

Informational Brochure

Izodom 2000 Polska



Design of structures for earthquake resistance

No9

According to Eurocode 8:
Design of structures for earthquake resistance - Part 1:
General rules, seismic actions and rules for buildings



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ANNEX to

1. Guidelines for calculating and constructing walls in the IZODOM 2000 POLSKA SYSTEM
2. Guidelines for calculating and constructing ceilings in the IZODOM 2000 POLSKA SYSTEM

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Related standards

[C1] PN-EN 1990:2004	Eurocode 0: Basis of structural design
[C2] PN-EN 1991-1-1:2004	Eurocode 1: Actions on structures - Part 1-1 : General actions - Densities, self-weight, imposed loads for buildings
[C3] PN-EN 1992-1-1:2008	Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings
[C4] PN-EN 1992-1-2:2008	Eurocode 2: Design of concrete structures - Part 1-2: General rules – Structural fire design
[C5] EN 1998-1:2004	Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings

General Information

In seismic areas the risk of seismic load should be taken into consideration already at the stage of developing the concept for a building, allowing one to design a structural system which, at an acceptable cost, meets basic requirements as contained in **2.1 PN-EN 1998-1-1**.

In developing a building's structural concept one should keep in mind the following:

- simplicity of the structural design;
- the uniformity, symmetry and hyperstatics (stiffening) of the whole system;
- two-directional strength and rigidity;
- torsional strength and rigidity;
- the work of ceilings as a skirt;
- appropriate foundations.

The IZODOM system makes it easy to meet all the above conditions. The walls and ceilings of reinforced concrete form a rigid three-dimensional spatial arrangement, capable of transferring seismic loads.

Buildings made of concrete are designed in accordance with PN-EN 1992-1-1:2004. The following rules should be seen as complementary to the general rules contained in the standard PN-EN 1992-1-1:2004 and documents [1] and [2].

I. Conditions for the structure layout design

Shaping the structure of the building one must take into account lateral rigidity and weight distribution. The design should be approximately symmetrical in respect of the two orthogonal axes of the coordinates system.

The layout design should be compact; the outline of the storeys should form a convex polygon. This condition may be considered met even in the event of a withdrawal of the elevation line (e.g., concave corners or recesses), if these indentations do not affect the rigidity of the floor plan or the area of any of them (calculated to the contracted convex line limiting the contour of the building) and does not exceed 5% of the storey's surface area.

The slenderness of the building in plan $\lambda = L_{max}/L_{min}$ should not exceed the value of 4 where L_{max} and L_{min} are respectively a larger and smaller dimension of the building in plan, measured along the perpendicular axes.

In each level of the building, in an analysis in both x and y directions, the value of structural eccentricity e_o and torsional radius r must satisfy two conditions, that for an analysis in the plane y may be defined as:

$$\begin{aligned}e_{ox} &\leq 0.30 r_x \\ r_x &\geq I_s\end{aligned}$$

where:

- e_{ox} is the distance between the centre of rigidity and the centre of gravity, measured along direction x, normal for the analysed direction y;
- r_x is the square root of the quotient of torsional rigidity and transverse rigidity in direction y (torsional radius);

- I_s is the radius of rotation of the ceiling mass as projected (the square root of the quotient of the polar moment of inertia of the ceiling mass as projected with respect to the centre of gravity of the floor mass, and the weight of the ceilings).

In single-storey buildings, the centre of rigidity can be defined as the centre of transverse rigidity of all the elements involved in the transfer of seismic loads. However, the torsional radius r is defined as the square root of the ratio of global torsional rigidity relative to the centre of transverse rigidity to the global transverse rigidity in one direction, taking into account all seismic load bearing elements in a given direction.

Definitions of the centre of rigidity and torsional radius can only be approximated in multi-storey buildings. These simplified values, serving to classify the regularity of the construction's layouts and an approximate analysis of their behaviour in torsion, can be defined when meeting two conditions:

- a) all systems transversely bracing the structure, such as cores, walls or frames run without interruption from the foundations to the top of the building;
- b) individual bracing elements have a similar form of deformation under a transverse load. This condition may be considered met in the case of framework and wall systems. In general, this condition is not met by mixed systems.

