Robust:
“Road Upgrade of Standards”
GRD1-2002-70021

Testing procedures and severity indices evaluation.

Marco Anghileri
Dipartimento di Ingegneria Aerospaziale
Politecnico di Milano
Italy

Scope of the activities.

- To harmonise the measurement practice in the European laboratories and remove possible discrepancies from different transducer and test set-up.
- Part of the consideration already presented by Lier.

- Fields:
  - Experimental
  - Analytical

Contribution.

1. Statistical analysis of already performed tests.
2. Severity indices definition.
3. Data acquisition and severity indices evaluation.
4. Instrumentation mounting.

Statistical analysis of already performed tests.

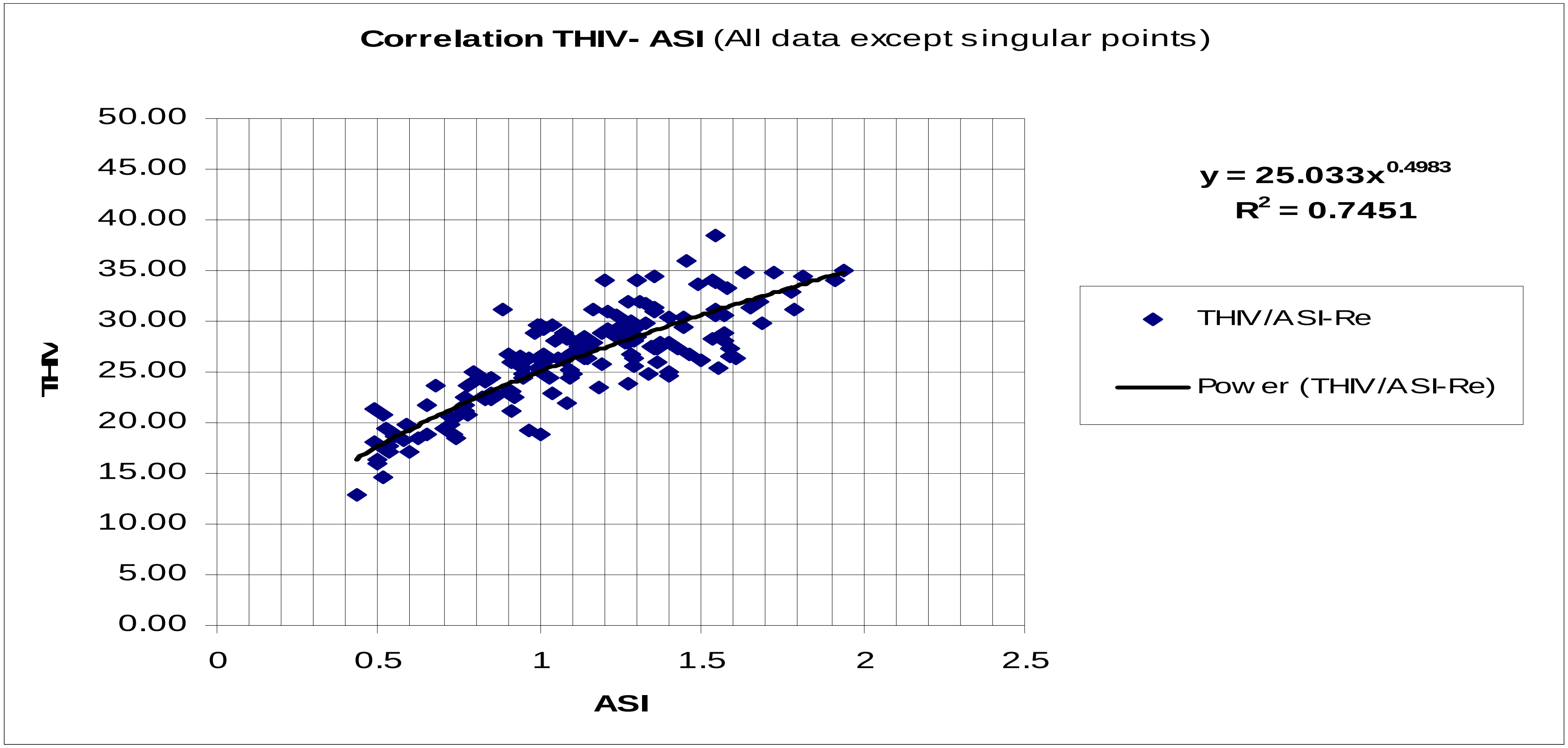
- Analysis of existing data obtained form European laboratories to investigate possible correlation between severity indices.

- Analysis of existing data obtained form European laboratories to investigate differences between tests houses

Data base.

- From European laboratories a set of 174 data of TB11 full scale crash tests have been obtained containing the following information:
  - year of test
  - vehicle make
  - vehicle test mass
  - data sample rate
  - actual speed and angle
  - barrier dynamic deflection
  - ASI
  - THIV/PHD
- Data were received from 7 Laboratories. Of 174 TB11 tests, 111 were successful and 63 unsuccessful. Some tests have been received without PHD data.

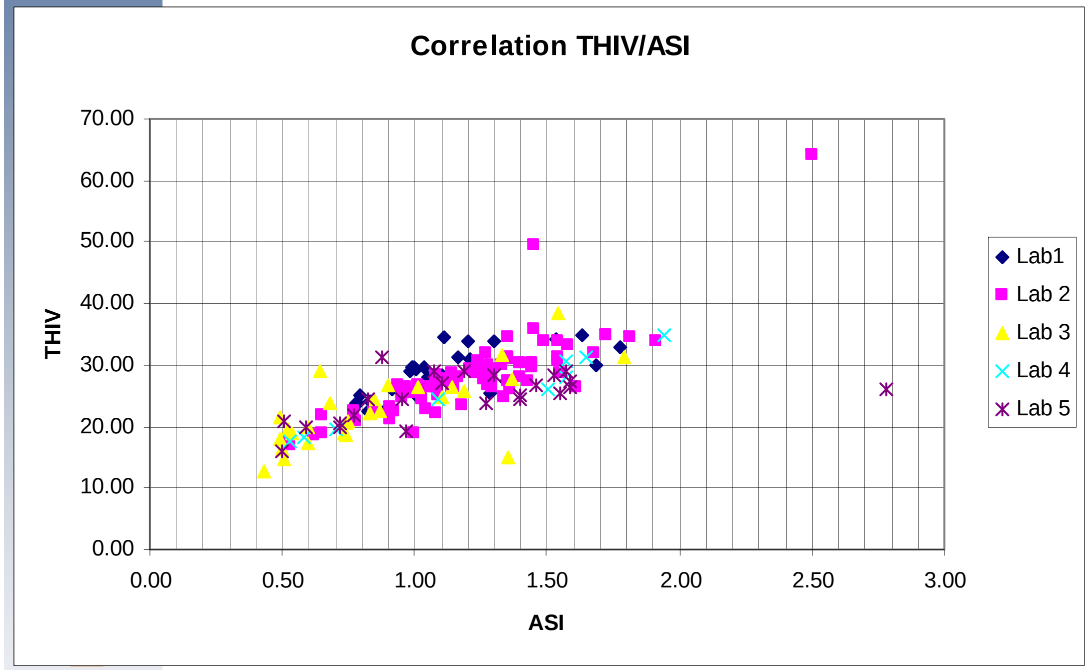
THIV-ASI



- This graph shows a fair correlation between ASI and THIV indices. Correlation factor of 0.7451

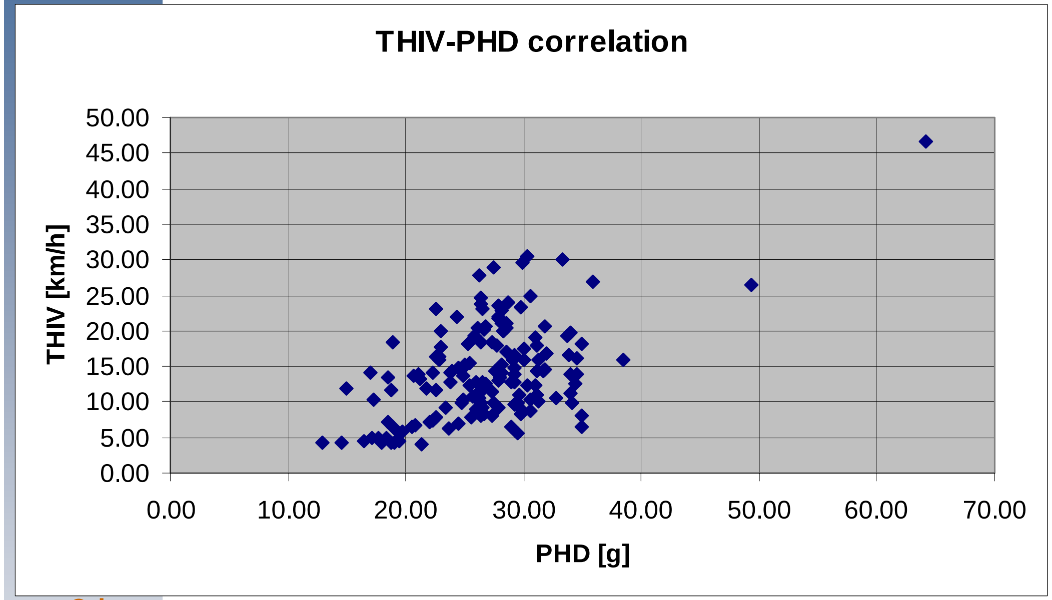
$$THIV = 25.033 \cdot ASI^{0.4989}$$

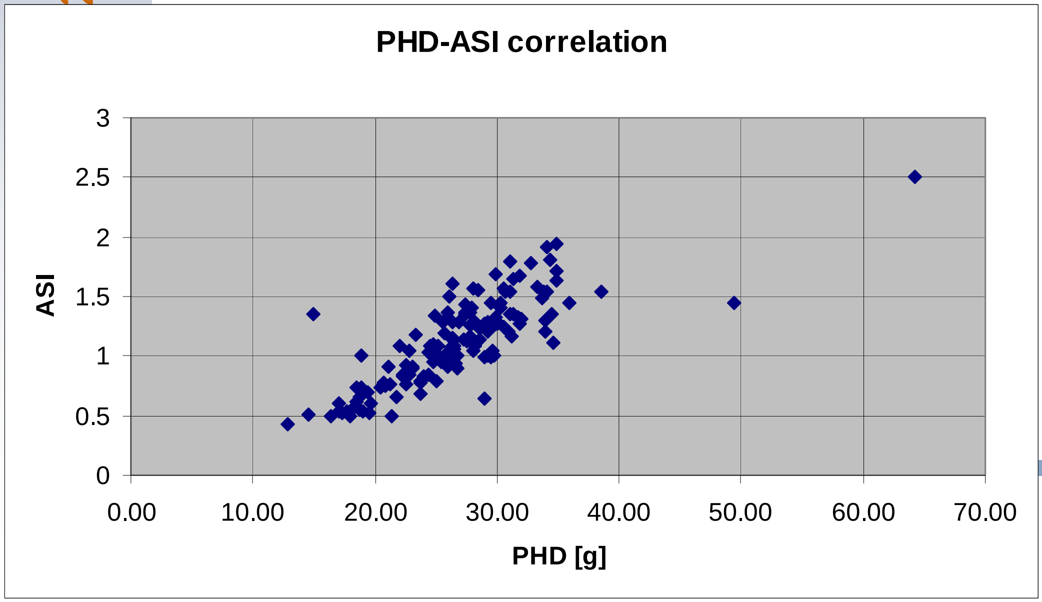
Thiv-Asi different labs.



