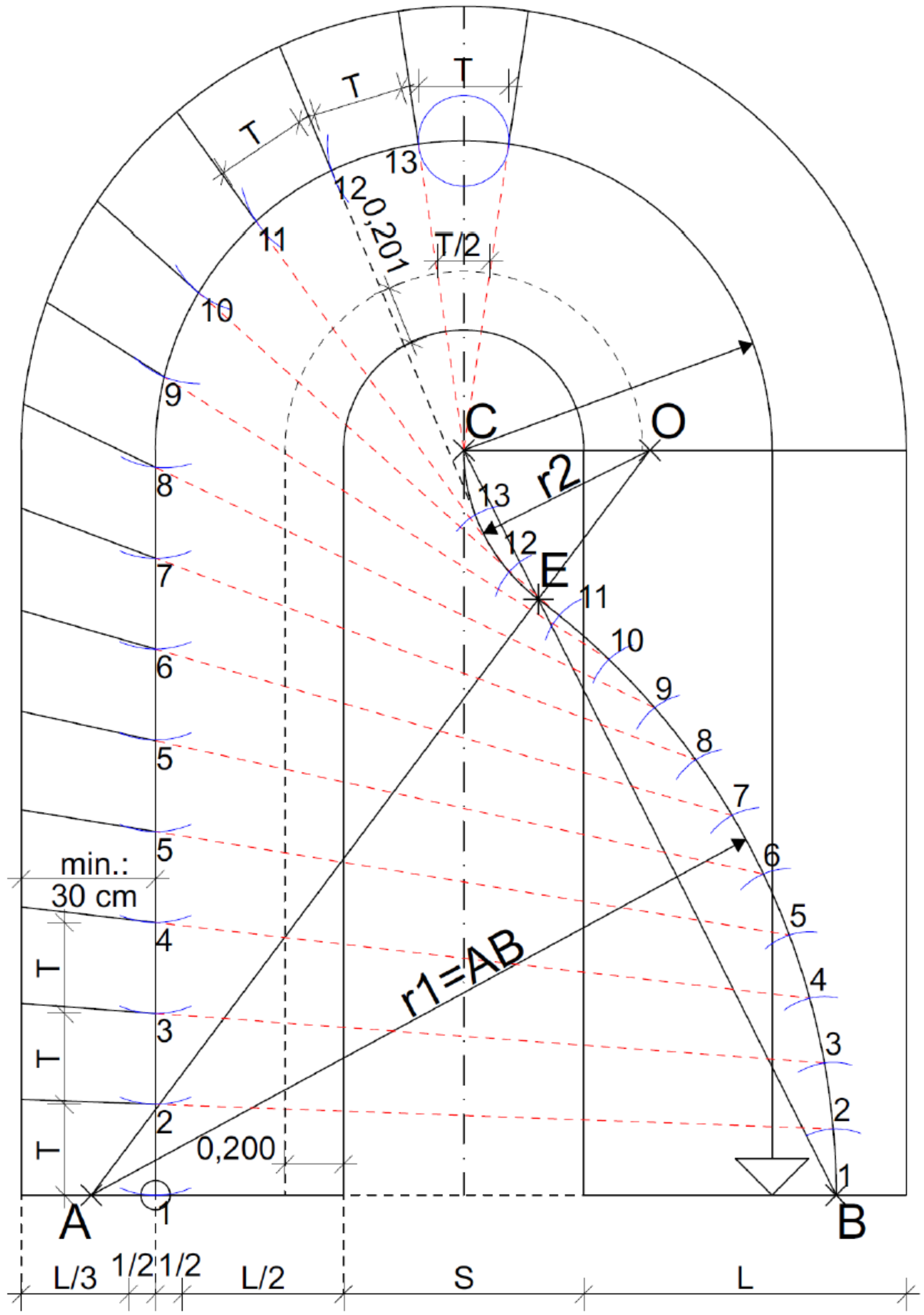
Building Constructions 2 Lecture materials and notes



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Building Constructions 2 Lecture materials and notes

Pécs

2020

The Building Constructions 2 Lecture materials and notes course material was developed under the project EFOP 3.4.3-16-2016-00005 "Innovative university in a modern city: open-minded, value-driven and inclusive approach in a 21st century higher education model".

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A Building Constructions 2 Lecture materials and notes. tananyag az EFOP-3.4.3-16-2016-00005 azonosító számú,
„Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben” című projekt keretében valósul meg.

BUILDING CONSTRUCTIONS 2
NOTE

WALLS, FOUNDATIONS and STAIRS
(for internal use only)

SZÉCHENYI 2020

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Content

The concept of building structures

The design of a building is a complex process, in addition to the functional layout and aesthetics, the structures of the building and their connections must be determined. The way in which the various materials and building elements are assembled is important for the design and construction of the building. With knowing the possibilities and limit of the individual structural element, we can determine the structural design of the building, and knowing their construction method, we can create an organic unit.
A well-designed building combines aspect of function, form and structure, while offering an environmentally friendly solution.

Subdivision of building structures

- Supporting structures
  - foundations
  - walls and pillars
  - roofs
- Spanning structures
  - lintels and arches
  - slabs
  - stairs
- Bracing structures
  - walls and bracings
- External boundary structures
  - non-load-bearing external walls
  - doors, windows and curtain walls
  - claddings
- Internal boundary structures
  - partition walls
  - doors
  - slabs
  - floors

I. Chapter

WALLS

1.1. WALLS

A wall is a structure that defines an area, carries a load, or provides shelter or security. There are many kinds of walls such as defensive walls in fortification, walls of buildings which are a fundamental part of the superstructure or which separate the spaces in buildings sections sometimes for the purpose of fire safety, walls which hold back earth called retaining walls, offer protection from oceans such as a seawall or river as a levee. Permanent, solid fences are walls, and border barriers between countries are sometimes walls.

1.2. Wall requirements

Structural requirements

- Strength
- Deformation
- Durability
- Fire safety

Building construction and energy requirements

- Thermal
- Energetics
- Airtightness
- Noise protection
- Moisture protection

Implementation and economy

- Aesthetics
- Carvability, engravability

Special requirements

- radiation protection
- biological protection

1.2.1. Structural requirements

Strength:
The required strength is determined by force acting on it (compressive, bending, share), load degree (low, medium or high load) and load type (static, dynamic) of the structural load. The strength depends on the material of the wall (stone, brick, concrete, etc.) and the quality of the mortar, as well as the typical dimensions of the wall.

Deformation:
Structural Deformation is the term given to warping, bending, twisting and springiness in structural components of a building. The building codes and standards specifies the maximum allowable deformation. Walls with significantly different properties or different load capacities can be constructed if these conditions have been taken into account during design of the walls.

Durability:
The expected degree of durability is determined by the structural type (permanent or temporary) and value (e.g., public building or outbuilding) of the building. The durability of the structure depends on the technical properties of the wall material, the thickness of the wall and climatic impacts.

Fire protection:
In case of a fire the basic objective is that the stability of the structure must be ensured during the evacuation time of all occupants. The available evacuation time depends on the materials chosen and their behavior during fire exposure. The most commonly used wall materials are brick, concrete and reinforced concrete have a good fire resistance property. In case of walls made of other materials (e.g., wood), their protection (coatings, insulation, claddings) must be ensured.

1.2.2. Building construction and energy requirements

Thermal properties:
Ensuring comfortable temperature and air conditions, as well as energy saving and protecting the exterior walls. Thermal protection is determined by the thermal insulation and heat storage capacity of the walls.

Thermal transmittance: „U” value, is the rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure. The units of measurement are W/m^2K. The better-insulated a structure is, the lower the U-value will be. Workmanship and installation standards can strongly affect the thermal transmittance. If insulation is fitted poorly, with gaps and thermal bridges, then the thermal transmittance can be considerably higher than desired. Thermal transmittance takes heat loss due to conduction, convection and radiation into account.

Thermal mass: In building design, thermal mass is a property of the mass of a building which enables it to store heat, providing "inertia" against temperature fluctuations. It is sometimes known as the thermal flywheel effect. For example, when outside temperatures are fluctuating throughout the day, a large thermal mass within the insulated portion of a house can serve to "flatten out" the daily temperature fluctuations, since the thermal mass will absorb thermal energy when the surroundings are higher in temperature than the mass, and give thermal energy back when the surroundings are cooler, without reaching thermal equilibriumm. This is distinct from a material's insulativee value, which reduces a building's thermal conductivity, allowing it to be heated or cooled relatively separate from the outside, or even just retain the occupants' thermal energy longer.

Thermal conductivity: „λ” The thermal conductivity of a material is a measure of its ability to conduct heat. Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity. For instance, metals typically have high thermal conductivity and are very efficient at conducting heat, while the opposite is true for insulating materials like rockwhool or polystyrol foam. Correspondingly, materials of high thermal conductivity are widely used in heat sink applications, and materials of low thermal conductivity are used as thermal insulation.

Energy efficiency requirements:

The European Council of March 2007 emphasised the need to increase energy efficiency in the Union so as to achieve the objective of reducing by 20 % the Union's energy consumption by 2020. The energy performance of buildings should be calculated on the basis of a methodology, which may be differentiated at national and regional level. That includes, in addition to thermal characteristics, other factors that play an increasingly important role such as heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building. The methodology for calculating energy performance should be based not only on the season in which heating is required, but should cover the annual energy performance of a building. That methodology should take into account existing European standards.[1]

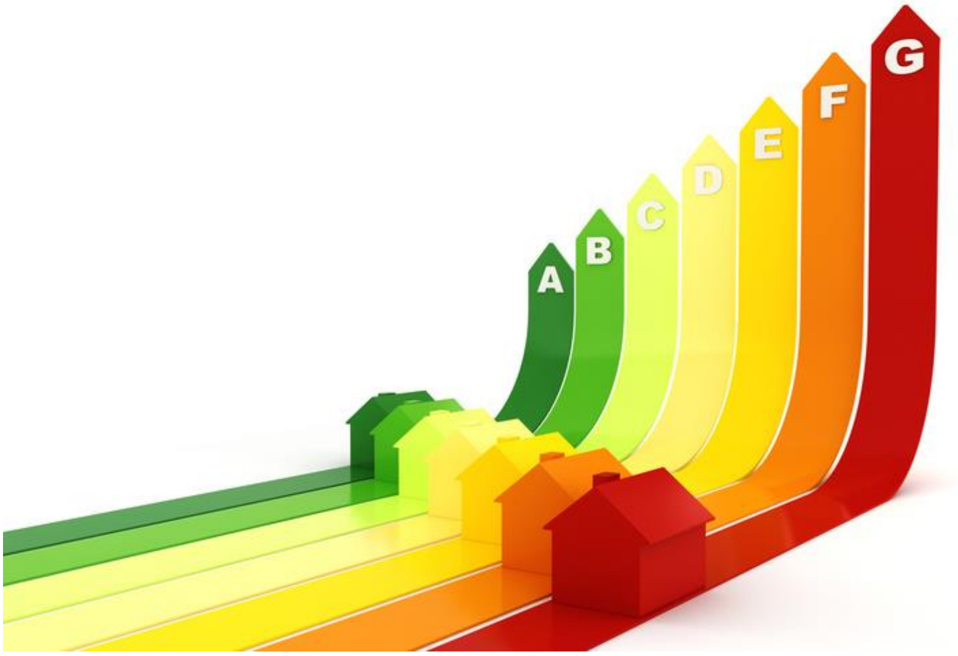


Fig.1. Energy efficiency rating

Airtightness:

Building airtightness can be defined as the resistance to inward or outward air leakage through unintentional leakage points or areas in the building envelope. This air leakage is driven by differential pressures across the building envelope due to the combined effects of stack, external wind and mechanical ventilation systems.[2]

Noise protection:

Noise is a physical form of pollution, which is negatively affecting indoor environmental quality by causing disruptions and having adverse effects on the health and wellbeing of occupants.

Airborne noise is a noise born and transmitted in the air (e.g. traffic, speech, tv, music, etc.)
Impact noise is a noise resulting from footsteps on the floor, dropping objects or moving the furniture.
The noise retardancy property defined by the weighted air noise resistance value or R_W, its unit is the dB.

[1] DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
[2] https://en.wikipedia.org/wiki/Building_airtightness

Moisture protection:
Buildings are exposed to a wide range of moisture; general requirement is the wall material must be waterproof and frost-resistant.

Buildings or particular rooms must be protected according the intended use against the effects of moisture. The dampness should be avoided by appropriate heat and vapour transfer calculations and resulting proper calibration of the wall layer structure.

Moisture protection of the walls can be improved:

- by choosing the right wall material and thickness;
- by thermal insulation;
- by waterproofing;
- by vapor proofing;
- by ventilation;

1.2.3. Implementation and economical requirements

Wall construction is economical:

- If the masonry element is large but still light;
- If it can be built quickly and cost-effectively using modern working methods;
- If the building floor plan is simple and the module size is compatible with the other structures;

Accuracy and aesthetic requirements:
The aesthetic construction of the masonry wall is a basic requirement. In case of well constructed wall the joints are evenly sized, masonry elements are in good position, and the number of carved elements is low as possible. A masonry wall is well executed if its appearance is aesthetic, even if it will be plastered later on.

Carvability:
In case of wall construction made of conventional solid bricks carvability was important because of the construction of the wall joints. The advenced masonry units can be cuted only with machine cutting without any destruction. Manufacturers also provide special elements (for ex. half bricks) for the construction of the wall joints.

Wall chases and channels:
Ideally, pipework and cabling for building services equipment should be concealed behind the plaster work. Exposed pipework and cabling is typically found only in ancillary rooms such as basements and lofts.
The location and arrangement of chases are mainly determined by the electrical and plumbing installations. Consideration should be given at the design stage to the avoidance of intersection points between the ducting systems of the two trades, in compliance with standards. Chases and channels weaken the wall cross-section and should therefore be kept to a minimum.

1.3. Classification of walls

1.3.1. Classification of walls by material

Natural wall materials

- Clay
- Stone
- Wood

Fig.2. Adobe, stone and timber walls

Artificial wall materials

- Brick, clay block
- Reinforced concrete
- Aerated Concrete
- Calcium silicate
- Formwork blocks

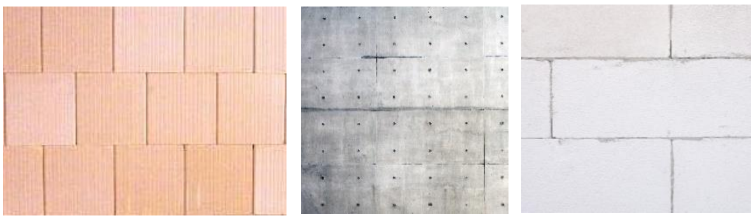
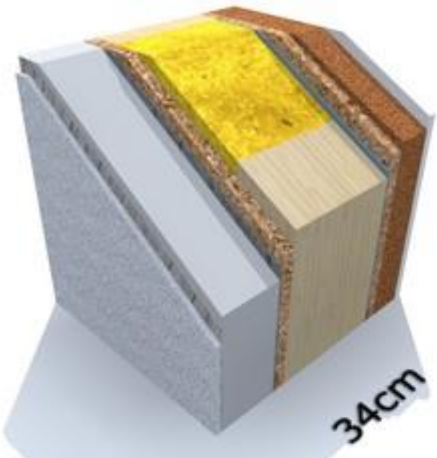


Fig.3. clay block, concrete and aerated concrete walls

Lightweight walls

- Timber frame
- Metal frame



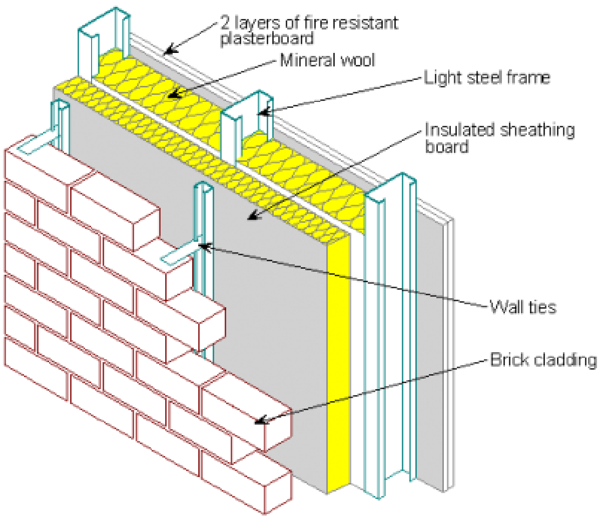


Fig. 4. Timber and metal frame walls

1.3.2. Classification of the walls by load bearing properties

Load bearing walls: A load-bearing wall is a structure which holds the weights of the structures above it, and transmit this load to a foundation structure below it.

Non-bearing walls: carry just a self weight (e.g., partitions, firewalls, cladding walls, etc.)

1.3.1. Classification of walls by construction technology

- Block walls
  - Small size bricks
  - Medium-sized masonry units
  - Large panels

- Semi-monolitchic walls
  - Precast wall panels with monolithic core

- Monolitic walls
  - walls built on site with poured technology

- Mounted walls
  - timber or metal framed lightweight walls or curtain walls

1.3.2. Classification of walls by structure

- Homogeneous walls
  A single-layer wall structure that fulfill the requirements in single layer. (eg fired clay block)

- Heterogeneous walls
  Multi-layer structures, additional layers of thermal insulation and cladding are attached to the wall. The several layers all together fulfill the requirements of the wall.

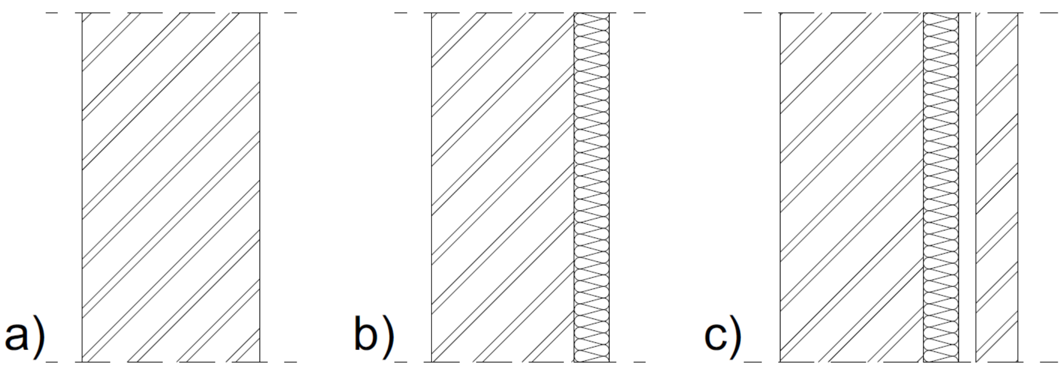


Fig. 5. a) homogeneous wall, b-c) heteregeneous wall

1.4. Masonry units

The oldest artificial building stone is fired clay brick. The artificial stone was invented in areas that poor of rock and rich in clay. This construction technique developed thousands of years ago along the Tiger and Euphrates. This is the building material of Assyrian, Babylonian and Persian empires.

Fig.6. Ishtar Gate, The Middle East Museum, Berlin

The **Ishtar Gate** (Arabic: بوابة عشتار) was the eighth gate to the inner city of Babylon. It was constructed in about 575 BCE by order of King Nebuchadnezzar II on the north side of the city. It was part of a grand walled processional way leading into the city. The walls were finished in glazed bricks mostly in blue, with animals and deities in low relief at intervals, these also made up of bricks that are molded and colored differently.[3]

1.4.1. The principles of masonry bonds

The wall constructed out of whole bricks and carved or cutted bricks like three-quarter, half, quarter and head bricks. The gaps (joints) between the bricks are filled with mortar. The joinst must be with equal size, horizontal joints (10-13 mm thick) and vertical (10 mm thick) standing joints.

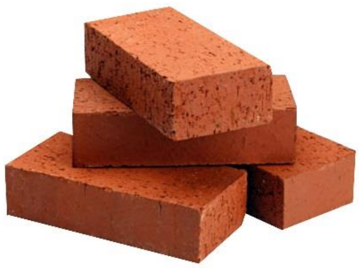


Fig. 7. solid brick

The principles of masonry bonds

1. Stretcher and header courses of masonry units are the prerequisite for a proper masonry bond;
2. The stretcher and header courses should alternate layer by layer, this significantly increase the stability of the wall;
3. The vertical joints of two successive courses should be offset by 1 /4 to 1 /2 of the length of masonry unit and should never coincide;
4. There should be as many whole bricks or blocks as possible and only as many bats as necessary to produce the bond;
5. There should be as many headers as possible in the core of every course;

[3] https://en.wikipedia.org/wiki/Ishtar_Gate

The wall joints shall be made of cutted bricks produced by carving or cutting. Cutted bricks required for brick masonry wall joints:

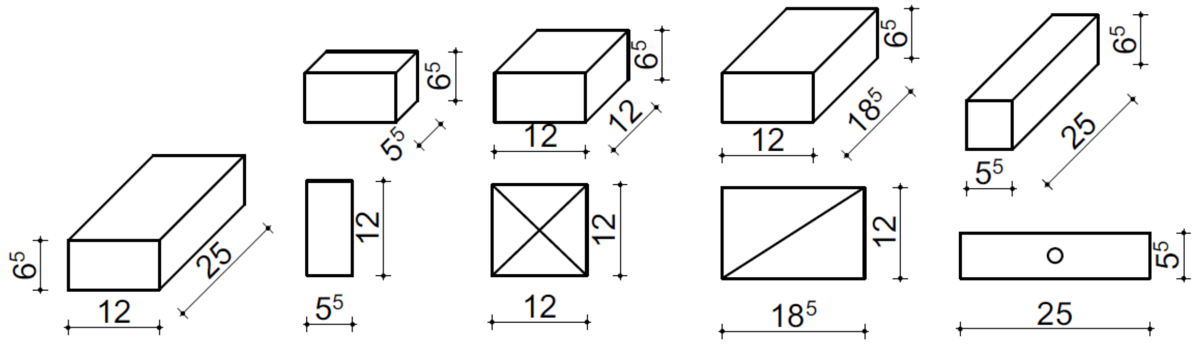


Fig 8.: solid brick, quarter bat, half bat, the-quarter bat, queen closer

The position of the brick within the wall:
The brick is in the **stretcher** position if its longitudinal side is parallel to the direction of the wall. The brick is in **header** position if its longitudinal side is perpendicular to the direction of the wall.

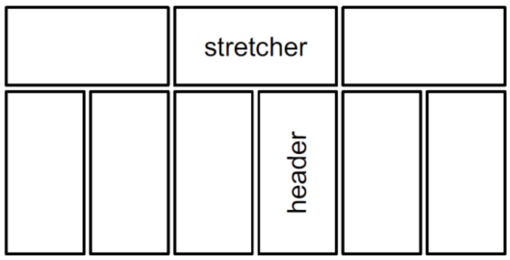


Fig. 10. position of the brick within the wall

Fig. 9. wall construction

The role of mortar

The mortar connects the bricks and forms a uniform structure called wall. The mortar fill and seal the irregular gaps between bricks, allows the compensation of inequality and spread the load evenly.

mortar content:

- binder + additive + mixing water
- binder: slaked lime + cement
- additive: 0-3 mm rough and sharp mine sand

mortar types:

walling, rendering and mortar bed walling

The **construction of the wall end** with the a quarter brick offset between the layers could be done with three-quarters or queen closer bricks. The three-quarter bricks are placed alternately in layers in a header and stretcher position.

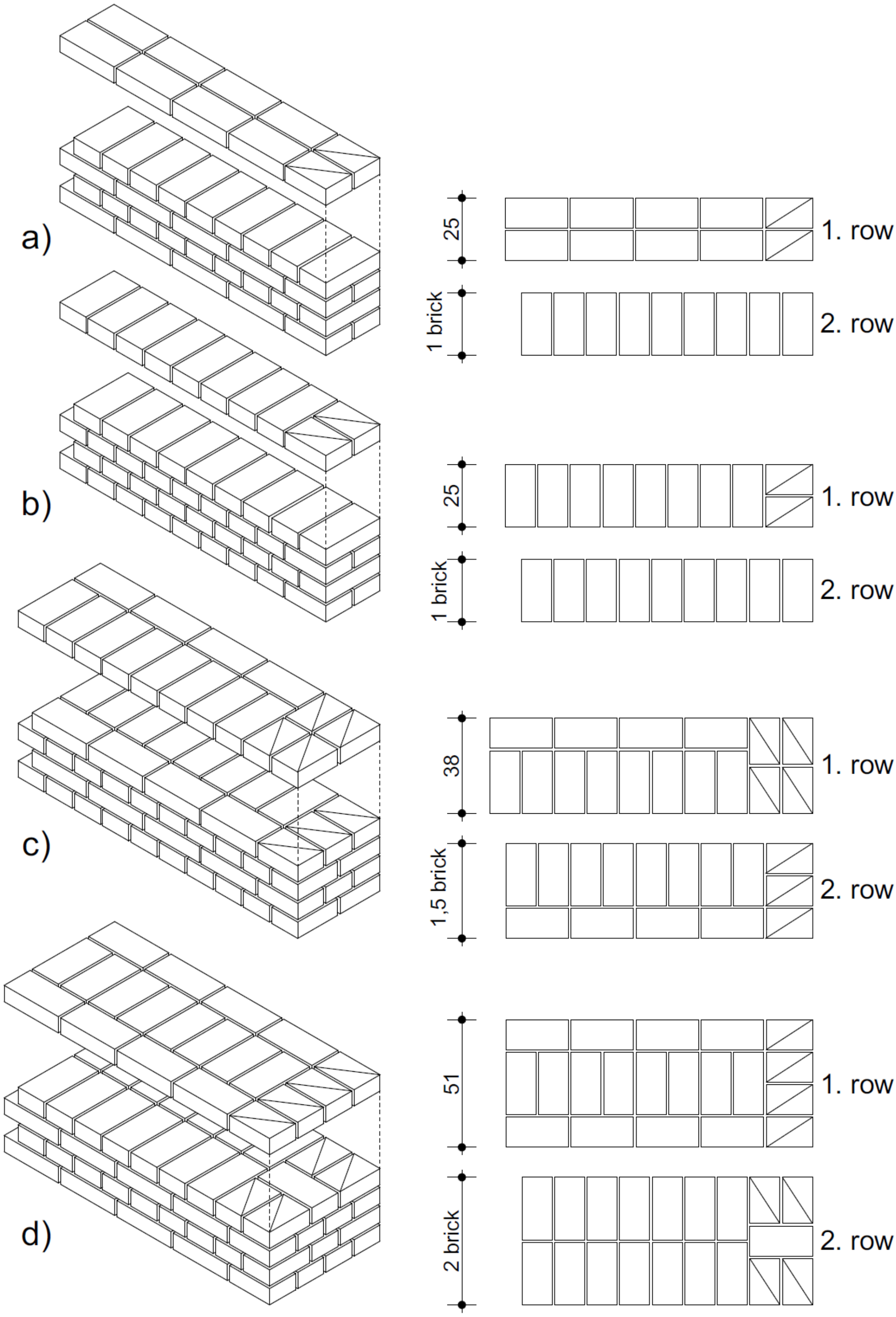


Fig. 11. a)-b) one-brick wall heder and strecher bond, c) english bond of half-and one-brick wall, d) english bond of two-brick wall

In the design of a perpendicular **wall corner**, the layers of connecting walls are led out alternately and closed with three-quarters bricks as wall ends. The position of the stetcher three-quarters bricks is follow the position of the header bricks of the connecting wall on the outside of the wall corner.

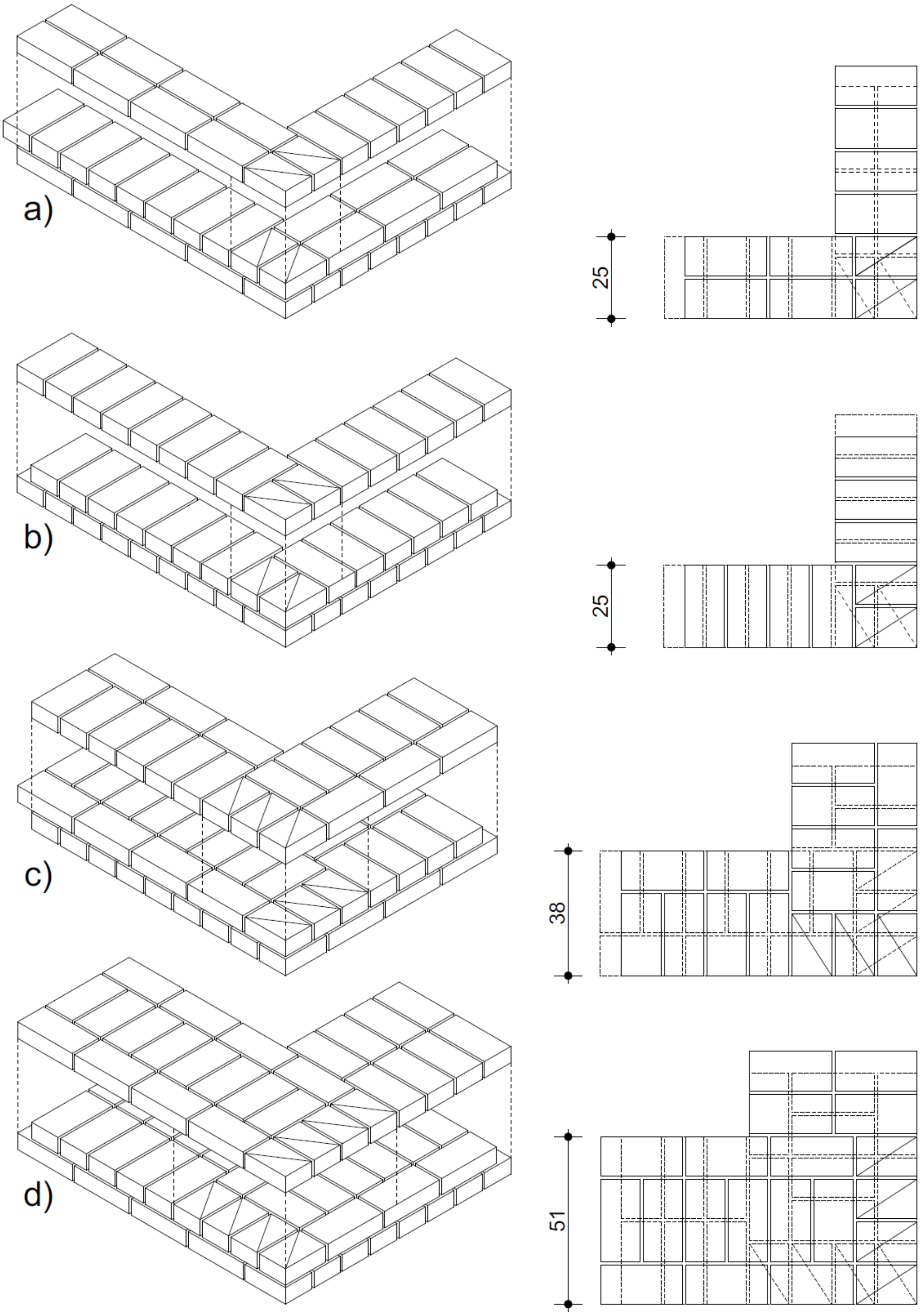


Fig. 12. Wall corner: a)-b) one-brick wall heder and strecher bond, c) english bond of half-and one-brick wall,d) english bond of two-brick wall

The construction of a perpendicular wall connection as **"T" junction**, the layers of the connecting walls are passed alternately and the leading end of the connecting wall is closed with three-quarters bricks as wall ends.

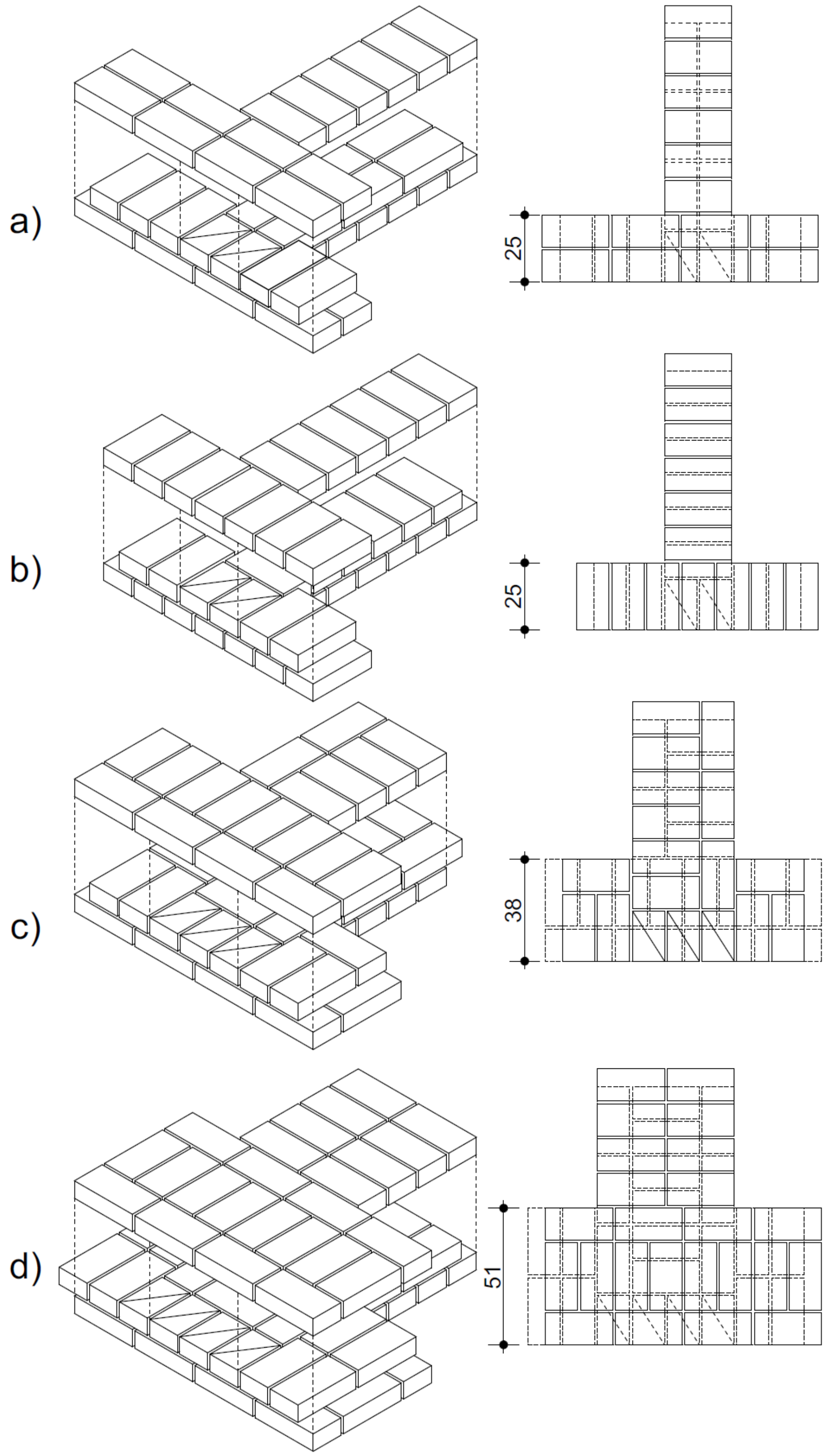


Fig. 13. T junction: a)-b) one-brick wall heder and strecher bond, c) english bond of half-and one-brick wall,d) english bond of two-brick wall

The wall bond also could be constructed with **cross bond**. In this case the standing joints of the stretcher rows are shifted by half a brick in relation to each other in every second row.

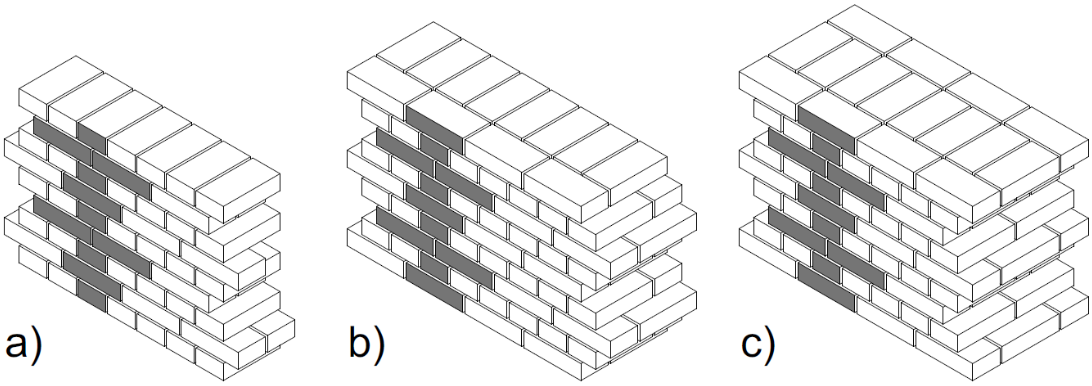


Fig. 14. Cross bond: a) one-brick wall, b) alf-and one-brick wall, c) two-brick wall

In the end of the work day the process of masonry bond must be interrupted in right way to ensure subsequent masonry and the continuation of the work process.

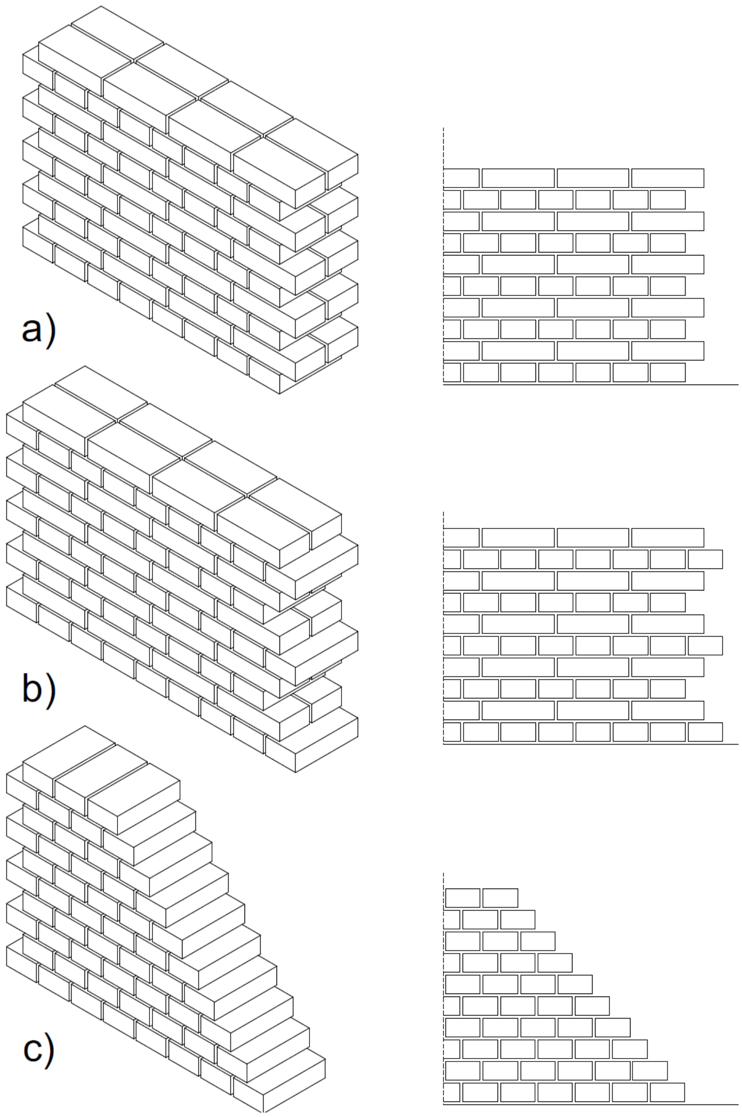


Fig. 15. Temporary interruption of the masonry bond

Pillars made of small bricks are still used today as a complementary structure, e.g. today's ceramic blocks are not suitable for building slender load-bearing pillars. Small brick pillars should be built according to the rules of brick bonding. The standing joints are made with an offset of half or a quarter relative to each other, which can be achieved by rotating of the layers.