In case of frames and slender walls, dominated by flexural deformations, the position of the centre of rigidity and torsional radius of all storeys can be calculated as for the moments of inertia of the transverse cross sections of vertical elements. If in addition to flexural deformation there is a significant degree of deformation by shearing, these values can be determined by introducing the equivalent moment of inertia of the cross-section.

II. Requirements with regard to materials

It is permitted to use Class B or C ribbed steel in accordance with the standard EN 1992-1-1:2004 [C3], Table C.1 and C.2N. This applies to vertical and horizontal longitudinal rods, as well as loops and stirrups.

Reinforcement in the form of bonded reinforcement meshes can also be used where the conditions described above are met.

In all structural elements class C20/25 to C40/50 concrete should be used.

III. Requirements for walls

All walls should be designed as reinforced concrete walls.

The vertical reinforcement required should be taken into account in calculating the load-bearing strength of walls due to bending and slenderness. For this one can use the nomographs quoted in [1], developed for walls with various transverse cross-sections, degrees of longitudinal reinforcement and slenderness, with axial force loads and a bending moment.

Note: In walls involved in the transfer of seismic loads, the value of the axial force

$$v_d = N_{Ed} / (A_c f_{cd})$$

should not exceed 0.4.

Vertical reinforcement should be connected at both wall surfaces by means of horizontal rods with a minimum diameter of #8 mm, arranged in each layer of hollow blocks (every 250mm). The two subsurface reinforcement meshes thus created should be joined using # 8mm diameter fasteners, using a minimum of 4 to every 1m² of wall surface. In the corners of walls and at the edges of apertures in walls, horizontal rods should be shaped in the form of open stirrups in the shape of the letter "U" (see Fig. K1 and K4 [1]).

With the assumption of a partial anchoring of ceilings in walls, wall reinforcement in the ceiling support area is to be used according to Fig. K9 [1].

Single channels may be made in the wall, but only around a single wall core and provided continuity of the horizontal reinforcement is maintained (Fig. K12 [1]). At the edges of apertures, one should place in the extreme wall cores adjoining them at least two #10mm rods, connected to each other by means of # 8mm stirrups in each layer of blocks.

Adequate susceptibility to curvature should be ensured in critical areas of walls. Strengthening (constraint) should be introduced in the vertical at the height of the critical area h_{cr} and in the horizontal cross-section at length l_c .

The height of the critical area h_{cr} , calculated from the base of the wall, can be estimated as:

$$h_{cr} = \max [l_w; h_w/\delta]$$

but

$$h_{cr} \leq 2l_w$$

$$h_{cr} \leq h_s \quad \text{for } n \leq 6 \text{ of the storey}$$

where

- l_w is the length of the wall;
- h_s is the clear height of the storey, where the base of the wall may be taken as the level of the foundation or the basement storey, as long as this has a rigid floor and perimeter walls;
- h_w is the height of the beam.

Length l_c is measured from the extreme most compressed fibre up to the end of the area where unconstrained concrete can chip off due to large compression deformations. The dimension of the reinforced edge section l_c (Fig.1) should not be less than $0.15l_w$ and $1.50b_w$.

