CE 388 – FUNDAMENTALS OF STEEL DESIGN

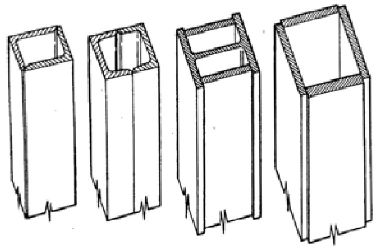
CHAPTER 3B: BUILT-UP COLUMNS

Types of Built-up Columns

- For heavy loads where common rolled shapes are not available, it becomes necessary to use built-up sections
- Types of built-up columns:
  - Solid wall section built-up columns
  - Open section built-up columns

Types of Built-up Columns

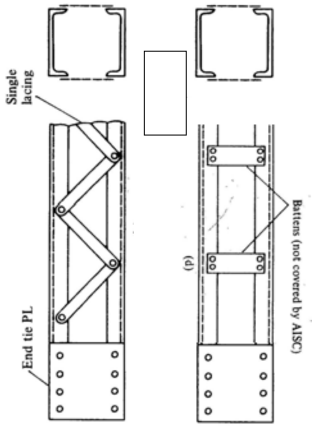
- Solid wall section built-up columns:
  - These columns are made up by welding several rolled shapes together
  - Such columns are analyzed as single structural shapes



Solid wall section built-up columns

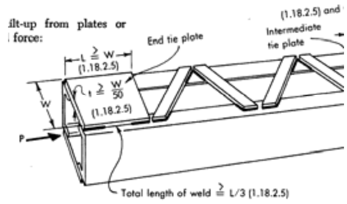
Types of Built-up Columns

- Open section built-up columns (latticed columns):
  - These columns are made up such that rolled shapes are connected together by laces (diagonals) and battens (horizontal ties) across their open side



Open section built-up columns

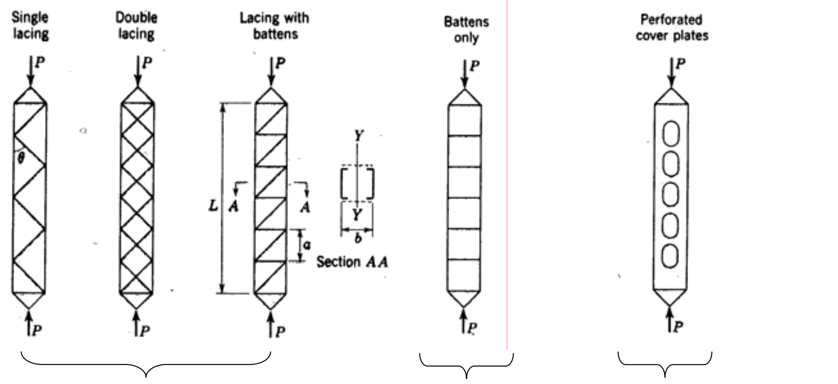
Types of Built-up Columns



Examples of open section built-up columns

Types of Built-up Columns

- The types of open section built-up columns:

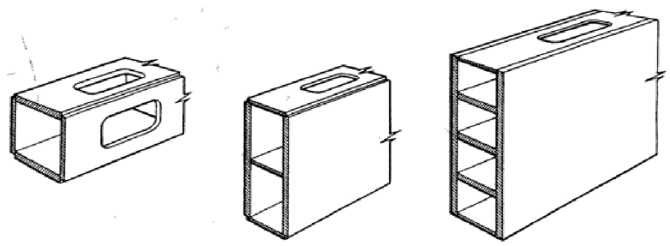


Laced columns

Battened columns

Columns with perforated cover plates

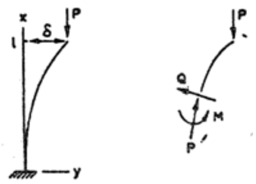
Types of Built-up Columns



Columns with perforated cover plates

Theoretical Aspects

- When buckling occurs, there will be shearing forces (Q) acting on the cross-section of the column
- If shear forces are included in the analysis, the critical buckling load:



Buckled column with shear forces

$$P_{cr} = \frac{P_e}{1 + \frac{nP_e}{AG}}$$

Euler buckling load ($\pi^2 EI/\lambda^2$) without considering shear effect

Shape factor

Cross-sectional area

Shear modulus

Theoretical Aspects

$$P_{cr} = P_e \cdot \frac{1}{1+\dfrac{nP_e}{AG}} = P_e.r \quad \leftarrow r$$

- The presence of shear reduces the critical load in the ratio "r"
  - For solid columns:
    - ✓ r ≅ 1.0 ($P_{cr} \cong P_e$, the effect of shearing forces can be neglected)
  - For open built-up sections:
    - ✓ r < 1.0 ($P_{cr} < P_e$, it is necessary to consider the effect of shear in the buckling analysis)

