Fundamental Vehicle Loads & Their Estimation

• The simplified loads can only be applied in the preliminary design stage when the absence of test or simulation data

• They should always be qualified and updated as more information becomes available

VEHICLE OPERATING CONDITIONS & PROVING GROUND TESTS

• The significant proving ground events can be divided into two types:
  a) Instantaneous overloads (large pot holes, kerb bump, large bump, panic braking, high g cornering, service loads)
  b) Fatigue damage (medium size pot holes, Belgium block road, twist course, Cobblestone track, service loads)

Example of service loads: towing, jacking, hoisting
LOADS CASES & LOAD FACTORS

• The vehicle designer needs to know the worst or most damaging loads in order to:
  a) ensure the structure does not fail in service due to instantaneous overload
  b) ensure a satisfactory fatigue life

• Common assumption at early design stage:
  *If the structure can resist the worst possible loads then it is likely to have sufficient fatigue strength*

• For early design calculation, the actual dynamic loading is often replaced by a factored static loading:

\[ P_{dyn} = P_{st} \times M \]

Or sometimes an extra FOS is used:

\[ P_{dyn} = P_{st} \times M \times FOS \]
SYMMETRIC VERTICAL LOADS

\[ P_{zs} = m_{zs} \left( G_c - G_{nr} \right) \] (kg)

- \( P_{zs} = \) the vertical force (kg)
- \( m_{zs} = \) 2.5 for private cars,
  2.5 for busses,
  3.0 for lorries
- \( G_c = \) total weight of the car (kg)
- \( G_{nr} = \) weight of unsprung mass (kg)
ASYMMETRIC VERTICAL LOADS

\[ P_{zn} = m_{zns} (G_c - G_{nr}) \] (kg)

- \( P_{zn} \) = the asymmetric vertical force (kg)
- \( m_{zns} \) = 1.3 for private cars, 1.3 for busses, 1.5 for lorries
- \( G_c \) = total weight of the car (kg)
- \( G_{nr} \) = weight of unsprung mass (kg)
ASYMMETRIC VERTICAL LOADS (cont.)

\[ M_s = m_{zns} \left( R_{pp} - R_{pl} \right) \left( \frac{r_p}{2} \right) \]  \hspace{1cm} \text{(kg.m)}

- \( M_s \) = torque (kg.m)
- \( m_{zns} = 1.3 \) for private cars,
  \hspace{1cm} 1.3 for busses,
  \hspace{1cm} 1.5 for lorries
- \( (R_{pp} - R_{pl}) \) = difference of forces on the front wheels (kg)
ASYMMETRIC VERTICAL LOADS (cont.)

For single bump:

\[ h_1 = f_{og} + f_{rp} \left( \frac{r_p}{z_p} \right) + f_{og} \left( \frac{r_p}{r_t} \right) + f_{rt} \left( \frac{r_p}{z_t} \right) \]  

\( f_{og} \) = deflection of the tyres (mm)

\( f_r \) = deflection of the springs (mm)

\( r \) = the track width (mm)

\( z \) = the width between suspension attachments (mm)
For double bump:

\[ h_2 = f_{og} + f_r \left( \frac{r}{z} \right) \quad (\text{mm}) \]

- \( f_{og} \) = deflection of the tyres (mm)
- \( f_r \) = deflection of the springs (mm)
- \( r \) = the track width (mm)
- \( z \) = the width between suspension attachments (mm)
### ASYMMETRIC VERTICAL LOADS (cont.)

Maximum heights of actual road surface bumps

<table>
<thead>
<tr>
<th>Bump Height</th>
<th>Type of vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_r$, mm</td>
<td>Cars</td>
</tr>
<tr>
<td></td>
<td>Buses</td>
</tr>
<tr>
<td></td>
<td>Lorries</td>
</tr>
<tr>
<td></td>
<td>±200</td>
</tr>
<tr>
<td></td>
<td>±250</td>
</tr>
<tr>
<td></td>
<td>±300</td>
</tr>
</tbody>
</table>
If \( h_{1,2} < H_r \), then one wheel may leave the road surface. The force acting on each wheel and the torque acting on the car body are given as:

\[
\begin{align*}
R_{pl} &= 0 \\
R_{pp} &= m_{zns} R_p \\
R_{tl} &= m_{zns} \left( \frac{R_t - R_{pp}}{2} \right) \left( \frac{r_p}{r_t} \right) \\
R_{tp} &= m_{zns} \left( \frac{R_t + R_{pp}}{2} \right) \left( \frac{r_p}{r_t} \right) \\
M_s &= m_{zns} \left( \frac{R_p r_p}{2} \right)
\end{align*}
\]
If $h_{1,2} > H_r$, then the force acting on each wheel and the torque acting on the car body are given as:

\[
R_{pl} = m_{zns} \left( \frac{R_p}{2} \right) \left[ 1 + \left( \frac{H_r}{h_{1,2}} \right) \right]
\]

\[
R_{pp} = m_{zns} \left( \frac{R_p}{2} \right) \left[ 1 - \left( \frac{H_r}{h_{1,2}} \right) \right]
\]

\[
R_{tl} = m_{zns} \left[ \left( \frac{R_t}{2} \right) - \left( \frac{R_p}{2} \right) \left( \frac{H_r}{h_{1,2}} \right) \left( \frac{r_p}{r_t} \right) \right]
\]

\[
R_{tp} = m_{zns} \left[ \left( \frac{R_t}{2} \right) + \left( \frac{R_p}{2} \right) \left( \frac{H_r}{h_{1,2}} \right) \left( \frac{r_p}{r_t} \right) \right]
\]

\[
M_s = m_{zns} R_p \left( \frac{r_p}{2} \right) \left( \frac{H_r}{h_{1,2}} \right)
\]
For single bump:

\[ h_1 = f_{og} + f_p \left( \frac{r_p}{z_p} \right) + f_t \left( \frac{r_p}{r_t} \right) + f_r \left( \frac{r_p}{z_t} \right) \quad \text{(mm)} \]

- \( f_{og} \): deflection of the tyres (mm)
- \( f_r \): deflection of the springs (mm)
- \( r \): the track width (mm)
- \( z \): the width between suspension attachments (mm)

If \( h_{1,2} < H_r \), then one wheel may leave the road surface. The force acting on each wheel and the torque acting on the car body are given as:

- \( R_{pl} = 0 \)
- \( R_{pp} = m_{zws} R_p \)
- \( R_d = m_{zws} \left( \frac{R_t - R_{pp}}{2} \right) \left( \frac{r_p}{r_t} \right) \)
- \( R_p = m_{zws} \left( \frac{R_t + R_{pp}}{2} \right) \left( \frac{r_p}{r_t} \right) \)
- \( M_s = m_{zws} \left( \frac{r_p r_p}{2} \right) \)

If \( h_{1,2} > H_r \), then the force acting on each wheel and the torque acting on the car body are given as:

- \( R_{pl} = m_{zws} \left( \frac{R_p}{2} \right) \left[ 1 + \left( \frac{H_r}{h_{1,2}} \right) \right] \)
- \( R_{pp} = m_{zws} \left( \frac{R_p}{2} \right) \left[ 1 - \left( \frac{H_r}{h_{1,2}} \right) \right] \)
- \( R_d = m_{zws} \left[ \left( \frac{R_t}{2} \right) - \left( \frac{R_p}{2} \right) \left( \frac{H_r}{h_{1,2}} \right) \left( \frac{r_p}{r_t} \right) \right] \)
- \( R_p = m_{zws} \left[ \left( \frac{R_t}{2} \right) + \left( \frac{R_p}{2} \right) \left( \frac{H_r}{h_{1,2}} \right) \left( \frac{r_p}{r_t} \right) \right] \)
- \( M_s = m_{zws} R_p \left( \frac{r_p}{2} \right) \left( \frac{H_r}{h_{1,2}} \right) \)

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<tr>
<td>( H_r ), mm</td>
<td>±200</td>
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LONGITUDINAL LOADS

These loads are caused by braking or accelerating the vehicle or by driving over a bump.

\[ P_x = \pm m_x (G_c - G_{nr}) \]  

(kg)

\( P_x \) = the longitudinal force (kg)
\( m_x \) = 0.7 to 1.0
\( G_c \) = total weight of the car (kg)
\( G_{nr} \) = weight of unsprung mass (kg)
LONGITUDINAL LOADS (cont.)

