MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL UNIVERSITY «YURI KONDRATYUK POLTAVA POLYTECHNIC»

BUILDING STRUCTURE DEPATMENT

E-LEARNING LECTURE NOTES FROM THE DISCIPLINE

BUILDING STRUCTURE

(reinforced concrete and masonry structures)

Poltava – 2022

Мультимедійний конспект лекцій із дисципліни «Building structures» для підготовки студенті спеціальності 192 – Будівництво та цивільна інженерія денної форми навчання, освітнього рівня «бакалавр» (англійською мовою). –Полтава: Національний університет імені Юрія Кондратюка, 2021 рік. – 150 с.

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41.02.

The subject
REINFORCED CONCRETE AND MASONRY STRUCTURES AND THEIR ROLE IN CONSTRUCTION OF BUILDINGS AND STRUCTURES

1.1 The essence of the reinforced concrete.
1.2 A short historical overview of the appearance of reinforced concrete structures.
1.3 Reinforced concrete structures properties and the fields of application.
1.4 The concept about pre-stressed structures.
1.5 The classification of reinforced concrete structure according to stress state, by destination and according to their manufacture method.
1.6 Materials of masonry and reinforced masonry structures. Buildings and structures parts are made of stone.

1.1 The essence of the reinforced concrete

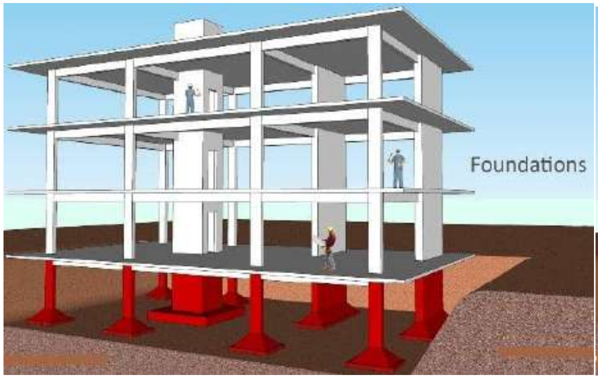
The place of reinforced concrete structures among other building structures:

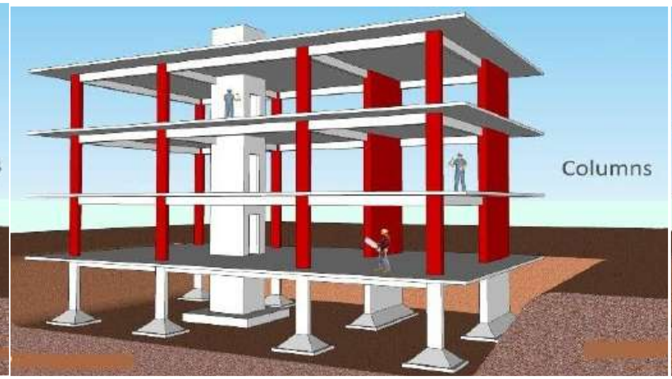
- **reinforced concrete structures ≈ 75 %;**
- metal structures ≈ 15 %;
- masonry structures ≈ 7%;
- wood structures ≈ 3%.

Reinforced concrete is complex building material, in which concrete and steel reinforcement, connected by mutual bond, work under the load as a monolithic body.

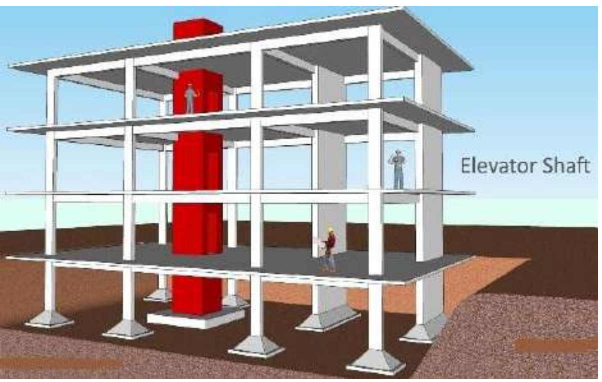
Features of concrete:

- concrete is characterized by a curvilinear and asymmetrical shape of the **mechanical state diagram** of the material;


Foundations


Columns

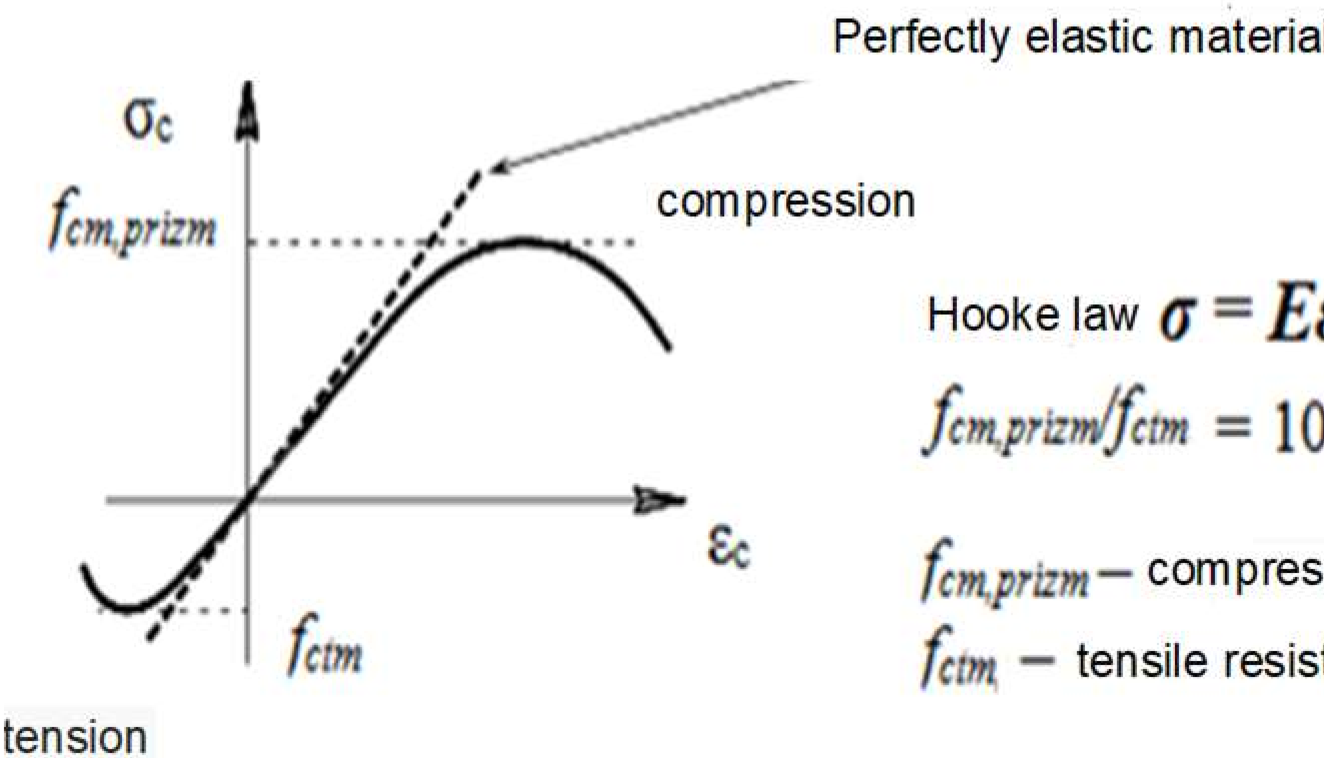

Shear Walls


Elevator Shaft


Beams


Slabs


HABAU



Hooke law $\sigma = E\varepsilon$

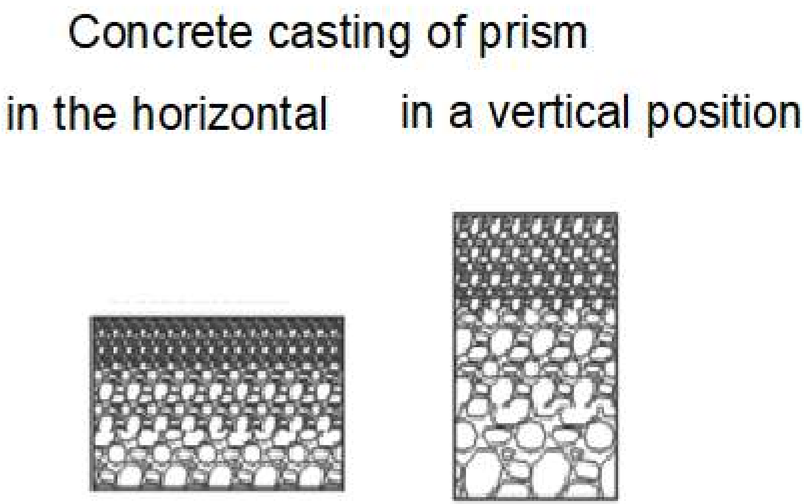
$f_{cm,prizm}/f_{ctm} = 10 - 20$

$f_{cm,prizm}$ – compressive resistance of concrete

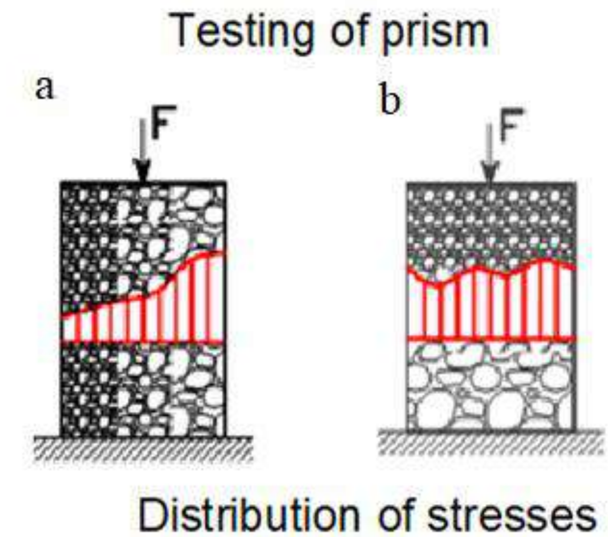
f_{ctm} – tensile resistance of concrete

- concrete works better in compression than in tension;
- concrete is not an elastic material (concrete modulus E_C – **inconstant value**);

- concrete is **inhomogeneous** material (it consists from coarse and fine concrete aggregates, hardened cement paste, water and air in the pores and capillaries);
- concrete is **anisotropic** material (it has different properties in different directions);



a b



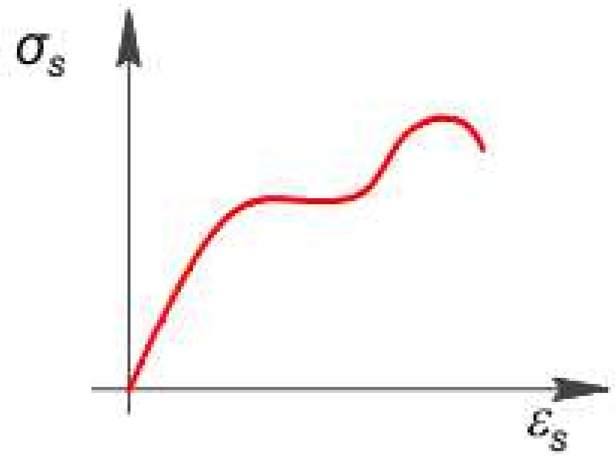
- in the concrete there are **initial stresses** of their own, conditioned:

. **shrinkage** processes during its hardening;

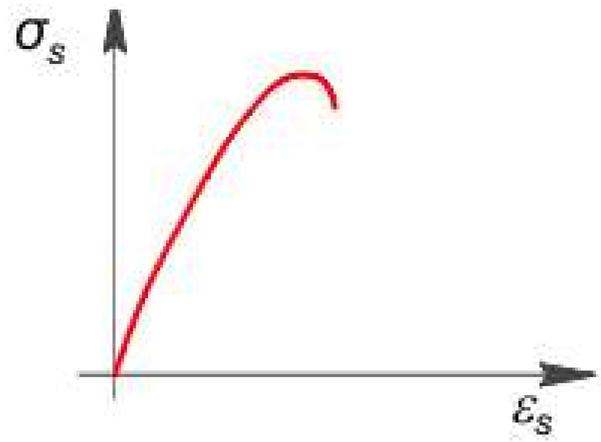
. physico-chemical processes occurring in concrete (**exothermic processes**).

Features of reinforcement:

- different nature of the diagram of the reinforcement mechanical state;



stress-strain diagram **with yield line for mild steel**



stress-strain diagram **without yield line for solid steel**

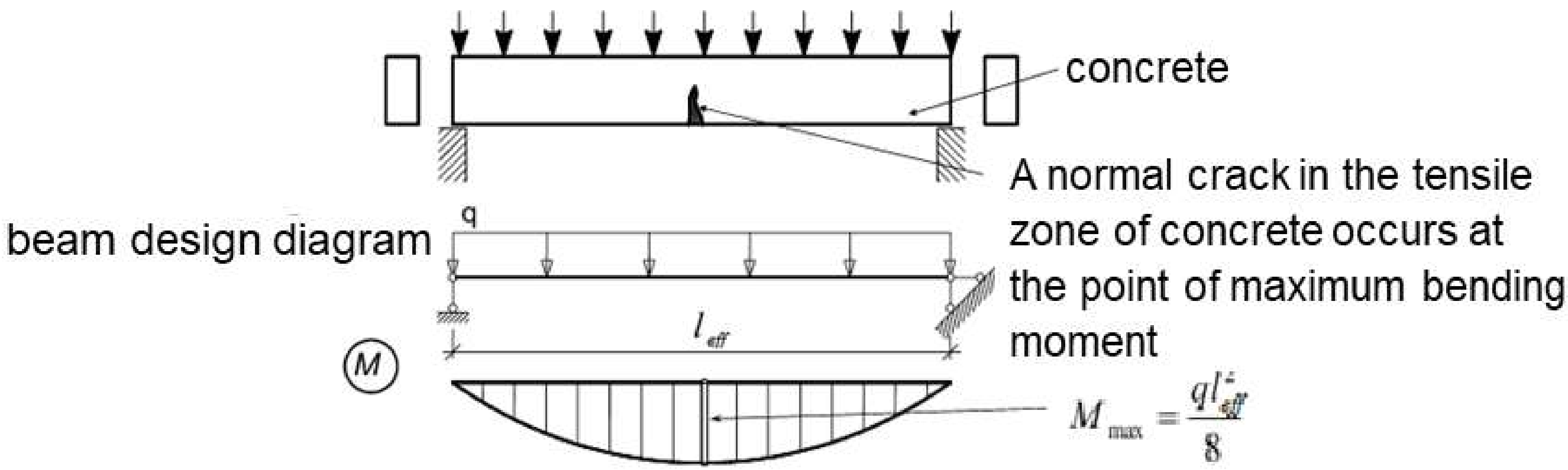
- the reinforcement has a large strength range 240 – 1500 MPa.

Features of reinforced concrete:

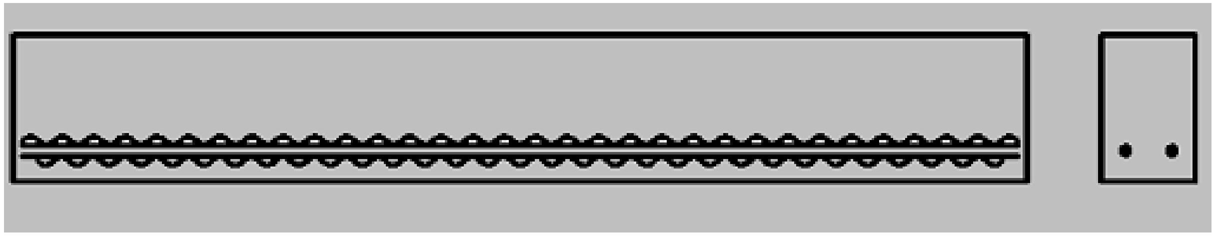
Flexible members

- the formation cracks normal to the longitudinal axis of the element;

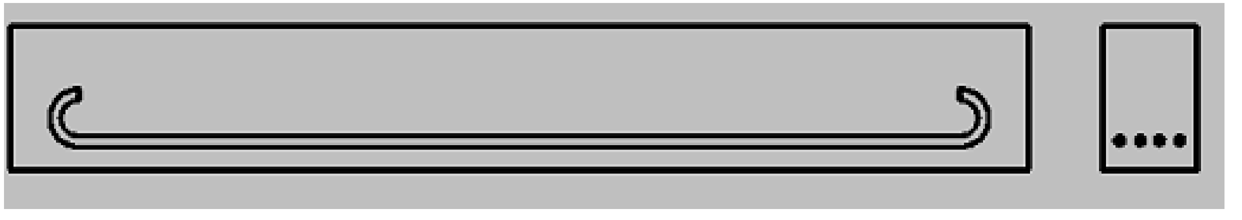
Concrete beam



Install in the tensile zone of concrete beam deformed (ribbed bar) reinforcement

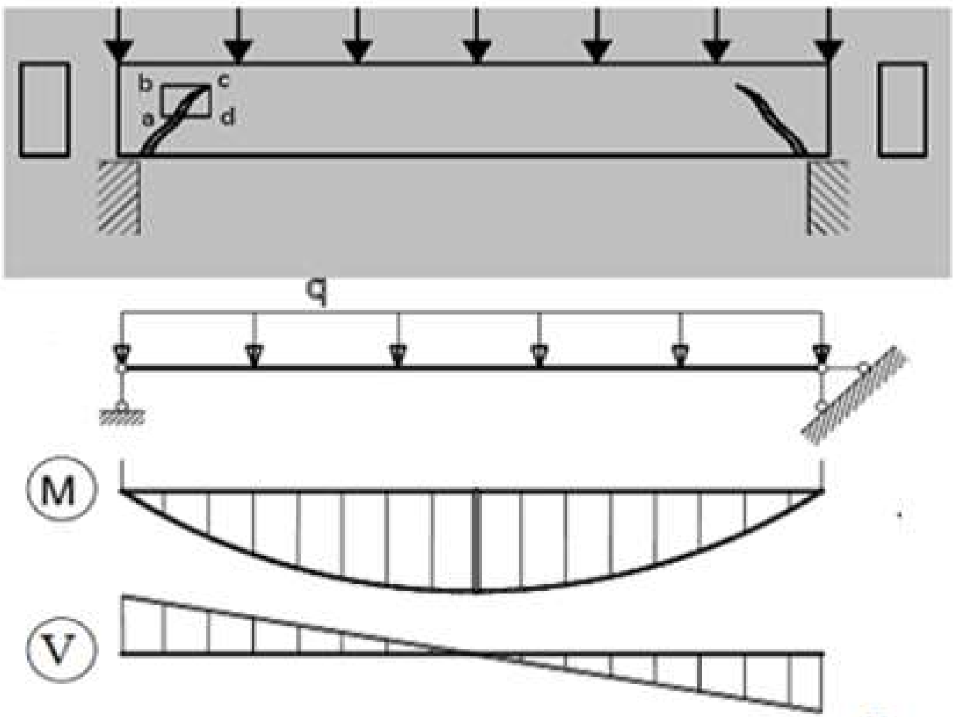


or plain (smooth bar) reinforcement

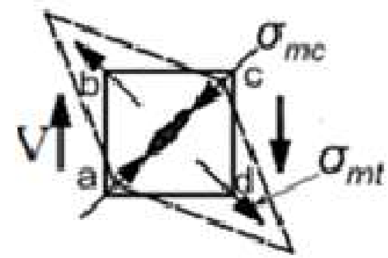


The bearing capacity of reinforced concrete beams will increase many times over

- the formation of inclined to the longitudinal axis cracks;

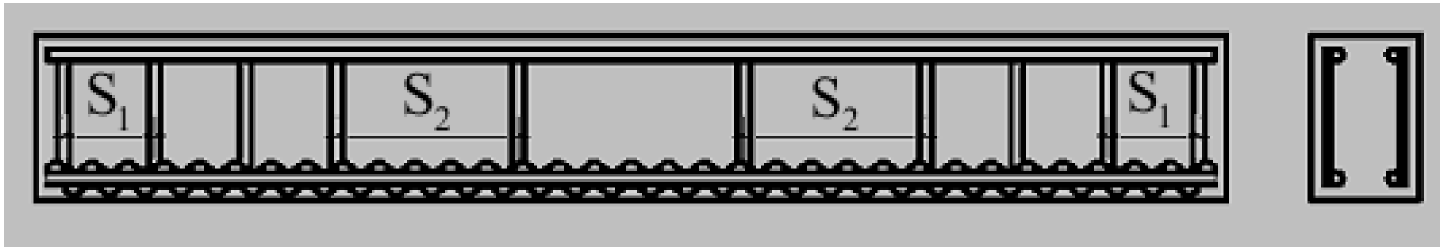


Inclined cracks occur on the support at the point of maximum shear force



$$\sigma_{\substack{mt \\ mc}} = \frac{\sigma}{2} \pm \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2}$$

Install in the beam transverse (shear) reinforcement:
vertical

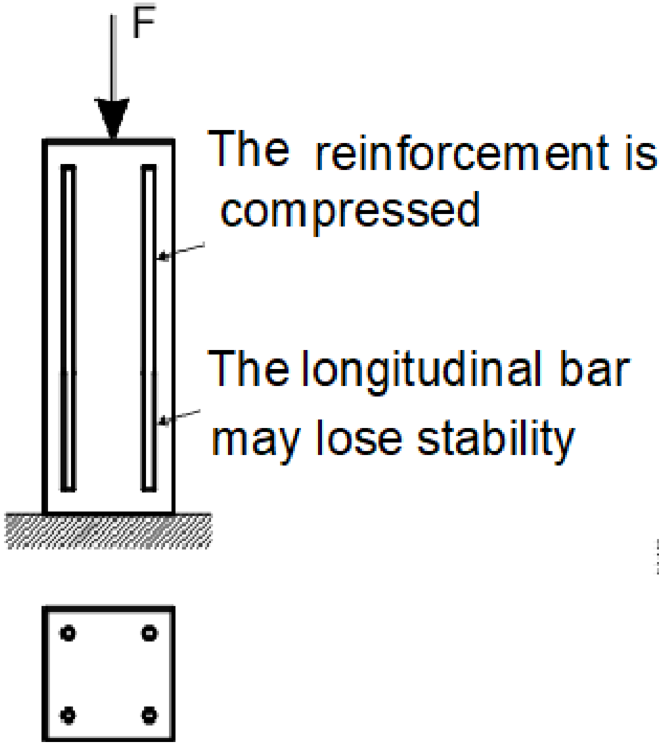


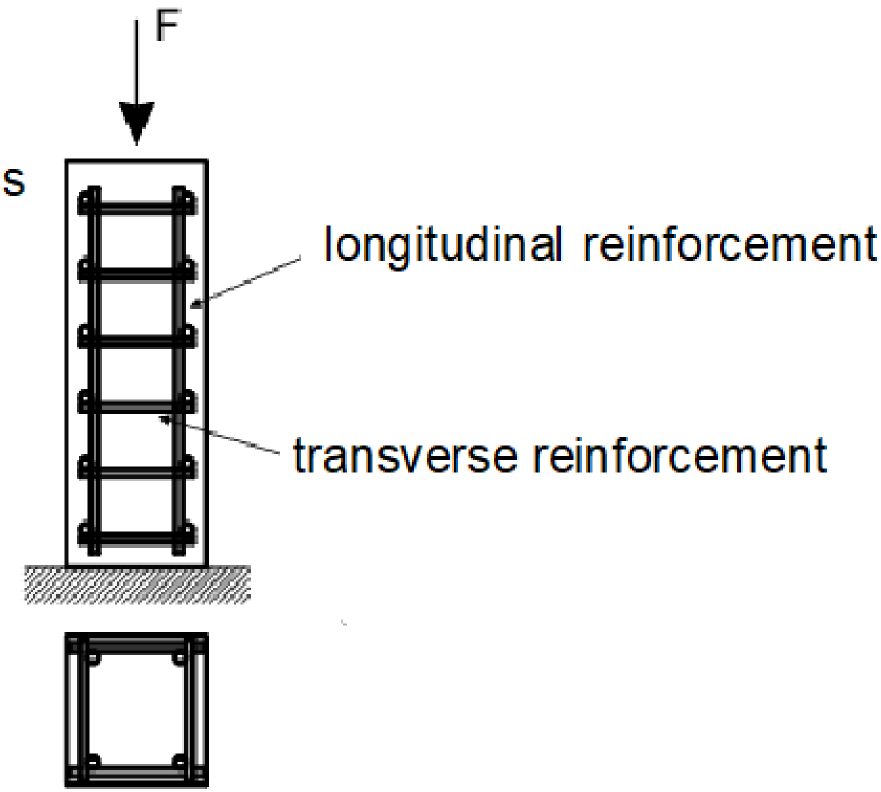
or inclined bars

The bearing capacity of reinforced concrete beams will increase many times over

Compressive members

The reinforcement is installed to increase the strength of concrete.





Cooperation of concrete and steel reinforcement are caused by an optimum combination of physical and mechanical properties of these materials, namely:

– during the concrete hardening between it and reinforcement there are considerable strength of bond, as a result materials are deformed under the load together;

– the dense concrete protects steel reinforcement from corrosion and direct action of fire;

– steel and concrete have similar coefficients of linear temperature expansion, therefore when the temperature is smaller than 100°C in both materials there are unimportant initial stress and slippage of reinforcement in concrete is not observed (for concrete $\alpha'_{c(t)}$ = **0.00001 C^{-1},** for reinforcement – $\alpha'_{s(t)}$ = **0.000012 C^{-1}**);

– reinforcement compensates disadvantages of concrete, changing its behavior in reinforced concrete structures.