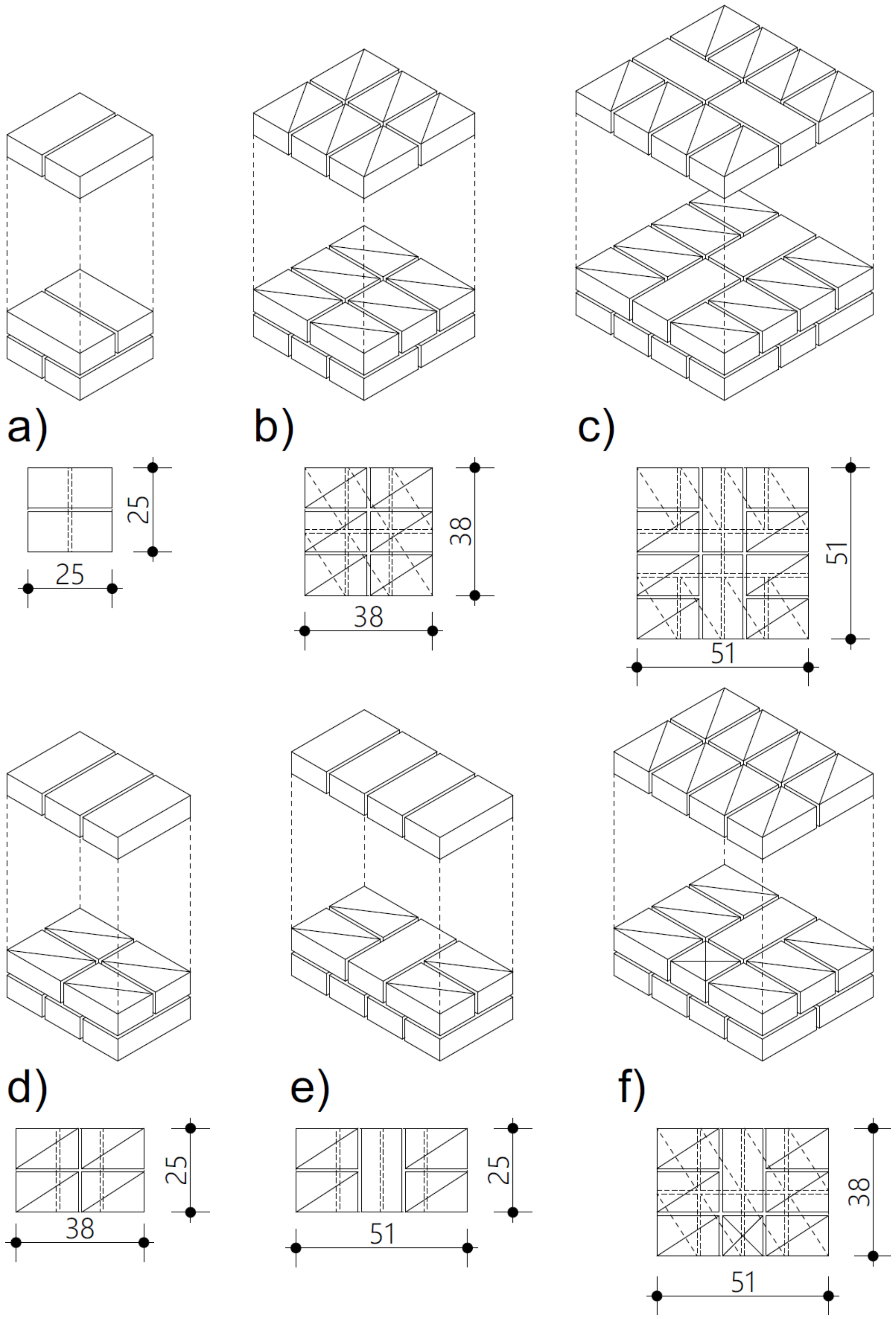


Fig. 16. Pillar bonds

1.5. Advanced masonry units

During the development of the masonry units, efforts were made to increase the thermal insulation capacity, to reduce the selfweight, to increase the size, and to reduce the construction time and the need for labor. The large masonry eunit reduces construction time and the number of joints. The cavity system reduces the selfweight of the masonry units while increasing its thermal insulation capacity.

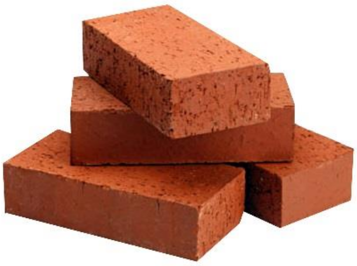
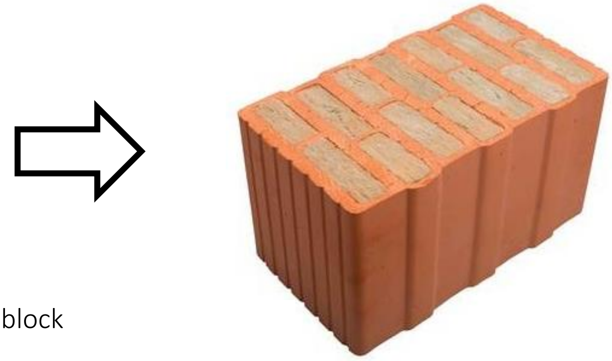



Fig. 17. standard solid brick and fired clay block

1.5.1. Clay blocks

Advanced clay block are large masonry elements with a large cavity volume, which are made of clay and various additives. During the production process polystyrene pearls or sawdust is mixed to the clay, these materials burn out during firing and increase the pore volume of the material.

The brick bonding of the clay blocks made according to the rules of brick bonding with half or cut elements. The position of the bricks within the wall is header in all cases.

Usual wall thicknesses that can be built with clay block: 25, 30, 38, 44, 50 cm.

The clay block masonry units can be categorized in three different groups

1. The shape and connection joints of the clay blocks:

- conventional brick shape, standing joints with mortar fill;
- bricks with mortar bag;
- caly block with tounge and groove interlock;

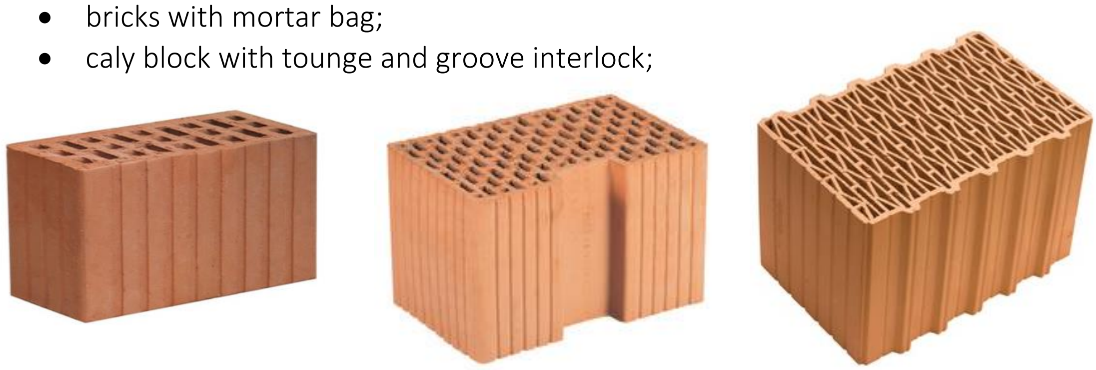


Fig. 18. brick with standing joints, mortar bag, tounge nad groove connection

The standing joints of traditional masonry elements were completely filled with mortar. On tThe disadvantege of this solution is that the joints form a thermal bridge in the masonry and increase the construction moisture in the structure. The next step of the development was the mortar bag masonry element, with this solution only the mortar bag was filled with mortar. In the case of a tounge and grooved masonry masonry units the connection allows vertical joints without mortar. Mortar is only required for non-grooved elements, e.g., for cuted elements at wall joints. Note that grooved bricks only meet the air tightness requirement with two-sided plaster.

2. The insulation capacity of the masonry elements largely depends on the design of the cavity system:

- Rectangular cavity arrangement - normal thermal insulation with less cavities;
- Diamond shaped cavities - the shape of cavities increase the path of the heat transfer;
- K shaped cavities - complex cavity arrangement increase the thermal insulation properties;
- Insulated cavities - advanced thermal insulation properties;

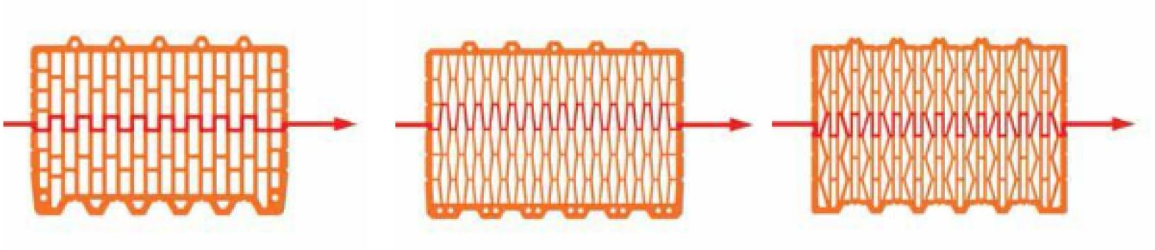


Fig.19. comparison of cavity arrangement and the heat transfer path

The cavity system of the clay blocks prolongs the path of heat conduction within the brick structure and reduces the heat loss.

3. According the bricklaying technology the horizontal joints can be:

- conventional mortar - non-polished surface
- thin-bed mortar - polished surface
- adhesive foam-polished surface

Fig. 20. conventional mortar, thin mortar and adhesive bond technology

In case of traditional mortar technology, the horizontal joints cause a thermal bridge and the construction moisture is also high, but there is adventege of the leveling possibility by the mortar thickness.
The thin-bed mortar technology is 1-3 mm thick, which significantly reduces the thermal bridge but does not allow leveling, therefore a polished brick must be applied. By using adhesive foam technology, the thermal insulation capacity of the wall can be improved.

1.5.2. Construction of the clay block wall

On the finished floor level must be set out the accurate position of the wall with stretched mason's string between the corners. After placing horizontal dampproof membranes underneath of the external and internal walls, the the first course of blocks must be completely level by up to 2 cm thick bed-mortar. The construction of the wall is started at the wall corners, and the level of layers must be checked by spirit level.

Fig. 21. setting of the corner brick

Fig. 22. laying of the first course

The thickness of the horizontal joint is 12 mm on average, so by the using of 238 mm high brick could be reached a module height of 25 cm. The height of the polished bricks is 249 mm, they are laid into thin mortar or adhesive foam with 1 mm mortar thickness. The overlap of the masonry units must be done according to the rules of brick bonding. The offset between standing joints should be at least 0,4 times the element height or 9,5-10 cm. The wall bonds can be built with supplementary elements like half bricks or cutted elements made by sawing an entire element.

Fig. 23. brick cutting machine

Fig. 24. adhesive foam technology

Half elements and individual elements can be created from the whole element by sawing or a brick cutting machine. Elements smaller than half should be placed in the intermediate part of the wall, according to the rules of brick bonding. The vertical joints of the cutted bricks without tounge ang groove joints must be filled with masonry mortar.

1.5.3. Aerated concrete blocks

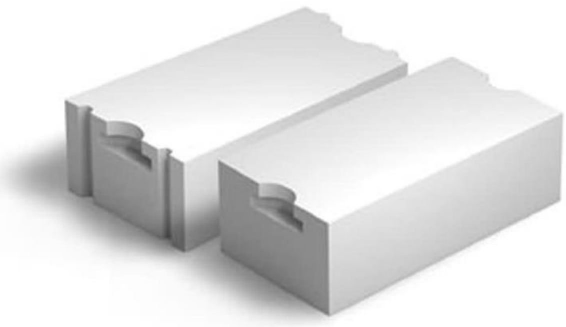


Fig. 25. Aerated concrete blocks with tongue and groove and/or grab recesses

Autoclaved aerated concrete (AAC) is a lightweight, precast, foam concrete building material suitable for producing concrete masonry units. Composed of quartz sand, calcined gypsum, lime, cement, water and aluminum powder, AAC products are cured under heat and pressure in an autoclave. The AAC bricks solid masonry elements without cavities. The AAC masonry units have a good thermal insulation capacity due to the large pore volume produced by aluminum powder component.
The possible wall thickness of aerated concrete walls: 20, 25, 30, 37,5, 45, 50 cm.

1.5.4. Construction of the aerated concrete wall

Due to the shape and dimensions of the aerated concrete masonry units, they are installed in a stretcher position. The length of overlap determined by the block height and the construction of head and bed joints. The distance between the standing joints is 0,4 times the hight of the block or at least 12.5 cm. The recommended thicknes of the bed mortar is 8-10 mm for conventional masonry mortar, 5-6 mm for thermal insulation masonry mortar and 0,5-3 mm for thin-bed masonry mortar. Bed joints must always be fully mortared.
Aerated concrete blocks can be laid quickly and easily using thin-bed mortar. However, this construction method requires the first course of blocks to be completely level. This is done by laying the first course of blocks in a bed of conventional mortar to even out any unevenness in the floor or ceiling slab, for this purpose a pure cement-based mortar is used. After placing horizontal dampproof the construction of the wall is started at the wall corners, and the level of layers must be checked by spirit level.

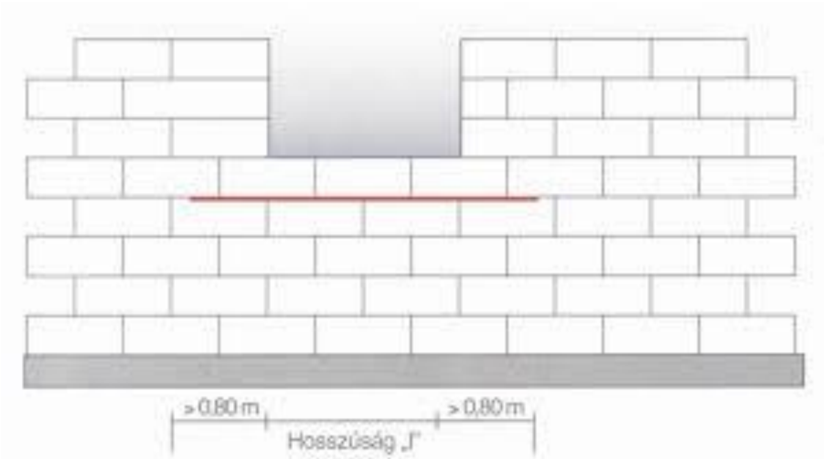


Fig. 26. installation of a steel reinforcement bar in the parapet wall

Becouse of structural reasons its recomenden to reinforce the parapet walls of the windows. The parapet reinforcement must be placed into the last joint below the top of parapet, at least 2 steel reinforcement bars with an 8 mm diameter. The parapet reinforcement is absorbing stresses and shear forces between the unloaded parapet wall and the pillar next to it. The reinforcement bars must be inserted into the 2 cm deep groove and fully mortared and at least 80 cm at each end of the rod is also embedded in the masonry.

1.5.5. Acoustic properties of the walls

Soundproofing is important in homes, apartments and in case of other functions to give the residents privacy from each other, and ensure the comfortable use of the space. The soundproofing requirements are regulated by building codes and standards. The walls must provide adequate acoustic protection against noise efects.
The minimum level of airborne sound resistance for dividing walls or floors between homes is 51 dB (decibels) This level should easily cut out normal levels of speech, TV and music playing. The airborne noises can be mitigated with a heavy, rigid, non-vibrating structure. In the case of wall with acoustic requirement mainly ceramic, concrete and calcium silicate brick products are used.

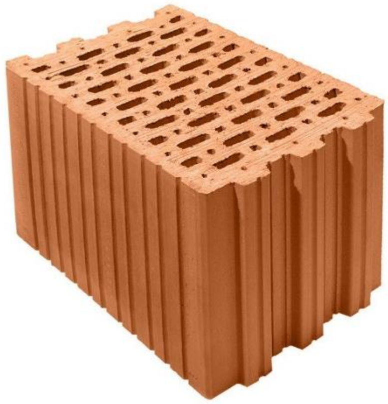


Fig. 28. Ceramic soundproof block

Fig. 27. Concrete soundproof block

The calcium silicate brick is a high-strength and high-mass masonry element, which is made of mixture of lime, sand and water. This mixture is transported to the press, where it is formed into brick shape. In the final step the bricks placed in an autoclave for hardening, this is done by means of steam under high pressure. The calcium silicate brick does not meet the thermal requirements, it only fulfills it with additional thermal insulation. Due to its high density and selfweight, it has good heat storage capacity and is excellent for building soundproof walls.

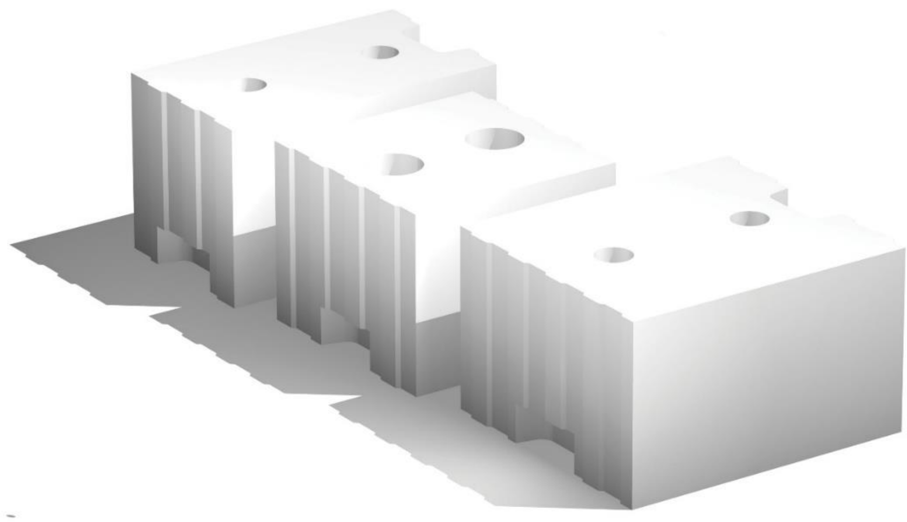


Fig. 29. Calcium silicate blocks

1.6. Partition walls

Partition walls are non-load-bearing masonry that divides interiors spaces. Partition walls typically made of fired clay and aerated concrete bricks, but the use dry walls is also widespread.

Usual thickness of partition walls:

- ceramic block partitions: 10, 12, 20 cm;
- aerated concrete partitions: 10, 12, 12,5, cm;

Partitions are thin and sometimes long and high structures which are also weakened by the openings and wall grooves formed in them. Stiffening of partitions is provided by soft iron wires or perforated steel strips embedded in the mortar of horizontal joints in each second brick course. Partition walls achieve structural stability only when connected to adjacent structural components. The connection between the partitions and the load-bearing walls is done with wall ties (steel strips) connectors placed in horizontal joints, and the stiffening wires are also attached to them. The stiffness of long partitions can be provided by intermediate pillars or reinforced concrete ribs. The stiffness of high partitions can be ensured by height-dividing beams.

Fig. 31. ceramic partition wall

Fig. 30. aerated cancrete partittion wall

The connection between the partitions and the slabs shall be made by taking into account of the expected movement of the structure. The load caused by slab deflection can jeopardize the stability of partition wall. In case of negligible deflection of the slab, the partitions could be clamped to the slab in the top row with two wedge shaped bricks facing each other. The partition must be wedged at least every third brick. The gap between the slab and the last brick course should be filled entirely with mortar. A common solution is to fill the gap between the slab and the partition wall with PUR foam. This solution is not durable due to the aging of the PUR foam, and it does not increase the stiffness of the wall sufficiently. If larger structural movements are expected, a sliding connection is recommended between the slab and the partition wall. In this case, U or two L metal profiles enclose the partition wall fixed to the bottom of the slab. The remaining gap between the top row of the partition wall and the slab must be instald with flexible filling e.g., mineral wool.

The electricity wires must be placed in the partitions as well as in the load-bearing walls. The depth of the grooves in the partition wall must not exceed 1/3 of the wall thickness and its width must be less then the wall thickness. Double-sided grooves in the same position must be avoided.

II. Chapter

FOUNDATIONS

2.1. Foundations

Foundation is a structure, that transmits the load of the building to the soil. In engineering, a foundation is the element of a structure which connects it to the ground, and transfers loads from the structure to the ground.

Loads:

Dead loads are permanent or stationary loads which are transferred to structure throughout the life span. Dead load is primarily due to self weight of structural members, permanent partition walls, fixed permanent equipments and weight of different materials. It majorly consists of the weight of roofs, beams, walls and column etc. which are otherwise the permanent parts of the building.

Live loads are either movable or moving loads with out any acceleration or impact. These loads are assumed to be produced by the intended use or occupancy of the building including weights of movable partitions or furniture etc.

Snow loads constitute to the vertical loads in the building. But these types of loads are considered only in the snow fall places. The minimum snow load on a roof area or any other area above ground which is subjected to snow accumulation is obtained by the expression.

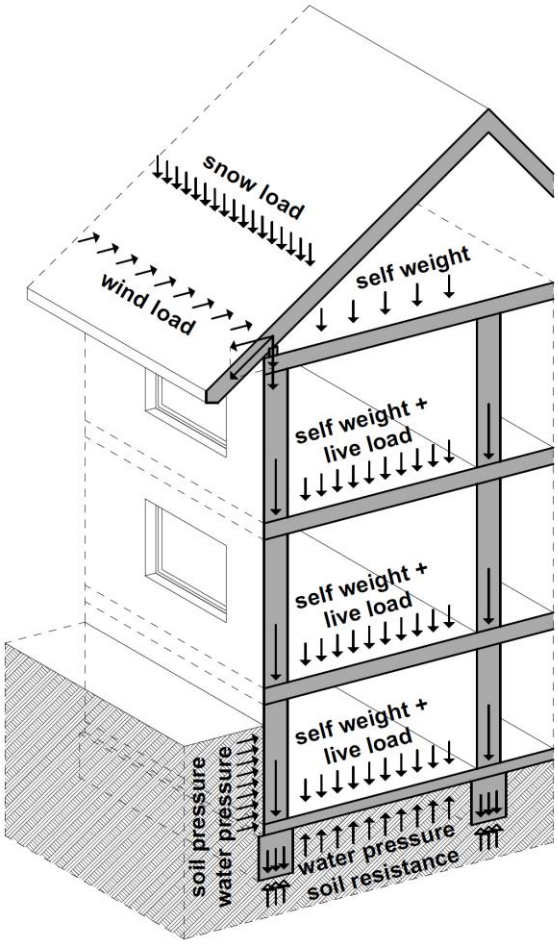


Fig. 32. Building loads

Wind load is primarily horizontal load caused by the movement of air relative to earth. Wind load is required to be considered in structural design especially when the heath of the building exceeds two times the dimensions transverse to the exposed wind surface

Load transfer is correct if harmful stresses and deformations not occur in the subfloor or in the structure, or even in adjacent or nearby structures, which endanger the structure.
The foundation even in the worst impacts and soil conditions must be:

- With sufficient load-bearing capacity, and the ground below safely bears the loads
- Stable, so it does not slip, tip over, etc.
- Its sinking stay within the permissible limits
- Protected against the harmful effects of aggressive soil or groundwater and the risk of frost

2.2. Foundation design requirements

- Sufficient strength
- The structure must be free from harmful stresses
- The even sinking must be kept to a minimum
- Do not produce uneven sinking
- Withstands to structural damage (frost, groundwater, aggressive groundwater)
- Economical design

Fig. 33. Manhattan Island badrock

The needed basic data for the design of the foundation:

Characteristics of the building

- Function
- Size
- Structural system
- Mass distribution
- Self weight
- Load

Ground conditions

- Soil stratification
- Inclination of the soil layers, deepness and thickness
- Soil physical characteristics (particle size, grain shape, grain structure, gap volume, water content, consistency, compressive and shear strength, etc.)

Groundwater conditions

- Groundwater level
- Groundwater level fluctuation
- Groundwater flow
- Chemical properties

Adjacent buildings or structures

- planned distance
- foundation type and deepness

Material of foundations

In the existing buildings we can find brick or stone foundations which was used in former times, nowadays we usually build concrete and reinforced concrete foundations. In case of different foundation materials, the stress due to the load spreads at different angles, this is called the load transfer angle.

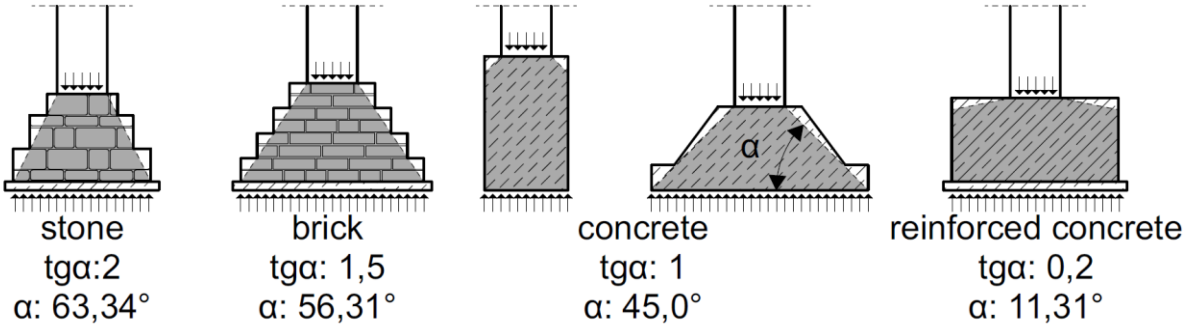


Fig. 34. Load transfer angle in different foundation materials

In addition to the materials listed above, there are also wood and steel foundations. Wooden pile foundations (not typical in Hungary), steel piles and sheet piles are mostly used for work pit delimitation or in the construction of bridge piers.

Interaction between foundations

The foundations built close to each other could cose the accumulation of stresses, harmful interactions can occur, this should be avoided during design. Therefore, e.g., the foundation level of the new building next to the existing building should the foundation level of the existing building.

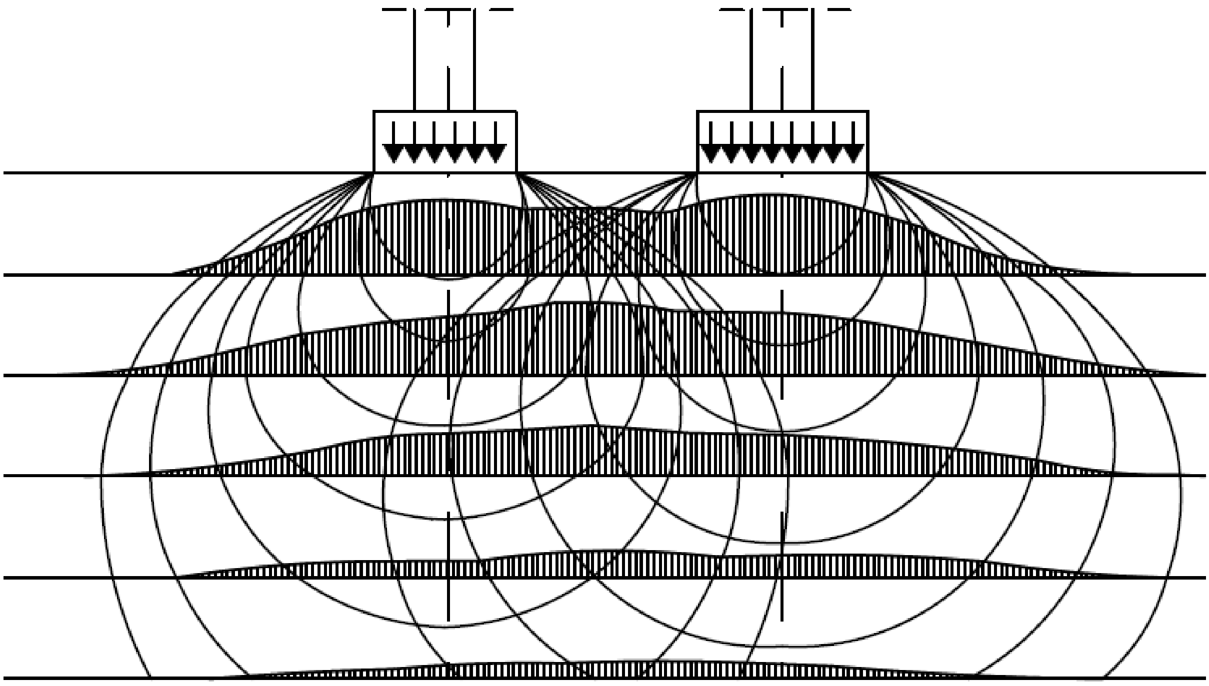


Fig. 35. Stress accumulation in soil layers

Foundations built close to each other can adversely affect the load bearing and load tranfer. The design should take into account the natural slope of the soil, the distance between the foundations, the load and structure of the buildings. If the foundations get too close to each other, its better to merge them.

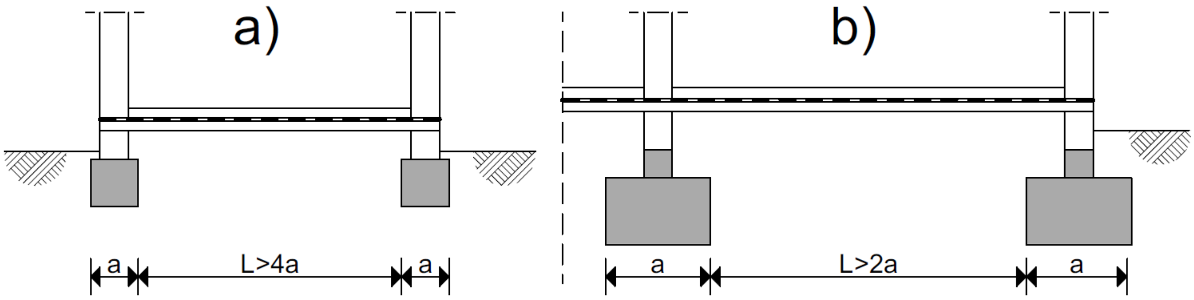


Fig. 36. a) minimum distance between strip foundations, b) minimum distance between pad foundations

The repair of improperly designed or constructed foundations expensive and difficult. The right foundation method has to be chosen according to the structure, load and soil conditions of the building.
In case of two building blocks with different number of levels could be significant diffrence in behaviour due to the stress diffrence on the ground. Therefore, the building structures must be separated by dilatation of the structure.

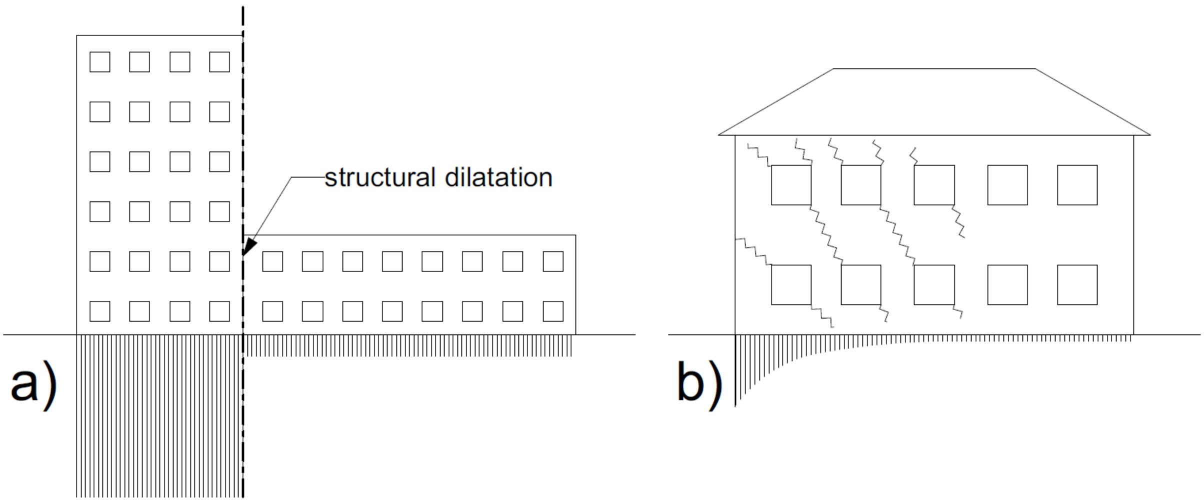


Fig. 37. a) Dilatation line of buildings with different height, b) Cracks due to uneven sinking

The uneven sinking of the building could be indicated by cracks rising from the corners of the openings in the direction of the sinking.

2.3. Types of foundations

Shallow foundations, often called **footings**. One common type is the spread footing which consists of strips or pads of concrete (or other materials) which extend below the frost level and transfer the weight from walls and columns to the soil or bedrock

- strip foundation
- pad foundation
- beam-grillage foundation
- slab (mat) foundation
- shell foundations

Deep foundations are used to transfer the load of a structure down through the upper weak layer of topsoil to the stronger layer of subsoil below. There are different types of deep footings including impact driven piles, drilled shafts, caissons, helical piles, geo-piers and earth stabilized columns.

- pile foundation
- well foundation
- box foundation
- slurry wall foundation

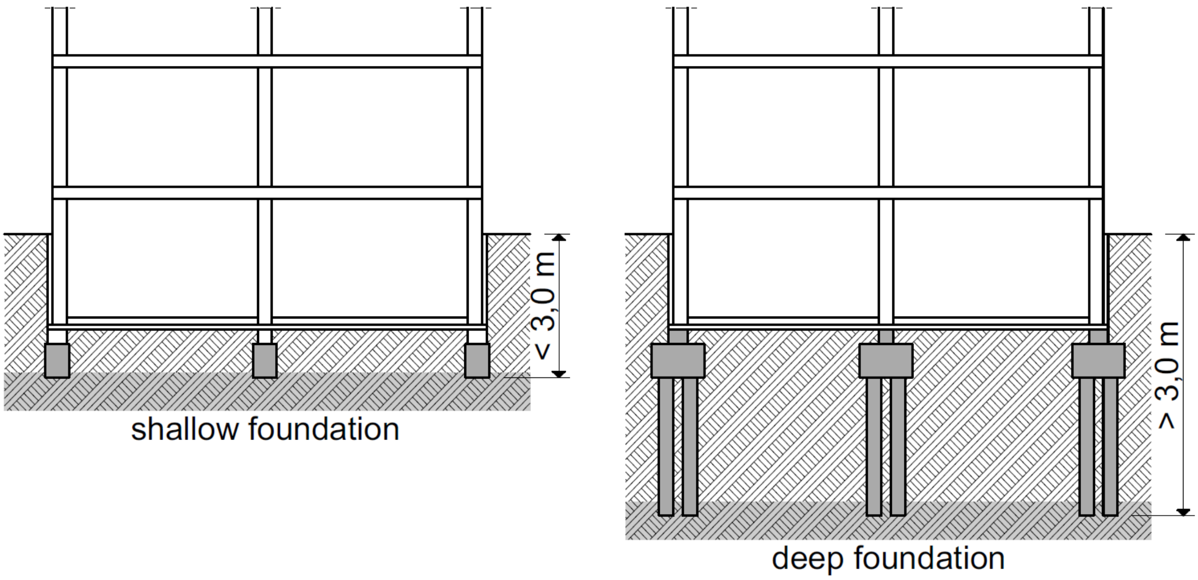


Fig. 38. Shallow and deep foundations schame

Both foundation methods can be prefabricated or on-site.

Semi deep foundations

- short drilled piles
- micro-piles
- mega-piles
- jet grounting

2.3.1. Foundation design

Deep foundation compare to shallow foundation is a complex and expensive solution. We can use a shallow foundation if the load-bearing subsoil close to the ground level and has adequate load-bearing capacity, if the soil load-bearing capacity is inadequate but the loads can be distributed over a large area, if the soil properties can be economically improved.

Soil bearing capacity: $\sigma_{th} = F/A$

Effective foundation surface: $A = F/\sigma_{th}$

A=5-10% pad foundation;
A=15-30% strip foundation;
A=5-10% beam-grillage foundation;
A>60% slab foundation;
A>100% deep foundation;

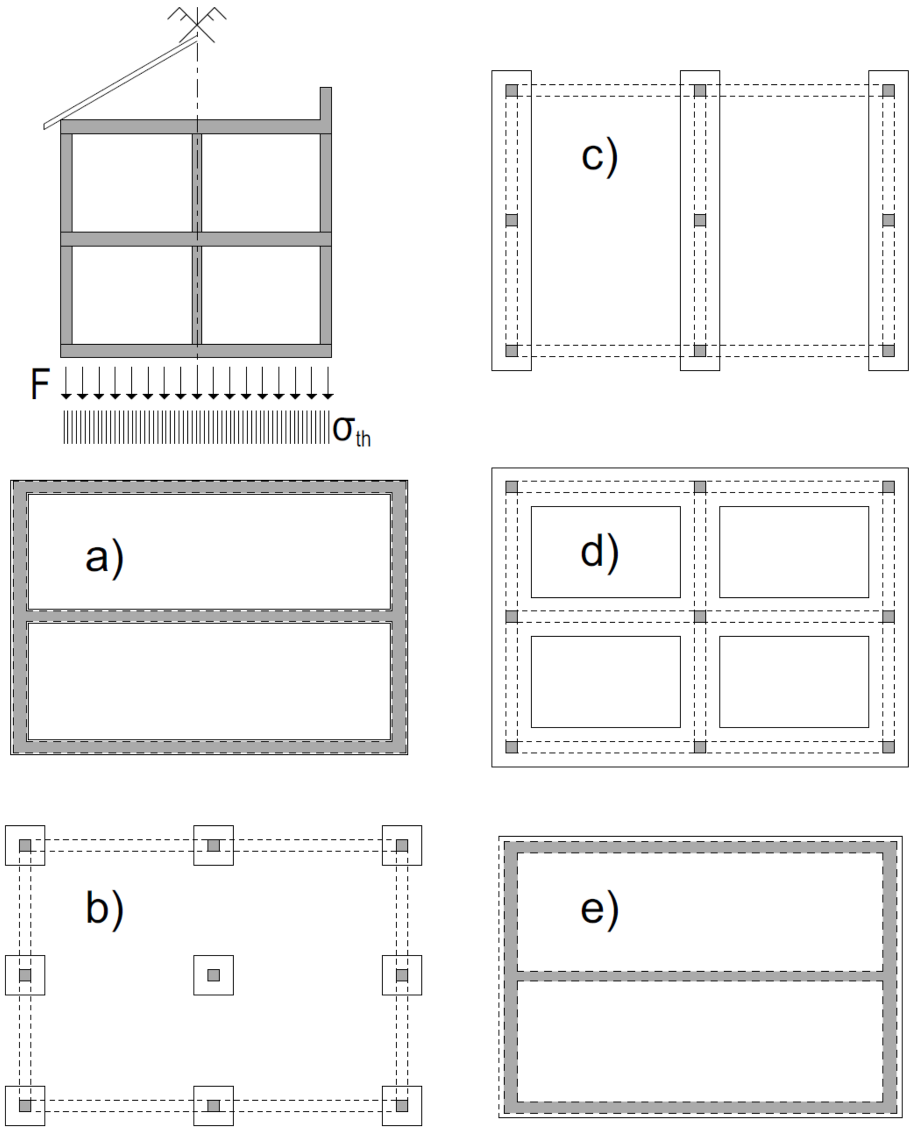


Fig. 39. a) strip foundation, b) pad foundation, c) beam foundation, d) grillage foundation, e) slab foundation

A deep foundation method is needed if the shallow foundation is not economical or not suitable, the load-bearing subsoil is on deep level, the groundwater level is high, there is a risk of water washing, slipping.

2.4. Shallow foundations

Determination of the foundation level

- the foundation level must be at least 10 cm below of the upper level of the loadbearing soil;
- the foundation level should be below the frost level (80-100 cm in Hungary);
- minimum foundation depth 50 cm;
- the foundation level preferably has to be above groundwater level;
- the foundation of a neighbor buildings must be taken into account;

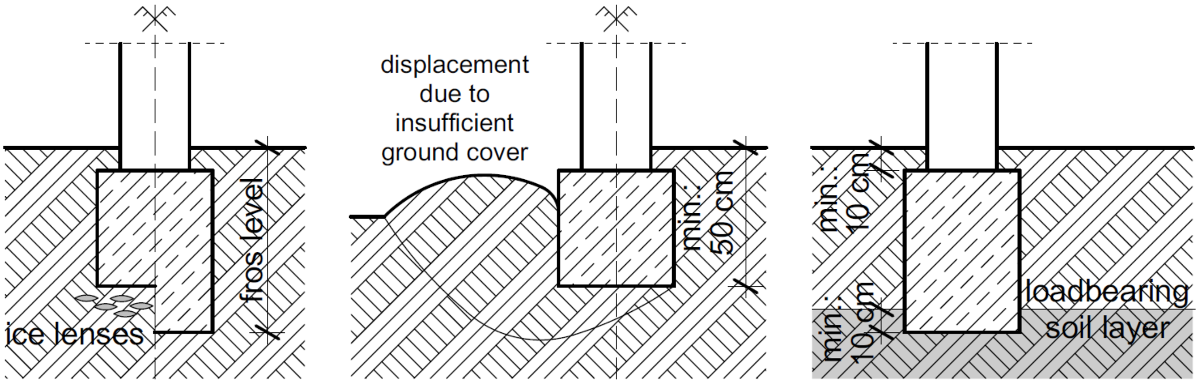


Fig. 40. foundation depth

2.4.1. Strip foundation

The **strip foundation** provides a continiuos support under linear structures such as a wals or closely-spaced rows of columns built centrally above them. The material of the strip foundation is usually concrete or reinforced concrete, in former times stone and brick masonry foundations have also been built. The strip foundation is a simply and economical method of foundation.

