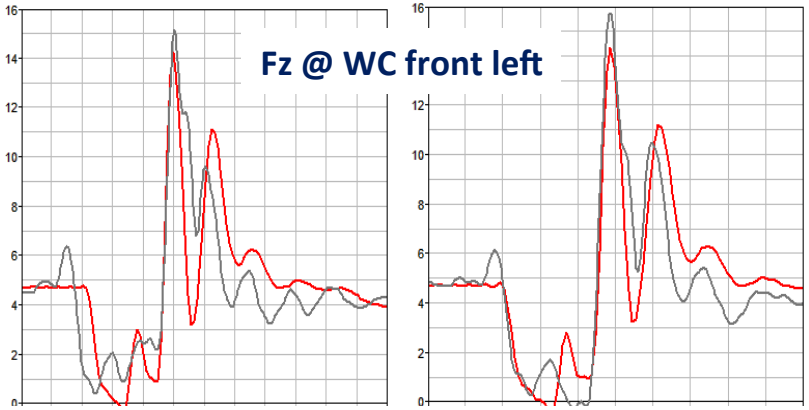
**Red = numerical**

**Grey = experimental**

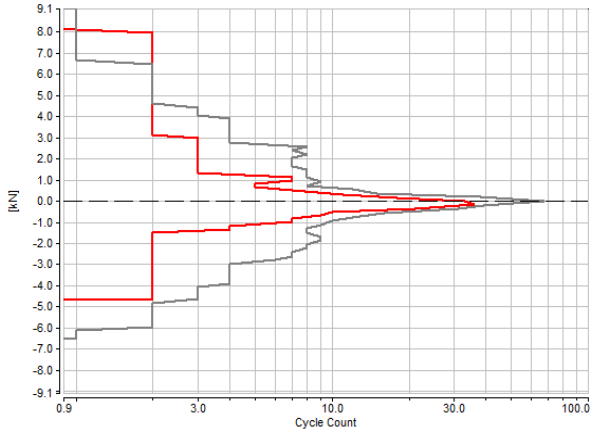
## Simulation vs testing : series of potholes

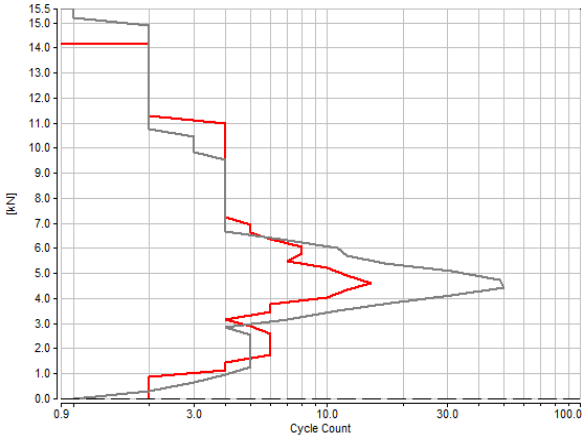



**Mean err% calc. - meas. Fx : 14%**




**Mean err% calc. – meas. Fz : 8%**



# Agenda

- Introduction
- Durability Schedule : Europe & US
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- Load prediction : Random road, Driven road, Misuse/Single event
- Complete Durability Schedule Simulation & correlation
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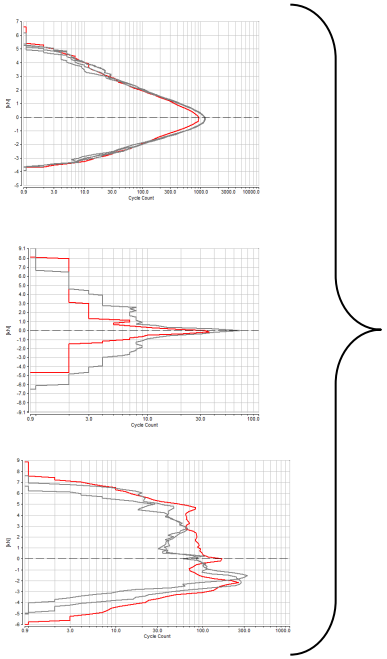
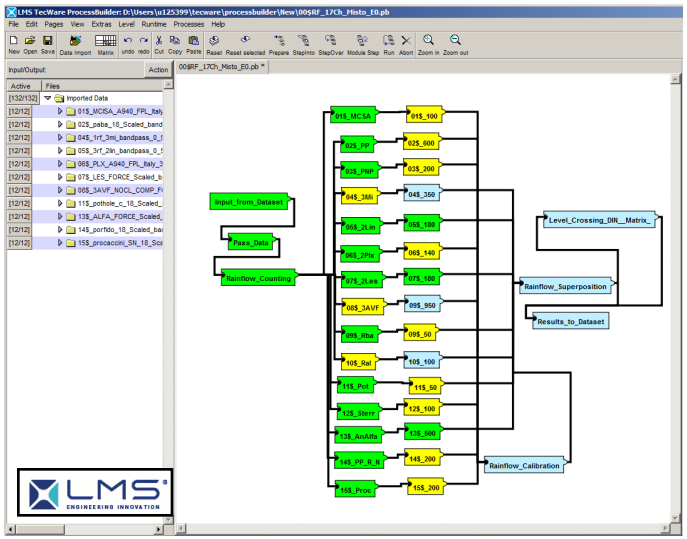
- Summary & Conclusions

# E0 program : tracks composition

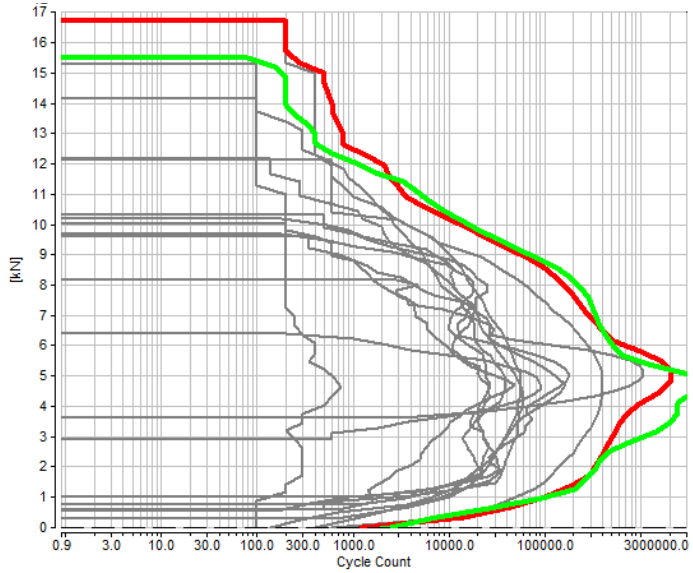
- Each track of the program is simulated
- Levelcrossing of all signals of different tracks are combined together with defined multipliers in order to build the complete durability schedule
- Comparison of overall numerical and experimental overall levelcrossing