Theoretical Aspects

- Laced Columns:

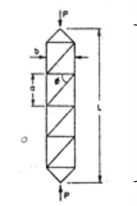


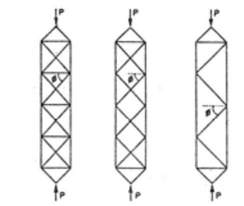
Fig. III. 13 Laced column

Euler buckling load without shear effect

$$P_{cr} = \frac{P_e}{1 + P_e\left(\dfrac{1}{A_d E Sin\phi Cos^2\phi} + \dfrac{b}{aA_b E}\right)}$$

Total cross-sectional area of the diagonals

Total cross-sectional area of battens

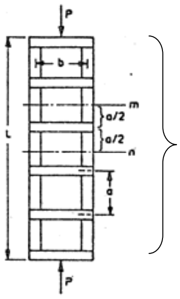


Lacing with battens (a) Double lacing (b) Single lacing (c)

$$P_{cr} = \frac{P_e}{1 + P_e \dfrac{1}{A_d E Sin\phi Cos^2\phi}}$$

Theoretical Aspects

- Battened Columns:



Euler buckling load without shear effect

$$P_{cr} = \frac{P_e}{1 + P_e\left(\frac{ab}{12EI_b} + \frac{a^2}{24EI_c} + \frac{na}{bA_bG}\right)}$$

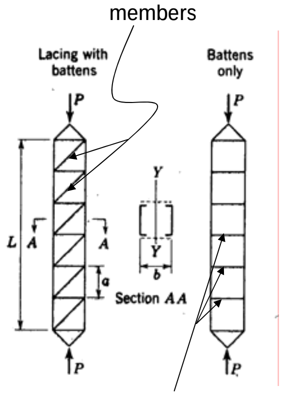
Moment of ineartia of one batten

Moment of inertia of one rolled section

Theoretical Aspects

- Results derived from the expressions:
  - Laces and battens show their effects in the form of an expression in the denominator of the critical load formula
  - Laces are assumed to work as axially loaded bars with stiffness A_dE
  - Battens work as beams with a stiffness EI_b
  - Infinitely stiff laces and battens imply that the built-up column will work as a solid column

laces as truss members



battens as beam members

Failure Modes of Built-up Columns

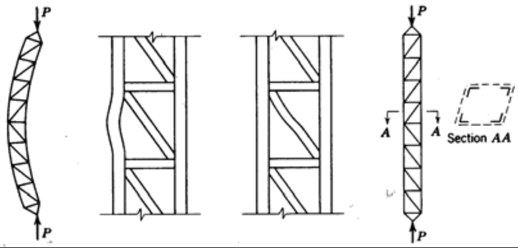
- Failure Modes of a Built-up Column:

  (a) Buckling of the column as a whole under axial load

  (b) Buckling or yielding of individual segments of the column

  (c) Failure of a lattice member

  (d) Distortion of the cross-section



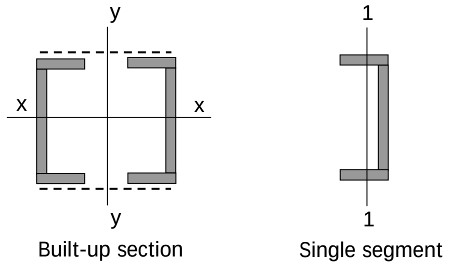
(a) (b) (c) (d)

Built-up Column Analysis According to TS648

- The use of theoretical equations derived previously is impractical for engineers
- The codes use an approximate approach, where the effect of shear is taken into account by ***increasing the slenderness ratio (λ)*** of a built-up column
- Depending on the open direction of the column, slenderness ratio is increased in that particular direction

Built-up Column Analysis According to TS648

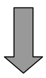
- The notation used in the analysis:



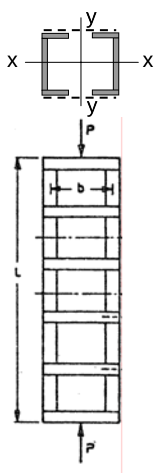
	Built-up section	Single segment
Principal axes	x-x, y-y	1-1 (minimum)
Cross-sectional area	F	F_1
Moment of inertia	I_x, I_y	I_1

Built-up Column Analysis According to TS648

- λ_x : slenderness ratio of the built-up column about x-axis, $\lambda_x = K_xL/i_x$
- λ_y : slenderness ratio of the built-up column about y-axis, $\lambda_y = K_yL/i_y$