1.2 A short historical overview of the appearance of reinforced concrete structures (independent study)

1.3 Reinforced concrete structures properties and the fields of application

The main **positive properties** of concrete include:

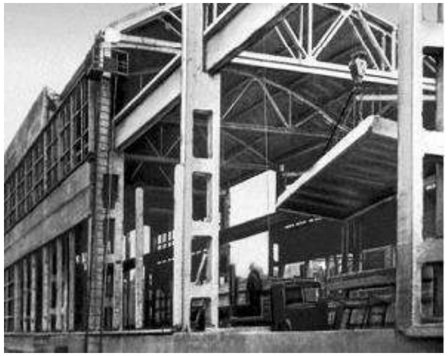
- practically inexhaustible reserves of raw materials for the manufacture of binders and aggregates;
- environmental expediency of using waste products as raw materials for concrete components;
- high reliability and durability of reinforced concrete structures, its resistance to high temperatures and aggressive environments, resistance to dynamic loads;
- possibilities to satisfy various requirements of construction, including the creation of underground and underwater structures;
- low energy process of manufacture reinforced concrete;
- relatively simple manufacture technology, possibility to create any shape;
- structural compatibility concrete with many building structures and decoration materials;
- low operating costs of maintaining buildings.

Disadvantages of concrete:

- cracking due to shrinkage and force effects;
- increased deformability;
- impossibility of rational using of reinforcement with yield strength more than 500 MPa;
- does not make any sense of using of modern high strength concrete due to the low strength of reinforcement, the low crack resistance and stiffness of reinforced concrete without pre-stressing;
- high density leads to excess weight, that limits values of spans, which are overlapping;
- high thermal and sound conductivity;
- complexity of alterations and strengthening;
- the necessity of additional time to acquire a predetermined strength of concrete;
- low resistance to dynamic loads.

Fields of application of RCS:

– industrial and civil construction (elements of the floor and roof, columns, crane beams, foundations, wall panels);



– engineering structures;

storage tank

chimney cooler

TV and radio towers

flue-pipe

- civil engineering construction;

residential estate

hotel

education institution

library

administration building

office building

shopping center

– transport construction (bridges, subways, metropolitan railway, airport runway);

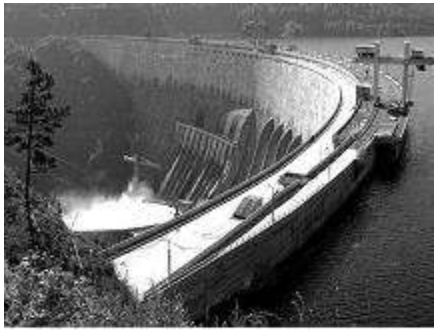
bridge

elevated road

subway

metropolitan railway

– power plant construction (check dams, canal locks, structures of HEPD and nuclear reactors);



hydro-electrical power district

heat and power station

atomic power plant

– hydro melioration construction (irrigation systems);

– vessel building (floating docks, pontoons);

– mining (fixing of rocks, on over mine constructs);

– extraction of mineral resources (floating oil platform);

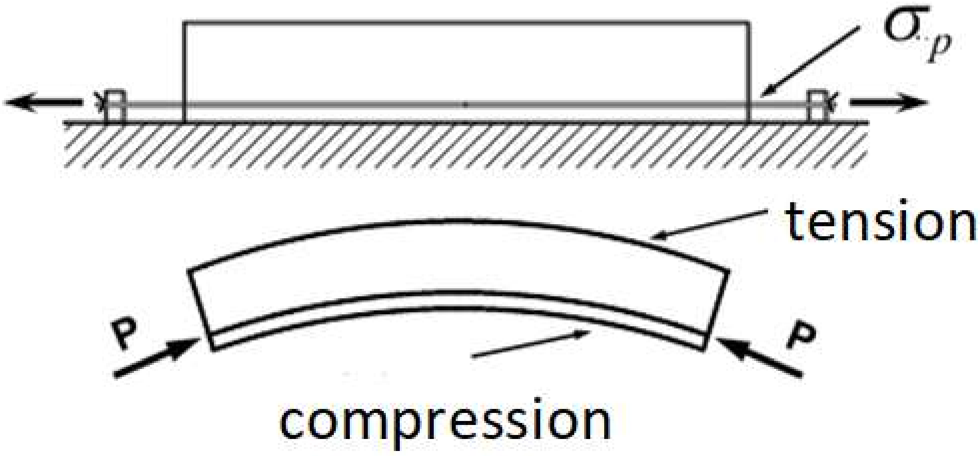
- sports and cults buildings.

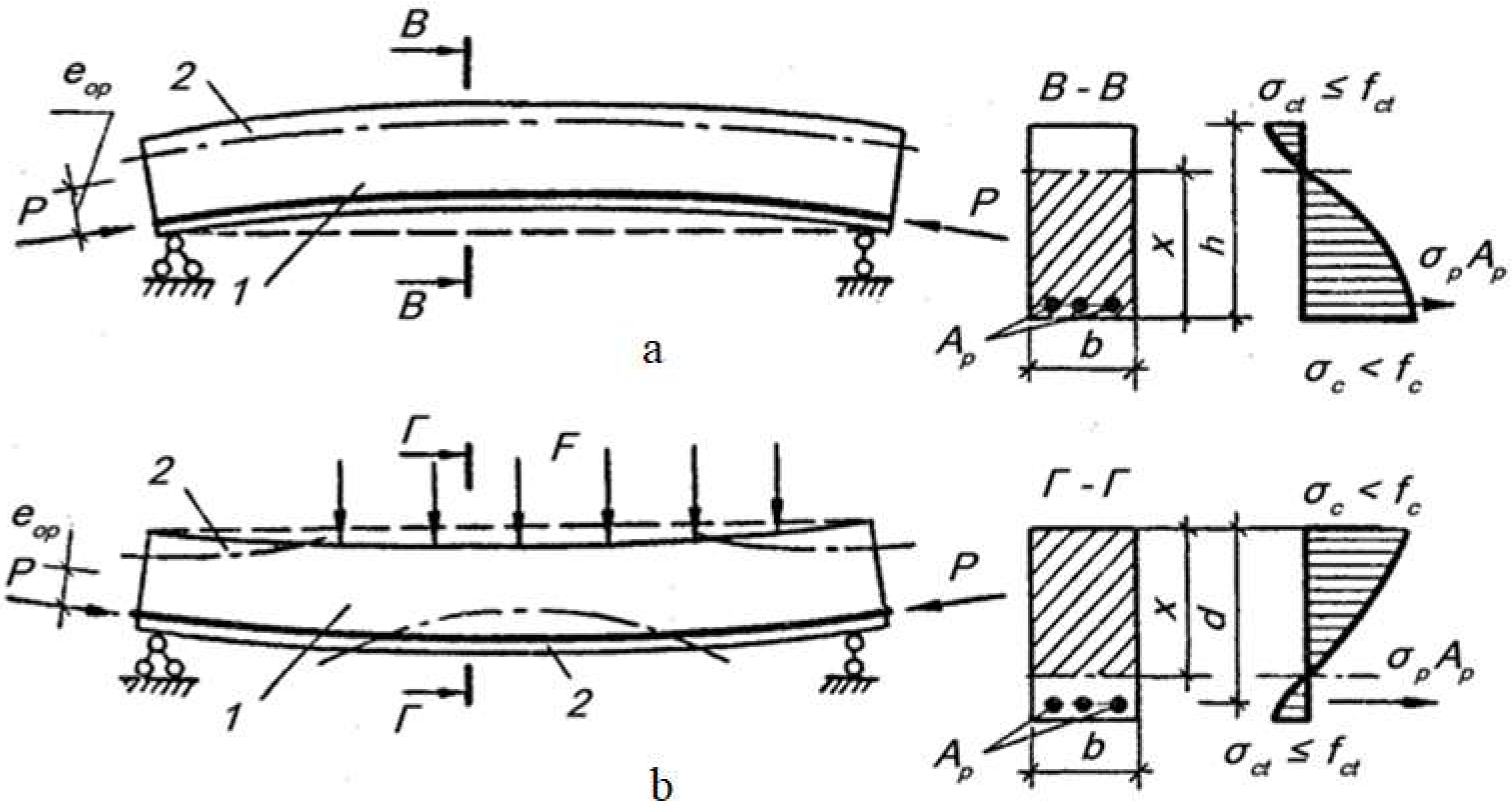
theatre

sports complex

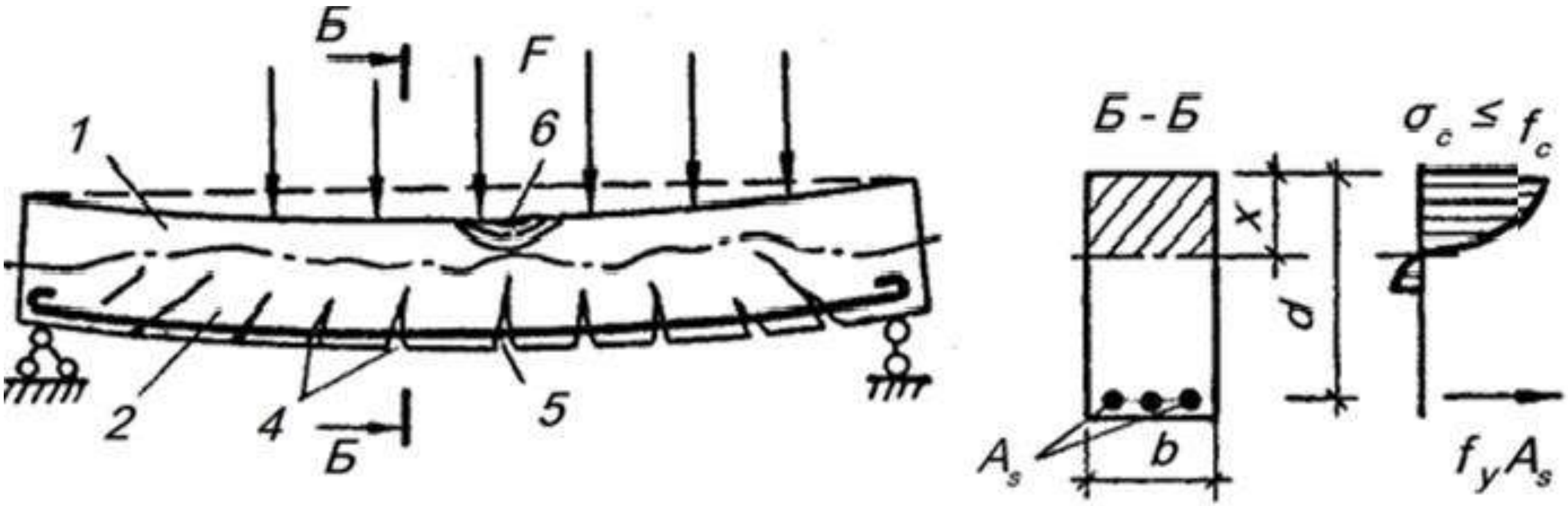
1.4 The concept about pre-stressed structures

In ***pre-stressed*** **reinforced concrete structures** in the process of manufacturing in accordance with the calculation the initial stresses of tension in the part of (or for all) reinforcement and compression for all (or part of) concrete are created artificially.



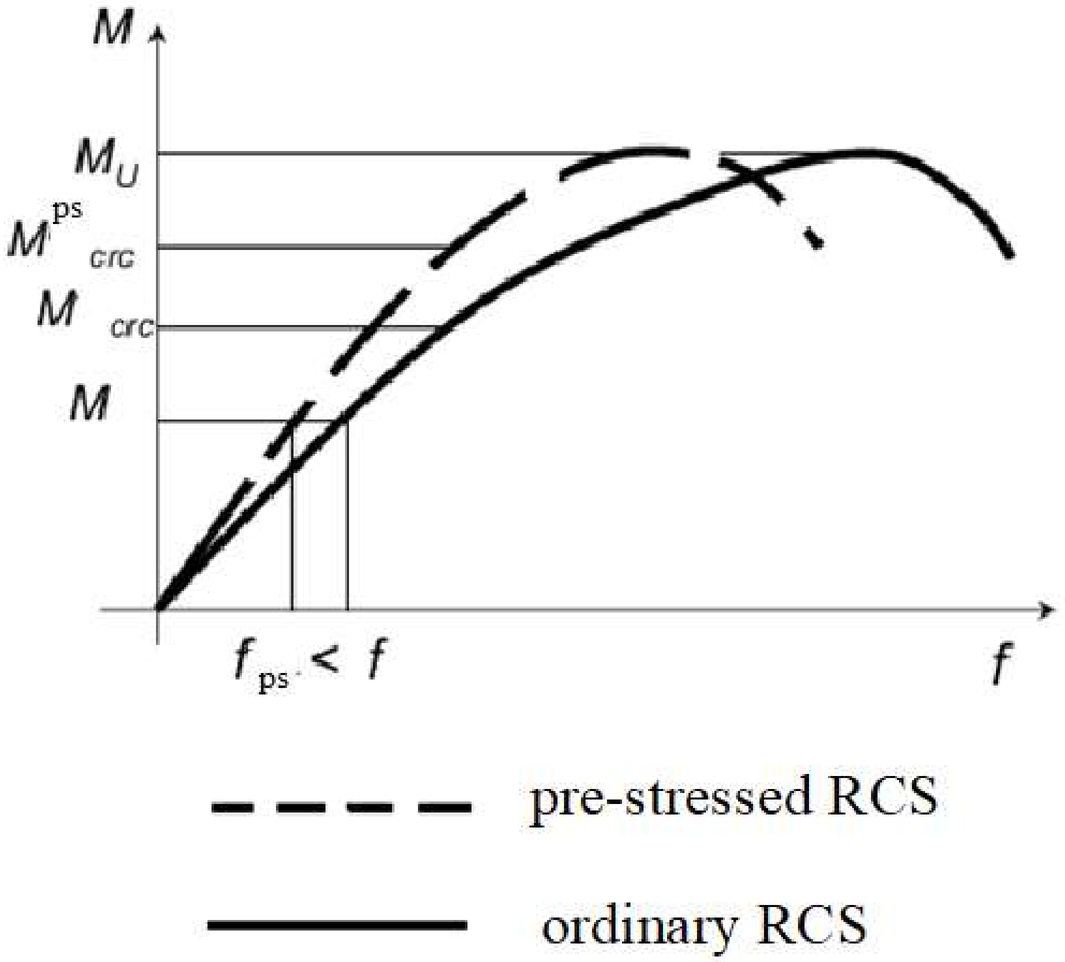


Stress-strain state of the pre-stressed beam:
a – at the stage of manufacture; b – the same as in the operation phase;
1 – the depth of neutral axis *x*; 2 – the tensile zone



The failure of reinforced concrete beams under the load:
1 – the depth of neutral axis *x*; 2 – the tensile zone;
4 – cracks in tensile concrete; 5 – the yielding zone of the reinforcement; 6 – the concrete crushing zone

Effect of pre-stressing to crack resistance, deformability and strength of RCS



The pre-stressing makes it possible:

- to increase the crack resistance of concrete in 2 – 3 times compared to structures without pre-stressing (the operation time of structures without cracks in the tensile zone is increased and the width of cracks is limited);

- to increase the stiffness of the elements and decrease its deflection;

- use of high-strength reinforcement allows to reduce the steel spread up to 50%;
- to increase fatigue of structures;

- to increase the overlapping of spans.

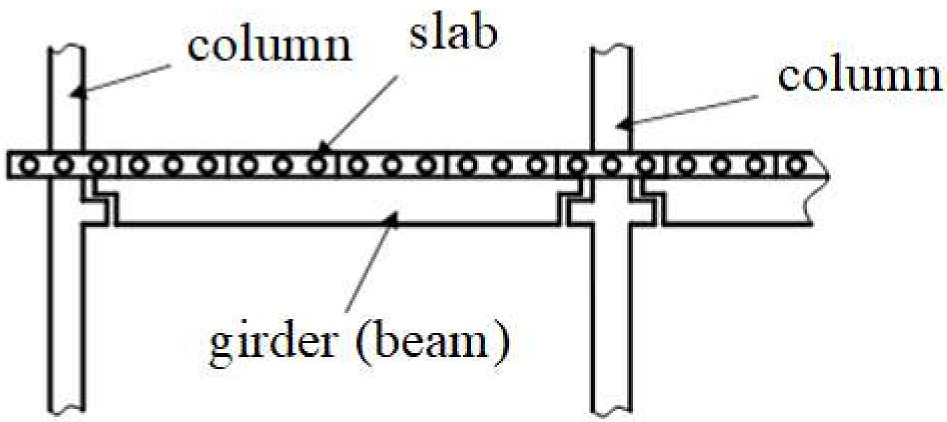
Pre-stressing does not affect the strength of structures.

1.5 The classification of reinforced concrete structure according to stress state, by destination and according to their manufacture method

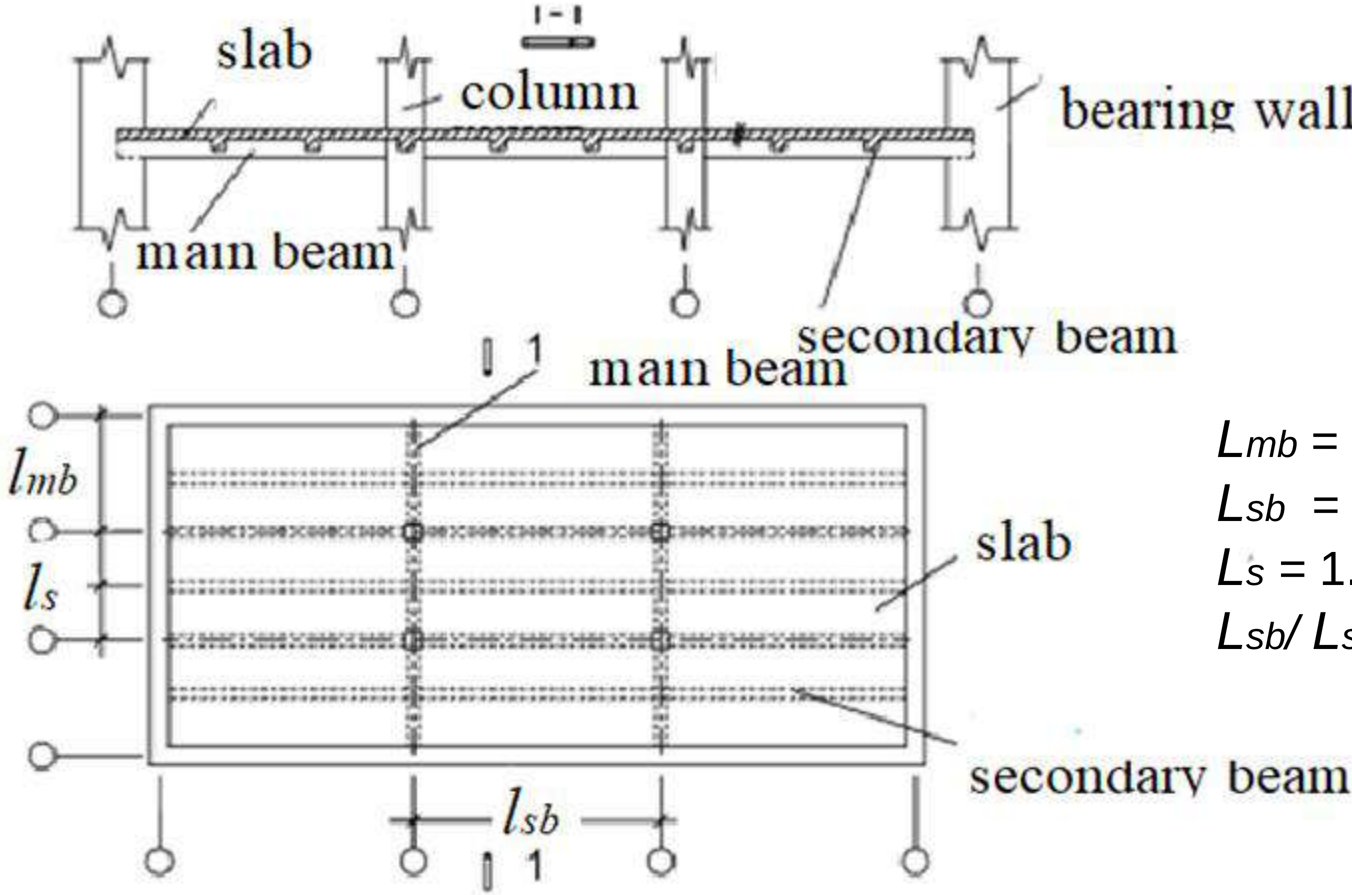
According to **stress state**, reinforced concrete members are classified into:

– **flexible members** – slabs and beams. **Slabs** are flat elements, which thickness is less than length and width. **Beams** are elongated elements which length is much longer than cross sections size.

Slabs and beams are elements of flat reinforced concrete floors and roofs;



precast beam floor



Cast-in-place beam floor

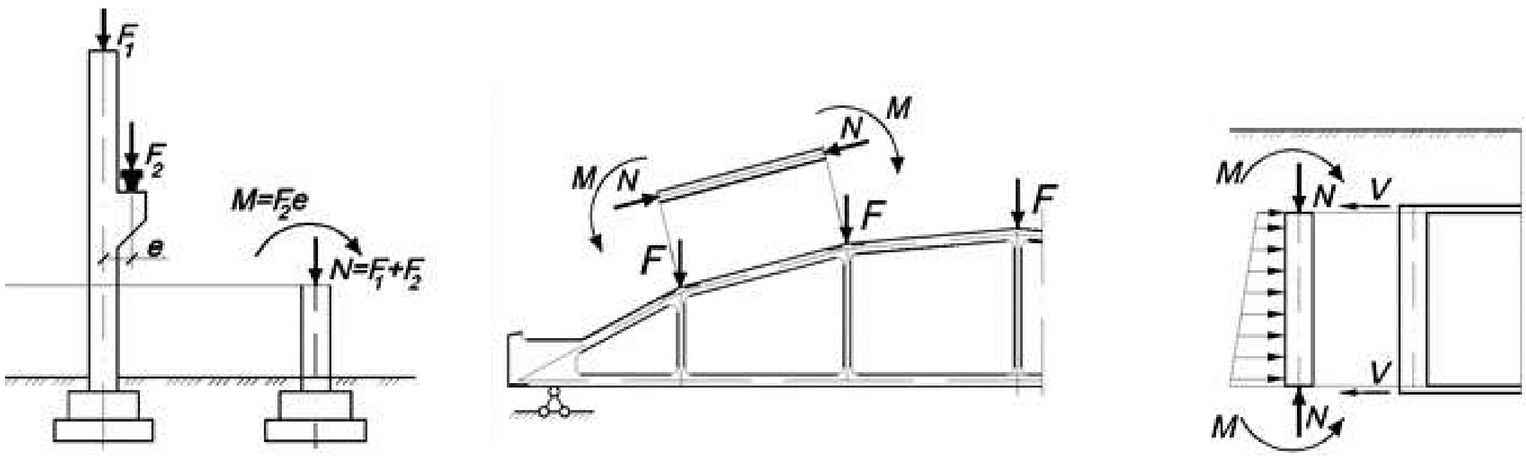
L_{mb} = 6 – 8 m

L_{sb} = 5 – 7 m

L_{s} = 1.7 – 2. 7 m

$L_{sb}/L_{s} \geq 2.5$

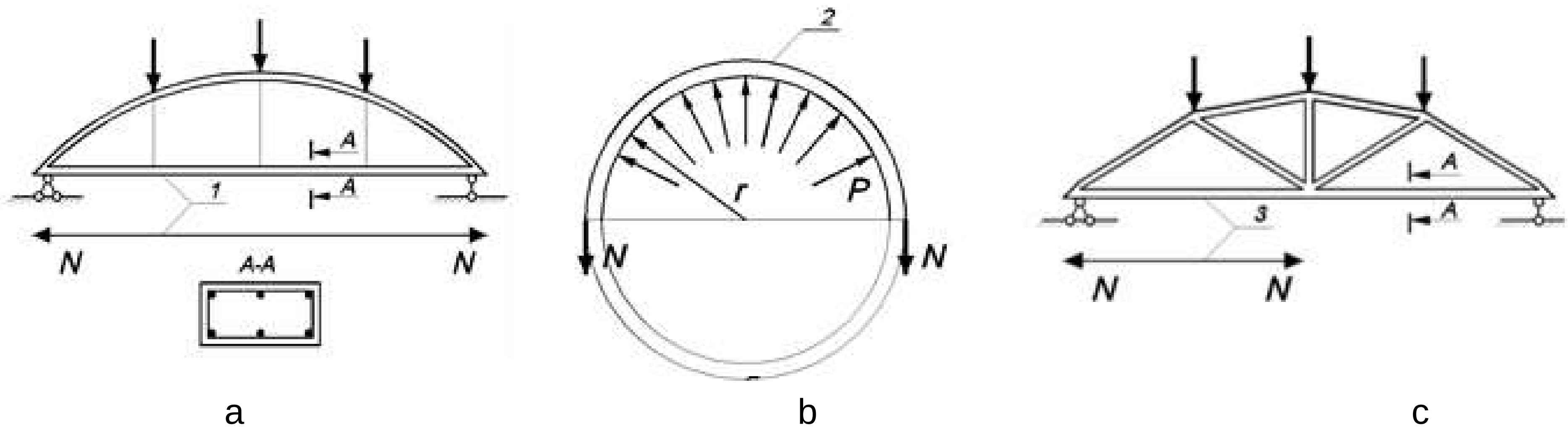
– **compressed members.** Axial compressed members include: middle columns of buildings and structures; top chords of trusses, which are loaded in a panel point; verticals and rising diagonals of truss. Eccentric compressed members include: columns of single-storey industrial buildings which are loaded by resistance of cranes; top chords of diagonals without trusses; arches; walls of rectangular-plan underground tanks that take up lateral pressure of ground or liquid and vertical pressure of roof. **In such members normal force *N*, bending moment *M* and shear force *V* are acting.**



a b c

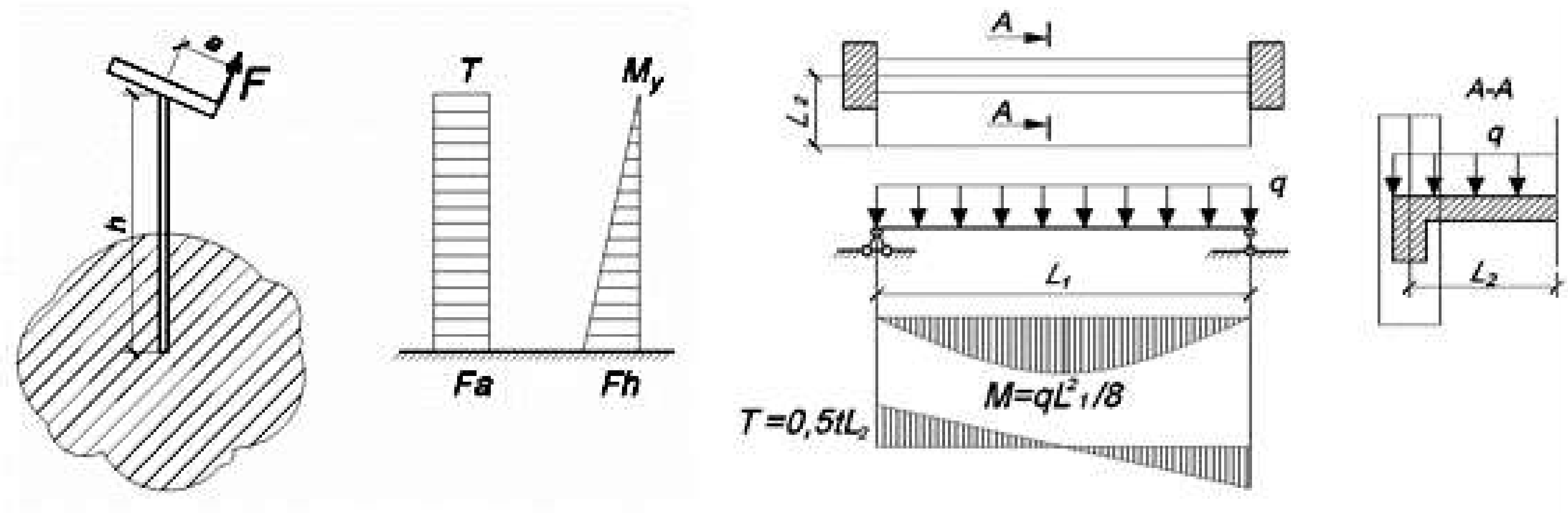
Structures and their elements under compression:
a – a column of an industrial building; b – a top chord of a truss; c – a wall of underground tank rectangular in plan