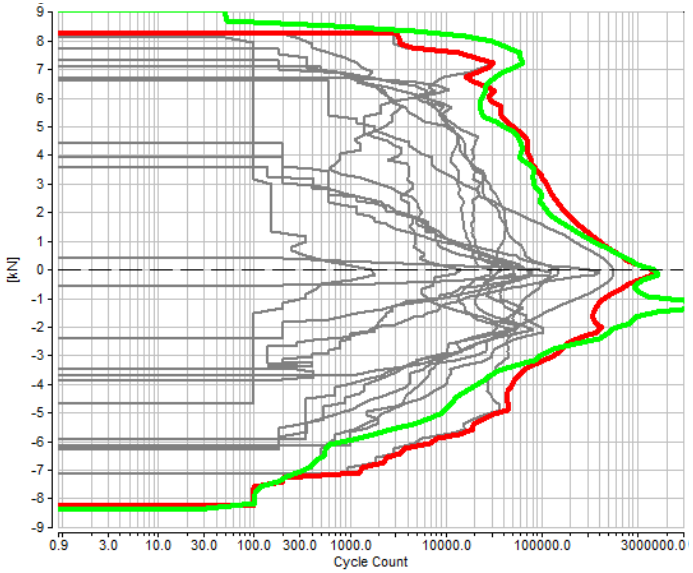



# E0 program : simulation vs experimental

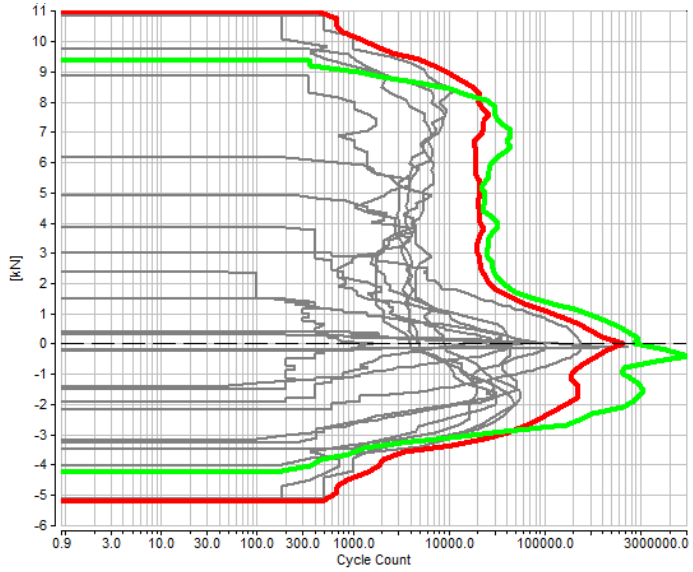
Fz




Fx




Fy




**Num Exp Comparison**

FRONT LEFT HUB Forces

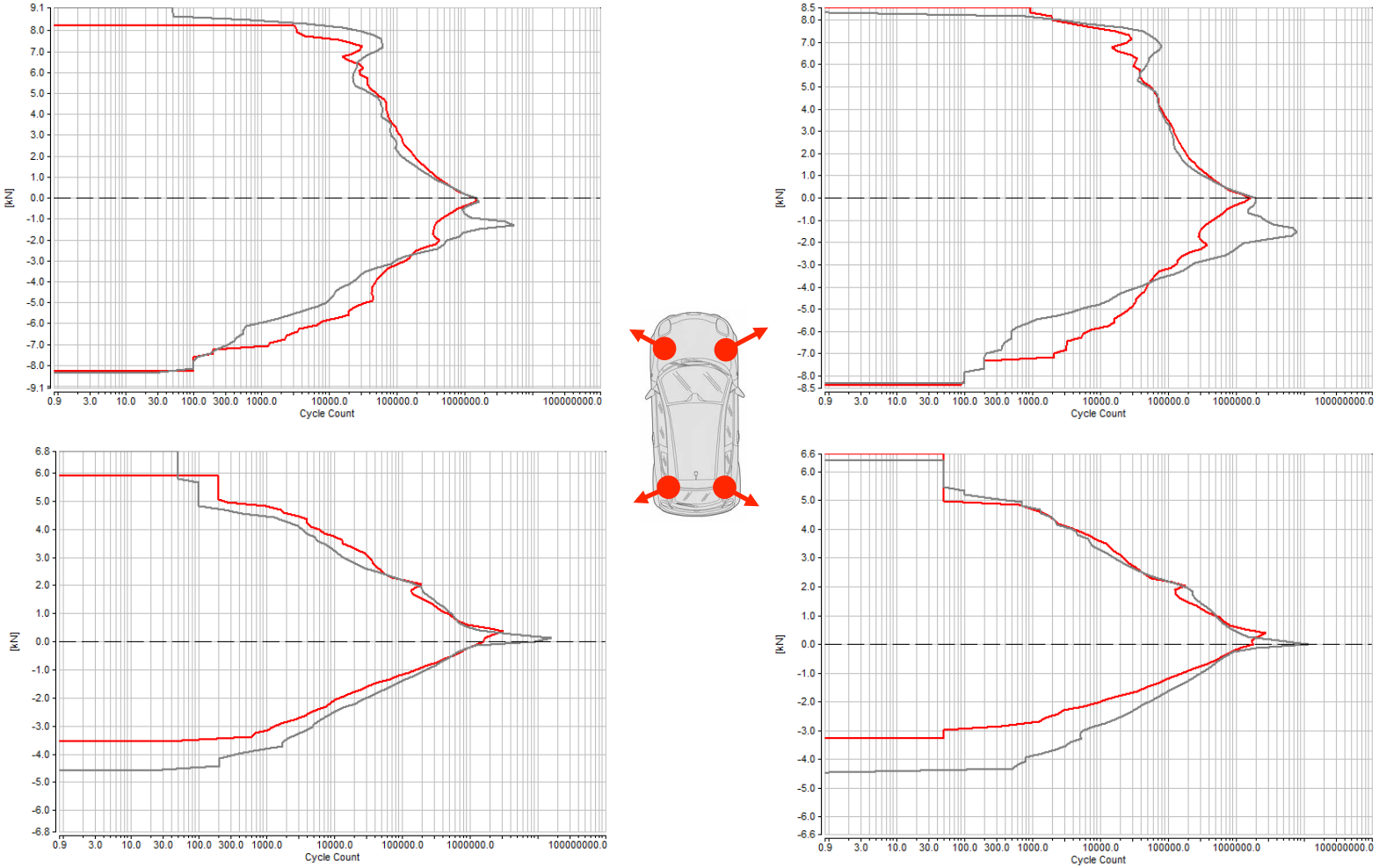
| | Calc | Exp | Ratio |
|---|---|---|---|
| FX | 1,55E-18 | 8,05E-19 | 1,93 |
| FY | 5,11E-19 | 2,27E-19 | 2,25 |
| FZ | 1,15E-18 | 1,04E-18 | 1,11 |