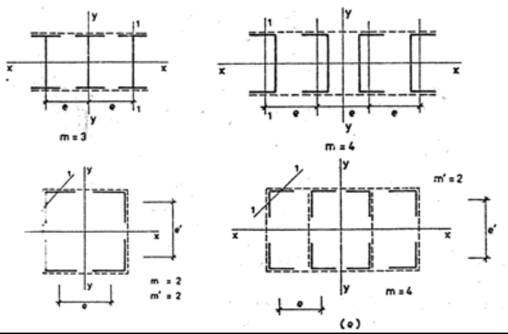


- λ_{xi} : increased slenderness ratio of the built-up column about x-axis
- λ_{yi} : increased slenderness ratio of the built-up column about y-axis



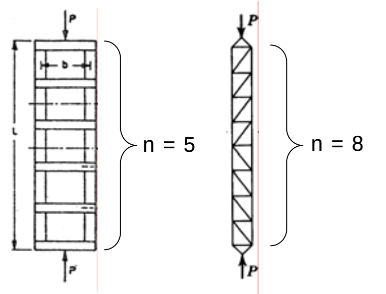
Built-up Column Analysis According to TS648

- m : the number of main segments in x-direction (connected by cross-ties to form a built-up section)
- m' : the number of main segments in y-direction (connected by cross-ties to form a built-up section)



Built-up Column Analysis According to TS648

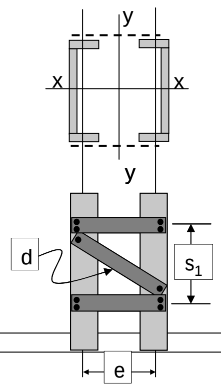
n : the number of spans into which the built-up column is divided by battens



e : distance between centroidal axis of the main segments

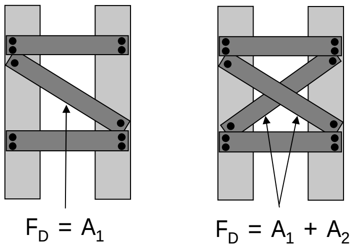
s_1: maximum spacing between battens

d : length of lacing (diagonal)



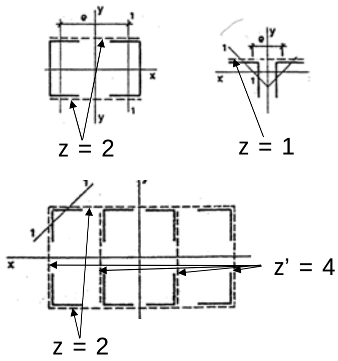
Built-up Column Analysis According to TS648

F_D : the cross-sectional area of a single diagonal (single lacing). It is summation of the cross sectional areas of two diagonals (double lacing).



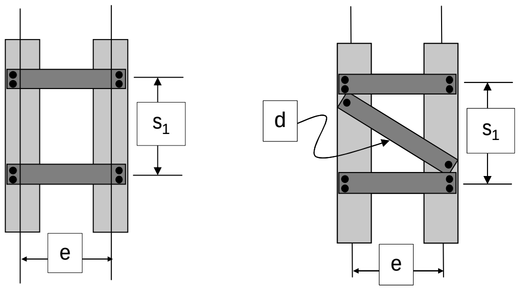
Single lacing Double lacing

z : the number of paralel planes with cross-ties



Built-up Column Analysis According to TS648

λ_1 : auxiliary value



$$\lambda_1 = \frac{s_1}{i_1}$$

Battened column

$$\lambda_1 = \pi \sqrt{\frac{F\, d^3}{z F_D\, s_1\, e^2}}$$

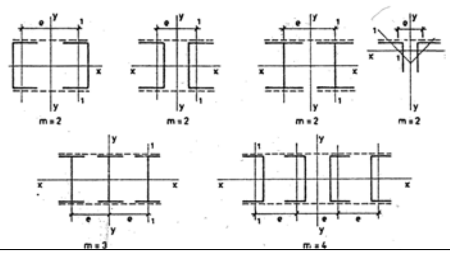
For columns with battens and laces

Built-up Column Analysis According to TS648

- For design and analysis, the built-up columns are divided into three groups:
  - Group 1 Built-up Columns
  - Group 2 Built-up Columns
  - Group 3 Built-up Columns

Built-up Column Analysis According to TS648

- Group 1:
  - x-x axis intersects all the segments (x-x is the material axis
  - Column is a close section normal to x-axis, an open section normal to y-axis