Choice of particular shape for the strip foundation

The dimensions of the strip foundations must be determined by starctural calculation. The minimum dimensions determind b by the thickness of the wall on it and the space requirements of the connecting structures (eg. protecting or supporting wall of the waterproofing), as well as the tolerance for earthworks (5 cm). The bottom or load-transfer width of the strip foundatione is determined primarily by the load-bearing capacity of the soil, and secondarily by the material of the foundation and its load transfer angle.

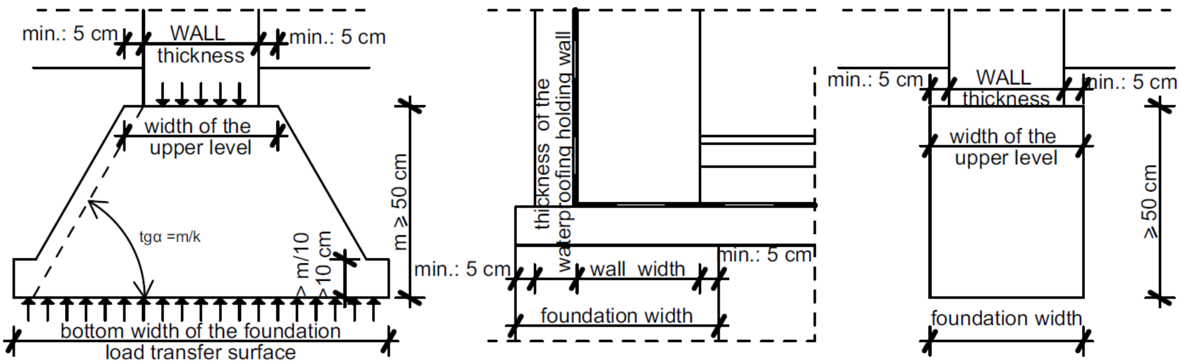


Fig. 41. Crossection fo strip foundation

The cross section of the strip foundation can be rectangular or trapezoidal shape, in today's practice trapezoidal foundations are not typical due to their formwork requirements.

Changing of the foundation level

Stepped foundation could be needed in the case of different foundation level of neighbour buildings, the slope of the terrain or becouse the design of the foundation of a partially basement building. In any case the foundation must be carefully designd, in order to avoid harmful stresses between the foundations, the change of the foundation plane must be done step by step following the natural slopeangle of the soil.

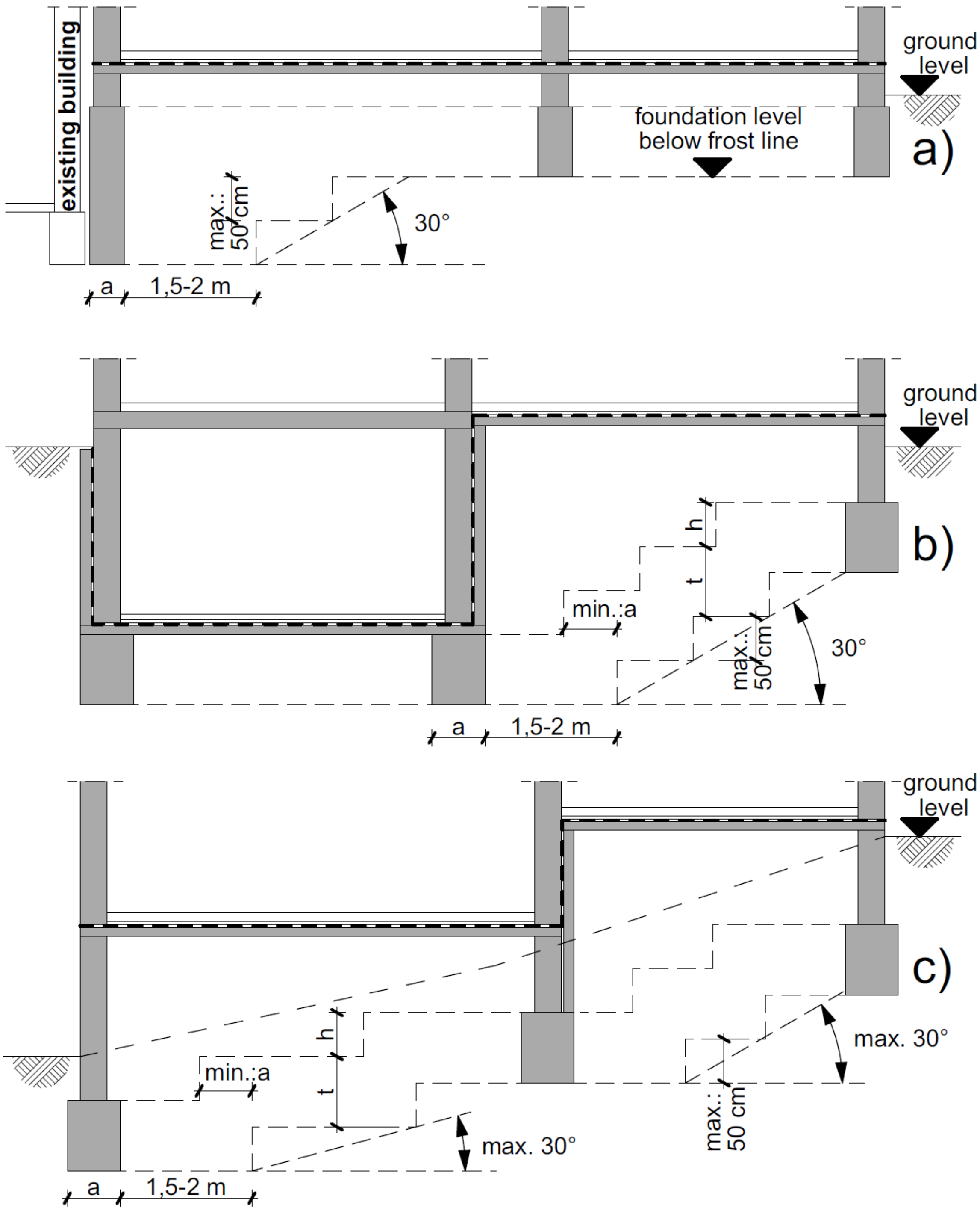


Fig. 42. Strip foundation stepping

The inclination angle of the steping must not be higher than the natural slope of the ground (max. 30 °); the height of a steps cannot exceed 50 cm. The overlap between the steps must not be less than the width of the foundation.

2.4.2. Pad foundation

Pad foundations are support localised concentrated loads of structural columns, groups of columns or framed structures. Pad foundations are a form of spread foundation formed by rectangular, square, or sometimes circular concrete of reinforced concrete pads. Reinforced concrete pad foundations can be on-site (monolithic) or prefabricated elements. In the case of monolithic reinforced concrete superstructures monolithic point bases are used, and in the case of prefabricated superstructure prefabricated sleeve foundations.

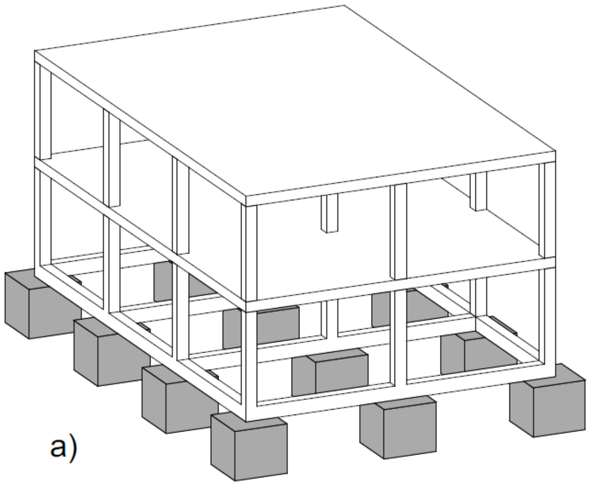


Fig. 43. Pad foundations

Sleeve foundation are prefabricated reinforced concrete elemets conected to the monolitchic pads on site. The binding reinforcement enables the connection with the monolithic foundation soles, thus increasing the execution speed.

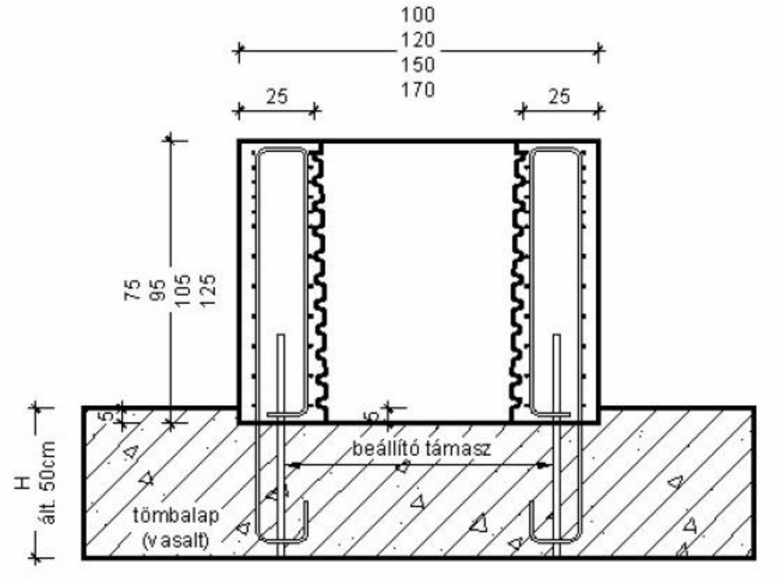


Fig.44. Precast sleeve foundation

2.4.3. Beam and Grillage foundations

Beam or grillage foundation like pad foundations are support concentrated loads of structural columns. The main diffrence is that the beam foundations can transfer much higher loads to potentially weak subsoil, and pad foundations would already be too large for adequate load transfer.

A beam or girder foundation could be used if:

- the building is sensitive to subsidence;
- the load on the building is high;
- the quality of the subsoil varies;
- the creation of point bases is no longer economical;

The **beam foundation** is made of reinforced concrete beams running in one direction under the pillars or wall sections. The connection between the beams is provided by sole beams in the line of the walls.

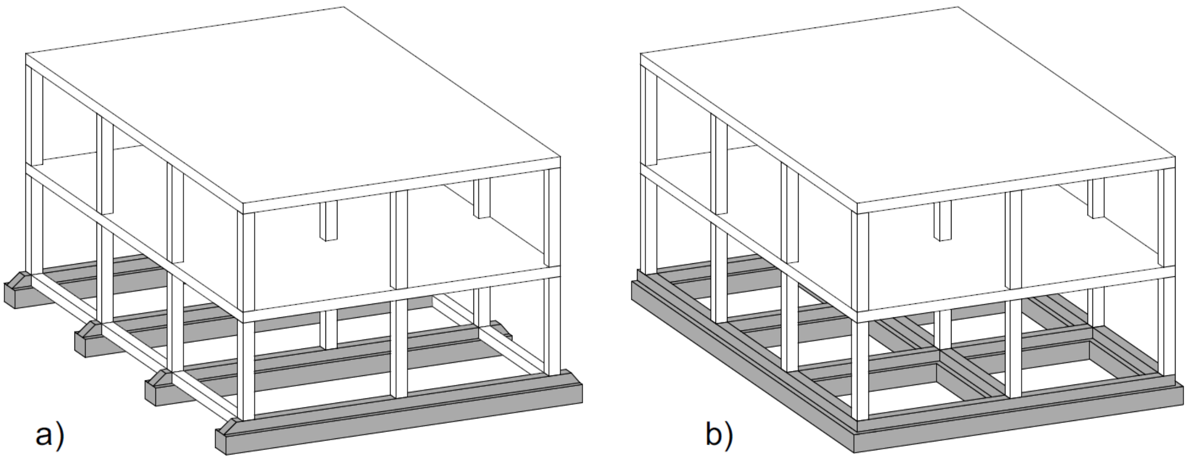


Fig.45. a) beam foundation, b) grillage foundation

The **grillage foundation** is a foundation made of reinforced concrete beams running in both directions in the raster of the pillars. This solution significantly improves the stiffness and stability of the building.
The cross-section of the beam and grillage foundations is made with a rectangular, inverted T-shape or a downward-widening trapezoidal shape. The beam foundations distribute the concentrated loads of the pillars and transfer them to the ground along a line.
The beam and grillage foundation foundations always follow the structural system of the building, the distribution of the beams and the load-bearing direction of the slabs.

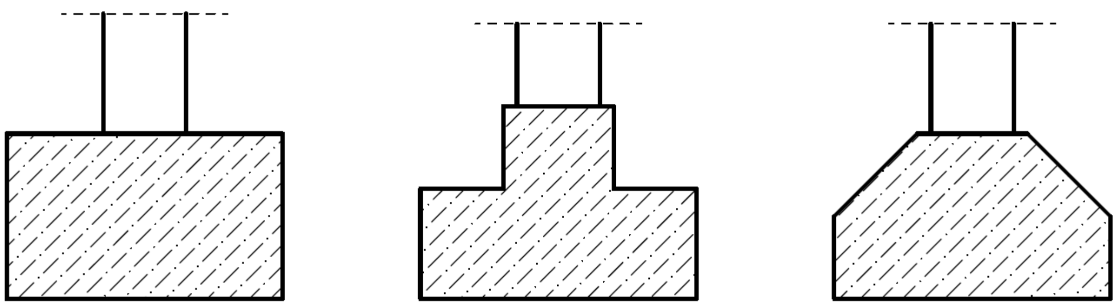


Fig. 46. Typical cros sections of beam and grillage foundations

2.4.4. Slab (mat) foundation

The slab foundation is a continuous reinforced concrete slab resting on the soil that extends over the the entire footprint of the building and transferring its weight to the ground. The slab foundation is often used in case of weak soils, as it distributes the weight of the buildingth.

A slab foundation could be used if:

- the soil is weak, not strong enough compare to the load of the building;
- soil quality is difare, there is a danger of uneven sinking;
- the basement level is partially below the groundwater level and water pressure acts on the structure;
- groundwater (or soil moisture) is having aggressive chemical properties and the protection of the foundation must be ensured;

The **advantage** of slab foundation is that it is not sensitive to subsidence and other external (eg dynamic) effects, the substructure of the building is simple and safe, the excavation can be well mechanized.
The **disadvantage** is that a horizontal foundation plane must be formed for the slab foundation, it is not possible to follow the sloping terrain or making a stepped foundation by the neighbor buildings.

The slab foundation is an inverted reinforced concrete slab, where the load is coused by the soil stresses and groundwater pressure on the slab, and the downward forces coused by the load of walls and pillars.

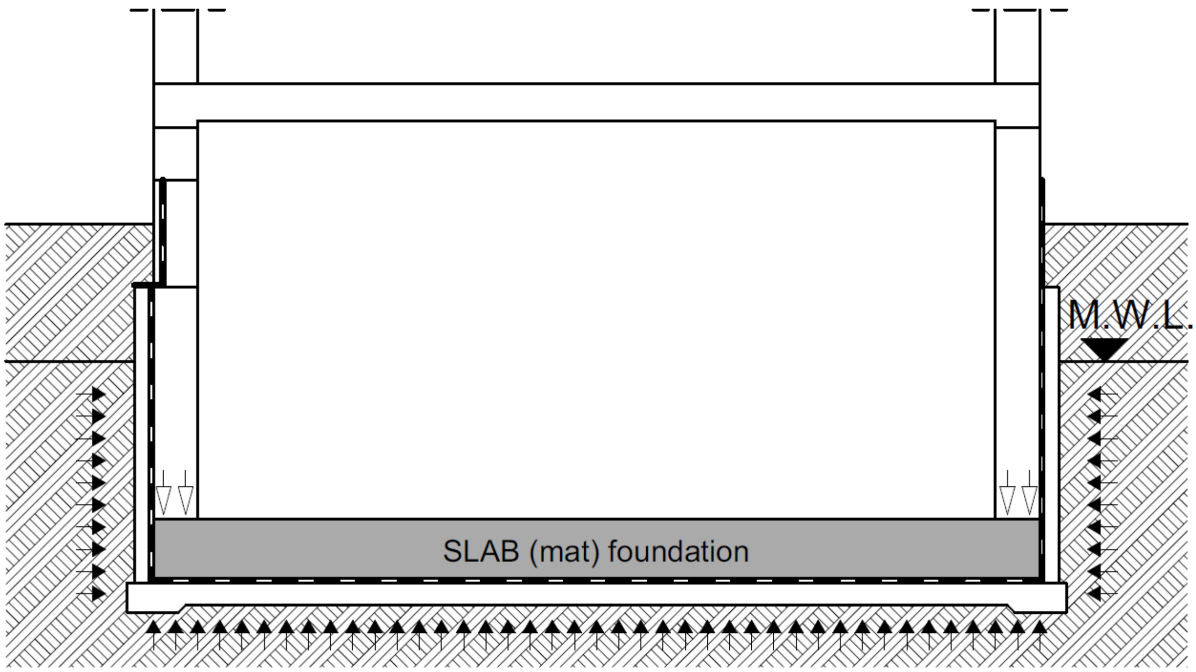


Fig. 47. Slab foundation

Slab foundation can be also used in small deepness, in this case the foundation must be protected of the frost affect. The foundation is usually surrounded with drainage system to reduce the water level and prevent the frost damage.

2.5. Deep foundation

A **deep foundation** is used to transfer the load of a structure down through the upper weak layer of topsoil to the stronger layer of subsoil below. Compared to shallow foundations, deep foundations have the merits of being suitable for more adverse soil conditions and less site constraints.

The deep foundations can be divided according to the design of the structures to the following groups:

- pile foundations;
- well foundations;
- box (caission) foundations;
- slurry wall foundations;

Area of application of the deep foundations:

- the load-bearing soil is positioned on deep level;
- there is a risk of outwashing or slipping in the upper soil layer;
- the groundwater level is high;
- the building is sensitive to subsidence;
- the new structure is too close to the existing buildings;
- retaining walls must be built;

Characteristics of deep foundations

The most important characteristic of a deep foundation, similar to a shallow foundation, is the foundation depth. In case of deep foundations, the load of the building is transferred to the deeper layer of soil by special load-bearing structure. These structural elements can be pile-type and well-type. In both cases, the primary goal in their design is to be able to construct the foundation in the simplest possible way, with less earthwork.

Load-bearing properties of deep foundations

The load-bearing capacity of deep foundations depends on the location of the load-bearing soil layer, the position of the groundwater and the subsidence of the building.

Thera are two main load transfer types:

- the loads transferred to the load-bearing soil layer through peak resistance
- the load transfer utilizes the frictional resistance force between the pile surface and adjacent soil.

In reality, it is always a combination of two load transfer becouse in any case the foundation transfers the loads in both ways.

2.5.1. Pile foundation

Pile foundation is one of the oldest and widespread methods of deep foundations. This foundation method transfers the loads of the building to the deep subsoil. Pile foundation can be well mechanized and quickly implemented, it can be used in case of solid wall structure and framed buildings too. Pile foundation can be done with soil displacement or soil replacement technologies.

A pile foundation could be used if:

- The load-bearing capacity of the upper soil layers is low, the loadable soil layer lies deep;
- There is a risk of slipping;
- There is a risk of uneven subsidence;
- The groundwater level is too high for the shallow foundation;
- The load of the building is too high;

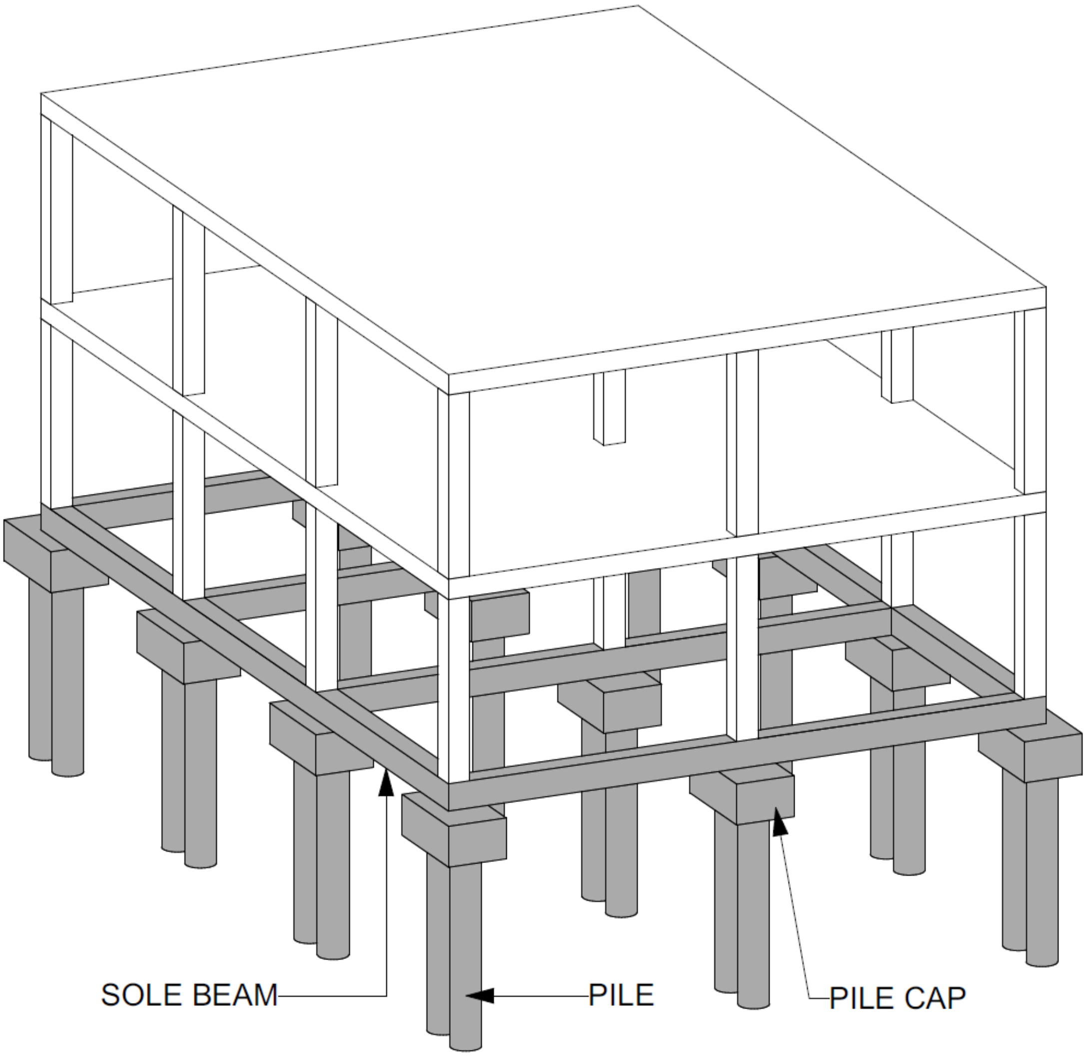


Fig. 48. Pile foundation

Parts of a pile foundation: pile or group of the piles joined by pile head, beam grid or slab connecting the pile heads.
The **material of the piles** can be wood, steel or reinforced concrete. Nowadays the application of the reinforced concrete pile is most common. Wooden piles are rarely used, in special cases steel piles are also applied.

The pile foundations can be divided according to the load transfer to the groups

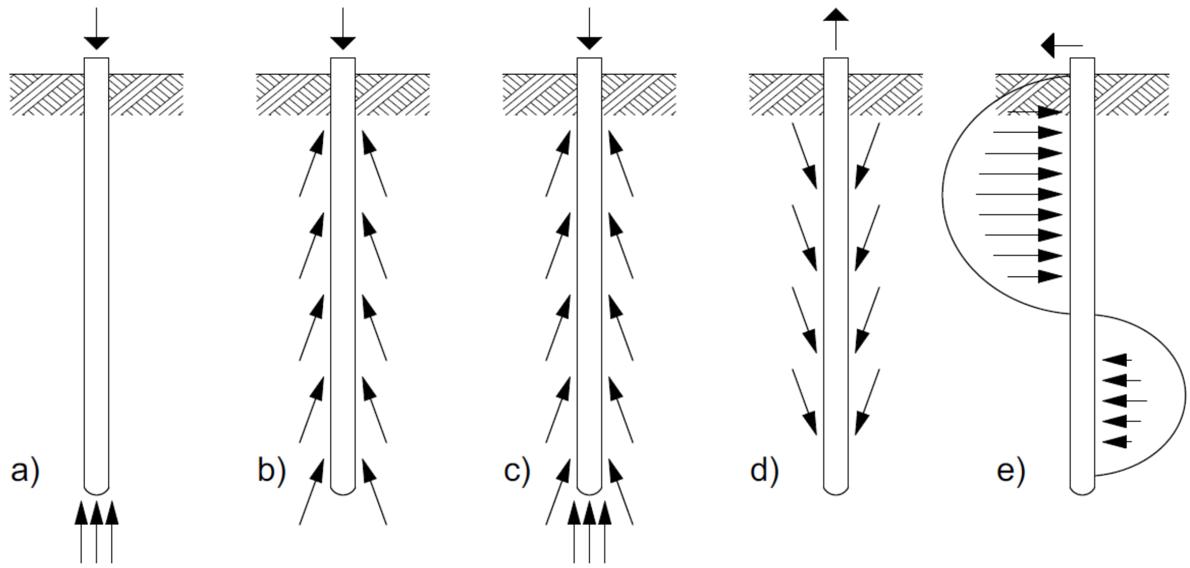


Fig. 49. a) end bearing pile, b) friction pile, d) combined pile, d) tension pile, e) anchor pile

The load transfer degree of piles

standing pile:	2/3 of the load capacity is transferred by the peak resistance;
friction pile:	2/3 of the load capacity is transferred by the friction;
combined pile:	33% of load by friction and 66% by the peak resistance;

The pile foundations according to the way they are made can be monolithic and prefabricated

The piles are always made longer than planned becouse the pile head have to be conected to the piles. In the case of monolithic piles, the pile head with inadequate strength must be demolished. The reinforcement bars of the pile head are unfolded, and then connected to the reinforcing bars of the pile cap. In the case of prefabricated piles, the pile head reinforcement cap is welded to the reinforcment of the pile cap.

Pile dimensions:

Micropiles:	D=8-30 cm mainly used for foundation reinforcement
Conventional piles:	D=30-80 cm buildings with usual load
Large diameter piles:	D> 80 cm buildings with high loads
Pile length:	2 – 100 m > 5D(diameter)
Pile diameter:	10 cm < D < 500 cm

Pile spacing:

End bearing pile:	X ≥ 2,5D
Friction pile:	X ≥ 3D

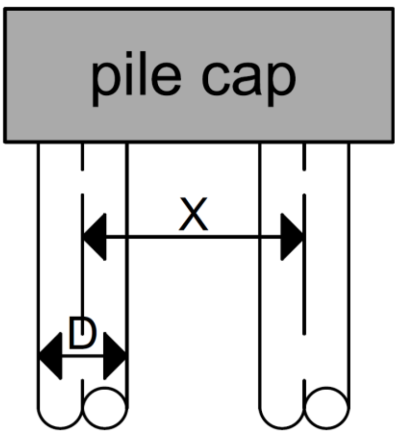


Fig. 50. Pile cap and spacing

Prefabricated piles

Prefabricated concrete piles made of high-strength concrete or prestressed concrete with a cross-section dimensions of 30-40 cm, with square, triangular or polygonal shape. The length of the piles is determined by the manufacturing technology and the transport.

A precast pile foundation could be used if:

- loose soil layers allow the pile driving, low driving resistance;
- the load-bearing capacity of the soil can be improved by pile driving;
- foundation depth max.: 10-12 m;
- the pile driving don not damaged the neigbour buildings;

Pile driving methods:

Pile driving by **dropping weight**. The hammer weight is raised a suitable height and dropped to the pile head and in that way the pile is drived to the required depth. The pile head must be reinforced with a stell cap, to avoid the demolish of the pile head. The advantage of this method is that during the piling the surrounding soil layers are compacted, thus improving the load-bearing capacity of the pile. The dynamic effects of pile driving can damage surrounding buildings and therefore cannot be used in urban environments.

Vibratory hammers are usually electrically powered or hydraulically powered and consists of contra-rotating eccentric masses within a housing attaching to the pile head. The amplitude of the vibration is sufficient to break down the skin friction on the sides of the pile. Vibratory methods are best suited to sandy or gravelly soil.

Jetting: to aid the penetration of piles in to sand or sandy gravel, water jetting may be employed. However, the method has very limited effect in firm to stiff clays or any soil containing much coarse gravel, cobbles, or boulders.

The combinations of technologies are also used e.g., jetting + vibration.

Fig. 51. Pile driving

Monolithic reinforced concrete piles

The bored piles made of monolithic reinforced concrete. Piles can be produced by casting concrete in the drilled void. The pre-assembled steel bar reinforcement is placed in the void before casting or vibrated into the fresh concrete.

Advantages of monolithic reinforced concrete piles:

- The piles reach the deep load-bearing subsoil;
- Heavy-duty piles, can be adjusted to the soil layer;
- Can be used in case of soil layers with variable load-bearing capacity;
- Can be used close to the adjacent buildings;

Continuous flight auger (CFA) drilling belongs to the dry rotary drilling methods. It is suitable for predrilling as well as for the installation of cast-in-place piles. The soil (under certain conditions also rock) is loosened and conveyed continuously using a continuous flight auger. The piles are bored and casted with concret in a continuous operation, while the drilling spiral is retracted the concrete is pumped through the drilling head on high pressure. The reinforcement is vibrated into the fresh concrete after concreting. The borehole wall is supported by the auger flights filled with drill cuttings.[4]

Bore diameter: 30-120 cm. Maximum foundation depth: 24-28 m.

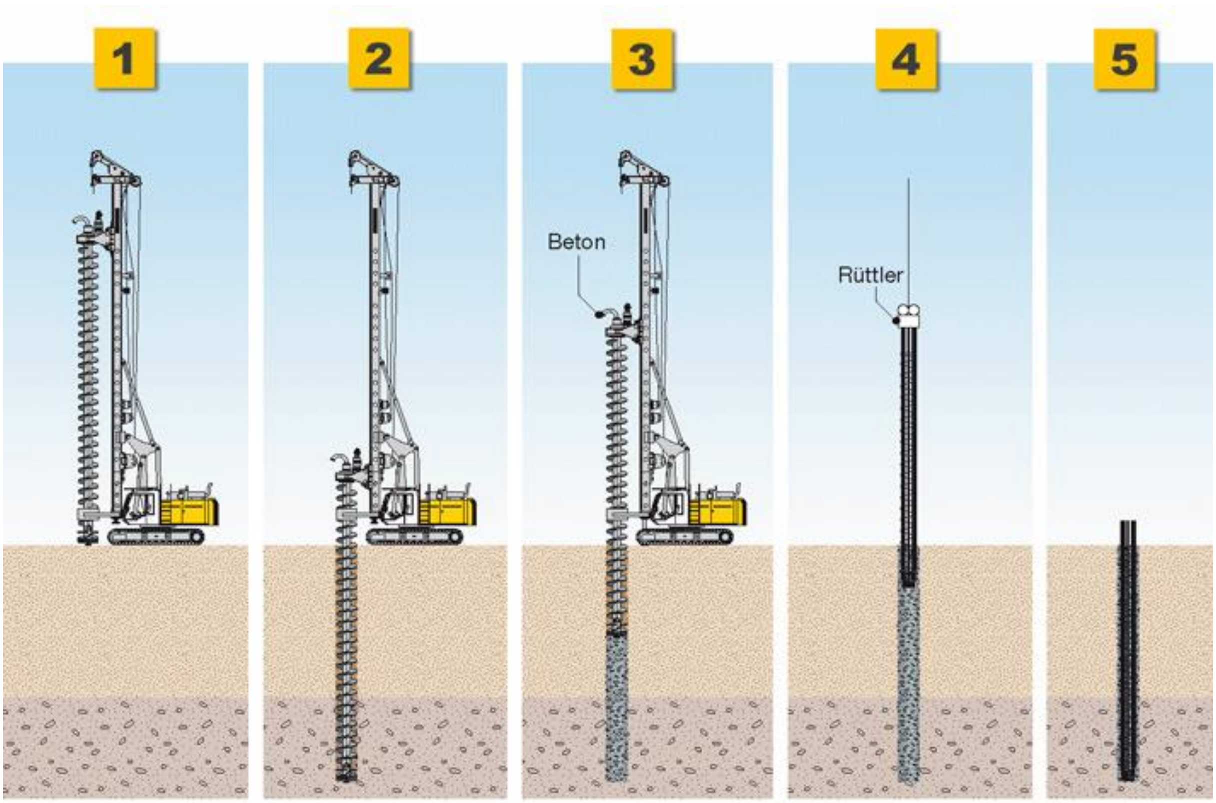


Fig. 52. Construction process of CFA piling

[4] https://www.liebherr.com/en/hun/products/construction-machines/deep-foundation/methods/drilling/drilling-methods.html#!/content=mcf-continuous-auger-drilling

Kelly drilling piles belongs to the most common dry rotary drilling methods and is used for the production of bored piles with a large diameter. The process is suitable for nearly all types of soil and rock. The soil is conveyed with short rotary drilling tools, such as augers, core barrels, buckets. [5] The pre-assembled steel reinforcement is inserted into the finished borehole, then a pipe is lifted to the bottom of the hole, which is continuously cast concrete during the retraction.

Bore diameter: 50-150 cm. Maximum foundation depth: 40-50 m.

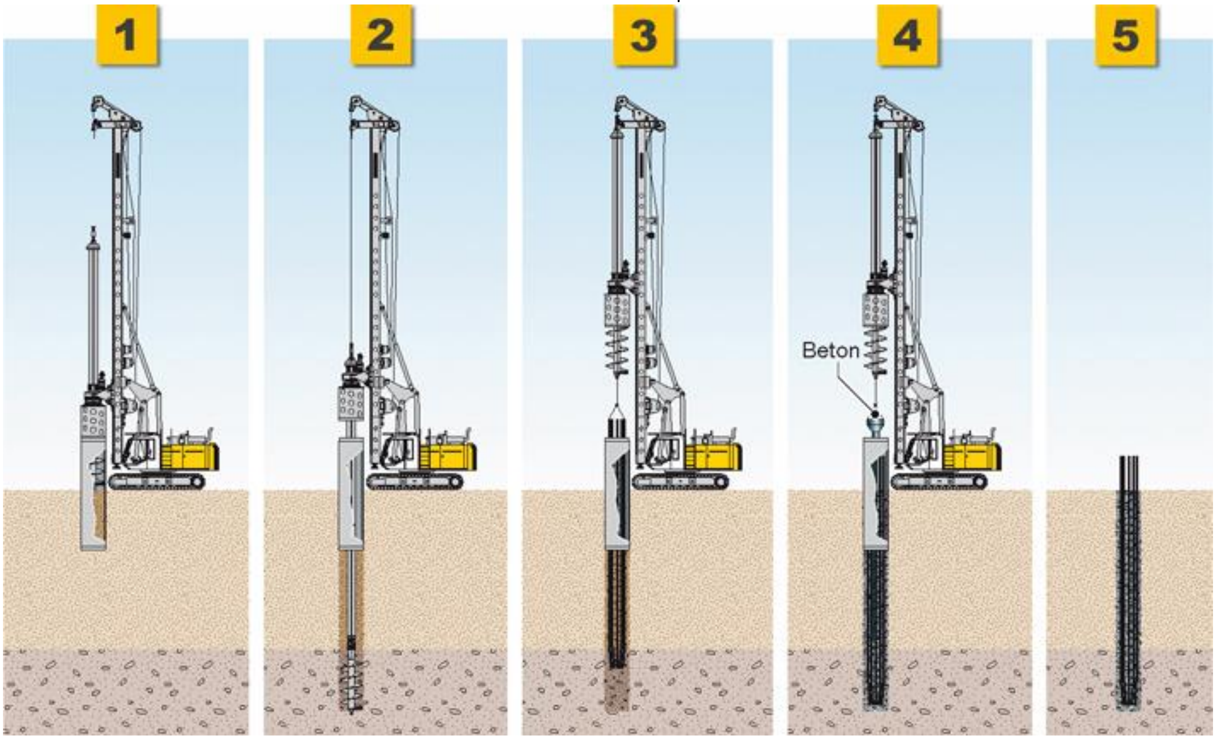


Fig.53. Construction process of Kelly drilling

Fig. 54. Pile boring

5 https://www.liebherr.com/en/int/products/construction-machines/deep-foundation/methods/drilling/drilling-methods.html

Grabb drilling

Drilling with bored pile grab is one of the oldest dry drilling methods and is still common today. Depending on the tools used, e.g., bored pile grab, chisel or special tools hanging on a duty cycle crawler crane, the soil is loosened either by cutting or impact driving. This method is applied, for instance, for well drilling with small drilling diameter or for the production of cast-in-place piles with sometimes very large diameters[6].

Bore diameter: 80-150 cm.
Maximum foundation depth: 40 m.

Fig. 55. Pile grab

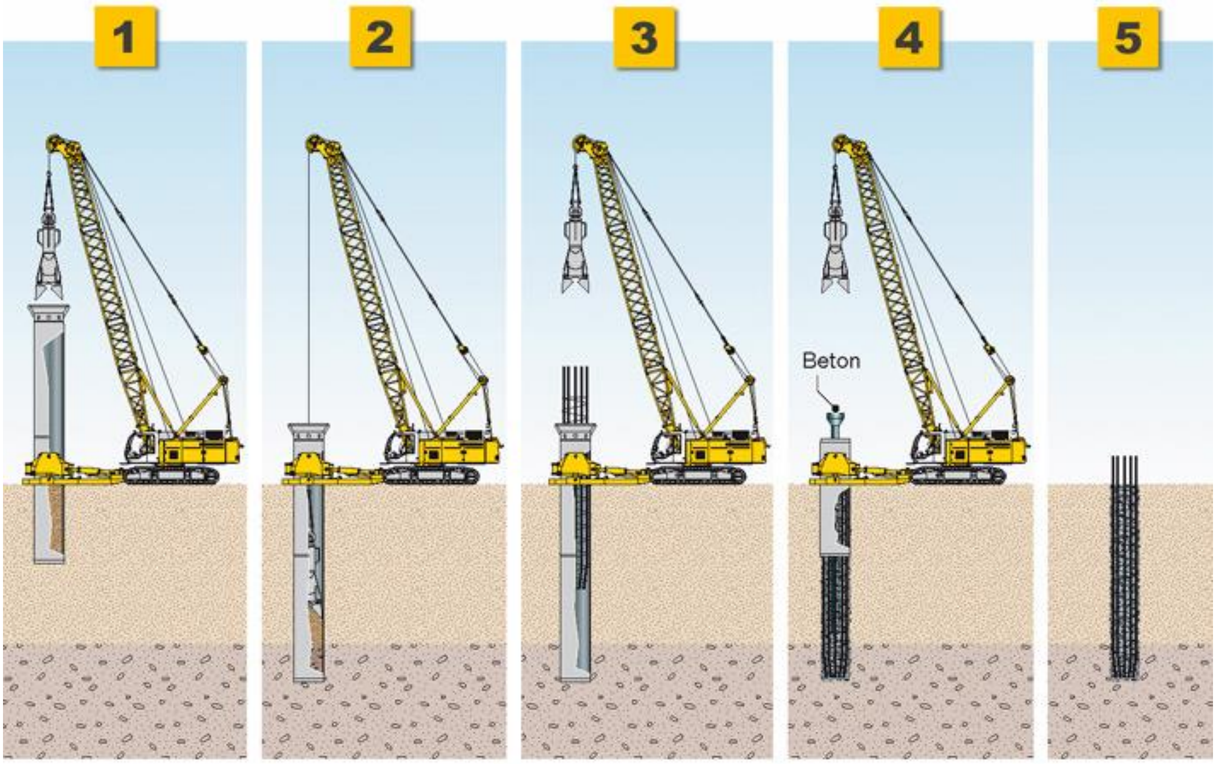


Fig.56. Construction process of Grab drilling

[6] https://www.liebherr.com/en/hun/products/construction-machines/deep-foundation/methods/drilling/drilling-methods.html#!/content=mcf-grab-drilling

The **Franki piling** system is a method used to drive expanded base cast-in-situ concrete (Franki) piles. It was developed by Belgian Engineer Edgard Frankignoul in 1909. This method can be applied to different site conditions and is still widely used due to its high tensile load capacity, and relatively low noise and ground vibration levels[7].

A steel tube is erected vertically over the place where the pile is to be driven, and about a metre depth of gravel is placed at the end of the tube. A drop hammer, 1500 to 4000kg mass, compacts the aggregate into a solid plug which then penetrates the soil and takes the steel tube down with it. When the required depth has been achieved the tube is raised slightly and the aggregate broken out wit a drop hammer. Concrete is now added and hammered until a bulb is formed. Reinforcement is placed in position and more concrete is placed and rammed until the pile top comes up to ground level.

Bore diameter: 45-60 cm. Expanded base diameter: 80-100 cm. Foundation depth: 16-18 m.

