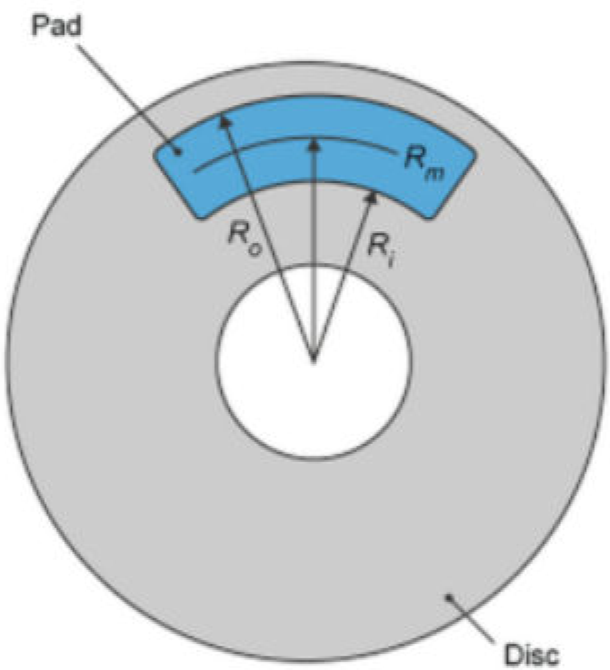
ES06 - Longitudinal Dynamics: braking - SIMULINK model

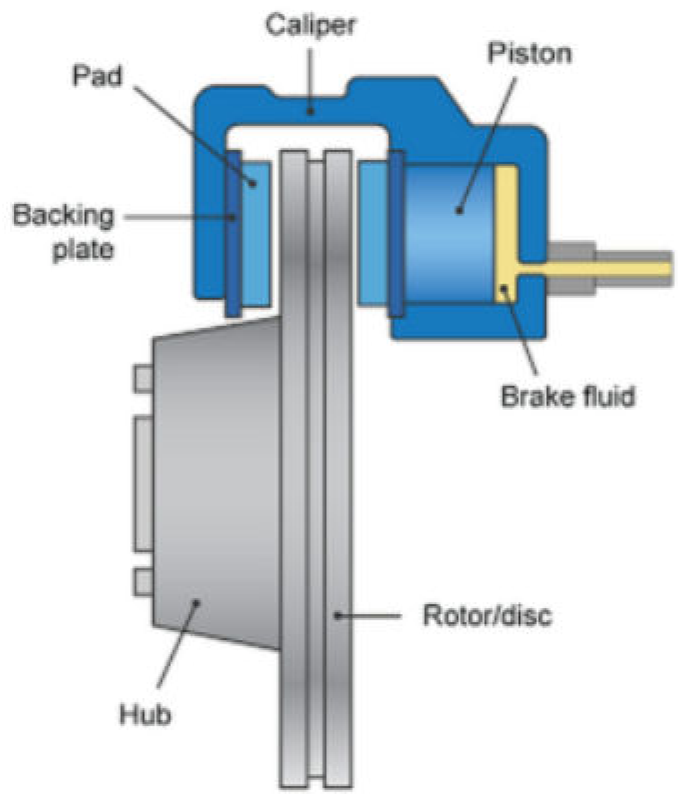
Modelling

The first part of this exercise is to propely develop two block, one regarding the braking torque acting on the wheel, the other is the calcualtion of the slip difference among front and rear axle.

Braking torque

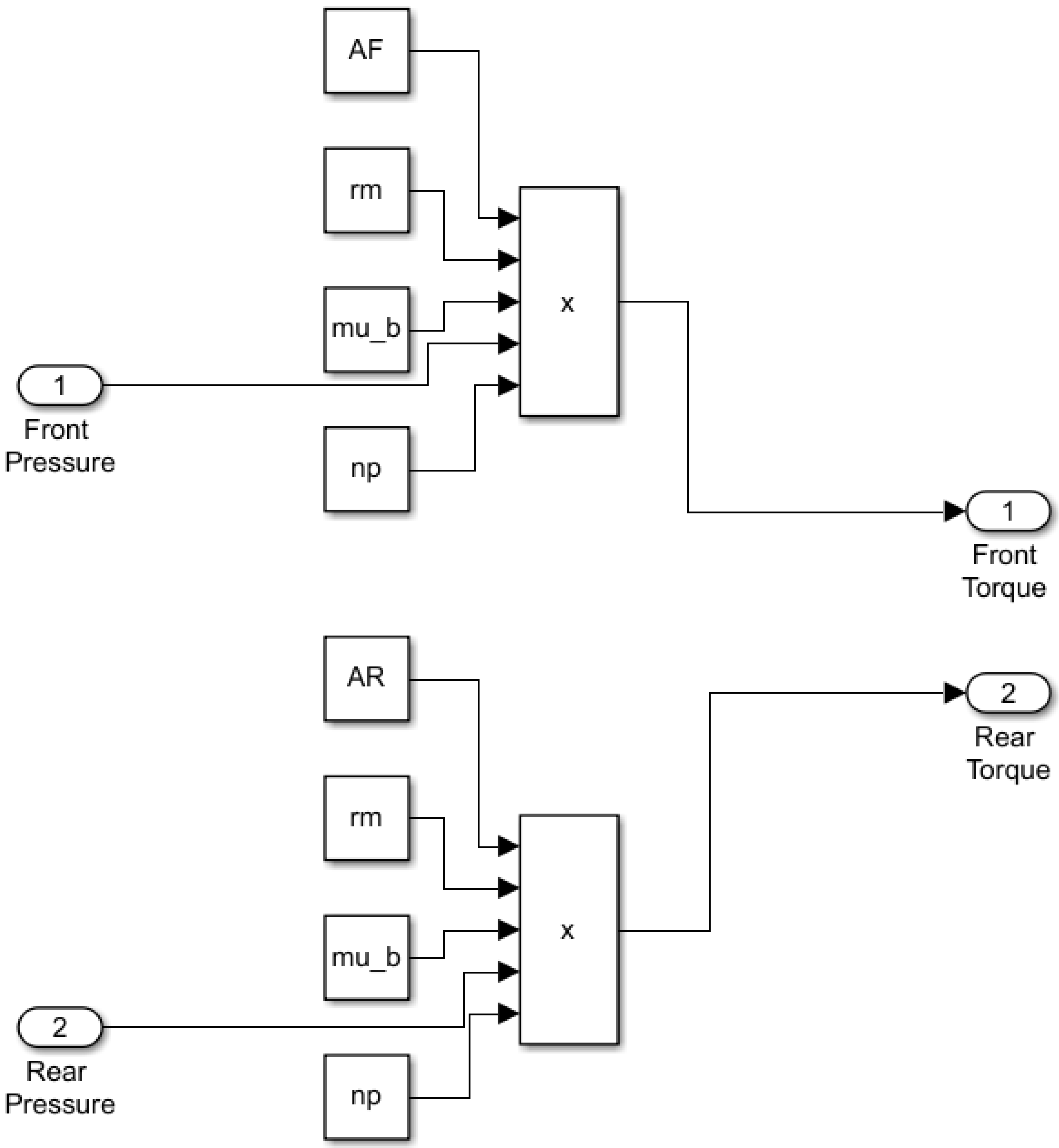
The formula for the braking torque calculation was presented also in the previous note chapter. However, it missed a fundamental parameter: the number of pads for each brake disk.





In fact, if the pads are two, double would be the braking torque delivered.

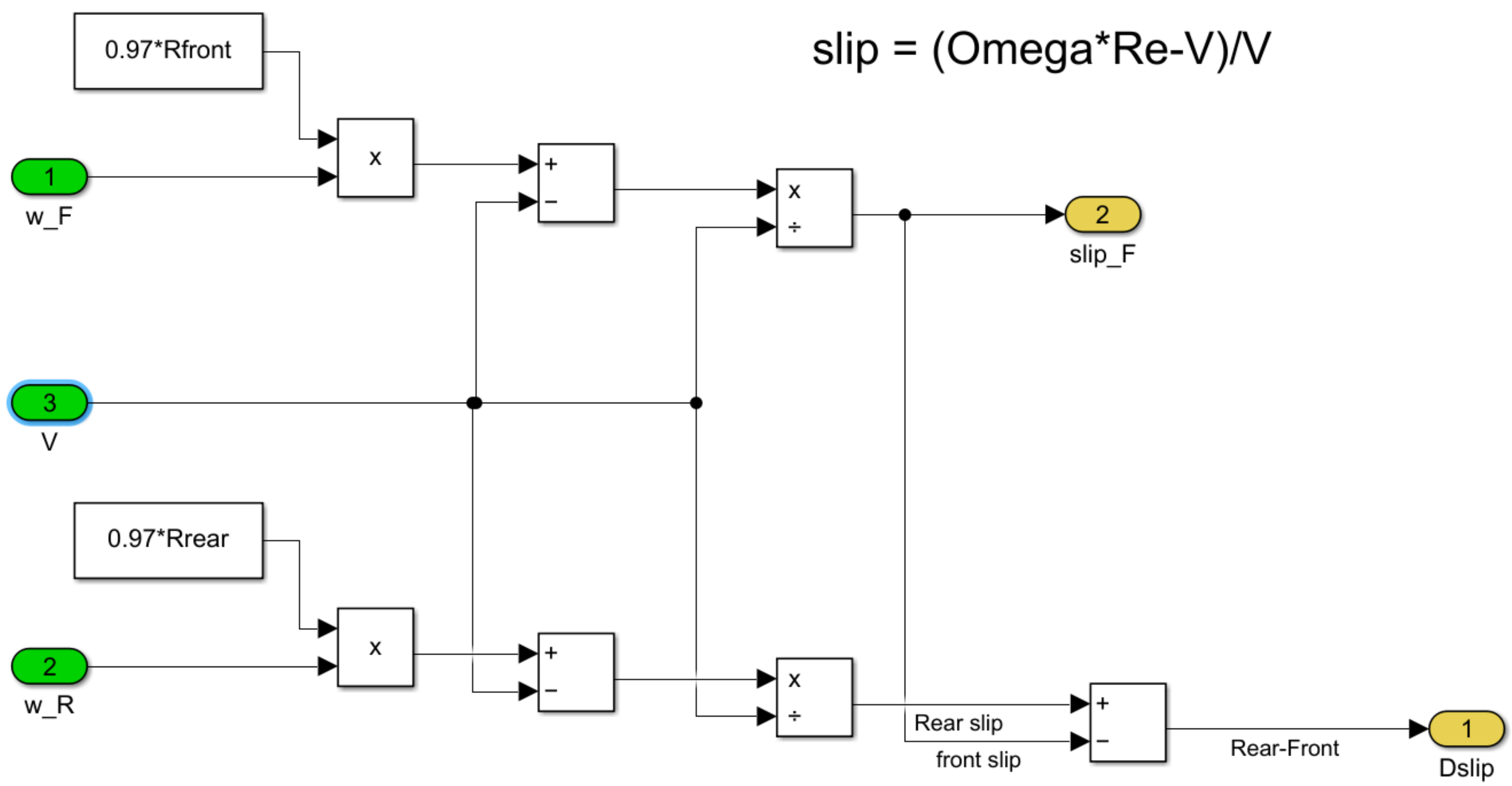
The `SIMULINK` blocks will be as following:



Delta slip

The EDB pratically is just a PID controller which works on the slip difference among the two axle, in this way it properly tune the rear pressure. It can be computed as front slip minus rear slip. How to evaluate the slip has been already seen in a previous exercise:

$\sigma = \frac{\omega - \omega_0}{\omega_0}$ which is trivial to remeber since it can be read as "how much differen is the rotational speed that we have from the pure rolling one). In the same way it can be computed considering the difference among wheel longitudinal speed and the vehicle one: $\sigma = \frac{\omega R_e - V}{V}$. The latter was adopted considering the input given to the block. Therefore the SIMULINK block will be:



Simulations

```
% Launch file for the SIMULINK model
% Run_Dyn_EBD_press
```

It is requested to perform a light braking case (set by the torque braking value) for three different torque ratio. An analysis over the differences in terms of braking time, deceleration, slip and forces will be carried out. The best braking bias is evaluated.

