STRUCTURAL SURFACES & FLOOR GRILLAGES
INTRODUCTION

Integral car bodies are 3D structures largely composed of approximately subassemblies- SSS

Planar structural subassemblies can be grouped into two categories based on their functions:
   a) SSS- carry in-plane loads-example: sideframe
   b) Grillage structures – carry out-of-plane loads-example: compartment floor

The floor carries both types of load but the two functions can be treated separately:
   a) Grillage- out-of-plane stiffness comes from attached beam
   b) Torsion-box- in-plane stiffness comes from very thin panel to carry almost all shear load
In-plane loads and SSS

• Structures which are flexible in-plane are *not* considered as SSS and tend to cause unsatisfactory break in load paths. Examples are discontinuous frames, missing edges, unreinforced cut-outs, open ring frame with pin-jointed or flexible-jointed corners.

• Typical effective SSS are:
  a) Thin walled panels
  b) triangulated planar trusses
  c) stiff jointed frames
  d) combination of the above
Shear Panels

- One role of SSS is to effectively carrying shear forces $Q$

Shear flow and shear stress
- shear flow is shear force per unit length, $q = Q/L$ (N/m)
- The average shear stress is shear force per unit area,
  \[ \tau_{avg} = \frac{Q}{A} = \frac{Q}{Dt} \]

Thus, $q = t\tau$
Stiffness of Shear Panel

- Shear stress = shear modulus x shear strain
  \[ \tau = G \gamma \]

Shear stiffness

\[ K = \frac{G t D}{B} \]

\[ \tau = \frac{Q_1}{Dt} \]
\[ \gamma = \frac{\Delta}{B} \]
\[ \frac{Q_1}{Dt} = G \frac{\Delta}{B} \]
\[ Q_1 = K \frac{\Delta}{G t D} \frac{\Delta}{B} \]
Shear panel as part of an assembly

- The edge shear forces $Q_1$ and $Q_2$ will have to be reacted by adjacent structural elements. These may be: a) other shear panels b) edge booms or flanges

i) Shear panel assemblies-torsion box (Transmission tunnel)
ii) Boom- panel structures

- to represent a cantilever structure

- assumption made to a beam composed by of booms and panel:

a) Bending moment is reacted by by the axial forces in the boom

b) The shear panel carries all the shear force $Q_1$

\[ P \quad P \quad Q_1 \quad Q_2 \quad Q_1 \quad Q_2 \quad P \]
Triangulated truss/bay

• This is composed of pin-ended members connected in a triangulated arrangement
• The individual members experience only tension and compression

\[ Q_1 = P_3 \cos \theta \]
\[ Q_2 = P_3 \sin \theta \]
Shear stiffness of triangulated bay

Strain energy method:

\[ U = \sum \frac{P^2 L}{2AE} \]

A = Cross-sectional area  
L = Length  
E = Young modulus

Assumed that the shear force Q is carried by member 3

\[ U_3 = \frac{P_3^2 L_3}{2A_3 E} = \frac{Q^2 L_3}{\cos^2 \theta 2A_3 E} \]

\[ K_{eq} = \frac{Q}{\Delta} = \frac{A_3 E \cos^2 \theta}{L_3} \]

\[ \Delta = \frac{2QL_3}{2A_3 E \cos^2 \theta} \]
Single or multiple open ring frames

- A rectangular open ring with stiff edge members and stiff corner joints

- more flexible in overall shear than a continuous panel because stiffness is derived from its local bending in the edge members

\[ M_{\text{max}} = \frac{Q_1 B}{4} = \frac{Q_2 D}{4} \]
Shear stiffness of single bay symmetric open ring

\[ M_1 = \frac{Q_1 X}{2}; M_2 = \frac{Q_2 Y}{2} = \frac{Q_1 BY}{2D} \]

\[ U_{1/4} = \int_0^{B/2} \frac{M_1^2}{2EI_1} \, dX + \int_0^{D/2} \frac{M_2^2}{2EI_2} \, dY \]

Total Strain Energy = \(4U_{1/4}\)

\[ U = \frac{Q_1^2 B^2}{2} \left( \frac{B}{I_1} + \frac{D}{I_2} \right)/(48E) \]

\[ \Delta = \frac{\partial U}{\partial Q} = \frac{Q_1 B^2}{2} \left( \frac{B}{I_1} + \frac{D}{I_2} \right)/(24E) \]

Shear stiffness, \( K = (24E) / B^2 \left( \frac{B}{I_1} + \frac{D}{I_2} \right) \)
EXAMPLE:
Cross – section beam  100x100x2mm
Width       500mm
Depth       500 mm
Young modulus  210 000 N/mm²
Shear modulus  80 000 N/mm²
Simple structural surface with additional external loads
• some panels experience extra external forces as well as edge loads
  • example: front bulkhead