Lab	Corr. function
ALL	y = 25.0 ASI^0.4983
1	y = 26.9 ASI^0.4305
2	y = 24.0 ASI^0.3305
3	y = 24.8 ASI^0.545
4	y = 25.1 ASI^0.5596
5	y = 23.6 ASI^0.4899

THIV-PHD PHD-ASI

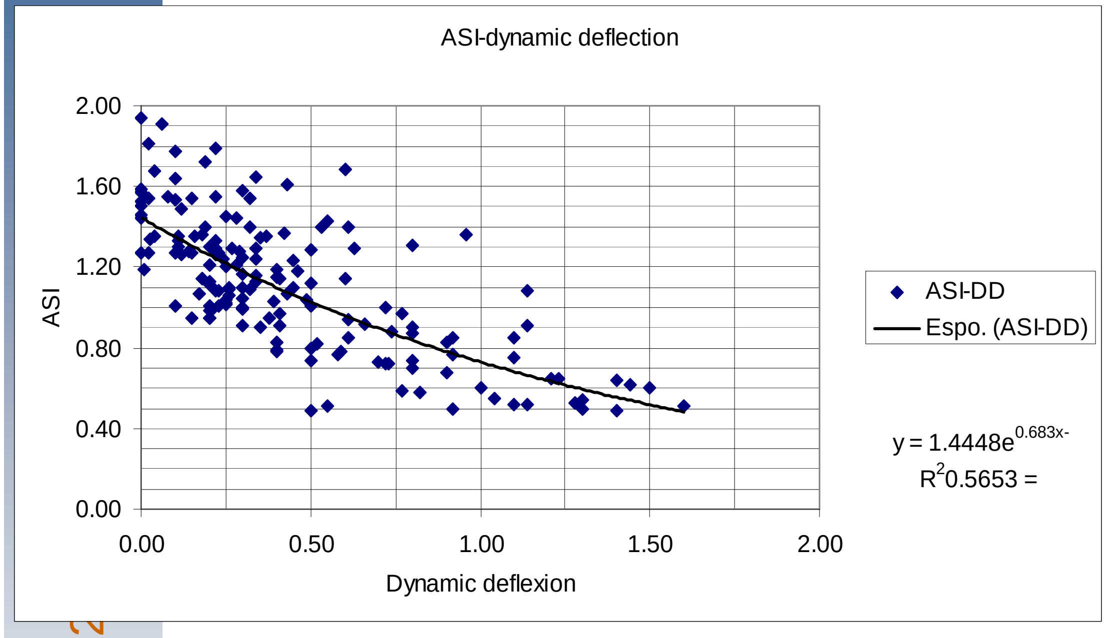


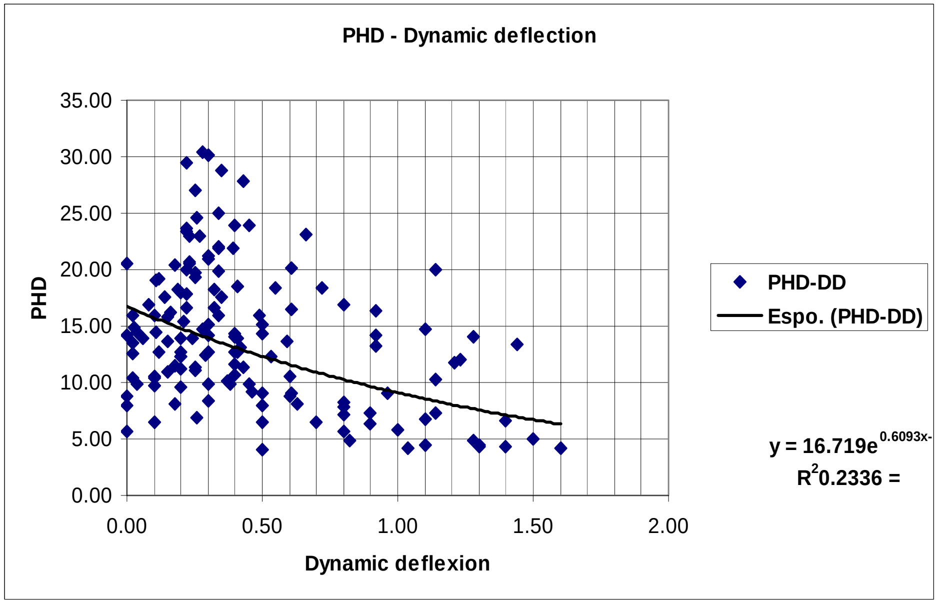


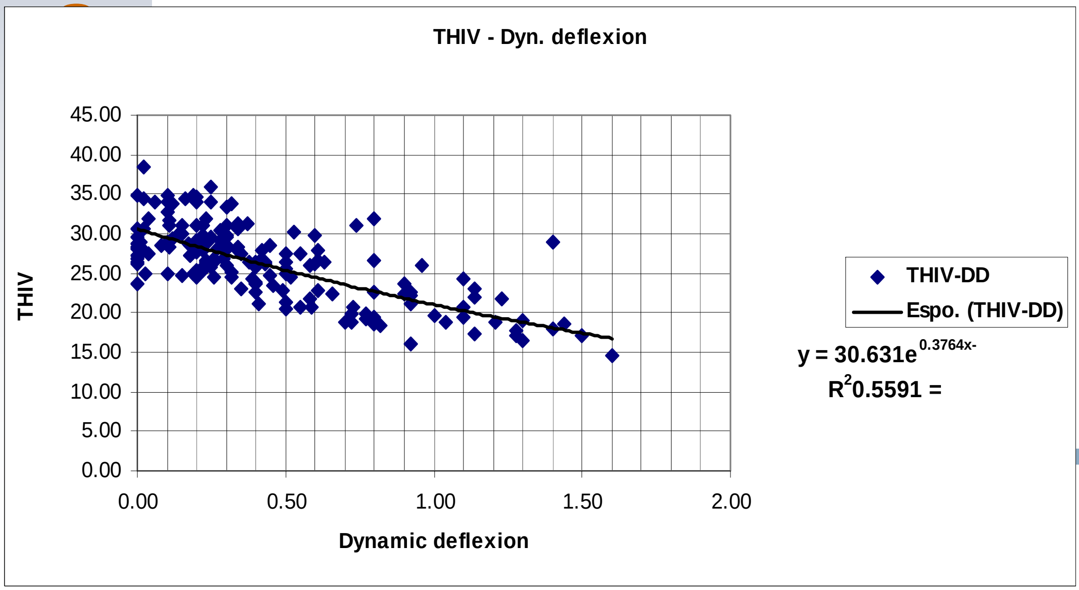
- no correlation between PHD and THIV or ASI

Road Barrier Upgrade of Standards

ASI-DD THIV-DD PHD-DD



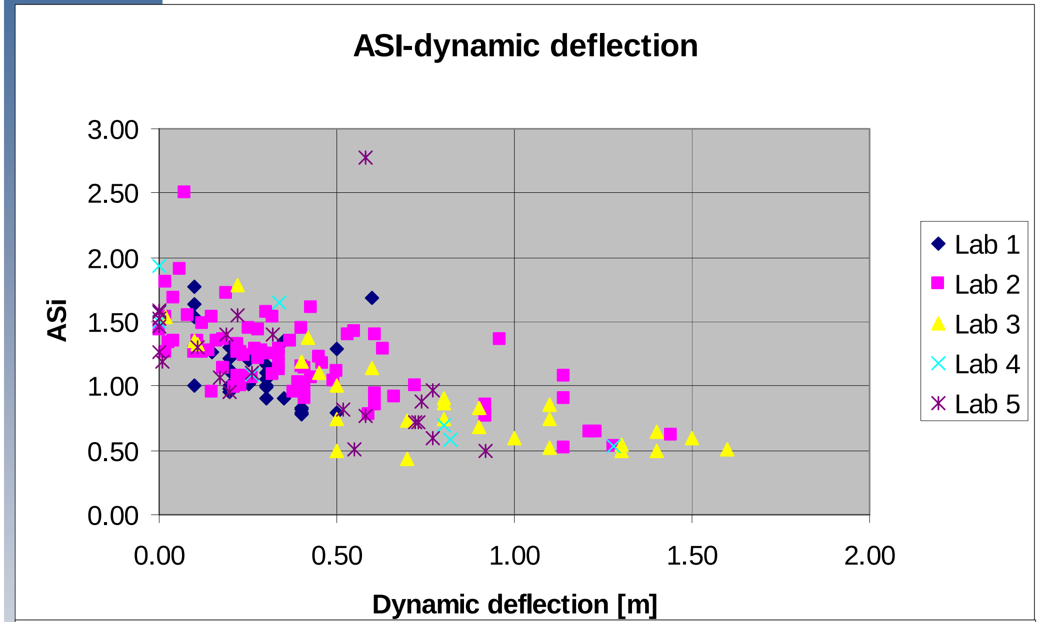




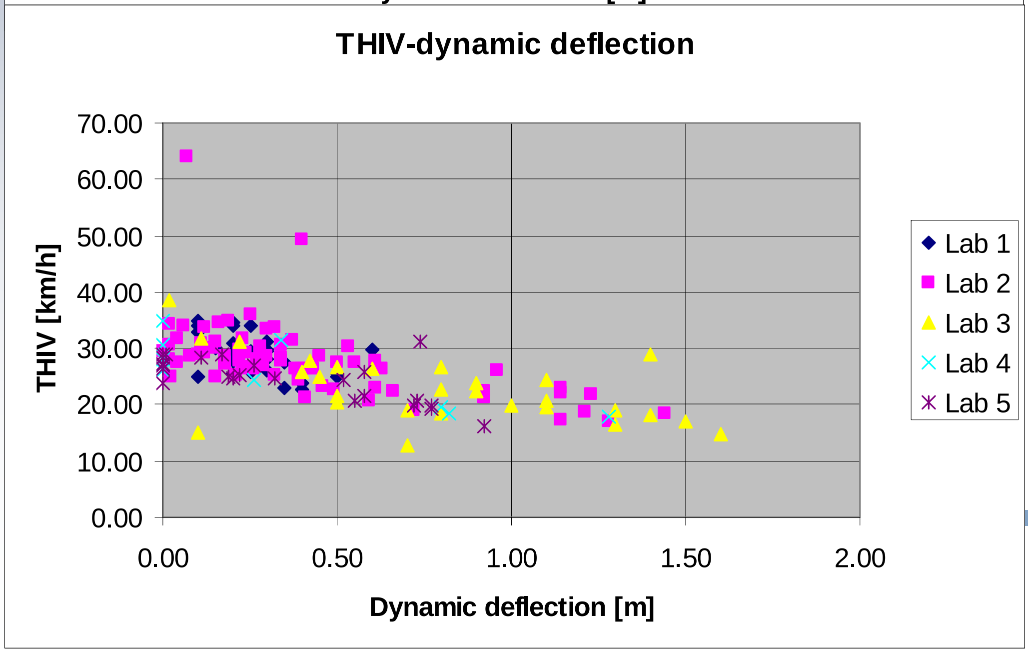
- PHD: no correlation.
- THIV-DD ASI_DD: weak correlations

ROBUS Road Barrier Upgrade of Standards

Different Labs



Lab	Corr. Function
All	y = 1.4448e-0.683x
1	y = 1.2829e-0.5836x
2	y = 1.4973e-0.6099x
3	y = 1.3841e-0.6902x
4	y = 1.6442e-0.9867x
5	y = 1.4716e-0.8779x



Lab	Corr. Function
All	y = 30.631e-0.3764x
1	y = 32.827e-0.5464x
2	y = 32.141e-0.4018x
3	y = 27.476e-0.2846x
4	y = 29.923e-0.4634x
5	y = 27.801e-0.3747x

Results of statistical analysis.

- These results show that there is a limited correlation between severity indices.
- Reason: from the scientific point of view, ASI, THIV and PHD are different things.
- The main differences between these severity indices are:
  - ASI is using three components of acceleration while THIV-PHD use a planar motion where the z acceleration component is not used.
  - THIV – PHD use a critical time that corresponds to the time where the theoretical head impact against the conventional box representing the vehicle interior.
  - THIV is affected also by the yaw motion while ASI does not take into account this measure into account.
- Test houses have similar tendencies.

Severity indices definition.

- EN 1317 requires, to evaluate barrier performance, to measure the following severity indices:

ASI

THIV / (PHD)

- Based on acceleration measured during the certification test on the vehicle CG.

ASI. Acceleration Severity Index

- "The index ASI is intended to give a measure of the severity of the vehicle motion for a person seated in the proximity of point P (CG) during an impact."
- Steps:
  - Measure three acceleration components of vehicle CG according with CFC180.
  - Apply a 50 ms moving average on these acceleration.
  - Evaluate Asi as:

$$ASI(t) = \sqrt{\left(\frac{\bar{a}_x}{a_{x\,lim}}\right)^2 + \left(\frac{\bar{a}_y}{a_{y\,lim}}\right)^2 + \left(\frac{\bar{a}_z}{a_{z\,lim}}\right)^2}$$

ASI. Acceleration Severity Index.

- Where: $a_{x\lim} = 12g \quad a_{y\lim} = 9g \quad a_{z\lim} = 10g$
  - "Are obtained from the human body tolerances limits."
- ASI is the maximum value of ASI(t).
- "The average in equation (of ASI) is actually a low pass filter, taking into account the fact that vehicle accelerations can be transmitted to the occupant body through relatively soft contacts, which cannot pass the highest frequencies."
- The equation (of ASI) is the simplest possible interaction equation of three variables x, y and z.
- The limit accelerations are interpreted as the values below which passenger risk is very small (light injures if any)."