The case of a car driving into a bump or kerb:

\[ P_x = m_z R_p \tan \theta \quad \text{(kg)} \]

- \( P_x \) = the longitudinal force (kg)
- \( m_z = 2.5 \) for cars
- \( R_p \) = static load on the front axle (kg)

The angle \( \theta \) is obtained as follows:

\[ \theta = \sin^{-1} \left[ 1 - \left( \frac{H_r}{r_d} \right) \right] \]

- \( r_d \) is the dynamic radius of the wheel (from tyre catalogue data) and \( H_r \) is the actual height of road surface bump.
SIDE LOADS

Side loads arise from driving on a curved track, or through a sideways collision with an obstruction. The maximum possible loading from the centrifugal force $C$ is determined by the relationship between the wheel track and the height of the centre of gravity:

$$\tan \gamma = \frac{r}{2Z_{sc}} = \frac{C_b}{m_{zs} G_c}$$

- $r =$ track width (mm)
- $Z_{sc} =$ height of centre of gravity (mm)
- $C_b =$ lateral component of the inertial force (kg)
- $m_{zs} =$ 2.5 for cars
- $G_c =$ total weight of the car (kg)
The loads at the suspension attachment points, front and rear, are

\[ C_b = R_y = m_{zs} G_c \left( \frac{r}{2Z_{sc}} \right) \] (kg)

\[ R_{py} = m_{zs} G_c \left( \frac{r}{2Z_{sc}} \right) \left( \frac{L_t}{L_o} \right) \] (kg)

\[ R_{ty} = m_{zs} G_c \left( \frac{r}{2Z_{sc}} \right) \left( \frac{L_p}{L_o} \right) \] (kg)

- \( L_o \) = the wheelbase (mm)
- \( L_t \) = the distance of the centre of gravity from the rear axle (mm)
- \( L_p \) = the distance of the centre of gravity from the front axle (mm)
Vehicle structures are divided into three types:

(i) closed integral structures
(ii) open integral structures
(iii) flat or punt-type structures

STRESS ANALYSIS

The idealisation of a closed integral structure.

The idealisation of an open integral structure.

The idealisation of a flat or punt-type structure.
STRESS ANALYSIS (cont.)

(i) Closed Integral Structures

A structure is closed if the main design surfaces form a closed system and if shear forces occur between them when loaded in torsion.

Figure (b) shows the distribution of edge forces when this closed integral structure is under torsional loading.

The application of torque $M_s$ onto the structural surface ABCD produces edge forces $K_1, K_2, \text{etc.}$ in all surfaces and also produces the reaction $M_s$ on the surface A'B'C'D'.
STRESS ANALYSIS (cont.)

(i) Closed Integral Structures (cont.)

Figure (c) shows the distribution of edge forces when this closed integral structure is under bending.
(ii) Open Integral Structures

A structure is open if it lacks the upper or the front and rear structural surfaces and if edge shear forces do not arise between all the surfaces.

Figure (a) shows the open integral structure open at the top.

Figure (b) shows the distribution of edge forces when the structure is under torsion.
(ii) Open Integral Structures (cont.)

Figure (c) shows the distribution of edge forces when the structure is in bending.
(ii) Open Integral Structures (cont.)

Figure (a) shows the idealisation of a vehicle structure open front and rear.

Figure (b) shows the distribution of forces in torsion.
ii) Open Integral Structures (cont.)

Figure (a) shows the idealisation of a vehicle structure open front and rear.

Figure (c) shows the distribution of forces in bending.
(iii) Flat or punt type structures

Figure (a) shows the idealisation of a flat or punt type vehicle structure.

Figure (b) shows the distribution of forces in torsion.
STRESS ANALYSIS (cont.)

(iii) Flat or punt type structures (cont.)

Figure (a) shows the idealisation of a flat or punt type vehicle structure.

Figure (c) shows the distribution of forces in bending.