– **tensile members.** Axial tensile members include: ties of arches; bottom chords and lowering diagonals of trusses; walls of water tanks circular in plan. Eccentric tensile members include: walls of rectangular-plan tanks that take up an internal pressure; bottom chords of diagonals without trusses etc.;



Axial tensile members:
1 – a tie of an arch; 2 – a wall of a tank circular in plan;
3 – a bottom chord of a truss

– **flexural-torsional members**: mast under the action of a horizontal force that is applied with an eccentricity relative to the longitudinal axis; a beam with one-sided corbel slab.



Flexural-torsional members:
a – a mast under the horizontal force *F* that is applied eccentricity relative to longitudinal axis; b – a beam with one-sided corbel slab

According to destination reinforced concrete structures can be classified as **bearing** and **enclosing structures**.

According to manufacture method reinforced concrete structures are: **precast structures, cast-in-place structures and precast-cast-in-place structures.**

Precast structures are manufactured in highly mechanized, automated **companies** which specialize in the manufacture of definite range of products and structures. They are widely spread because **their usage does not depend on weather conditions** and they reduce a labor intensity of construction. At the same time, they have serious **disadvantages**: labor intensity, **high** cost, **metal intensity of elements of joints**; **decrease of stiffness of the structure in total** as a result of general space continuity disturbance (redundancy); significant costs of establishing and rebuilding of industrial base and transportation costs. **If their number of members is limited and an amount of usage is large the precast structures are effective.**

Standardized large-panel building

Multistoried frame building

Single storey industrial building

Cast-in-place structures are made of concrete mix which is placed into formwork on site.

Their **main advantage** is a space continuity which provides less metal intensity (without embedded item and transport and erection reinforcement).

Their **effective usage** is possible

- in complex geological conditions,
- in seismic regions,
- during reconstruction

and application of complex architectural forms.

The **main disadvantages** of cast-in-place structures are: seasonality of works; necessity of formwork; dependence of building time from concrete normal-curing terms; low level of industrialized methods of construction.

Cast-in-place beam-and-slab floor

Cast-in-place flat slab floor

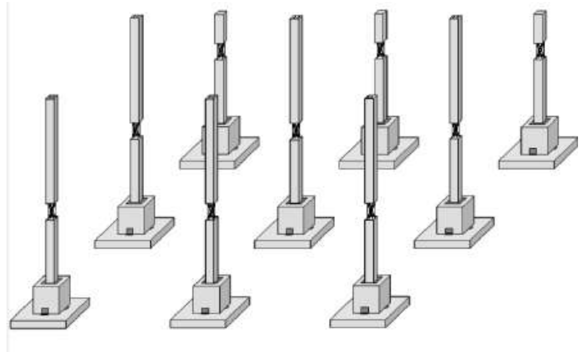
Precast-cast-in-place structures are composite structures in which precast and cast-in-place concrete work under load as a whole.

Bond is carried out

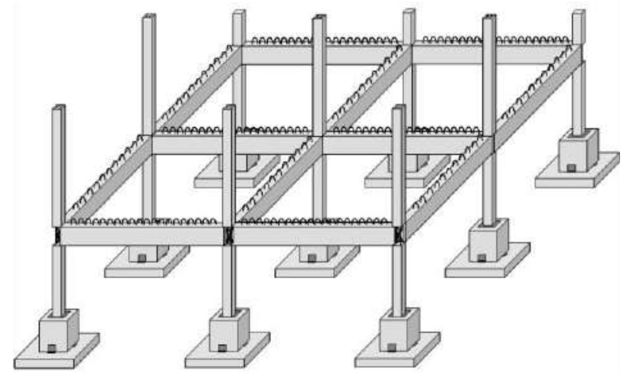
- by selecting the shape and size of elements,
- hacking of their surfaces,
- making keys
- and free lengths of reinforcing bars.

Precast-cast-in-place structures superpose positive properties of cast-in-place structures and precast structures: relatively lower labor intensity of construction and space continuity.

They are mainly used in buildings (structures) under large loads and during reconstruction.



a



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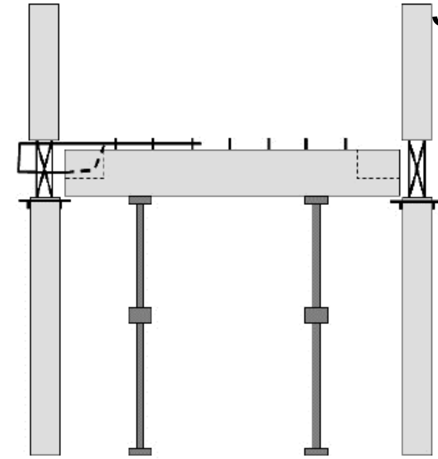
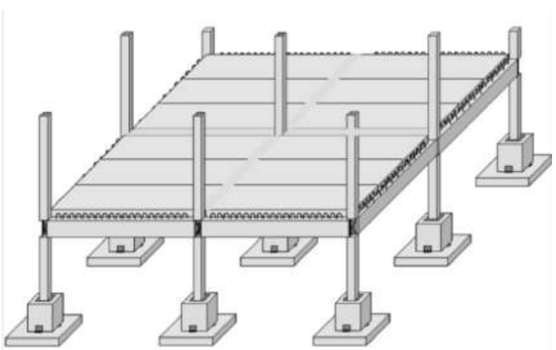
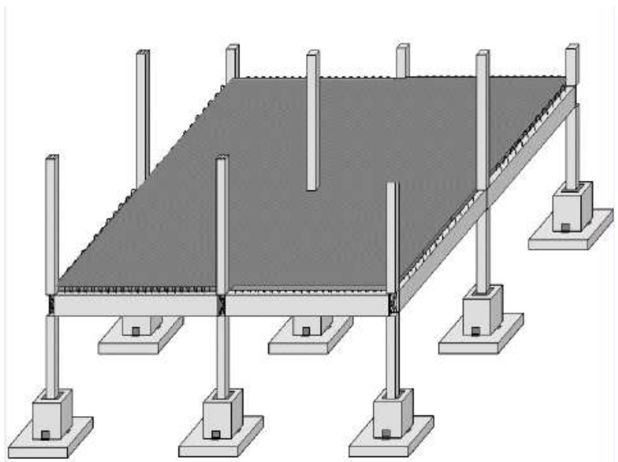


c



d



i

Building technological order of cast-in-place structural system **SARET**:
a – columns; b – girders;
c – girder mounting scheme; d – slab floor installation; i – monolithic slabs layer work

1.6 Materials of masonry and reinforced masonry structures. Buildings and structures parts are made of stone (independent study)

The subject
MATERIALS FOR REINFORCED CONCRETE AND MASONRY STRUCTURES AND THEIR PHYSICAL AND MECHANICAL PROPERTIES

THE STRENGTH AND DEFORMABILITY OF CONCRETE

2.1 Types of concrete. Concrete structure and its influence on the strength and deformability.

2.2 The strength of concrete.

2.3 Non-tensional strain of the concrete.

2.4 Strain of the concrete under the load action: strain of concrete under the actions of short-term load, strain of the concrete under the long-term load, creep of the concrete, concrete strain under multy-repetitive load, ultimate strain of the concrete, a concrete strain module.

2.1 Types of concrete. Concrete structure and its influence on the strength and deformability

Concrete is manufactured complex material in which coarse and fine aggregates connected by binder resists the load as a single monolithic body.

Depending on the starting materials, the structure and composition there are the following **types of concrete**:

heavy;

lightweight;

no-fines concrete;

cellular concrete;

special.

There are same physical qualities:

- **frost resistance *F*** (F50, F75, F100, F150, F200)**;**
- **water resistance *W*** (W2, W4, W6)**;**
- **fire resistance**;
- **heat resistance**;
- **corrosion resistance**.

The main physical properties of concrete are evaluated by grades.

Concretes are classified by:

– **function** (constructional and special);

– **structure** (heavyweight, no-fines, cellular, porous);

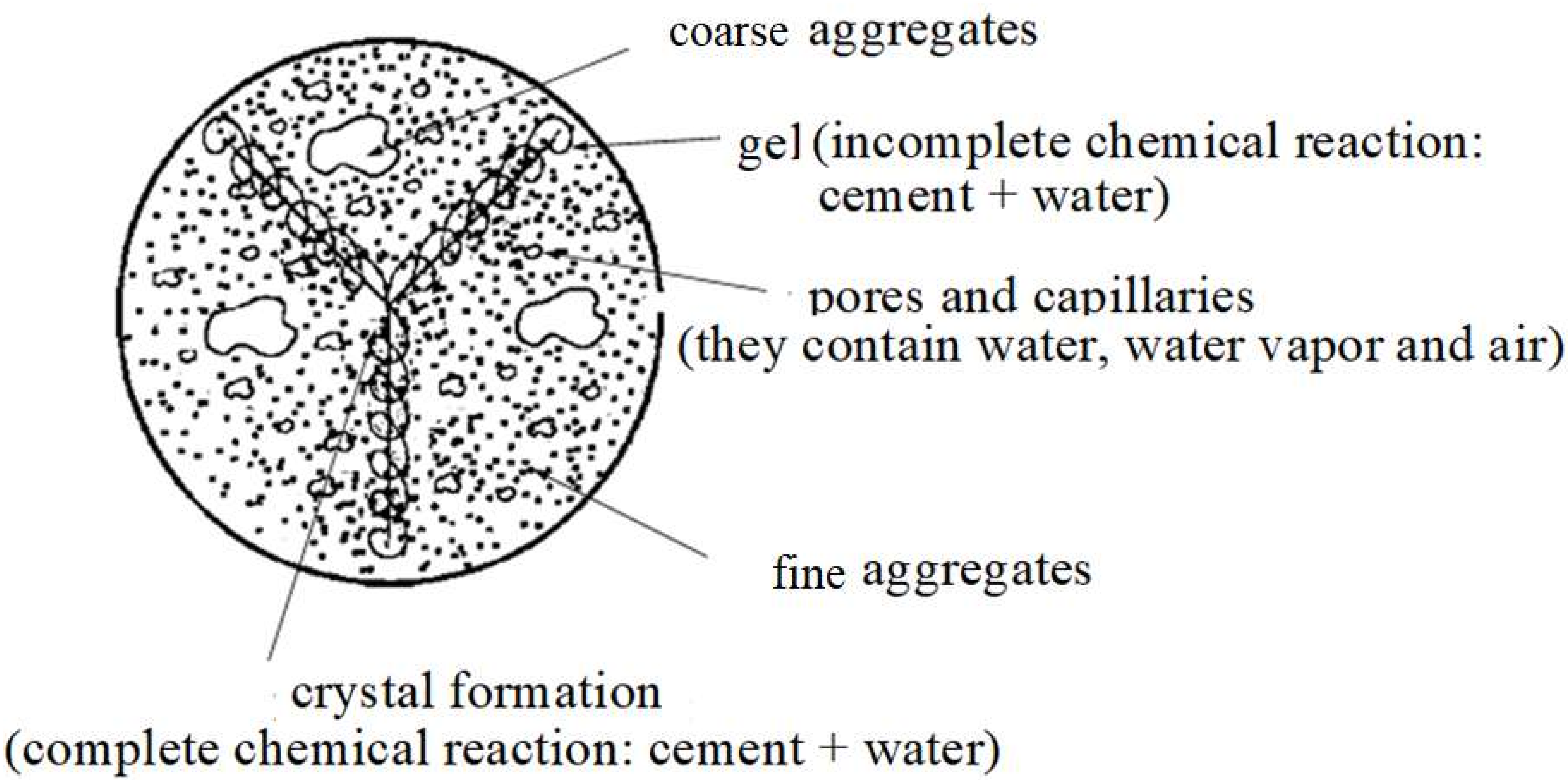
– **average density** (especially heavy with γ > 2500 kg/m^3, heavy – γ = 2000 – 2500 kg/m^3, especially light – γ = 1800 – 2000 kg/m^3, light – γ = 800 – 2000 kg/m^3);

– **type of binder** (cement, polymer, lime, plaster or on mixed binders, special);

– **type of aggregates** (for dense natural, porous natural, porous manufactured, special aggregates);

– **curing conditions** (natural, steam curing, autoclave curing).

Concrete structure

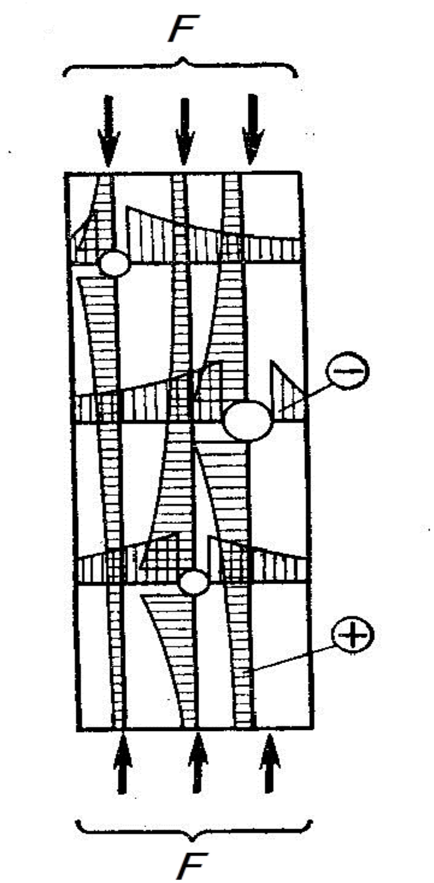


Cement stone = crystal formation + gel

2.2 The strength of concrete

The strength of solid body is its ability to resist the influence of external forces without failure.

The strength of concrete is significantly influenced by its structure.



Longitudinal compressive and transverse tensile stresses take place in concrete specimen under axial compression.

Since the resistance of concrete to tension is much lower than compression, firstly tensile stresses reach limit values and micro cracks are formatted.

With an increasing the value of load the number of micro cracks increases, they are combined in macro cracks. After that macro cracks are developed to mistral crack and element fails.

Therefore, concrete element under the axial compressive forces fails from transverse tensile stresses.

There are two groups of influence factors on the strength of concrete.

The **first** group includes the **structure of concrete**, **grade of cement**, **its type** and **quantity**, **quality aggregates**, **water-cement ratio** (W/C).

For chemical compound of water with cement **W/C ≈ 0.2** is needed;

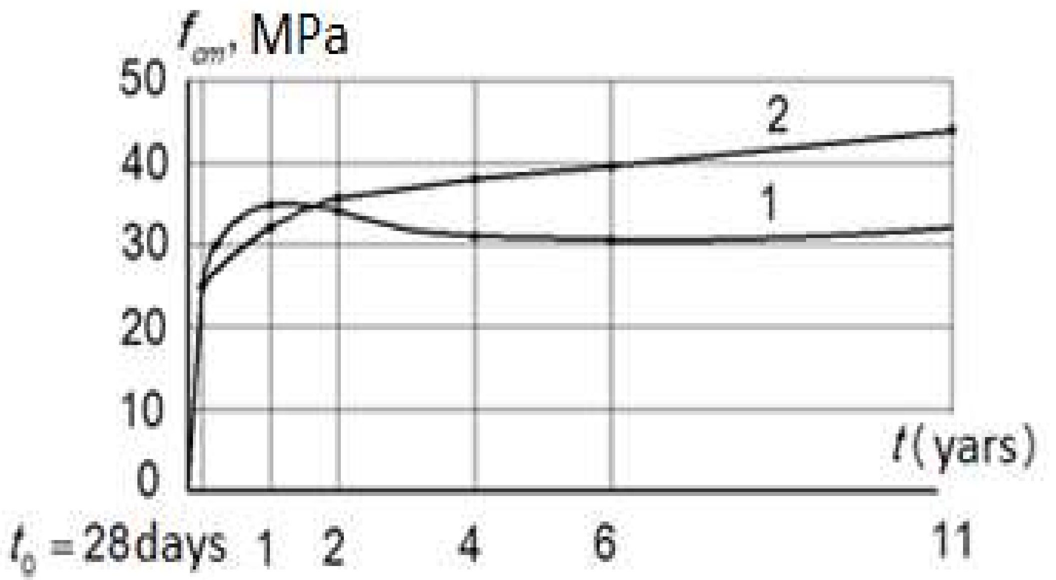
W/C = 0.3 – 0.4 – low-slump concrete;

W/C = 0.5 – 0.6 − high-slump concrete.

The part of chemically free water reacts later with less active particles of cement or fills the numerous pores and capillaries and then gradually evaporates, releases them. **If the W/C decreases, the porosity decreases and the strength of concrete increases.**

The **second group** of factors that influence the strength includes: **age of the concrete, conditions of its preparation and curing (humidity, temperature), the size and shape of the samples, the stress state and load types.**

The strength of concrete when favorable conditions of the natural curing gradually increases during first 10 years or more. The concrete acquires strength during the first 28 days in the most intensive way.



The increase of strength of concrete over time during storage:
1 – dry environment; 2 – wet environment

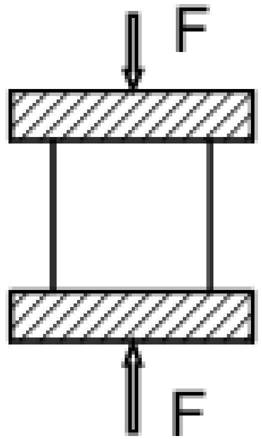
If the temperature and humidity of environment are higher the hardening of concrete significantly accelerates. Therefore, in the enterprises of precast reinforced concrete products they undergo to **steam** (90°C temperature and humidity to 100%) or **autoclave processing** under the high pressure of steam and temperature nearby 170 °C.

These methods allow to receive strength equal to 70% of the design strength per day.

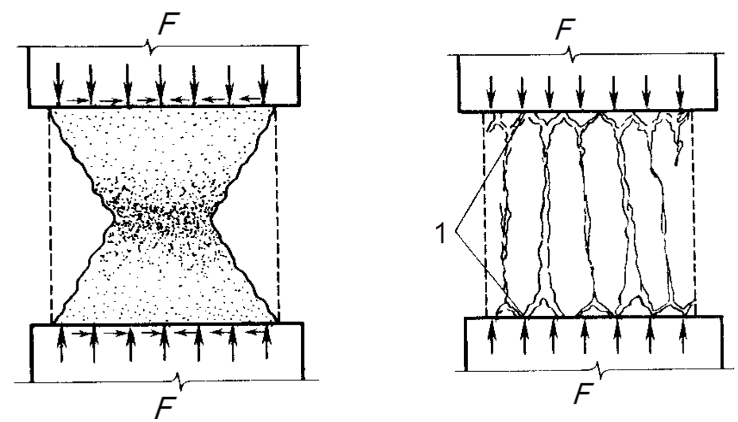
Concrete hardening significantly **slows down** at temperature below +5°C. When the concrete mix temperature is -10°C, the concrete hardening is practically **suspended.** After thawing of concrete mix concrete hardening is updated, but its finish strength is lower than the strength of concrete hardening in normal conditions.

During concreting at low temperatures conditions (up to -30°C) the cooled mixture is **electrical warmed to +70°C**. Using of the **quick-hardening cement** and heat insulation of structures allows to acquire the strength of concrete up to 70% from the design strength before its freezing. This allows to eliminate the influence of freezing concrete on its strength. **Anti-frost supplements** provide concrete curing at temperatures down to -10°C.

In RCS the concrete is usually used for perception of **compressive stresses**. Therefore, its strength under axial compression is a fundamental characteristic of concrete. The simplest and most reliable way of determination of the strength of concrete is crushing of standard cubes with dimensions 15x15x15 cm in the press. The maximum resistance of standard cubes $\boldsymbol{f_{cm,cube}}$ is adopted as **cube strength**.



Test setup



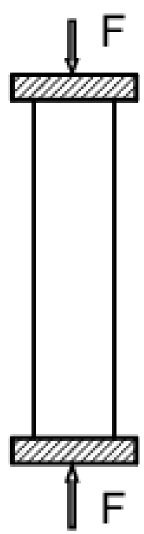
a b

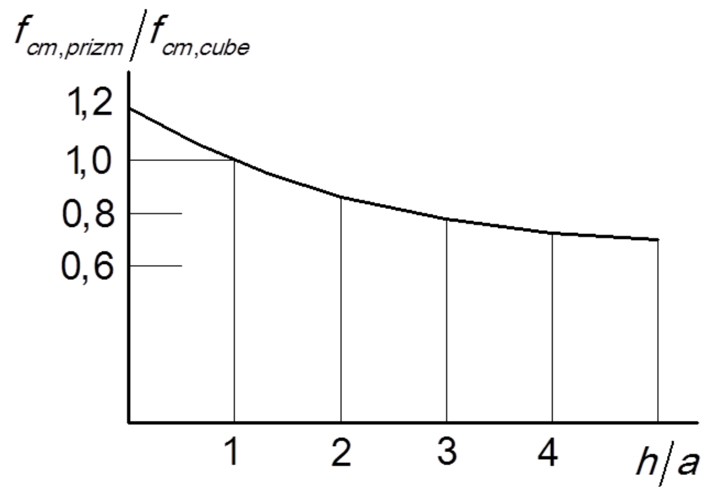
The character of failure of concrete compressed cubes:
a – with friction forces on support surfaces; b – without friction; 1 – the lubrication

The shape and size of the samples significantly effect on value of strength: if the cube is smaller, that the strength is bigger.