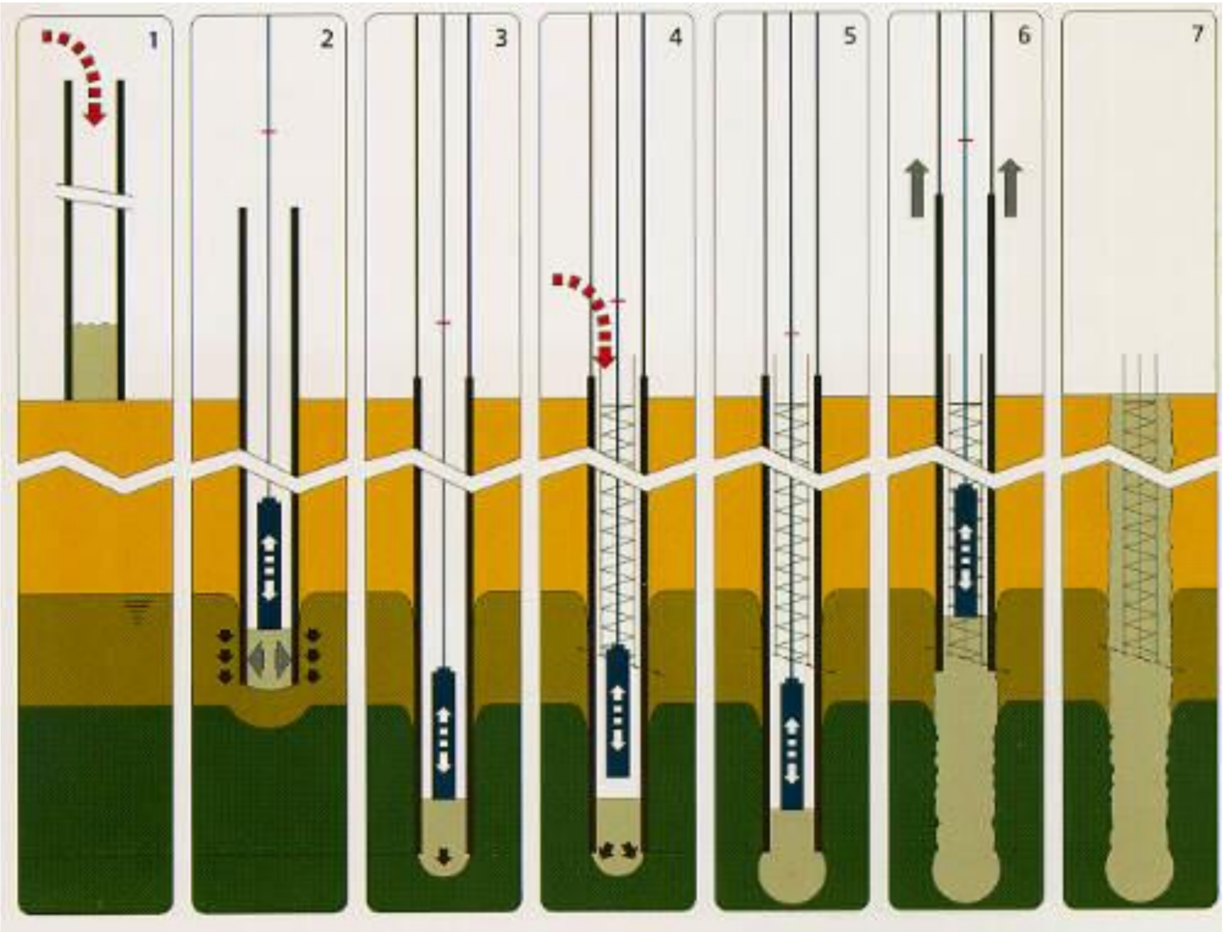


Fig. 57. Construction process of Franki piles

[7] https://en.wikipedia.org/wiki/Franki_piling_system

2.5.2. Well and Box cassion foundations

The well and box cassion foundations are types of deep foundations which are usually installed on the ground level and sunken to the required depth. Well and box foundations are large diameter foundations which could be used in case of underwater situations as bridge foundations.
The difference between well and box foundations in their layout, floor plan and size. The well foundation folow the arrengent and support the superstructure like pad foundations, but with deeper foundation level. In case of box foundation, the floor plan shape and size of it is usually have a same size and contur as the structure placed on it.

Variations according to the construction method:

- open well or box foundations;
- pneumatic box (cassions) foundations;
- thin-walled foundations (vibrated or pressed);
- floated well foundations (transported to the final position by floating on water);

A well or box cassion foundation could be used:

- if the subsoil can be easily dredged, the foundation level is above the bed rock;
- if the soil is highly waterpermeable, coarse-grained soils, where difficult to solve the watertightness, but the dewatering can be done by pumps;
- if the water cannot be pumped because of high water level and fine-grained soil;
- for retaining of the working a pit or for the construction of structures below ground and/or water level (in the case of large box foundations);

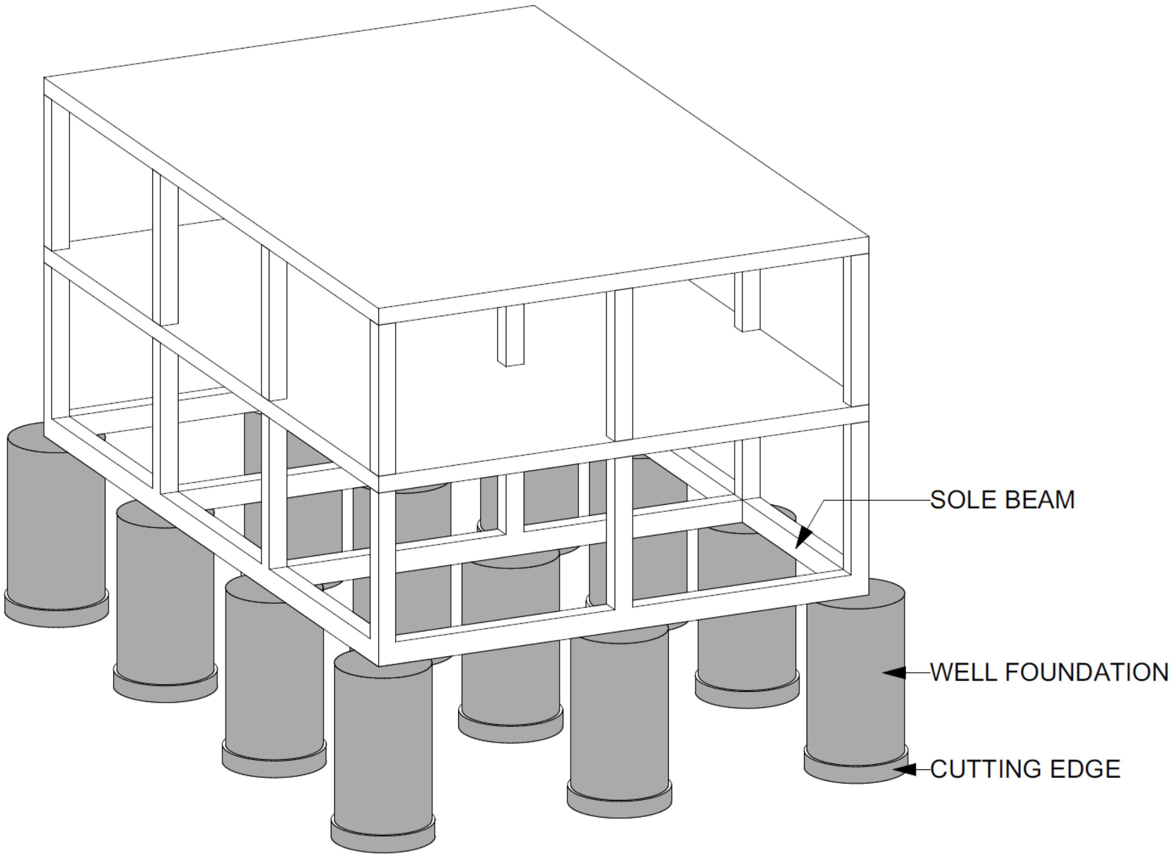


Fig. 58. Well foundation

Well foundation is used when the load-bearing soil is located at a depth (4-8 m), the well foundation can be easily sinked in to the ground and the ground can be dredged. Well foundation is used in case of heavy building loads and for the buildings which are sensitive to subsidence, or in the case of highly waterpermeable soils, because in coarse-grained soils it's difficult to solve dewatering.

Components of well foundation

- the cutting edge and edge wreath, this part is responsible for cutting through the soil layers, and for the load distribution in case of uneven soil layers
- the staining wall is resisting the earth and water pressure and transfer the loads

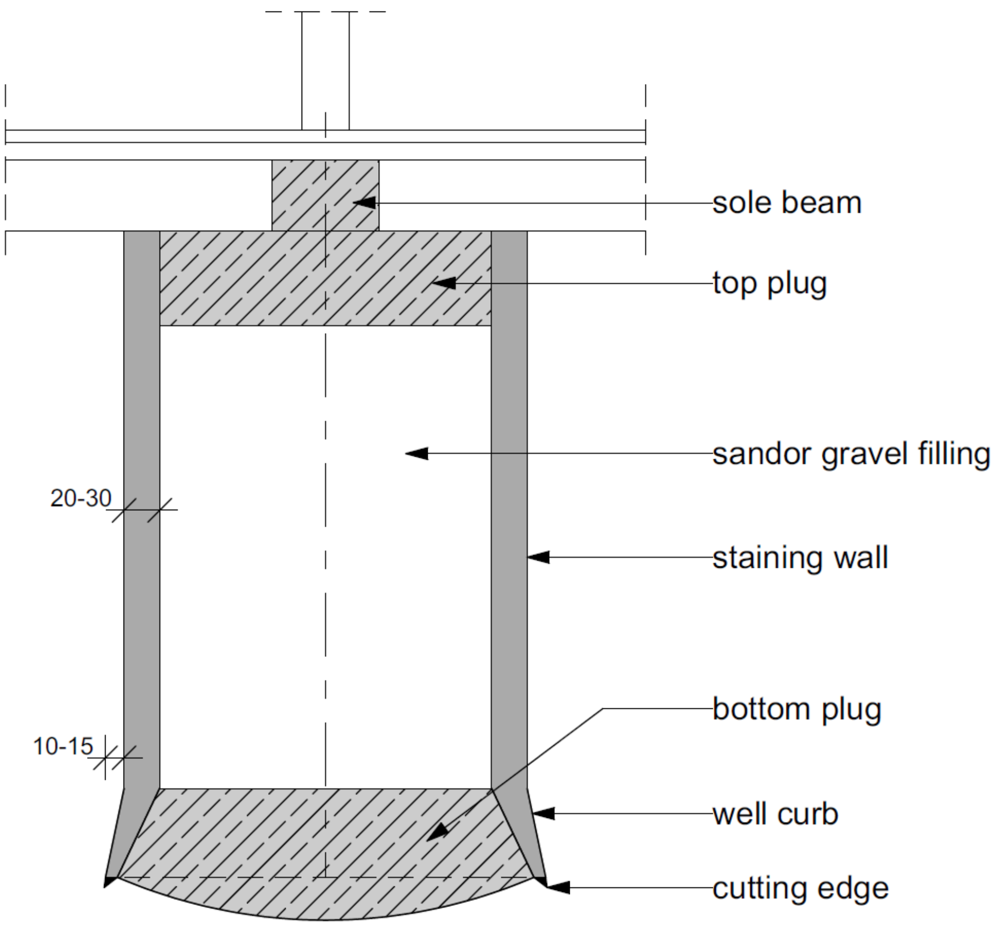


Fig. 59. Components of well foundation

The structural solution of the well foundation is nearly similar to the water wells, except that the inside of the well is filled. The name comes from the similarity and the way it is made. The well may sink by the extraction of soil from the well ring.
To facilitate the sinking of the well, a steel cutting edge is mounted on its edge. The staining wall by the cutting edge should be formed with increised diameter to reduce frictional resistance between the ground and the wall. Friction-reducing material (e.g., rolling gravel or bentonite suspension) can be filled into the remaining gap between the ground and the staining wall. When the well is sunk to the required depth, the bottom is closed with a concrete bottom plug. The inside of the well is filled with sand or gravel and the top is sealed with a concrete top plug. The well foundations are usually connected with reinforced concrete sole beam on the top of the upper plug.

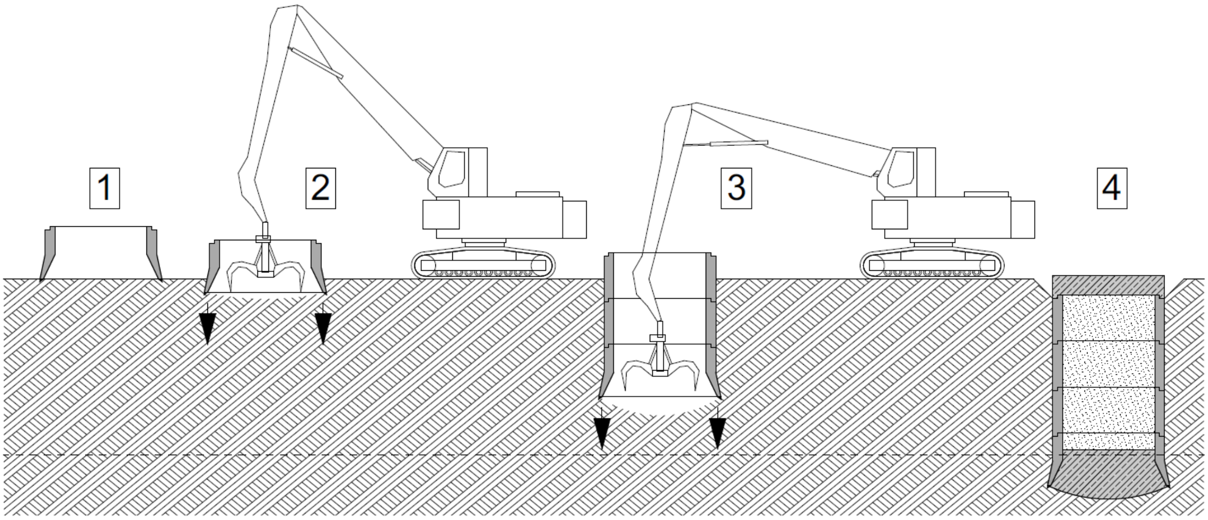


Fig. 60. Construction process of well foundation

Box caisson foundation

The box foundation is principally the same as the well foundation, but while the well foundation supports the structure of the building point by point, the box foundation is extending over the the entire footprint of the structure above. The soil is extracted in same way, from the cutting edge within the box foundation. Box caissons can be used up to 40-50 meters depth.

Types of box caisson foundations:

- open box caisson, the ground is removed by underwater dredging from the cutting edge;
- pneumatix box caisson, a chamber in the bottom fo the cassion serve a workspace for dredging, and the water is pressed out by high air pressure;
- the box closed at the bottom and floated on open water to the final position;

A special version of box caisson is the pneumatic caisson, which is usually used below groundwater level or in the construction of bridge piers. In the bottom of cassion a closed workspace is created, by high overpressure in cahmber. The high air pressure displaces the water from the chamber and the soil around the cutting edge can be extracted. In former times the dredging was done by hand, in present days the work is done by machines.

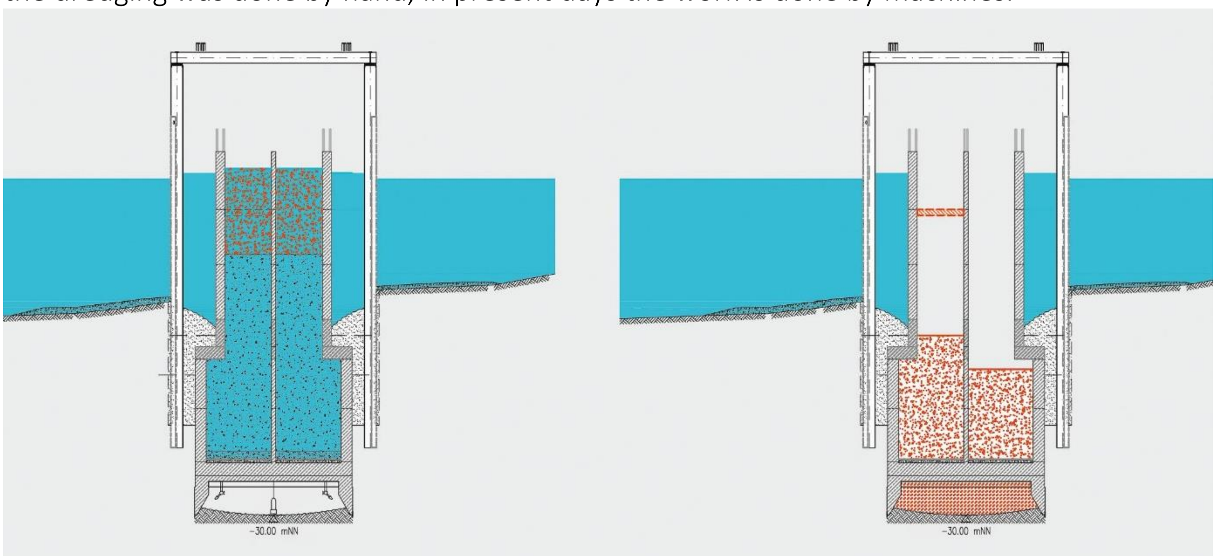


Fig. 61. Bridge pillar construction with pneumatic caisson

2.4.3. Slurry wall

Slurry walls are deep wall structures made of concrete or reinforced concrete which have static or sealing function. During the construction trenches are excavated in panels. A support fluid fills up the trench (usually bentonite suspension) and prevents the soil around the trenches from caving in. In case of reinforced concrete slurry walls after the final depth has been reached the premounted reinforcment cage is lifted to trench, then the support fluid is pumped out of the trench and replaced by concrete. The slurry wall can be made of monolithic or precast concrete elements, intermittent or continuous sealing panels and separate pillars.

Slurry wall thickness 40-180 cm, depth 6-110 m

A slurry wall foundation could be used:

- if the load-bearing soil is located on deep level;
- in case of construction between neighbor buildings;
- in case of big underground spaces (underground garage);
- in case of buildings with concentrated loads (higrise building);
- the building structure is sensitive to subsidence;

The advantages of slurry wall foundation:

- can be used in various soil conditions, regardless of groundwater;
- harmful dynamic or noise effects do not occur during construction,
- can be used directly next the foundation of existing buildings;
- any deep foundation procedure can be replaced by it;
- the work is almost fully mechanized, there is low live work needs;

Slurry wall construction process

The position of the slurry wall trench is ensured with guide wall that support the topsoil and guide the equipment during construction. Excavation can be done with a grab or a hydromill depending on the soil conditions and reqiured depth. During excavation, the trench is filled with support fluid (bentonite susopension), which ensures the stability of the trench and also keeps water away. During the concrete casting the heavier concrete displaces the bentonite suspension, which is pumped out, filtered, and stored in tanks for use in the next wall panel, or recycled.

The length of individual slurry wall panels can be maximum 10m. The wall panels are connected by extracting of the remaining ground between the panels and by the repeating of construction steps described above.

Fig. 62. Slurry wall grab

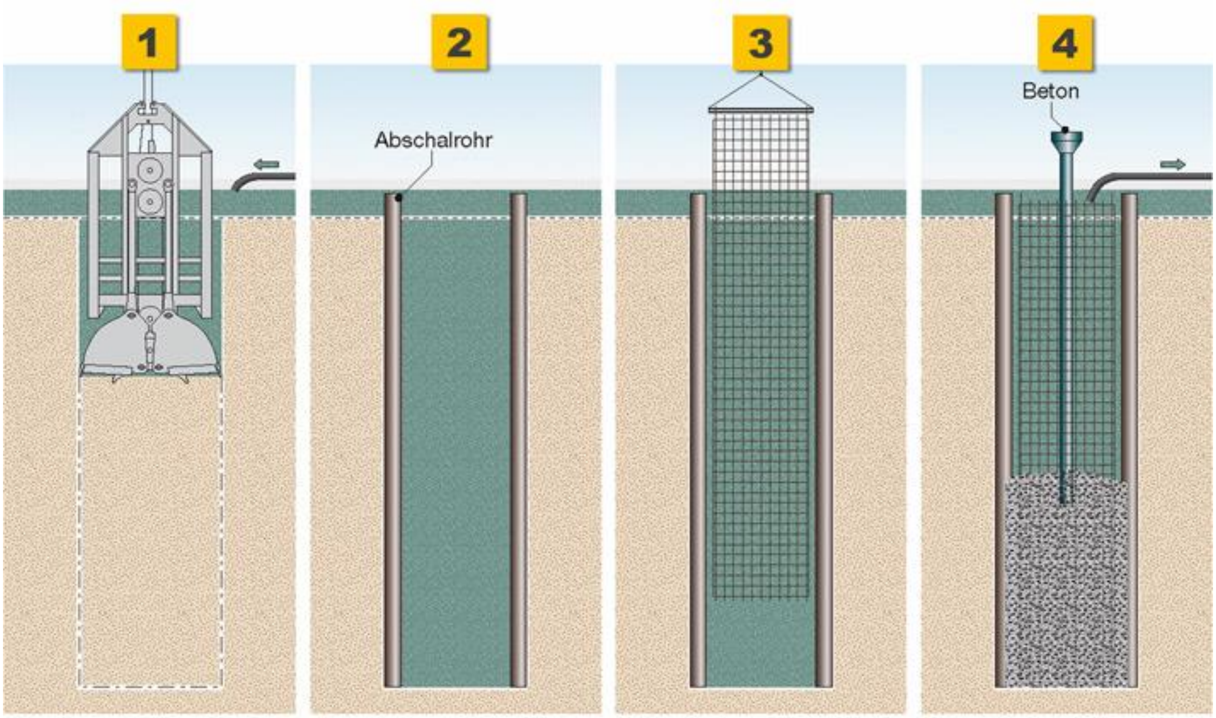


Fig. 63. Slurry wall construction process with grab

The horizontal length of the panels is determined by the structural requirements, trench stability, ground resistance and concreting conditions. The connection of the wall panels depending on the needs can be made watertight. In case of the construction of a continuous watertight wall, the individual panels are connected with shuttering pipes. The diameter of the shuttering pipe is equal to the thickness of the slurry wall.

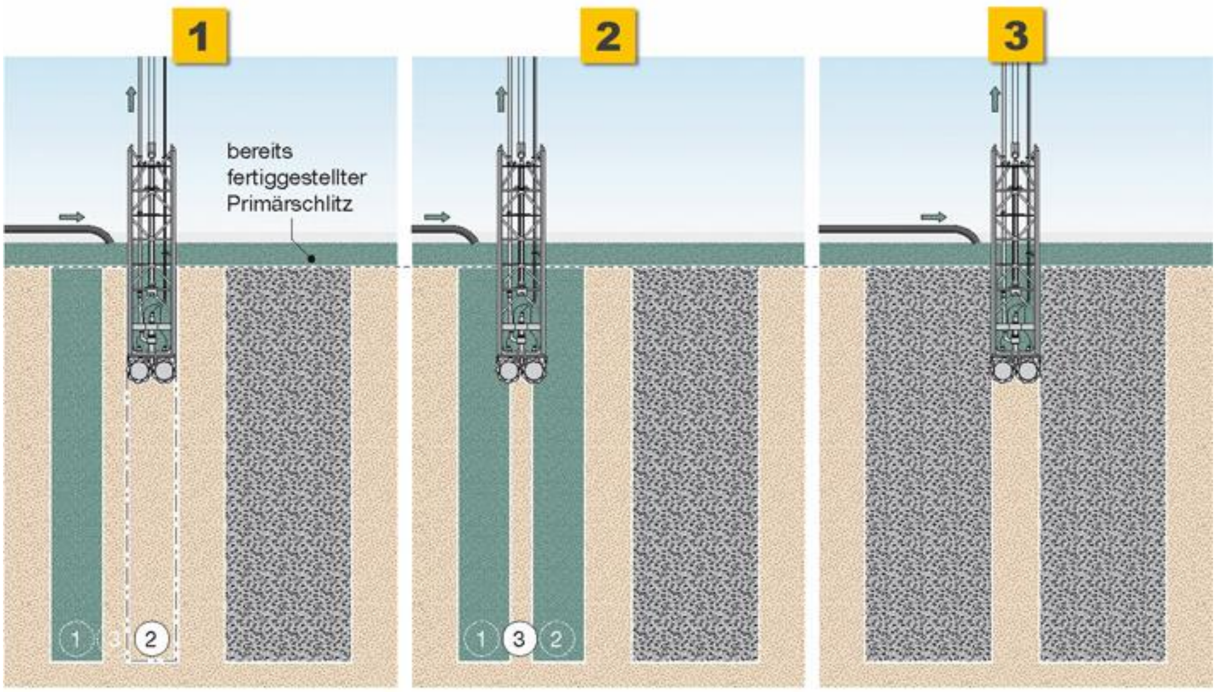


Fig.64. Slurry wall construction process with hydromill

After the construction of slurry wall, the extraction of the soil within the footrprint of the structure can be started. Since the slurry wall is relativly thin and tall straucture, care must be taken to support it during construction.

When a soil extraction reaches a certain depth, ground anchors are drilled through the wall to ensure the stability by anchoring the wall to the soil behind it. In the corners of the slurry wall, horizontal support beams must be placed, which can be removed during the construction of the slabs. In the case of a multi-level slurry wall, the anchors and reinforcements are formed on several levels according to the srtactural requirements.

Fig. 65. Kossuth square underground garage and visitor center, Budapest

Grouping of the slurry wall solutions

Depending on the structural requirements, the cross-section and design of the slurry walls, the layout of the walls can be as follows: independent slurry pillar foundations, continuousstrip-like slurry walls, closed shapes, with ribbed stiffeners or with combination of these. Slurry wall also can be made out of precast elements, these elements can be connected with precast pillars or with tongue and groove connection.

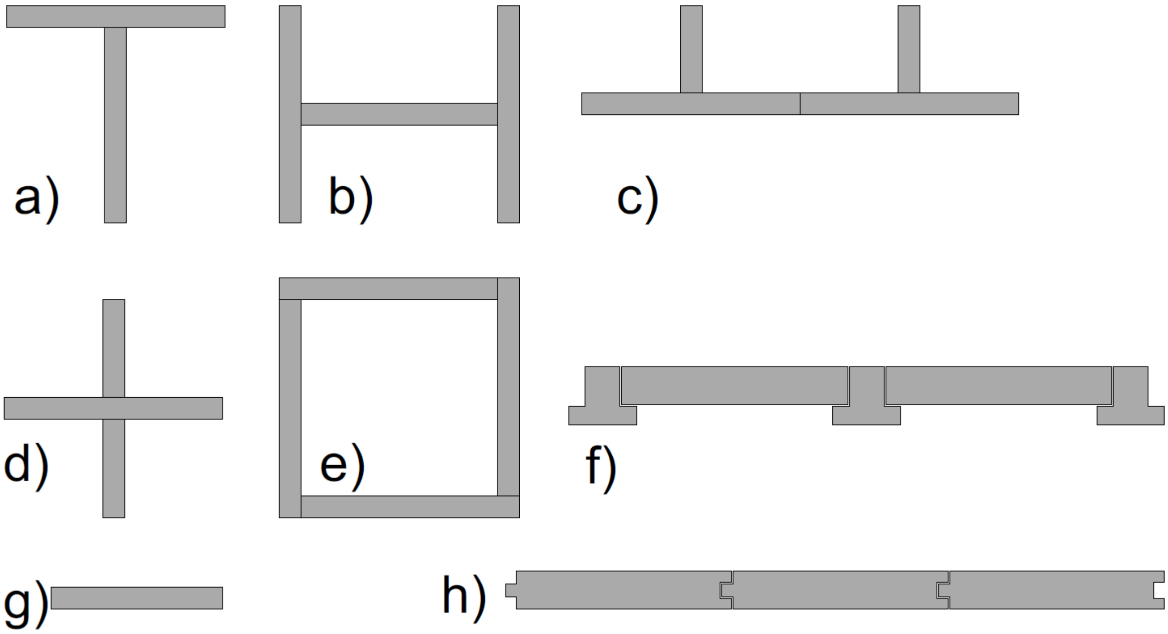


Fig. 66. a),b),d),e) slurry wall pillars, c) ribbed slurry wall, g) wall panel, f),h) precast slurry wall panels

2.6. Semi deep foundations

2.6.1. Jet-Grouting

Jet-Grouting is a special engineering technology which can be used for various purposes, underpinning of the existing foundations, watertight curtain walls, new foundations etc. The drill rod pushed into the ground, and by rotation of drill head inject a high water and/or air pressure which erode the soil structure. When the required depth reached, the drill rod retracted and a binder (cement grout) fluid injected on high-pressure, which mixes the soil, and create a column.

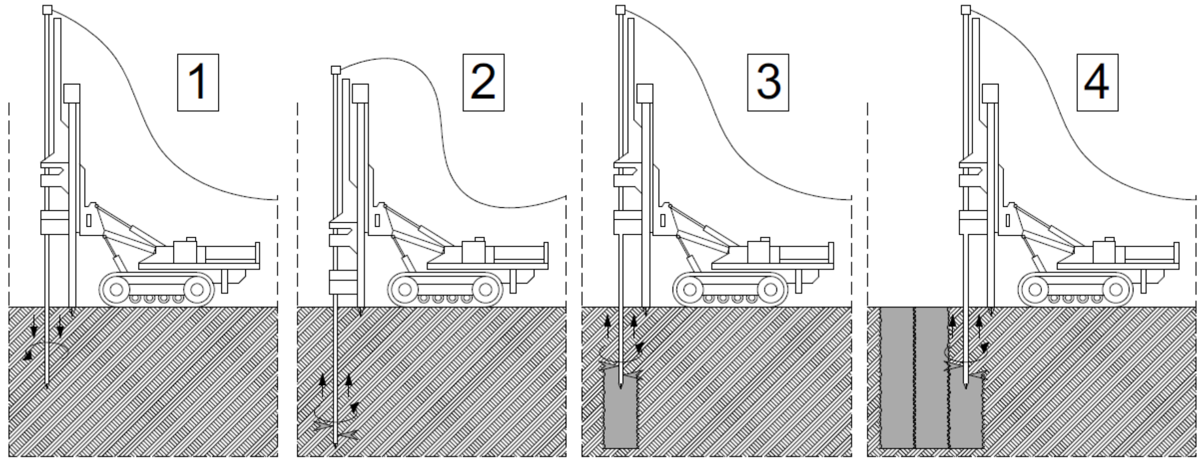


Fig. 67. Jet-Grounting construction process

The characteristics (columns diameters, length of the panels, composition of the mix, permeability, compression strength etc) of the jet grouting elements depend on the treatment parameters (extraction speed, rotation speed, grout injection pressure, flow and density etc), the soil conditions (type of soil, grain size distribution, compaction etc) and on construction method (single, double or triple-jet).[8] The rotation speed of the drill bit can vary between 10-20 rpm (revolutions per minute), the retraction speed is 20-50 cm/min.

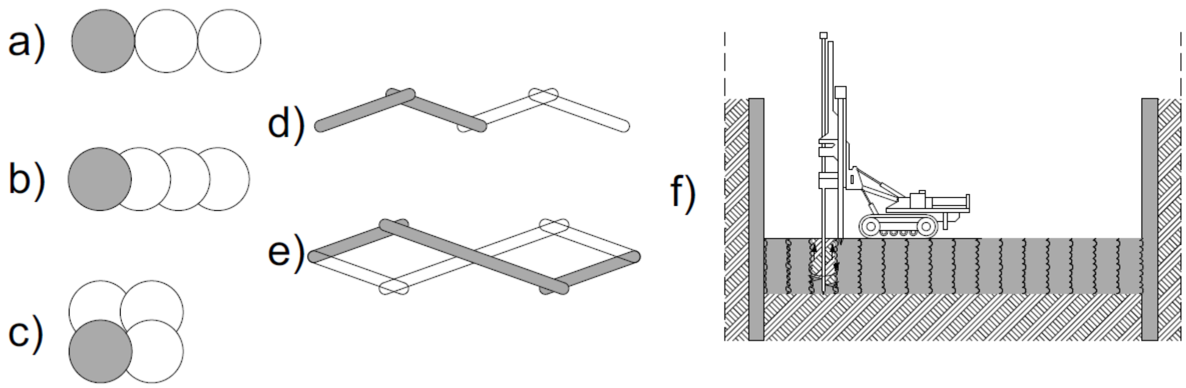


Fig 68. a) reinforcing columns, b) secant columns wall, c) plug, d) single curtain wall, e) double curtain wall, f) bottom plug

The jet-grounting tecnology can be used in various ways, columns and curtain walls can be created. By the retracting of the drill bit without rotation a curtain wall can be formed. The intersecting columns can produce watertight plugs or watertight curtain walls.

[8] https://menardoceania.com.au/technique/jet-grouting/

Jet-Grouting construction methods

Single fluid Jet Grouting

The grout directly fulfils three distinctive functions of breaking down the soil matrix, mixing with the soil and remowing excess material. The single-fluid system can be used at various angle of inclination and is therefore widely applicable to existing structural stabilization, underpinning of foundations or for tunnel canopy structures. The single fluid system allows the penetration of grout to 40-120 cm.
Binder pressure: 300-900 bar

Double fluid Jet Grouting

A two-phase internal fluid system with a coaxial air-jet supply line around the grout-jet supply increase the efficiency of the mixing process and range of slurry actions. Spoil extraction through the drilling rods due the air-lifting effect. The double fluid system allows the penetration of grout to 80-180 cm.
Binder pressure: 300-900 bar; Air pressure: 7-12 bar

Triple fluid Jet Grouting

This system combines the air, water and grout injection. Coaxial air and high velocity water are used to erode the soil structure wit additional improvement through partial subsitiution of the finest soil particles. Cement grout is then injected through independent nozzies located below the water/air jets. [9] The triple-fluid system allows the penetration of grout to 200 cm or even more.
Binder pressure: 300-900 bar, Air pressure: 7-12 bar, Water pressure: 300-900 bar

Fig. 69. Jet grouting

[9] https://menardoceania.com.au/technique/jet-grouting/

2.6.2. Micropiles

Micropiles, also known as minipiles, pin piles, needle piles, and root piles, are foundation element constructed using high-strength, small-diameter steel casing and/or threaded bars.[10] Micropiles can be made by drilling or impact driving. Depending on the soil conditions, the borehol can be supported by fluid or cement material. When the planned depth is reached piles are injected with cement grout.
The diameter of micropiles 8-30 cm, the usual depth 4-10 meters but can reach depths of up to 20 meters.

diameter of drilled micropiles: D < 300 mm
diameter of drived micropiles: D < 150 mm

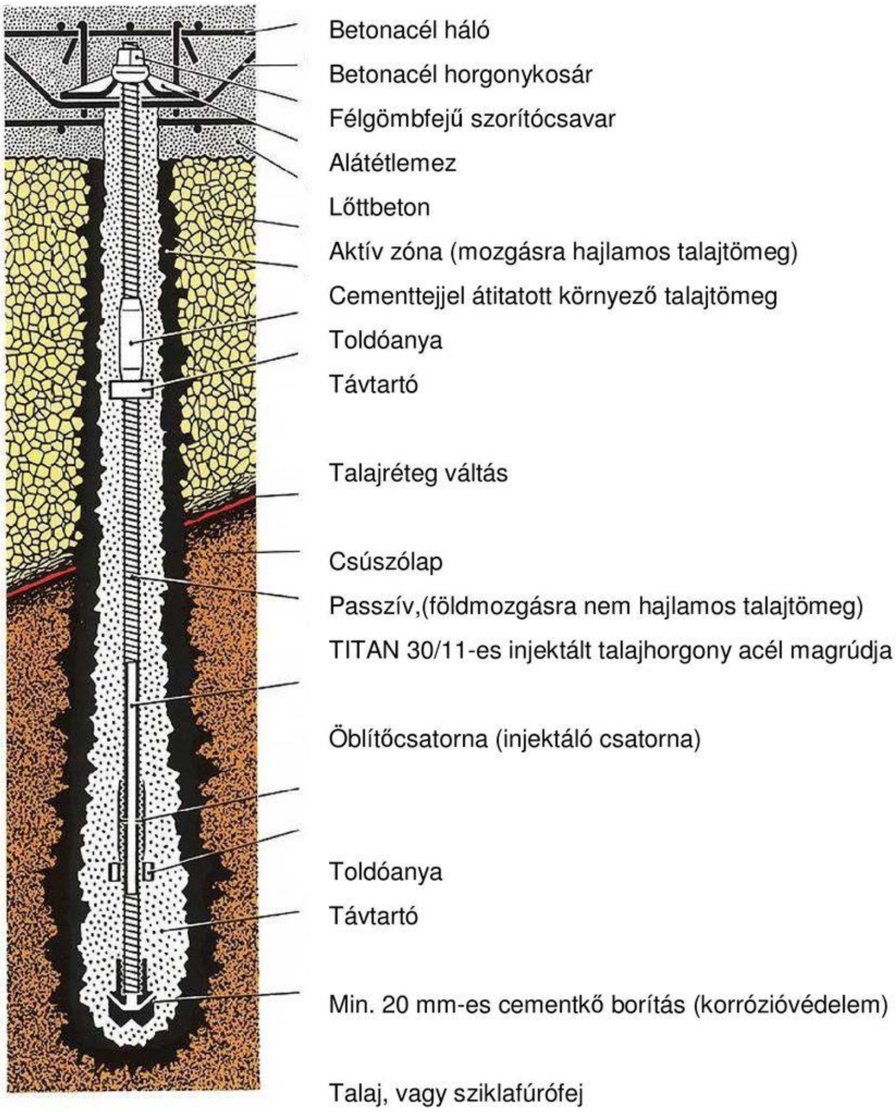


Fig. 70. Finjected micropile

The micropiles is excellent for deepening or underpinning the foundations of existing buildings. The piles can be drilled at any angle and small space-consuming tools can even be used indoors.

[10] https://www.keller-na.com/expertise/techniques/micropiles

2.6.3. Mega-piles

The **Mega Pile** is used for underpinning of existing structures. It is a jacked pile that consists short cylindrical or rectangular section elements, made of steel or precast concrete. By excavating underneath a structure, short lengths of pile can be inserted and jacked into the soil with a hydraulic jack, using the existing structure as a contra load. With that solution it's possible to lift the sunken structure to the original level. The connection of the pile elements is done by steel pins.

The piles dimensions: cross section of 25 or 30, and length of 60-80 cm.

Fig. 71. Mega pile elements

The constriction is starts by diging of 100 cm deep and 50 cm wide working pit under the foundations of the load-bearing superstructure. The pile elements are pressed by hydraulic jack using the building as a counterweight until they reach the proper load-bearing soil. In final step an cast-in-situ reinforced concrete pile cap is made between the superstructure and the top of piles.

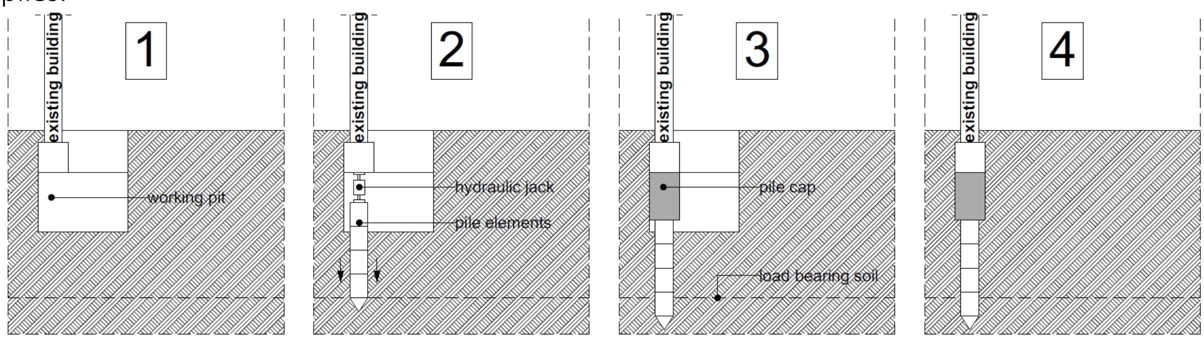


Fig. 72. Construction process of the underpinning of the existing foundation

Short bored pile foundation

The short bored piles due to their low foundation depth can be classified as semi deep foundation, their depth is 2-4m. Where the subsoil is of firm, shrinkable clay which is subject to volume change due to deep rooted vegetation for some depth below surface and where the subsoil is of soft or uncertain bearing capacity for some few metres below surface, it may be economic and satisfactory to use a system of short bored piles as a foundation.

