Lecture no. 13:

REINFORCED CONCRETE WALLS, WALL SYSTEMS, TIE-BEAMS, LOCAL COMPRESSION
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Introduction, definition of walls

Walls are planar structures loaded in their plane, lying in general in vertical plane. Difference between columns and walls can be given geometrically by the condition:

\[
\text{length of the horizontal cross-section of walls} \geq 4t
\]
1. Constructional rules

\[ t \geq 8 \text{ cm} \]

if \( t < 100 \text{ mm} \): one-layer reinforcement possible
if \( t > 200 \text{ mm} \): two-layer reinforcement necessary

\[ s \leq \min(3t, 400 \text{ mm}) \]

\[ s_{\text{horizontal}} \leq 400 \text{ mm} \]

S-hooks: 4 pcs/m²

\[ \rho_{\text{min}} = 0.3\% \quad \rho_{\text{max}} = 4\% \quad A_{s,\text{horizontal}} \geq 0.25 \ A_{s,\text{vertical}} \]
2. Resistance to axial compression

\[ N_R = \varphi N_u \]

\[ N'_u = A_c f_{cd} + A_s f_{yd} \]

\[ \varphi = f \left( \frac{l_o}{h} \right)_{nax} \] tabulated in the design aids

here in general \( l_o = m \) = storey height, or in plane of the multistorey wall: \( l_o = 1,2H \), where \( H \) is the overall height of the wall
3. Resistance to eccentric compression

Two possibilities:
1. Only part of the wall section, concentric to the eccentric compression force is working, which is to be handled as subjected to axial compression (see above)
2. The wall section is handled like a column section, but the length of the part $l_s$ subjected to tension is estimated – and corrected later if necessary

Check of steel stress ($x_c \leq x_{cc}$ or reduction of steel stress necessary)

Correction of $l_s$ if necessary $l_s$
4. Design of the wall reinforcement for shear

Numerical analysis of the wall disc results in shear stress distribution $\tau$:

$$\tau dxt = \tau st = A_s f_{yd}$$

If $dx = s$ (spacing of the reinf.)

$$\rightarrow A_s = \frac{\tau st}{f_{yd}} \quad \text{(one bar)}$$

$$a_s = \frac{\tau 1000 t}{f_{yd}} \quad \text{(mm}^2\text{/m)}$$
5. Shear connection between columns and walls and between walls concreted in two different construction phases

If – due to formwork placing technology used – construction of T-joints of rc walls is made in two different construction phases, U-bars to improve shear connection are placed in metal plate sheathing in the the wall concreted first, and then bent to horizontal position before the 2nd phase of construction.
6. Reinforcement details of rc walls

Horizontal section of corner and T-joints of monolithic rc walls – constructed in the same phase, showing the correct detailing of the interconnecting bars: the bars can not be bent at the internal corner, because when subjected to tension they would split the concrete there.
Reinforcement system of an rc wall section at ground floor level showing doublesided welded meshes H1 with transverse overlap of 250 mm (the vertical overlap is 350 mm) and elements of the column-like reinforcement at the wall extremities. Hooks no. 2 are interconnecting the the two reinforcement layers.
7. Stiffening wall systems
-ways of bracing
-rigidity of sheared-walls and bracing frames
-stiffening wall systems

Beside solid sheared-walls, bracing of buildings can be assured by use of

diagonals (Andrew-crosses, characteristic for steel constructions)

- rigid frames
- frame filling walls

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The effectiveness of elements of the rc bracing system of multistorey buildings is very much depending from the level of being broken through

Displacement rigidity $k$: the magnitude of a horizontal force causing unit displacement at top

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Straight bracing walls have negligible rigidity in direction perpendicular to their plane. Consequently, the bracing wall system should have minimum three members, because any planar force system can be equilibrated by three forces acting in the plane, if they are not lying along one line and the do not intersect each other in one point.

The effectiveness of the bracing wall system can be increased by
- symmetric arrangement of the walls
- placing the walls near the contour of the building

If the number of bracing walls is greater than 3, as a safe approximation, the three most rigid bracing walls can be considered by checking the system.

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8. Distribution of horizontal loads between elements of the wall system

C: center of rigidities

Bracing walls: 1 to 8

Resultant of wind forces: \( R_y \) and \( R_x \)
In the plane of the bracing wall units: \[ k = \frac{3EI}{H^3} \]

As \( E = E_{c,\text{eff}} = \text{const. and } H = \text{const} \), rigidity of the wall units is proportional to \( l = \frac{th^3}{12} \).