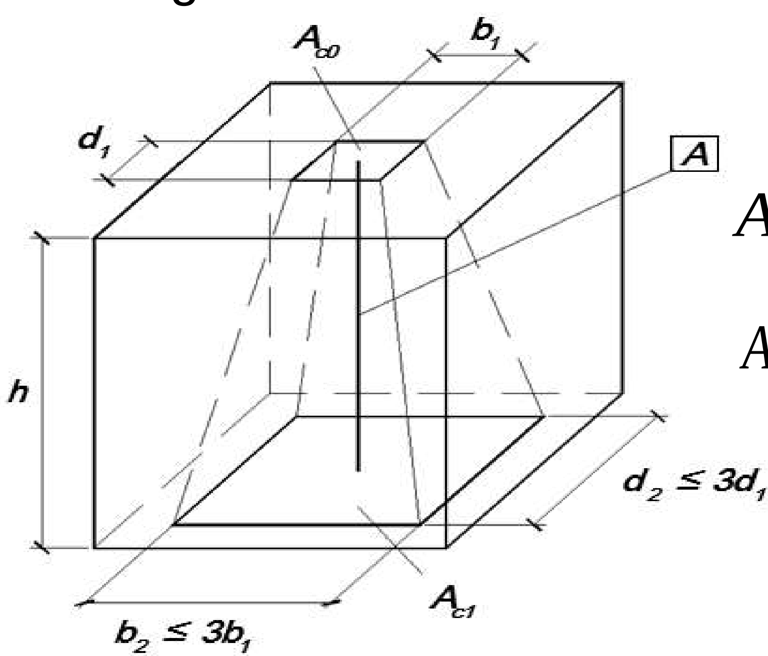
In real structures the stress state of concrete is close to the stress state of prisms, that's why the prism strength is a main characteristic for calculation of structures. It is approximately equal 0.75 of cube strength for concrete with class C20/25 or higher and equal 0.8 for the other classes of concrete.

The prism strength $f_{cm,prizm}$ is a limit resistance to axial compression of concrete prism with ratio of the height *h* to the size of the square cross section which is equal to 4. There is no influence of friction forces on support surfaces and ratio of slenderness of sample to character of failure and the value of ultimate load.





Local compressive strength (crushing), according to experiments, significantly is higher than the prism strength. This phenomenon is explained by the influence of unloaded part of concrete element (concrete casing effect). Such cases in reinforced concrete structure are quite common, namely: under supports of beams, in joints of precast columns, under anchors in pre-stressed structures. Local compressive resistance of concrete $f_{cm,loc}$ according to the standards is determined by the Bauschinger formula and depends on the prism strength and coefficient of conditional increasing of concrete strength:



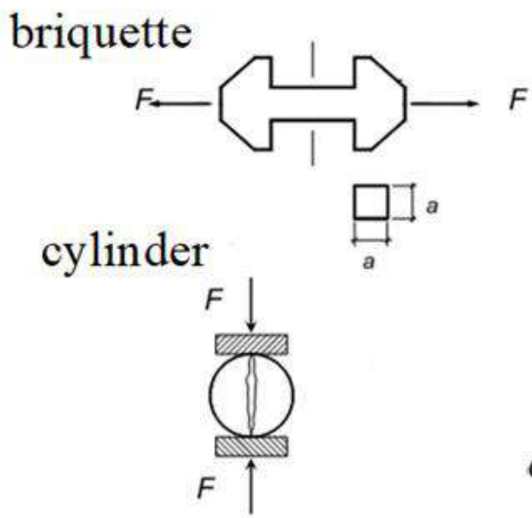
$$\sqrt{A_{c1} / A_{c0}} \leq 3$$ where

A_{c1} is maximum design area of distribution;

A_{c0} is area of loading.

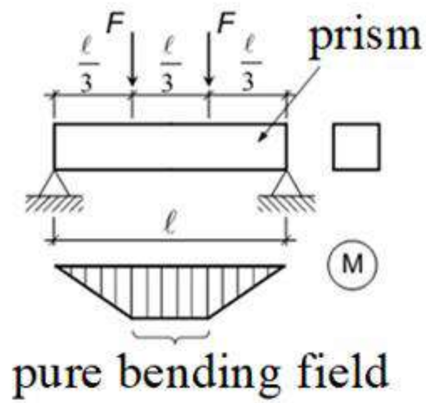
The axial tensile strength of concrete f_{ctm} is $0.1\, f_{cm,prizm}$ – for concrete with class C8/10 and is 0.05 $f_{cm,prizm}$ for concrete with class C40/50.

tensile testing of



split test

flexural strength



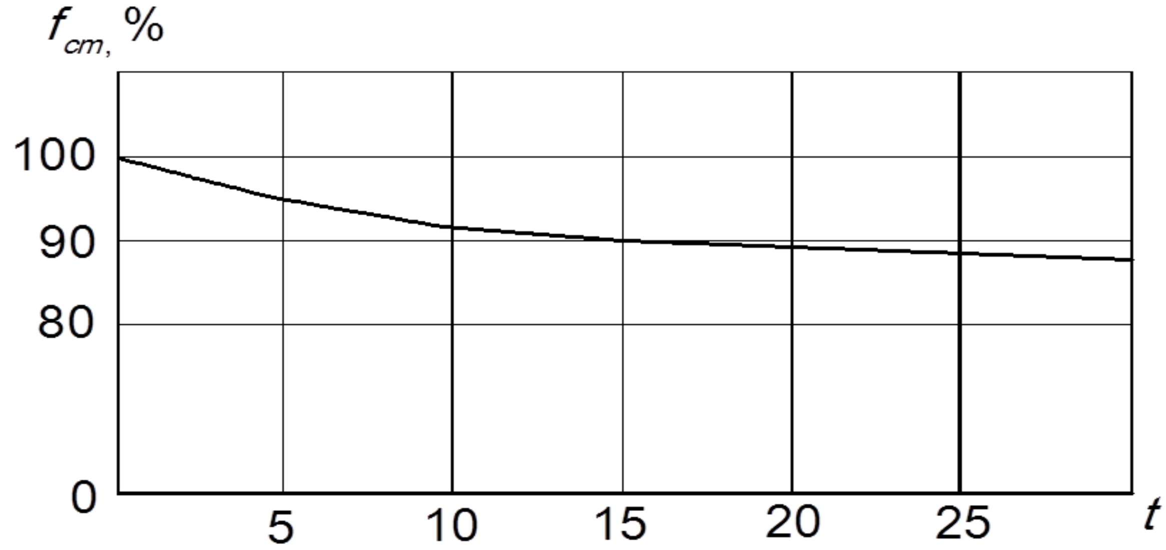
$$\sigma = \frac{M}{W} \qquad f_{ct} = \frac{M_u}{W\,\gamma_1}$$

$$\gamma_1 > 1$$

Scheme of sample test to determine the tensile strength of concrete

The greatest statically constant stress that it can withstand during long time without failure is **the limit long-term resistance of concrete.** Under long-term load the concrete specimen is destroyed at stresses which are lower than under short-term load. It is conditioned by the influence of developing large inelastic strains, and changing structure of concrete. The limit long-term resistance of concrete depends on the loading mode, initial strength and age of samples. Long-term resistance is up to 90% of the short-term resistance

$$f_{cm,l} = 0.9 f_{cm}$$



The dependence of the strength of concrete on the loading time

The strength of concrete at repeated load **(the fatigue strength)**

$$f_{cm,\, fat}$$

is the stress at which the number of cycles to failure the sample is at least 10^6. The fatigue strength is below then the prism strength and depends on the asymmetry of the cycle (the ratio of the largest to smallest stresses of the concrete) and is equal (0.5 – 0.95) f_{cm}.

The short-term dynamic load of high intensity is the increasing of strength of concrete. It is a **dynamic strengthening**. It is increasing when the time of loading the sample is decreasing. It is a result of energy absorbing capacity of concrete, which is elastic under a short-term dynamic loads. **Dynamic resistance** is $f_{cm,d} = \gamma_d f_{cm}$

when the time of load is equal 0.1 s, the coefficient of dynamic concrete strength is $\gamma_d = 1.2$.

As a class of concrete compressive strength C (MPa) is understood the limit compression resistance of concrete cubes with dimensions 15x15x15 cm, which are tested according to the standard after 28 days storage at 20 ± 2°C into account the statistical variability of strength (the limit strength with a probability 0.95).

For concrete structures it is not recommended to use the concrete with class of concrete compressive strength which is lower C12/15.

2.3 Non-force strain of the concrete

Deformability of solid bodies is their ability to change the size and shape under the influence of force and non-force factors.

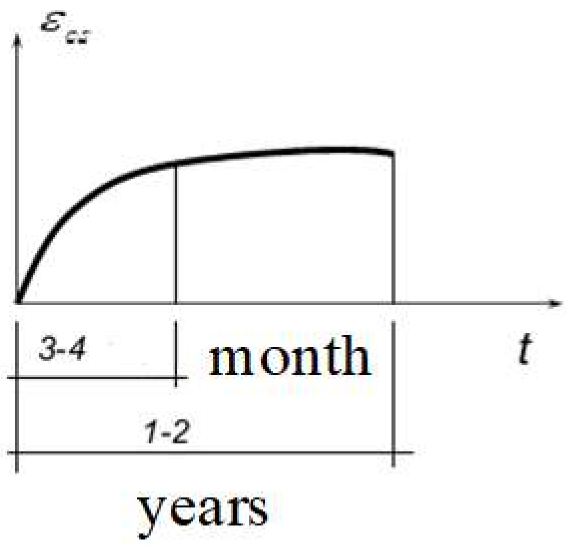
There are **force** (developed along the line of force) and **non-force** (three dimensional) **strains**.

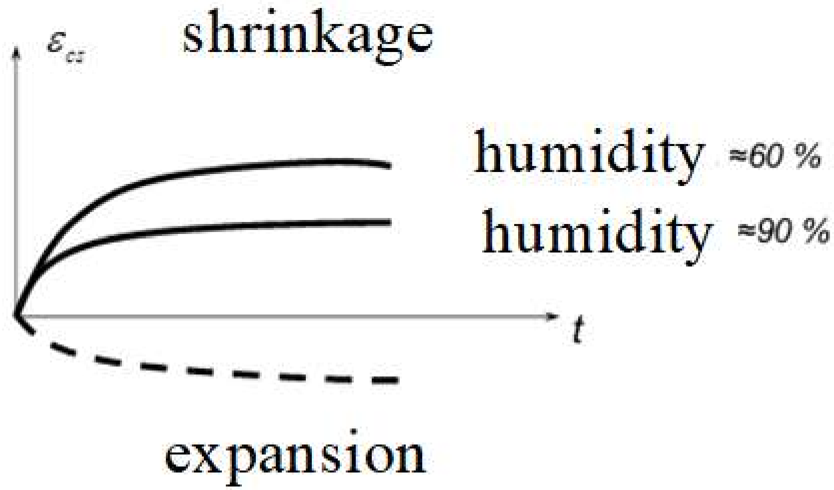
The **force strains** are divided into **elastic** and **plastic**.
They are classified according to the time of loading: under the action of
- single short-term load;
- long-term load;
- repeated load.

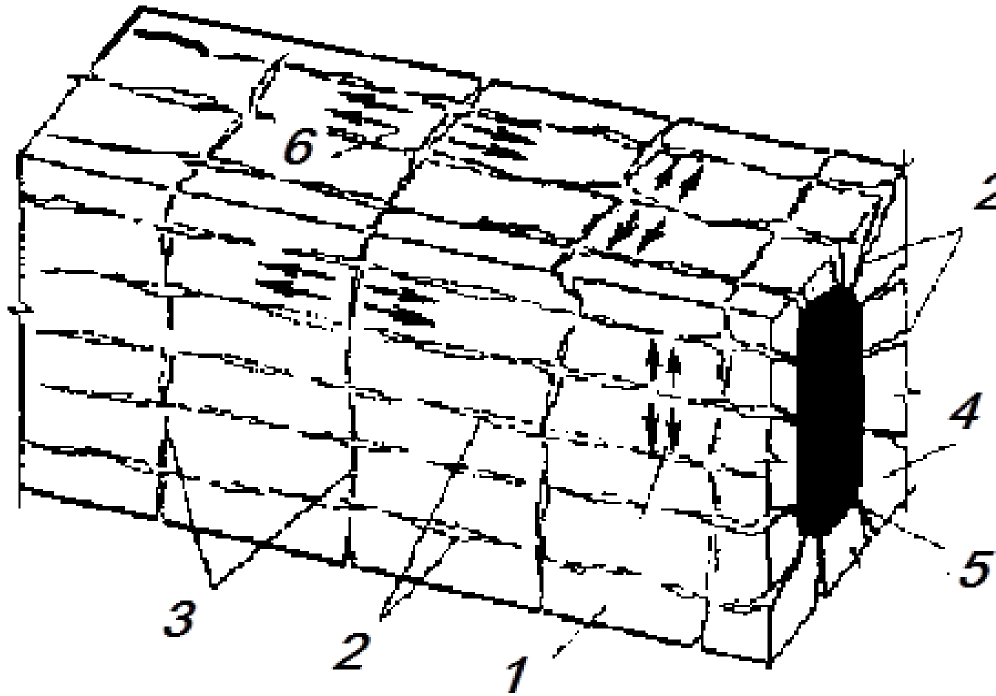
Shrinkage, expansion and temperature strains (shortening or lengthening) are **non-force strains**.

Shrinkage is a decrease of the volume of concrete during hardening it on the open air. The quantity of cement, its view, W/C ratio, temperature and humidity in which concrete is hardened, type of aggregates are factories of influence. The relative shrinkage strains

ε_{cs} is (30 – 70)x10^{-5}.







Concrete shrinkage:
1 – part of concrete beam; 2, 3 – longitudinal and transverse shrinkage cracks;
4 – the outer surface; 5 – the inner part; 6 – the tensile stress

There are tensile stresses on the open parts of outside elements, which dry quickly, and compressive stresses in inside volume of concrete which is more humid. The result of the initial tensile stress is formation of shrinkage cracks in concrete, especially on the surface of element.

Reducing shrinkage, shrinkage stress and the development of cracks can be achieved by as technological and as constructive methods.

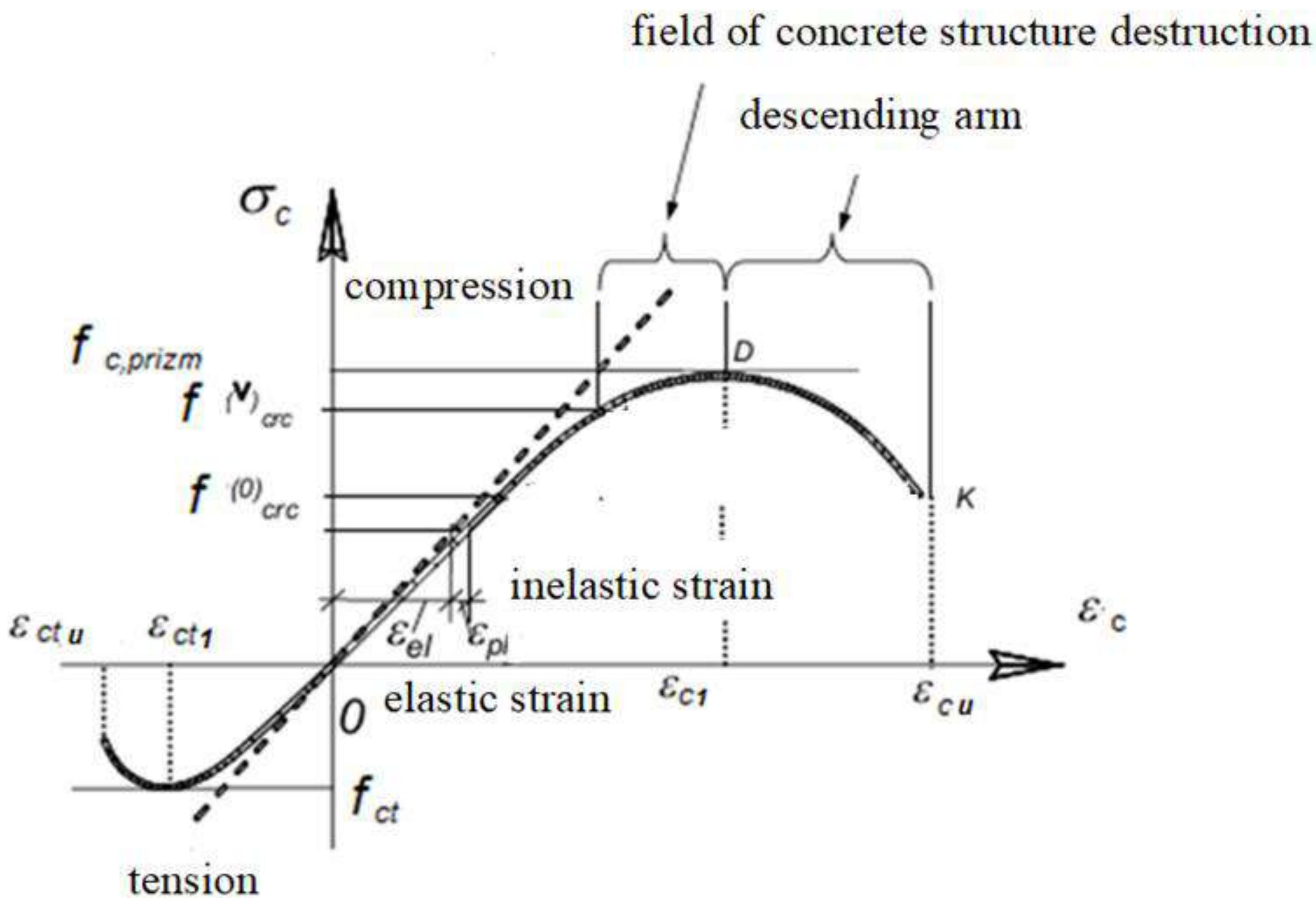
For example: selection of grain size composition and type of aggregate to reduce their surface and voids volume and reduce quantity of cement and W/C ratio, increasing the density of concrete and moisturizing of its outside surface.
There are such constructive methods: the reinforcement of structures and creation shrinkage joints in its.

There is the **expansion** of the concrete during hardening in water – increase of its volume at strong moisture. This strain is much smaller than the shrinkage strain, and they do not take into account in the calculations of structures.

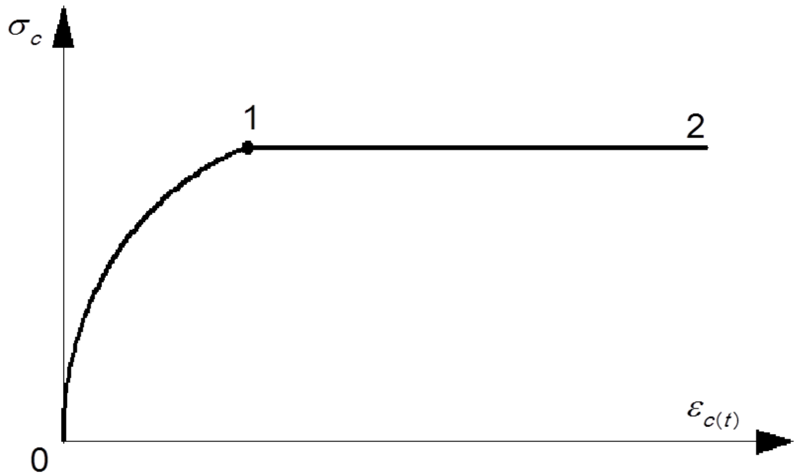
With increasing **temperature**, the concrete expands, with decreasing temperature the concrete reduces. These **strain** is characterized by the coefficient of linear thermal deformations (of relative elongation (or shortening) of the sample at heating (or cooling) by 1°C (when the temperature changes within -40 to +50° C).

2.4 Strain of the concrete under the load action

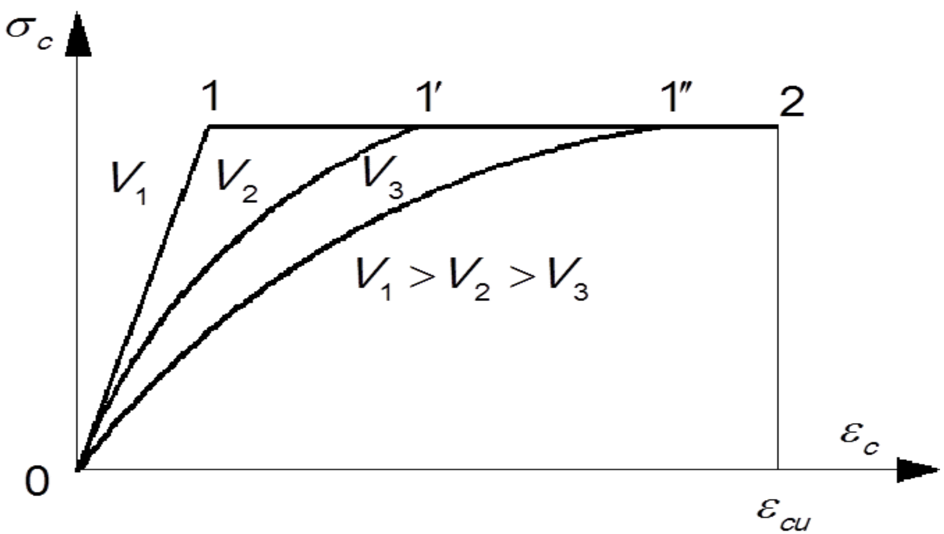
Diagram of mechanical condition of the concrete specimen under short term load



During long-term load the plastic strain of concrete continue is grow for a long time (for years). They increase in the first 3 – 4 months the most intensive. Part 0 – 1 describes the strain of concrete during loading, part 1 – 2 describes the growth of plastic strain at constant stress.



The diagram σ_c - ε_c concrete sample under long-term compression test



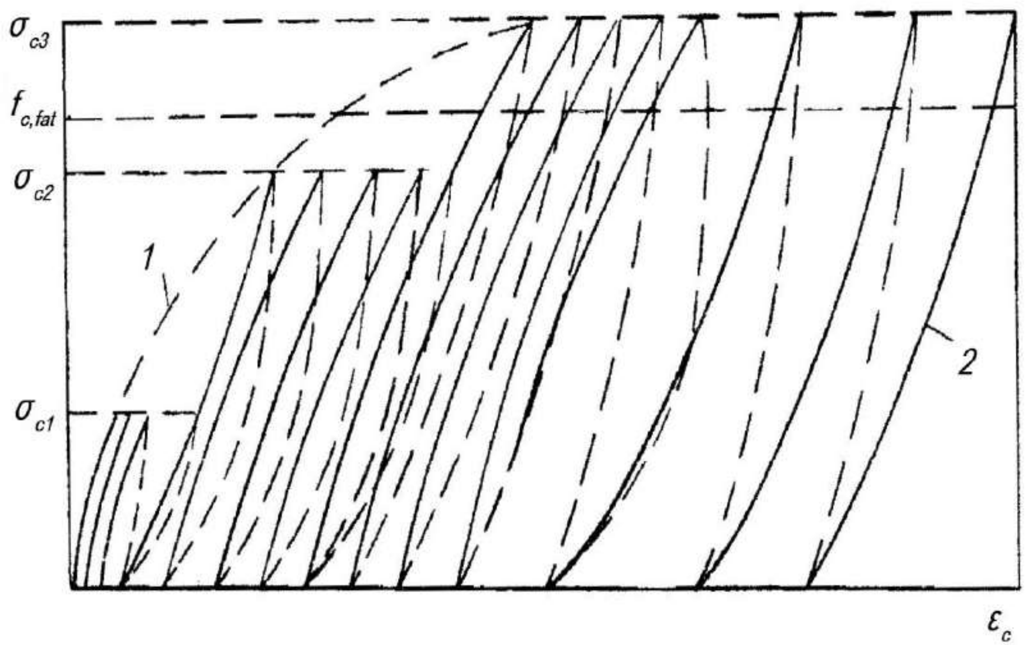
The dependence of the strain from speed of loading *v*

The property of concrete, which is characterized by increasing plastic strain under long-term constant load, is called **creep**. Nature of creep is explained by change in the time structure of cement stone, that hardens. The creep is determined by the redistribution of stresses from gel to crystalline formation and aggregate grain. As a result, more elastic components of concrete are loaded and additional strains are created.

Creep of concrete increases with:

- increasing the level of stress and under long-tern load;
- increasing the W/C ratio and humidity of the environment;
- reducing the size and age of the samples which are tested;
- the use of stone aggregates with high strength and modulus of elasticity.

Multiple repetition cycles of loading and unloading of concrete sample leads to a gradual accumulation of plastic **strain**. After a large number of loading cycles when plastic strain reaches to its limit, the concrete begins to work elastically. This behavior of concrete occurs if stresses do not exceed the fatigue strength. If $\sigma_c > f_{cm,fat}$, after several cycles of load the diagram becomes reverse curvature, the plastic strain on increases without limit, and the sample is destroyed.