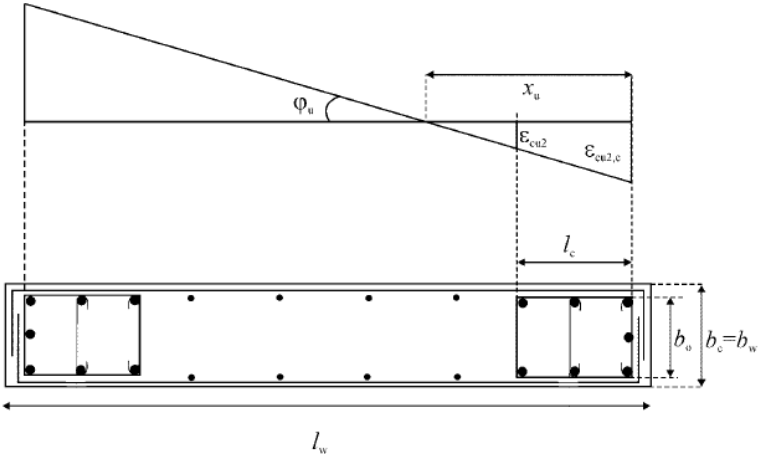


Figure 1. Reinforced edge sections closing the free ends of the walls

(top: deformation and curvature limit, bottom: cross-section of the wall) [EN 1998-1 [C5]]

The degree of longitudinal reinforcement of the cross-section of the edge sections should not be less than 0.005.

The reinforcement required and permissible axial force are given in Table 1

Table 1 Reinforcement required and the permissible axial force in the edge area of the wall's cross-section

Nominal wall thickness b_w [m]	Minimum A_s mm^2/m	Minimum length l_c as $1.5 b_w$ mm	The axial force should not exceed: [kN/m]		
			C20/25	C30/37	C40/50
0.15	750	225	746	1120	1493
0.20	1000	300	1013	1520	2026
0.40	2000	600	2080	3120	4160

Horizontal and vertical reinforcement (tie beams) should be introduced continuously through all the walls, connections with perpendicular walls and around apertures in the wall. Reinforcement should at least satisfy the conditions contained in standard PN-EN 1992-1-1 [C3], section 9.10 Tying systems.

Closed stirrups should be used in these areas. Each of the longitudinal rods should be caught up by the corner of the stirrup or by using additional connection clips (Fig. 1).

The spacing between stirrups s (in millimetres) should not exceed:

$$s = \min \{b_0/2; 175; 8d_{bl}\}$$

where

- b_0 is the smallest dimension of the concrete core, calculated to the central line of the stirrups,
- d_{bl} is the smallest diameter of the longitudinal rods.

The distance between successive longitudinal rods held in place by the stirrups or additional connectors should not exceed 200 mm, in accordance with the requirements [C3].

IV. Requirements for ceilings

Ceilings in the IZODOM 2000 POLSKA system have been designed as monolithic, densely-ribbed units. Ceilings are filled with Styrofoam hollow blocks (Fig. 2), designed for rib spacing equal to 0.75 m