The same procedure will be reapated for an emergency braking manouvre, trying to find also the best braking bias to avoid rear locking.

In the end, a comparison among EBD and proportional valve is done, considering an emergy manoeuvre.

Light braking manoeuvre - Tb = 1000 Nm

To avoid eccessive braking dynamic, the Tb max is reached in 2 second window through ramp+ saturation block.

```
% Run_Dyn_TbMAX_press -> Asks for the K_B_F and for the typology of the
% manoeuvre, then run the simulation applying 1000 or 6000 Nm to the front
% or rear axle depending if K_B_F > 50
%
% wheel_chart_script -> script to generate the wheel transversal chart
```

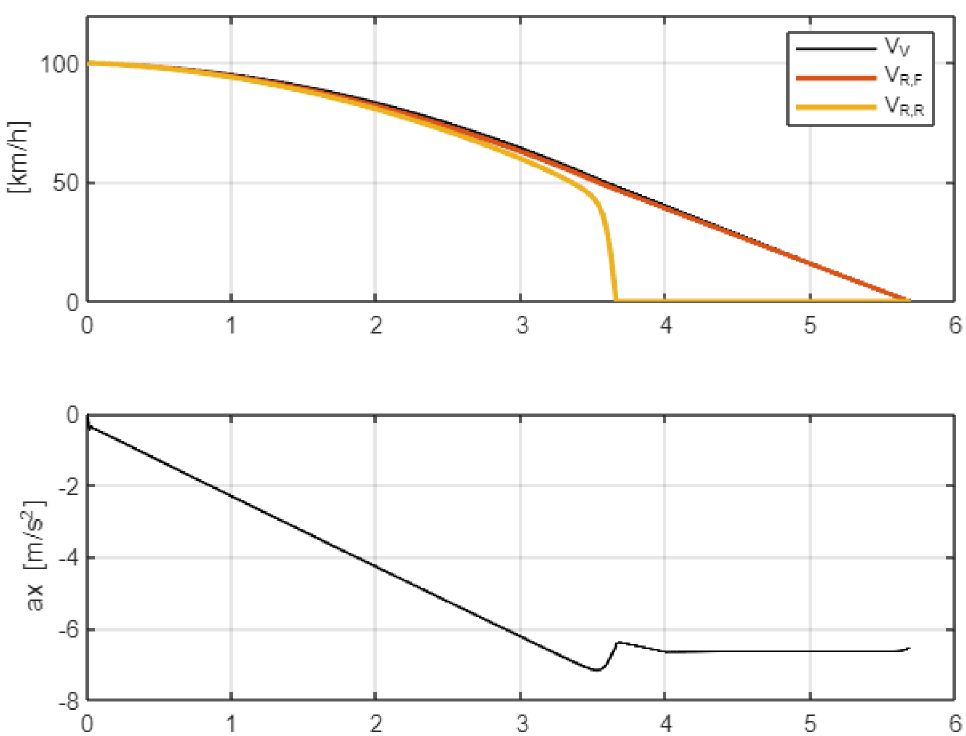
NOTE: K_B_F influence over the braking torque is not done over the pressure but over the area of the rear brake caliper piston. This beacause this is the design precedure for size this component.

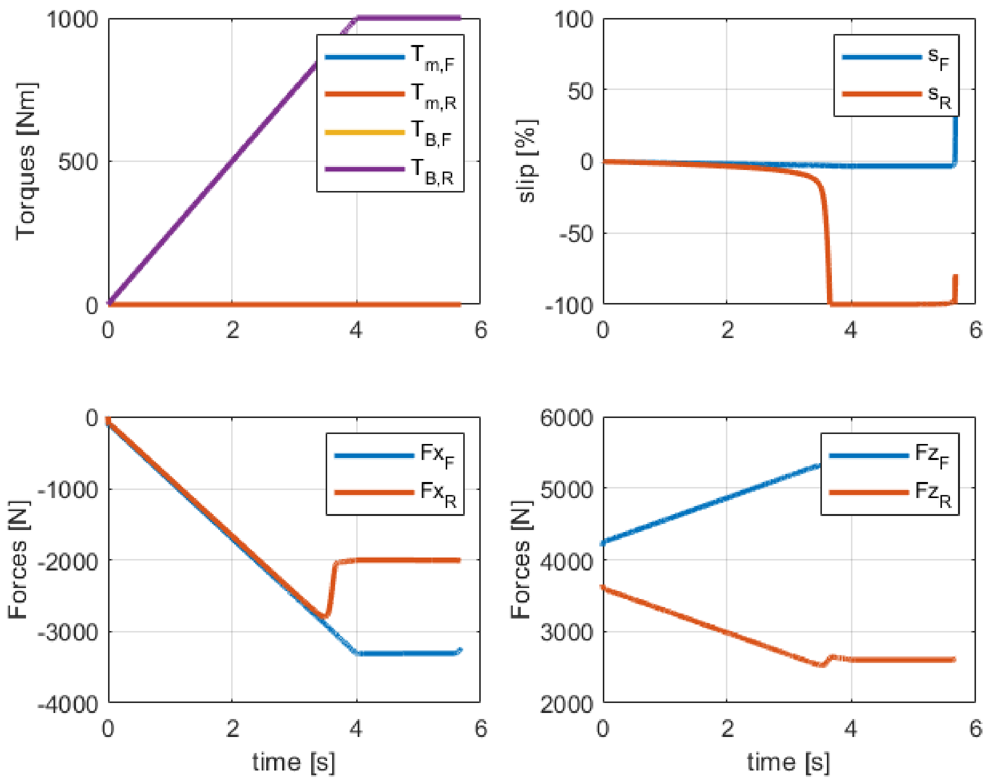
Brake bias: 50/50

```
Run_Dyn_TbMAX_press
```

```
Braking torque applied to the front = 2000 [Nm]
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 50:50 with Fixed brake bias
Road friction coefficient: 1
Time of braking: 5.6776 seconds
Acceleration reached: -6.5358 m^2
```

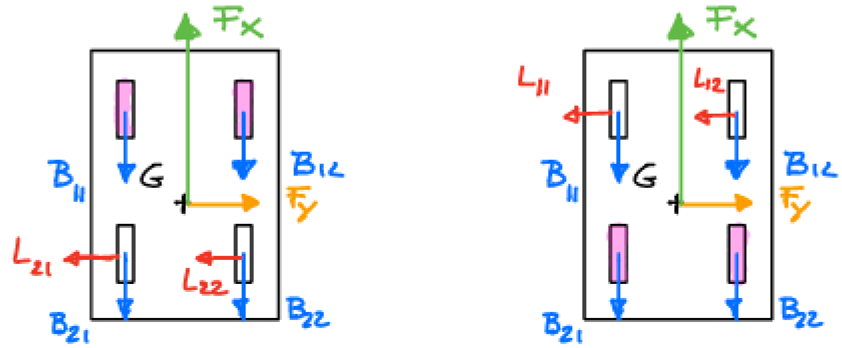
```
wheel_chart_script
```



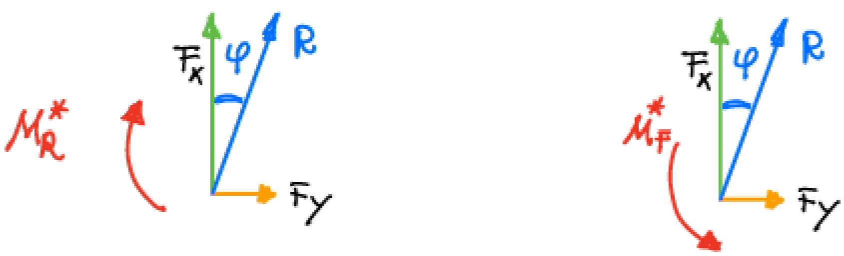


This is the best solution regarding the stopping time. However, the reak wheels lock at a certain time. From longitudinal perspective, not always locking the tyre is a negative phenomena, in some cases the car stops before with locking wheel respect to not locking (as this simulation suggest). Of course this has huge disadvantages in real case due to the lateral dynamic influence:

FRONT wheels LOCKING   REAR wheels LOCKING



How can tires equilibrate side force F_y? → only tires which are NOT locked can generate a lateral force



M^*: moment due to tire side forces

M_R^*: tends to reduce angle φ (tends to rotate the vehicle clockwise) → loss of directional control

M_F^*: tends to increase angle φ (tends to rotate the vehicle counter clockwise) → INSTABILITY

That's the reason why the rear axle should never lock.