The deformability of concrete at repetitive loading:
1 – the diagram of the strain in the primary load; 2 – the same as in multicycle load to stress that exceeds the fatigue strength

Deformation properties of materials are characterized by **module of strains.**

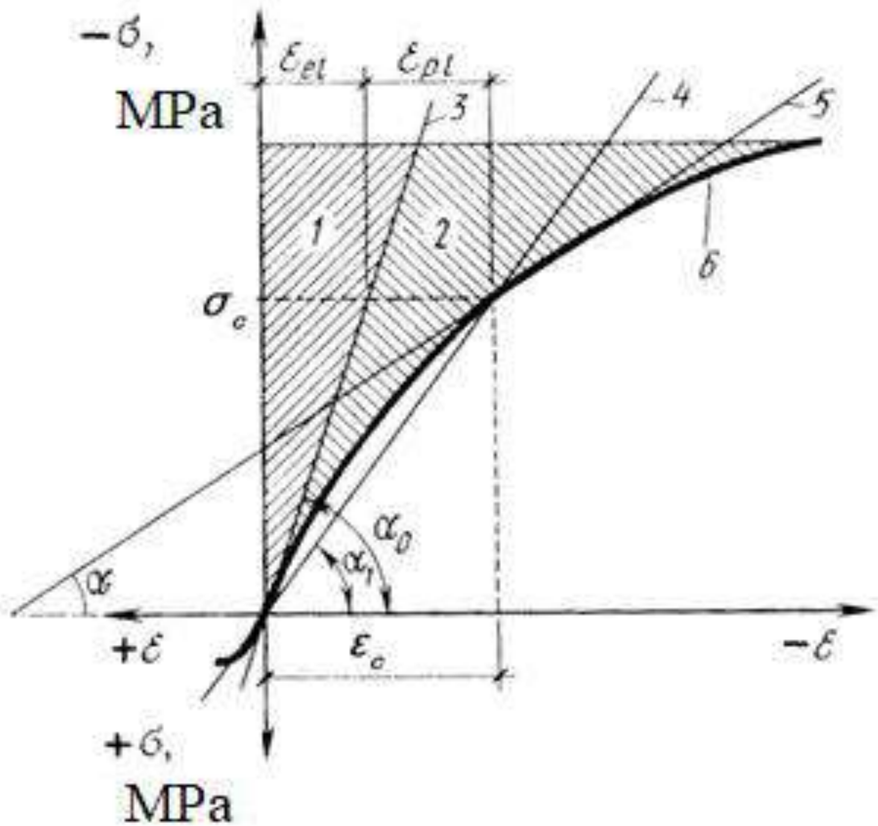
The initial module of elasticity of concrete *E_{cm}* depends on the class and type of concrete. It is defined as $E_{cm} = \sigma_c / \varepsilon_{el} = tg\alpha_0$.

Total strain of concrete is characterized by **module of strain** that for each level of stress is equal to tangent of the angle of inclination of tangent line to the curve $\sigma_c - \varepsilon_c$ – *α* **.** Angle *α* is a variable. It depends on the level of stress and speed of loading.

$$E_{cm,pl} = \sigma_c / \varepsilon_c = \sigma_c / (\varepsilon_{el} + \varepsilon_{pl}) = tg\alpha$$

Mean value of strain module is equal to tg α_1 the secant line to horizontal axis.

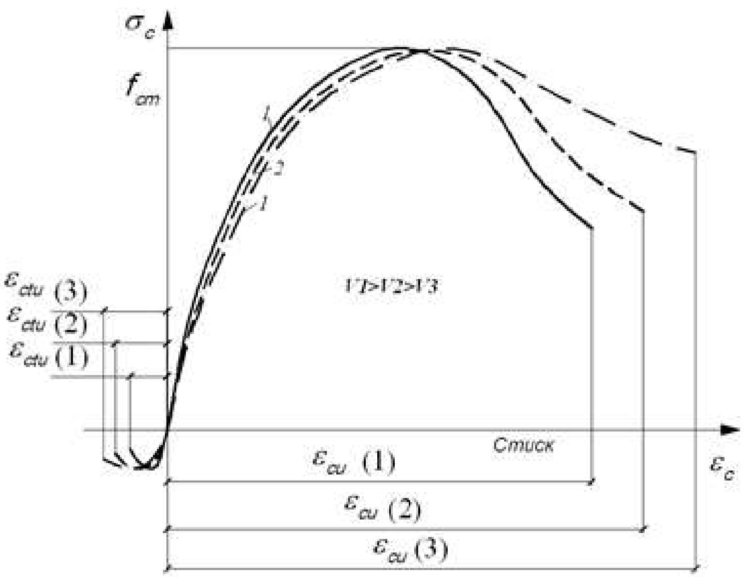
The module of strain is variable value.



Relationship between strain and stresses:
1 – the part of elastic strain; 2 – the part of plastic strain; 3 – the boundary of elastic strain; 4 – the secant line; 5 – the tangent line; 6 – the curve of total strain

Total stain of concrete ε_{c1} is corresponded to the maximum stress f_{cm}. **Nominal ultimate compressive strain** ε_{cu} and **tensile strain** ε_{ctu} concrete in the test diagram σ_c – ε_c depend on strength of concrete, it composition and speed of loading.

According to experiments, strain, which characterize the failure of central compressed concrete samples, is ranged from 0.001 to 0.003; strain, which characterize the failure of central tensile concrete samples, is ranged from 0.00015 to 0.00030.



Under the influence of short-term load concrete has not only longitudinal but also transverse strain. They are characterized by **Poisson ratio ν**. Experimental study of concrete strain shows that at low stresses, not exceeding $0.5 f_{cm}$, *ν* can take to provide for all concrete is equal 0.2 for concrete without crack and is equal 0 for cracked concrete.

The subject
MATERIALS FOR REINFORCED CONCRETE AND MASONRY STRUCTURES AND THEIR PHYSICAL AND MECHANICAL PROPERTIES

REINFORCEMENT
FOR REINFORCED CONCRETE STRUCTURES

3.1 Types of reinforcement by function.

3.2 Physical and mechanical properties of reinforcing steel.

3.3 The classification of reinforcement.

3.4 Reinforcing products.

3.5 Joints and intersection of reinforcement.

3.1 Types of reinforcement by function

The **reinforcement** is a flexible or hard steel bars, placed in concrete in accordance with the diagrams of bending moments, longitudinal and shear forces.

The **main function** of reinforcement is to **perceive tensile stresses** (in bending, in eccentric compression, in tension) and also shrinkage and temperature stresses in the elements of structures. Considerably rarer it is applied for strengthening of compressed area of concrete.

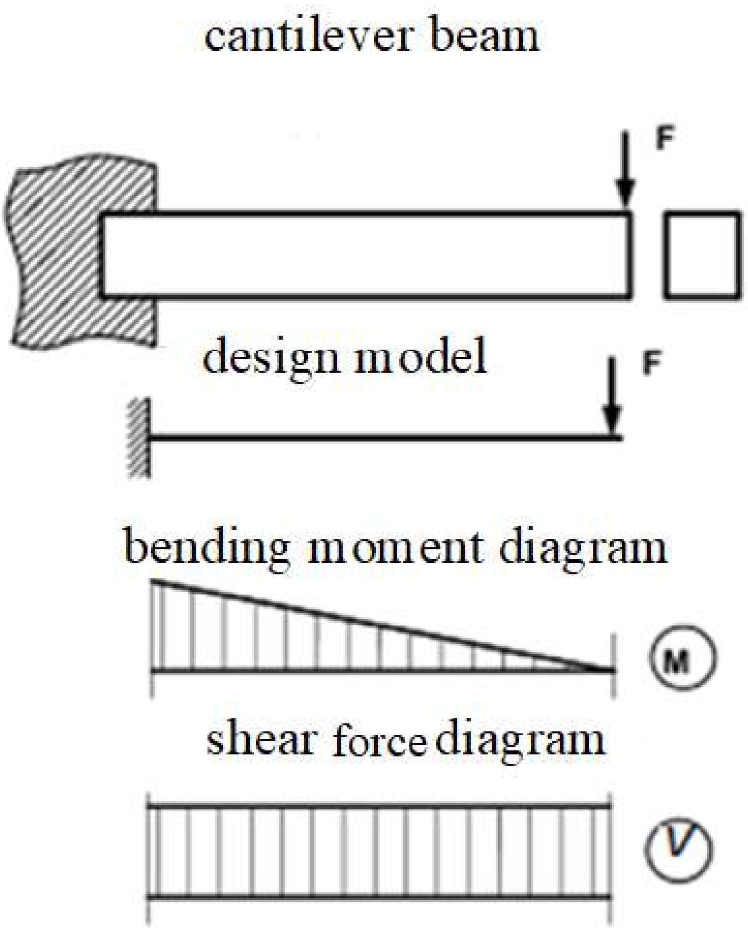
By the **function**, reinforcement is divided into **principal** and **constructive** (mounting, distribution) bars.

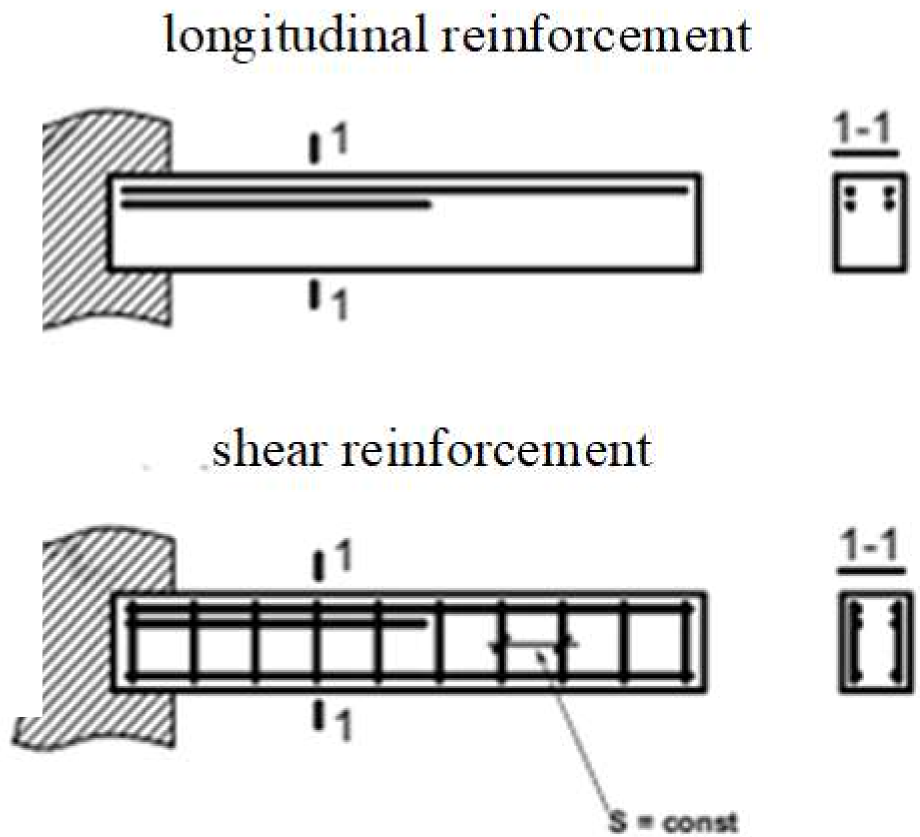
Area of the principal reinforcement (A_s) is determined **by calculation** on the effect of external load.

The longitudinal reinforcement takes longitudinal forces; it is parallel to the longitudinal axis of element.

$\rho_f = A_s / A_c$ – ***reinforcement ratio***, it characterizes amount of the longitudinal reinforcement in the RCE, it is often expressed as a percentage.

The shear reinforcement is oriented perpendicularly or at an angle to the longitudinal axis and takes shear forces.


cantilever beam
F
design model
F
bending moment diagram
M
shear force diagram
V


longitudinal reinforcement
1
1
1-1
shear reinforcement
1
1
1-1
S = const

The area of *the constructive reinforcement* is **not calculated**. It is accepted by constructive or technological conditions.

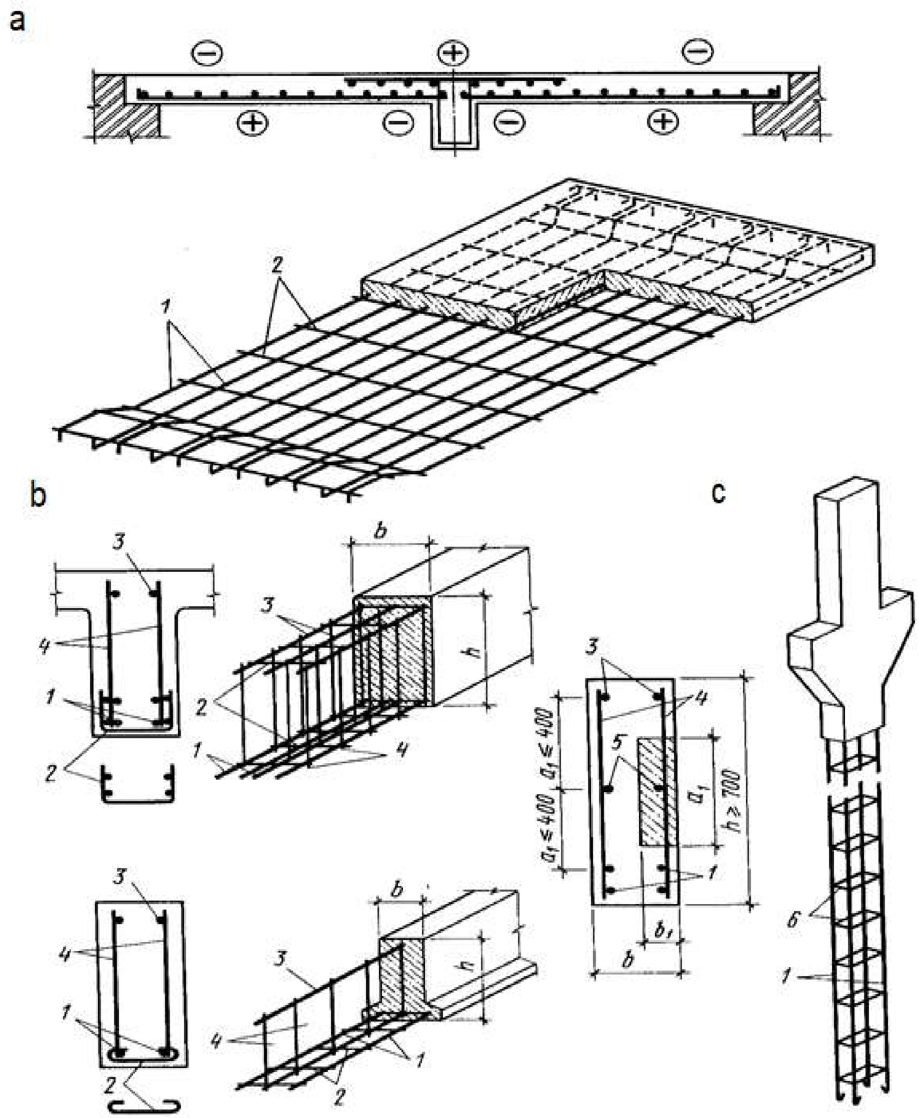
It is intended for:

- more uniformly distributing of the concentrated effort between the separate bars of the longitudinal reinforcement (**distribution reinforcement**);

- maintaining the design position of the longitudinal reinforcement during concreting (**distribution reinforcement**);

- for perception of stresses which is caused by shrinkage and creep of concrete, temperature stresses, local stresses, random stresses that arise during the fabrication and storage of structures, as well as the impact on them the mounting and transport effort (**assembling bars**).

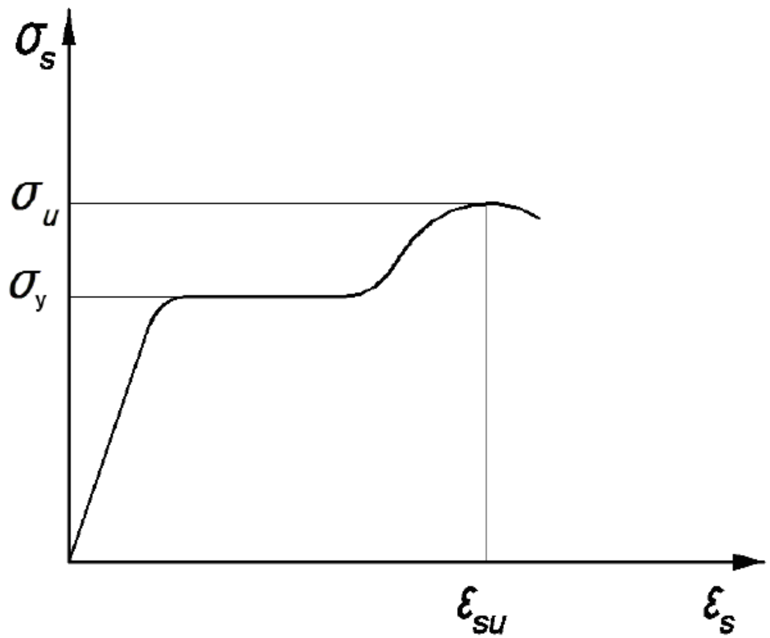
The diameter of the constructive reinforcement is accepted not less than 10 – 12 mm and not less than diameter of the shear reinforcement.



Reinforcement of RCS: *a* – slabs; *b* – beams; *c* – column;
1 – the longitudinal reinforcement; 2 – the constructive reinforcement; 3 – the mounting reinforcement; 4 – the shear reinforcement; 6 – lateral ties of column cage

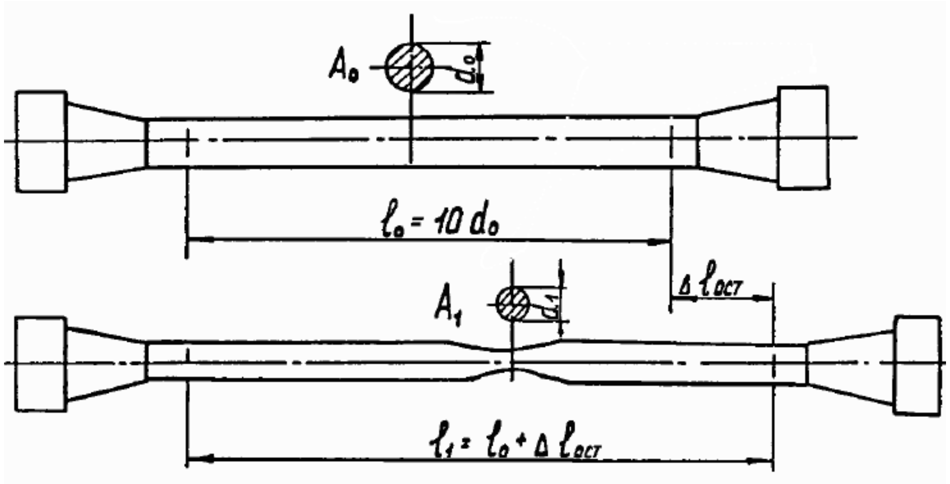
3.2 Physical and mechanical properties of reinforcing steel

Basic characteristics of reinforcement are strength and deformability which depend **on** **make-up** and **technology of reinforcement making**.
Steels with a pronounced yield line are called “**mild**”.

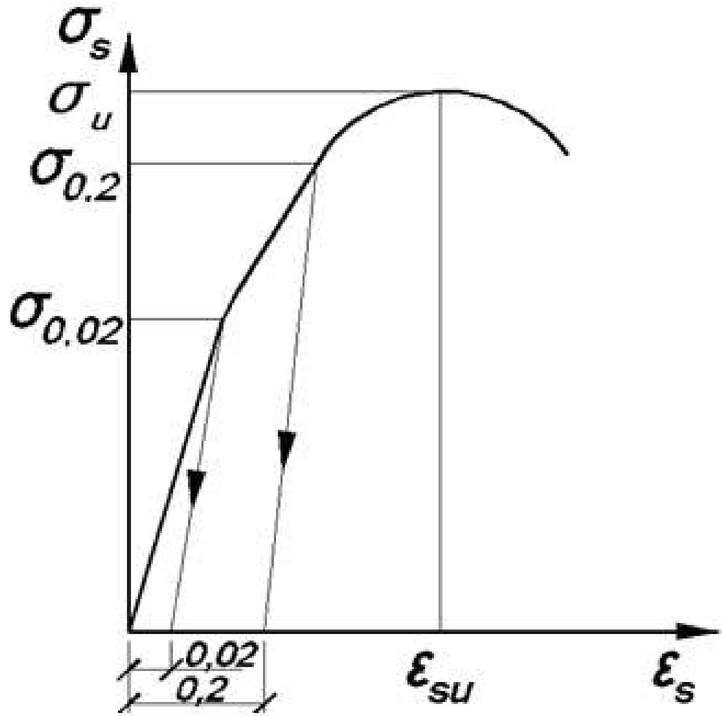


Stress-strain diagram $\sigma_s - \varepsilon_s$ for reinforcement steels with physical yield stress: σ_y – physical yield stress ; σ_u – ultimate strength

The basic strength index of mild steels is the physical yield stress σ_y for RCS.


A0
d0
l0 = 10 d0
Δ lост
A1
d1
l1 = l0 + Δ lост

Solid steels – steels without yield line.



Stress-strain diagram $\sigma_s - \varepsilon_s$ for reinforcing steels
with proof at 0.2 percent set yield stress:
$\sigma_{0.02}$ – offset limit of elasticity – stress at which there are residual relative strain, which is equal 0.02% of the limit residual strain; $\sigma_{0,2}$ – the proof at 0.2 percent set yield stress – the stress corresponding to a residual strain of 0.2%, σ_u – ultimate strength

The basic strength index of solid steels is the proof at 0.2 percent set yield stress $\sigma_{0,2}$ for RCS.

The **fatigue strength** is the strength, for the achievement of which there is no fragile failure of steel with the number of cycles 10^6.

The **reinforcement creep** is the growth of strain in time under load, it increases with increasing of stresses and temperature.

Relaxation is decreasing of pretesting in time at the hard fixing of reinforcement ends (which restrains free strain of reinforcement).

This quality **negatively affects** to behavior of pre-stressed structures. It predetermines the considerable pre-stress loss which reduce crack resistance and rigidness of structures.

The pre-stressed reinforcement is classified in obedience to norms by character of relaxation as follows:

- class 1 is a wire or rope with ordinary relaxation;
- class 2 is a wire or rope with low relaxation;
- class 3 are hot-rolled or treated bars.

3.3 The classification of reinforcement

Reinforcement is classified by:

- the **functionality**;

- the **method of application** (pre-stressed and without pre-stressing);

- the **method of manufacture** (bar diameter of 5.5 – 40 mm and wire diameter 3 – 12 mm);

- the **method of further strengthening** (thermomechanical-strengthened and strengthened in the cold state);

- surface form (smooth and ribbed profile).

The **type of reinforcement** by the **method of manufacturing, surface form** and **further strengthening** is determined:

- **hot rolled smooth** (Ø 5.5 – 40 mm) and **ribbed profile** (Ø 6 – 40 mm);
- **cold deformed wire ribbed section**;
- **thermo-mechanical strengthened ribbed profile**;
- **reinforcing rope** diameters from 6 mm to 15 mm.

Depending on the yield strength flexible reinforcements are divided into **classes**.

Produce hot-rolled bar reinforcement classes:

- **A240C** (smooth);
- **A400C** (ribbed profile with the surface “herringbone").

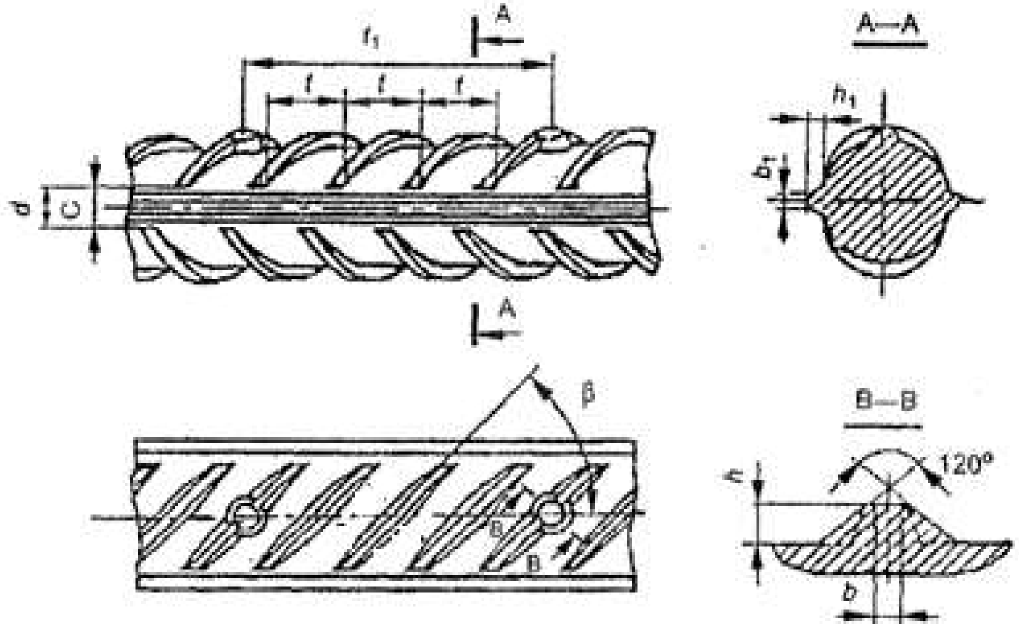
Thermomechanical strengthening subject classes reinforcement ribbed profile:

A500C, A600, A600C, A600CK, A800, A800K, A800CK, A1000.