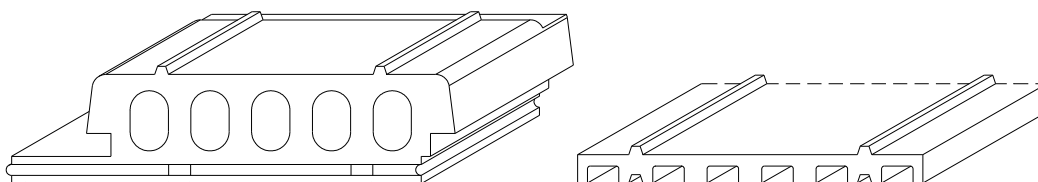
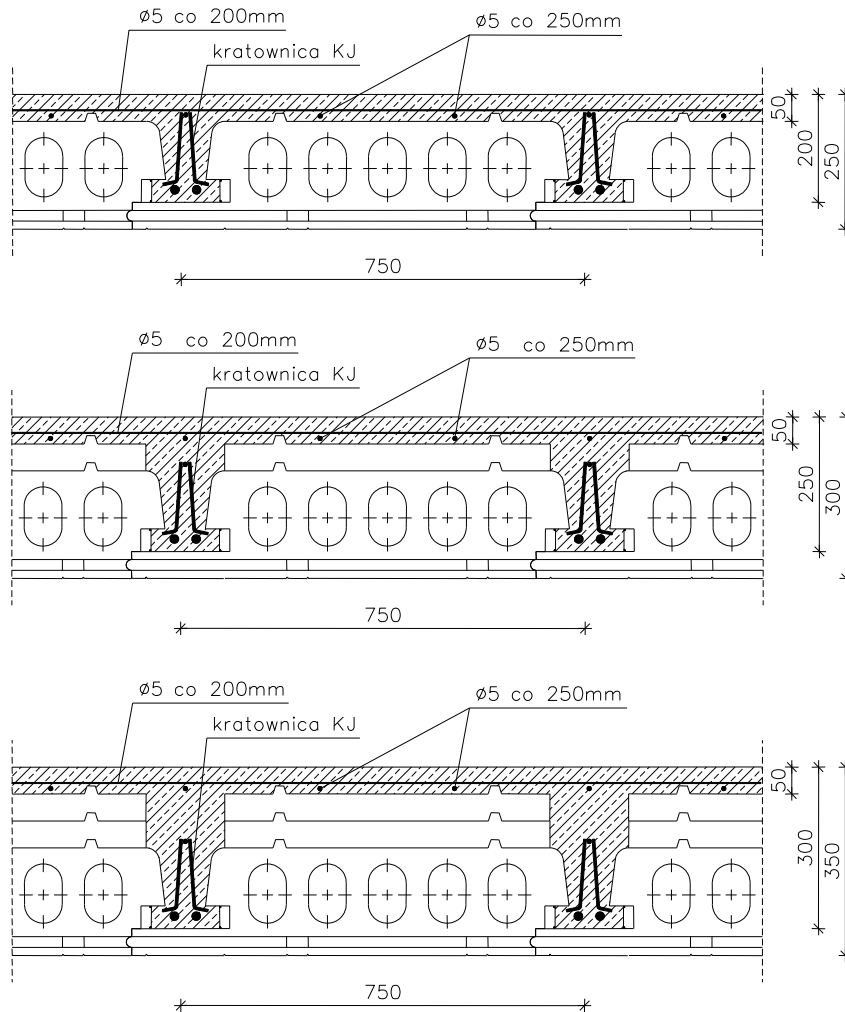


Figure 2. Ceiling type hollow block and cap in the IZODOM 2000 POLSKA system [2]

Thanks to this configuration of hollow blocks, very good thermal insulation of the ceiling is obtained. This is important when building ceilings above an unheated basement or beneath a periodically unused attic – in such a case the ceiling does not need an extra layer of insulation.



kratownica = grating

Figure 3. Cross-section of IZODOM ceilings of varying design heights [2], in seismic regions, the ceiling's shelf of tee ribs requires stronger reinforcement - the #5 and #6 rods should be replaced by a grid of #8 rods every 150mm in both directions

The thickness of the concrete layer over the hollow blocks amounts to 50 mm, which ensures the ceiling high rigidity and R30 fire resistance [C4].

With a hollow block height of 200mm and a reinforced concrete slab thickness of 50mm, the ceiling has an overall height of 250mm and a structural height of 200mm. The system provides for 50mm high flat Styrofoam caps, formed with longitudinal through channels (Fig. 2). These caps make it possible to increase the ceiling's structural height to 250 and 300 mm (Figure 3).

So-called locking sections are featured in these hollow blocks and caps, which facilitate stacking of the elements, stabilize their position relative to each other, and improve the thermal insulation of the whole partition. The fusion of the Styrofoam elements obtained in this way ensures their stability during the pouring of the concrete.

The main reinforcement of the ceiling ribs constitutes KJ gratings, factory-made as welded frames (Fig. 4) using RB500W steel rods with a characteristic strength of $f_{yk}=500\text{MPa}$. The lower gratings type reinforcement is designed for the distribution of bending moments by a shortening of No.2 and No.3 rods.