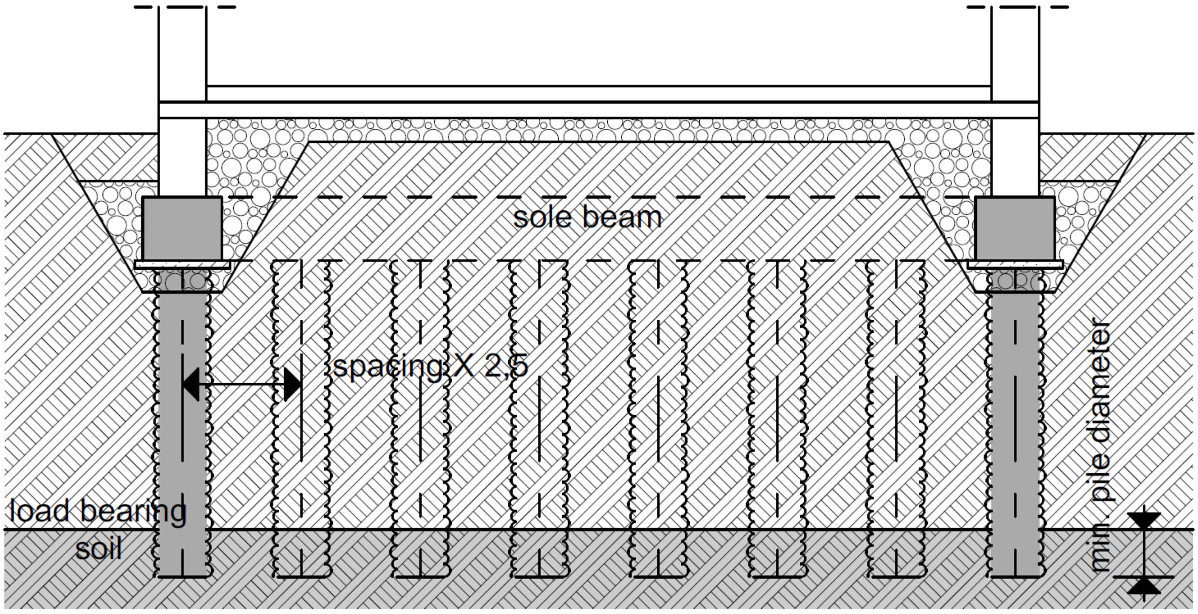


Fig. 73. plug foundation

A short bored pile foundation could be used:

- if the load-bearing subsoil is close to the surface and is accessible with short piles
- if the upper soil layers have low load-bearing capacity
- the soil is easy to drill

The material of the piles is concrete or reinforced concrete. The diameter of boreholes is 30-60 cm, drilled with a drilling rig. The distance of the piles must be determined by calculation, but it must be at least 2.5 times the pile diameter. The piles must be sunk under the of load-bearing soil layer to a depth at least equal to their diameter.
The pile heads are conected by ground beams, which is ensure the stability of the building and make a base for the superstructure. The ground beams must not transfer load to the subsoil, for that the soil under the beams is replaced with gravel.

2.7. Foundation next to an existing building

In case of new construction whih is located by the neigbour buildings the foundation level must be chosen carefully, to avoid the damge of existing structures. The foundation level of a new building in ideal case must be positoned on the same level as the foundation of existing building, but this is often not possible as the existing foundation is located deeper or higher than the new structure require.
If the floor level of the new building is above the floor level of the existing building, the simplest solution can be if the foundtion level of the new structure follow to the level detrmined by the existing foundation.

If the floor level of the planed new building is below the floor level of the existing building and at the same time its foundation plane is lower, the foundation of the adjacent building must be deepened or strengthened.
In the past, the intermittently excavated foundation was underpinned with masonry structure, nowadays the underpinning is done by mass concrete or Jet Grounting. The slurry wall foundation also can be a solution, especially in the case of constructing of deep basements like underground garage.

Underpining of the existing foundations

The underpinning of existing foundation by masonry structure or mass concrete underpinning must be done in controlled stages to ensure the stability of the existing structures.

The foundation of the existing building is excavated in approx 1m sections and underpinned by new foundation. Once the under-concreted foundation has solidified, it is preloaded by hydraulic jacks. When the subsidence process is over, the gap between the existing foundation and the new under-concreted foundation is tightly concreted. This solution minimizes the subsidence of the existing building.

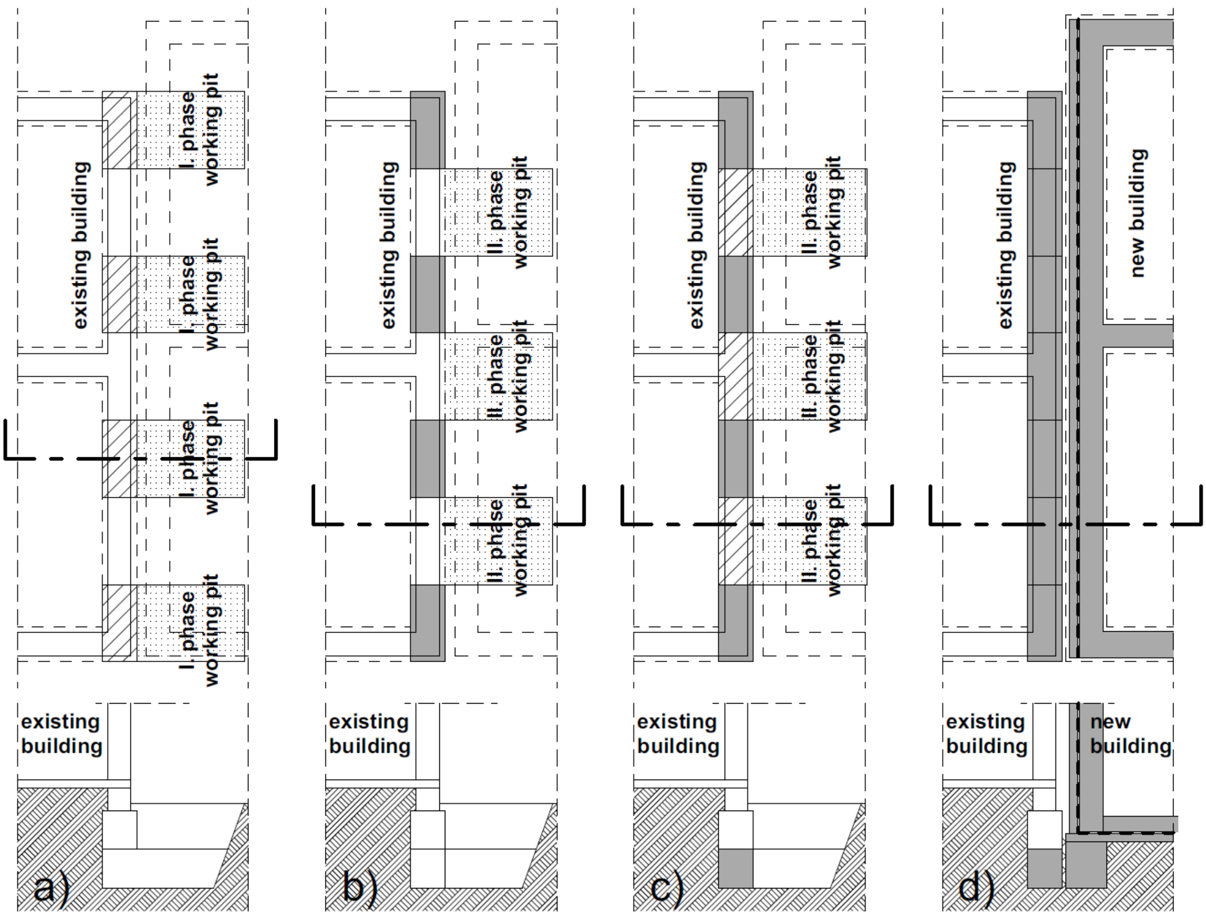


Fig 74. Construction steps of underpinning

Traditional underpining with masonry or mass concrete is a labor and time consuming process. The **Jet-Grounting** technology is more advanced alternative, which is widy used nowadays. By the concrete columns injected under the foundation of an existing building, the deepening of the foundation level can be done without subsidence damage.

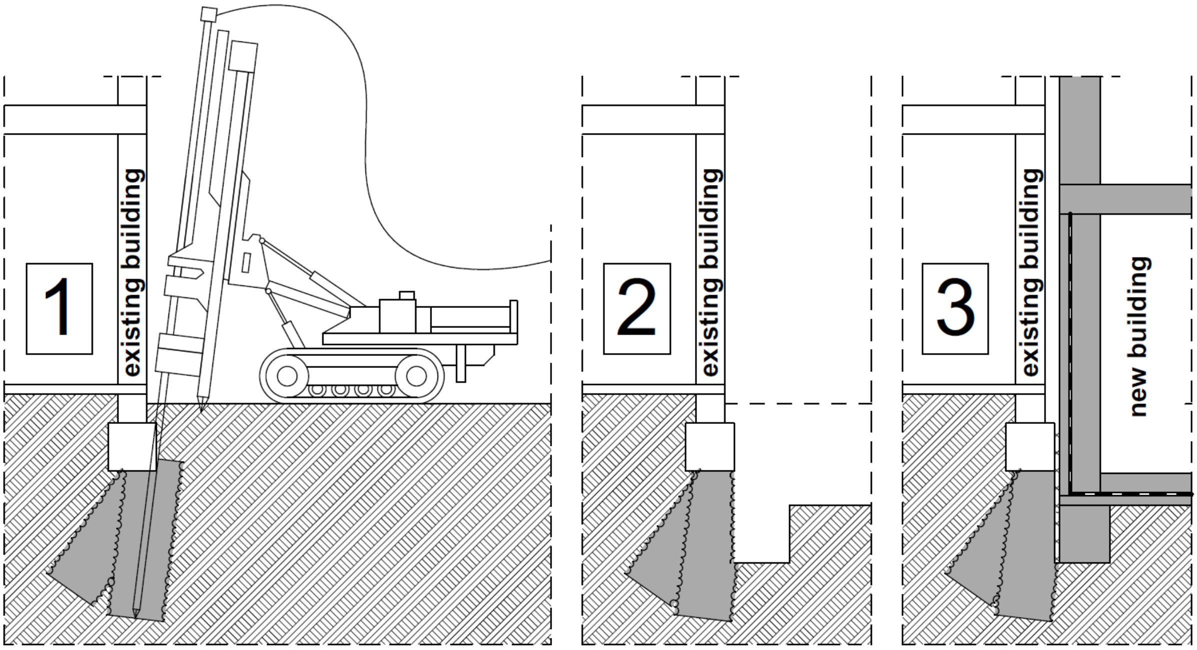


Fig 75. Underpinning of the foundation by Jet-Grouting

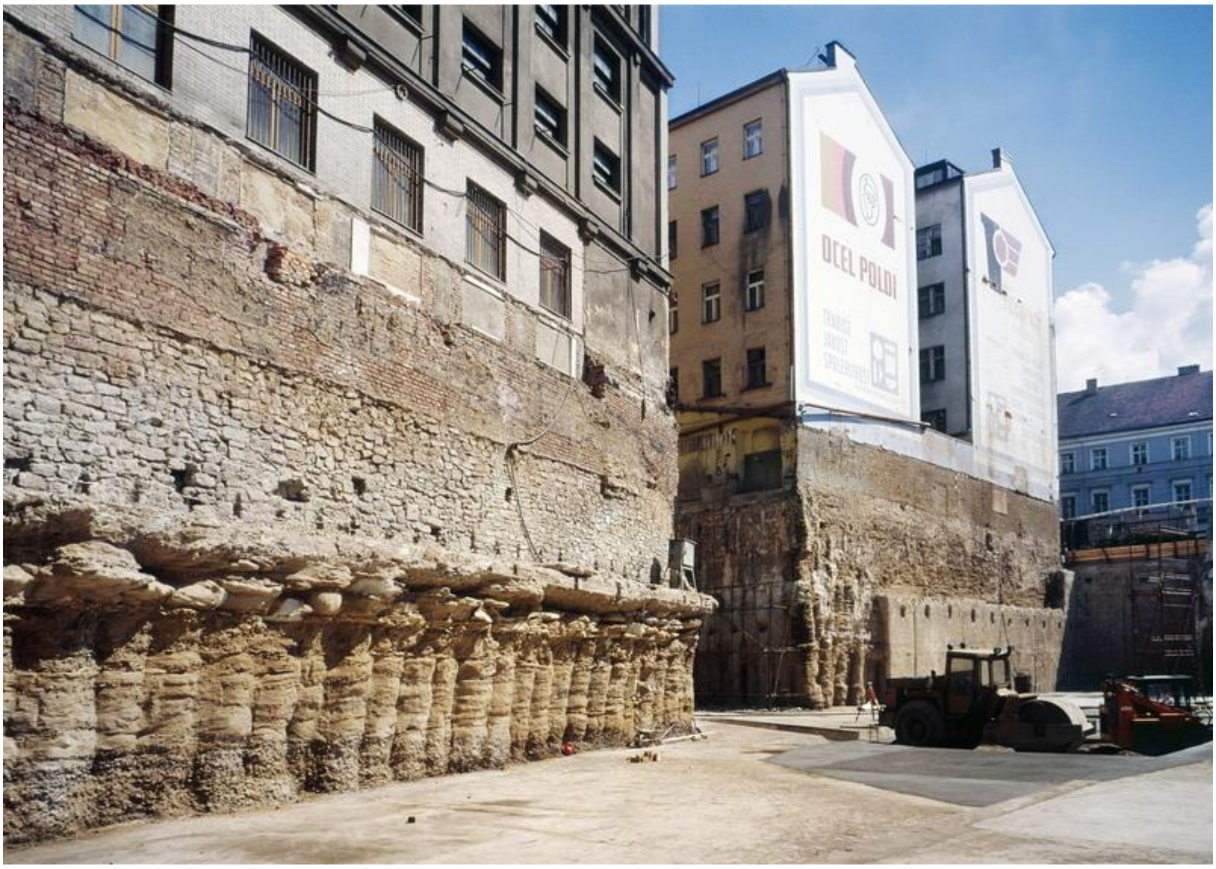


Fig. 76. Deepening of the foundation level by the new construction

The **slurry wall** foundation is excellent for the construction for new buildings without jeoprdize of the stability of adjacent buildings. With this technology, it is possible to build several level depth underground garage directly by the neigbhoru buildings. The slurry wall can be built directly next to the adjacent building, taking into account the capabilities of the machine and the structures of the existing building. The construction of the slurry wall must be done in steps to ensure a stability.

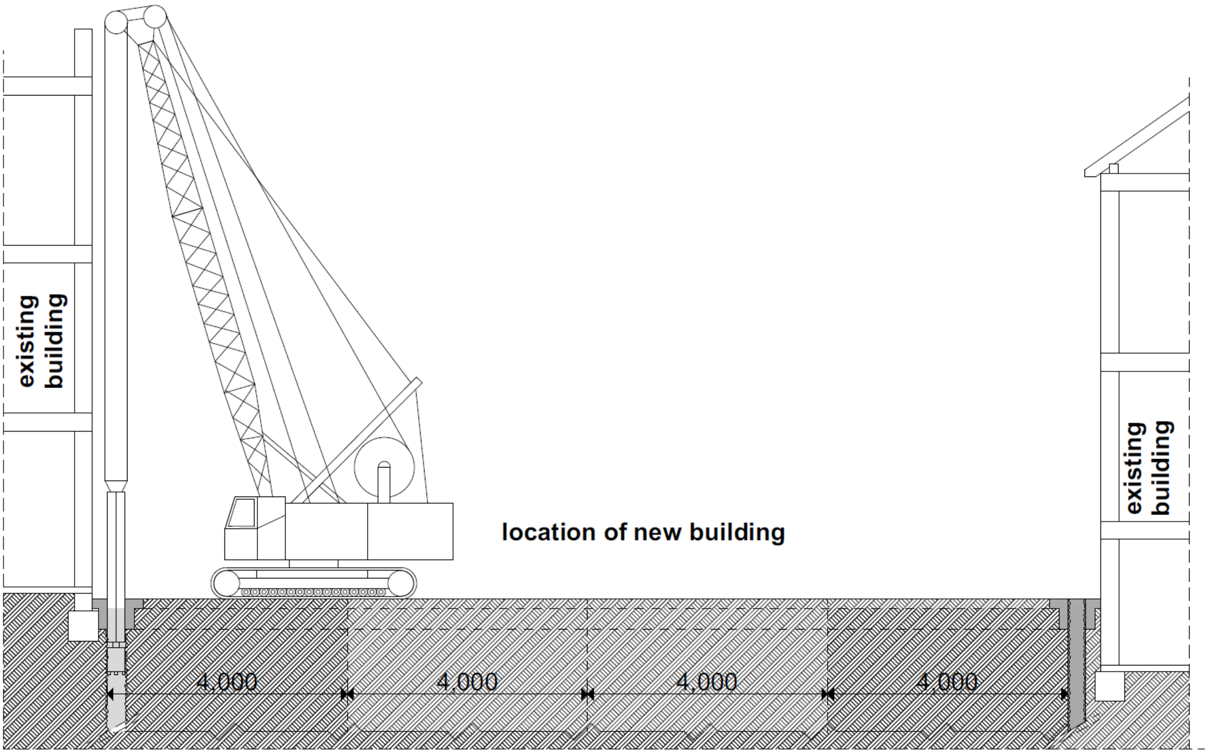


Fig. 77. Slurry wall construction by the adjacent buildings

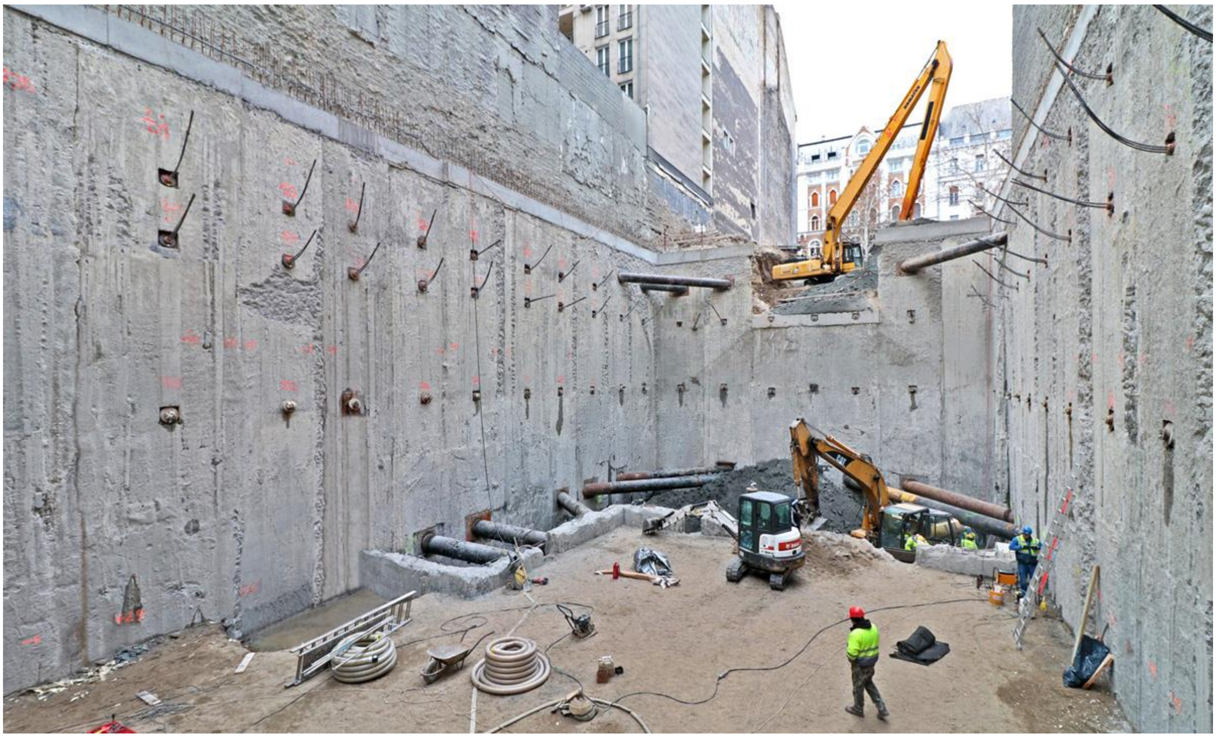


Fig. 78. Slurry wall construction between the adjacent buildings

Pad foundation by the existing building

The construction of the pad foundation placed directly next to the foundation of an existing building can be done in severela ways. To avoid eccentric load of the pad foundation the pillar of the new building must be shifted away from the wall of the adjacent building, pad foundations of the two neighbeour pillars should be combined or pad foundations of two neighbeour pillars should be connected by moment resisting beam.

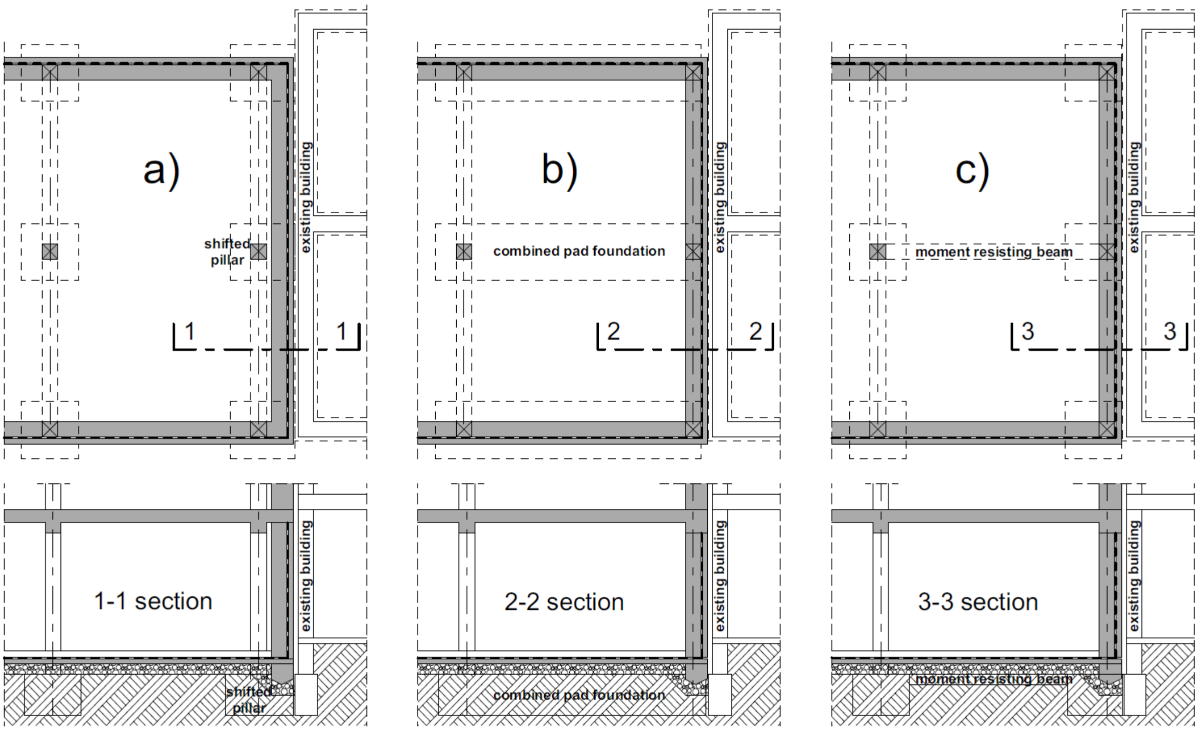


Fig. 79. Construction of the pad foundation next to an existing building. a) shifted pillar, b) combined pad foundation, c) pad foundations connected connected by a moment resisting beam

III. Chapter

STAIRS

3.1. Staircase

A staircase is a construction designed to bridge vertical distance by dividing it into smaller vertical distances.

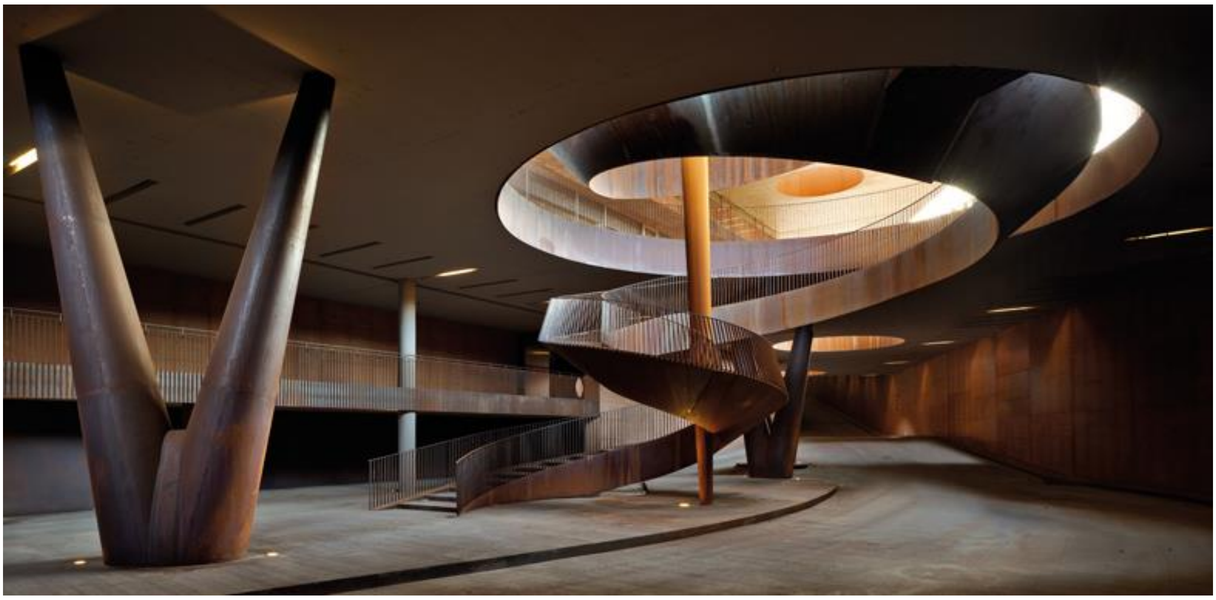


Fig. 80. Antinori vinery, Archea Associati 2012

3.1.1. Staircase requirements

- Architectural
- Traffic
- Structural
- Implementation and economical
- building code

3.1.2. Architectural requirements

The location of stairs in the building should be in an easy-to-find place, at the main traffic hub, into a functional center. The staircase have to fitt well into the floor plan and traffic system of the levels, the dimesions of the stairs have to be adapted to the scale of the building and the space, and its architectural apperance adapted to the design of the space.

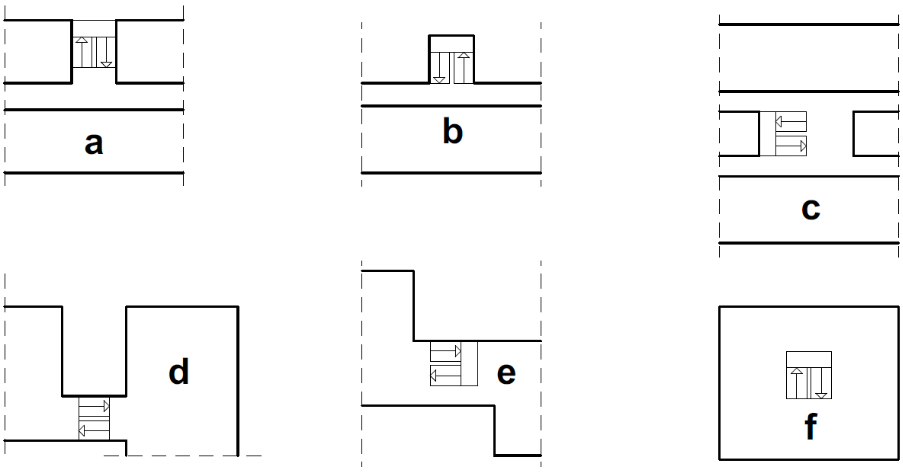


Fig.81. The location of the stairs in the building: a-c) middle corridor, d) level shift, e) connecting the wings of the building, f) centrally located

3.1.3. Traffic requirements

The dimesnions of staircase like, the free width of the flight, the inclination angle, the dimension of riser and tread must comply with the traffic volume, the evacuation calculation and the function of use.

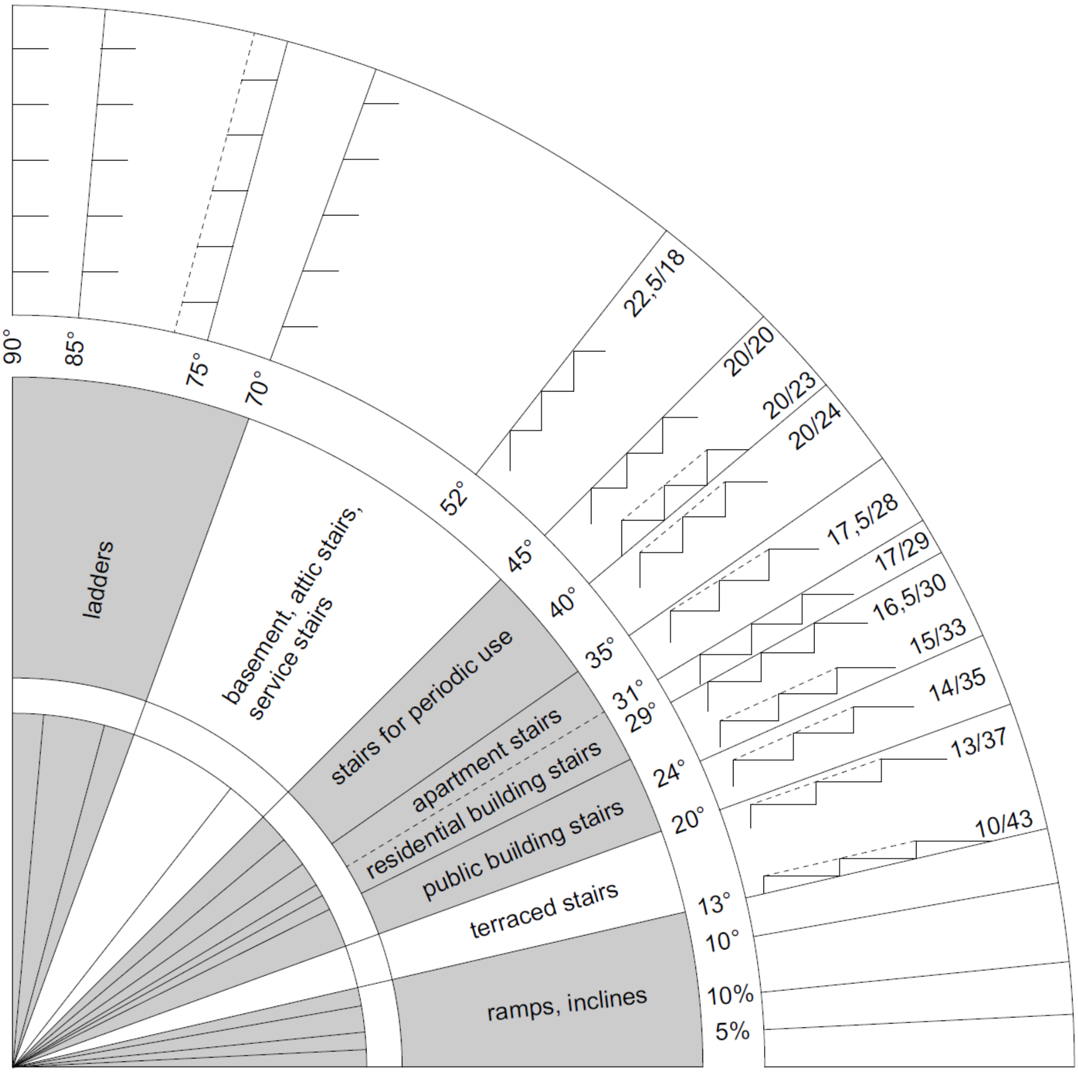


Fig. 82. Inclination angle of the stairs

The free width of the stair flight is important dimension from the point of view of traffic, as this is the width dimension which allows the safe pass through of people in case of evacuation.

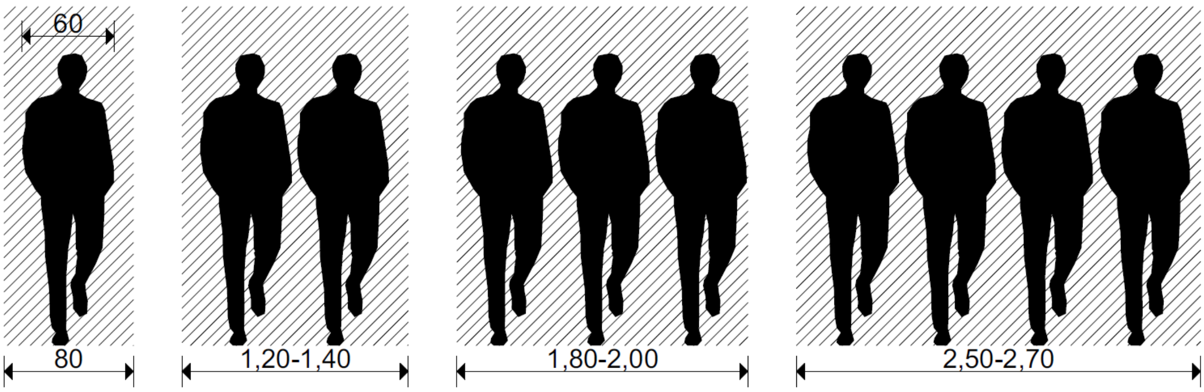


Fig. 83. the minimum width required for simultaneous pass through according to the number of people

3.1.4. Structural requirements

The staircase design and structural calculation must be done according the building codes. The structure of the stairs should be as simple as possible, the load transfer should be clean, the design of the details not least should be nice.

National Town Planning and Building Requirements (OTÉK)

OTÉK, SECTION 51. (1) The edifices and parts, structures, installed equipment and cable and pipe network thereof shall be designed and built by ensuring that the expected loadings and effects that are liable to act on them during their construction and use should not lead to

a) the complete or partial collapse of the edifice or parts thereof,

b) deformations of the edifice and parts thereof to an inadmissible degree,

c) damage to installed equipment and fittings as a result of major deformation of the load-bearing structure of the edifice, and

d) the destruction of the structures under construction or the connected or neighbouring structures during the construction.[11]

According to **DIN 1055 standard**, the following traffic loads must be taken into account for stairs: 3.5 kN / m2 in residential buildings and 5.0 kN / m2 in public buildings. Treads with open risers shall be designed for the most unfavorable loads: 1.5 kN / m2 in residential buildings and 2.0 kN / m2 in public buildings.

3.1.5. Implementation and economical requirements

The construction of the stairs should be simple, and if it is possible with the minimum amount of the material used.

3.1.6. Acoustic requirements

Quietness is an elementary basic need that is synonymous with a high level of living comfort, especially within one's own four walls. However, this tranquillity can quickly be disturbed by noise from neighboring rooms or the staircase. One of the causes is impact noise, which is generated by walking on a slab or staircase.[12]

The weighted standard impact sound pressure level **Ln,w** in the receiving room arises as a result of the stimulation, using a standard tapping machine, of the reference landing respective stairs flight in the source room.

Schöck Tronsole®	Load-bearing level	$L_{n,w}$ Test bench measurement according to DIN 7396	$\Delta L^{*}_{n,w}$ tested in accordance with DIN 7396	$L'_{nT,w}$ Berechnung nach DIN EN ISO 12354-2
Type F	V1	≤ 35 dB 1)	≥ 32 dB 1)	≤ 34 dB
	V2	≤ 37 dB 1)	≥ 30 dB 1)	≤ 36 dB
Type B	V1	≤ 35 dB 1)	≥ 32 dB 1)	≤ 33 dB
	V2	≤ 37 dB 1)	≥ 30 dB 1)	≤ 35 dB
Type T	V2	≤ 34 dB	≤ 33 dB	≤ 33 dB
	V4	≤ 36 dB	≥ 31 dB	≤ 35 dB
	V6	≤ 38 dB	≥ 29 dB	≤ 37 dB

Fig. 84. The level of weighted standard impact sound pressure with different types

[11] https://ec.europa.eu/growth/tools-databases/tris/en/index.cfm/search/?trisaction=search.detail&year=2012&num=237&mLang=HU

[12] https://www.schoeck.com/en-gb/impact-sound-insulation

In case of slabs, the structures are usually separated by socold a floating layer. This layer prevent the propagation of impact sounds by the layer of soft foam (a simple thermal) insulation. In the case of stairs, this is not possible due to the complex geometry. The acoustic separation must be provided in a different way by acustic separators.

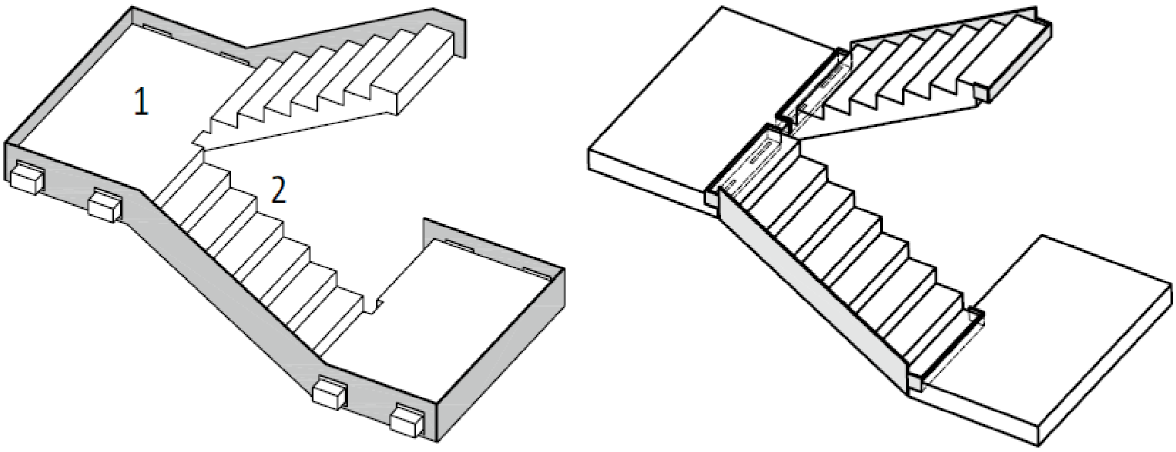


Fig. 85. Impact sound insulation of the stairs

Impact sound insulation is important in both the in-situ and pfrecast conrete stairs too. The structures can be separated by separation of the conncetion of stair structure to the load bearing structures. The complete separation of the stair structure must be ensured, and acoustic separators must be installed on the contact surface of the structures.

3.2.1. Materials of the stairs

- stone and artificial stone
- reinforced concrete
- wood
- steel
- glass

Fig. 86. Stone and reinforced concrete stairs

Fig. 87. Wood, steel and glass stairs

3.2.2. Basic staircase geometries

The layout and floor plan of the stairs are depence by several factors:

- The purpose of the stairs: is it main staircase, decorative staircase, evacuation staircase, maintance staircase
- The architectural idea
- Floor plan of the building, traffic system
- The floor space requirement of the stairs
- Structural system of the building, pillar distance, span of the slabs

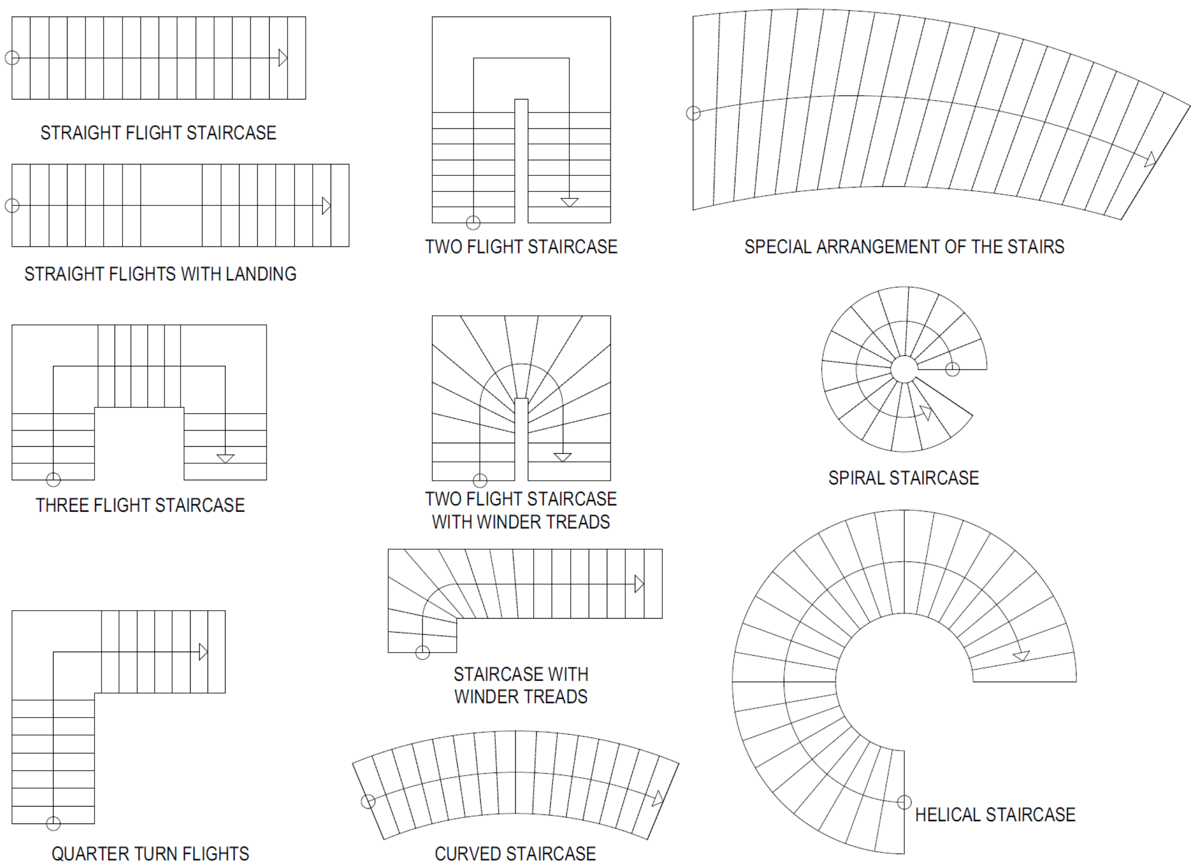


Fig. 88. Examples of floor plan layout of stairs (without claiming completeness)

The staircase is one of the most important element of building, which is in addition to its functional benefits, has a significant architectural impact. In the case of a public building, the staircase is often part of the entrance hall, so its shape, material, layout and its sculptural appearance can be the decorativ part of the building. In residential buildings, the staircase is typically located on the smallest possible floor plan area, but its architectural role is also significant. Everyday use of the stairs requires a comfortable and safe solution, but at the same time its aesthetic appearance also important.