Depending on the properties reinforcing bars are divided into:

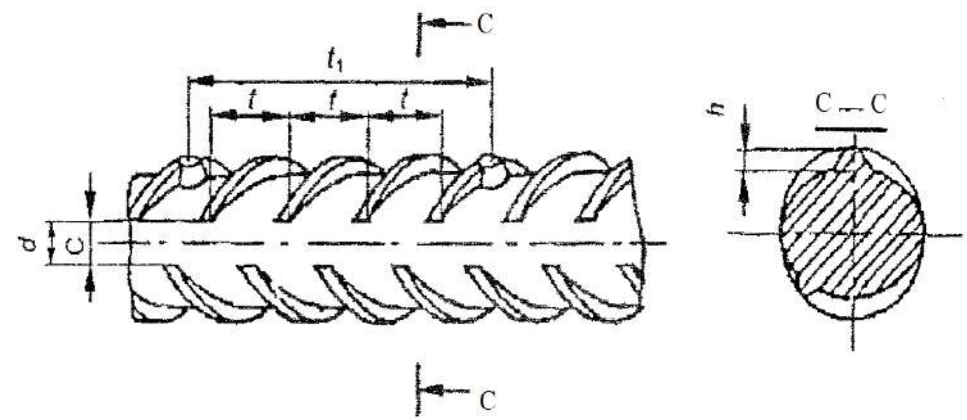
- welded (labeling index has C);
- not welded (no index C);
- resistant to stress corrosion cracking (index K);
- unstable to stress corrosion cracking (no index K);
- welding and resistant to corrosion cracking (CK index).

Smooth reinforcement

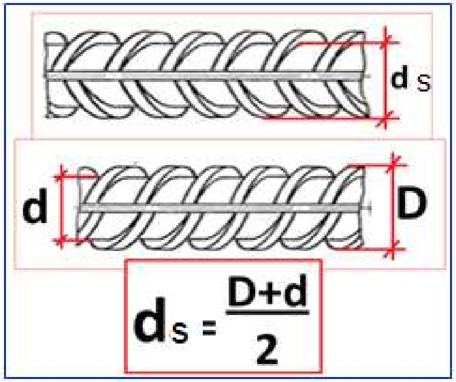


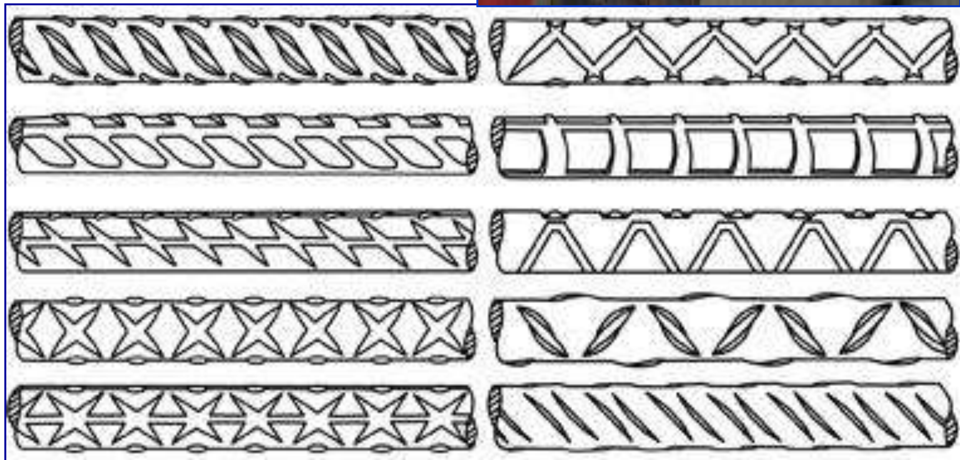
a

b



Bar reinforcement with ribbed profile with longitudinal projections (a) and without it (b): *t* – the distance between adjacent projections; t_1 – the distance between the marks, the court indicates class reinforcement; h (h_1), b (b_1) – height and width of projections


d S
d
D
$d_S = \frac{D+d}{2}$



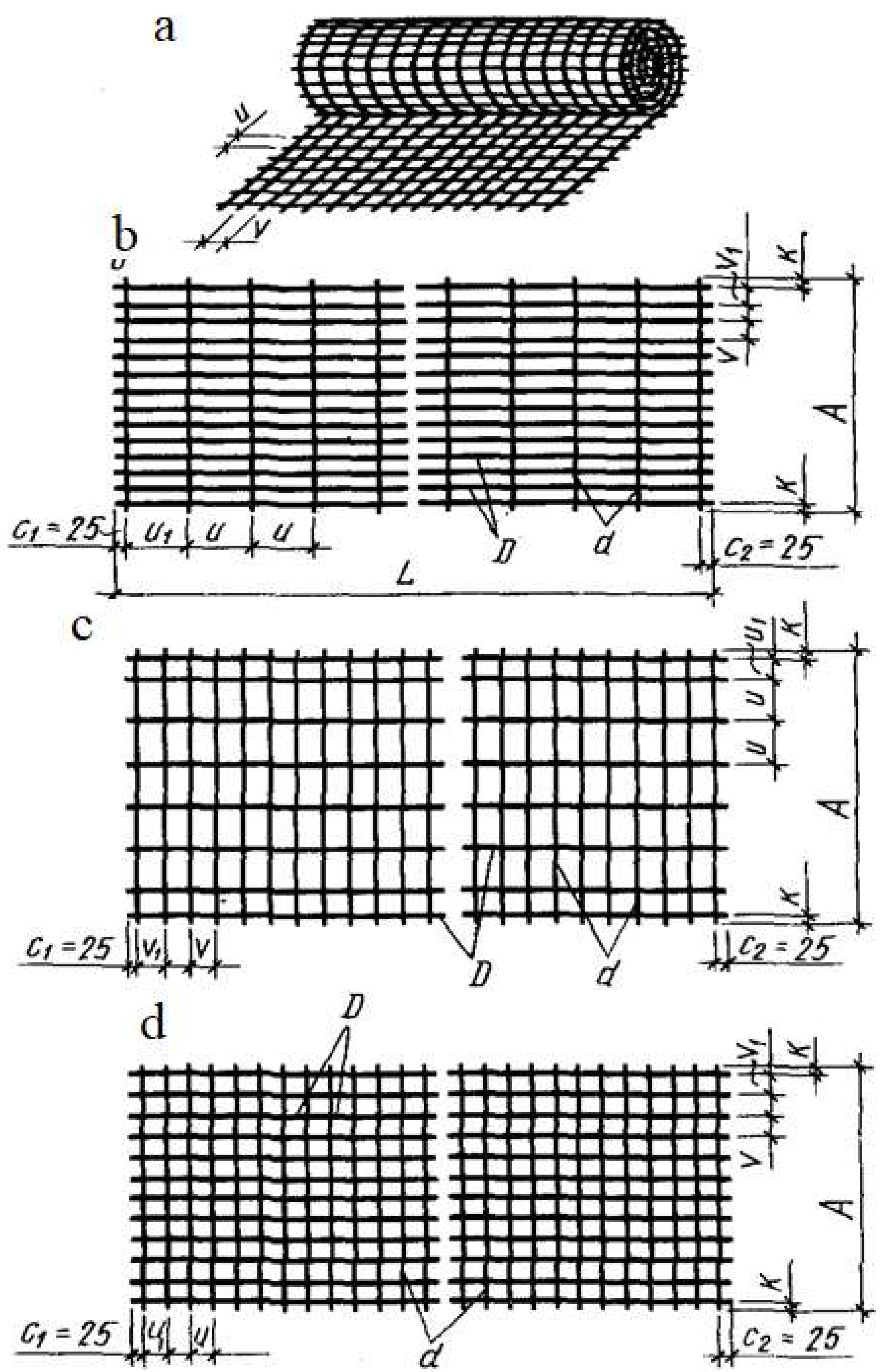
Produce **cold deformed wire ribbed section** classes: B500, Br -1, Br1200 – Br1500

There are **reinforcing rope** classes: K1400, K1500

3.4 Reinforcing products

For speed-up the manufacturing of reinforced concrete, it is reinforced with a reinforcing mesh, two-dimensional (plane) cage and tree-dimensional (space) cage, which includes principal (non-tensioned) and the constructive reinforcement, embedded parts, assembly loops.

Welded mesh is used mainly with perpendicular arrangement of principal and distribution wire B500 with a diameter of 3 – 5 mm and bar class A400C with a diameter 6 – 10 mm.

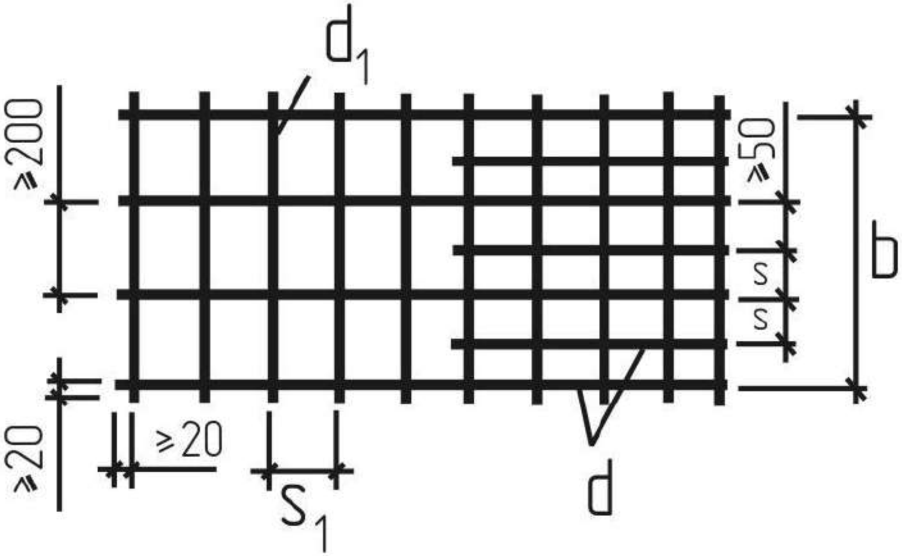


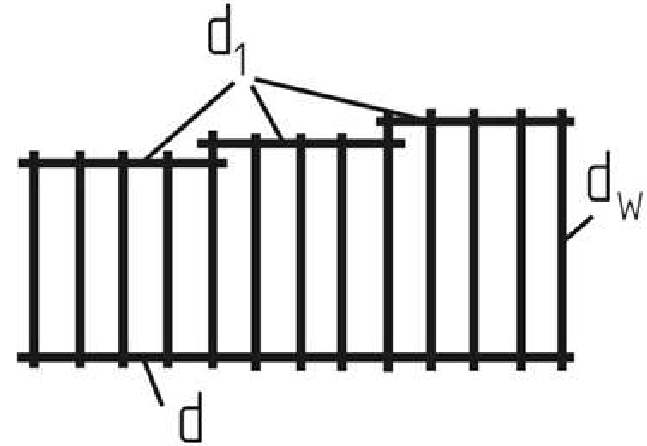
In rolled mesh, the largest diameter of the longitudinal bars is 8 mm, the width is within 1040 – 3630 mm, the length from the condition of the mash mass is 900 – 1300 kg. Welded meshes, as a rule, are made up to 3800 mm wide.

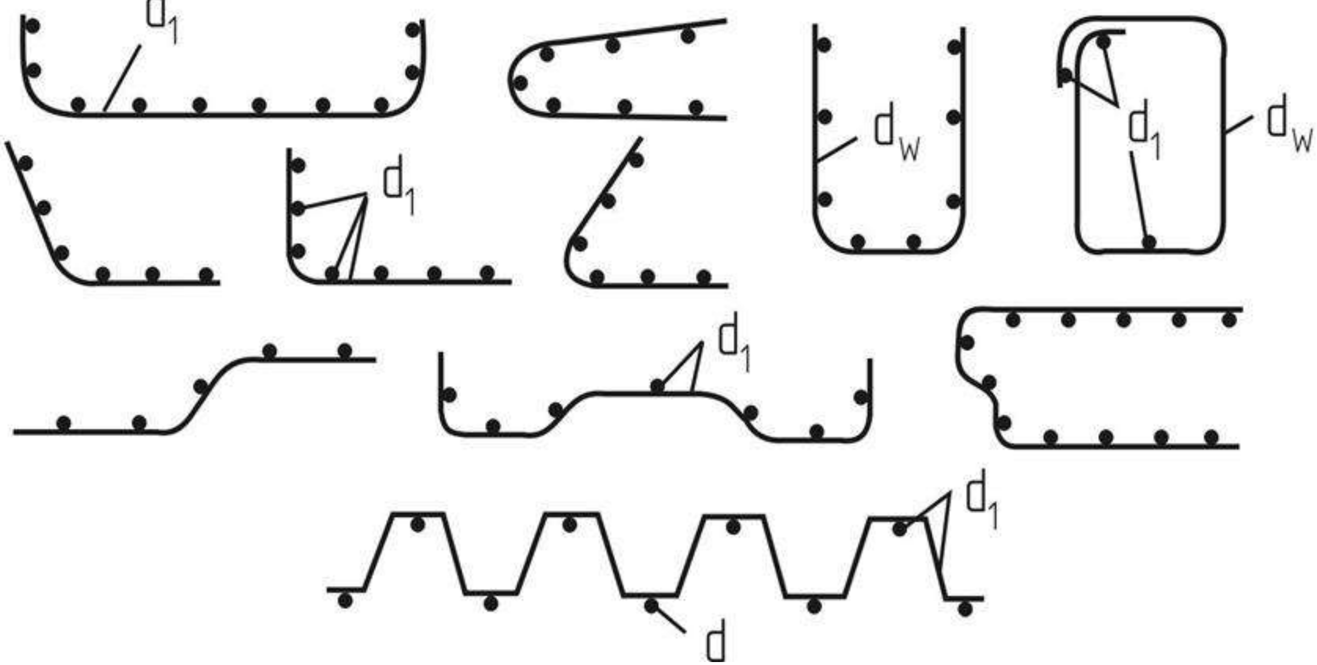
The minimum size of the free lengths of longitudinal and shear bars in the meshes and cages should be $c \geq 0.5\varnothing_1 + \varnothing_2$ or $c \geq 0.5\varnothing_2 + \varnothing_1$ and not less than 15 mm.

Welded reinforcing mesh as:

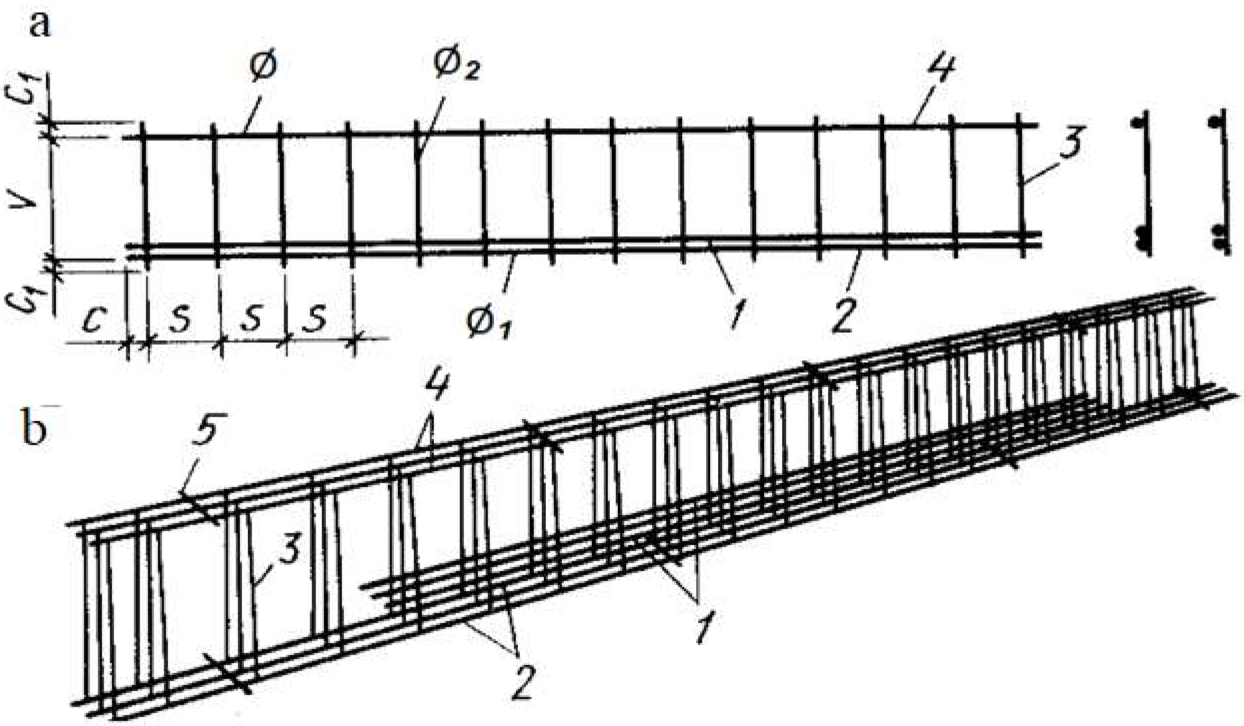
a – a rolled; b, c, d – flat with the principal reinforcement respectively longitudinal and transverse in both directions


d_1
≥200
≥50
b
s
s
≥20
≥20
s_1
d


d_1
d_w
d

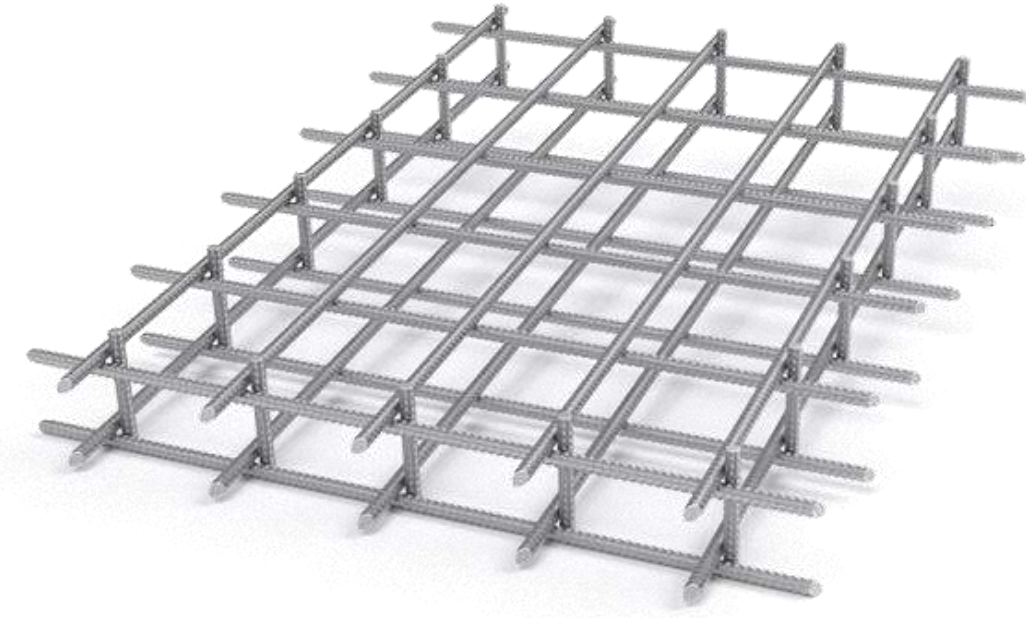

d_1
d_1
d_w
d_1
d_w
d_1
d_1
d

Welded cages are made **plain** or combined in **spatial** by mounting bars. The longitudinal principal bars are placed in one or two levels on one or both sides of the shear bars.



Types of reinforcement cages:

a – the plain; b – the spatial; 1 – a second row of principal reinforcement; 2 – the lower row of principal reinforcement; 3 – the shear reinforcement; 4 – the assembly bars; 5 – the constructive bars, which combines plain cages in spatial cage

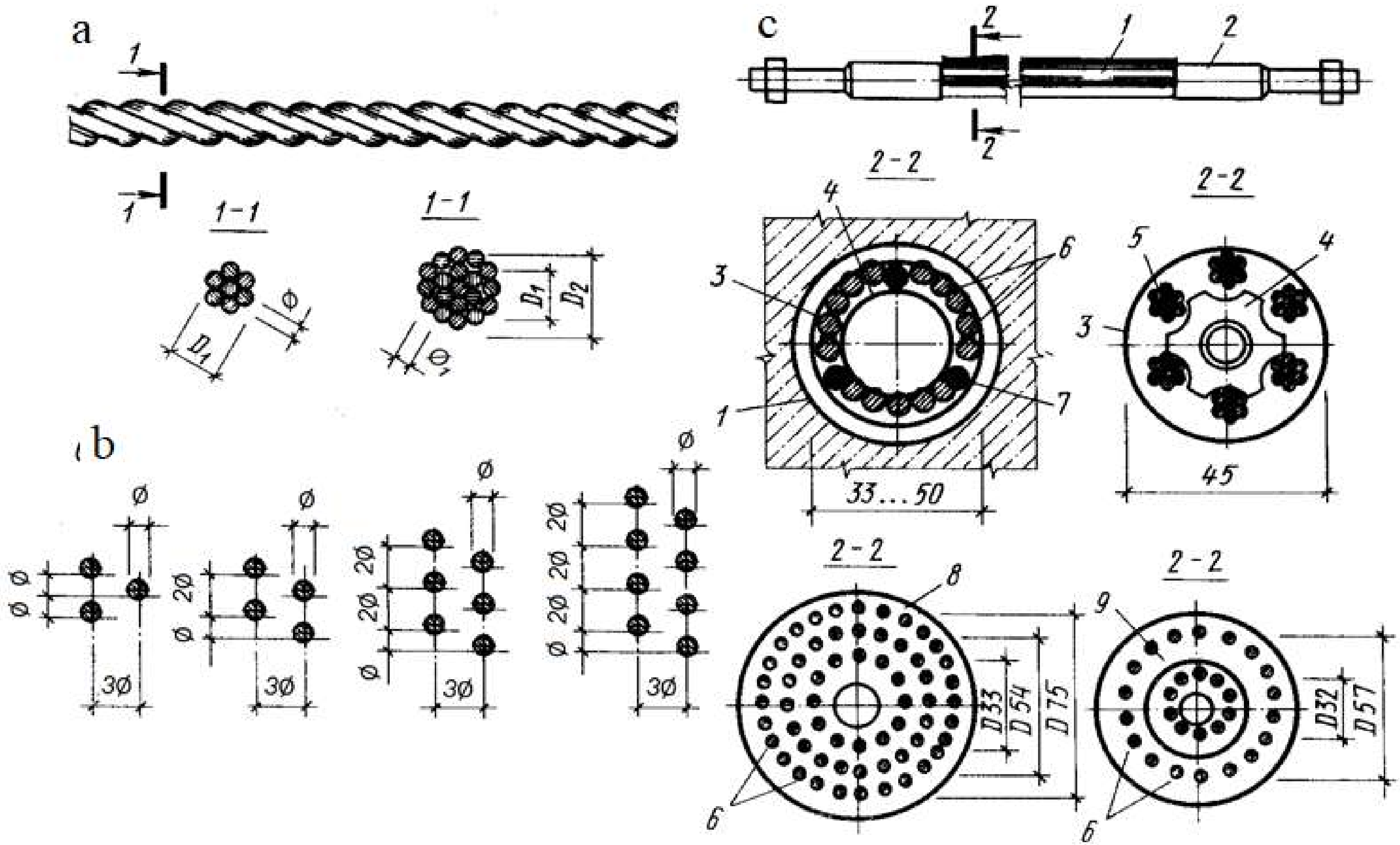


Embedded parts

The using of **high-strength wire** as pre-stressed reinforcement is the most economical because it has a lower unit cost compared to bar reinforcement. However, these advantages significantly reduced through

- the increase of a concrete croc-sectional sizes for accommodate the large number wires,
- limiting the maximum size of a coarse aggregate concrete,
- need for more plastic concrete,
- increasing metal intensity of anchor and gripping devices,
- increasing costs for corrosion protection.

Therefore, high-strength wires are used as **ropes, bundle, packages**.