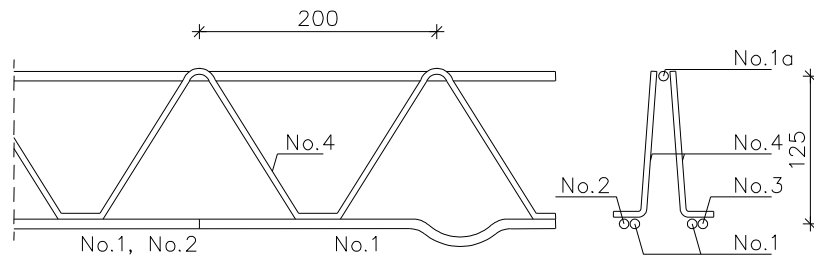


Figure 4. Welded steel grating KJ

KJ gratings are supplied by the manufacturer together with the ceiling's polystyrene elements.

If instead of using KJ prefabricated gratings, one uses rib reinforcing frames made directly on site, all rods (Nos. 1, 2 and 3, Figure 4) should be the same length, and should be anchored on supports. In this case, the shearing reinforcement used should be closed stirrups with a diameter of 6mm. Stirrups should be adapted to the calculated height of the rib - 200, 250 or 300 mm (Fig. 5).

If the ribs have two or more spans, additional upper and lower connecting reinforcements must be used on the internal supports. This reinforcement should be equal to the lower cross-section reinforcement used in the middle of the span.

All shearing moments and forces are specified for a class of concrete not lower than C20/25 and class B or C longitudinal and transverse steel reinforcement with a characteristic strength of $f_{yk} \geq 500\text{MPa}$ [2]. These calculations were made in accordance with PN-EN 1992-1-1. The factor adopted is $\gamma_c = 1.5$ and $ctg(\Theta) = 2.0$.

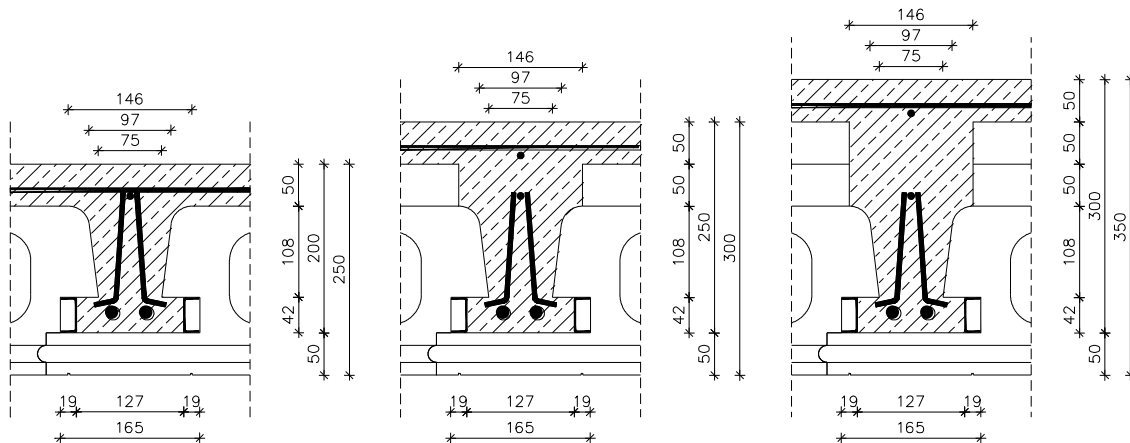


Figure 5. Cross-sections of ribs for various ceiling heights [2]

Due to the presence of ribs in two directions, and a cross-reinforced slab connecting ribs, IZODOM system ceilings can be treated as horizontal plate. Reinforcement of the slab must meet the minimum reinforcement requirements contained in [C3]. In this case the spacing of the weight distribution ribs must not exceed 1.5 m

In calculations, the reinforced concrete ceiling escutcheon can be modelled in the form of a high beam (beams - walls), a flat grating or a strut-and-tie model, on spring supports. The calculated strength shall be determined in accordance with the standard [C3].