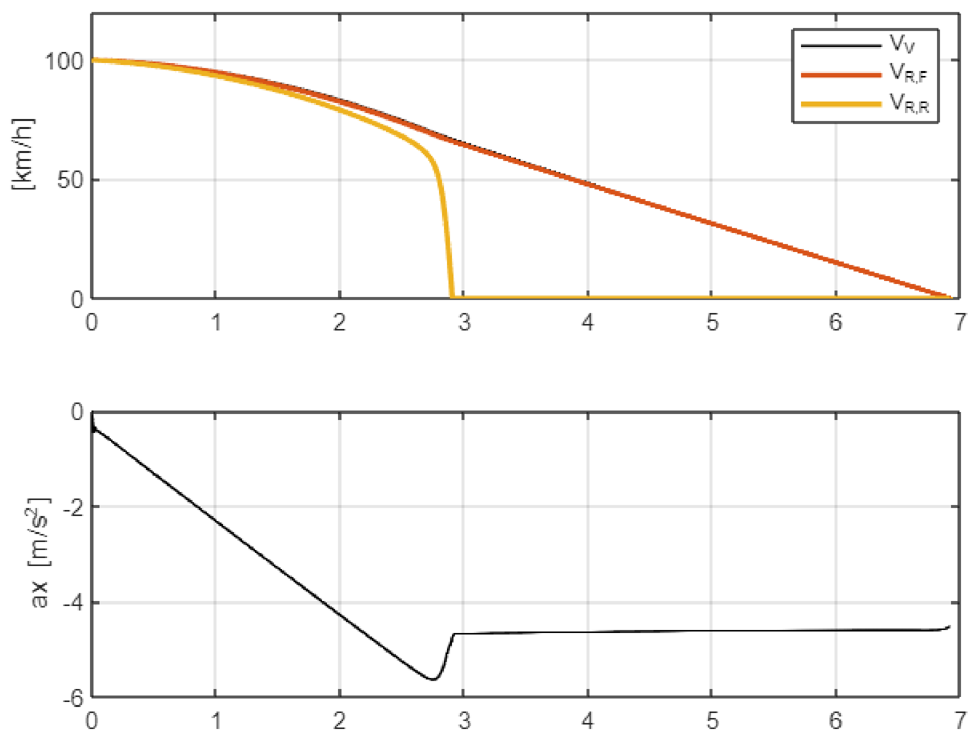
Brake bias: 30/70

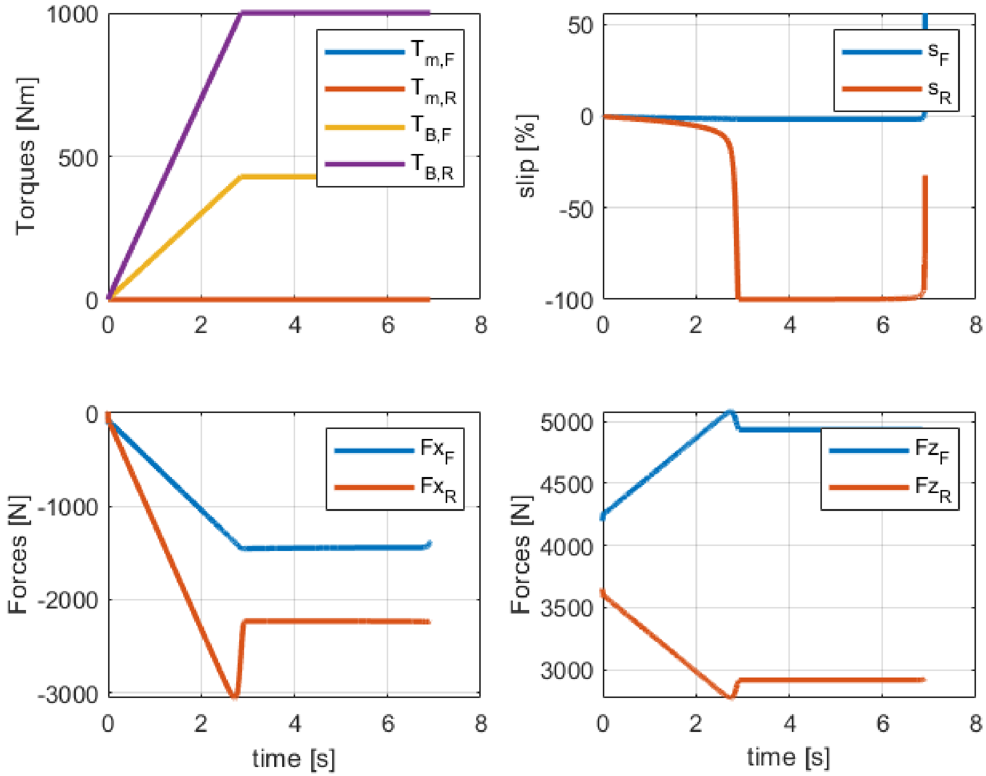
```
Run_Dyn_TbMAX_press
```

```
Braking torque applied to the front = 1428.6 [Nm]
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 30:70 with Fixed brake bias
Road friction coefficient: 1
```

```
Time of braking: 6.9133 seconds
Acceleration reached: -4.5161 m^2
```

```
wheel_chart_script
```





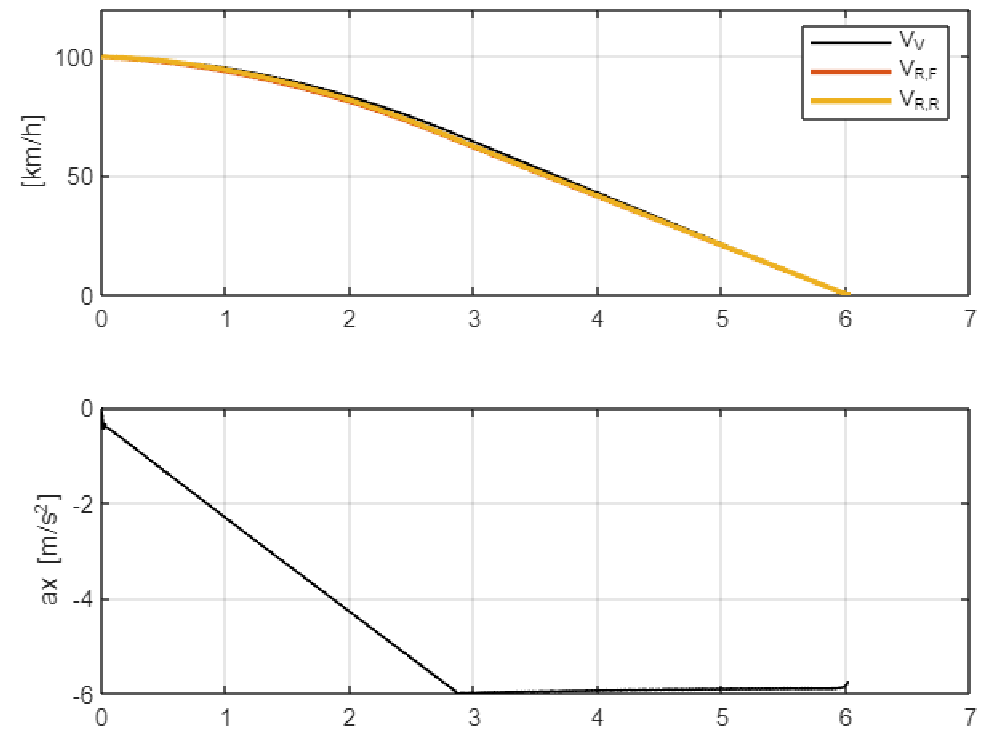
Worst case seen. Rear wheels lock and neglecting the isntability due to the lateral dynamic (assuming that the vehicle will always have a longitudinal trajectory), this configuartion has the highest time of stoppage. Moreover the locking occurs before than the 50/50 case.

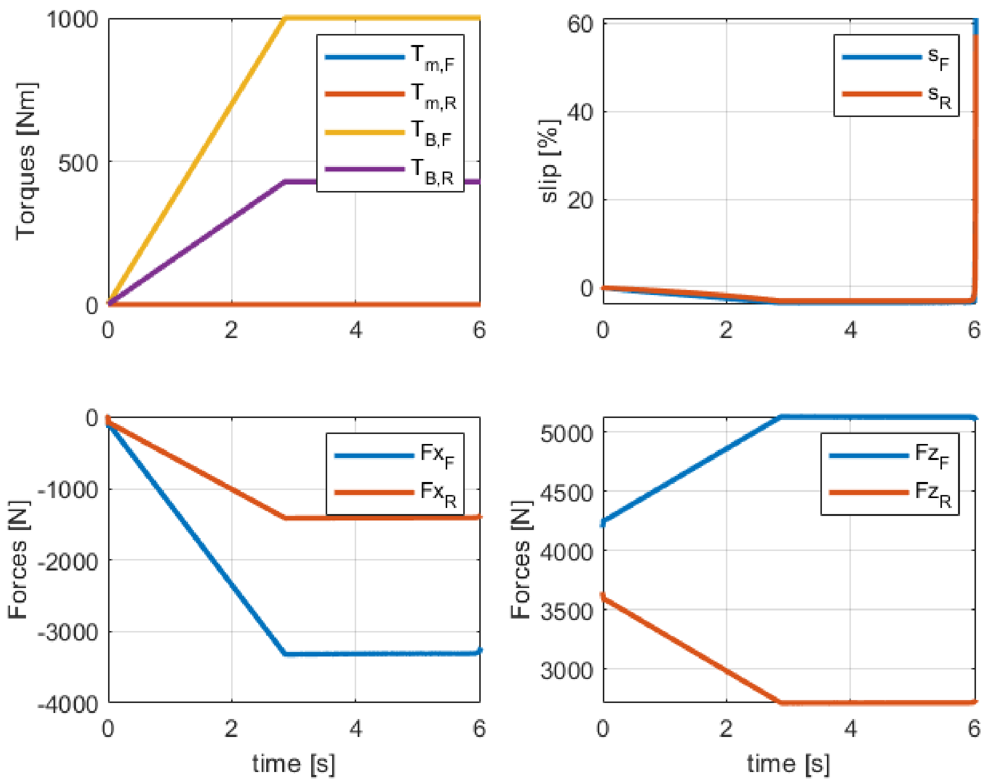
Brake bias: 70/30

```
Run_Dyn_TbMAX_press
```

```
Tb_max = 1.4286e+03
Braking torque applied to the front = 1428.6 [Nm]
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 70:30 with Fixed brake bias
Road friction coefficient: 1
Time of braking: 6.0138 seconds
Acceleration reached: -5.7367 m^2
```

```
wheel_chart_script
```





Even if the the rear wheels do not lock, it is intresting to observe how this does not imply the lowest time of stoppage. Also, since the lock never occurs (slip increases only at the end), the forces are constant and overally it is possible to appreciate the stability of all the system. The fact that the forces do not reduce means that the vehicle is able to expolit the maximum braking capacity.