Position of the center of rigidities (C):

\[
\begin{align*}
    x_0 &= \frac{\Sigma (I_{x_i} x_i)}{\Sigma I_{x_i}} \\
    y_0 &= \frac{\Sigma (I_{y_j} y_j)}{\Sigma I_{y_j}}
\end{align*}
\]

The polar inertia \( I_\omega \) of the rigidities with respect to the center C:

\[
I_\omega = \Sigma (I_{yi} r_{yi}^2) + \Sigma (I_{xj} r_{xj}^2) \quad i = 1, 2, \ldots, n \text{ for walls in } x - \text{direction} \\
\quad j = 1, 2, \ldots, m \text{ for walls in } y - \text{direction} \\
\quad r : \text{is the perpendicular distance of the wall unit from the center of rigidities}
\]
Moments of the wind load resultants with respect to C:

\[ R_x e_{yo} \quad \text{where:} \quad R_x = q_{wx,d} H L_y \quad \text{and} \quad e_{yo} = 0,5L_y - y_o \]

and \( R_y e_{xo} \quad \text{where:} \quad R_y = q_{wy,d} H L_x \quad \text{and} \quad e_{xo} = 0,5L_x - x_o \)

\( q_{wx,d} \) and \( q_{wy,d} \) are the design value of the wind load in x- and y-directions respectively (sum of wind pressure and suction) in kN/m\(^2\)

The forces absorbed by the bracing walls in x and y-directions:

From \( R_x \) in walls in x –direction:

\[ S_{xi}^{R_x} = R_x \left( \frac{I_{yi}}{\Sigma I_{yi}} + e_{yo} \frac{r_{yi}I_{yi}}{I_\omega} \right) \quad i = 1,2,\ldots,n \]

From \( R_x \) in walls in y-direction:

\[ S_{xj}^{R_x} = R_x e_{yo} \frac{r_{xj}I_{xj}}{I_\omega} \quad j = 1,2,\ldots,m \]
9. Determination of the design eccentricity of the compression force in walls

\[ e = e_e + e_i + e_2 \]

\[ e_e = \frac{M_{Ed}}{N_{Ed}} \]

\( e_i \) can be substituted by the effect of an additional horizontal force \( H_i \):

\[ H_i = \theta_i (N_b - N_a) \]

\[ \theta_i = \alpha_n \alpha_m \theta_o \]

\[ \alpha_n = \frac{2}{\sqrt{l}} \geq \frac{2}{3} \]

\[ \alpha_m = \sqrt{0.5(1+1/m)} \]

\[ \theta_o = \frac{1}{200} \]

where \( l \) is the height of the wall in m, \( m \) is the number of parallel bracing walls
$e_2/d$ is tabulated in the design aids in function of the slenderness ratio $\ell_0/d$ of the wall in the plane under consideration:

Equilibration of the eccentric force at basement level can be done as detailed in point 3.
10. Tie-beams

They are designed for better distribution of loads and effects, in extreme cases to prevent progressive collapse by providing alternative load paths after local damage.
- Peripheral and internal ties at floor levels
- Vertical ties where required

Independent ties for diff. dilatation joints
They work generally in tension
Min. reinforcement: 4\(\phi10\) long. bars +\(\phi8/200\) links

Functions of tie beams:
- absorb tension due to thermal expansion, uneven settlement, damage of the structure
- partial restraint of prefabricated floor beams
- distribution of concentrated loads
- lintel above openings with additional steel
Column ties 4 cm$^2$/column
Corner columns should be tied in two directions
11. Local compression

Due to the spatial stress state, the capacity force can be determined from the expression:

\[ F_{Rd} = A_{c0} \alpha f_{cd} \]

where \( \alpha = \min \left\{ \sqrt{\frac{A_{c1}}{A_{c0}}} \right\} \)

\[ x_1 - x_0 \leq h \text{ and } y_1 - y_0 \leq h \]

(The spreading angle is maximum 45 degrees)
In case of several spot-like loaded areas, the areas $A_{c1}$ can not intersect each other.

The diagonal spreading of compression stresses may split the concrete in vertical plane, which should be impeded by horizontal reinforcement designed for:

$$T = \frac{1}{4} \left(1 - \frac{a}{b}\right) F$$

and distributed between 0,3$h$ to 0,9$h$ depth.