# E0 program : simulation vs experimental

**Red = numerical**

**Grey = experimental**

## Fx – longitudinal force @ WC

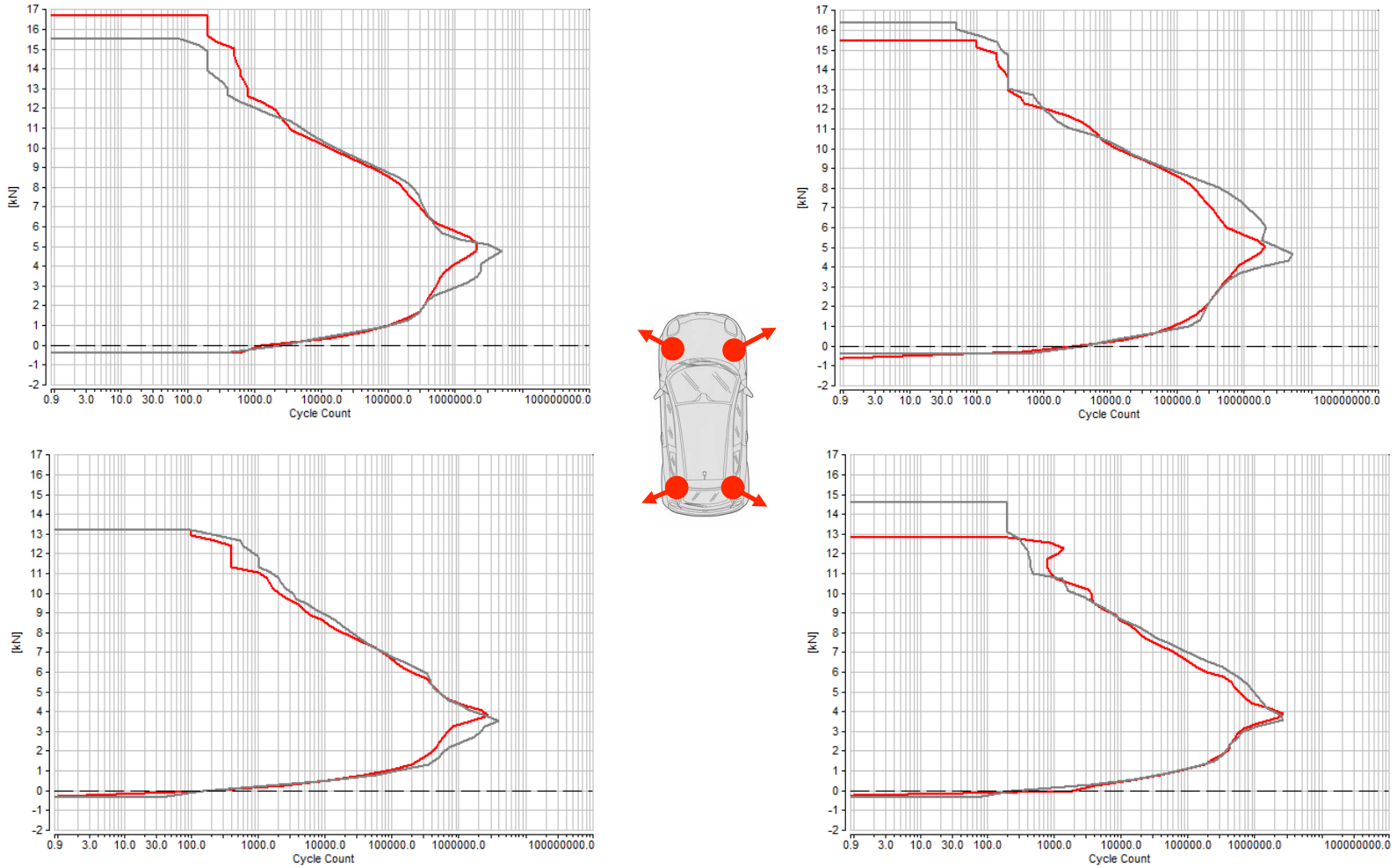


# E0 program : simulation vs experimental

**Red = numerical**

**Grey = experimental**

## Fz – vertical force @ WC

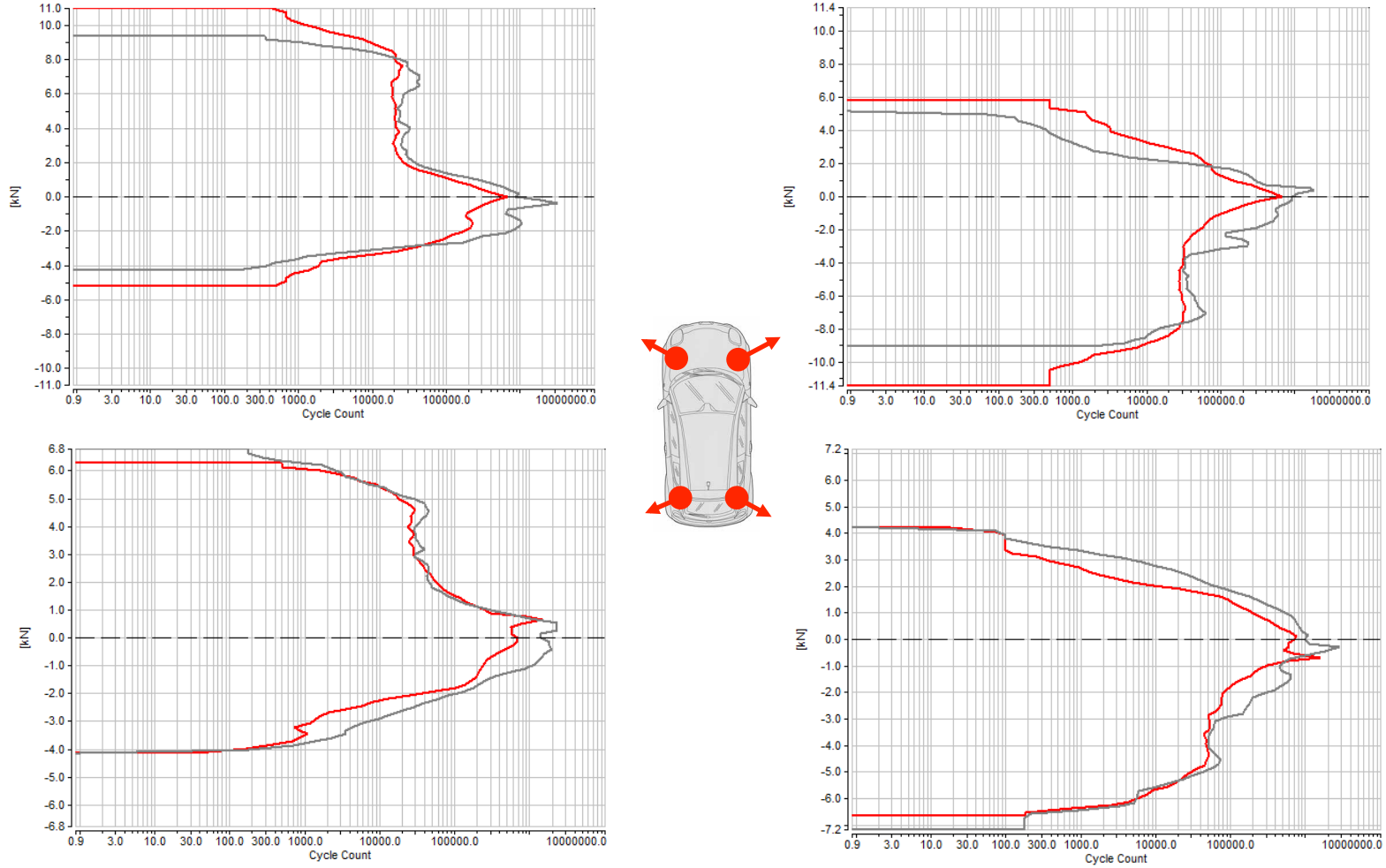