Moving average

- Asi and Phd evaluation requires moving average techniques:
  - ASI 50ms
  - PHD 10ms (NCHRP-350 ORA 10 ms)
  - The original idea was to have a window to observe the acceleration time histories.
- Questions:
  - Is moving average a true filter?
  - Can moving average give wrong information?

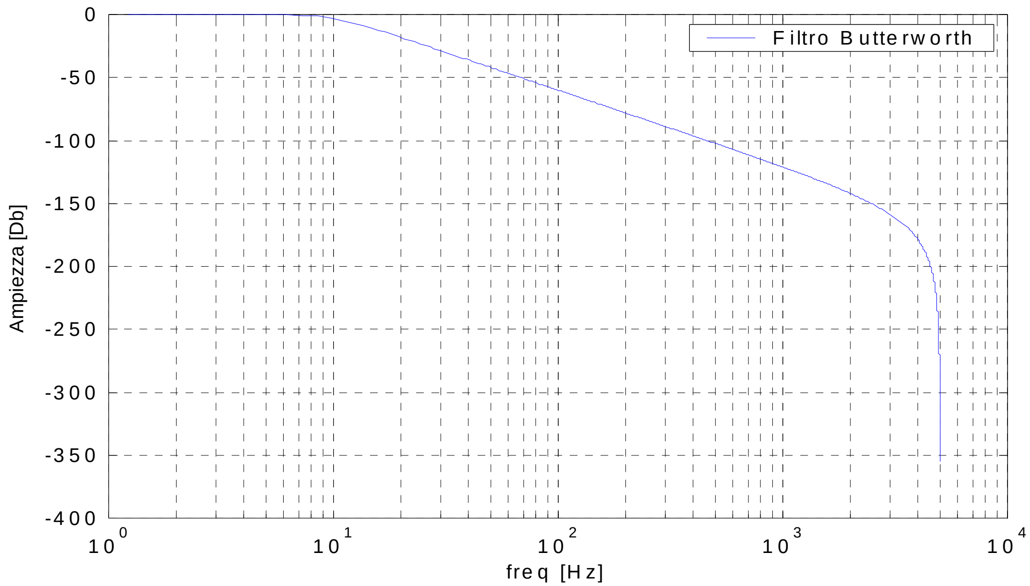
Filtering

- Signal processing (analog, digital or mechanical) to:
  - Eliminate noise or oscillation
  - Amplify frequencies
  - Avoid problems (example: aliasing)

- Attenuation:

$$Db = 20 \log_{10} \left(\frac{Out}{In} \right)$$

Typical low-pass filter frequency response

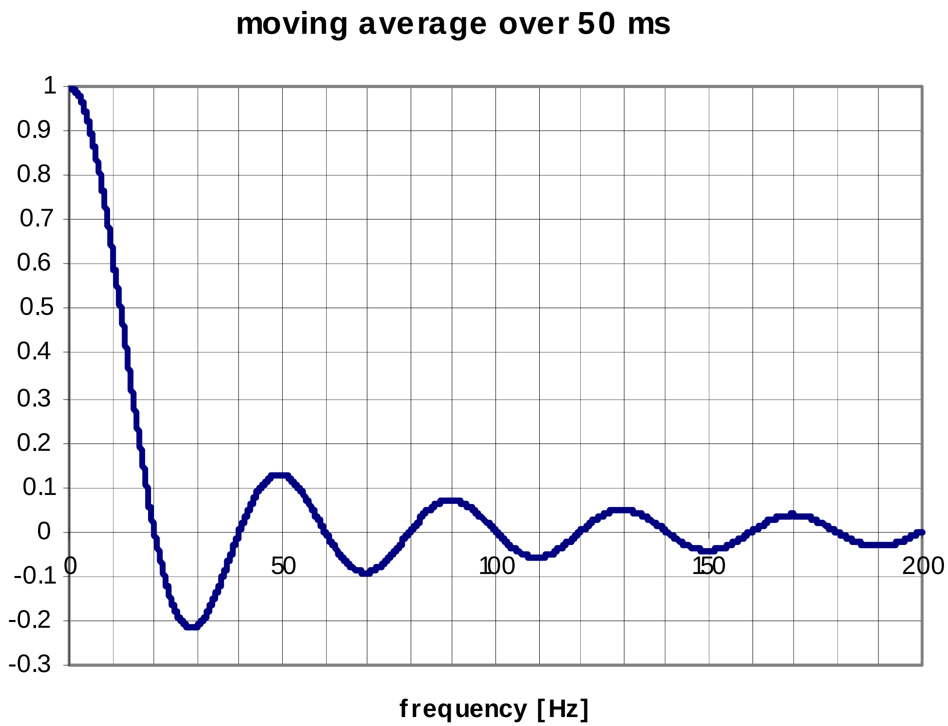


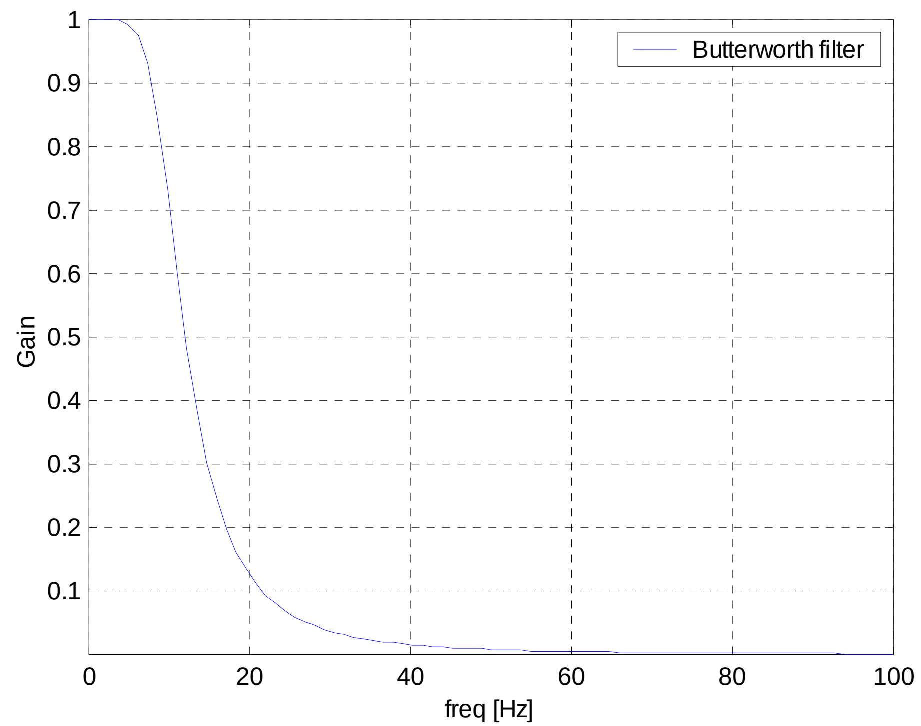
- -20 db means Output=0.1* Input

- The moving average is a filter in the sense that it modifies the original signal.

50 ms moving average – standard filtering gain.

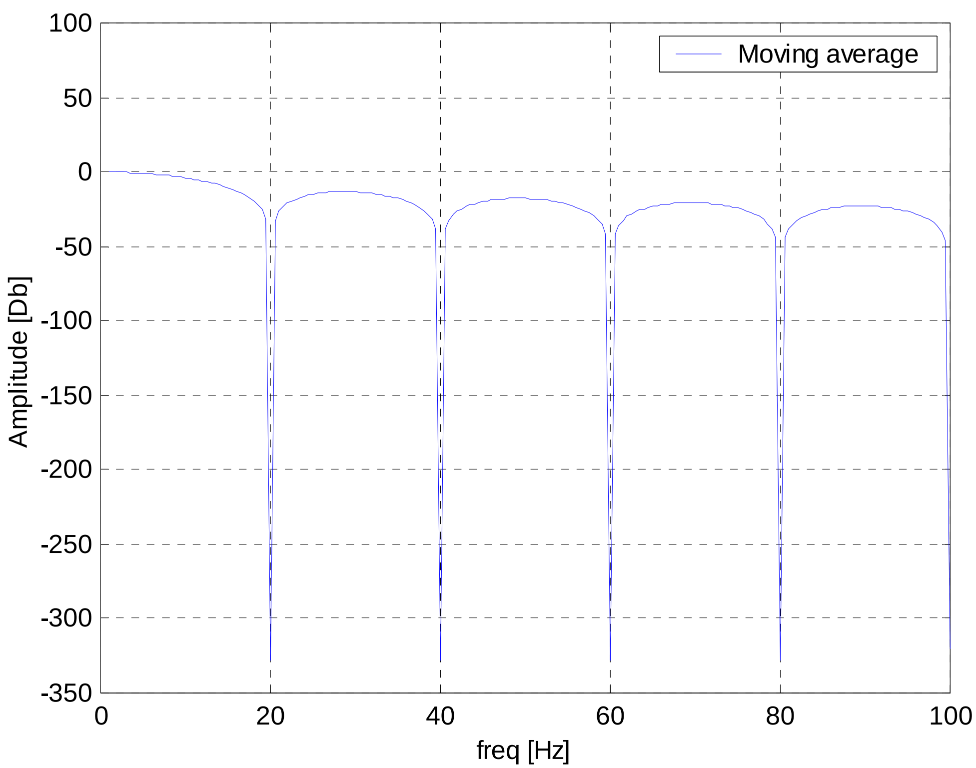
- Gain=output/input

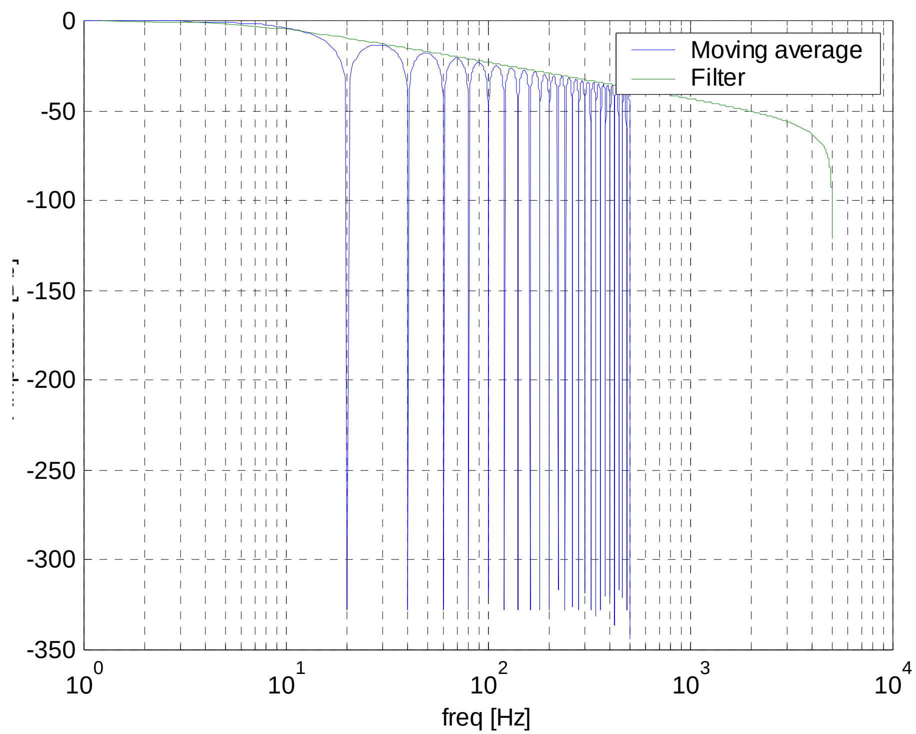




50 ms moving average – standard filtering attenuation.