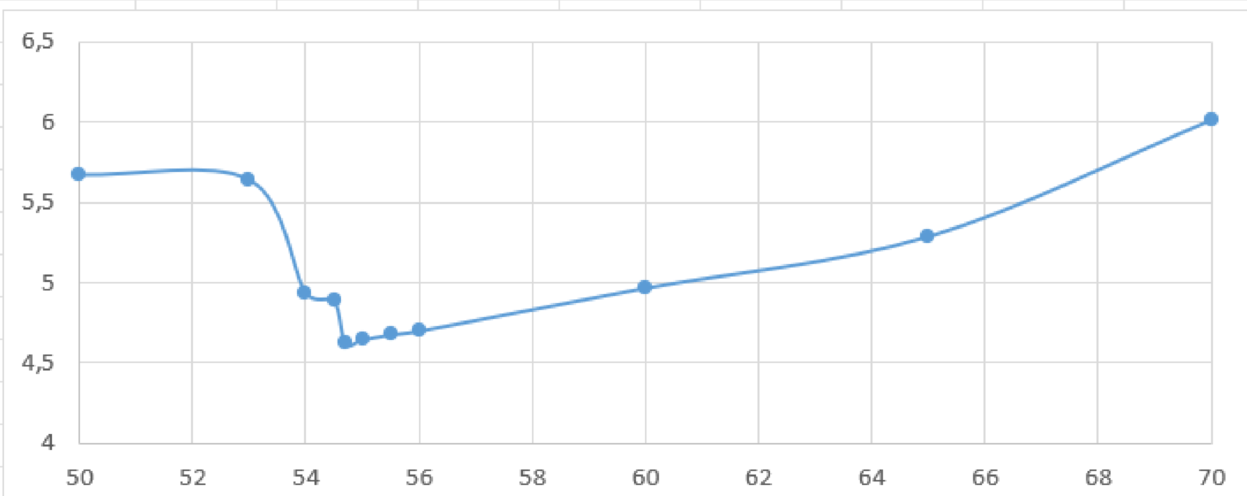
Best brake bias for light manoeuvre

A step-by-step procedure was adopted. Some simulation were run and the time of stoppage was plot as variable of the K_B_F. This until a satisfactory value was obtained. Moreover, in this way it is possible to appreciate the high instability of the braking dynamic.

```
% BEST FOUNDED: 54.7
Run_Dyn_TbMAX_press
```

```
Braking torque applied to the front = 1828.1536 [Nm]
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 54.7:45.3 with Fixed brake bias
Road friction coefficient: 1
Time of braking: 4.6268 seconds
Acceleration reached: -7.3572 m^2
```

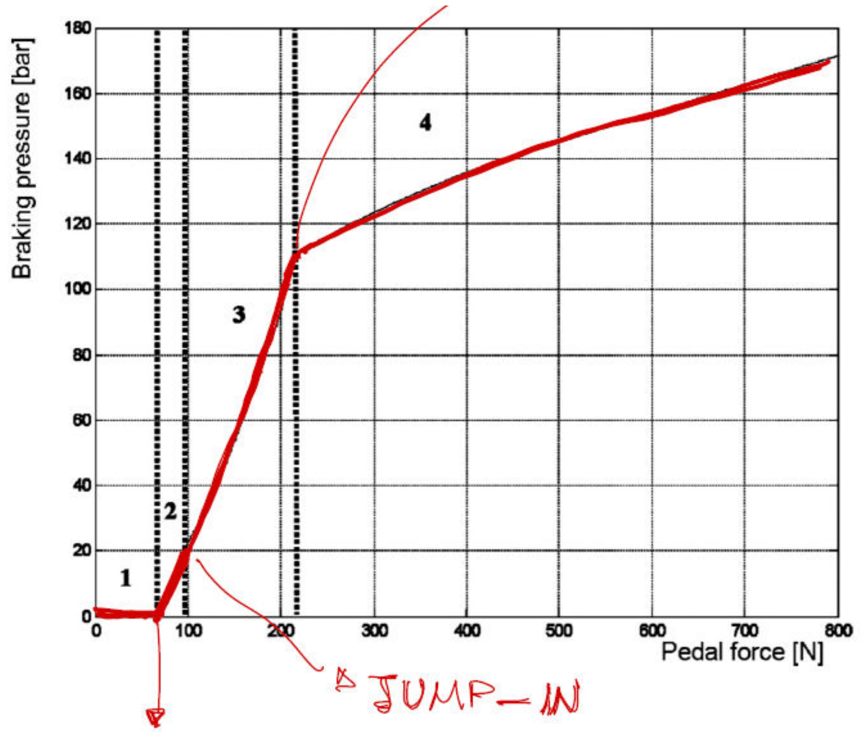
KBF	Time
50	5,67
53	5,64
54	4,9392
54,5	4,89
54,7	4,6268
55	4,6461
55,5	4,6781
56	4,7012
60	4,9674
65	5,2877
70	6,01



Emergency braking manoeuvre - Tb = 6000 Nm

The braking torque applied is enormously big. The aim of this simulation is to observe which is the braking bias at which the rear start to lock before the front in an extreme situation. This bias is usefull as reference for braking perfomanrce design.

A typical value for oli pressure in the braking system for a standard car is as following:



Taking 180 bar as the worst cse, let's now try to computhe the value of pressure necessary to develop 6000 Nm of braking force:

```
hpy_bar = Tb_emer/(np*rm*mu_b*AF)/1e05 % [bar]
```

```
hpy_bar = 267.8571
```

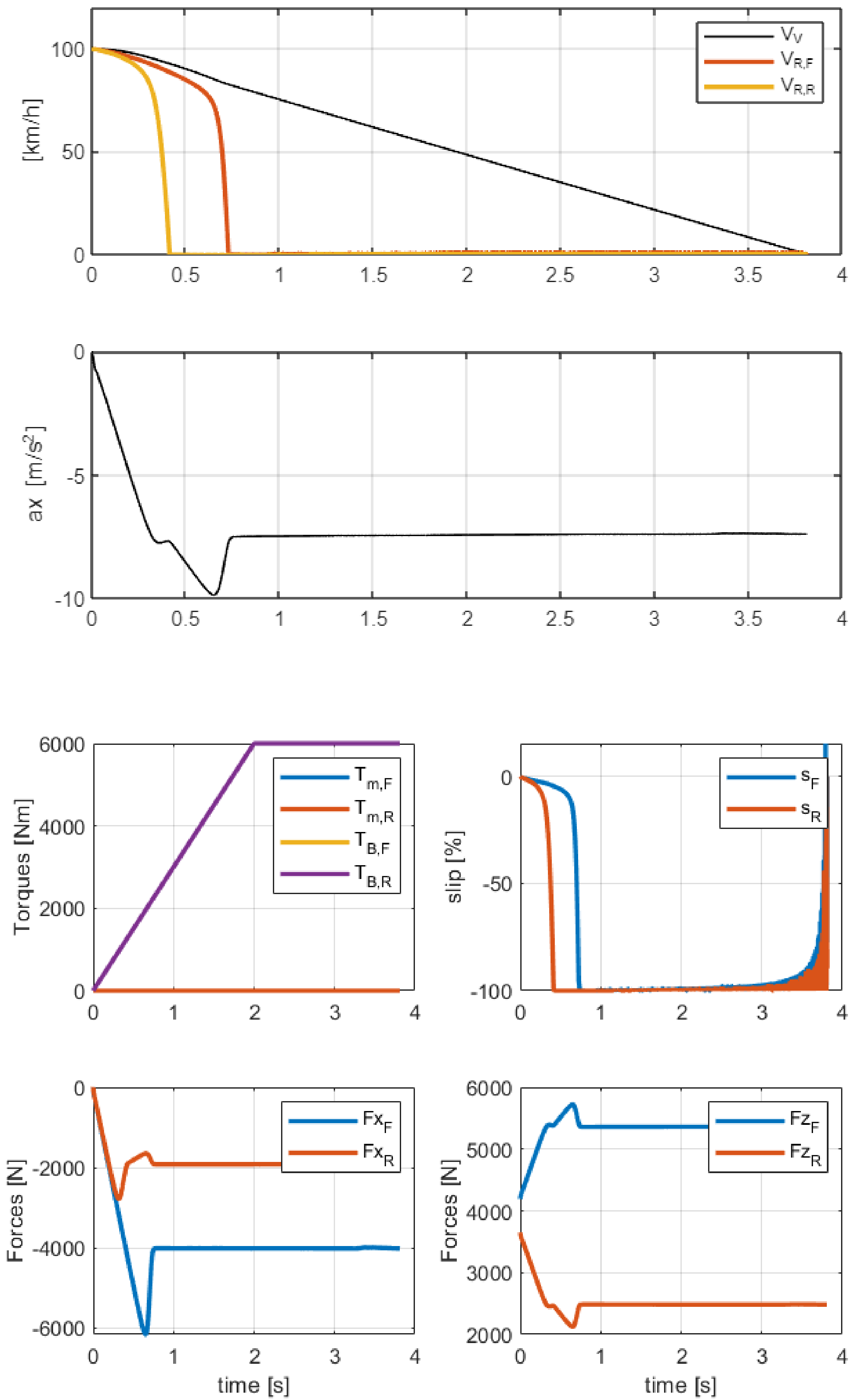
Which as hypothesized is way bigger than the maximum possible pressure allowed, suggesting that the hypothesis done can be assumed correctly: no worries in seeing wheel locking like nothing!

Brake bias: 50/50

```
Run_Dyn_TbMAX_press
```

```
Braking torque applied to the front = 12000 [Nm]
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 50:50 with Fixed brake bias
Road friction coefficient: 1
Time of braking: 3.8121 seconds
Acceleration reached: -7.3901 m^2
```

```
wheel_chart_script
```



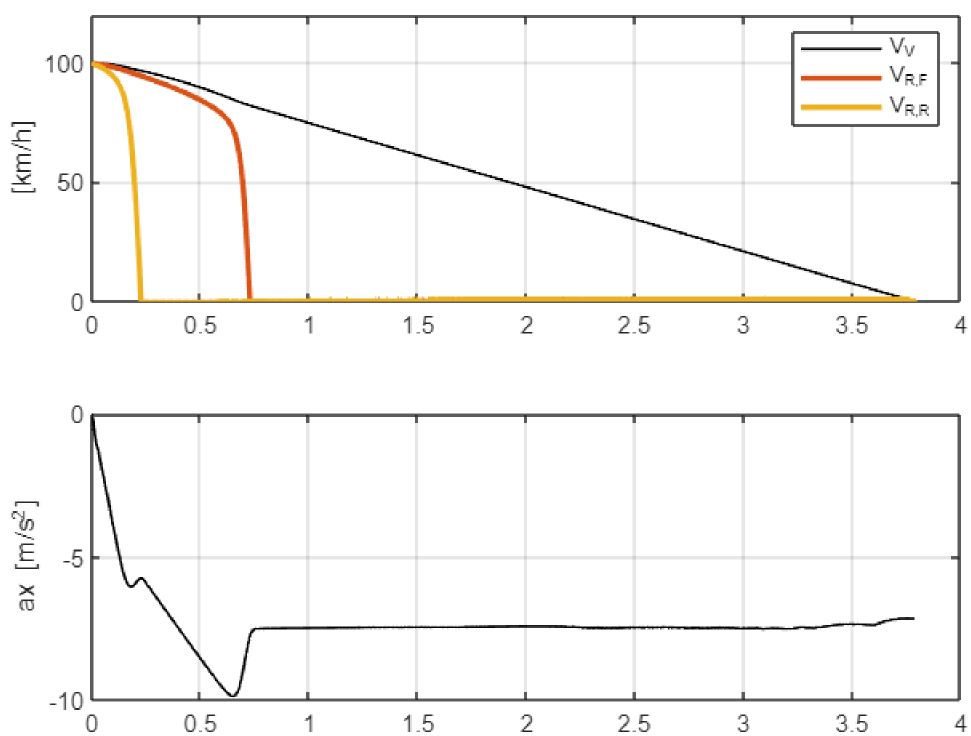
With an even pressure braking torque distribution, the rear locks before thna the front. During braking in fact the longitudinal load transfer apply a positive delta of vertical force on the front, having as consequence to exploit bigger longitudinal forces. As explained, the longitudinal force is proportional to the braking capability of an axle, therefore here lies the explanation for which the front locks before.