3.2.3. Staircase Terminology

Staircase:
The entire structure relating to a stair, comprising steps, treads, risers, strings, balustrading, landings etc.

Stairway:
The space/void provided for the stairs.

Stairwell:
The space between the flights

Total Rise:
The height between floors (or landings) that the flight of stairs is spanning.

Riser:
The height of an individual step

Tread:
The horizontal part of the stair that is stepped on (includes the nosing). The walking or stepping surface of the stair.

Nosing:
The part of a tread that extends beyond the riser.

Step:
The step is composed of the tread and riser.

Flight:
An uninterrupted series of steps.

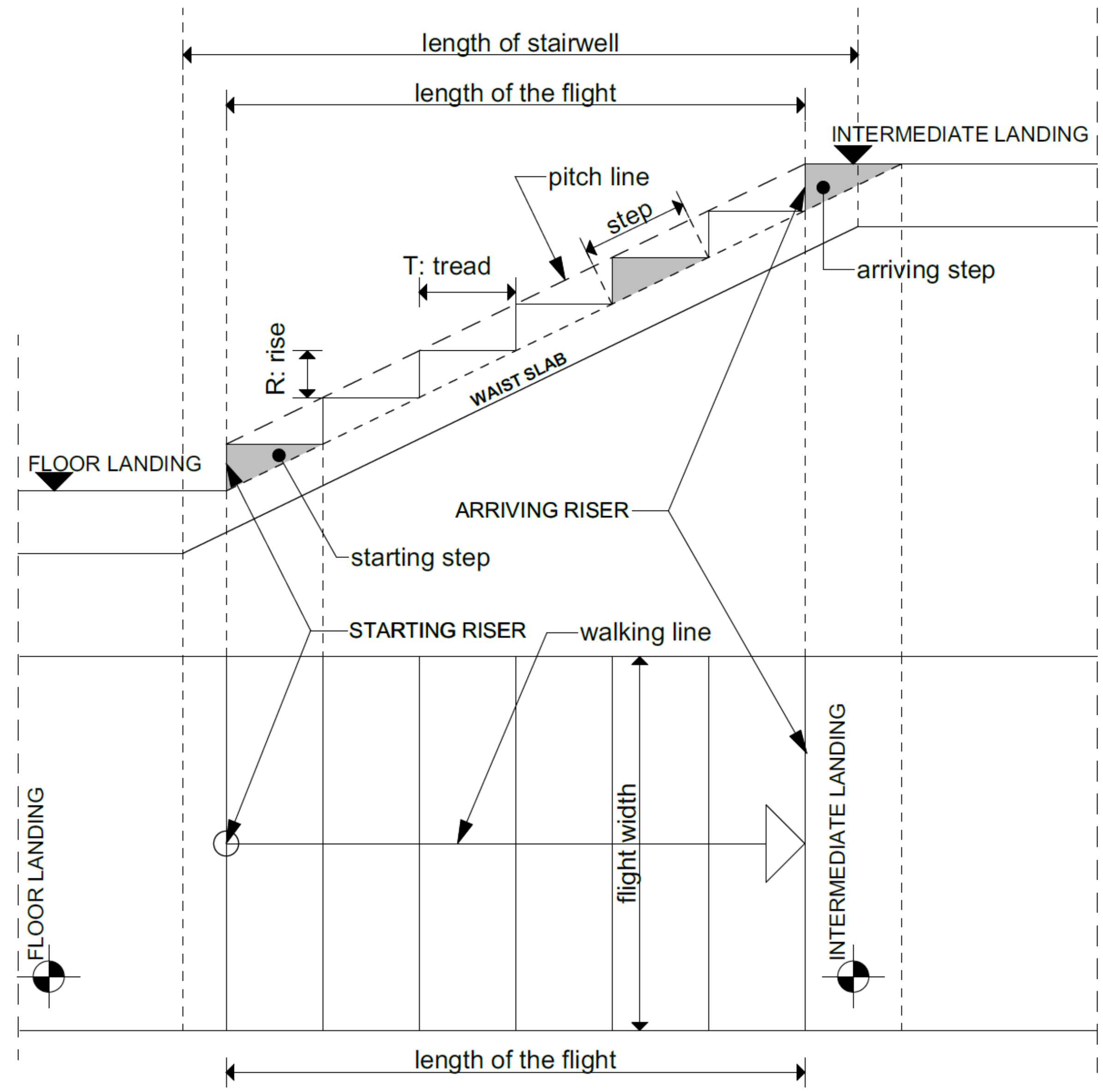
Run:
The horizontal width of a tread between the faces of adjacent risers.

Walkline:
The path that an individual would follow up or down a staircase

Pitch:
The slope of the staircase measured as the ratio between the rise and going

Pitch Line:
The notional line connecting the nosings of all treads in a flight of stairs.

Landing:
A horizontal platform at the end of a flight or between two flights of stairs, usually used to make a change in direction.



1. ábra. A lépcső elemei

Landing tread:
A part used as the tread on a landing that forms a level surface with the finished floor on the second floor.

Starting tread:
The first riser and tread at the bottom of a stair or the flight of stairs.

Stairwell
The space (gap) between the flights

Stringer
The staircase stringer is a structural member that supports the treads and risers. There are typically two stringers, one on either side of the stairs; though the treads may be supported many other ways. The stringers are sometimes notched so that the risers and treads fit into them. Stringers on open-sided stairs are often open themselves so that the treads are visible

from the side. Such stringers are called “cut” stringers. Stringers on a closed side of the stairs are closed.

Spandrel

If there is not another flight of stairs immediately underneath, the triangular space underneath the stairs is called a “spandrel”. It is frequently used as a closet.

Terraced stairs:

An outdoor staircase which is not connected to the building and follow the final tidy terrain inclination.

Handrail:

Following the staircase to support and guide during ascending or descending a staircase and an element to grasp in case of a fall.

Newel:

A large vertical column or post to which the handrail is attached. Newels provide structural support for the balustrade.

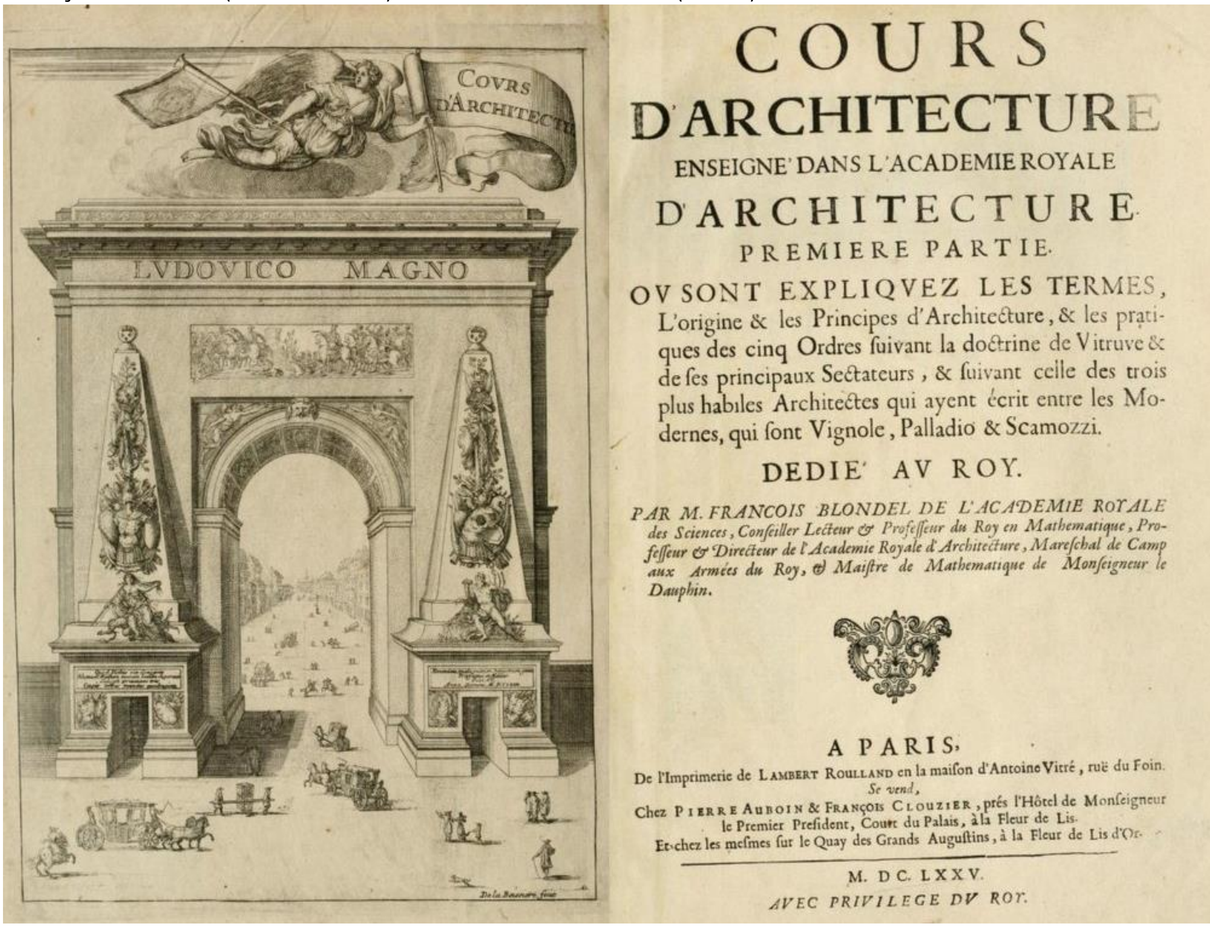
Winder:

A stair that is narrower on one side to enable a turn in the staircase. A series of winders form a circular or spiral stairway. When three steps are used to turn a 90° corner, the middle step is called a kite winder as a kite-shaped quadrilateral.

3.3. Staircase dimensions

3.3.1. Proportions of the riser and tread

The comfort of the stairs is determined by the slope ratio determined by the French architect, François Blondel (1618 –1686) Cours d'Architecture (1675).



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PAR M. FRANCOIS BLONDEL DE L'ACADEMIE ROYALE des Sciences, Conſeiller Lecteur & Profeſſeur du Roy en Mathematique, Profeſſeur & Directeur de l'Academie Royale d'Architecture, Mareſchal de Camp aux Armées du Roy, & Maiſtre de Mathematique de Monſeigneur le Dauphin.
A PARIS,
De l'Imprimerie de LAMBERT ROULLAND en la maiſon d'Antoine Vitré, ruë du Foin.
Se vend,
Chez PIERRE AUBOIN & FRANÇOIS CLOUZIER, prés l'Hôtel de Monſeigneur le Premier Preſident, Court du Palais, à la Fleur de Lis.
Et chez les meſmes ſur le Quay des Grands Auguſtins, à la Fleur de Lis d'Or.
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Fig.90. François Blondel, 1675 Cours d'Architecture

"The length of a comfortable step of a man who walks on the level is two feet, that is to say, twenty-four inches, and the height of the step of a man who climbs a ladder erected is only a foot or twelve inches. From which it appears that the natural length of the level step is double that of the natural height of the same in the vertical. And therefore that to join them with each other, as done in a ramp, it is necessary that each part in height is compensated for by two parts of level, and that both together compose a natural step of two feet or twenty-four inches long."13

Based on the above description, the following formula can be written:

$$2r + t = 60\text{-}64 \text{ cm}$$

The tread (t) is the distance from the first edge of one step to the first edge of the next step. The riser (r) is a vertical dimension from the tread surface of one step to the tread of the next step. The step lenght of a person is 60-64 cm, on average 63 cm.

[13] https://www.practicalarchitecture.com/blog/the-geometry-of-a-comfortable-staircase (2021.02.16)

Safe tread proportion of stairs: r + t= 46-48 cm

This rule focuses on the comfort of staircase, the r + t formula determines the safety of the stair tread. A staircase is safe if the sum of the riser and the width of the tread is 46-48 cm. In order to save space, in many cases this value does not reach 46 cm. However, space-saving stair design must also pay attention to dimensions, even if there is not enough space for the stairs, we should strive to be as close as possible to 46 centimeters.
A basic safety requirement is that the riser and run of the stairs must not change within a staircase.

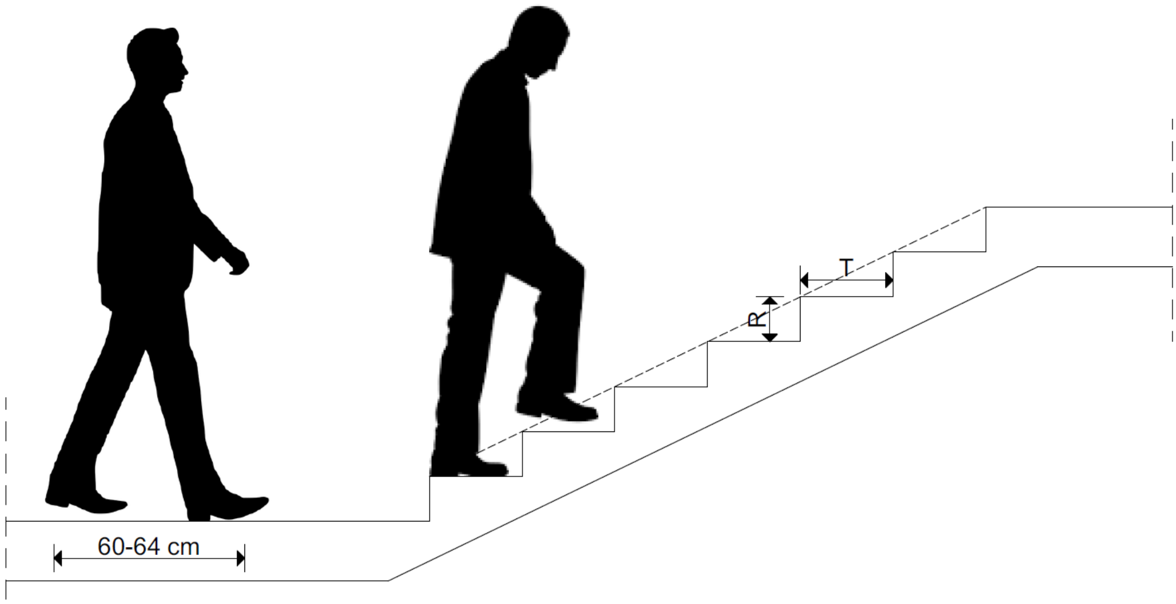


Fig. 91. Average step length and the riser-tread ratio: 2r+t=60-64

Common dimensions of riser and tread in case of stairs with different functions

Terrain stairs:	8,5/46 - 12/40
Public building stairs:	14/35 - 15/33
Residential building stairs:	15/33 - 17/29
Apartment stairs:	17/29 - 20/23

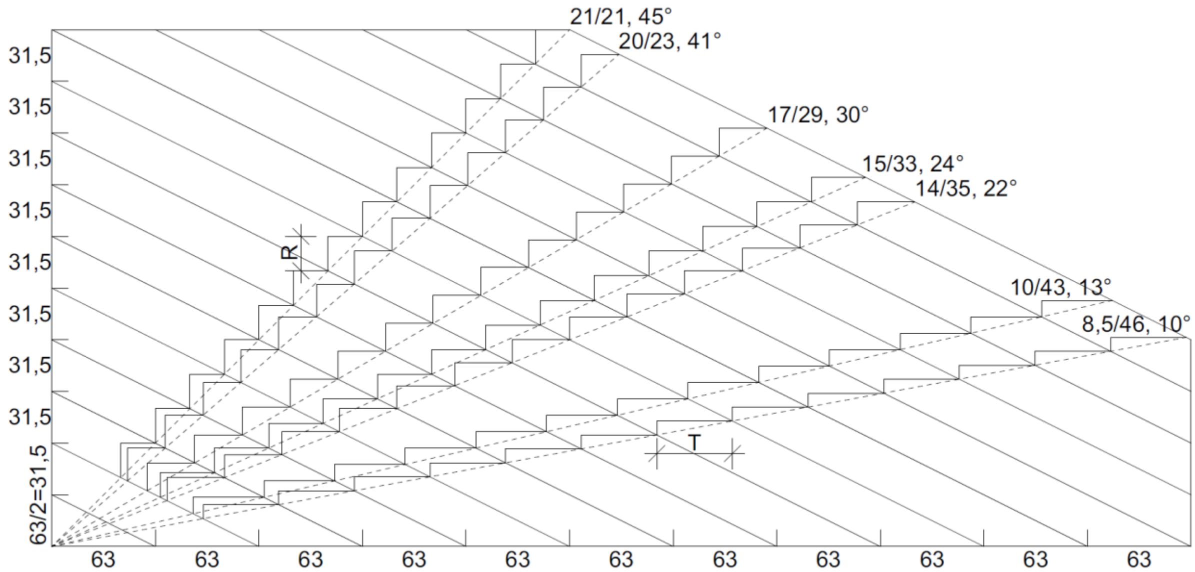


Fig. 92. The slope of the stairs according to the proportions of the riser and tread

3.3.2. Design of the tread

The design and shape of the treads can be made in many ways for ex. with open or closed risers. If the staircase is formed with closed risers the connection between the riser and the tread has several ipmportnat factors. The edeg of the tread that extends beyond the riser is called nosing, and overhangs 2-3 cm. This solution is not favourable for barrier-free traffic, it increases the danger of the tripping. On the other hand, it helps to identify the edges of the steps by forming a shadow on the cladding. This solution ensures the proper drainage of the water by dropping down the water on the edge of the nosing, especially in the case of stairs in the exterior space. The staircase design with open risers gives light appearance for the stairs whish is architectural advantageous, however, it must be taken into account that the open riser can be dangerous.

OTÉK, SECTION 65 (2-3) The height of the riser (r) in general shall not exceed 17 cm and in case of barrier-free traffic 15 cm. The height of the risers within the dwelling or holiday units, and in case of stairs with intermittent use or industrial function, shall not exceed 20 cm.

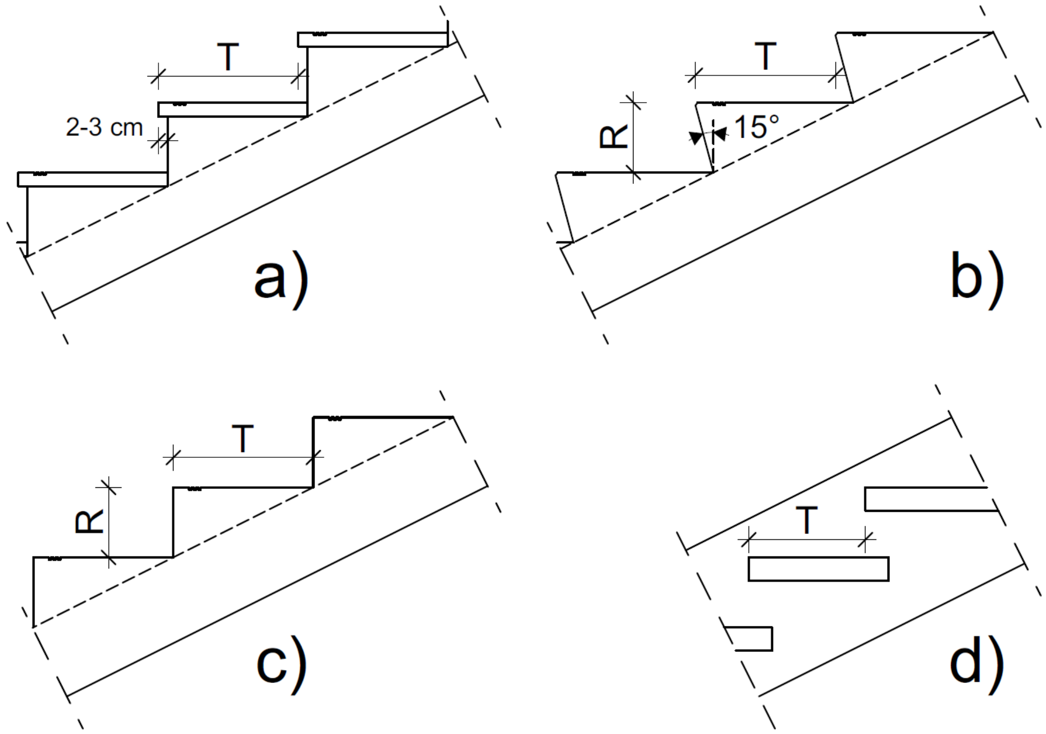


Fig. 93 a) tread with nosing, b) undercut riser, c) tread without noising, d) tread with open riser

OTÉK, SECTION 65. (4) In edifices used by the public, steps used for barrier-free access shall be built with a rise and tread without nosing, to avoid the risk of tripping. The first and last step must be clearly marked.
A change in step height, indistinct edges, or inappropriate landing measurements can all disturb the rhythm of movement up and down stairs. Treads should be slip-resistant and have a contrasting front edge. Additional slipreducing profiles on the edges of the steps will increase safety. Undercut risers must be avoided or should be slight and used only to provide additional profile[14].

[14] https://www.stadtentwicklung.berlin.de/bauen/barrierefreies_bauen/download/handbuch/00_BarrierefreiesBauen_gesamt_engl.pdf

3.3.3. Flight of stairs

OTÉK, SECTION 64. (1) Stairs, ramps, and slopes shall be designed and built ensuring that they facilitate safe passage by the users.

The basic safety requirement of a staircase is that it contain only same step hights. During the use of the stairs, we feel its "rhythm" and we use to it, so the different size can cause a tripping hazard. For comfortable use of the stairs, a stair flight can contain up to 20 steps and can bridge maximum 1,8 m a level difference.

OTÉK ,SECTION 64. (4) In edifices used by the public, flights of stairs used for barrier-free access shall be designed and built by ensuring that they are straight, and a flight of stairs may not bridge more than 1.80 m difference in levels.

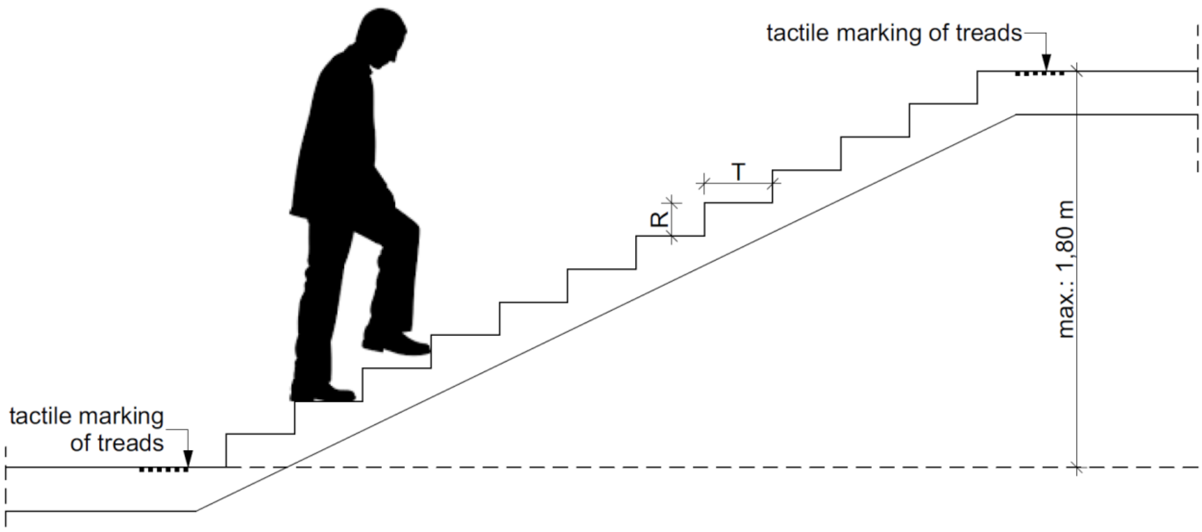


Fig. 94. Barrier-free staircase

The barrier-free design of the stairs, it's not means that's it suitable for wheelchair use, but in case of stairs we have to ensure the comfortable and safe traffic for persons with reduced mobility and special needs.

Barrier-free acces

Barrier-free access sets out the design requirements of providing proper access to and appropriate facilities in a building for persons with a disability and other sectors of the population including the elderly, who at times require the same provisions as persons with a disability.

Target groups:

- people with reduced mobility
- visually and hearing impaired
- the mentally handicapped, autistic
- the elderly, expectant mothers and children,
- chronic patients (epilepsy, diabetes)
- injured in the short term - e.g., leg fracture

3.3.4. Landing

Az **OTÉK, SECTION 67.** (2) The length of the landing of a straight staircase is measured on the walking line and shall be at least 0,60 m long. The calculation of the landing length is recommended as follows.

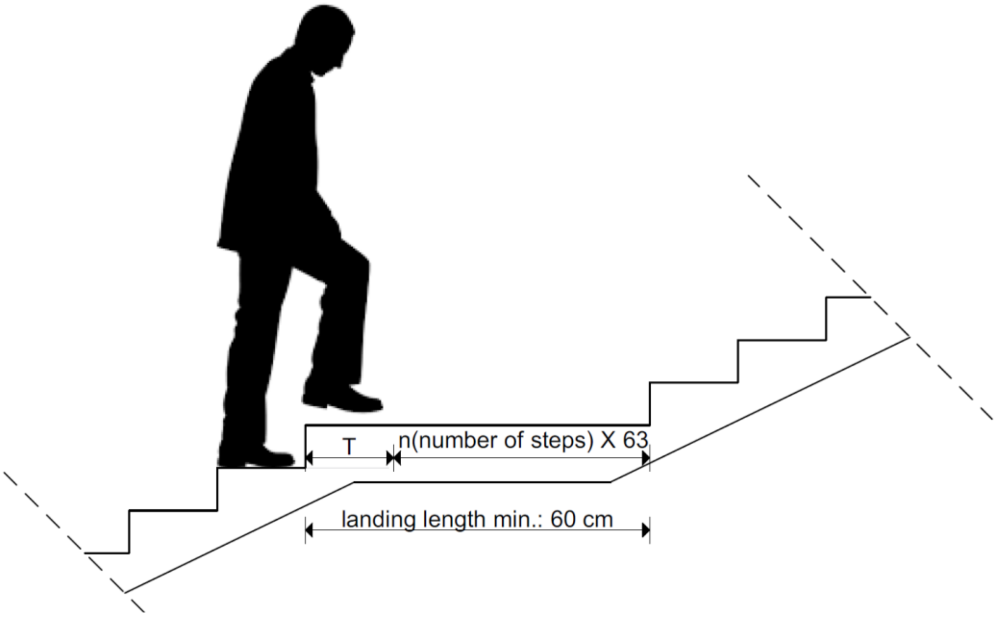


Fig. 95. Intermediate landing of the straight stairs

The intermediate landing of the two flight staircase must be not less than the width of the flight, but it is advisable to increase the width of the landing areas in order to ensure safe traffic. The landing area should be wide enought for the turning with stretcher and the moving of furniture should also be considered. The opening of the doors is not allowed to the landing area, and its width is at least flight width +20 cm. The width of the intermediate landing is at least flight width +10 cm.

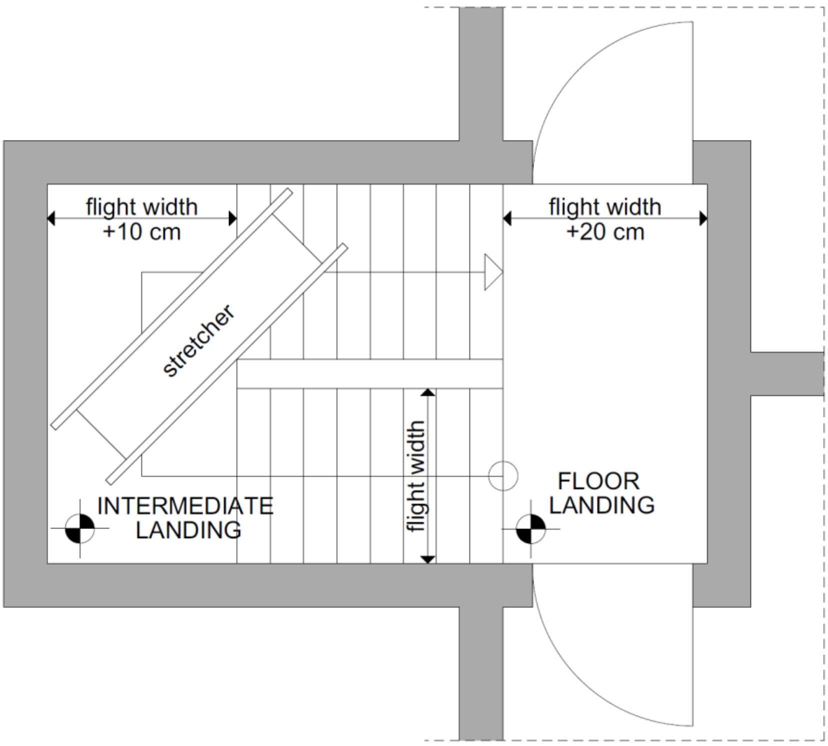


Fig 96. Landings of the two flight staircase

3.3.5. Clearance

OTÉK, SECTION 64. (7) The clear headroom above a flight of stairs and the landing shall be at least 2.20 m. In a dwelling or resort unit, furthermore, above stairs leading to a periodically used level in edifices, in justified cases the minimum clear headroom may be 2.00 m. The clear headroom above the flight of stairs shall be measured along the central line of the stairs, vertically from a tangential line on the edge of the tread.

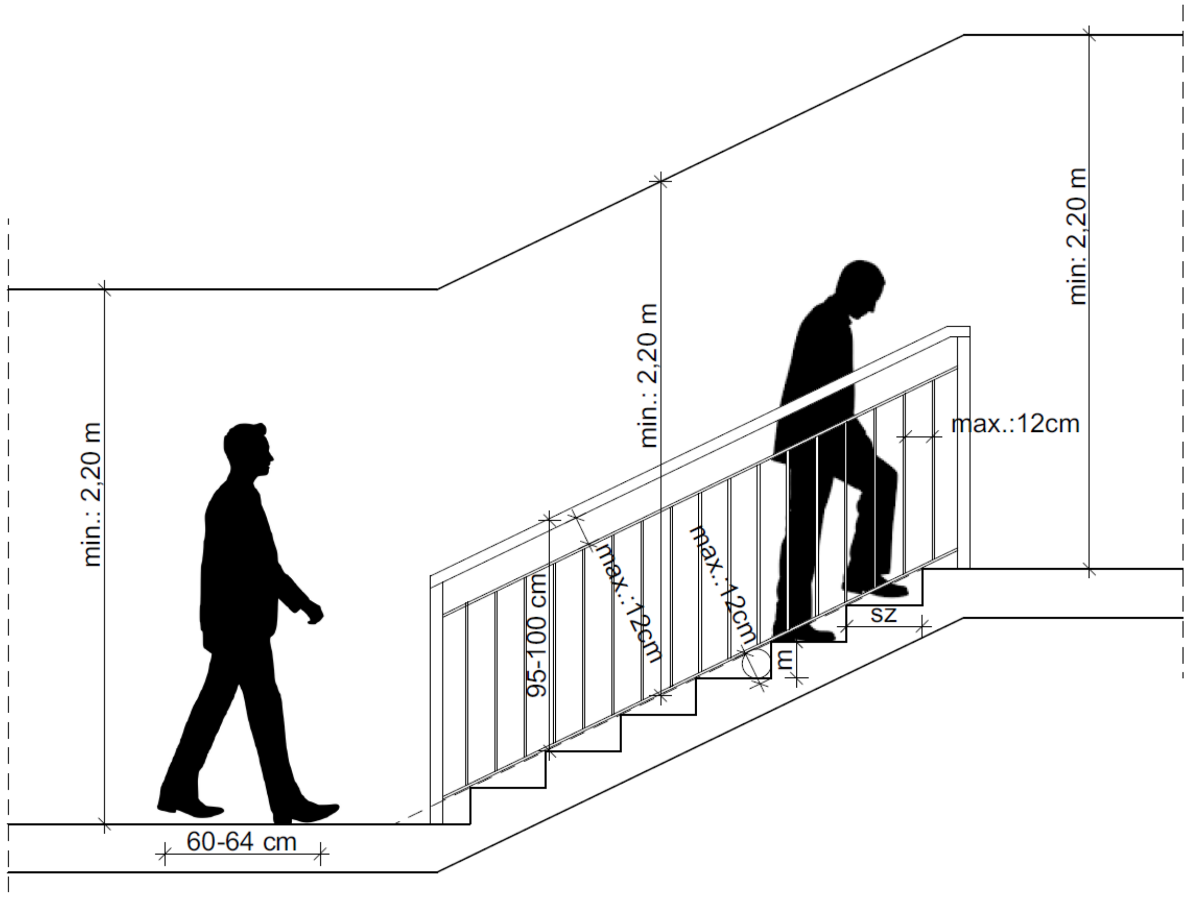


Fig. 97. Staircase headroom and railing design

3.3.6. Handrails and fences

The staircase level which is higher than 0.80 m above the ground level, shall be delimited by at least 0.95 m high fall barrier or parapet wall. The filling of the stair railing can be solid or openwork.

OTÉK, SECTION 68. (1) In edifices or parts thereof, in the interest of safe use, railings or parapet walls shall be built for all floor levels whose users have a risk of falling out or falling during their use. The railings shall be designed in such a way that an object with a diameter of 120 mm should not fit through their gaps, and they should not include any elements that help climbing or serve as steps. The railings and parapet walls shall be built with a structure suitable to withstand the prescribed horizontal loads, taking into account when necessary the loads created by a jostling crowd. Railings containing glass shall be built with safety glass.

OTÉK, SECTION 68. (2) In the interest of safe use by pedestrians, stairs, ramps, and gradients with a horizontal projection exceeding 1.0 m shall be designed and built with handrails. Stairs, ramps and gradients whose tread compared to the adjoining ground level

a) is at the most 0.17 m higher, shall be designed and built with an appropriate size anti-slip protective edge above the handrail,

b) is at least 0.95 m higher, shall be designed and built with railings or parapet wall that prevent slipping down.

OTÉK, SECTION 68. (3) At least one side of the flight of stairs shall be built in a way suitable for a handhold. In edifices used by the public, both sides of flights of stairs that are more than 2.0 m wide shall be built with the possibility of a handhold.

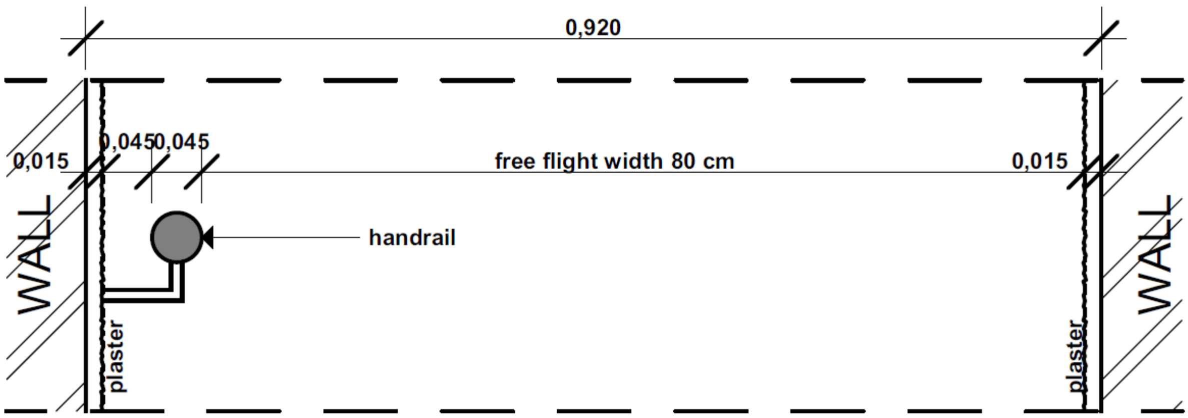


Fig. 98. The free flight width

3.3.7. Width of the staircase flight

The free width of the stair flights depends on the traffic amount.

The width dimension of the staircase flight:

In common case	1,10 m
Stairs for periodic use	0,60 m
Stairs for barrier-free use	1,20 m
Stairs within an apartment	0,80 m
Stairs in public building	1,65 m

OTÉK, SECTION 64. (6) The free width of a flight of stairs used for evacuation shall be determined by taking into account the number of people spending a considerable period in the edifice or parts thereof served by the stairs and the amount of traffic expected simultaneously, and in compliance with the regulations regarding evacuation, however, this width shall not be less than 0.60 m in the case of periodically used stairs, and 0.80 m within a dwelling.

Remember that the minimum size of the free flight width must be realized with free width, so add the space requirement of the handrails, and the thickness of the plaster on the boundary walls must also be taken into account. That means, in the case of a staircase surrounded by a plastered wall, a real flight width maust at least 92 cm to reach a clear flight width of 80 cm.

3.3.8. Position of the walking line

Fig. 99. Paris, Louvre museum stairs, I.M. Pei 1989

A walking line is a theoretical line that is most favorable for a person walking up stairs. The dimesnions of the treads shal be mesured on the walking line. In the case of a straight stair flights, the walking line is located in the middle of the width of the flight parallel to the direction of the traffic. In case of a curved stairs the position of the walking line depends on the width of flight and shal be determined for the idividual case.

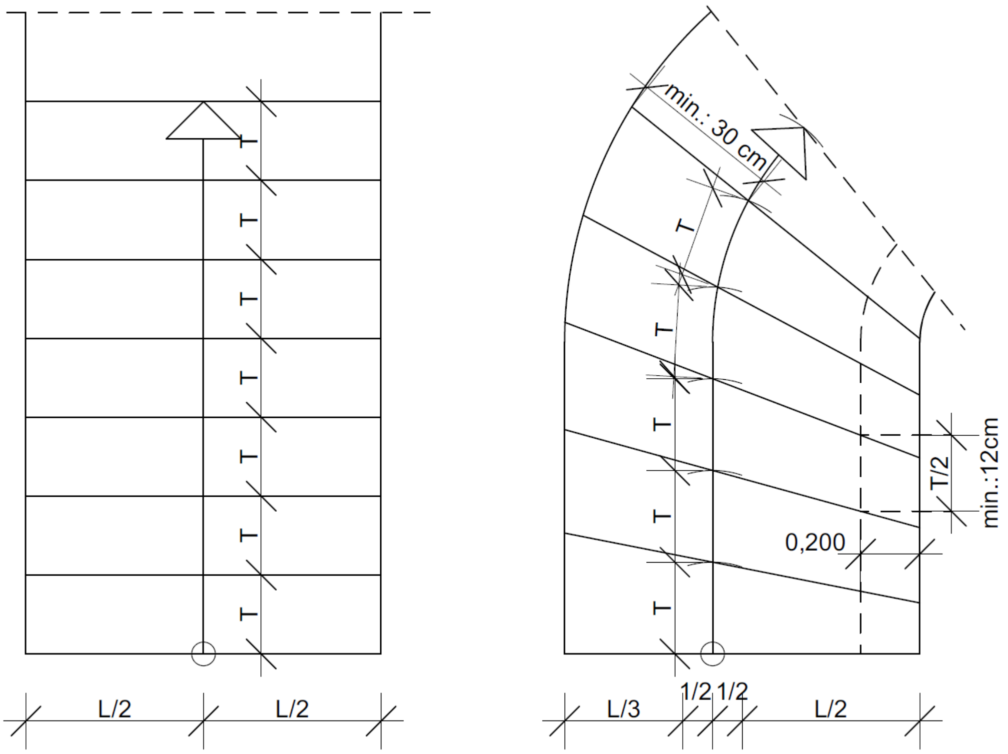


Fig. 100. The walking line position in case of straight and curved stairs

The position of the walking line is obvious in case of straight stairs, but in case curved and spiral stairs its much more complex and also closely related to flight width.
In the case of winder steps for a spiral staircase, or circular stairway, the location of the walking line significantly affects the size of the stairway because the treads are measured on it. If the walking line is positioned in the inner third of the flight width, we get a much longer stairway, while if it is in the outer third of the flight width the stairway can be much shorter.
In the case of a staircase with a relativly small flight width, the walking line is usually placed at a distance between the half and third of the stair flight on the wider side of the stair, observing the following rules.