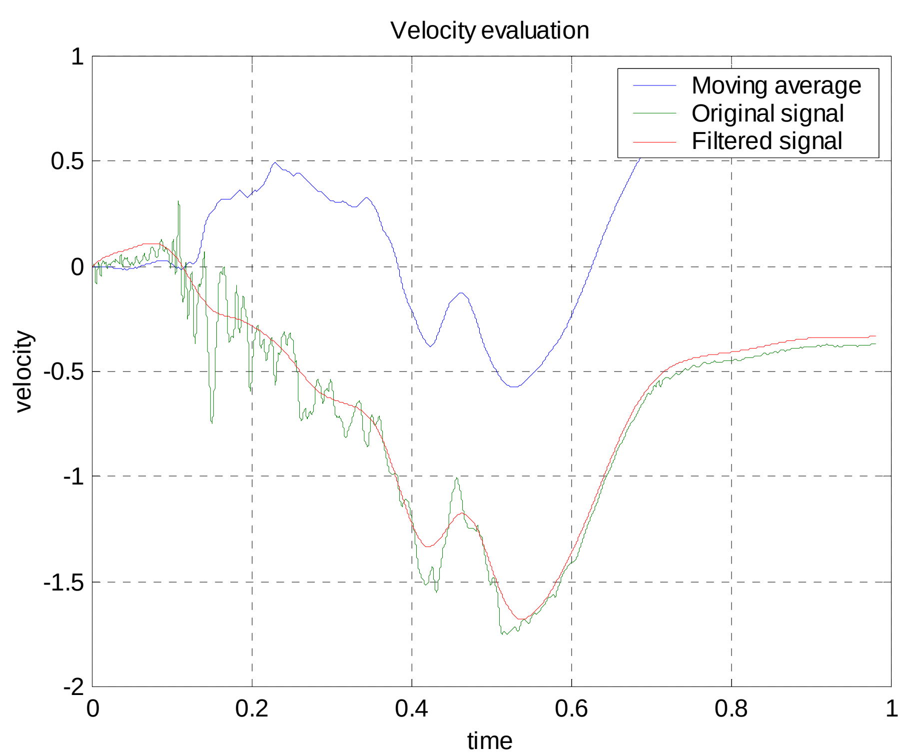
- Comparison with a CFC shaped filter

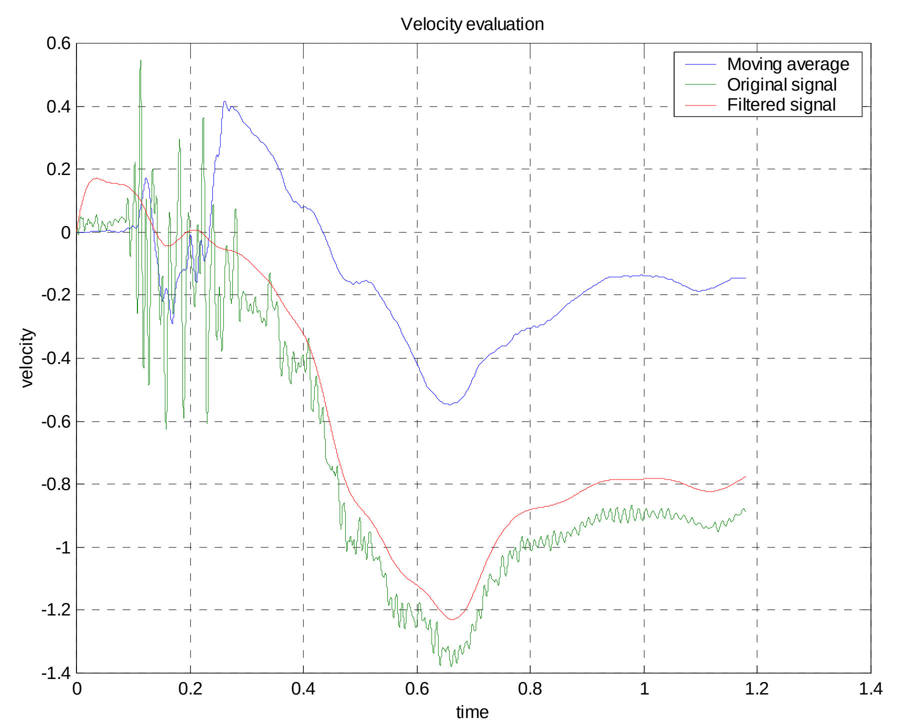




Moving average does not preserve energy.

- Velocity evaluation with:
  - Original signal
  - Filtered signal (Butterworth)
  - Moving Average



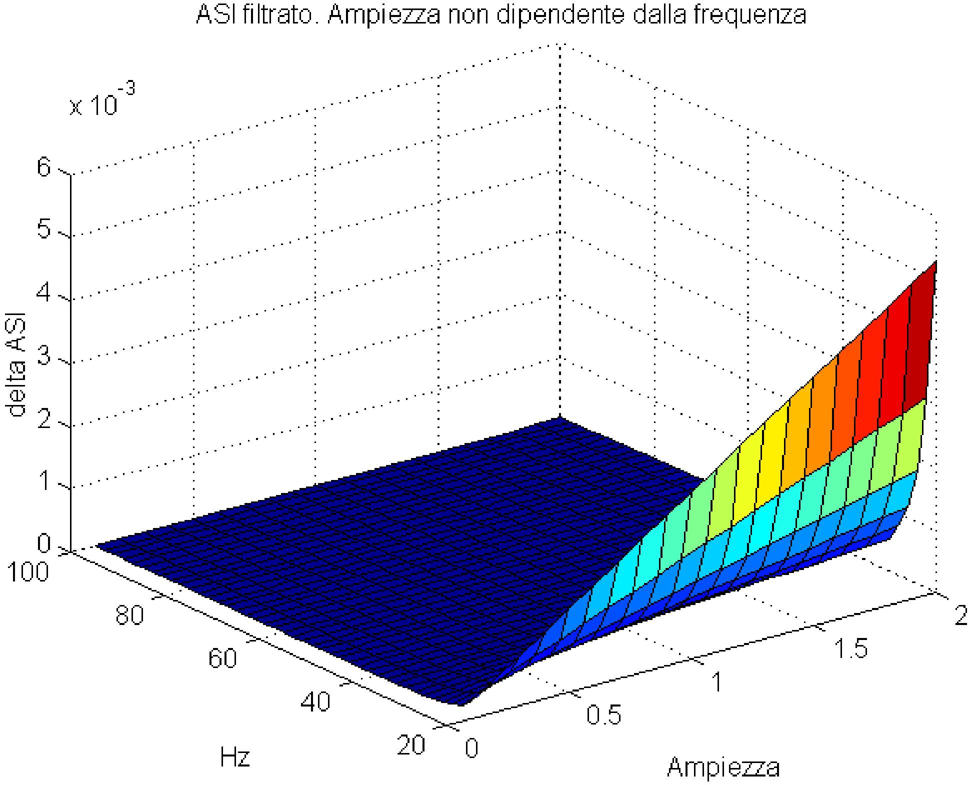


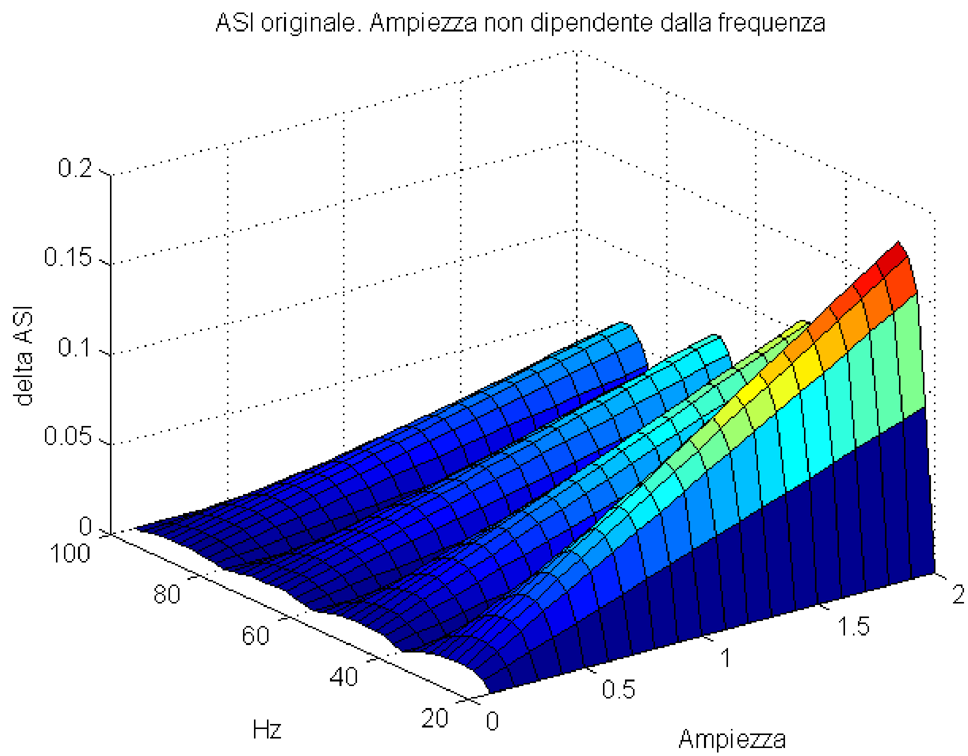
Moving average sensitivity to noise.

- Different acceleration noises:
  - Constant amplitude acceleration for different frequencies.
  - Constant energy (same velocity), the amplitude is modified with frequencies.

– How these noises are seen by the moving average and a “correct” filter.
  - “Correct” = equivalent filter:
    – 10 hz two poles Butterworth “forward-backward” (four total poles) to avoid time shift.

Noise influence on ASI with moving average



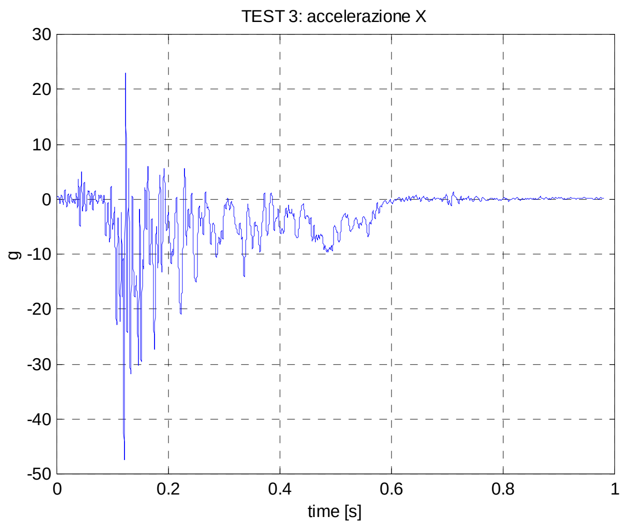


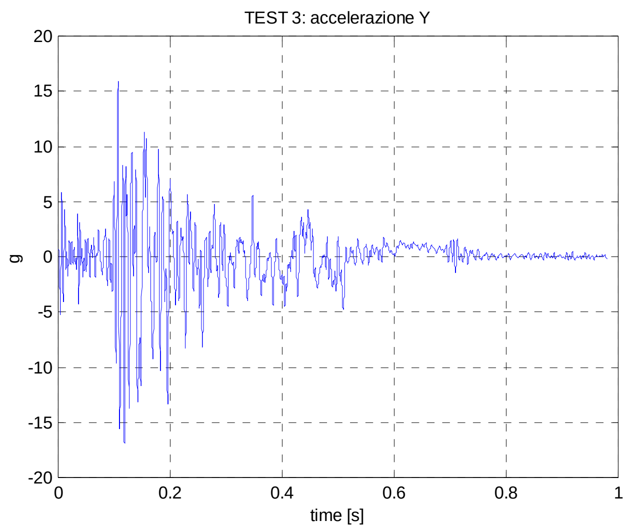
ROBUS Road Barrier Upgrade of Standards

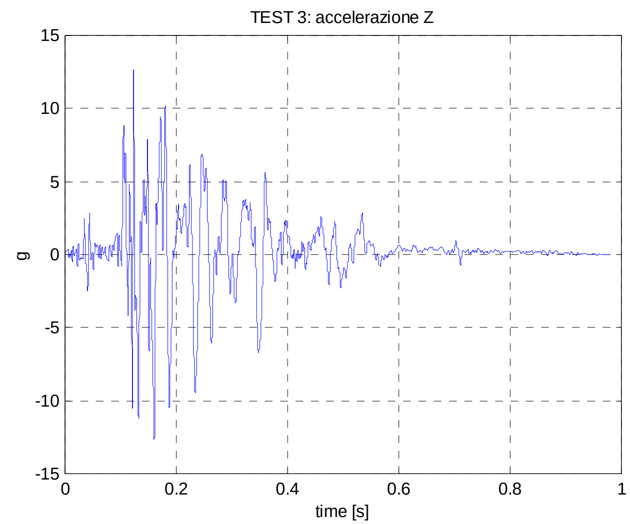
Is this a real problem?