Group 1 built-up columns

Built-up Column Analysis According to TS648

- Buckling about x-axis (solid section):
  - No increase in slenderness ratio ($\lambda_{xi} = \lambda_x$)
  - Calculate λ_x,

$$\lambda_x = \frac{K_x L}{i_x}$$

  - Find buckling coefficient w_x for λ_x from the table

- Buckling about y-axis (open section):
  - Increase in slenderness ratio ($\lambda_{yi} > \lambda_y$)
  - Calculate λ_{yi},

$$\lambda_{yi} = \sqrt{\lambda_y^2 + \frac{m}{2}\lambda_1^2}$$

$$\lambda_y = \frac{K_y L}{i_y}$$

  - Find buckling coefficient w_{yi} for λ_{yi} from the table

Built-up Column Analysis According to TS648

- Determine buckling strength:
  - Determine critical buckling coefficient,

$$w_{cri} = \text{larger of } (w_x, w_{yi})$$

  - Calculate σ_{bem},

$$\sigma_{bem} = \frac{\sigma_{çem}}{w_{cri}}$$

  - Calculate P_{all},

$$P_{all} = \sigma_{bem} F$$

Cross-sectional area of the built-up column

Built-up Column Analysis According to TS648

- For buildings, we have the following restriction:

$$\lambda_1 \leq \frac{1}{2}\lambda_x (4 - \frac{3w_{yi}P}{F\sigma_{çem}})$$

If $\lambda_x/2 \leq 50$

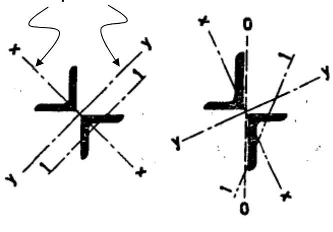
If, the following conditions are satisfied,
- $n \geq 3$
- batten spacings are equal
- battens are connected to main segments by at least two fasteners and comparable welding

then $\lambda_x/2 = 50$

Built-up Column Analysis According to TS648

- Group 2:
  - They are made up of two angles whose corners are arranged back to back
  - For these columns, no matter the segments are equal or unequal leg angles, buckling about x-x is more critical

principal axes for built-up column

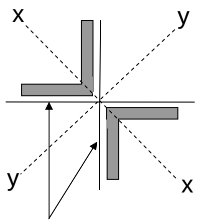


Group 2 built-up column

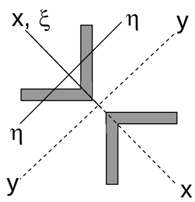
Built-up Column Analysis According to TS648

- Buckling about x-axis (solid section):
  - No increase in slenderness ratio ($\lambda_{xi} = \lambda_x$)
  - Calculate λ_x, $\lambda_x = \dfrac{K_x L}{i_x}$

$$K_x = \frac{1}{2}\left(K_{plane} + K_{out\ of\ plane}\right)$$

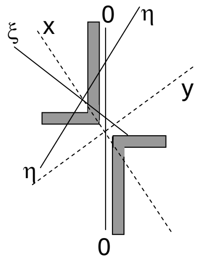


plane and out of plane for calculation of effective length factor



$$i_x = i_\xi$$

Equal leg



$$i_x = \frac{i_0}{1.15}$$

Unequal leg

Built-up Column Analysis According to TS648

- Determine buckling strength:
  - Find buckling coefficient w_x for λ_x from the table
  - Calculate σ_{bem},

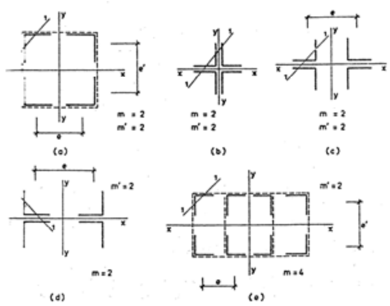
$$\sigma_{bem} = \frac{\sigma_{çem}}{w_x}$$

- Additional restriction:

$$\lambda_1 \leq 50$$

Built-up Column Analysis According to TS648

- Group 3:
  - They are built-up columns with no material axis
  - Column is an open section both normal to x and y-axes