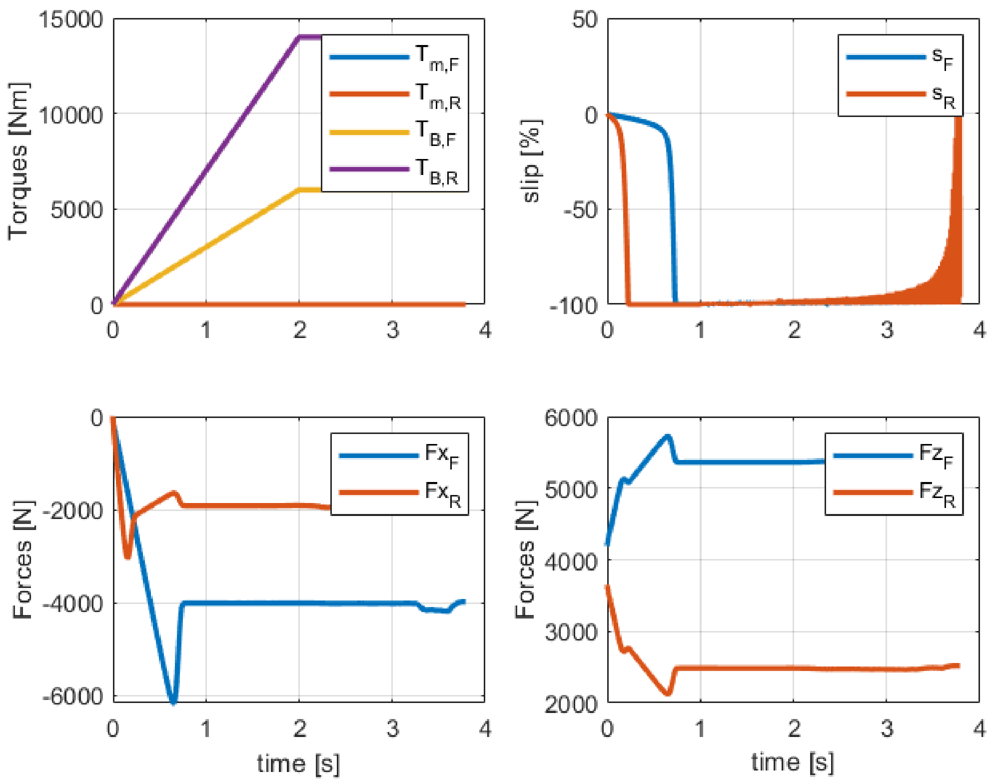
Brake bias: 30/70

```
Run_Dyn_TbMAX_press
```

```
Braking torque applied to the front = 20000 [Nm]
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 30:70 with Fixed brake bias
Road friction coefficient: 1
Time of braking: 3.7868 seconds
Acceleration reached: -7.1541 m^2
```

```
wheel_chart_script
```





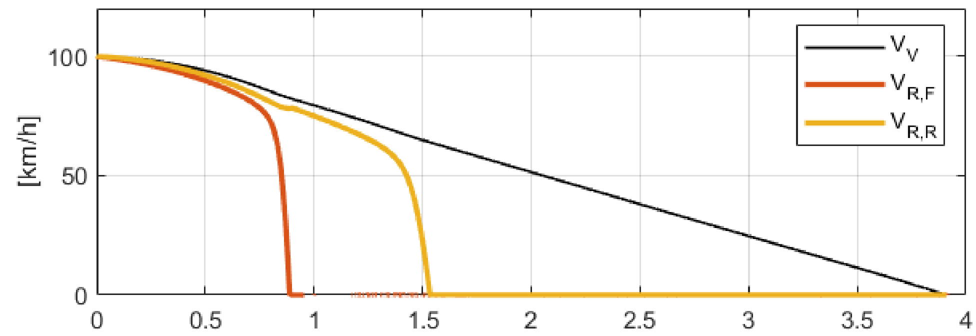
Having bigger braking action on the rear a critical situazion was expected. The simulaiton respect the premises, since the rear force present an incredible overshoot. Dynamically speking, it is better to have a longitudinal force as constant as possible at its maximum, since this will imply a constant braking capacity of the car. With great overshoot means that the car has huge difficulties in braking, suggestion questionable safety.

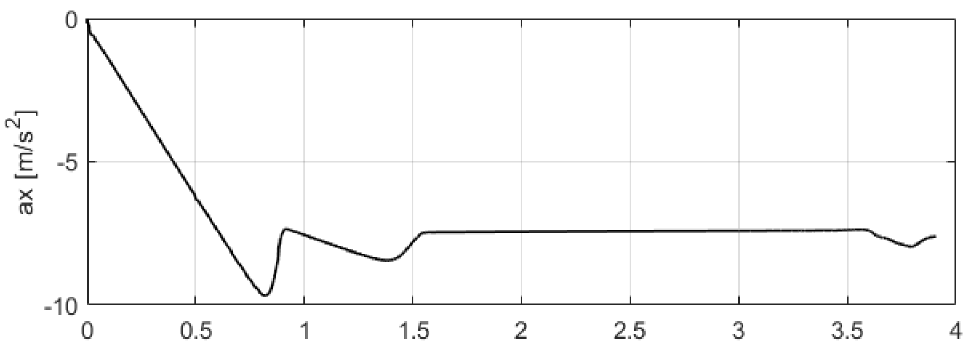
Brake bias: 80/20

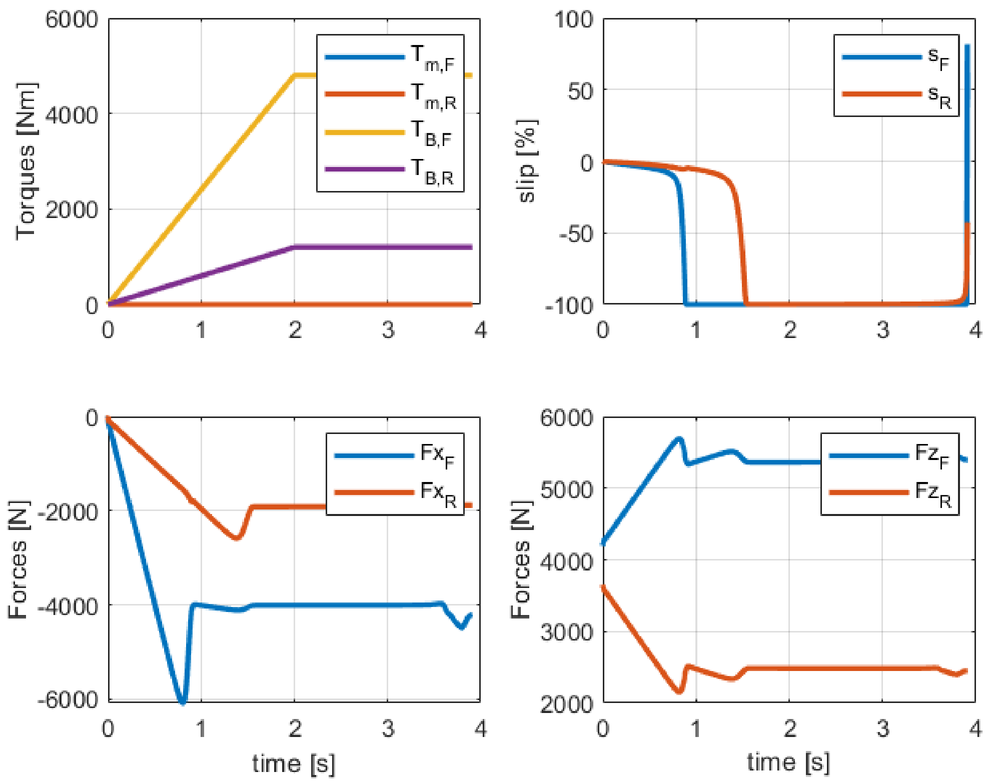
```
Run_Dyn_TbMAX_press
```

```
Braking torque applied to the front = 6000 [Nm]
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 80:20 with Fixed brake bias
Road friction coefficient: 1
Time of braking: 3.9104 seconds
Acceleration reached: -7.603 m^2
```

```
wheel_chart_script
```







As anticipated in the preface of this part, due to high pressure applied the axle will both lock no matter what. However here it is appreciable how first of all the front locks before, which is appreciated due to lateral stability.

Moreover the rear force overshoot is limited respect to the previous cases, suggesting a favorable longitudinal force exploitation.

Best brake bias for emergency braking - no rear lock

Up to now the consequence of this high torque were commented on three different braking bias. Then what?

This extreme conditon is taken as reference to evaluate whoch is the optimal one in order to guarantuee stability in normal cases. In fact, if the braking system designed is capable to assure front locking firs, with a constant rear longitudinal braking force (low overshoot), then the system designed is prepared to the worst case condition.

Running several simualtions, for each of them the locking phenoma was observed and the braking bias which allow for a similar locking time was set as the most adeguate one. Not by chance the longitudinal force observed has the lower overshoot observed.