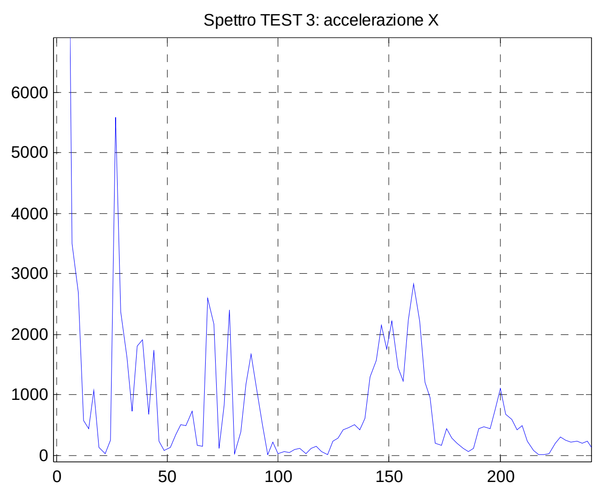
- To verify the presence of this problem:
  - Test cases obtained from some standard crash tests.
- For each test case:
  - Acceleration time-history.
  - Frequency spectrum.
  - Evaluation of ASI with moving average.
  - Evaluation of ASI with “correct” filter.

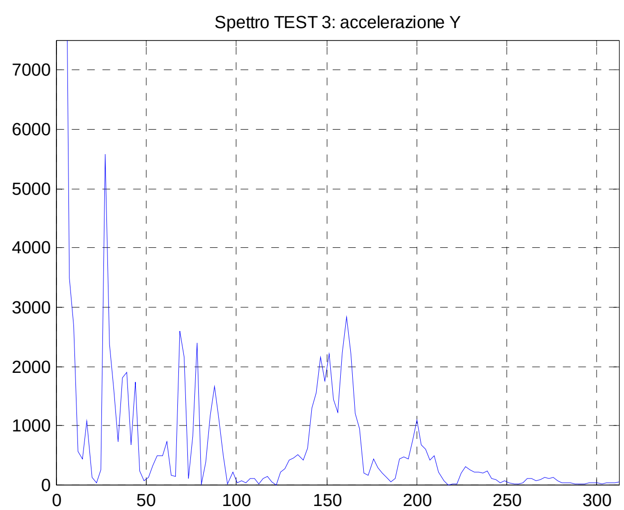
Example.

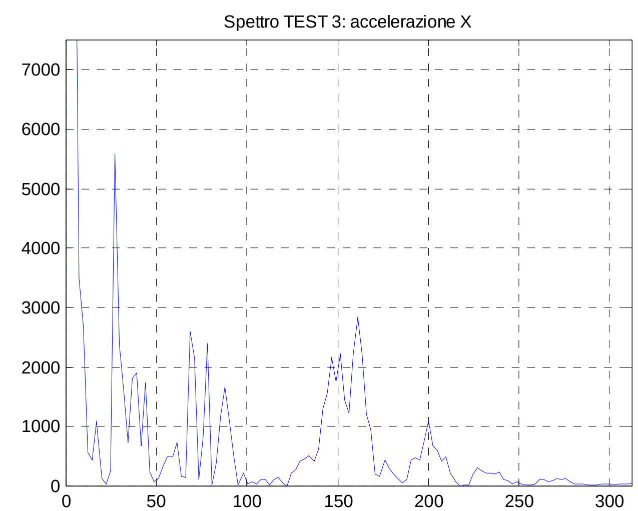

TEST 3: accelerazione X
g
time [s]

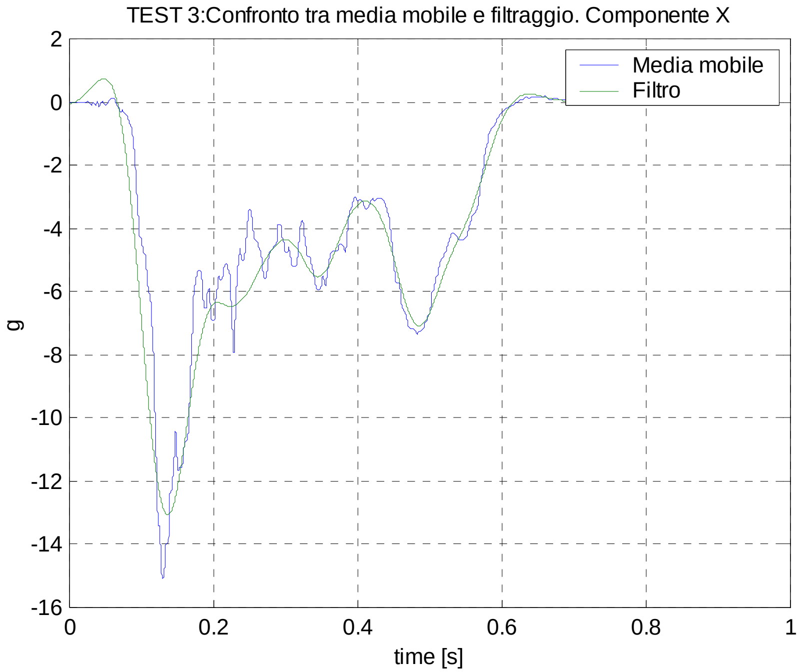

TEST 3: accelerazione Y
g
time [s]

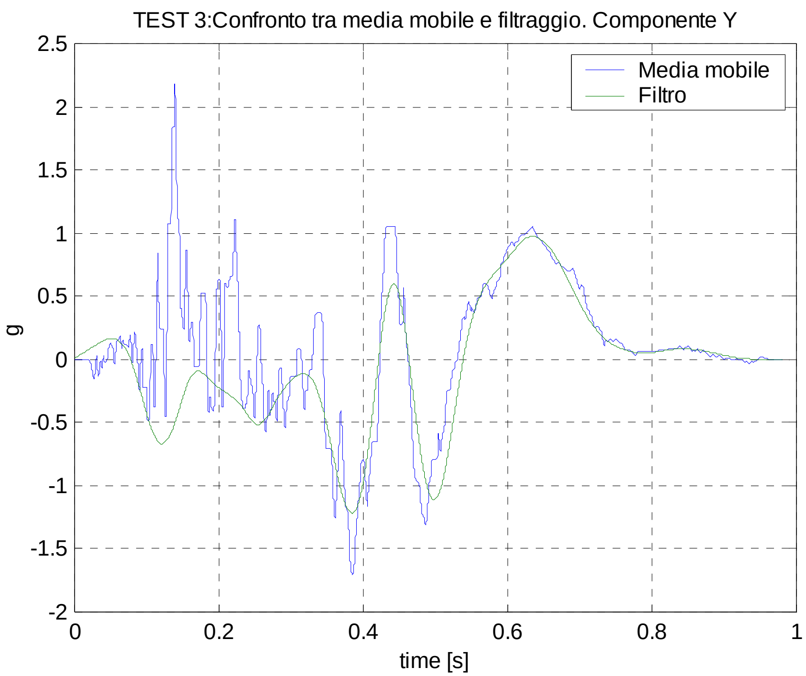

TEST 3: accelerazione Z
g
time [s]

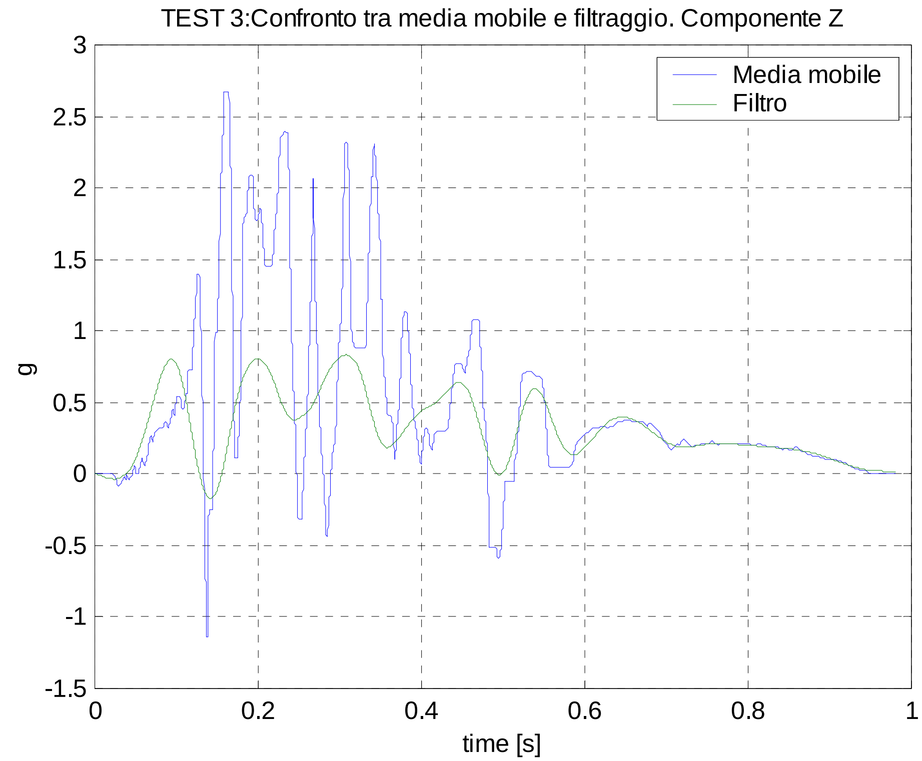

Spettro TEST 3: accelerazione X


Spettro TEST 3: accelerazione Y


Spettro TEST 3: accelerazione X


TEST 3:Confronto tra media mobile e filtraggio. Componente X
Media mobile
Filtro
g
time [s]
2
0
-2
-4
-6
-8
-10
-12
-14
-16
0
0.2
0.4
0.6
0.8
1


TEST 3:Confronto tra media mobile e filtraggio. Componente Y
Media mobile
Filtro
g
time [s]
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.2
0.4
0.6
0.8
1


TEST 3:Confronto tra media mobile e filtraggio. Componente Z
Media mobile
Filtro
g
time [s]
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.2
0.4
0.6
0.8
1

Moving average

- The modification of original signals driven by the moving average has been demonstrated but:
- Is this strange behavior of moving average desired by the original designer of ASI?
- Or was simply not observed?

History of ASI.

- I.Laker: “ A short summary of three vehicle Impact Severity Measure- ASI THIV/PHD NCHRP 230” 1991.

2.1 Evolution of Acceleration Based Injury Criteria.

Shoemaker (1961) of the Cornell Aeronautical Laboratory produced a table given below of the tentative limits of tolerable deceleration. The table originates from the work of Stapp (1955) and Severy (1957); the studies were based on full scale tests without theoretical guidance. Shoemaker emphasised that his criteria were tentative, nevertheless the table was reproduced by many workers as a standard, even though certain factors such as duration and onset rate of deceleration were controversial.

LIMITS OF TOLERABLE DECELERATION

(TENTATIVE)

RESTRAINT	LATERAL			LONGITUDINAL			TOTAL		
	Max. Dec. (G)	Duration Sec	Rate-of Onset G/Sec	Max. Dec. (G)	Duration Sec	Rate-of Onset G/Sec	Max. Dec. (G)	Duration Sec	Rate-of Onset G/Sec
Unrestrained Occupant	3	0.200	500	5	0.200	500	6	0.200	500
Occupant Restrained by Lap Belt	5	0.200	500	10	0.200	500	12	0.200	500
Occupant Restrained by Lap Belt and Shoulder Harness	15	0.200	500	25	0.200	500	25	0.200	500

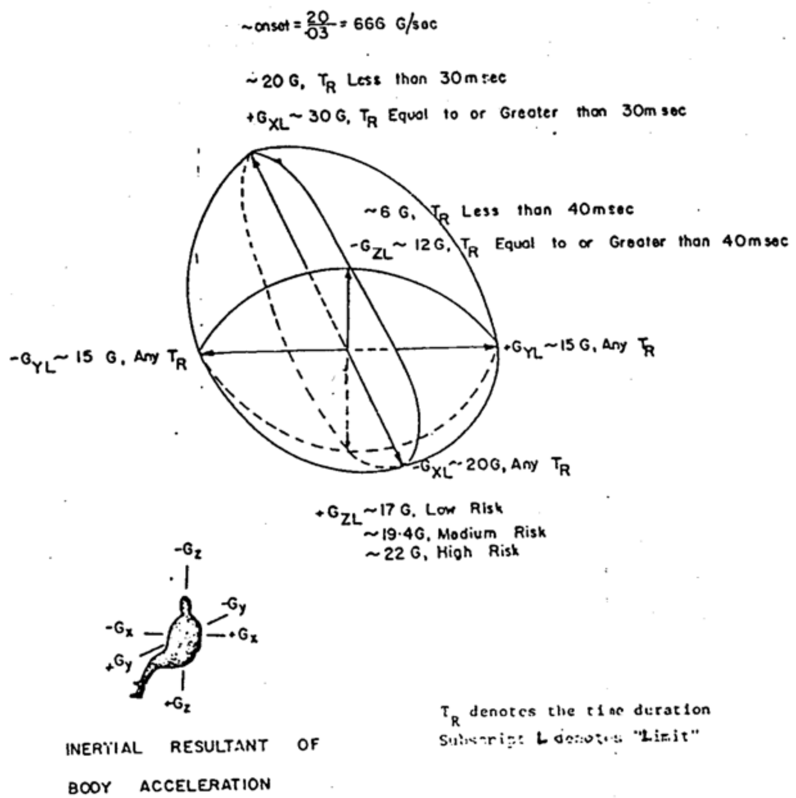
ASI History.