Group 3 built-up columns

Built-up Column Analysis According to TS648

- Buckling about x-axis (open section):
  - Increase in slenderness ratio ($\lambda_{xi} > \lambda_x$)
  - Calculate λ_{xi},

$$\lambda_{xi} = \sqrt{\lambda_x^2 + \frac{m'}{2}\lambda_{1x}^2}$$

$$\lambda_x = \frac{K_x L}{i_x}$$

  - Find buckling coefficient w_{xi} for λ_{xi} from the table

- Buckling about y-axis (open section):
  - Increase in slenderness ratio ($\lambda_{yi} > \lambda_y$)
  - Calculate λ_{yi},

$$\lambda_{yi} = \sqrt{\lambda_y^2 + \frac{m}{2}\lambda_{1y}^2}$$

$$\lambda_y = \frac{K_y L}{i_y}$$

  - Find buckling coefficient w_{yi} for λ_{yi} from the table

Built-up Column Analysis According to TS648

- Determine buckling strength:
  - Determine critical buckling coefficient,

$$w_{cri} = \text{larger of } (w_x, w_{yi})$$

  - Calculate σ_{bem},

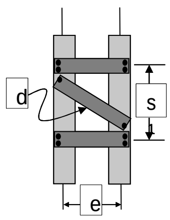
$$\sigma_{bem} = \frac{\sigma_{çem}}{w_{cri}}$$

- For buildings we have the restriction:

$$\lambda_{1x} \le 50 \quad \text{and} \quad \lambda_{1y} \le 50$$

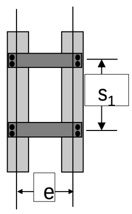
Design of Battens / Diagonals

- Battens and lacings are designed based on an assumed shearing force Q_i:
  - For laced columns



$$Q_i = \frac{F\sigma_{çem}}{80}$$

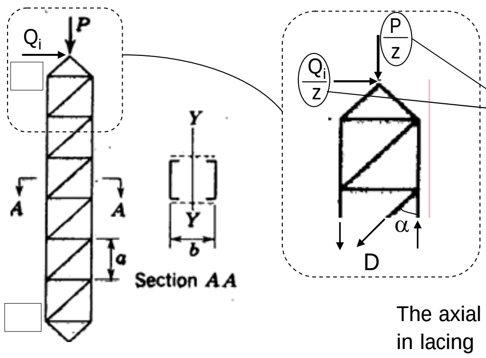
  - For columns with battens only



$$Q_i = \begin{cases} \dfrac{F\sigma_{çem}}{80} & \text{if } e \le 20 i_1 \\ \dfrac{F\sigma_{çem}}{80}\left\{1 + \dfrac{5}{100}\left(\dfrac{e}{i_1} - 20\right)\right\} & \text{if } e > 20 i_1 \end{cases}$$

Design of Battens / Diagonals

- In case of laced columns, the axial force in the diagonals can be found assuming that the whole system behaves as a truss.



z: the number of paralel planes with cross-ties

Axial and shear forces carried by each paralel plane

$$\sum F_x = 0$$

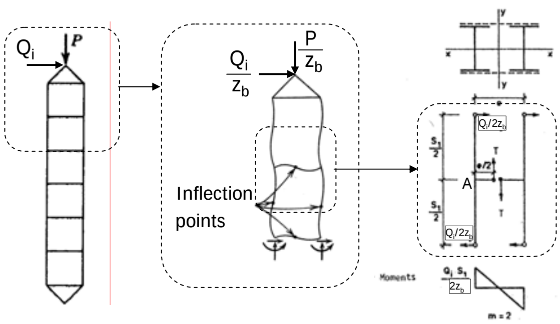
$$\frac{Q_i}{z} = DSin\alpha$$

The axial force in lacing

$$D = \frac{Q_i}{zSin\alpha}$$

Design of Battens / Diagonals

- In case of battened columns, each member acts as a beam member.
- The forces in battens are obtained by estimating points of inflection points and writing moment equilibriums.



z_b: the number of paralel planes with battens

$$\sum M_A = 0$$

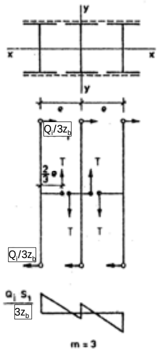
$$T.\frac{e}{2} = 2.\frac{Q_i}{2z_b}.\frac{s_1}{2}$$

$$T = \frac{Q_i s_1}{z_b e}$$

The force carried by one batten

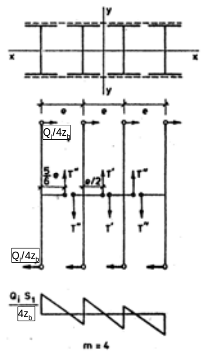
Design of Battens/Diagonals

- For sections with m=3:



$$T = \frac{0.5Q_i s_1}{z_b e}$$

- For sections with m=4:



$$T' = \frac{0.40Q_i s_1}{z_b e} \qquad T'' = \frac{0.30Q_i s_1}{z_b e}$$

Design of Built-up Columns

Example Problems