V. Requirements for tie beams and lintels

With regard to the beams forming part of the seismic system, the conditions governing local deformability in critical areas may be considered fulfilled if at both the beam's supports:

- at least half of the calculated reinforcement in the tension zone is placed in the compression zone of the cross-section, apart from the compression reinforcement computationally required due to ULS conditions for the seismic load;
- The degree of longitudinal reinforcement ρ over the entire length of the beam is not less than the minimum value ρ_{\min} :

$$\rho_{\min} = 0.5(f_{ctm}/f_{yk}) = 0.5(2.2/500) = 0.0022$$
- the l_{cr} sections from the face of the beam's support are designed as critical areas (Fig. 6);
- in critical areas, stirrups are used with a diameter of not less than 6mm and spacing of no more than $h_w/4$, where h_w is the height of the beam;
- the first stirrup is placed not further than 50mm from the face of the support (beam end cross-section).

These requirements are included in Tables **W1** and **W2** concerning the design of tie beams and lintels. The values in these tables have been determined for a concrete class not lower than C20/25 and Class B or C (longitudinal and transverse) reinforcement with a yield strength of $f_{yk} \geq 500\text{MPa}$ [2]. Calculations were made in accordance with the provisions of standard PN-EN 1992-1-1 [C3] assuming a coefficient of $\gamma_c = 1.5$ and $\cot(\Theta)=2.0$.

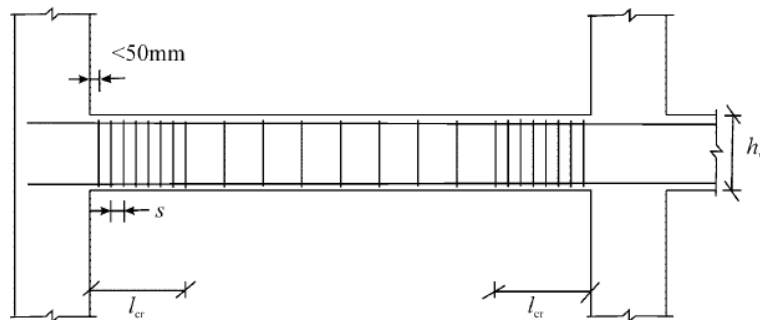


Figure 6. Transverse reinforcement in critical areas of the beam [EN 1998-1 [C5]]

In critical areas of the elements constituting part of the seismic system, the adopted angle of inclination of the concrete cross brace in the grating model must be equal to 45° . In this case, the $V_{Rd,max,45}$ and $V_{Rd,s,45}$ values may be determined on the basis of the sizes specified in Tables W1 and W2, assuming respectively:

$$V_{Rd,max,45} = 1.25 V_{Rd,max}$$

$$V_{Rd,s,45} = V_{Rd,s} / 2$$

The $V_{Rd,c}$ value does not change.

VI. Requirements for foundations

In the event of seismic effects, both the design and construction of foundations and their connection to the rest of the structure should take into account that the entire building is exposed to uniform seismic excitation.

If the building structure features discontinuous fragments of load-bearing walls of different width and rigidity, the foundations should be designed as rigid foundation frames or footing chambers containing base slabs and surface (ceiling) slabs.

If the building is designed to have individual foundations in the form of footings or piles, it is recommended that between these are used foundation slabs or tie-beams in two main directions, taking into account the specifications of EN 1998-5:2004, 5.4.1.2, in the form of:

$$b_w \leq \min \{b_c + h_w; 2b_c\}$$

where b_w is the cross-section width of the beam transferring the seismic effects, h_w is the height of the beam, and b_c is the greatest dimension of the column's cross-section, perpendicular to the longitudinal axis of the beam.

Tie-beams and foundation beams should in accordance with [C5] have a cross-section width of not less than $b_{w,min}$ and a height of not less than $h_{w,min}$.

The values described as $b_{w,min}$ and $h_{w,min}$, in force in a given country, may be quoted in the national Annex to the standard [C5]. The recommended values are: $b_{w,min} = 0.25\text{m}$ and $h_{w,min} = 0.4\text{m}$ for buildings of up to three storeys, and $h_{w,min} = 0.5\text{m}$ for buildings with over three storeys above ground.