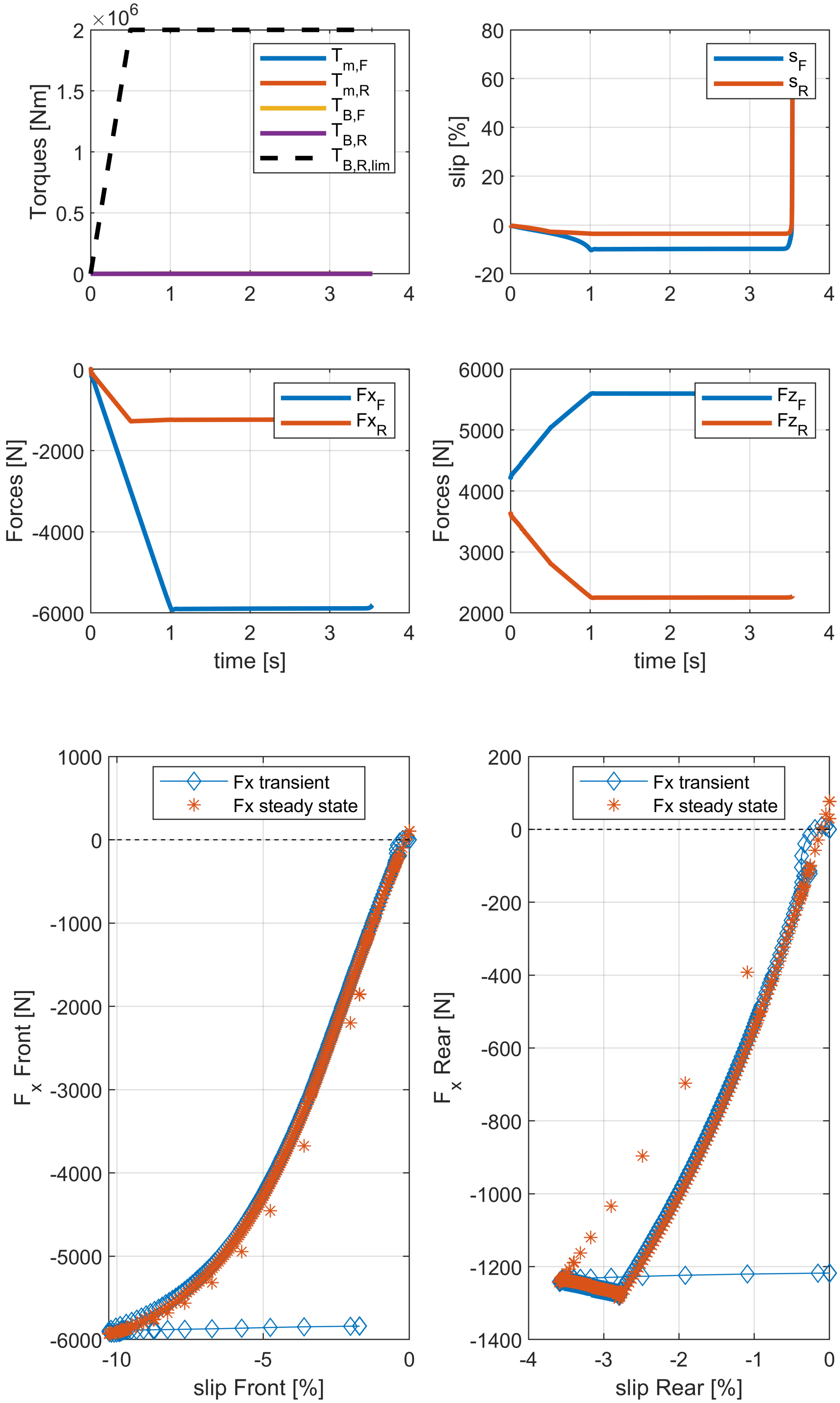
```
Run_Dyn_TbMAX_press
wheel_chart_script
```