• panels A & B are purely in complementary shear
In-plane forces in sideframes

- comprises of multiple ring frames
- such frames are statically indeterminate, determination of shear forces and bending moment in each pillar is complicated
- Finite element method can be used to predict those parameters
- or simplified rough estimation can be performed:
  a) Pillar with rigid end joints
\[ M_{\text{max}} = Q \frac{H}{2}, \]

deflection, \[ \Delta = 2 \left( \frac{Q \left( \frac{H}{2} \right)}{3EI} \right) = \frac{QH^3}{12EI} \]

\[ \Delta = \Delta_{\text{pillar1}} = \Delta_{\text{pillar2}} = \Delta_{\text{pillar3}} = \ldots \]

\[ Q_{\text{total}} = (12E\Delta) \sum \frac{I_i}{H_i^3} \]

\[ Qj = Q_{\text{total}} \left( \frac{I_j}{H_j^3} \right) / \left( \sum \left( \frac{I_i}{H_i^3} \right) \right) \]

\[ M_{\text{max}} = QH \]

\[ \Delta = \frac{QH^3}{3EI} \]
c) Mixture of joint conditions

- stiff joints at B- and C- pillars and a poor joint at A-pillar

\[ Q_A = \frac{3EI_A}{H_A^3} \]
\[ Q_B = \frac{12EI_B}{H_B^3} \text{ and } \]
\[ Q_C = \frac{12EI_C}{H_C^3} \]

\[ Q_A = Q_{\text{TOTAL}}(3I_A/H_A^3)/(3I_A/H_A^3 + 12I_{Br}/H_B^3 + 12I_C/H_C^3) \]
\[ Q_B = Q_{\text{TOTAL}}(12I_B/H_B^3)/(3I_A/H_A^3 + 12I_{Br}/H_B^3 + 12I_C/H_C^3) \]
Loads normal to surfaces: floor structures

- floors are subjected to loads normal to their plane
- the floor is stiffened against out-of-plane load by added beam member called a grillage
- a true grillage is a flat frame loaded normal to its plane and the active forces are normal force, bending moment and torsion
- The grillage members consist of:
  a) members integral to the floor panel, e.g. transmission tunnel
  b) added members e.g. separate beams welded onto the floor
  c) bulkhead
Load distributions in floor member

- the share of forces in the different floor members influences the shear force and bending moments in the sideframe

i) Perfect joints
   - the distribution of forces will be in proportion to the stiffness of the members

\[
\Delta = K_1 \frac{L_1^3}{3EI_i} = K_2 \frac{L_2^3}{3EI_2} = K_3 \frac{L_3^3}{3EI_3}
\]

\[
F = 2K_1 + K_2 + K_3 = \left\{ \frac{2I_1}{L_1^3} + \frac{I_3}{L_2^3} + \frac{I_3}{L_3^3} \right\} 3E\Delta
\]

If the lengths of all the limbs are the same

\[
K_i = \frac{I_i}{(2I_1 + I_2 + I_3)} F
\]

\[
K_1 : K_2 : K_3 = \frac{I_1}{L_1^3} : \frac{I_2}{L_2^3} : \frac{I_3}{L_3^3}
\]
Effect of joints flexibility on load distribution

• the joints between the members has great influence on load distribution

• Example: transmission tunnel is continuous and cross-member is attached to it

• The effect was if F is loaded to the central joint, all the load will transfer along the tunnel. However, seat loads applied part-way along the tunnel and the rocker panels

• Corrective measures:
7.4.4 Swages and corrugations

The out-of-plane stiffness of a thin panel may be increased locally by swages (i.e., impressed grooves). In effect, this entails the local addition of ‘beams’ to the panel, increasing its ‘apparent depth’. If the swages merge together as a series of adjacent members, then the panel is referred to as ‘corrugated’.

Basic properties of individual swages (see Figure 7.33):

(a) Swages only increase the bending stiffness of the panel about the axis transverse to the swage.
(b) Bending stiffness is negligible about the axis parallel to the swage.
(c) The out-of-plane panel load will be transferred along the swages to their ends by local bending.
(d) The in-plane membrane stiffness of the swaged panel is negligible in the direction normal to the swage. This is because such loading causes local bending of the sheet about an in-plane axis due to the offset of the panel load from the top of the swage.
(e) For greatest transverse stiffness of the panel, the swages should run across the shortest width of the panel.
(f) Where two swages cross each other, the bending stiffness of both swages is reduced locally. This should be avoided where possible.
(g) A local flat area of sheet metal, between the end of the swage and the supporting floor beam, leads to high local transverse shear flexibility, and can significantly reduce the overall stiffening effect of the swage.