# E0 program : simulation vs experimental

**Red = numerical**

**Grey = experimental**

## Fy – lateral force @ WC

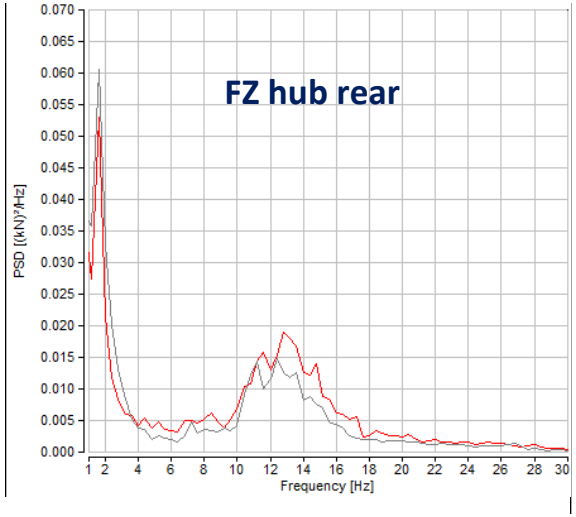


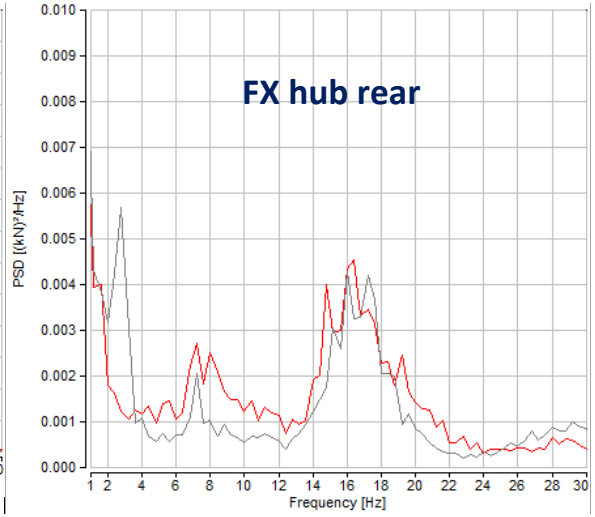
# E0 program : simulation vs experimental