Graham (1969) adopted as a severe injury threshold a limit of 10g over 50 msec. The discrepancy between time duration of 200 msec in Shoemaker's table and the 50 msec quoted by Graham was not addressed, although Olson (1970) considered that Graham's 10g theory was supportable if the duration of the impact was less than 200 msec. Nordlin (1971) inserted under an abridged version of Shoekaker's table the comment "highest 50 m.sec average, vehicle passenger compartment". Michie (1971) included the amendment in NCHRP118 and reintroduced the 500 g/sec onset rate. NCHRP 153 (1974) adopted Nordlin's version of the Shoemaker table with some exceptions, the most important of which were, lap and shoulder restraint figures were deleted and impact angle was limited to 15 degrees.

ASI History

2.2 The ASI Ellipsoidal Envelope.

A Military Specification (1967) for defining multiaxial acceleration limits was developed at the Wright-Paterson Airforce base. The concept is shown in the figure below.



The Texas Transportation Institute (H. Ross. 1972) adopted this concept in their investigation of the traffic-safe characteristics wherein vehicles could become airbourne over the terrain in the vicinity of sloping grate culverts.

- 1955 Stapp tests.
- 1969 Limits in 3 direction
- 1971 moving average.
- 1972 Ellipsoidal Envelope from US Air force documents

OBUS Road Barrier Upgrade of Standards

Acceleration time histories.

- Aeronautical deceleration:
  - Source: Us Army "Aircraft Crash Survival Design Guide".
  - Single peak: from 15 to 30 g
  - Time duration from 0.1 to 0.15 s

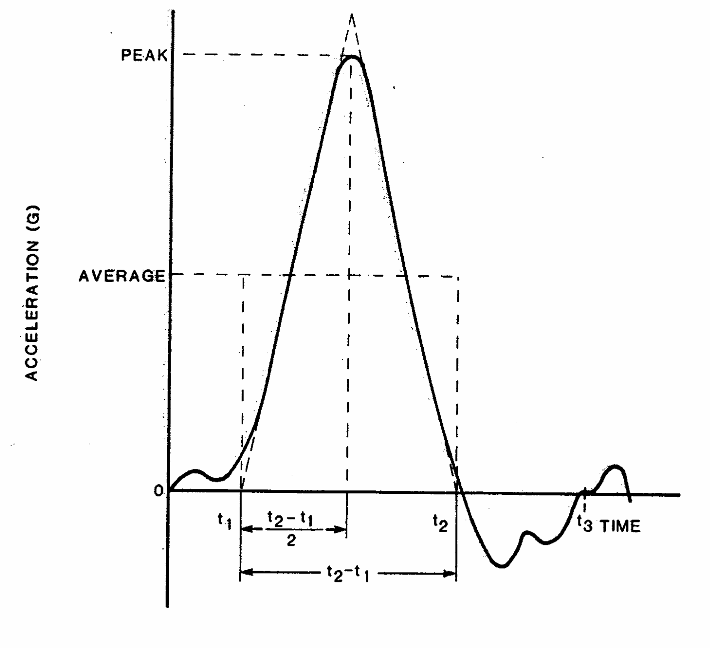
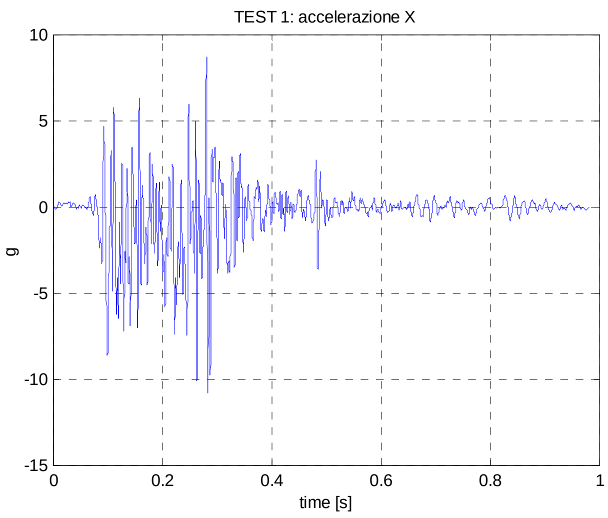


FIGURE 4. TYPICAL AIRCRAFT FLOOR ACCELERATION PULSE.

- Safety barrier deceleration.



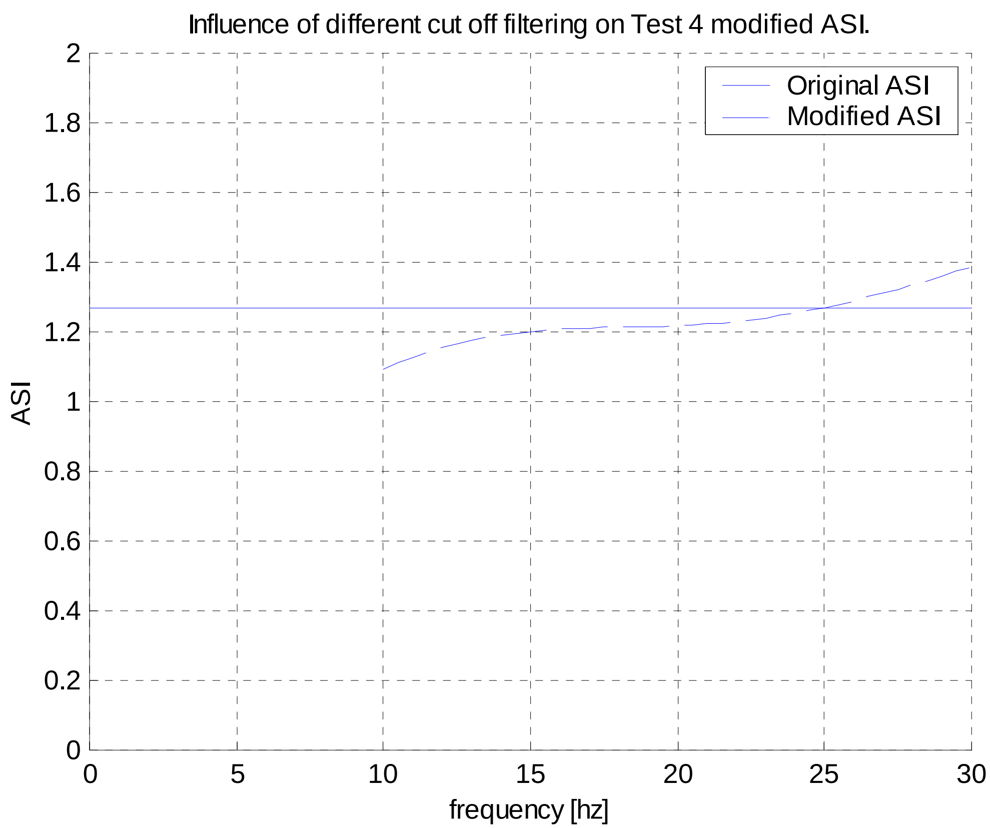
ASI History

- The origin of ASI calculation procedure was based on research on the injury assessment of vehicle and aircraft occupants in phenomena such as re-entry space capsule impacts and combat airplane maneuvers.
- These phenomena have limited or no oscillations throughout the event.
- For this reason, computing an average over a period of 50 ms was used to obtain an average value to be compared with the tolerable limits.
- Impacts against road restraint systems generally have a duration much greater than 50 milliseconds, and show strong oscillations at different frequencies.
- The 50 ms moving average when applied over such longer acceleration pulses becomes a low-pass filter, but it does not behave like filters used conventionally for crash analysis.

ASI modification.

- To avoid the problem related to the moving average a standard filtering technique should be used.
- Which filter?
- Which cut off frequency?

Asi modification with different "correct" filtering cut off frequency. Test 3



hz	Modified ASI
10.0	1.0915
15.0	1.2009
20.0	1.2181
25.0	1.2705
30.0	1.3876

Modification of ASI formulation.

- 126 tests analyzed
  - 65 from Autostrade
  - 17 from Lier
  - 20 from TRL
  - 16 from Italian producers
  - 8 from Round Robin

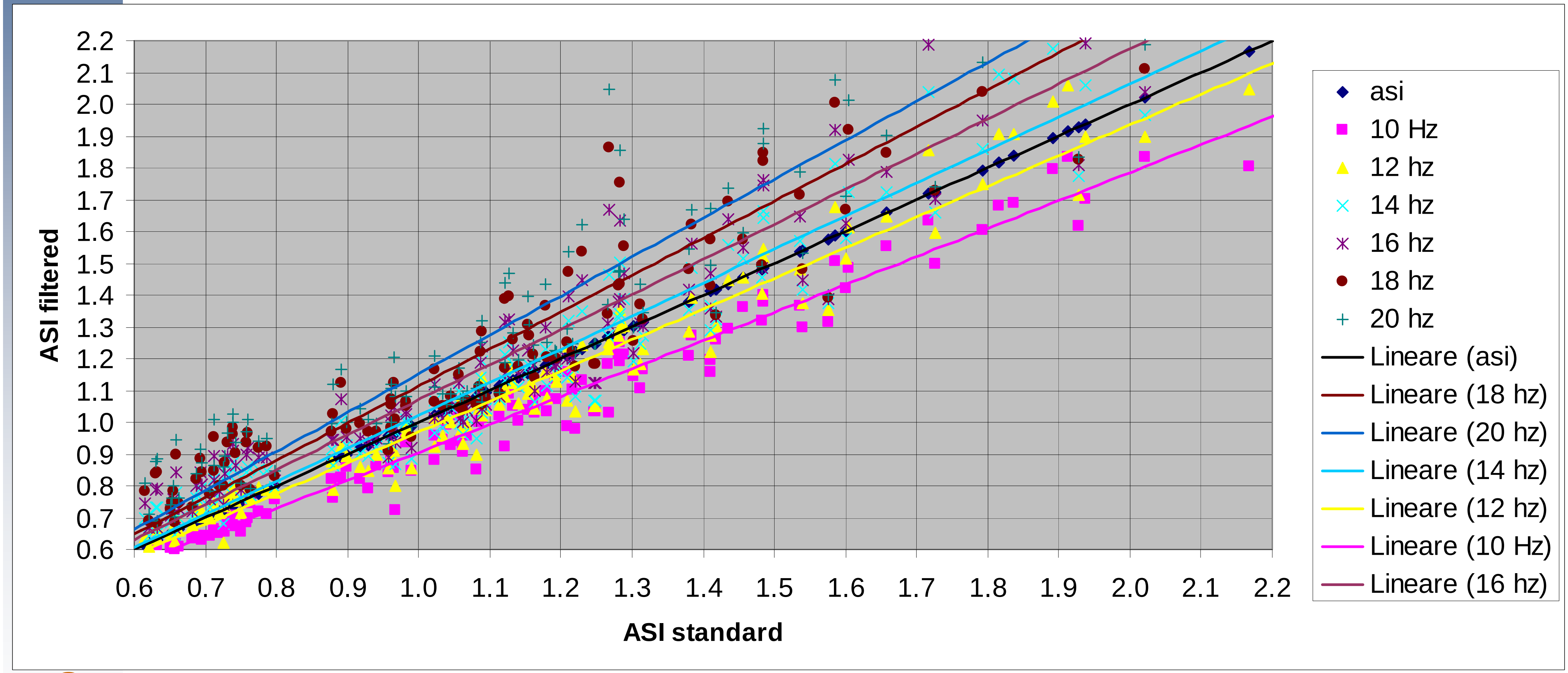
- Evaluation of ASI using filtering instead of moving average.