The reinforced wire products:

a – wire ropes K1400 and K1500; b – packages with wire of class Br1200 and with diameter of 5 mm; c – single row (with 18 individual wires and with 6 seven-wires ropes) and multi rows (60 and 28 wires) bundles; 1 – the tube of roofing steel; 2 – the anchor; 3 – the clamps of soft wire diameter 3 mm; 4 – the pieces of spiral wire with a diameter of 2 mm (the star distribution in bundles of ropes); 5 – seven-wires ropes; 6 – separately deposited wires; 7 – units with diameter 18 mm, length 100 mm, with step 1000 mm increments for comfortable filling of bundle cavity by mortar; 8 – multi-row bundles

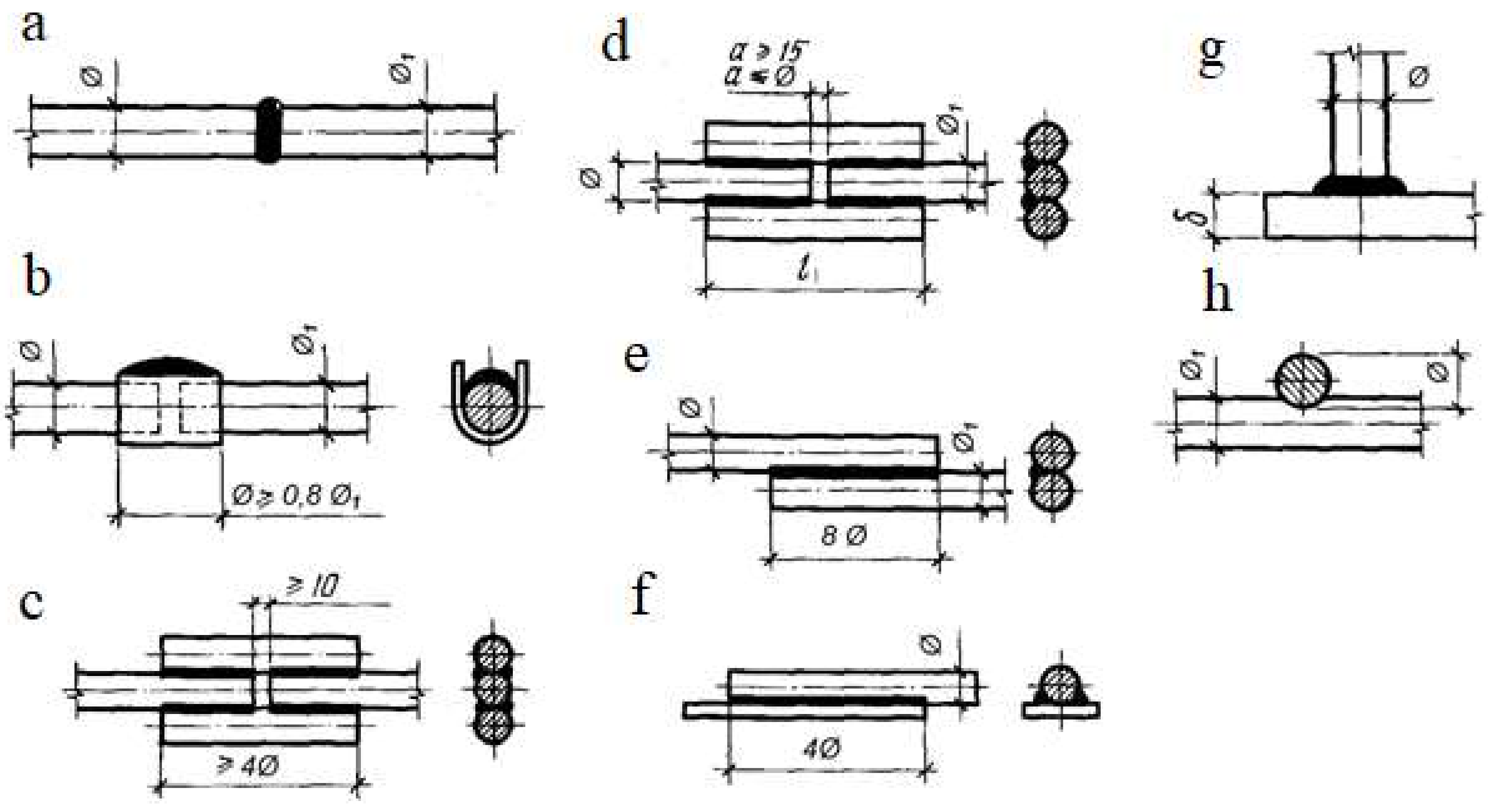
3.5 Joints and intersection of reinforcement

Rod steel – the B500 reinforcing wire rod and bar reinforcement of all classes with a diameter of 8 mm (inclusive) are produced in bobbins. The length of such reinforcement is sufficient for reinforcing structures of large sizes.

The bar reinforcement diameter of 10 mm and above are produced like **rebar** with length of 6.5 – 14 m, which are needed to join together.

By the **manufacturing method**, the joints of bar reinforcement are divided into **welded** and **lap without welding** and by the **place of manufacturing** they are divided into **assembly and factory**.

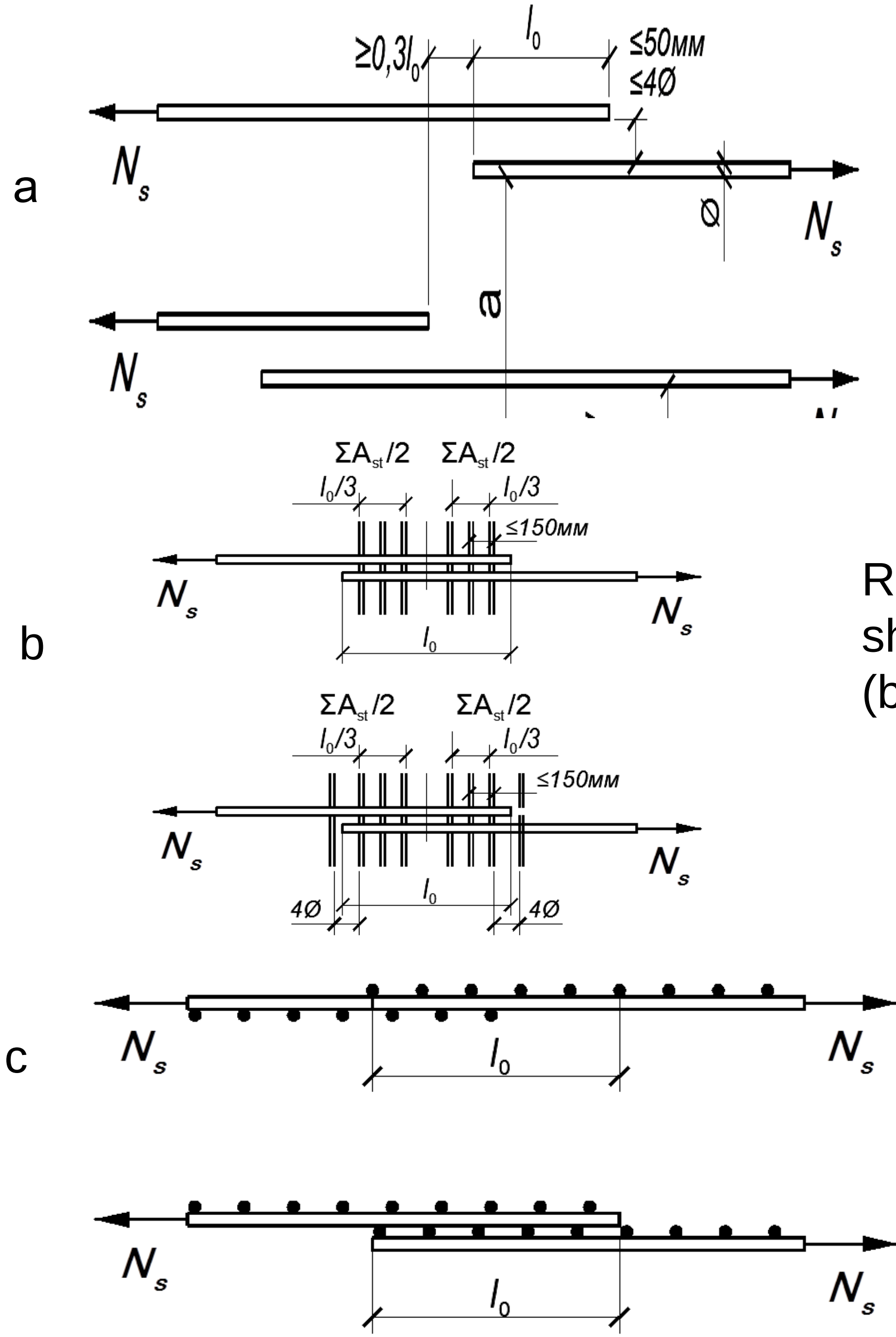
As most economical, the welding joints got distribution in the building. Depending on the type of reinforcement and manufacturing conditions various types of welded joints are used.



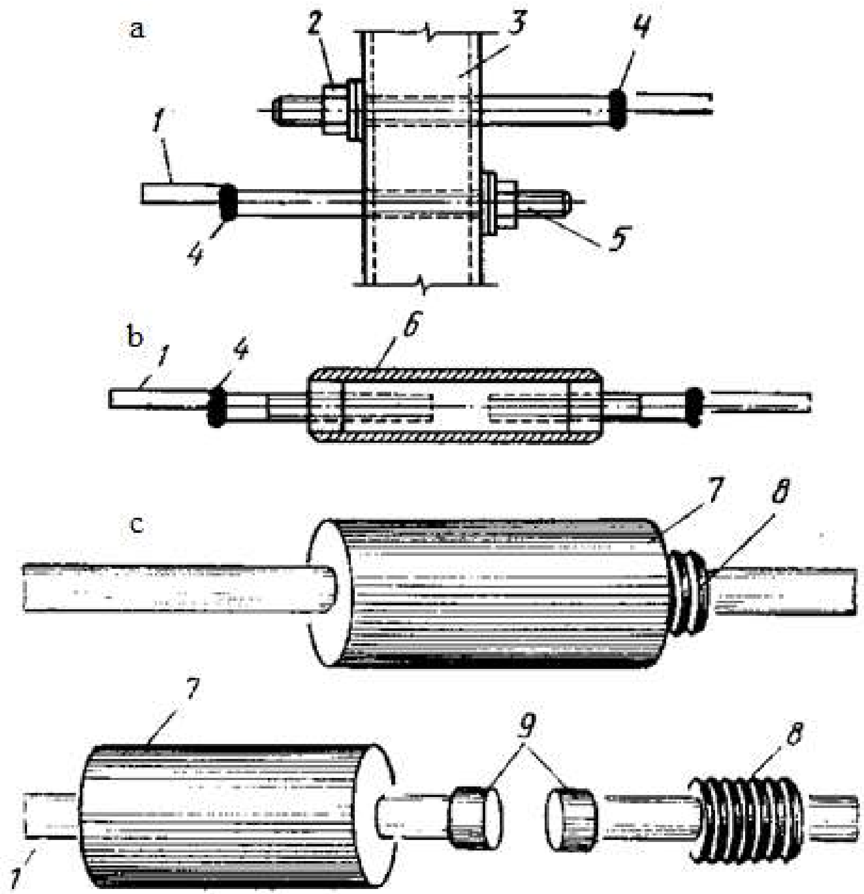
Welded joints of non-tension reinforcement:

a – contact; b – in the inventory form; c – a two-way seam with the lining; d – a one-way seam with the lining; e – in lap when connecting two bars; f, g – is the same when bar connected to plate; h – contact-point stitch by connecting bars, meshes and cages that intersect

The lap without welding



Rules of joining the individual bars (a), shear reinforcement in the joining area (b), the overlap of welded meshes (c)



Joints of pre-stressed reinforcement:

a – using nuts; b, c – by sleeve; 1 – reinforcement; 2 – tensioning nut; 3 – steel channel stock; 4 – electric contact welding; 5 – threaded end; 6 – tension sleeve; 7 – beads; 8 – threaded plug; 9 – anchor

The subject
MATERIALS FOR REINFORCED CONCRETE AND STONE STRUCTURES AND THEIR PHYSICAL AND MECHANICAL PROPERTIES

THE PHYSICAL AND MECHANICAL PROPERTIES OF REINFORCED CONCRETE

4.1 Shrinkage and creep of concrete.

4.2 The bond of reinforcement with concrete.

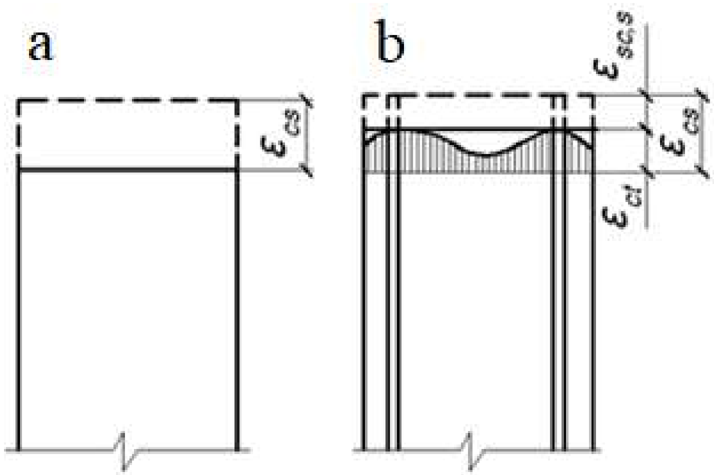
4.3 The anchoring of reinforcement.

4.4 The concrete cover.

4.5 Corrosion of reinforced concrete.

4.1 Shrinkage and creep of concrete

The **shrinkage** of reinforced concrete elements **is much less** than concrete elements. Steel reinforcement due to its bond with concrete, is an internal connection that prevents free shrinkage of concrete. As a result, in RCS is implemented self-balanced state of stress (caused without external forces), **in concrete there is a tension**, in reinforcement there is a compression.



$$\varepsilon_{ct} = \varepsilon_{cs} - \varepsilon_{cs,s}$$

the tensile relative strains of concrete are equal to the difference between the free shrinkage relative strain of concrete and shrinkage of reinforced concrete elements

$$\sigma_{ct} = \varepsilon_{cs} / (1 / E_{ct} + 1 / \rho E_s)$$

These stress contribute to an earlier formation of cracks in tensile zones of reinforced concrete element under load. However, in the operation, effect of shrinkage decreases, in failure stage shrinkage does not affect the bearing capacity of statically indeterminate reinforced concrete structures.

The dangerous **for concrete tensile stress** depends on

- the value of free shrinkage,
- the amount of the reinforcement,
- reinforcement and concrete class.

The reinforcement prevents to free creep of concrete similarly shrinkage.

Under the influence of creep there is redistribution of forces between concrete and reinforcement (stress in concrete decreases, stress in reinforcement increases leading to the full of its bearing capacity).

The creep affects differently on the behavior of RCS:

- in short compressed elements – provides total use of the strength of concrete and reinforcement;
- in flexible compressed elements – increases the initial eccentricities, which can reduce the bearing capacity of structures;
- during bending – causes an increase in deflections;
- in pre-stressed RCS – causes to loss of pre-stressing of reinforcement.

Under the influence of temperature in RCS there are the internal self-balanced force caused by the difference of the coefficients of linear expansion of cement, aggregates and steel reinforcement.

During the action of ***t* ≤ 50°C** they are small and **do not affect the strength of concrete**;

at ***t* = 60 – 200°C** must be considered slight decrease mechanical strength of concrete (by **30 %).**

Prolonged heating to ***t* = 500 – 600°C** with subsequent cooling the element is destroyed due to an increase in the volume of free lime released during dehydration of minerals of cement and is extinguished by moist air.

The bond strength of reinforcement with concrete decreases

at ***t* = 500 °C** at **30 % (**for deformed reinforcement bar**)** and

at **250 °C** sharp (for reinforcement with smooth section).

In statically indeterminate RCS under the influence of seasonal changes in temperature have additional stress, which in large size of structure can be significant. To reduce it the building is divided into separate units by **temperature seams**, which usually coincide with **shrinkage seams**.

4.2 The bond of reinforcement with concrete

The basis of effective collaboration of reinforcement with concrete in one monolithic body – reinforced concrete – is the bond – a set of physical and mechanical phenomena on the contact surfaces of reinforcement and concrete, which ensure their communication and shear resistance of reinforcement in concrete.

The bond strength depends on:

- **class and properties of concrete:**

with increased grade of cement,

its quantity,

age of concrete,

increased density,

reduced W/C

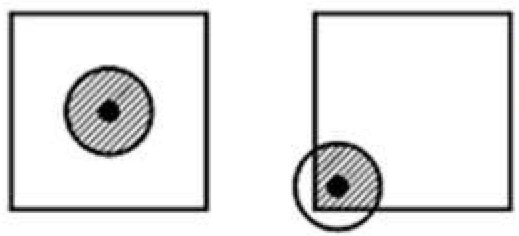
the bond strength increases;

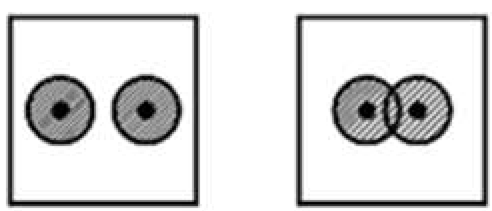
– **quality of reinforcement:**

the surface forms;

cross section forms;

section location of bar;

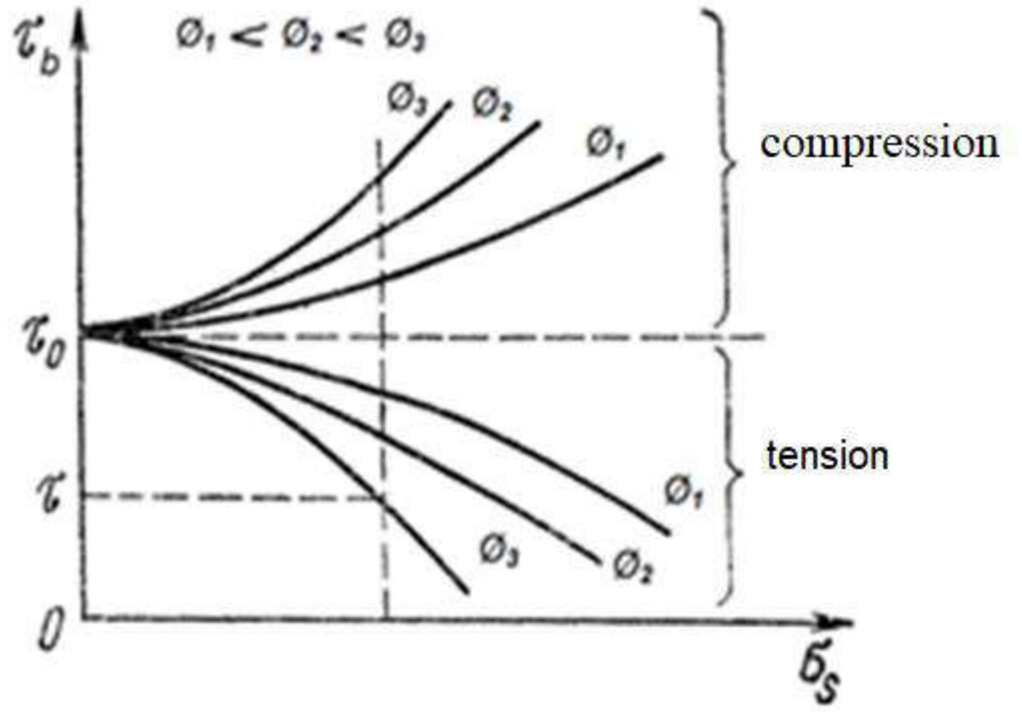




the bar diameter.

With the increasing the diameter of bar and the stress in it, the bond stress increases in compression and decreases in tension.

For better bond of the reinforcement with concrete during the designing of reinforced concrete elements **tensile bars diameter should be limited**;



– manufacturing technology

Experiments have shown that bond of the reinforcement with concrete is possible due to:

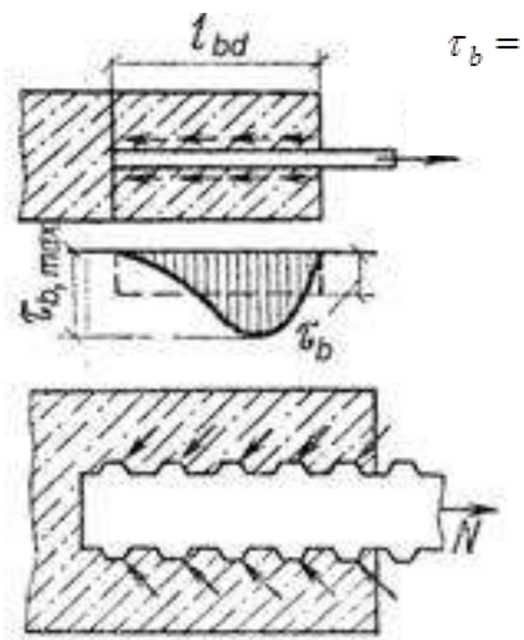
- resistance of concrete for crushing and shearing due to irregularities and projections on the surface of the reinforcement (70 – 75%). The smooth profile bars have the bond 3 times less than the deformed bars;

- gluing the reinforcement with concrete (10%).

– **?**.

To the bond test is used in different ways, most often pulling out the concreted bar

$$\tau_b = \frac{N}{ul_{bd}}; \quad N = \sigma_s A_s; \quad u = \pi \varnothing; \quad A_s = \frac{\pi \varnothing^2}{4}; \quad \tau_b = \frac{\sigma_s \varnothing}{4 l_{bd}}.$$



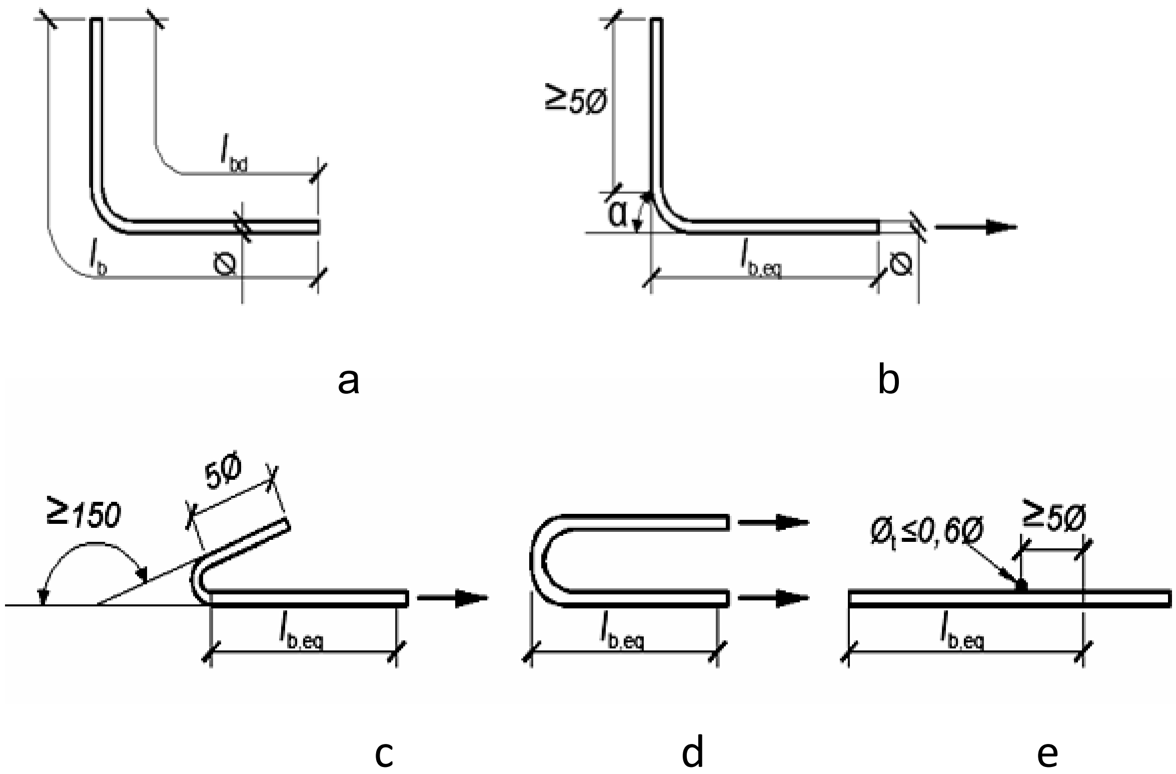
The rules provide determining the estimated values of the bond stress f_{bd} for deformed bar

4.3 The anchoring of reinforcement

Joint work reinforcement with concrete is usually provided by the bond. However, sometimes these forces are not enough. Then additional means of ensuring collaboration with concrete reinforcement is used – **the anchoring**.

The length of the anchoring zone, at which the bond must be the greater, must be as higher as higher the strength of reinforcement and diameter bar.

To reduce the length of the anchoring zone (for saving metal)
- limit the tensile diameter valves,
- increase class of concrete and
- use deformed reinforcement bars.