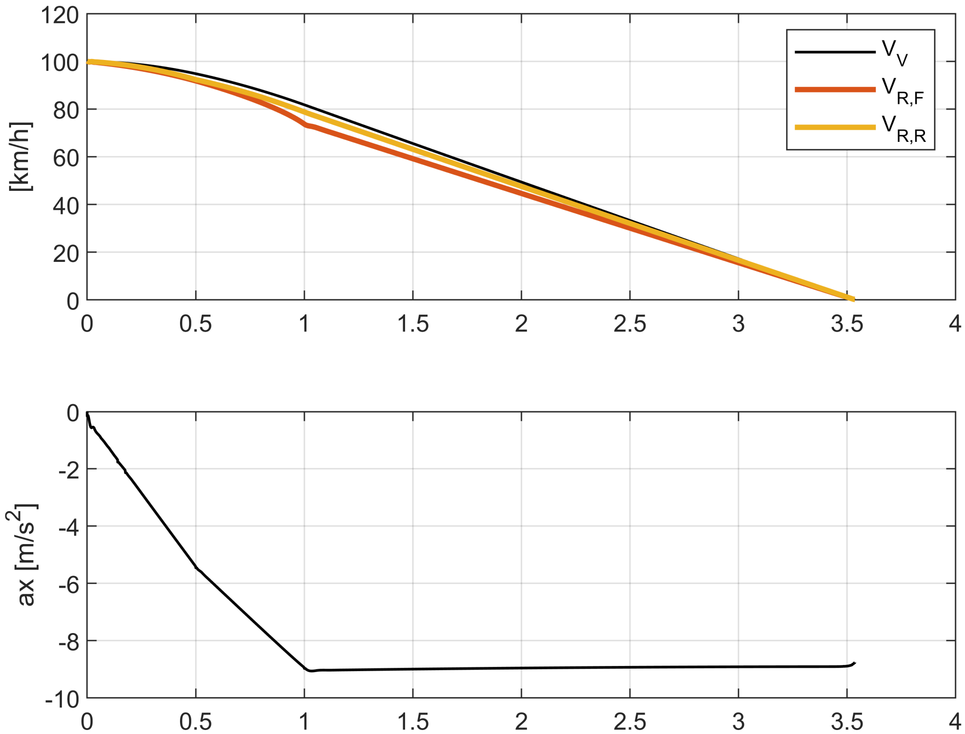
EBD vs Rear proportional valve

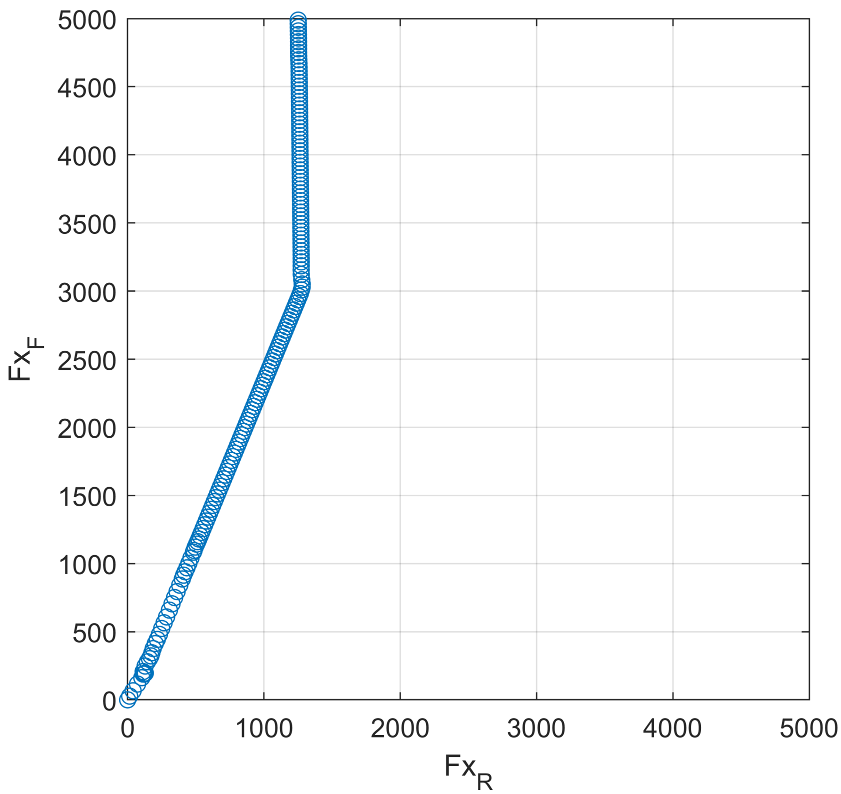
RPV - 70/30

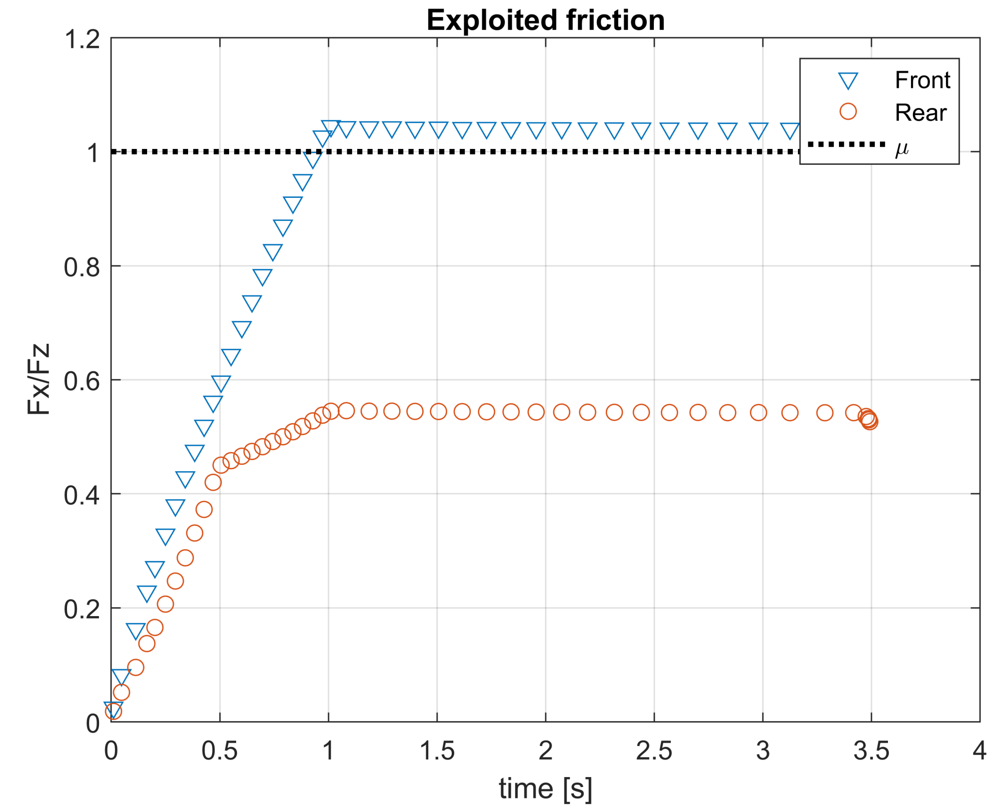
```
Run_Dyn_EBD_press
```

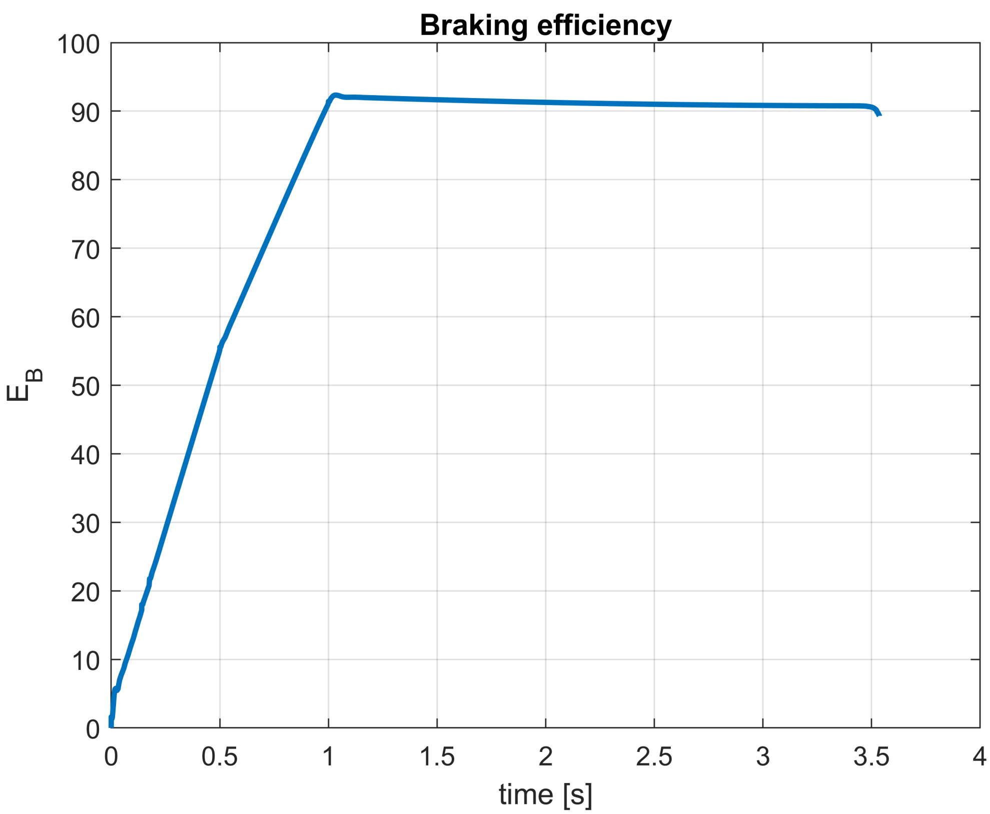
```
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
Brakes 70:30 with Rear brake limitation
Road friction coefficient: 1
```

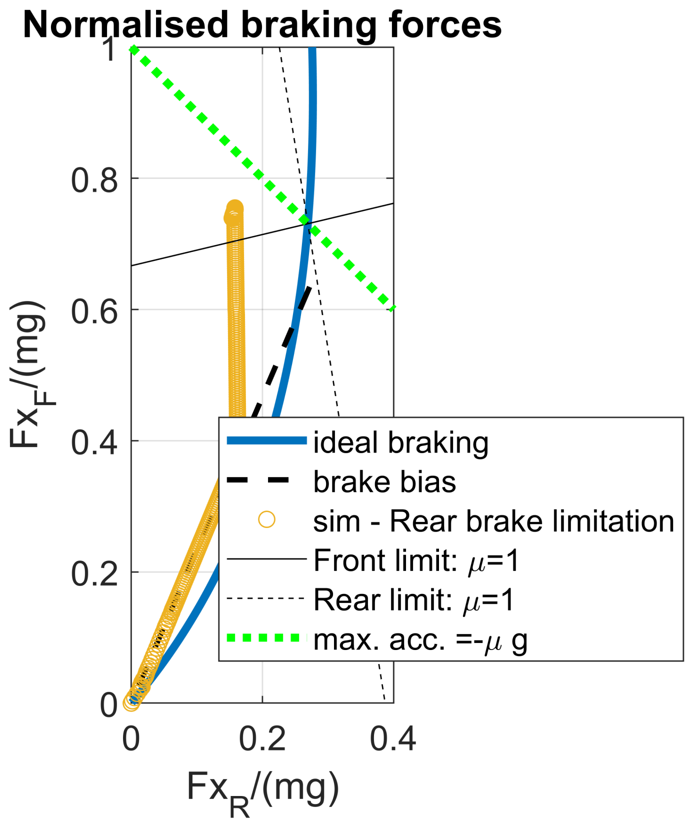

×10^6
Torques [Nm]
T m,F
T m,R
T B,F
T B,R
T B,R,lim
slip [%]
s F
s R
Forces [N]
Fx F
Fx R
time [s]
Forces [N]
Fz F
Fz R
time [s]
F x Front [N]
Fx transient
Fx steady state
slip Front [%]
F x Rear [N]
Fx transient
Fx steady state
slip Rear [%]


[km/h]
ax [m/s2]
VV
VR,F
VR,R


FxF
FxR


Exploited friction
Front
Rear
μ
Fx/Fz
time [s]
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4


Braking efficiency
E_B
time [s]
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
3
3.5
4



The rear proportional valve is a valid braking control system. However its critical point is that it does exploit all the braking capability of the braking system. It efficiency is around 90%, since some braking force is not used. This can be seen also in the ideal braking parabola, in fact the x-distance between the actual curve and the ideal braking parabola is interpetred as "braking force not used". The same conclusion can be taken also considering the grip exploited chart.

As consequence, this little inefficiency physically translates into a longitudinal rear force which is not at its maximum. Since Fxr can be considered as teh force usefull for braking, the overall deceleration also is not the maximum one. The maximum should be equal to g. From the deceleration chart it is possible to state that the one with a proportional valve is slightly less.

Moreover there is some minor chnages among the two axles wheels velocity, so an overall slip of about 10%. The latter is also a factor about Fxr not maximaized, since usually the highest value of longitudinal force is get for slip around 15%.

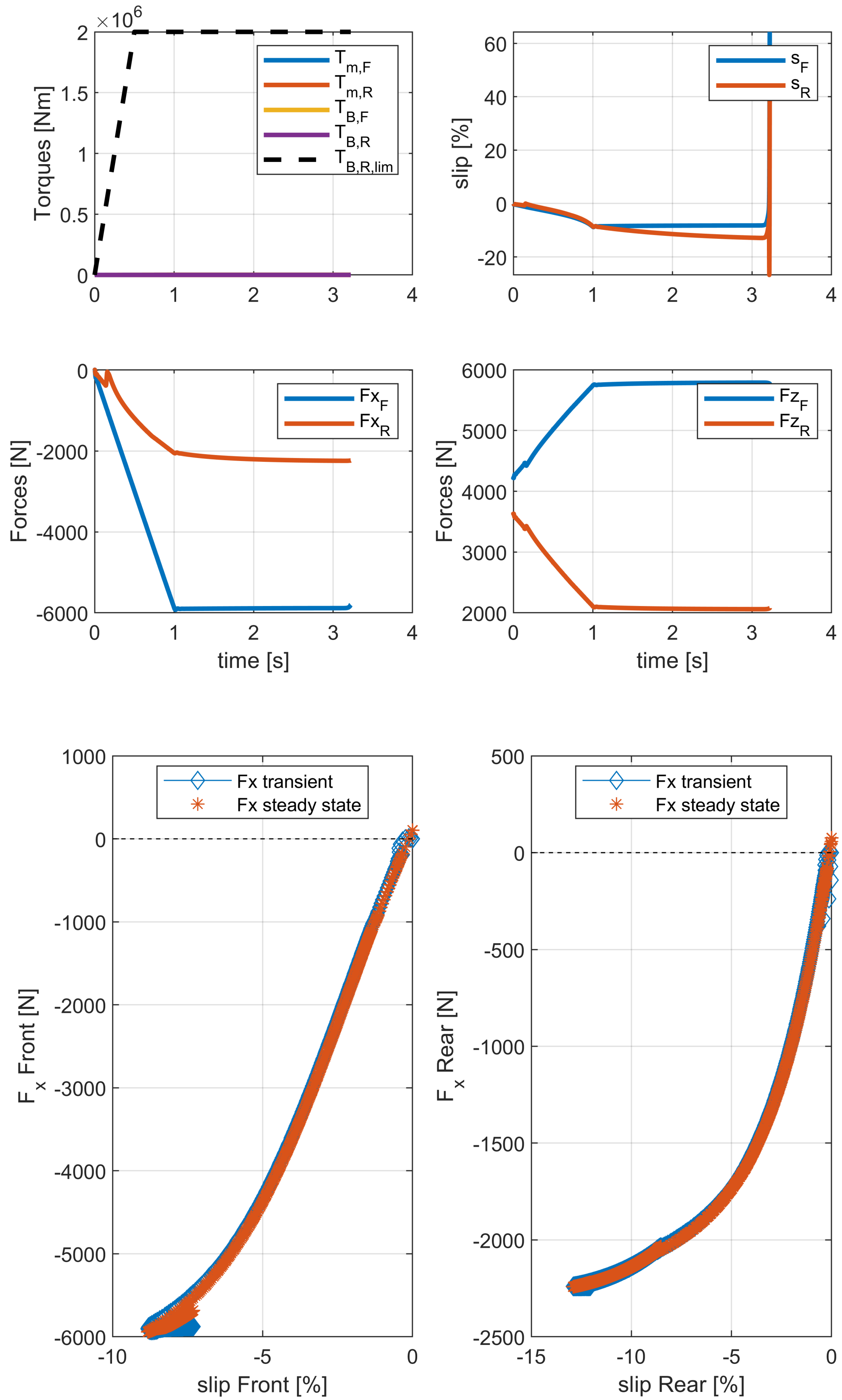
However this discussion does not mean that the rear proportional valve is not a great solution, it is but note the best one.