For the safe pass of one person a minimum 60 cm width is needed, so the walking line must be not (60/2) closer than 30 cm to any side of the stairs. Furthermore, on the shorter side of the stair flight, where the winder steps narrow, it is advisable to design at least 10 cm wide steps.

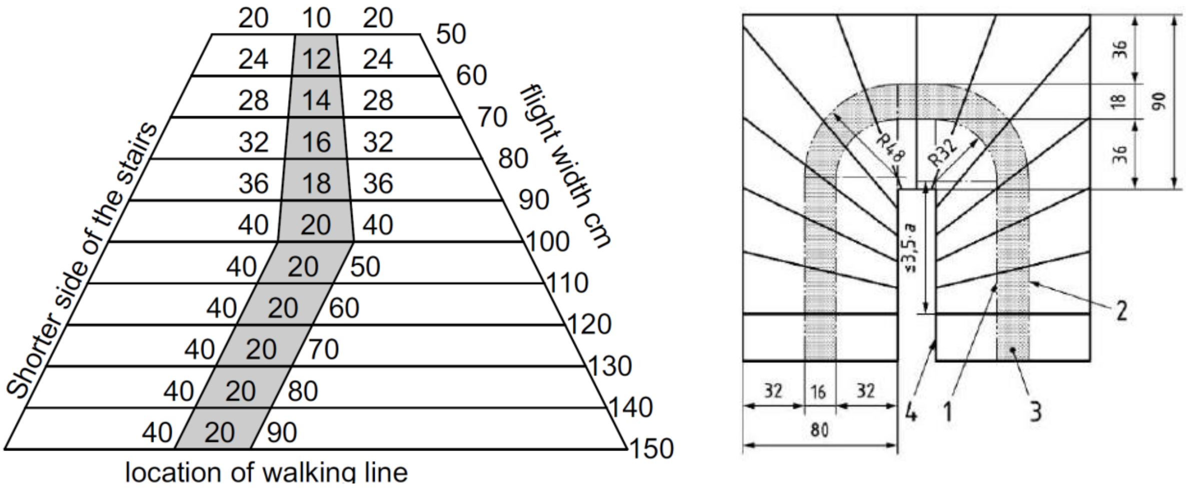


Fig 101. Position of the walking line according DIN 18065 standard

According to the **DIN 18065** standard, the winder treads must reach at least 12 cm depth, on an additional walking line measured on 20 cm distance from the shorter side of saircase. The DIN standard also regulates the position of the walking line, according on the width of the stair arm. In case of flight width wider than 1 m, the walking line is placed within 20 cm strip on 40 cm distance from the shorter side of the stairs.

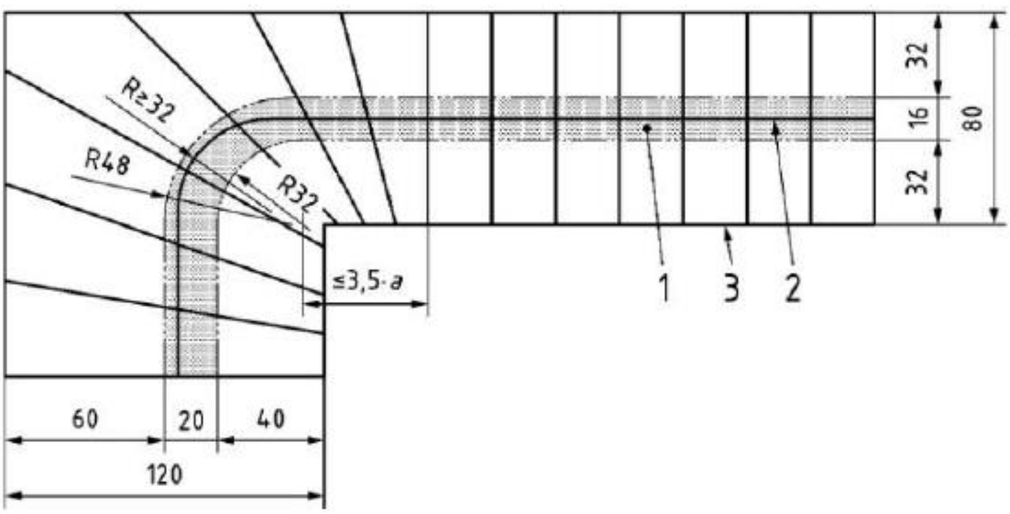


Fig. 102. Walking line of the L shaped staircase according DIN 18065

The design of the curved stairs sometimes can be a complicated task, and the position of the walking line significantly influence the design. The determining the position of the walking line is always a unique task depending on the given situation, width of the flight, function etc.
In case of detached houses, we usually try muinimalize the space requirements and design the staircase to the smallest possible size with a small flight width. In this case we position the walking line is between the outer third and the bisector of the stair flight, but anyway the safety requirements must also be observed. Do not sacrifice the safe design of the stairs to reduce the space requirements. If we want to design a good staircase, it is worth placing the walking line near the middle of the flight width.

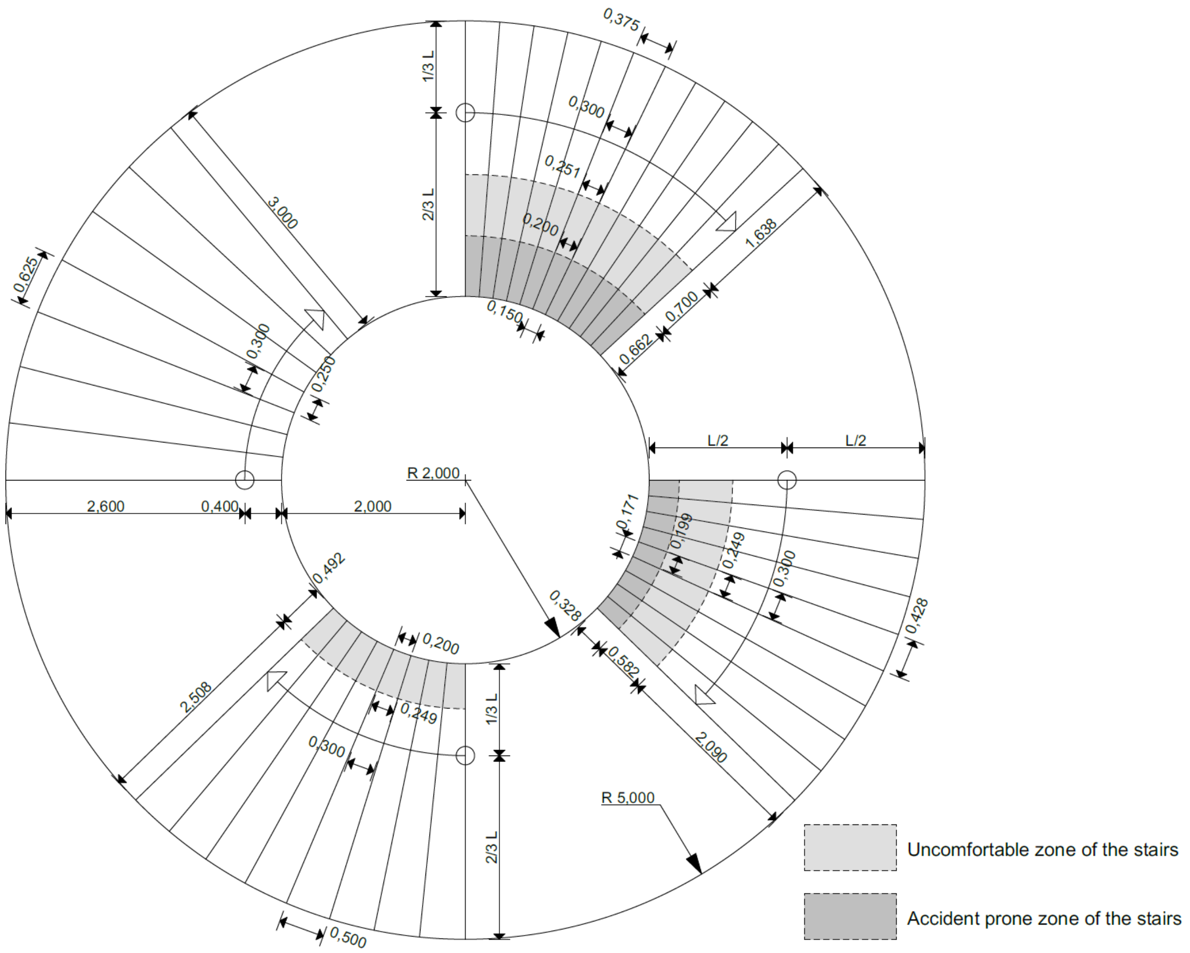


Fig. 103. Comparison of walking line position effects on helical stairs

In case of stairs with flight width of more than 1 m the walking line should be placed in a 20 cm wide strip measured on 40 cm from the shorter side of the stairs. In case of wide flight widths, this is especially important because if the walking line is placed in the middle of the flight, a significant port of the stairs will be uncomfortable due to narrow treads and on the shorter side. Usually, we tyr to walk on shortest possible way on the inner part of the fligh, where the treads are narrow and unsafe.
Curved stairs with wide flight widths are obviously not for space saving purposes, such stairs often appear as a significant architectural element in the foyers of buildings or in outdoor spaces. Therefore, in order to ensure the safety and comfortable use of the stairs, the walking line should be placed along the shorter side of the stairs. The shortest path of the stairs will have sufficient step depth, and on the outside will be a longer route with large steps.

3.4. Structural system of stairs

The load bearing system of the stairs can be made in many ways and different combinations of structural solutions are possible.

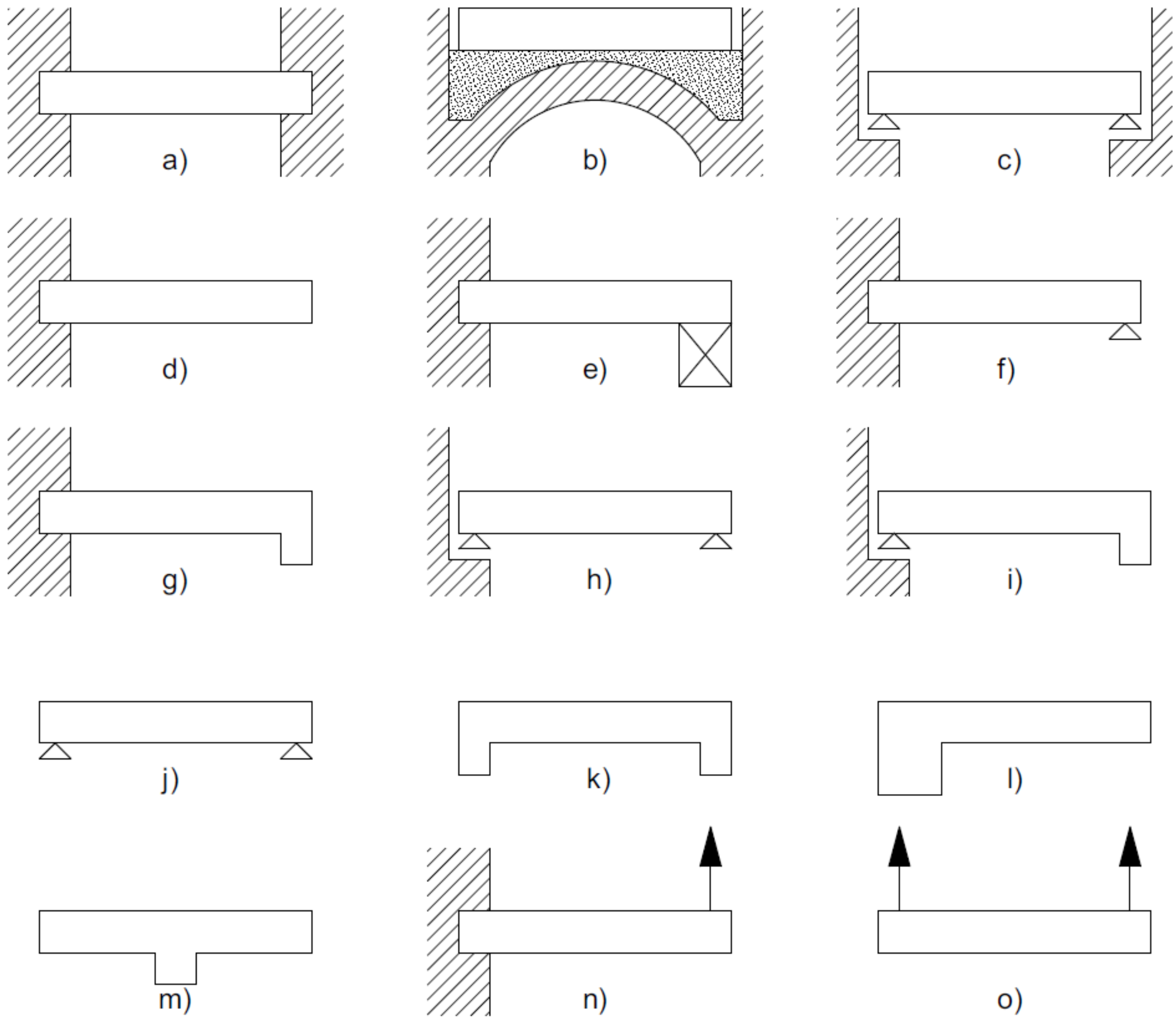


Fig. 104. a) wall-restrainted stairs, b) vaulted stairs, c) wall supported stairs, d) cantilevered floating stairs, e) wall-restrainted and arch supported stairs, f) wall-restrainted and beam supported stairs, g) wall-restrainted with edge beam, h) stairs with wall and beam support, i) stairs with wall support and edge beam, j) stairs with beam support, k) stairs with edge beams, l) stairs with edge beam, m) stairs with center beam, n) wall-restrainted and suspended stairs, o) suspended stairs

In past centurys the **structure of the stairs** was supported by walls and beams, arches or vaults. The structure of the stairs can be done in many combinations, both sides of the stairs are sit on or restrainted in to the wall, sitting on beams, or on one side on the wall on the other side on the beam, or an arch. In the case of a staircase reinforced by edging beams, the waist slab acts as a two-way girder, its load-bearing direction is perpendicular to the beams, so the slab thickness and the self-weight of the staircase can be significantly reduced. The position of the edge beam in relation to the waist slab can be downstanding, upstanding or simultaneously upstanding and downstanding.

Suspended stairs are suspended from some kind of load-bearing structure, e.g. stairs suspended from the slab by the steel structure.

Floating stairs are stairs cantilevered from the wall on one side. In the past, stone and artificial stone treads were fixed by wedges in the grooves of the load-bearing wall. The treads are fixed into the wall and partly sit on each other by the overlaps, this solution ensure the stability of the stairs. Due to the cantilevered fixation, the maximum width of the stair flight is 1,3m. Today, stairs of this type are made of reinforced concrete or steel structure.

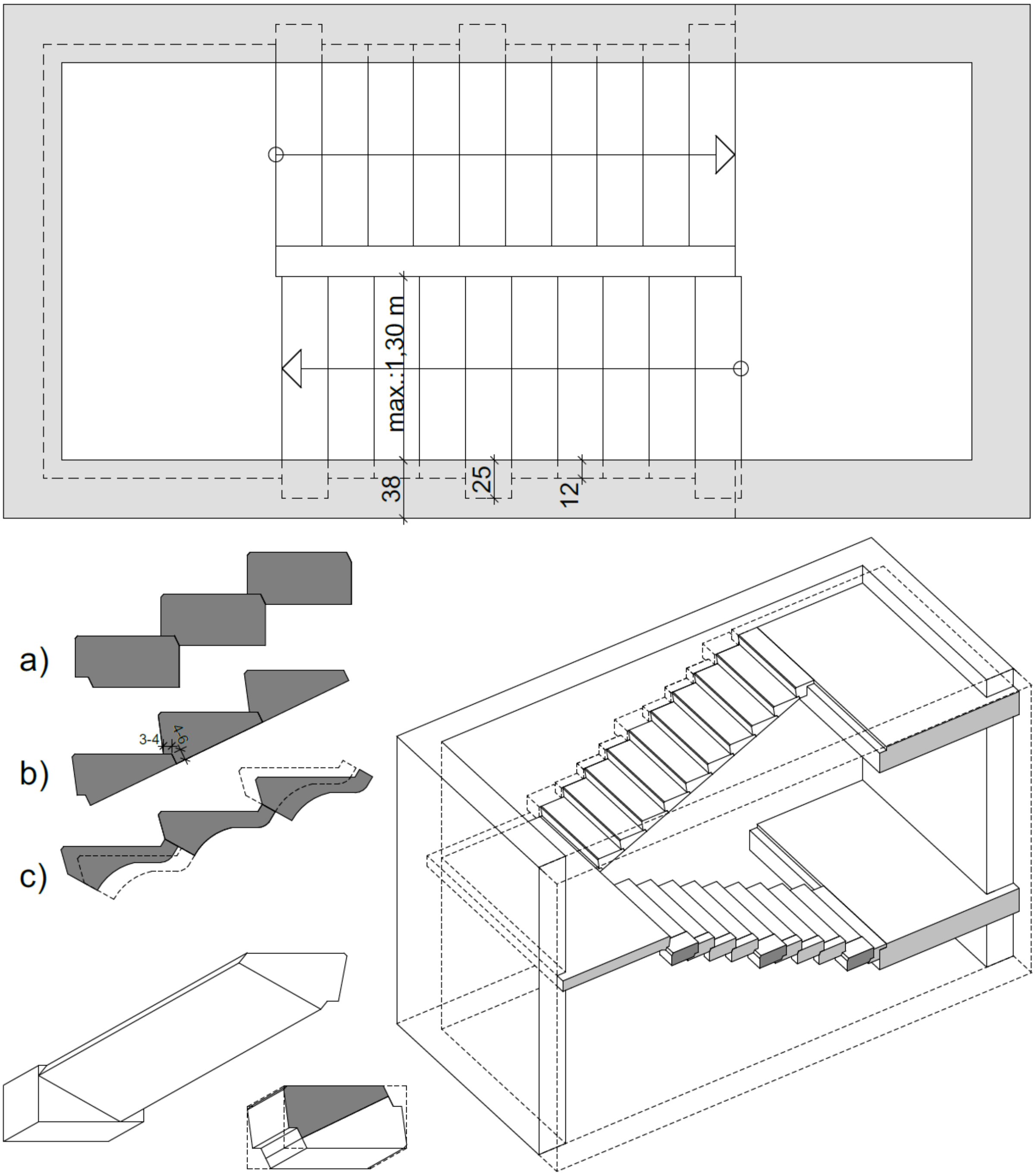


Fig. 105. Stone-artificial stone treads and their connection, a) block, b) wedge, c) special profile

Reinforced concrete slab stairs are bridges between walls, beams or between walls and beams without edge beams. Depending on the structural solution and the static model, the waist slab can be single or double folded slab or can sit on the beams at both ends. In the case of a stair with a folded slab, the waist slab and the landing represent one structural unit, the reinforcement of the fracture line between the waist slab and landing must be designed according that. Due to the structural lenght of the folded slabs, the thickness of the waist slab increases significantly.

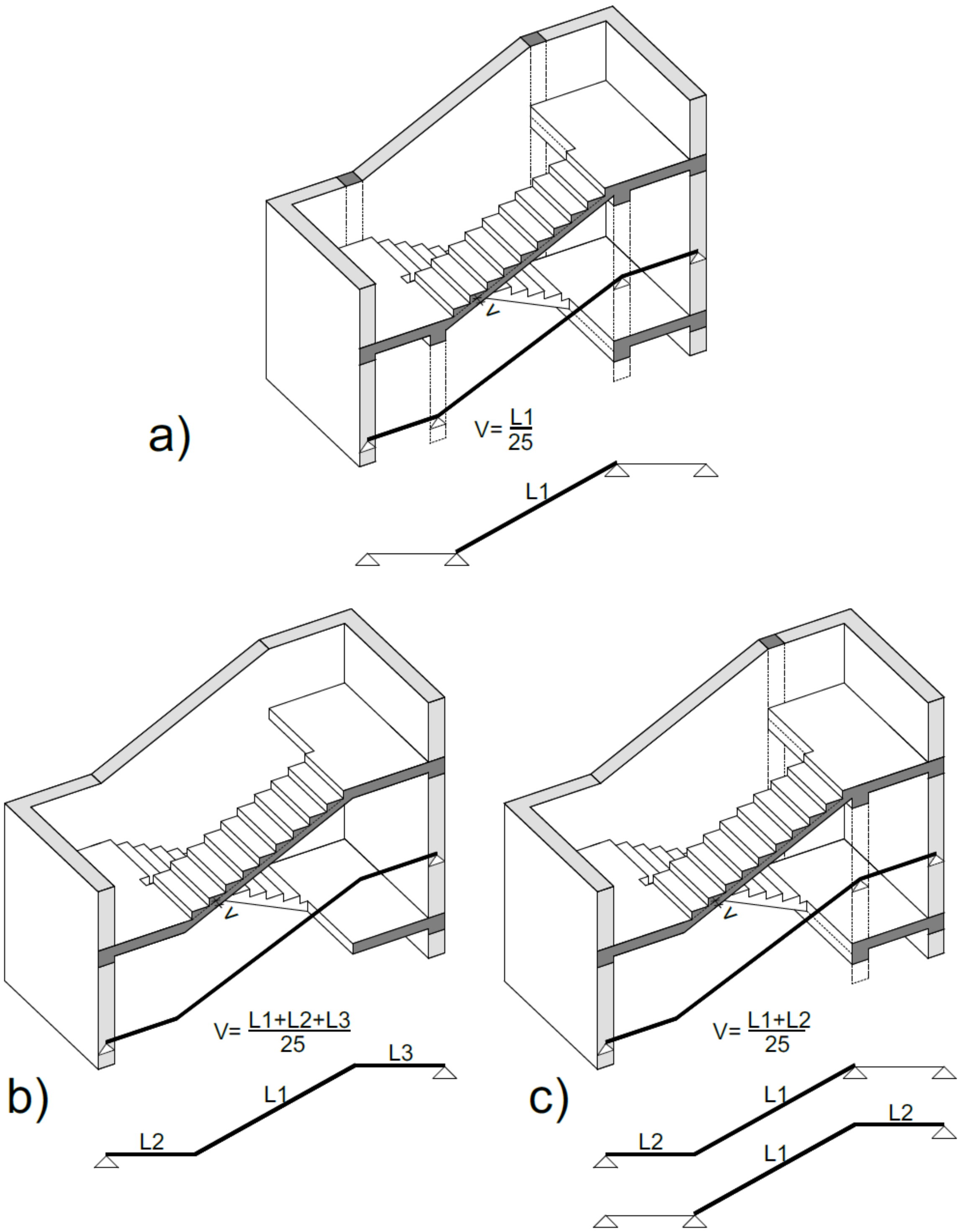


Fig. 106. a) single span waist slab, b) double folded waist slab, c) single folded waist slab

3.5. Design of the staircase

The design of the stairs starts with determining of the basic dimensions

- Total rise
- Maximum size of risers
- The function of staircase
- Minimum width dimension of the staircase flight
- Number of flights

First of all, we need the basic dimensions and purpose of staircase (building codes), with that information we can start the calculation

First step: Determine the number of risers (n).

$$\frac{\text{Total rise}}{\text{maximum size of the riser}} = \text{number of risers (must be rounded up)}$$

in this step we have to decide to use an even or odd number of risers in the staircase. In the case of a two-flight staircase, it is advisable to choose an even number of raisers, so if we get an odd number by the calculating the number of risers (step 1), we can increase it to an even number. Note that the increasing of the number of risers also increases the floor space requirement of the stairs!

Second step: Determination of the final riser height (r)

$$\text{size fo the risers} = \frac{\text{Total rise}}{\text{number of risers (n)}}$$

Third step: Determination of tread depth (t)

$$2R + \mathrm{T} = 60 - 64$$

Fourth step: The tread depth **(T)** obtained from the calculation is usually not a round number. Therefore, the tread depth can be rounded up for easier design and construction. It is advisable to check the rounded tread by the formula. Note that the rounded tread can significantly increase the length of the stair flights, thereby increasing the floor space requirement of the stair!

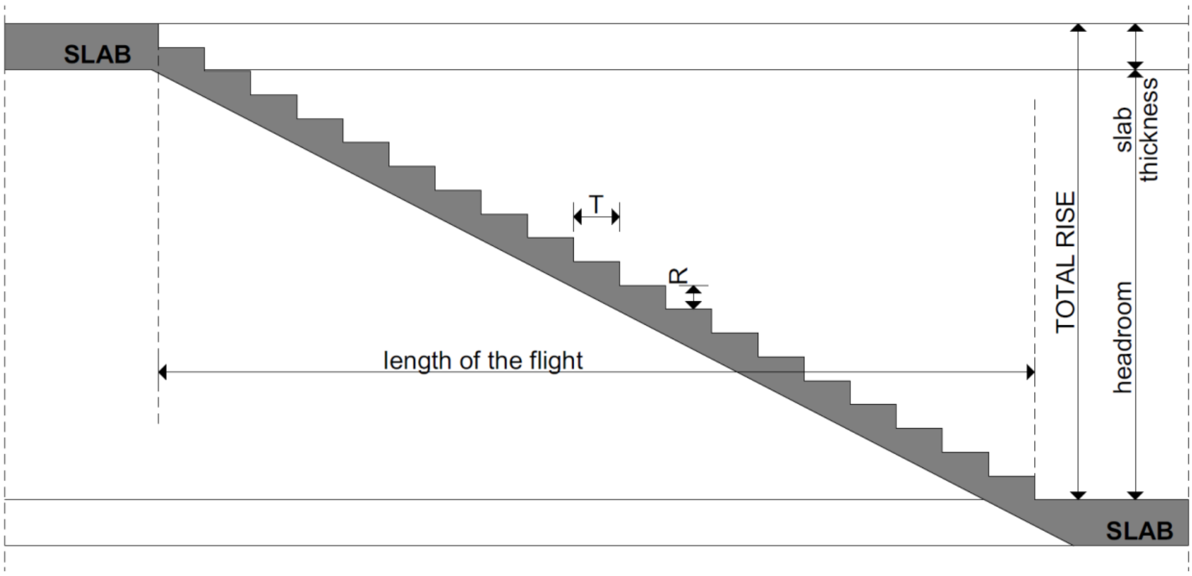


Fig. 107. Stair dimensions

3.5.1. Staircase calculation example

Total rise (storey height):	3,20 m
riser maximum:	17 cm
flight width:	1,20 m
number of flights:	2
stairwell width:	20 cm

First step: Determine the number of risers **(n)**.

$$\frac{\text{Total rise}}{\text{maximum size of the riser}} = \frac{3{,}20}{0{,}17} = 18{,}823\ldots \approx 19 = \text{n}$$

Since we design a two-flight staircase with the same number of risers in flights, the 19 risers are rounded to 20, so the final number of risers **n = 20.**

Second step: Determination of the final riser height **(R)**

$$\frac{\text{Total rise}}{\text{number of risers (n)}} = \frac{3{,}20}{20} = 0{,}16\text{m} = \mathbf{16cm}$$

Third step: Determination of tread depth (t)

$$2R \ + \text{T} = 60 - 64$$
$$2x16 \ + \text{T} = 60 - 64$$

From the calculation we gat that the tread depth can range between the following values:

$$\text{T} = 28 - 32\ cm$$

Fourth step: It is advisable to choose the smallest possible tread deph if we want to achieve a short stair flight, or the largest if you want to design a more comfortable stair. In this case, we choose a **30 cm tread depth** between the two values.

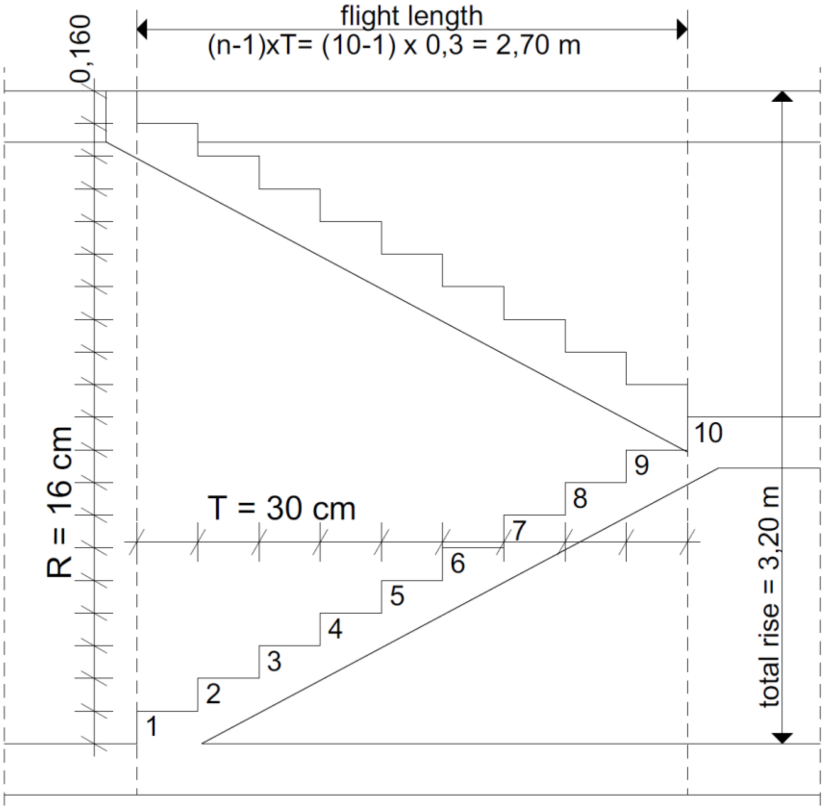


Fig 108. Dimensions of two-flight stairs

3.5.2. Turning detail of reinforced concrete stairs

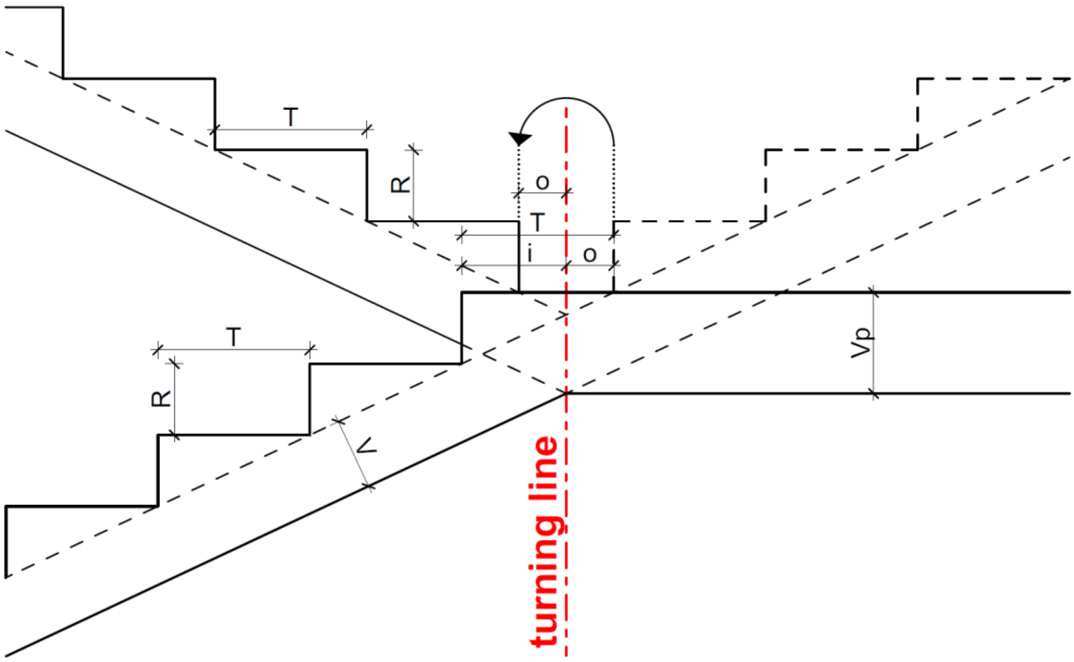


Fig. 109. Principle of the turning detail

The turning line is determining the clear intersection of the bottom plane of the waist salbs and the bottom of the landing platforms. The turning line devide the last tread to the **incoming(i)** and **outgoing(o)** parts. For the correct solution we have to mirror the outgoing(o) on the turning line, which is give the position of the first riser of the next flight. The design of the correct turning detail is important for the aesthetical apperance and structural solution.

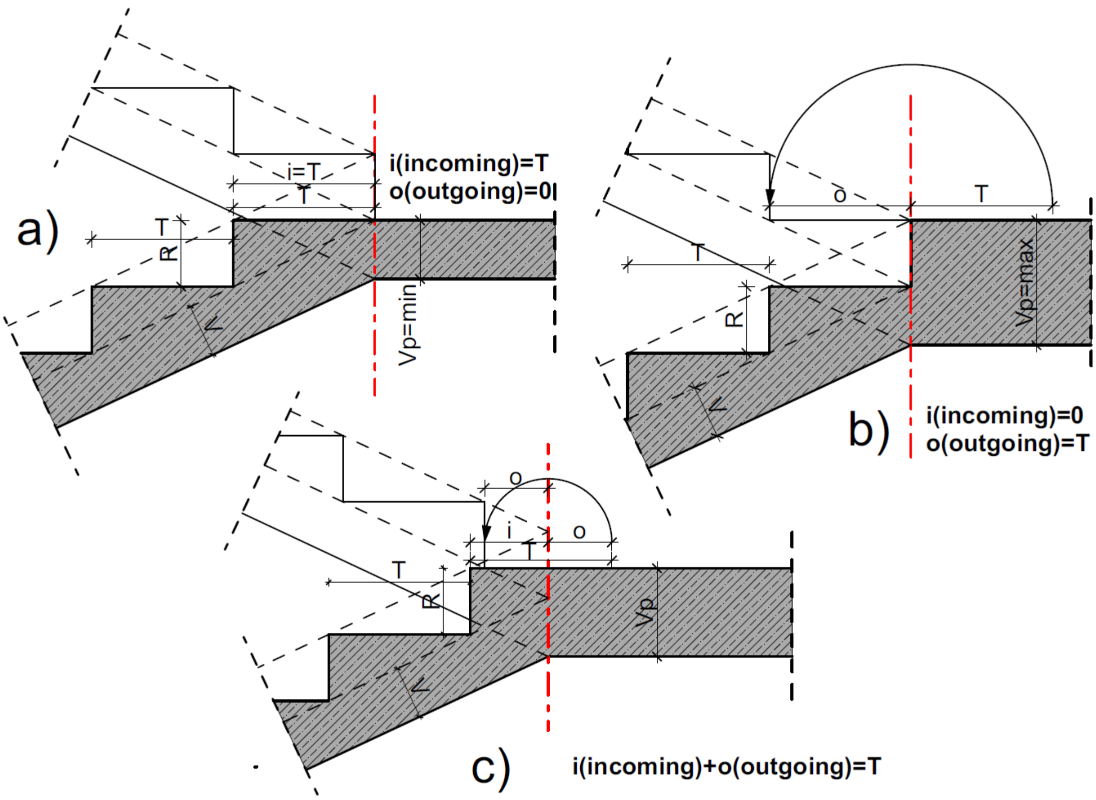


Fig. 110. Relationship between the position of the turning line and the thickness of the landing: a) minimum, b) maximum landing thickness

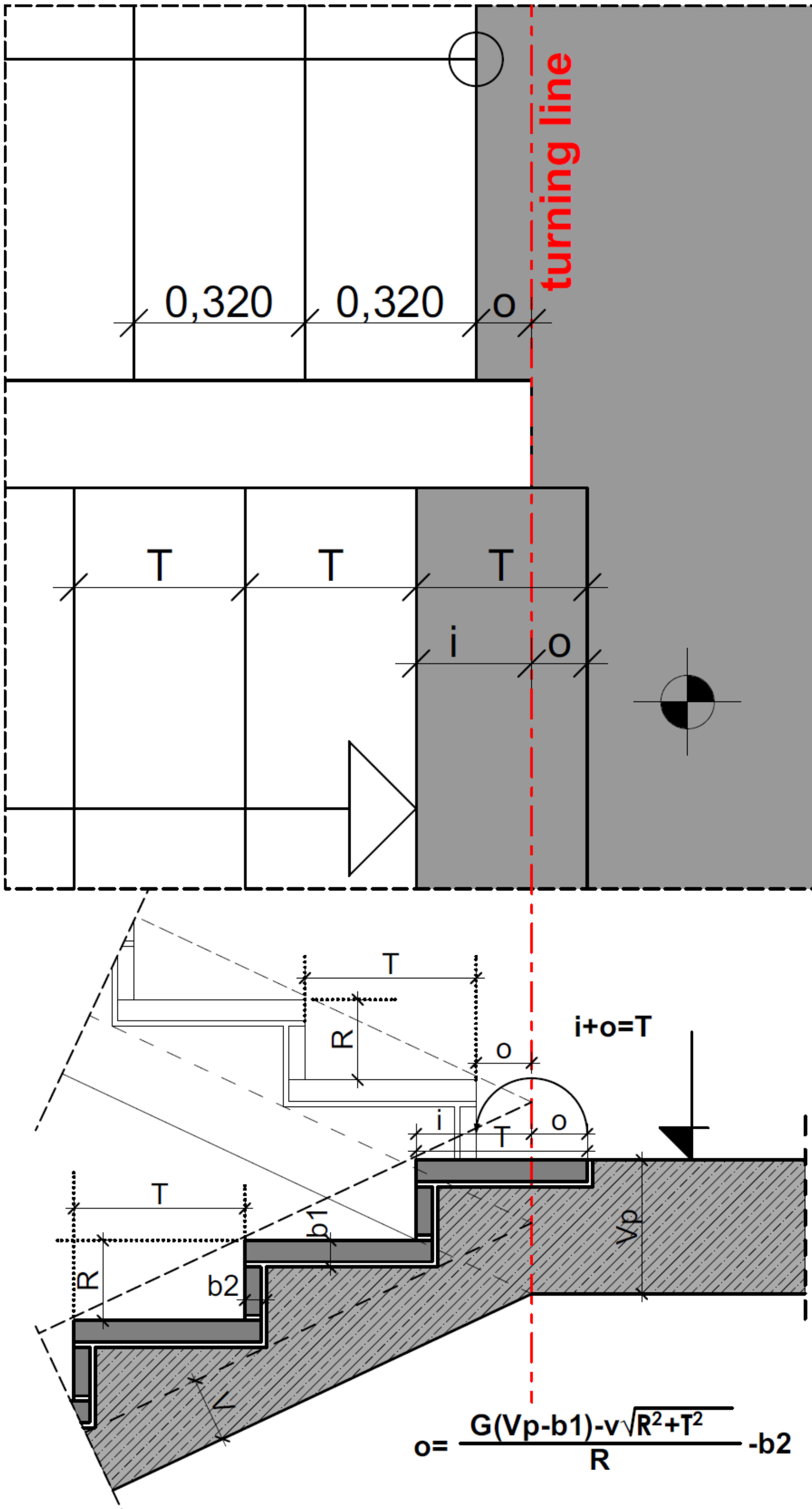


Fig. 111. Turning detail of the cladded staircase and the formula for value check

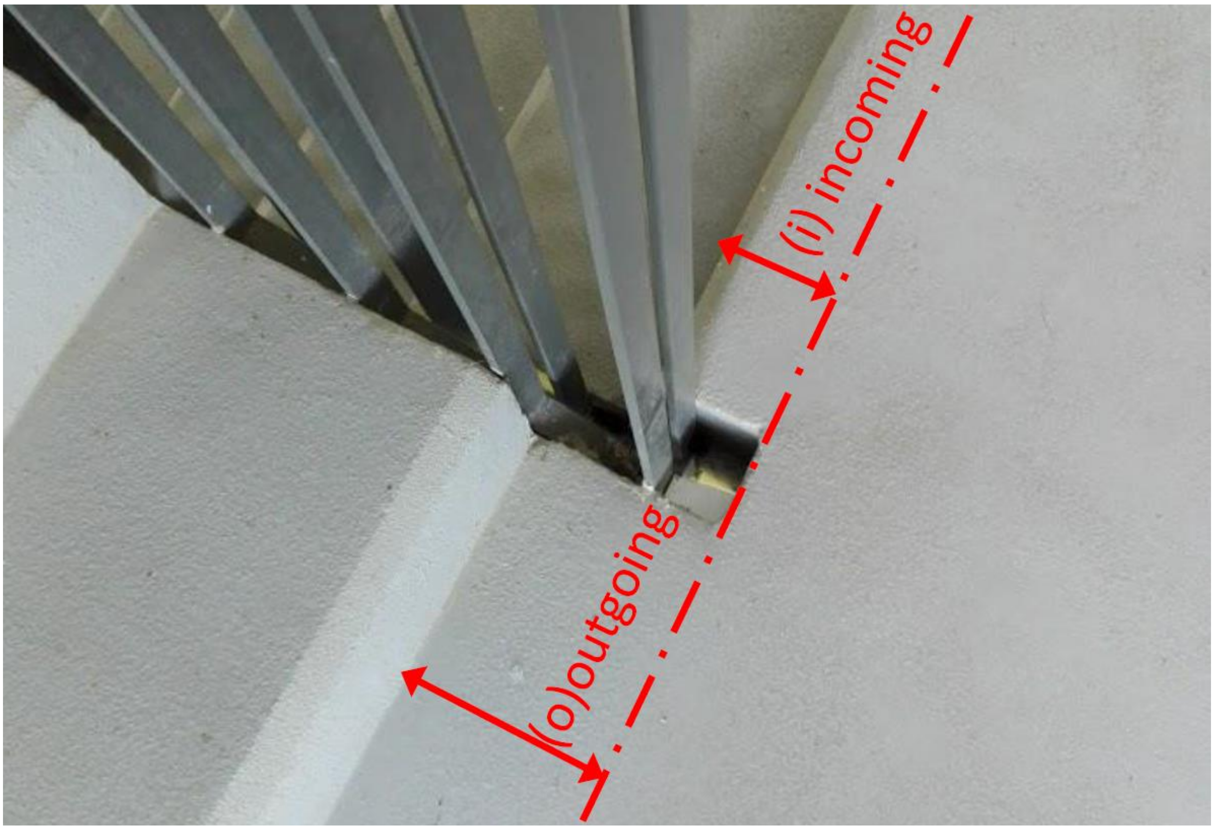


Fig. 112.. Offset of incoming and outgoing steps at the turning line

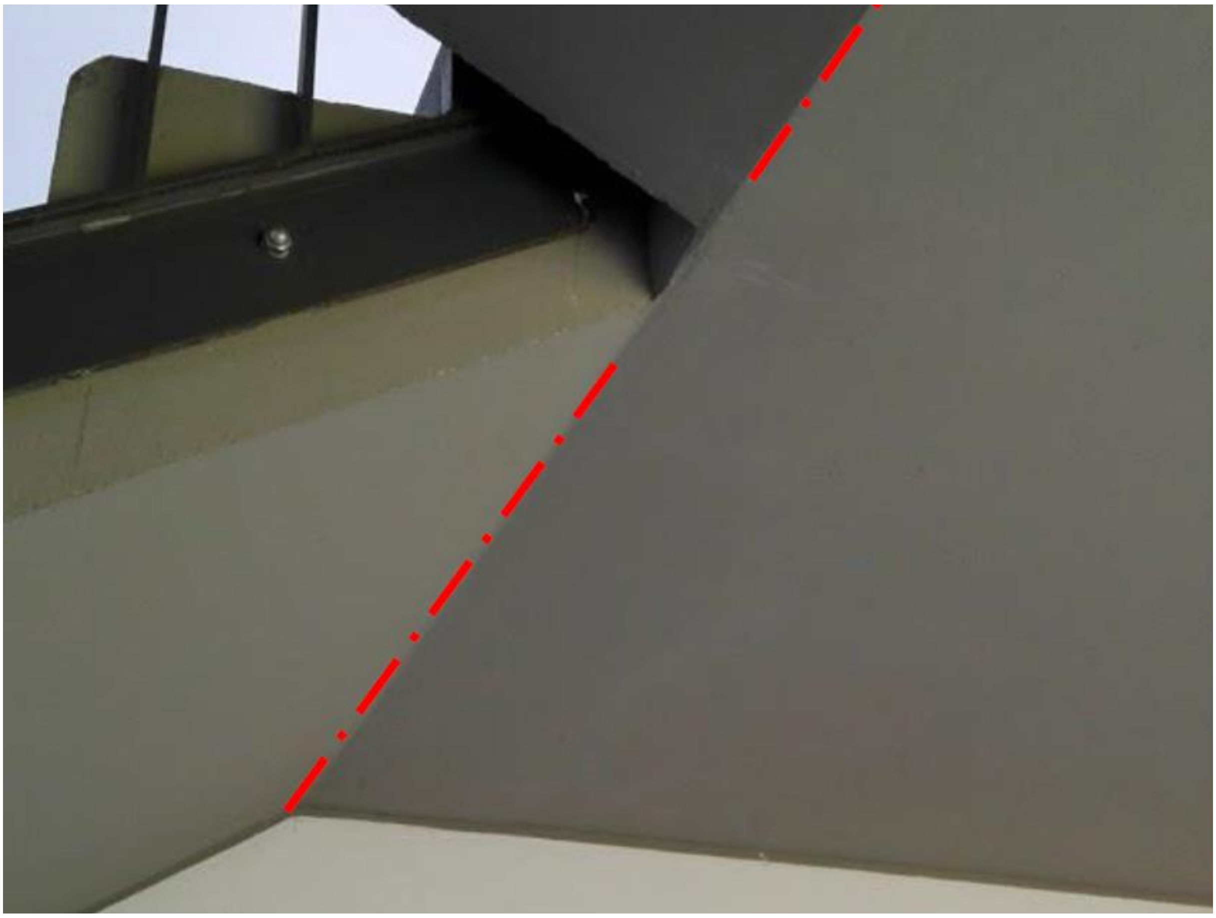


Fig. 113. The clean intersection of the slab planes at the turning line

3.5.3. Determining of the required space of the stairs

After editing of the turning line position, we can continue to determine the space requirement of the stair with the data obtained from the stair calculation.