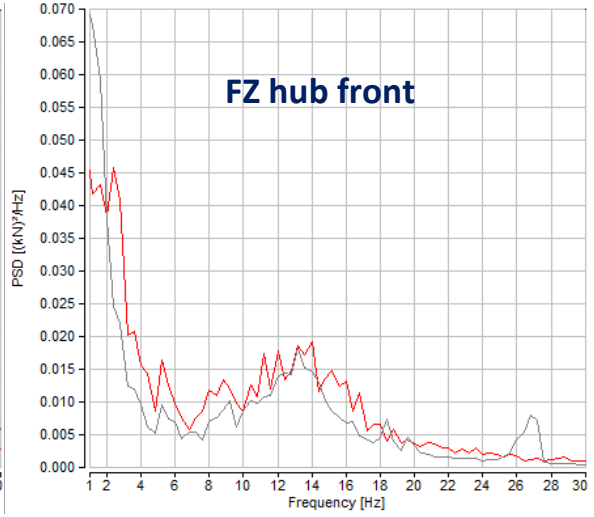
**Red = numerical**

**Grey = experimental**

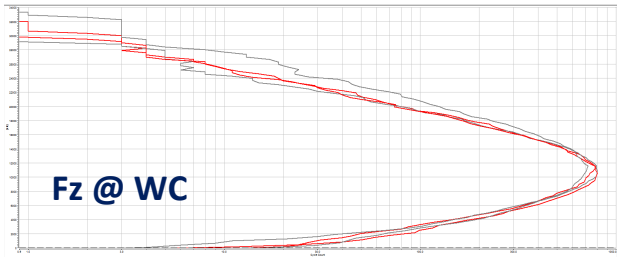
## PSD of forces @ WC

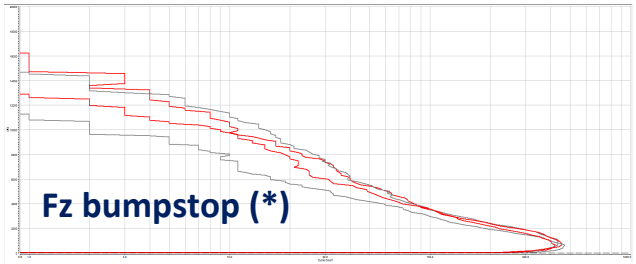



**Correlation of PSD of forces and accelerations it's necessary to have a good prediction of loads at each components**




**(*) measured with load cells**

# E0 program : simulation time

| ADAMS/MB-SHARC Model | | |
|---|---|---|
| PABA (400m/60s) | : | 18min |
| PORF (400m/25s) | : | 8min |
| PROC (200m/15s) | : | 7min |
| POT (15s) | : | 8min |
| NGALL (15s) | : | 6min |
| RAL/RBA | : | 2min |
| MISTINO + ALFA (82s+193s) | : | 7min |
| LANGHE INT (253s) | : | 6min |
| LANGHE EXT (225s) | : | 5min |
| OTHER TRACKS | : | 12min |
| **TOTAL** | : | **79min** |

TWS Intel XEON CPU E5630
2.53GHz - RAM 12 Gb
S.O. 64bit

- **Complete simulation of durability program requires less than 1.5hs !**
- **Multiple runs are possible in a short time in order to validate model, improve correlation, make setup variants**
- **Inputs are available from the beginning for the STRUCTURE-TEAM**

# Agenda

- Introduction
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# Durability schedule comparison : SXV reproduction in E0

## Comparison between E0 Balocco and Chelsea proving ground

## Definition of a new schedule in Balocco to obtain the same Chelsea damage

- Data acquisition in E0-Balocco and in SXV-Chelsea proving grounds with the same reference vehicle (twins vehicles , double acquisition)
- Load data analysis : pseudodamage, levelcrossing, psd, min-max of acquired signal
- Optimization procedure applied on pseudodamage, psd's, levelcrossing in order to obtain multipliers for each track in Balocco to match Chelsea proving ground
- Definition of a new schedule in Balocco to reproduce SXV program in Chelsea : new mix of tracks with different multipliers and new procedure for some tracks (i.e. change speed or payload condition)
- Statistic validation and cross validation with different class of vehicles and different suspension layouts

## New durability schedule -> SXV Balocco

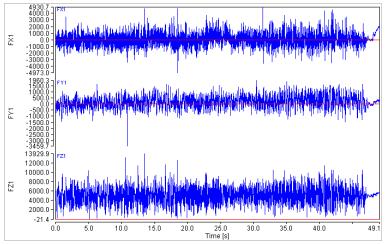
# Durability schedule comparison : SXV reproduction in E0

**TRACKS COMPARISON METRICS :**

- Level Crossing/Range Pair
- MIN, MAX, MEAN Values
- PSEUDO DAMAGE
- PSD

**SIGNALS :**

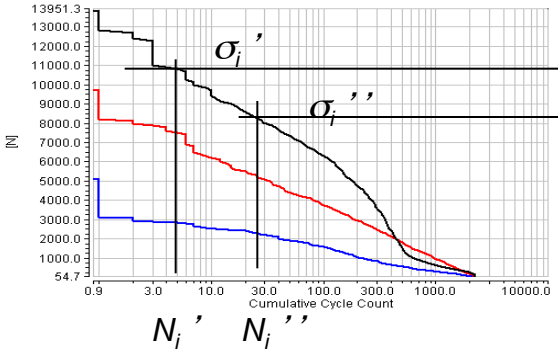
- Forces,accelerations, displacements @ WC
- Forces @ components (load cells)
- Strain gauges

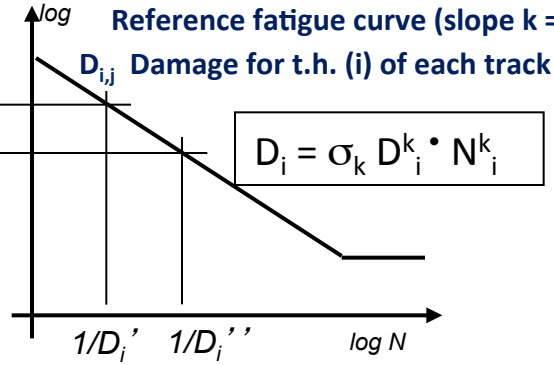


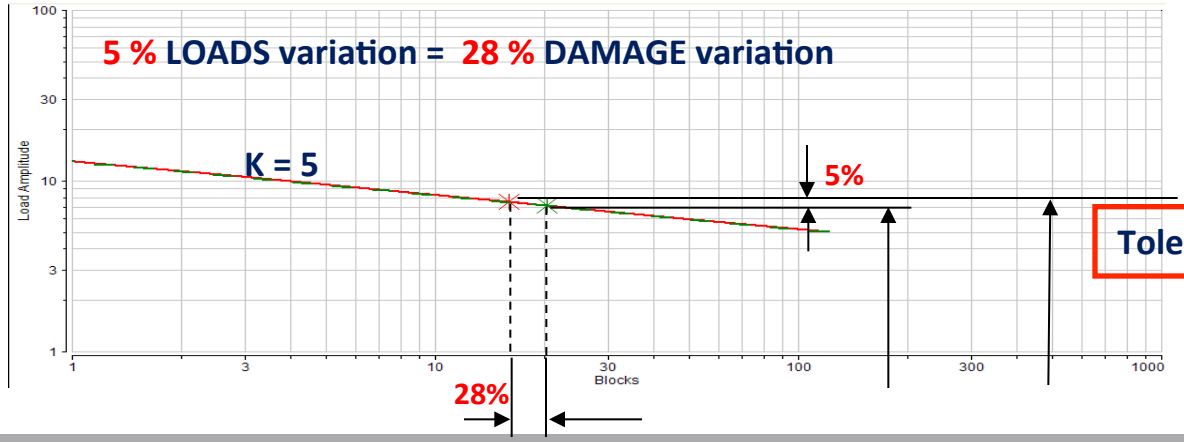
Time histories of loads (Fx-Fy-Fz-Mx-My-Mz)