Foundation slabs, introduced in accordance with [C5] for the purpose of a cross connection of individual foundations, should have a thickness of not less than t_{min} and a degree of both top and bottom reinforcement not less than $\rho_{s,min}$.

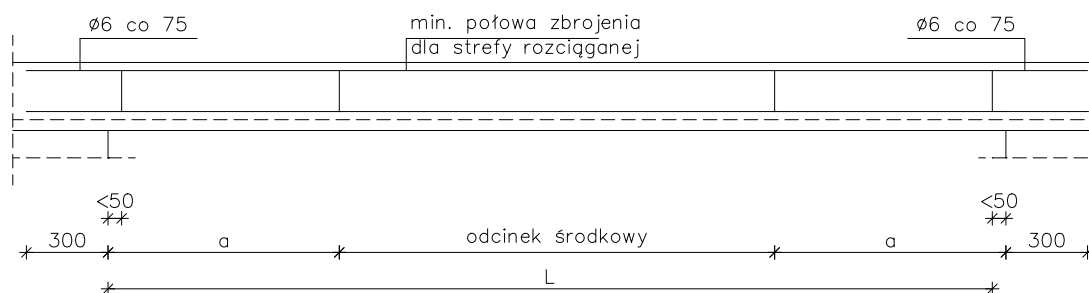
The t_{min} and $\rho_{s,min}$ values in force in a given country may be quoted in its National Annex to the standard [C5]. The recommended values are: $t_{min} = 0.20\text{m}$ and $\rho_{s,min} = 0.2\%$.

In accordance with [C5], tie-beams and foundation beams should have along their entire length such a longitudinal reinforcement that its degree is not less than the value $\rho_{b,min}$, for both the lower and upper reinforcement.

The $\rho_{b,min}$ value applying in a given country may be quoted in its National Annex to the standard [C5]. The recommended $\rho_{b,min}$ value is 0.4%.

IZODOM 2000 POLSKA / KJ

Tie beams and lintels. Load-bearing walls with a core thickness of 0.15 m



min. połowa zbrojenia dla strefy rozciąganej = min. half of reinforcement for the tension zone

odcinek środkowy = midsection

$$V_{Ed} = \frac{1}{2}qL \quad V_{Ed} \begin{cases} \leq V_{Rd,max} \\ \leq V_{Rd,s} \end{cases} \quad \alpha = \frac{V_{Ed} - V_{Rd,c}}{V_{Ed}} \frac{L}{2} \geq h_{cr}$$

V_{Ed} - calculated lateral force, kN/m

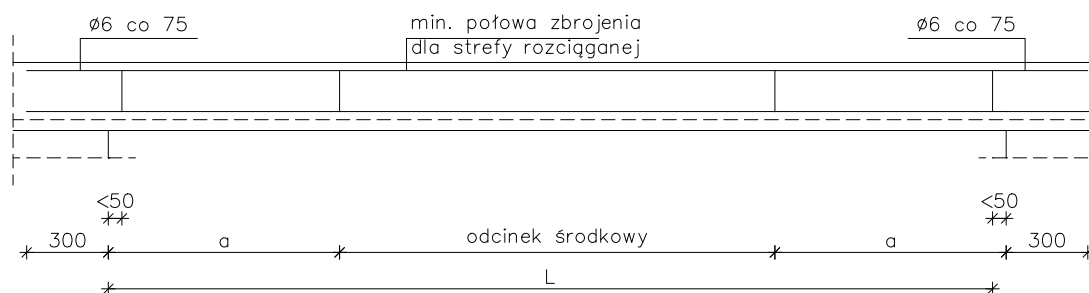
q - total calculated load on the tie-beam, kN/m