Filtered ASI

- Raw data have been filtered with CFC180 and a new ASI technique has been applied avoiding moving average and using:
- 2 poles Butterworth forward – backward (to avoid time shift) filter. 4 total poles.
- Cut off frequencies tested:

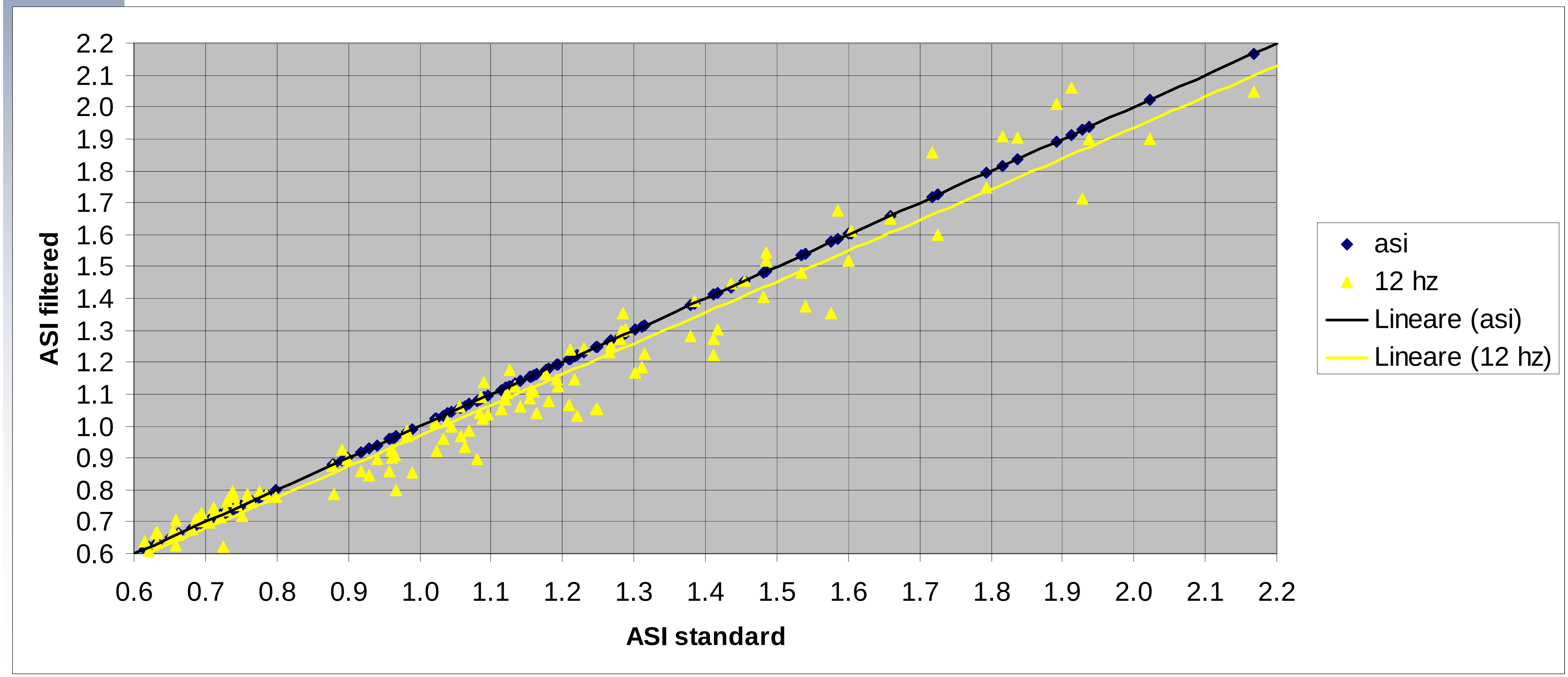
  10 – 12 – 14 – 16 – 18 – 20 hz
- The final cut off frequency has been identified as the one with the better correlation with the standard ASI formula. The idea is to avoid, if possible, modification of the current limits for the ASI formula.

Filtered ASI results



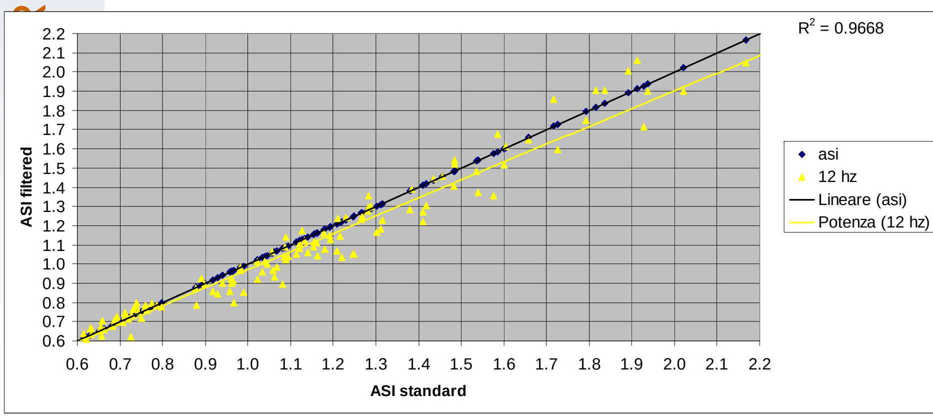
Filtered ASI.

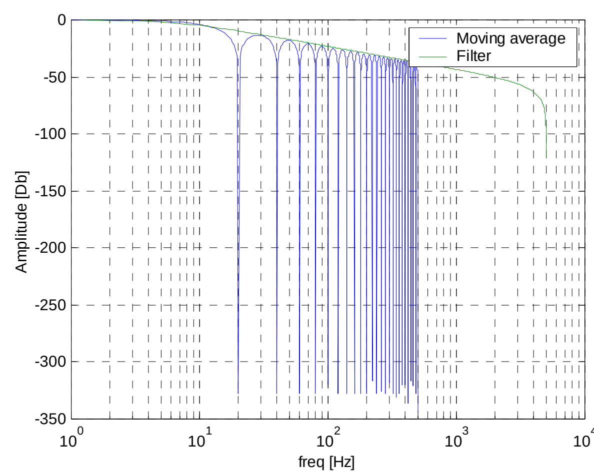
- Best correlation (not in all the domain):
  - 12 hz cutoff frequency.
  - 2 pole forward-backward Butterworth filter. (4 resultant poles)



Filtered ASI.

- Comparison with original ASI values:
  - Up to 1 small modification (for some tests new ASI value is higher than the standard value)
  - From 1 to 1.5 global decrease if compared to standard ASI.
  - For higher ASI value a slightly decrease of the new value.
  - Cut off frequency must carefully considered.
- Moving average effect cancelled.
- Less sensible to noise.





rier

rds

RD1-2002-70021

Data acquisition and severity indices evaluation (experimental).

- Round Robin 1: TB11 tests, same new car (Peugeot 106), same concrete rigid barrier in all the labs. Only, transducers, data acquisition system and software is different.

- Round Robin 2: TB11 tests, different cars (each lab uses own standard car), same concrete rigid barrier.

Round Robin

- A first analysis show a large scatter between labs and strong differences between different indices evaluation of the same signals.
- Some of the differences came from different testing procedures. Some other from software and data acquisition.
- To better understand this problem a first analysis found as a key point the offset evaluation that can produce strong influences on THIV value and medium influences on ASI and PHD.

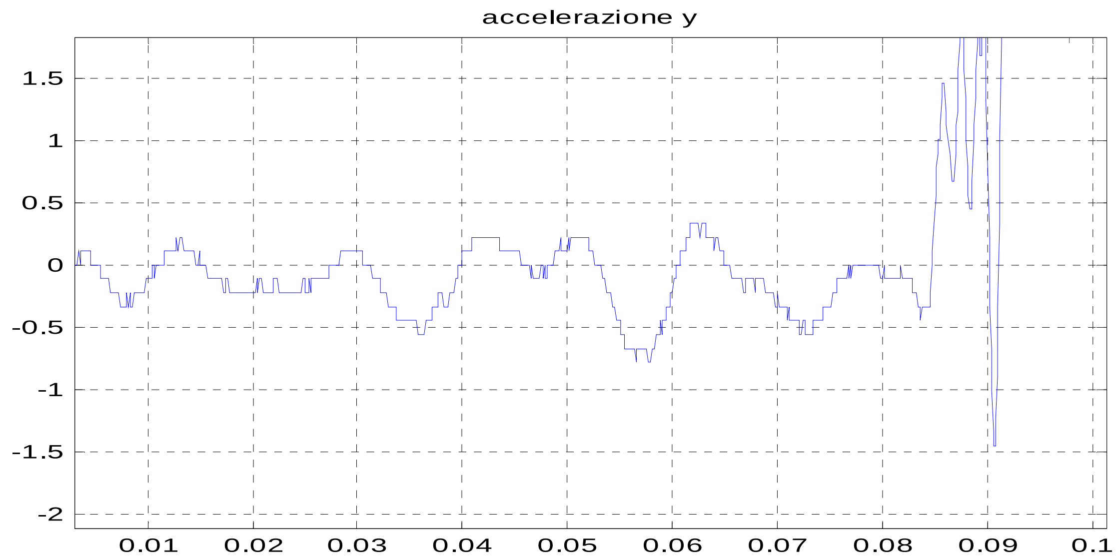
	Med	max	%	min	%
Asi	1.86	0.05	2.83	-0.03	-1.48
THIV	32.89	1.31	3.98	-0.49	-1.5
PHD	14.15	3.55	25.1	-2.75	-19.4

Offset removal.

- Offset is usually evaluated obtaining the mean value of that channel for some milliseconds before the impact. The number of milliseconds used as well as the precise impacting point sample evaluation can produce different offset results on the same signal.
- Acceleration time histories just before the impact can contain oscillations transmitted from ground and (mainly for pushed or pulled car systems) the release of the car induces movements of the vehicle that can influence offset evaluation.
- For this reason the evaluation of zero-level should be better defined and improved.

Offset removal.

- Oscillation with amplitude of about 1 g are present before the impact being the mean value zero but can be understood that a different offset window or a real vehicle acceleration can strongly influence the output.
- A different offset evaluation of .5 g on each channel can produces a delta in ASI of about 0.1 and in THIV of 1.74 km/h.
- Drift of signals during the preparation must be taken into account to find a better solution.



Software influence.

- To investigate the influence of different software a benchmark file has been produced where the different offset evaluation procedures would not generate influences.
- This signal is simply one of the original signals where the impacting point has been defined and all data before this point are equal to 0.
- With this file the influence of offset removal has been avoided.

Software influence.

- Can be seen that the different software used evaluate indices with scatter that should not be present. Conclusion to this point is that a validated and common software should be used to evaluate severity indices .

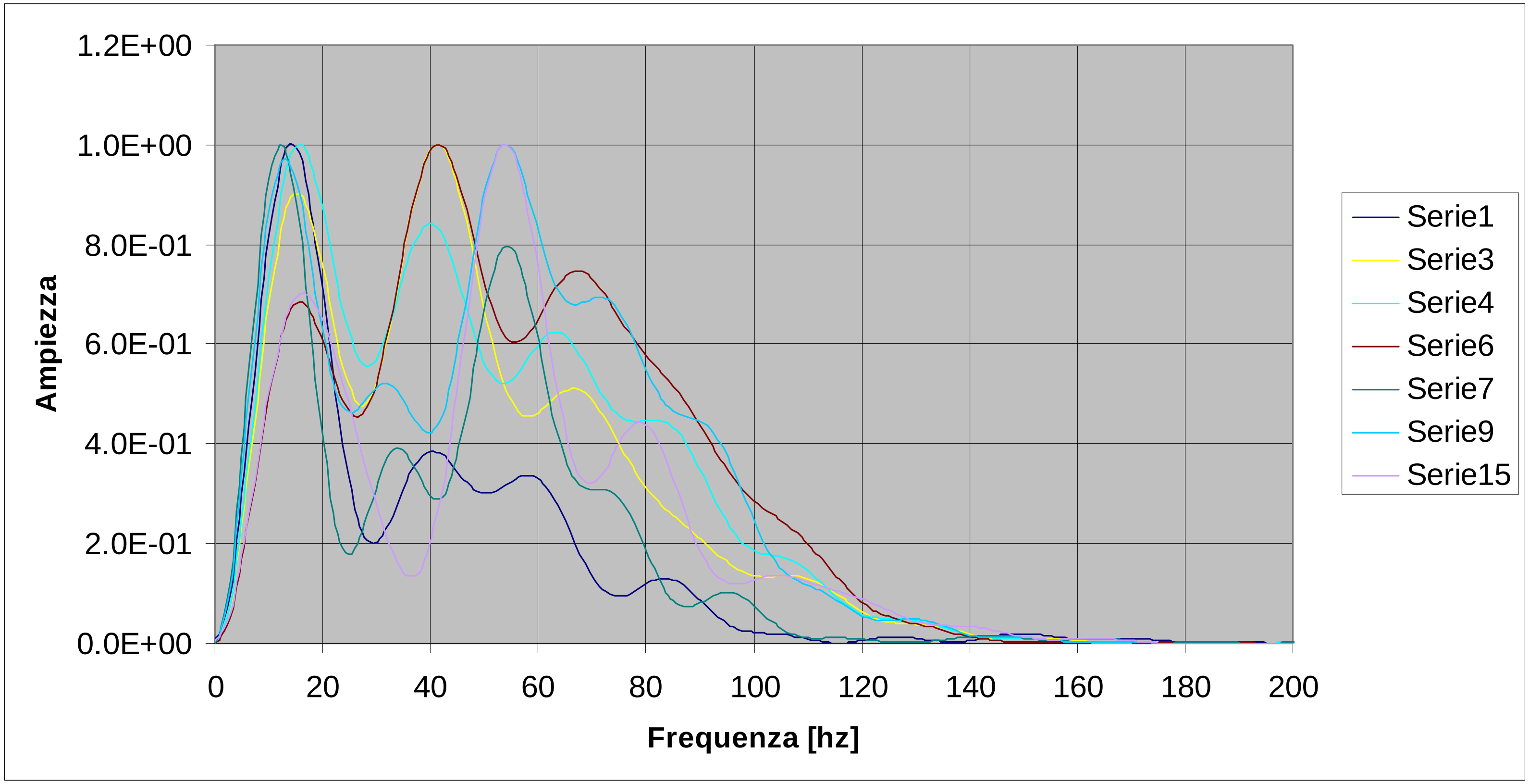
	BENCH DATA					
	ASI	t (s)	THIV	t (s)	PHD	t (s)
L1	1.84					
			32.43	0.0766		
					12.15	0.1369
L2	1.84	0.0097				
			32.45	0.0766		
					11.88	0.1370
L3	1.84	0.0099				
			32.49	0.0767		
					12.15	0.1370
L4	1.84	0.1148				
			32.43	0.1566		
					13.69	0.2220
TRAP	1.84	0.0098				
			32.4	0.0779		
					11.9	0.1370