$S_j D_{i,j}$ = Total damage for each channel (i) of whole track

Signals Range pair



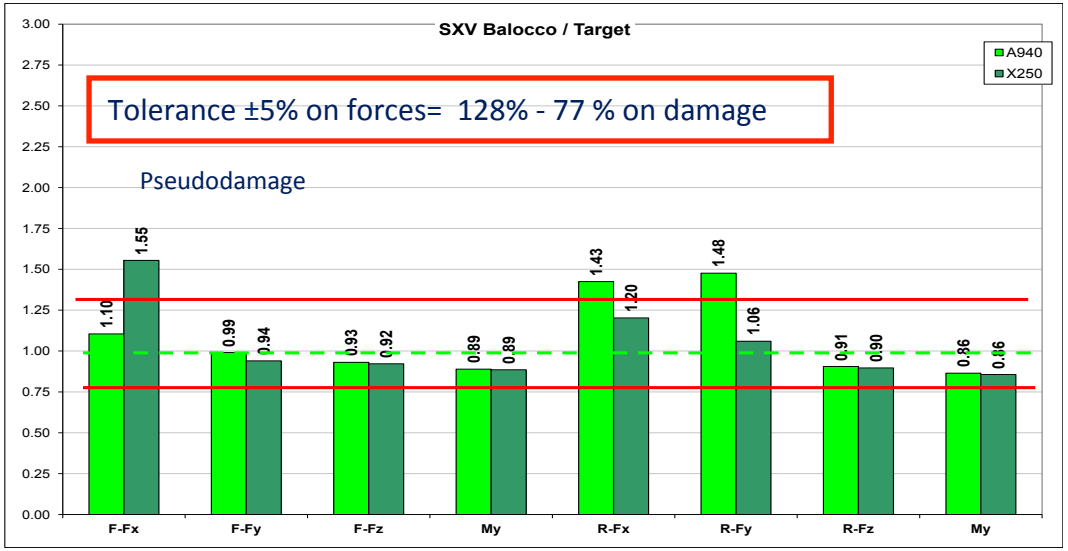




| Equivalent Load Ratio | Iso Damage Ratio |
|---|---|
| -40% | 0.08 |
| -30% | 0.17 |
| -20% | 0.33 |
| -10% | 0.59 |
| -5% | 0.77 |
| 0% | 1.00 |
| 5% | 1.28 |
| 10% | 1.61 |
| 20% | 2.49 |
| 30% | 3.71 |
| 40% | 5.38 |

# Durability schedule comparison : SXV reproduction in E0

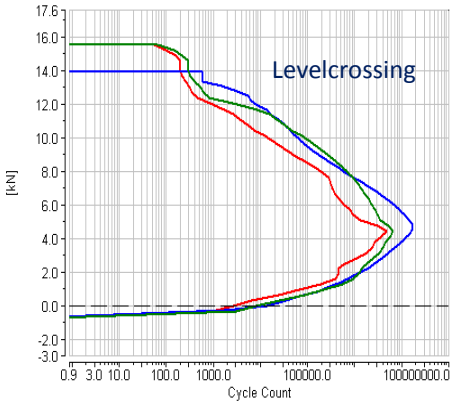
## New durability schedule : SXV Balocco vs SXV Chelsea

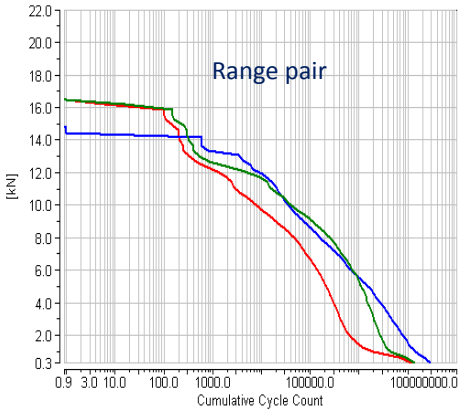


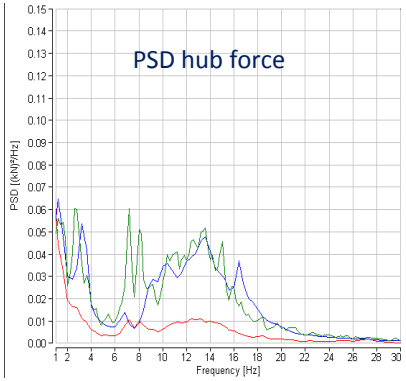

| TRACKS | Speed [km/h] | Length (m.) |
|---|---|---|
| Pavé Pesante Balocco (PABA) | 25-30 | 400 |
| Porfido Rosso/Grigio (PORF) | 60 | 400 |
| Procaccini (PROC) | 50 | 200 |
| Pavè Pesante Mandria (PAMA) | 25-30 | 900 |
| Acciottolato Pesante Russo (APES) | 20-25 | 450 |
| Sterrato (STERR) | 50 | 1570 |
| Cisa (MCISA) | Max | 4170 |
| Pavimentazioni Speciali Langhe (PLX) | 50 | 6700 |
| Mistino (3MI) | Max | 7200 |
| Anello Esterno Alfa (ALFA) | Max | 5100 |
| Langhe Esterne (2LES) | Max | 10600 |
| Langhe Interne (2LIN) | Max | 13400 |
| Anello Veloce (3AV) | Max | 22700 |
| Nidi di Gallina (NGALL) | 20 | 290 |
| Rampe Basse 13% (RBA) | 15-20 | 240 |
| Rampe Alte 16% (RAL) | 15-20 | 240 |
| Pot Holes (POT) | 40 (25-30) | 180 |

**NEW MIX WITH DIFFERENT REPETITIONS AND PROCEDURES FOR EACH TRACKS**

## Comparison between new mix of tracks and procedures of E0 Balocco and Chelsea proving ground in terms of pseudodamage, levelcrossing, range pair, PSD