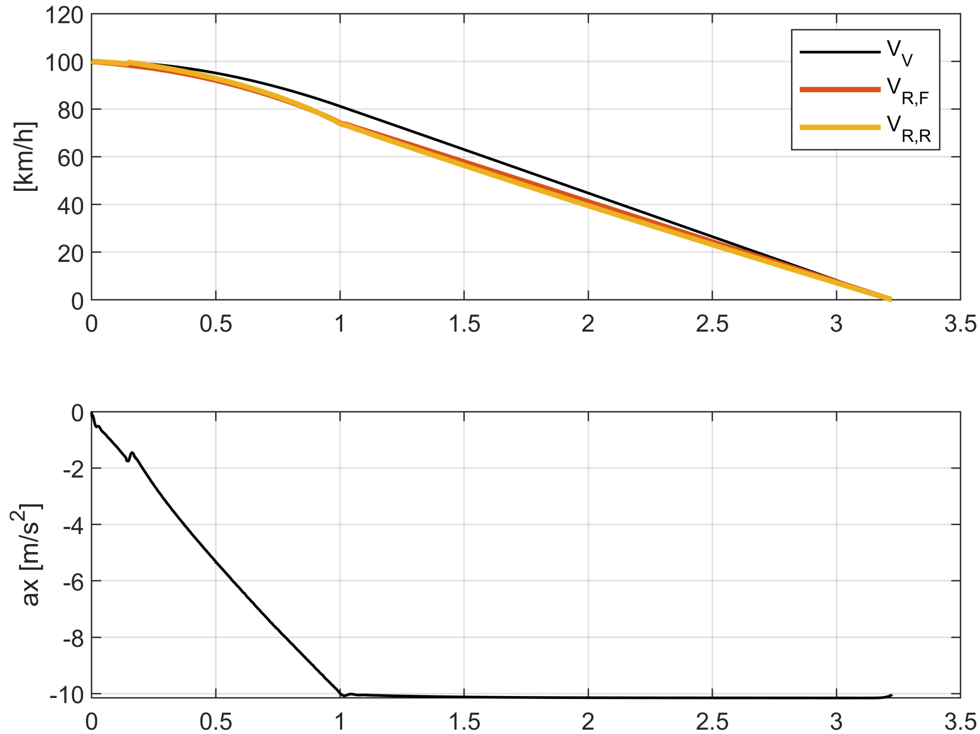
EBD - 70/30

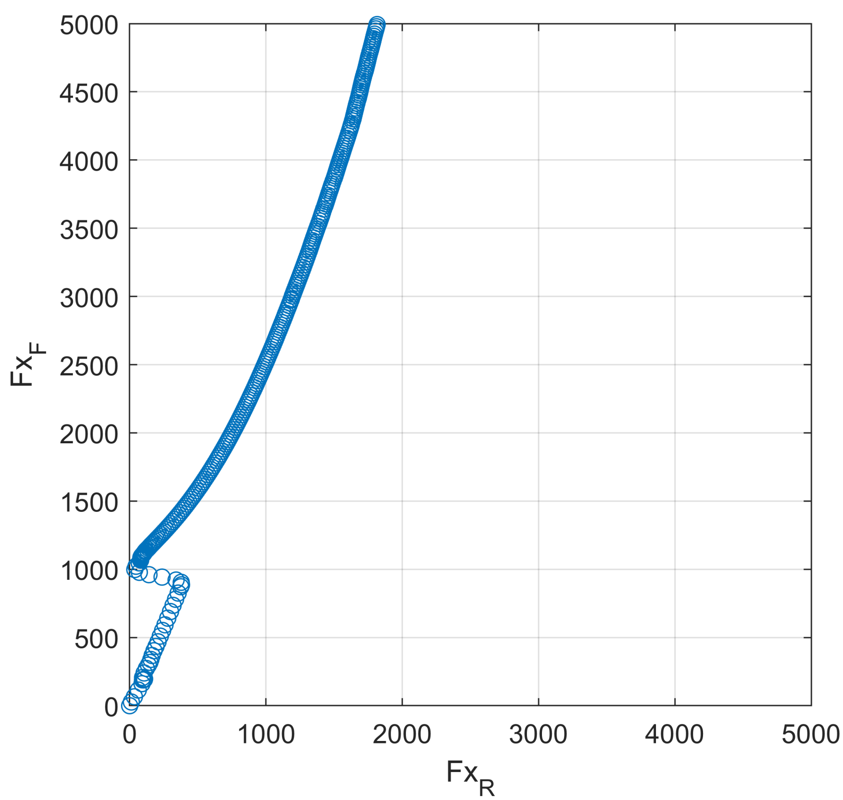
```
Run_Dyn_EBD_press
```

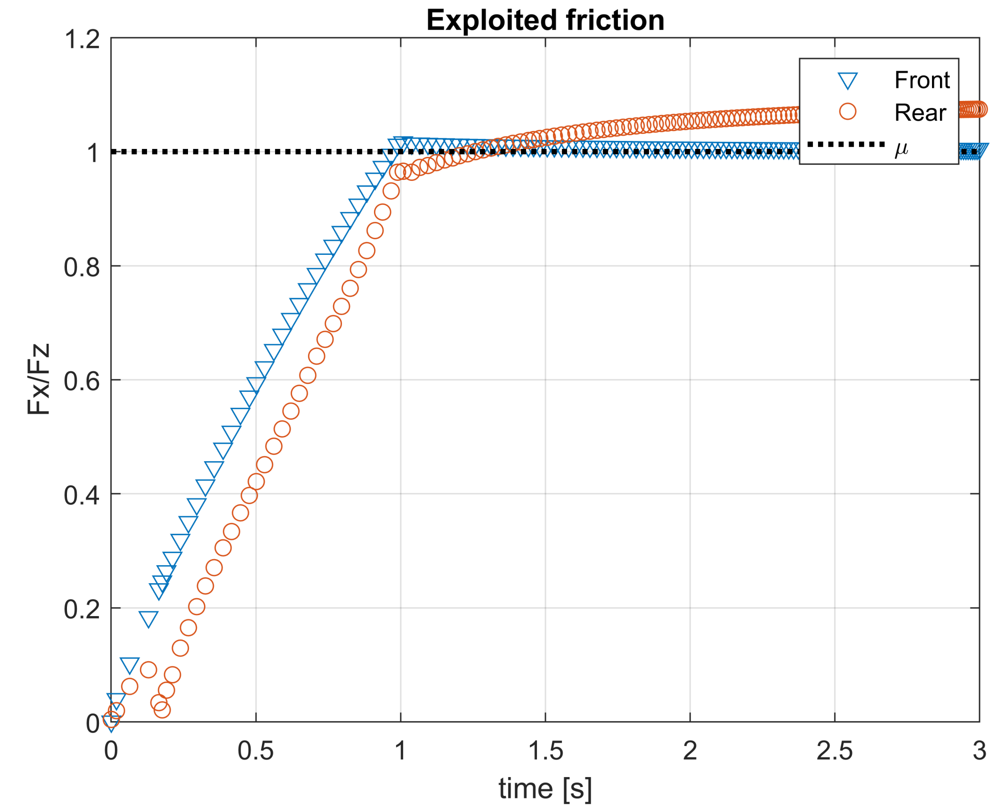
```
Braking manouvre
Initial speed: 100 km/h
Initial gear: 2
Road slope: 0%
```

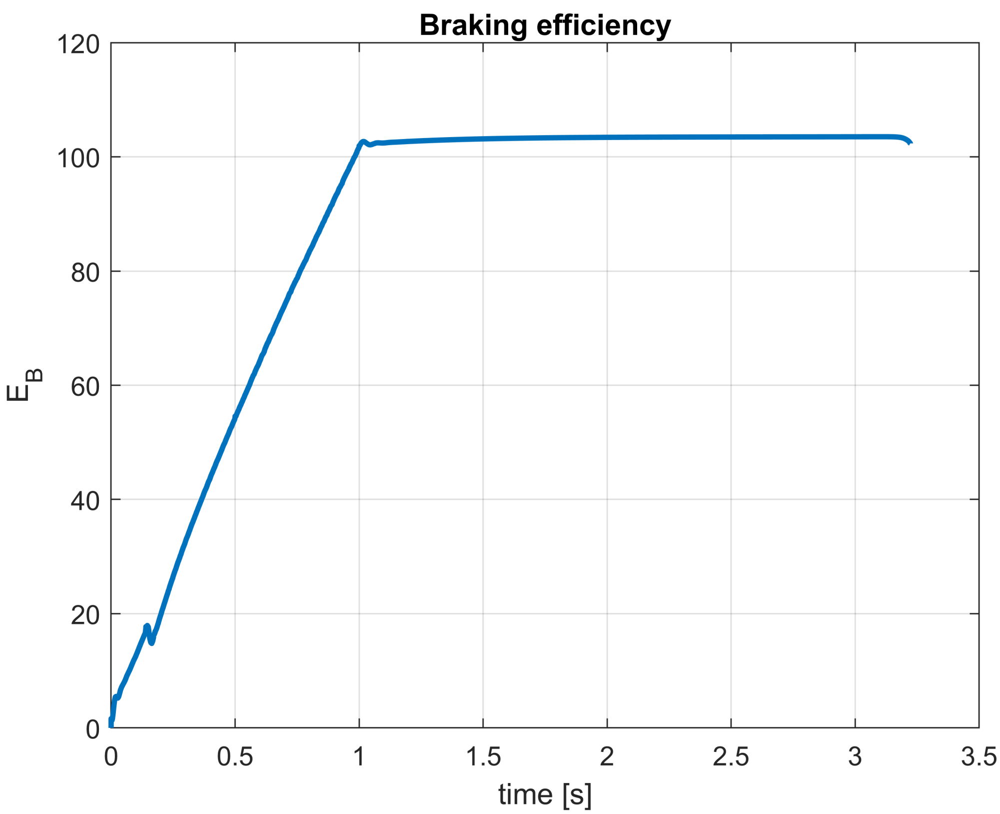
```
Brakes 70:30 with EBD
Road friction coefficient: 1
```

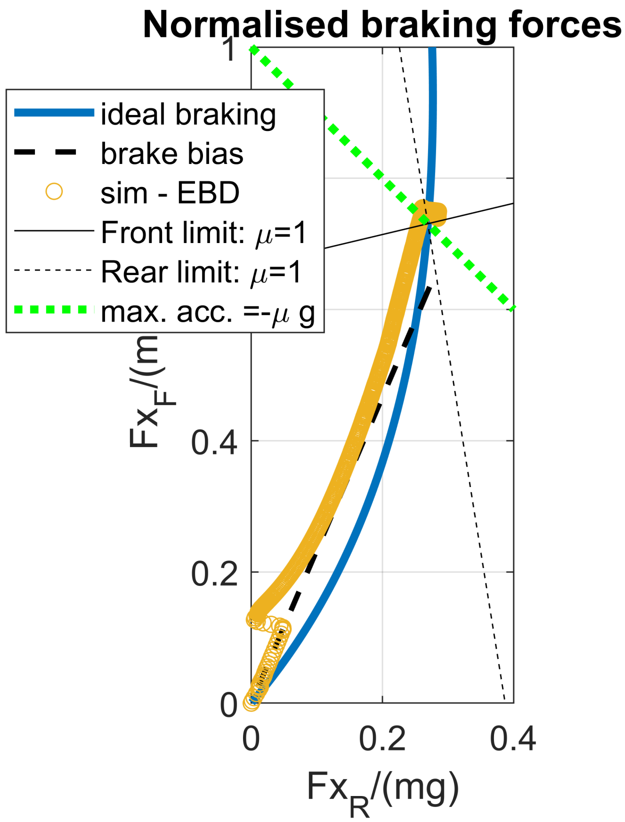



[km/h]
ax [m/s^2]
V_V
$V_{R,F}$
$V_{R,R}$


Fx_F
Fx_R


Exploited friction
Front
Rear
μ
Fx/Fz
time [s]
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3


Braking efficiency
E_B
time [s]
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5



EBD instead shows the better control possible for several reason.

Starting from the ideal braking parabola, the x-distance is kept as low as possible, suggesting that there is a limited loss of braking capacity. As consequence the efficiency is pratically always the best one (it goes above probably due to the PID, sicne it was set with fixed parameter, probably is not perfectly tuned).

This high efficiency transletes into a considerable amount of rear longitudinal forces, in fact it values is stably on 2000 N. The friction expolitation chart confirm this observation. Moreover, the Fxr is maximum thanks also to the slip value which is around the 15% (welcomed one).

The two axles also do not show particualr difference in their translational velocity, assuming that the braking dynamic is stable and comfortable.

As a conslusion, the deceleration is perfect: -10 m/s^2, slighlty more even than the one permitted, probably also this is due to the PID tuning.