Accelerometer mounting

- The structure of the floor of a car is made of thin plates that, during the test, produces vibrations.
- These vibrations can be affected by the mass of the structure used to install the accelerometers in the proper position.
- The severity indices can be affected by the structure used to install the accelerometers.

Different mounting block natural frequencies

- First natural frequencies located between 10 and 15 hz.



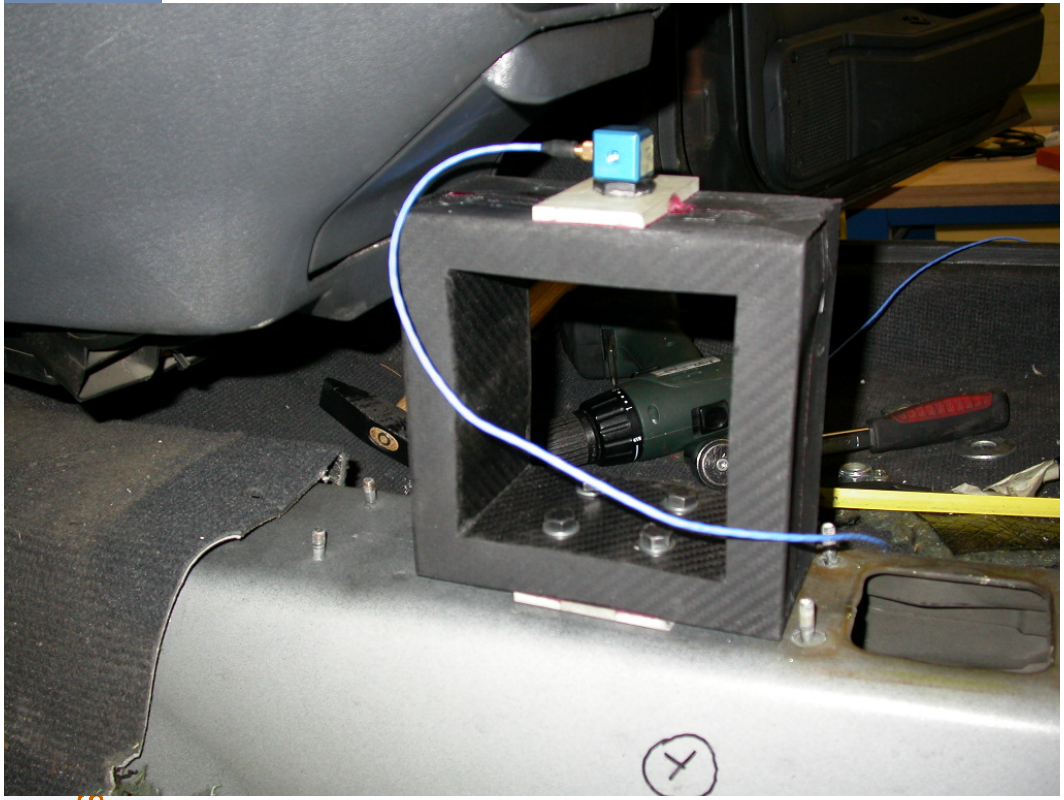
Results

- These frequencies are lower that the target design ones (about 30 hz).
- 15 hz is a frequency not modified by the moving average.
  - This frequency can influence severity indices
- Mounting block influence:
  - weight of the block in general decreases the first frequency.
- Mounting block should be described inside the standards.

Composite mounting block

- To demonstrate the influence of the mass a composite mounting block has been designed.
- Structure:
  - Carbon fiber /nomex structure.
  - Glass fiber plates to be easily machined to fix the structure to the car and install accelerometers.
  - 8 blocks produced.
- Some tests houses used this structure to verify the influence on the final results.
- The idea is not to suggest the use of this structure but to demonstrate how can affect the results.

Composite mounting fixing.

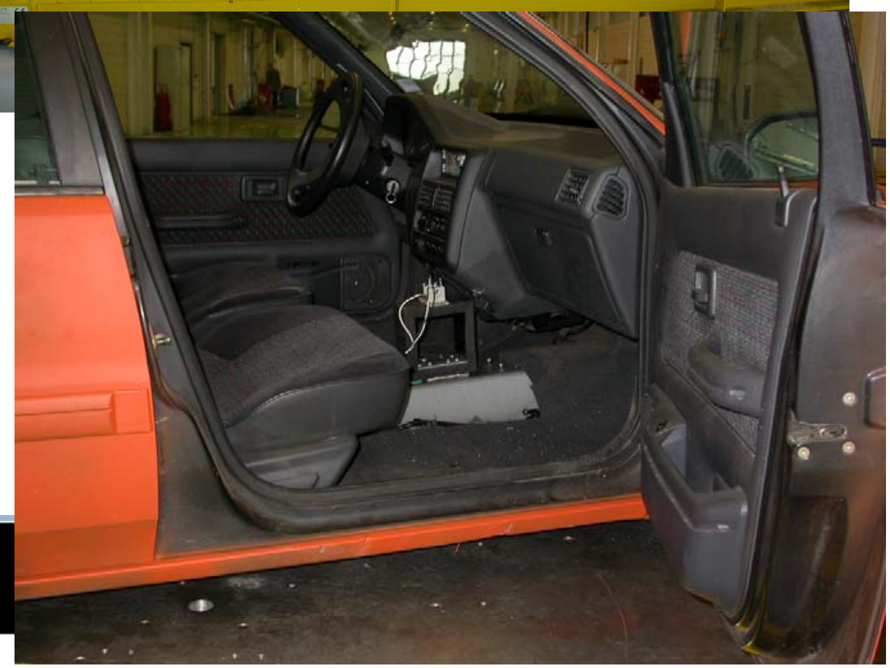


Robus

rier

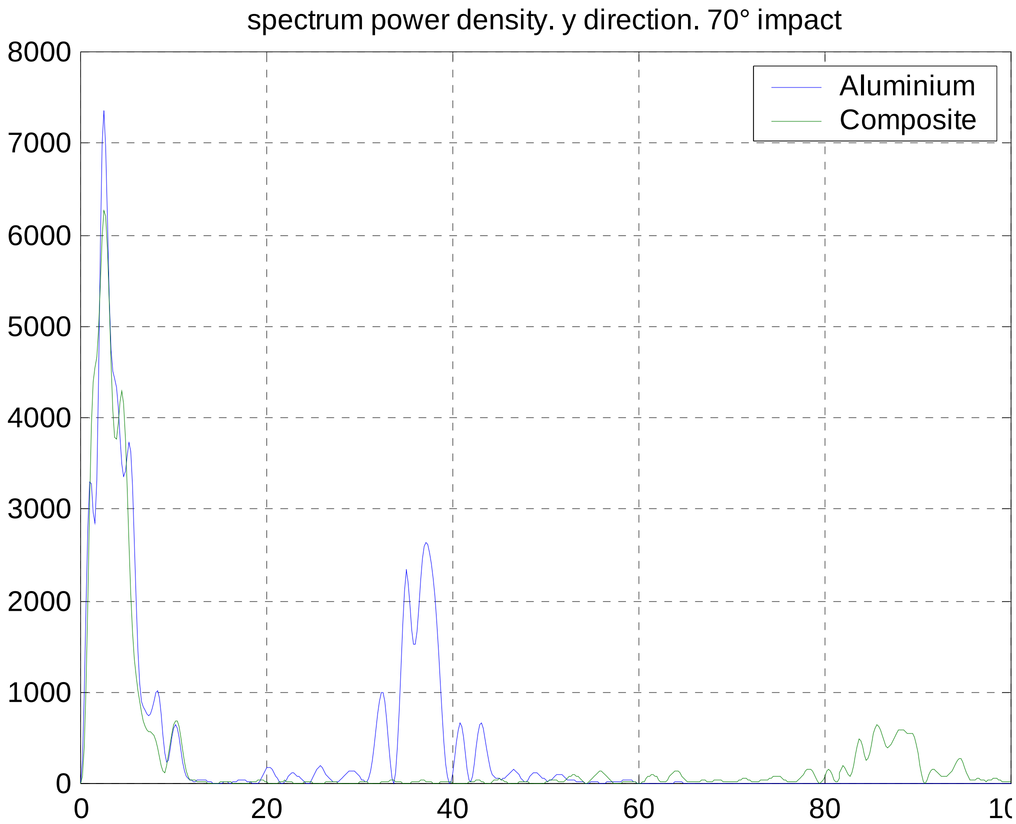
rds

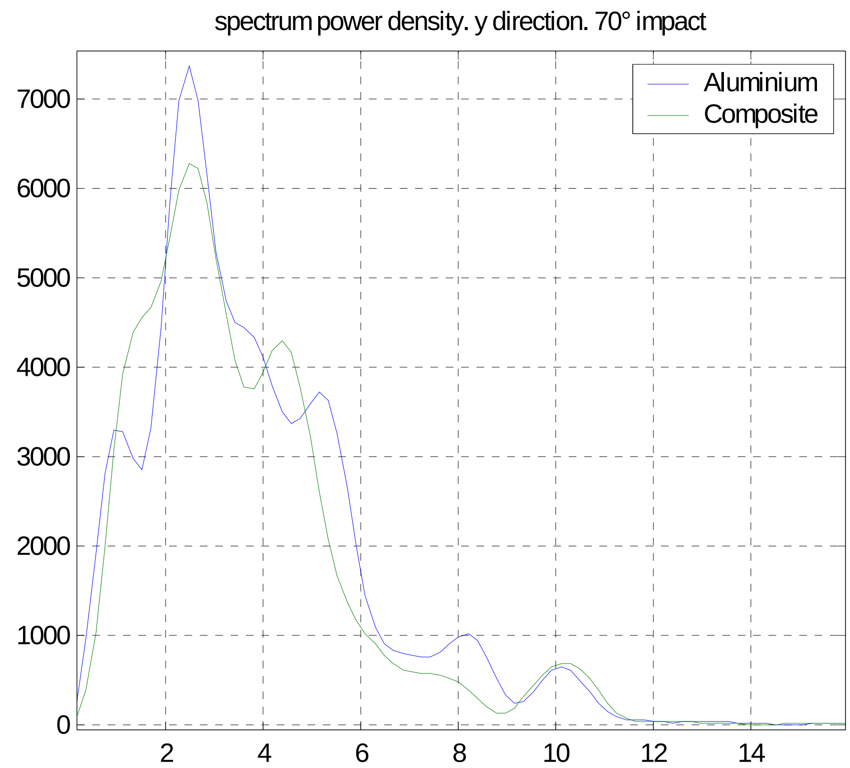
Deceleration tests.



Deceleration tests. Results.

- Frequency response:
  - Strong differences between different mounting blocks
  - Differences also at lower frequencies





Conclusion.

- Validated software should be used during certification tests.
- A precise procedure to evaluate the offset value must be inserted in EN 1317
- Mounting block structure can influence the acceleration time histories.
- EN 1317 should describe the technical requirements to avoid this kind of influences on the results.

Questions?