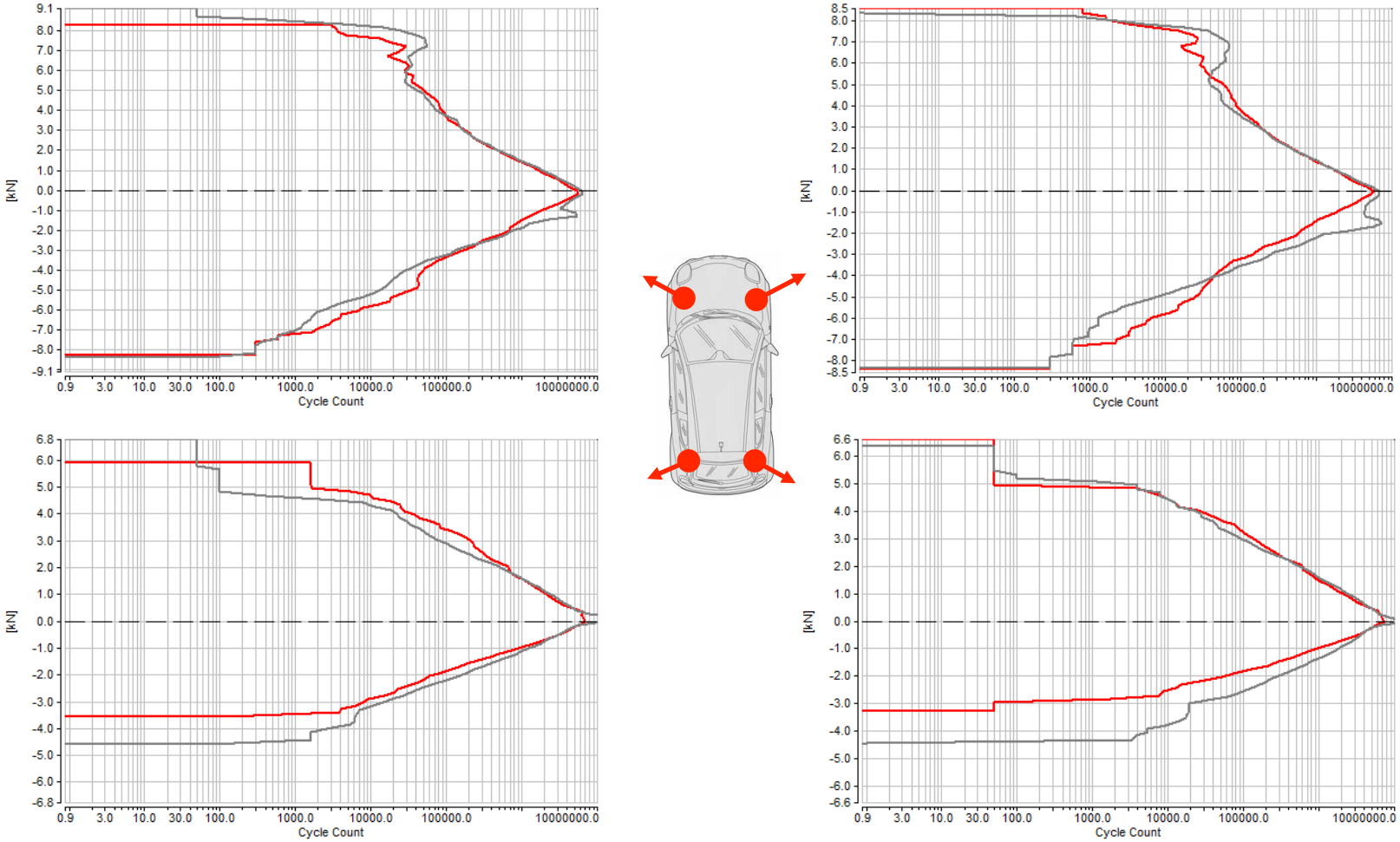

E0
SXV Chelsea
SXV Balocco

# Durability schedule comparison : SXV Balocco

**Red = numerical**

**Grey = experimental**

Fx – longitudinal force @ WC

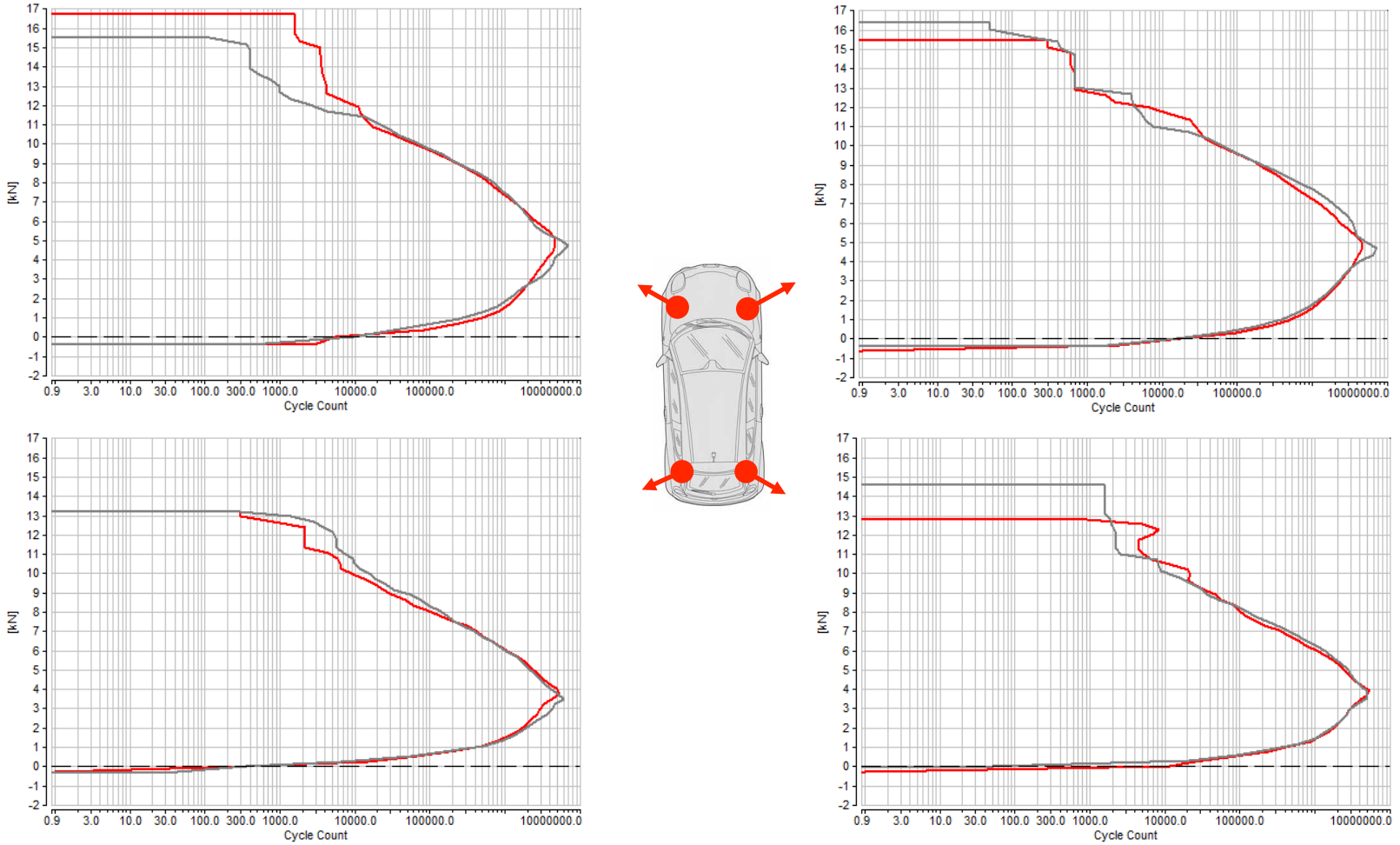


# Durability schedule comparison : SXV Balocco

**Red = numerical**

**Grey = experimental**

Fz – vertical force @ WC

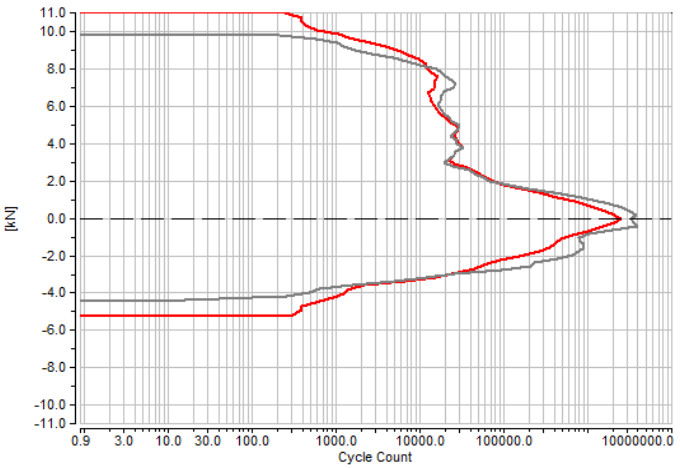


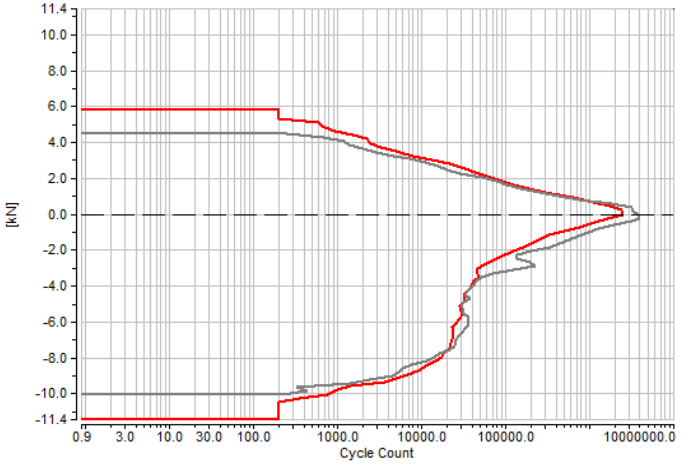
# Durability schedule comparison : SXV Balocco

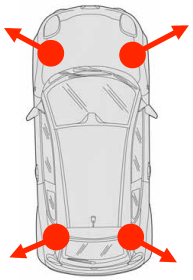
**Red = numerical**

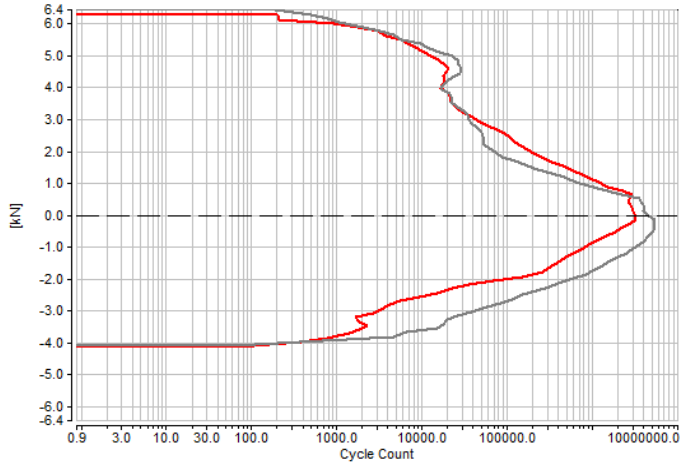
**Grey = experimental**

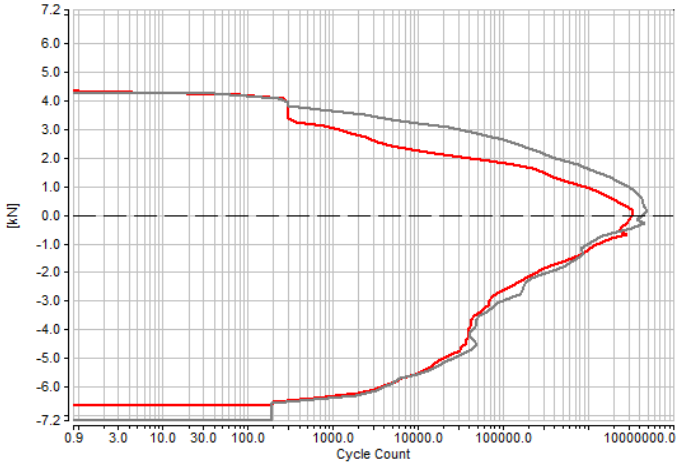
Fy – lateral force @ WC





# Agenda

- Introduction
- Durability Schedule : Europe & US
- Durability Process & Simulation
- Load prediction : Random road, Driven road, Misuse/Single event
- Complete Durability Schedule Simulation & correlation
- Tracks comparison
- Summary & Conclusions

# Summary & Conclusions

- Simulation of complete durability schedule including a mix of different road such rough roads, driven roads, obstacles and misuse events, shows a very good level of accuracy.
- During development of vehicle performances, durability has to be taken in account from the beginning : the load prediction must be included in a common process with the simulation of handling and ride comfort performances.
- Durability Model correlation start from K&C, handling and ride comfort, so a well correlated model is a result of at least 3 steps of development & validation
- Different road profiles can be compared, correlated and simulated combining measurement and calculation
- Simulating with high fidelity models drastically reduces the development time and the costs due to possible late failures of structural components
- The durability process, including load prediction, has to be treated in a statistical way: extended database plus experience are in any case factors to be included in the process

# Thanks !

## Thank you for your attention