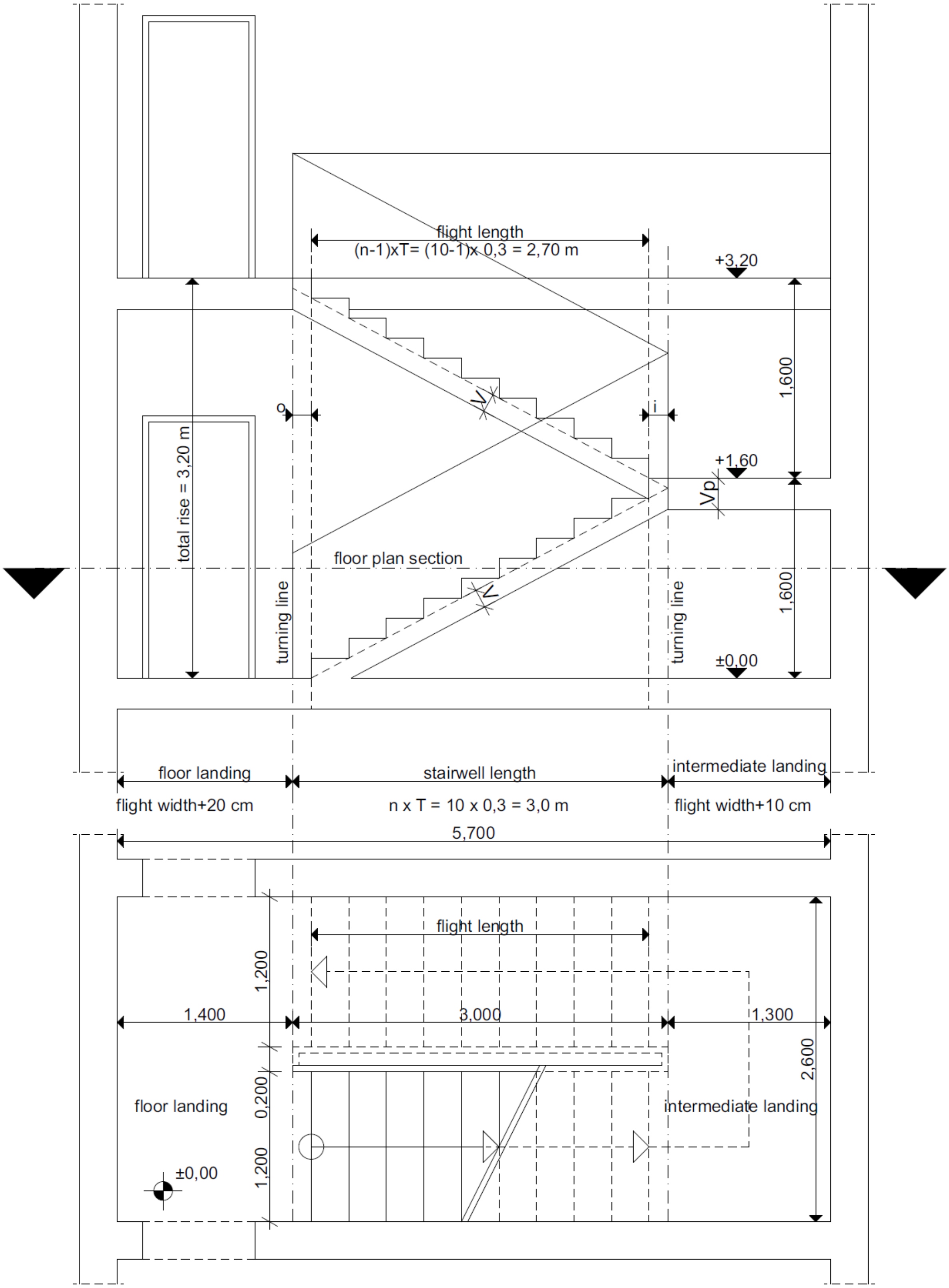


Fig. 114. Determination of two-flight staircase dimensions

The floor plan size of the staircase can be determined based on the given dimensions (eg flight and stairwell width) and the values obtained in the calculation (stair flight and stairwell length).

The width of the two-flight staircase: arm width x 2 + stairwell space, if a railing is required only on one side of the flight and fits in the starwellspace. If the handrail is fixed at the top of the flogths, its width + free flight width must be taken into account.

Length of the two-flight staircase: length of the stairwell space + floor landing width + intermediate landing width

Width of floor landing: flight width +20 cm
Width of intermediate landing: flight width +10 cm

During the design of the staircase, we try to reduce the footprint of the stairs as it possible, becouse this area can be used for no other than traffic. At the same time, make sure you design a safe staircase as this is the primary consideration during designing of the staircase

During the design of the staircase quite often the riser height given by the calculation is non-round number, it may be a problem to set it out on site during construction.
e.g.: If we want to divide the total rise of 3.20 m into 18 risers
Result of the risers r = 3,20/18=0,1777777....cm

The setting out is facilitated by editing an inclined line within the total rise, which can be easily divided into 18 sections. In this case, e.g. A 3.60 m long straight line, which is divided into 18 sections give 20 cm sections, it can be easily measured on any scale. The resulting division can be projected horizontally to set the riser hights.

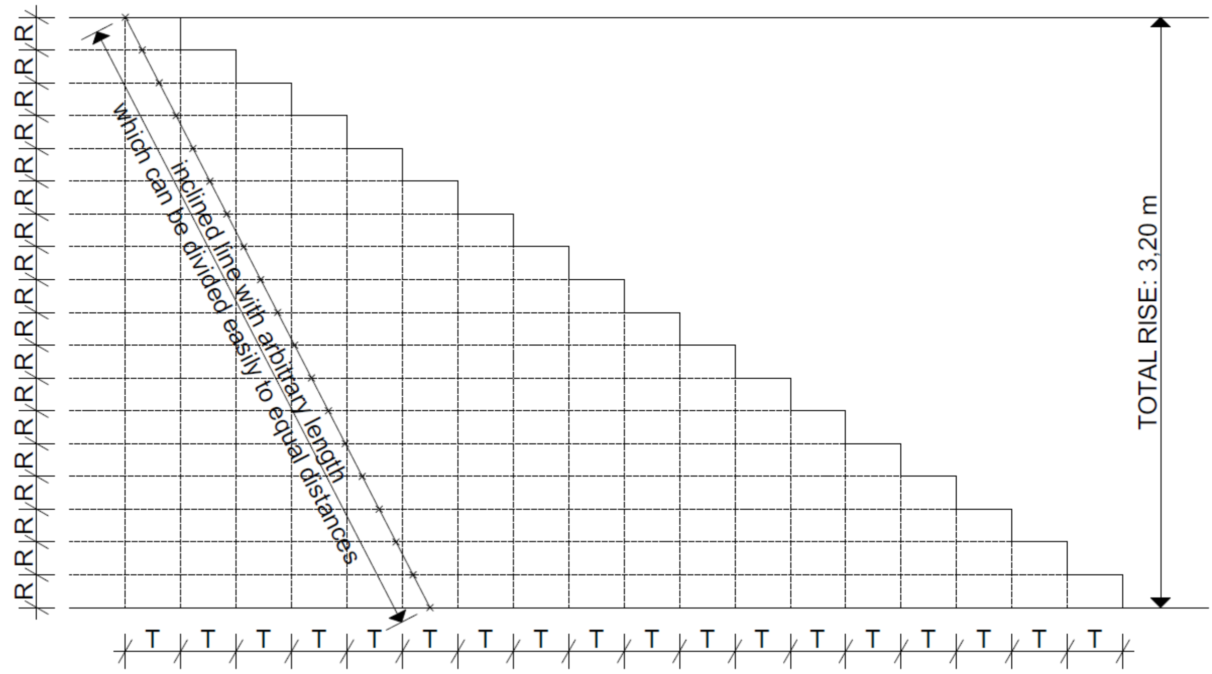


Fig. 115. Set-out of the risers

3.5.4. Turning detail of three flight staircase

The design of a three- or four-flight reinforced concrete staircase is not substantially different from the design of a two-flight staircase. The difference occurs with the intermidiate flight inserted between the two flights on opposite side, where the outgoing value is rotated 90 degrees instead of 180.

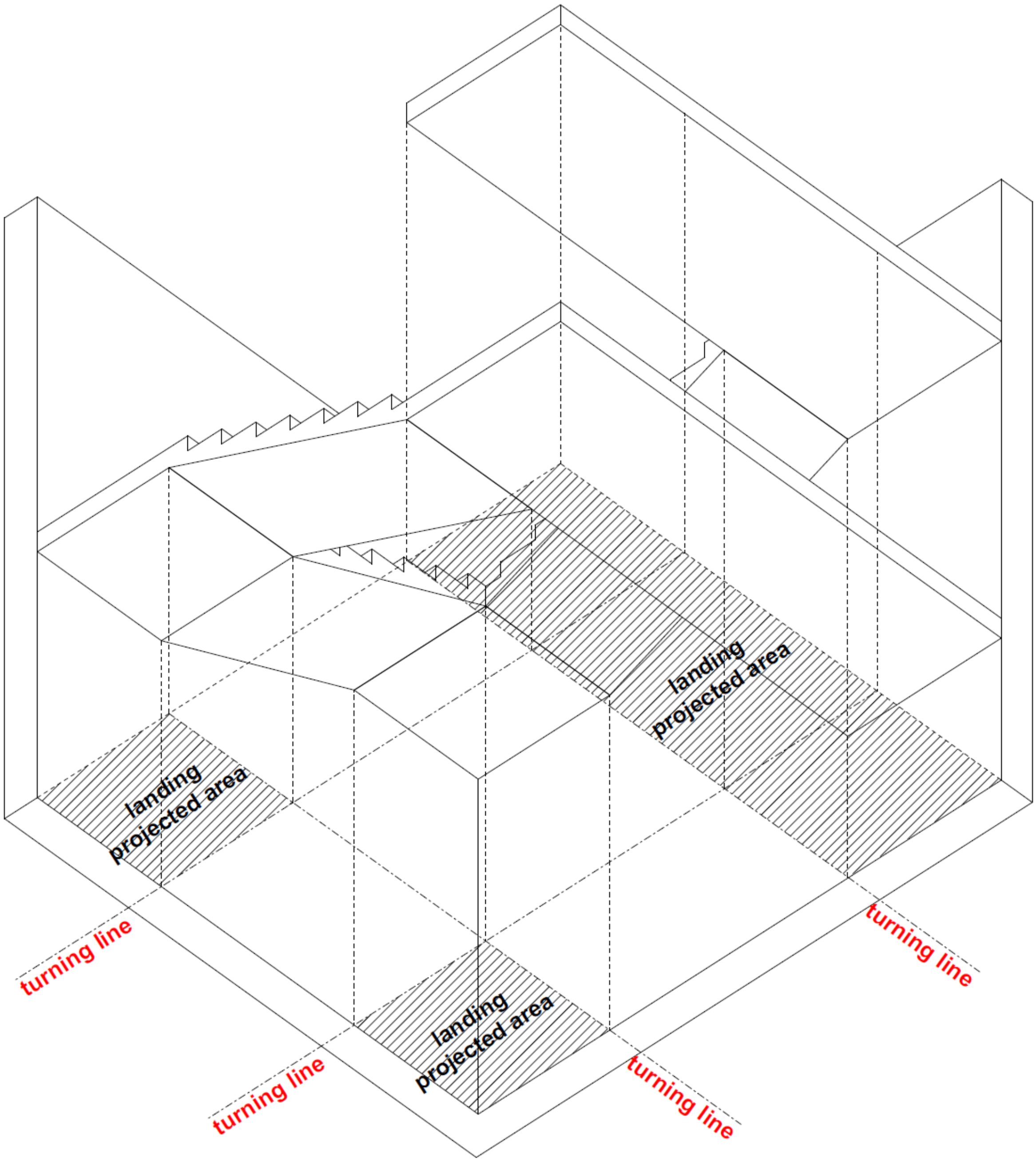


Fig. 116. Axonometric view of the three-flight staircase with the location of turning lines

In the case of three- or four-flight stairs, the turning lines determine the footprint of the stairwell space and also the size of the intermediate landings. Due to the geometry, the size of the intermediate landing cannot be larger than the width of the flights, therefore it is advisable to design the flight width to be larger the required.

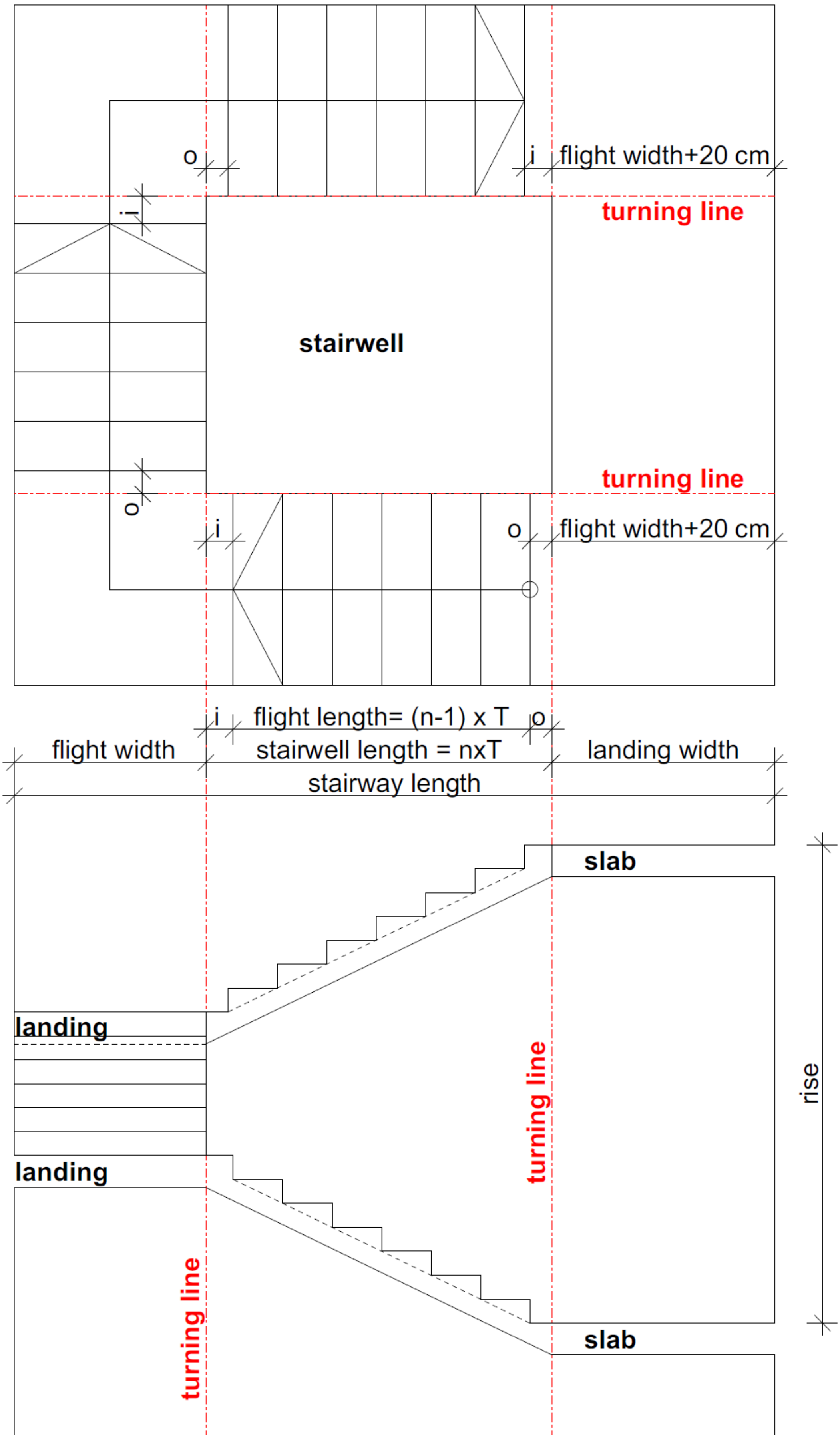
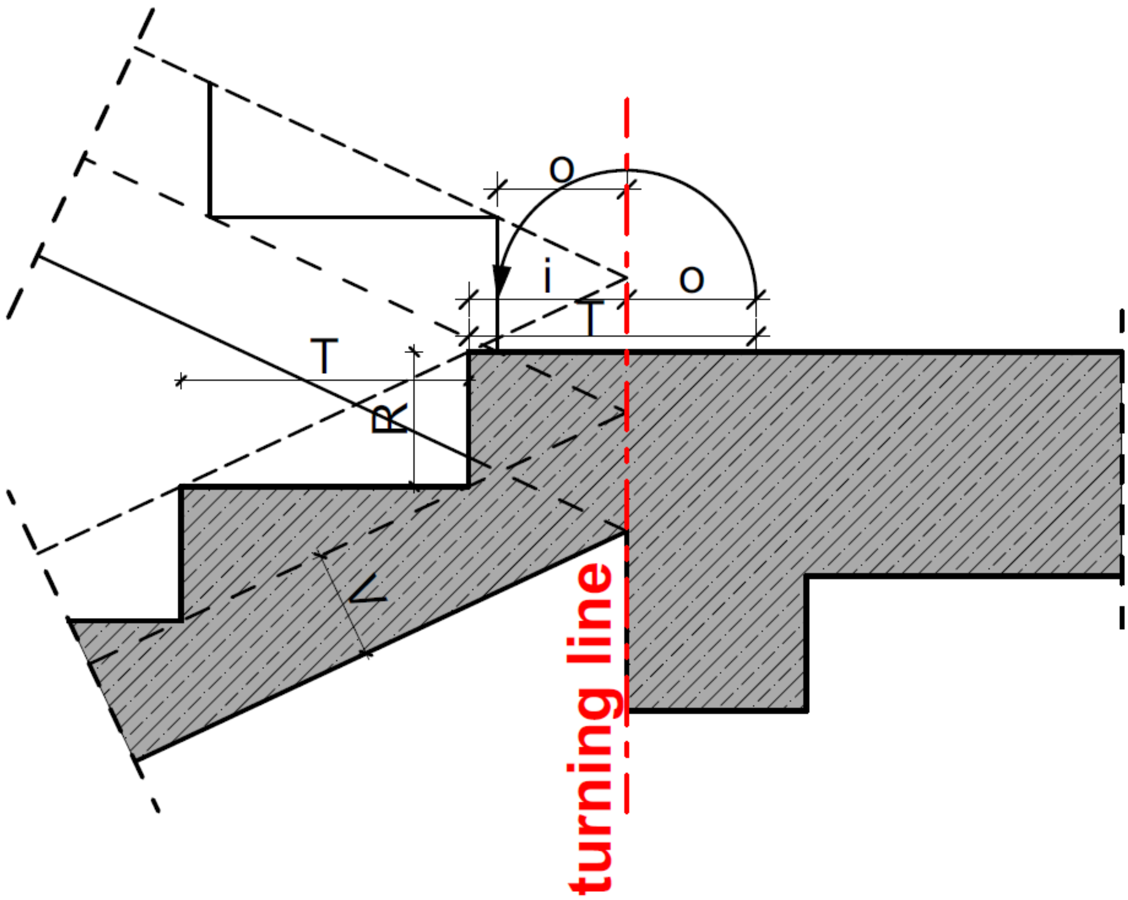


Fig. 117. Turning line design of the three-flight staircase

3.5.4. Turning detail with edge beam

In the case of beam supprted landings, the waist salb acts as a two-way slab, which is a favorable design from the point of view of the structure, but unfavorable from the aesthetic point of view. In the case of a beam supprted landings, the position of the beam is fit with the position of the turning line. The turning line also determine the end of the stairwell space. If the beam is offset beyond the turning line towards the stairwell space, the design is structurally incorrect, if it is offset in the direction of landing, the design is aesthetically incorrect.



Gig. 118. Turning line with beam supported landing

The thickness of the floor landing and the intermediate landing usually different as the intermediate landing is usually thin slab without a soundproofing layer, while the floor landing is made with the same thickness as the slabs. In such cases, the turning lines at the floor landing and the intermediate landing are not the same. If a beam supports the edge of the floor landing, the different slab thicknesses do not cause a geometric problem at the turning line, since the waist slabs connected to the beam.

3.6. Design of curved stairs

The design of curved stairs is quite tricky and sometimes can be a really complicated task. In the first step its important to correctly determine the location of the walking line, this issue has already been addressed in a previous chapter. The following examples show the design of space-saving staircases, where the position of the walking line placed along the outer, longer side of the flight width.

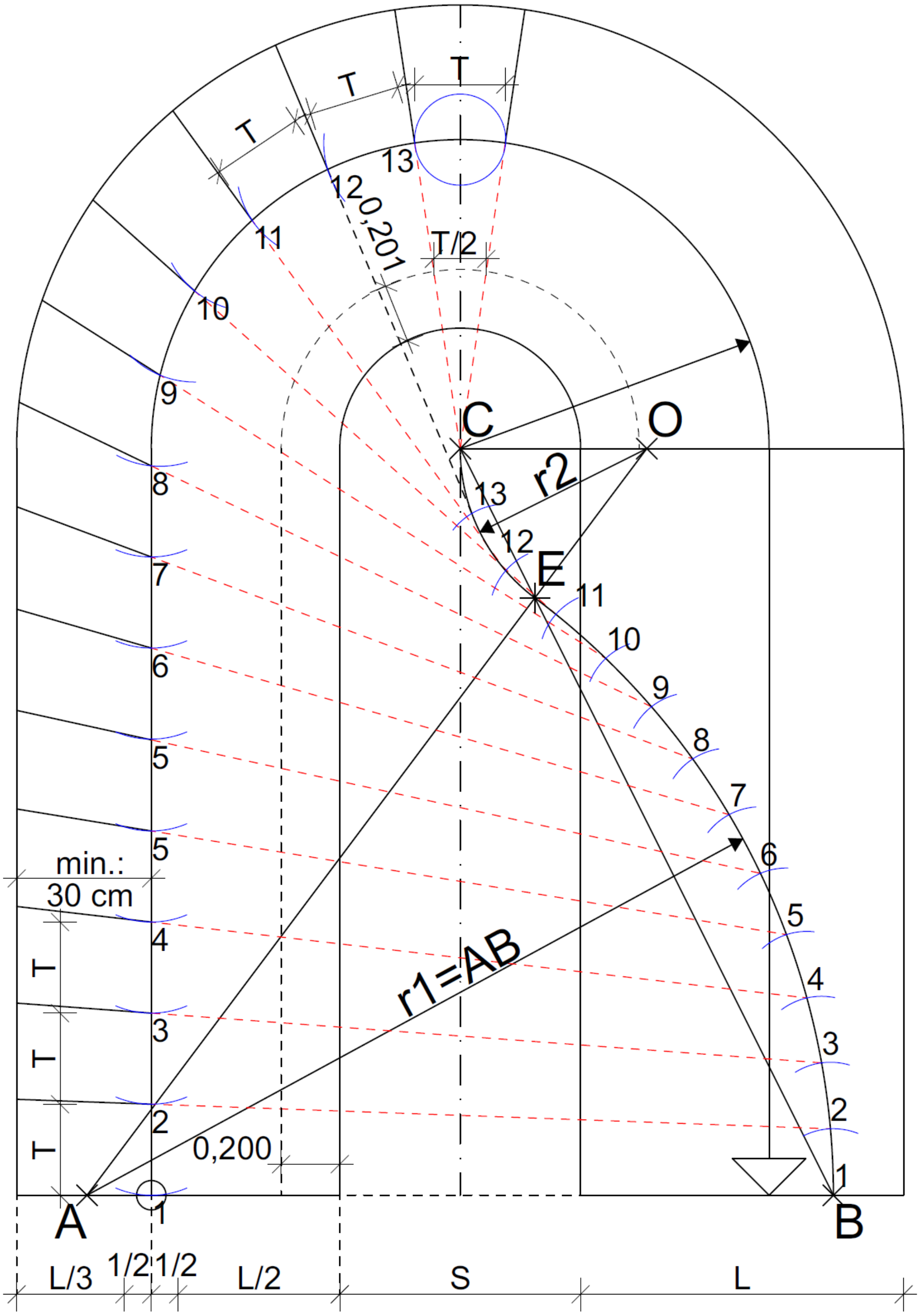


Fig. 119. Design of the winder treads with the ogee arch

One of the best solutions of winder treads arrangement can be made with ogee arch shape. The arrangement of the winder treads starts from the line of the last straight tread, at that line we can arbitrarily set the **AB** width of the ogee arche. The design of the ogee arch has already been described in the section on arches. The next step is to divide the ogee arch into equal numbers equal to the number of winder treads. We can set the middle traed from **C** center point. The divisions on the ogee arche are connected in series with the tread positions surveyed on the walking line. In the case of an odd number of risers, the middle tread is placed on the axis of symmetry.

Design of the winder treads of L shaped floor plan staircase

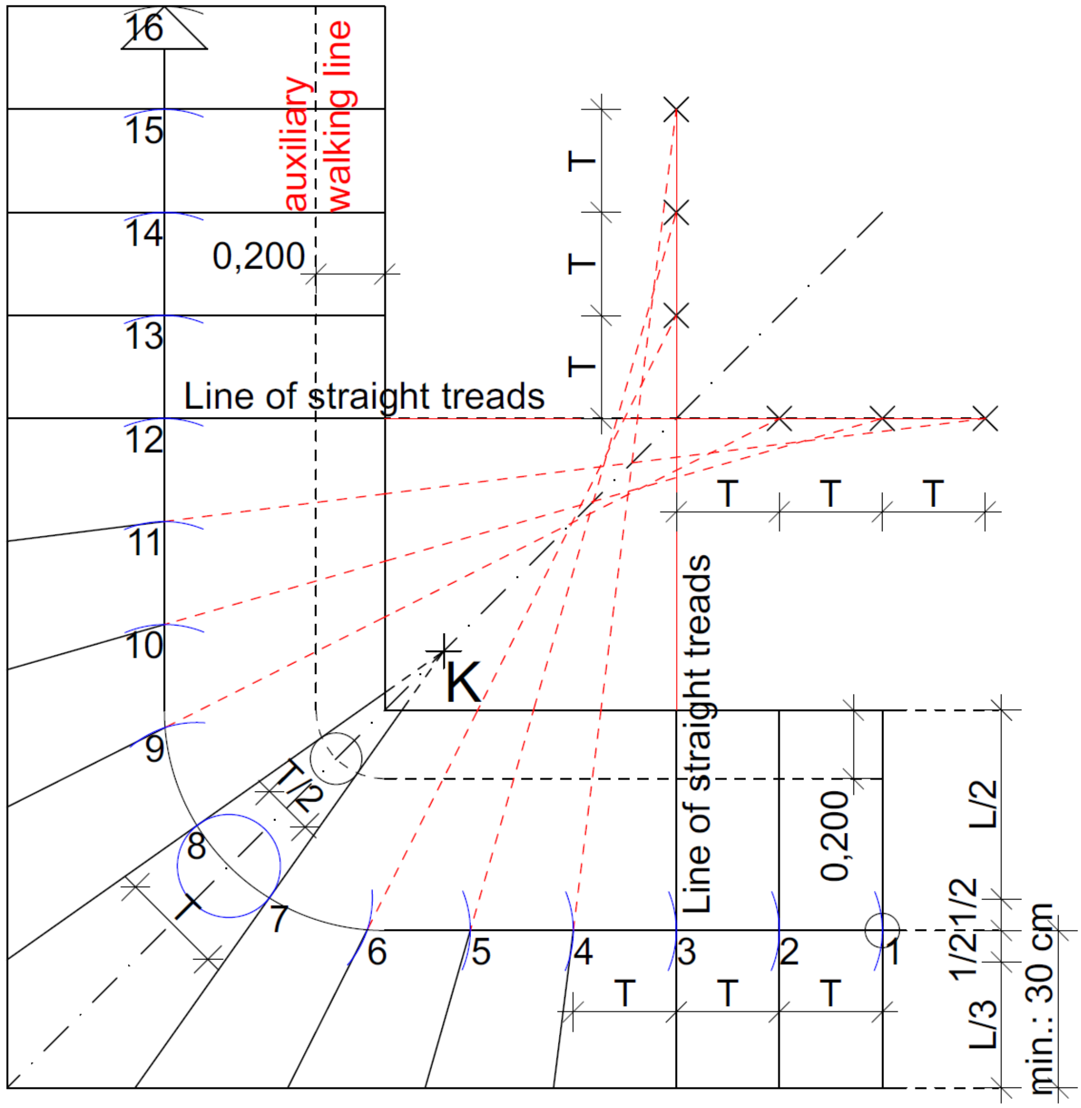


Fig. 120. Staircase with L shaped floor plan

The arrangement of the winder treads starts with the setting of the middle tread in the corner of the stairs. The middle tread is messured on the walking line in both directions with half the tread depth, and the minimum required depth **(t/2)** is messured on the auxiliary walking line at a distance of 20 cm from the inner side of the stairs. The middle tread is setted out by connecting the set points. The edges of middle tread are extended inwards to obtain the intersection point **K**. The last straight treads in both flights of the stair are extended to the inner side, the number of straight treads must be equal compare to the central axis (asymmetric editing is also possible). The extended edges of the straight treads intersect the extended edges of the middle step. The appropriate number of tread depth have to be setted out from the intersection points. The treads are measured in both directions, and the points on the walking line are connected in series in both directions, thus obtaining the edges of the winder steps.

3.7. Low slope stairs (terraced stairs)

The Italian staircase is usually and outdoor staircase with low slope, pruduced by low risers and long treads as landings. This kind of stairs often used in public buildings and public spaces. The tread depth of the Italian staircase is supplemented by multiple of a step distance, this produces a long but at the same time comfortable landings beetwen risers.

Fig. 121. Italian staircase

Due to the low slope of the Italian stairs, it is not necessary to create intermediate landings, but for the convenience of the stairs, it may be important to determine the number of steps between the risers.

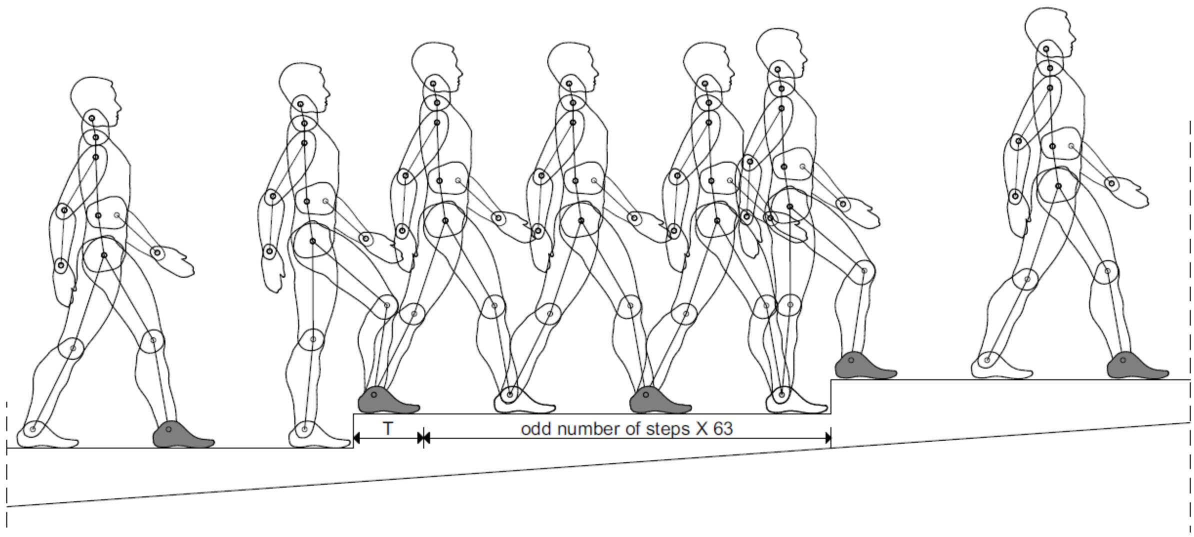


Fig. 122. Italian stairs with an odd number of steps

The step up always falls on the same foot if we take an odd number of steps between the risers. Its not cause discomfort in case a short staircase, but can be uncomfortable in case of long staircase.

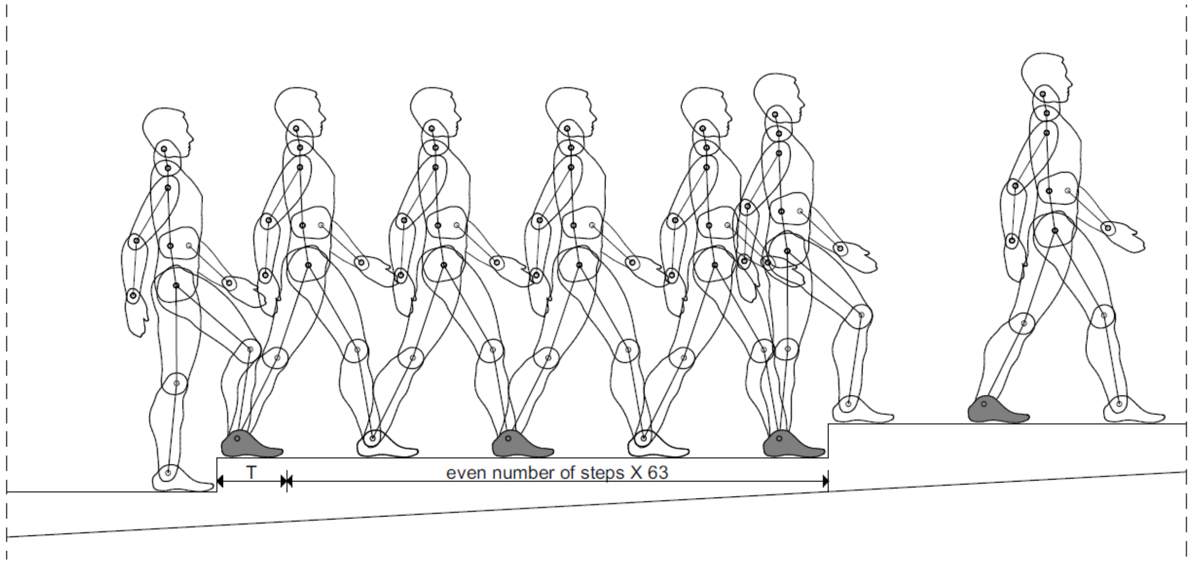


Fig. 123. Italian stairs with even steps

The step up will take turns if you take an even number of steps between two performers, making the stairs significantly more comfortable, but in same time much longer.

OTÉK SECTION 64. (3). Terraced stairs may be built in edifices or outdoors. It is not necessary to insert landings in flights of stairs built as terraced stairs. The central line of terraced steps may have a maximum of 8% longitudinal decline.

This means that in case 15 cm high risers and an even number of steps, it is necessary to insert at least four steps between risers, which significantly increases the length of the stairs. If the risers are reduced to 12 cm, a smaller rise will result in more steps, but may reduce the overall length of the stairs depending on the level difference to be bridged.

Fig. 124. Stairs of the Vatican Museum, Giuseppe Momo 1932

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V. List of figures