Table W1

Calculated values for C20/25 concrete		Tie beam h = 0.20 m	Tie beam - lintel height		
			0.20m	0.25m	0.30m
Bending moment [kNm] for the lower longitudinal reinforcement:	2Ø10 2Ø12 3Ø12 2Ø16 3Ø16	10.84 15.29 22.30 25.85 32.05	10.84 15.29 22.30 25.85 32.05	14.24 20.21 29.67 34.60 47.23	17.66 25.12 37.04 43.34 60.34
Load capacity without reinforcement against shearing $V_{Rd,c}$ [kN] for the lower longitudinal reinforcement:	2Ø10 2Ø12 3Ø12 2Ø16 3Ø16	14.02 15.83 18.12 19.18 20.68	14.02 15.83 18.12 19.18 20.68	15.95 18.01 20.62 21.83 24.98	17.37 19.61 22.45 23.76 27.20
Lateral force $V_{Rd,s}$ [kN] transferred by the two-arm stirrup for $\cot\theta = 2.0$ diameter/spacing [mm/mm]	Ø6/200 Ø6/150 Ø6/100 Ø6/75	39.46 52.62 78.92 105.24	39.46 52.62 78.92 105.24	50.42 67.23 100.85 134.47	61.39 81.85 122.77 163.70
$V_{Rd,max}$ [kN] for $\cot\theta = 2.0$		66.77	66.77	85.32	103.86
Stirrups at the midsection		Ø6 co 200	Ø6 co 200	Ø6 co 200	Ø6 co 200
Critical area h_{cr} [m]		0.40	0.40	0.50	0.60
Spacing of stirrups on the section h_{cr} [mm]		50	50	60	75

IZODOM 2000 POLSKA / KJ

Tie-beams and lintels. Load capacity of load bearing walls with a core thickness of 0.20m



$$V_{Ed} = \frac{1}{2} qL$$

$$V_{Ed} \begin{cases} \leq V_{Rd,max} \\ \leq V_{Rd,s} \end{cases}$$

$$\alpha = \frac{V_{Ed} - V_{Rd,c}}{V_{Ed}} \frac{L}{2} \geq h_{cr}$$

min. połowa zbrojenia dla strefy rozciąganej = min. half of reinforcement for the tension zone

odcinek środkowy = midsection

V_{Ed} - calculated lateral force, kN/m

q - total calculated load of the tie-beam, kN/m

Table W2

		Tie beam h = 0.20 m	Tie beam - lintel height			
			0.20m		0.20m	
Calculated values for C20/25 concrete						
Bending moment [kNm] for the lower longitudinal reinforcement:	2Ø10	11.03	11.03	-	-	
	2Ø12	15.53	15.53	20.45	25.36	
	3Ø12	22.70	22.70	30.08	37.45	
	2Ø16	26.52	26.52	35.26	44.00	
	3Ø16	36.77	36.77	49.88	63.00	
	4Ø16	40.17	40.17	61.16	78.84	
Load capacity without reinforcement against shearing $V_{Rd,c}$ [kN] for the lower longitudinal reinforcement:	2Ø10	17.19	17.19	19.56	21.29	
	2Ø12	19.41	19.41	22.08	24.04	
	3Ø12	22.21	22.21	25.28	27.51	
	2Ø16	23.51	23.51	26.75	29.12	
	3Ø16	26.92	26.92	30.62	33.34	
	4Ø16	28.07	28.07	33.71	36.69	
Lateral force $V_{Rd,s}$ [kN] transferred by the two-arm stirrup for $\cot\theta = 2.0$ diameter/spacing [mm/mm]	Ø6/200	39.46	39.46	50.42	61.39	
	Ø6/150	52.62	52.62	67.23	81.85	
	Ø6/100	78.92	78.92	100.85	122.77	
	Ø6/75	105.24	105.24	134.47	163.70	
$V_{Rd,max}$ [kN] for $\cot\theta = 2.0$		90.48	90.48	115.79	140.95	
Stirrups at the midsection		Ø6 co 200	Ø6 co 200	Ø6 co 200	Ø6 co 200	
Critical area h_{cr} [m]		0.40	0.40	0.50	0.60	
Spacing of stirrups on the section h_{cr} [mm]		50	50	60	75	