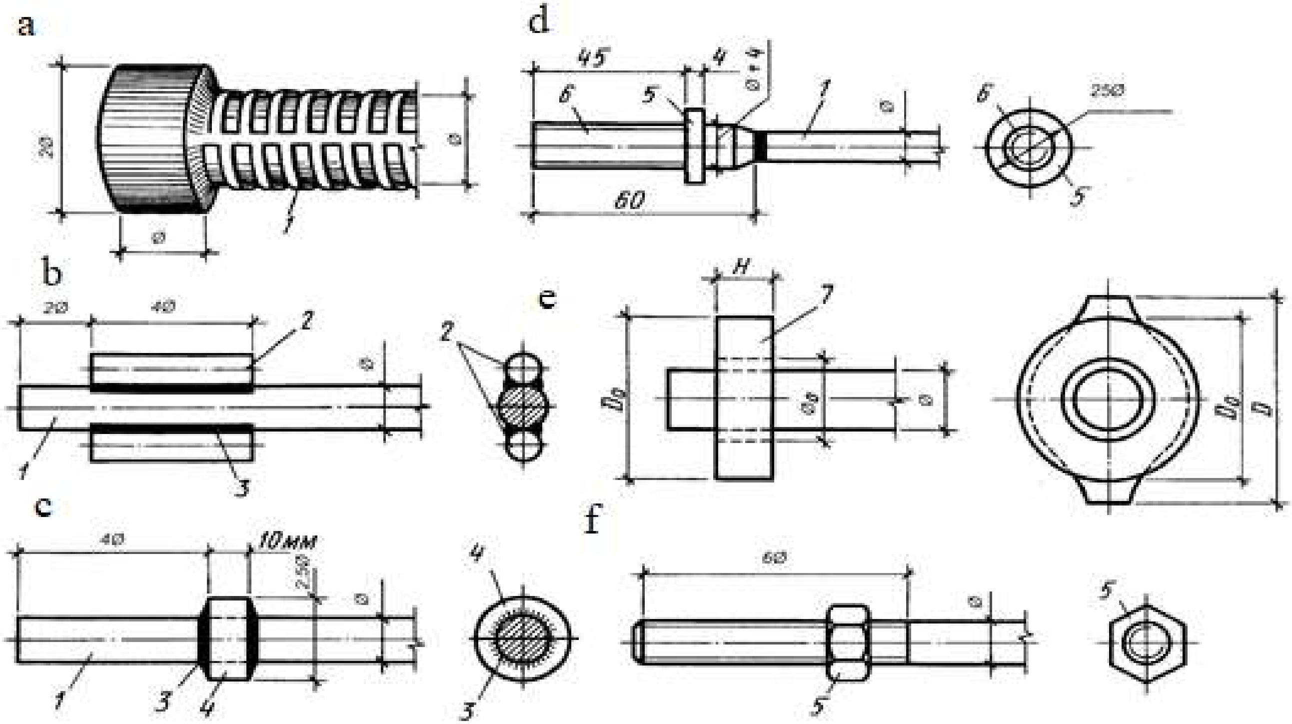


The minimum length of anchoring restrictions is adopted by norms. Anchoring at tension can be achieved through an equivalent length of anchoring $l_{b,eq}$, which is taken $\alpha_1 l_{b,rqd}$ or $\alpha_4 l_{b,rqd}$

Methods for indirect anchoring bars:

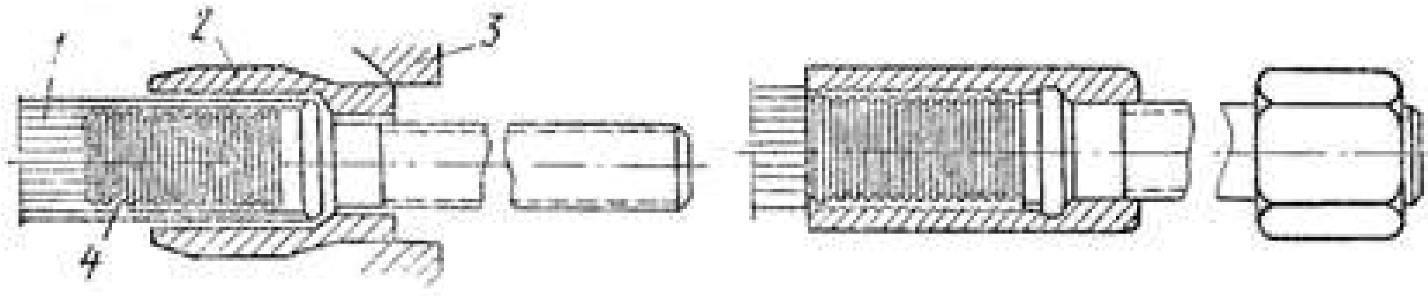
a – anchoring base length l_b for any form along the axis; the anchoring equivalent length b – for standard bend bar; c – for standard hook; d – for standard loop; e – for welded bar

Pre-stressing reinforcement – deformed bars or wire ropes – with pre-tensioning and sufficient strength of concrete used in the structure without special anchors; with post-tensioning or pre-tensioning in low bond to concrete special anchors used.



Technological anchor of bars of pre-stressed reinforcement:
a – the blown head; b – the welding of short bars; c – welding ring; d – wrap nut; e – compressed gasket; f – wrap nut; 1 – reinforcing bars; 2 – short bars; 3 – welding; 4 – ring; 5 – nut; 6 – stamped steel tip with chasing, which is welded to the reinforcement; 7 – compressed gasket

Factory **sleeve anchorage of tendons** consists of a bar with chasing that wound up in a tendon, and sleeve with mild steel, which is superimposed on top of the tendon. When pulling out through a special metal ring the sleeve metal flows and press the wires of tendon. Fixing of this anchor after post-tensioning of tendon by jack is made by nut of end bar that tighten to the better end to the end surface of element.

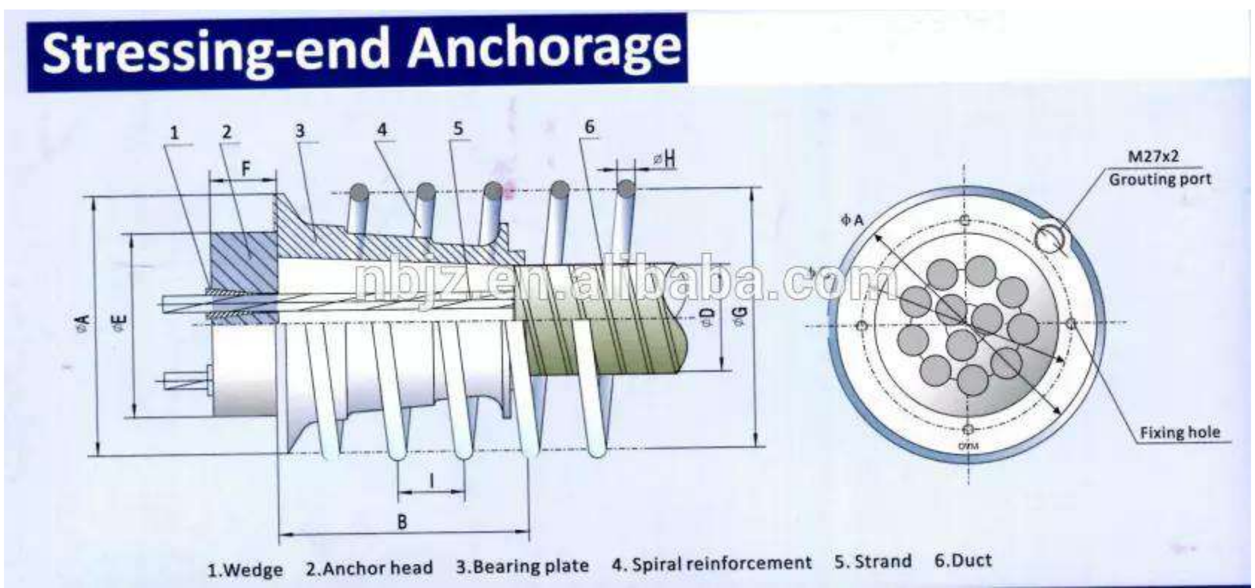


a b

Sleeve anchorage:
a – before pressing tendon; b – after pressing; 1 – the tendon;
2 – the anchorage; 3 – the special ring; 4 – the bar with chasing

Multi-strand post-tensioning anchor

Post-tensioned tendon anchorage; four-piece "lock-off" wedges are visible holding each strand



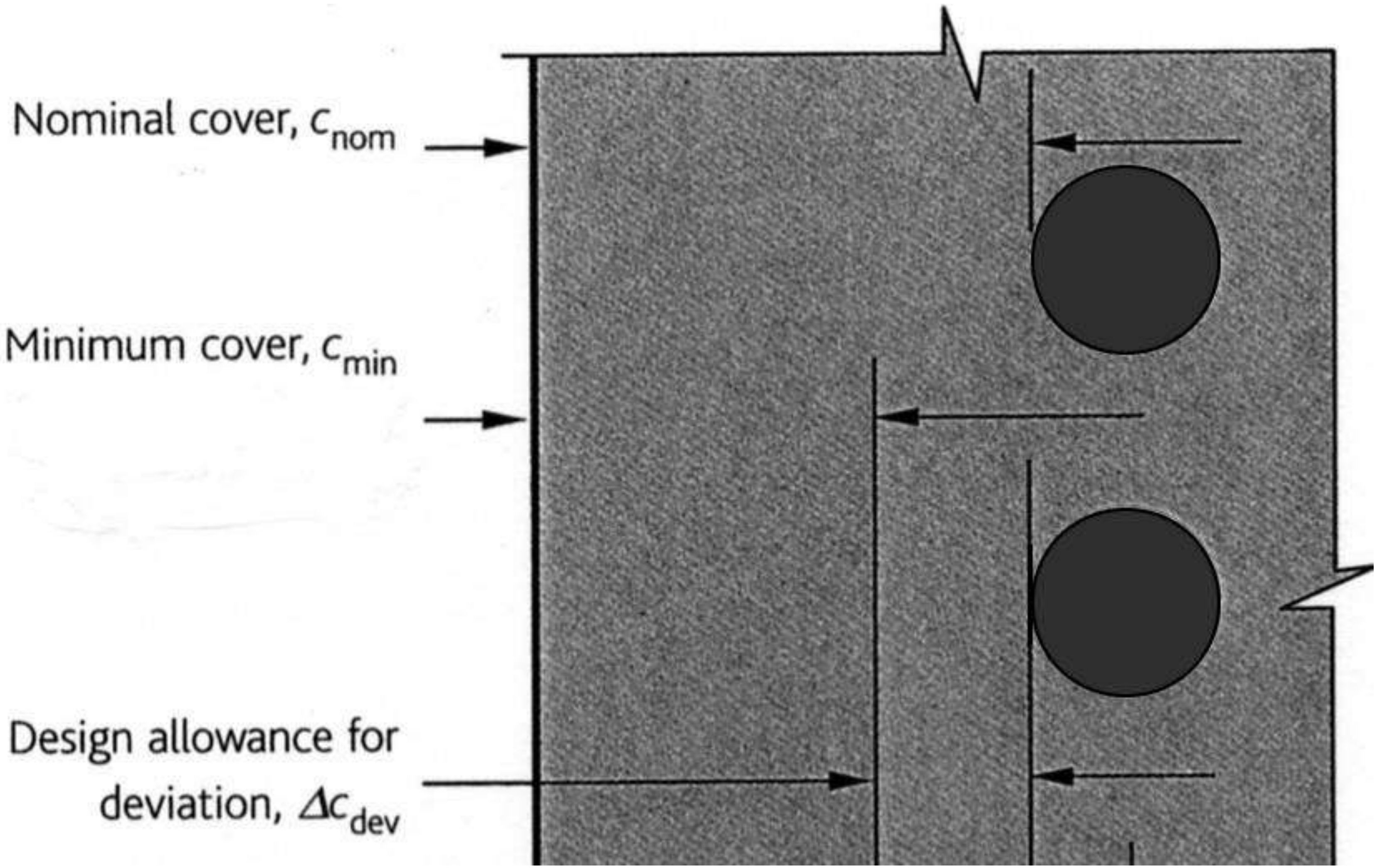
4.4 The concrete cover

Concrete cover is prescribed

- to protect against corrosion,
- prevent rapid heating at high temperatures and
- better bond reinforcement with concrete.

The thickness of the concrete cover is prescribed depending on

- the type and diameter of reinforcement,
- cross-sectional dimensions of the elements,
- the type and grade of concrete,
- application conditions of structure.



Nominal cover, c_{nom}
Minimum cover, c_{min}
Design allowance for deviation, Δc_{dev}

The nominal cover shall be specified on the drawings. It is determined by a minimum cover (tab.) and allowance in design for deviations

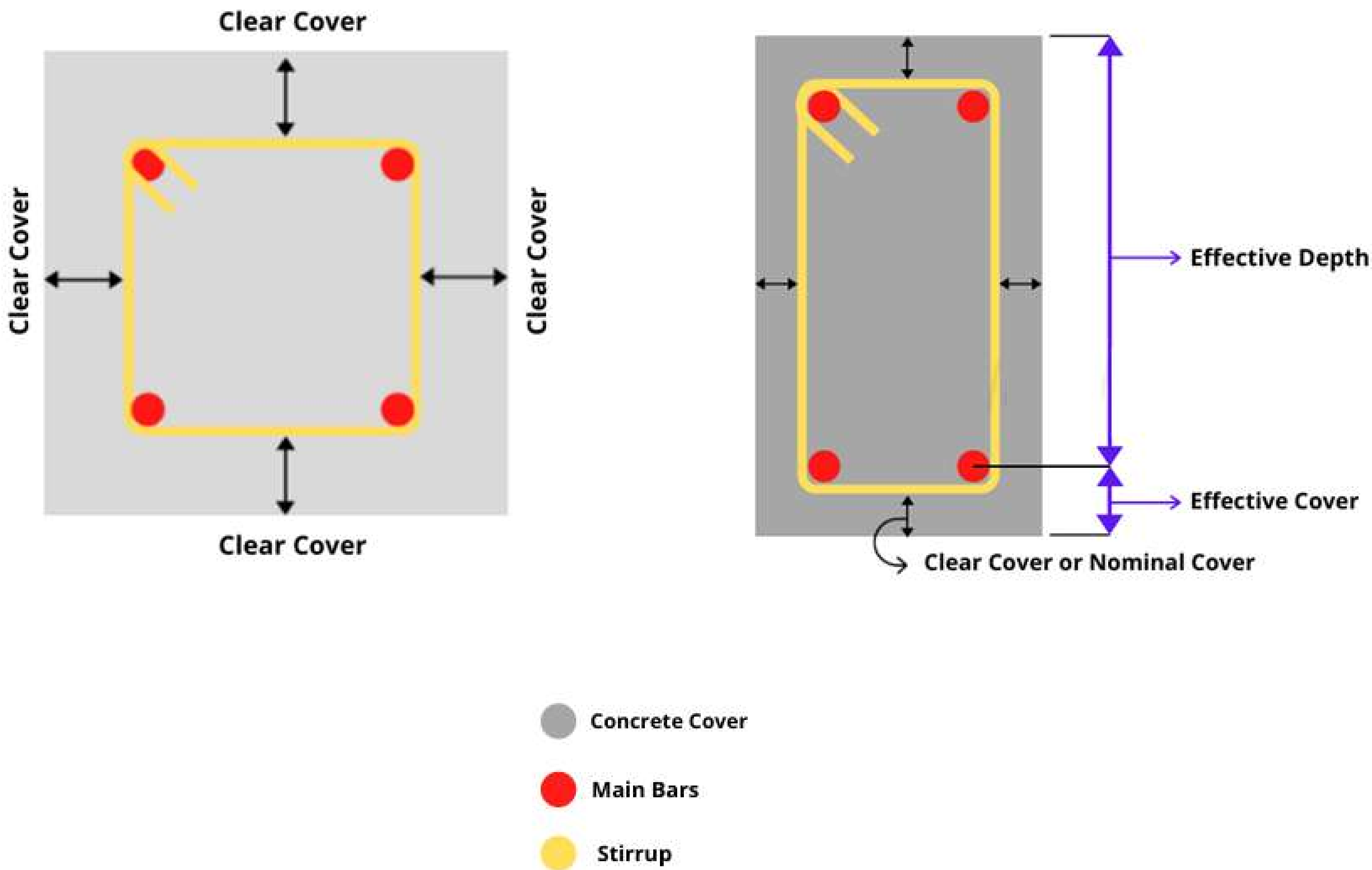
$$C_{nom} = C_{b,\min} + \Delta c_{dev}$$

Table - Minimum cover requirements with regard to bond

Arrangement of bars	Minimum cover $C_{b,\min}$
Separated	The diameter of the bar
Bundled	The equivalent diameter $Ø_p$
Note. If the nominal maximum aggregate size is greater than 32 mm, $C_{b,\min}$ should be increased by 5 mm; $Ø_p$ – equivalent diameter is determined according to relevant norms	

In order to transmit bond forces safely and to ensure adequate compaction of the concrete, the minimum cover should not be less than

$C_{b,\min}$


Clear Cover
Clear Cover
Clear Cover
Clear Cover
Effective Depth
Effective Cover
Clear Cover or Nominal Cover
Concrete Cover
Main Bars
Stirrup

From the design experience the following minimum value for concrete cover for structures without pre-stressing is recommended:

- in **slabs and walls with thickness of 10 cm** which is made of heavy concrete – at least **10 mm**, for lightweight concrete – **15 mm**;

- in slabs and walls with **thickness of more than 10 cm**, as well as **beams and ribs with height of less than 25 cm** – **15 mm**;

- in **beams and slabs with height of 25 cm or more**, and in the **columns** – **20 mm**;

- the **foundation beams and foundations** in the presence of foundation mattress – not less than **35 mm**, without foundation mattress – not less than **70 mm**.

The thickness of the concrete cover **for shear bars in the beams and columns** shall not be less than **15 mm**.

Exposure	**Nominal Concrete Cover Not Less Than (mm)**
Mild	20
Moderate	30
Severe	45
Very Severe	50
Extreme	75

Cover for Beam and Column

In a beam for a longitudinal reinforcing bar, the cover should be less than **30 mm or not less than the bar diameter.**

In a column for longitudinal steel, reinforcement cover should not be less than **40 mm or not less than such bar diameter.**

In the situation when the column dimension is 200 mm or under, which steel reinforcements don’t exceed 12 mm, **25 mm cover** for reinforcement should be provided.

Cover For Slab

In a slab for compressive shear, tensile or other reinforcement, the cover should not be less than **15 mm or not less than such bar diameter.**

For pre-tensioning reinforcement recommended values are:

- 1.5Ø for smooth rope wire or rope;
- 2.5Ø for deformed bar.

With post-tensioning reinforcement the thickness of the concrete cover should not exceed:

- with round cross-section of the channel – Ø;

- with a rectangular – must be more than two values: the smaller side or half more.

When the thickness of the concrete cover, which exceeds 45 mm, it is necessary to provide constructive reinforcement.

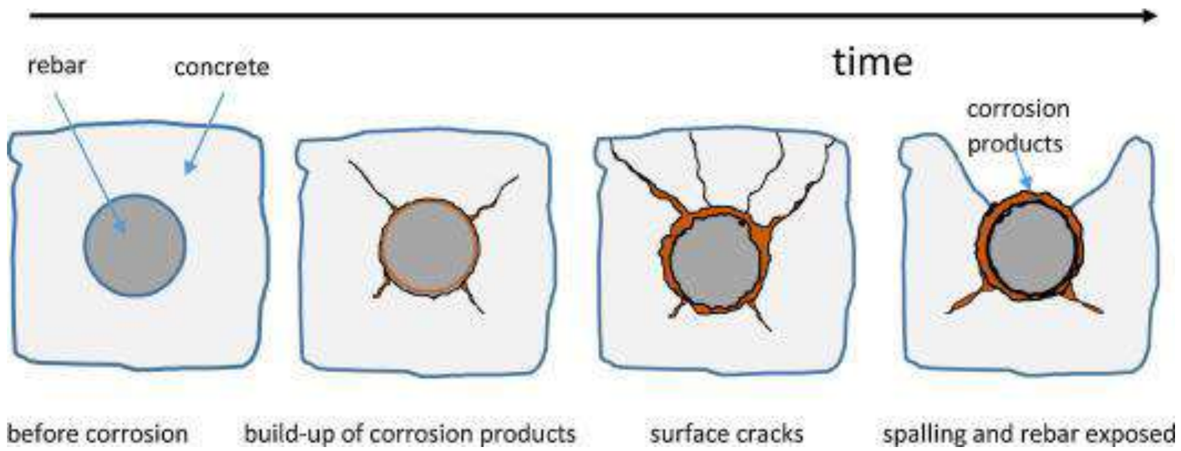
4.5 Corrosion of reinforced concrete

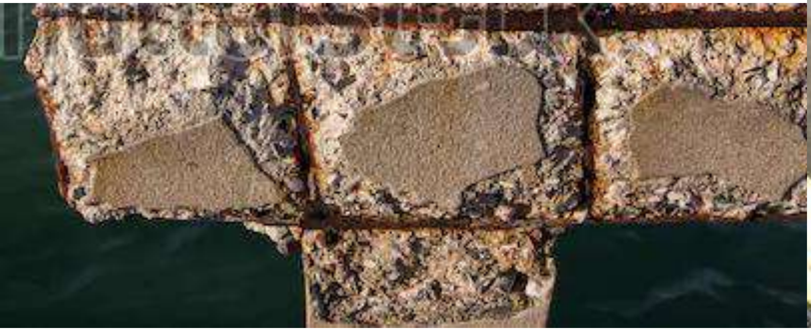
From different types of concrete corrosion should identify the most typical:

the first type includes processes that occur during action on reinforced concrete water with low rigidity. Products of dissolution **carry up** by water on the surface of concrete, which are white flakes or smudges.

- the second type of corrosion occurs under the influence of gas or liquid aggressive environment: acid gases, combined with high humidity, acids and other solutions. The interaction of acid with calcium oxide hydrate fails crashes the concrete. Products of chemical aggressive environment interaction and concrete during crystallization gradually fill the pores and channels in concrete, leading to rupture of its walls. The most negative influence to a concrete is a number of salts of acids, especially sulfuric.

Corrosion of reinforcement is the result of chemical or electrolytic action of the environment. Corrosion of steel products has a larger volume than the reinforcement, in the result considerable radial pressure on the layer of the concrete is generated. In this case, along the reinforcing bars there are cracks with partial exposure of the reinforcement.





For **corrosion protection** should reduce

- the filtering ability of concrete introduction of special additives to increase the thickness of concrete cover,
- apply mastic paint and coatings,

-replace portland cement in special types,

-use acid-concrete, concrete.

MASONRY

5.1 Strength characteristics of the masonry.

5.2 Deformability of the masonry.

5.3 Reinforcing the masonry.

The subject
GENERAL PROVISIONS OF BUILDING STRUCTURES DESIGN

6.1 Types, steps and tasks of building structures design.

6.2 The concept of stress-strain state (SSS) stages of reinforced concrete members.

6.3 The main provisions of limit states design method.

6.1 Types, steps and tasks of building structures design

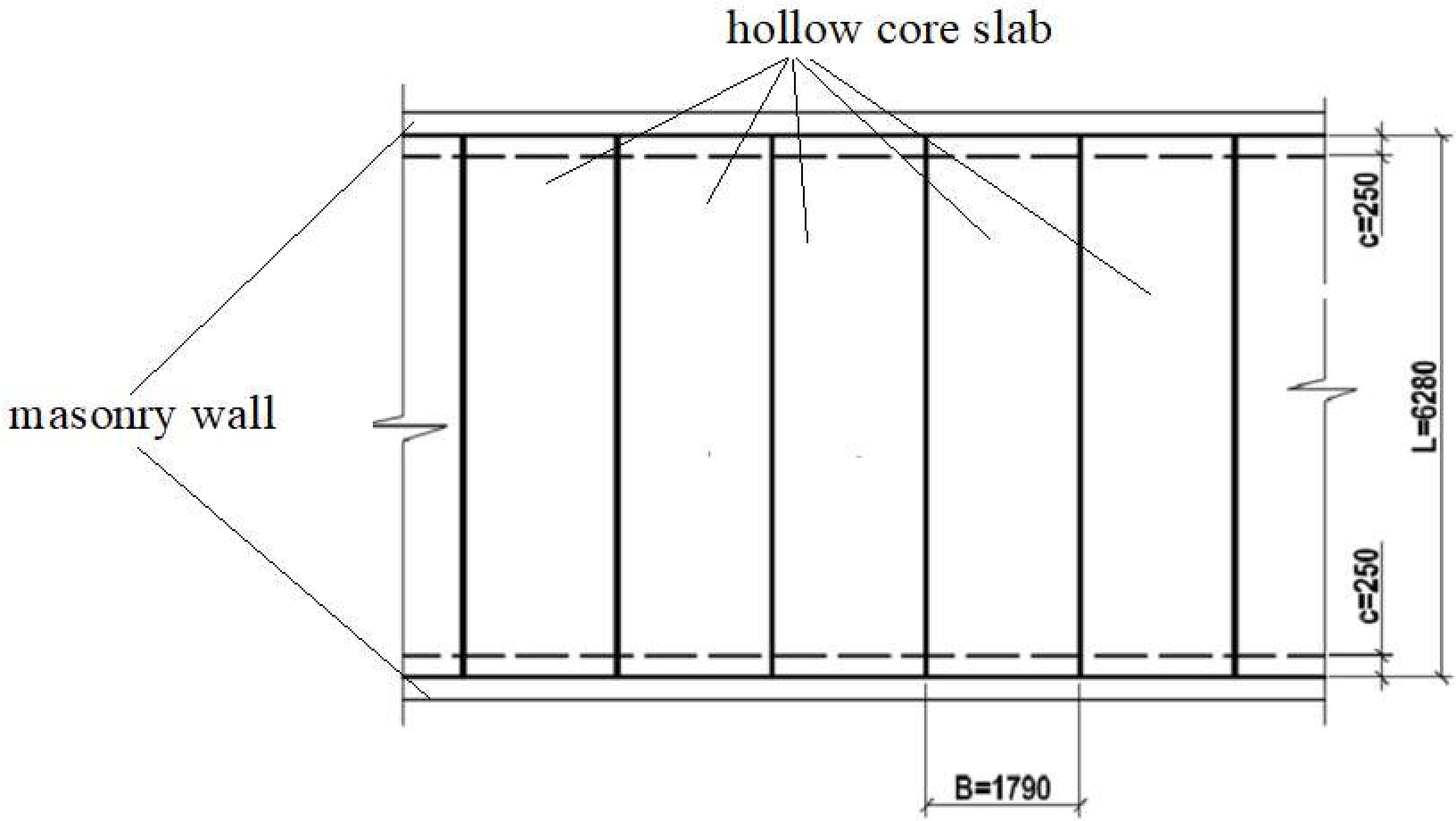
Structural design includes a static (or dynamic) analysis, an individual member section analysis, and detailing.

***Static analysis* includes**:

- making of design models which the most closely correspond to the real structural behavior;
- calculation of external loads which act on structures during operation;
- analysis of efforts (bending moments *M,* shear forces *V* and axial forces *N*) in specific sections of structures which are designed.

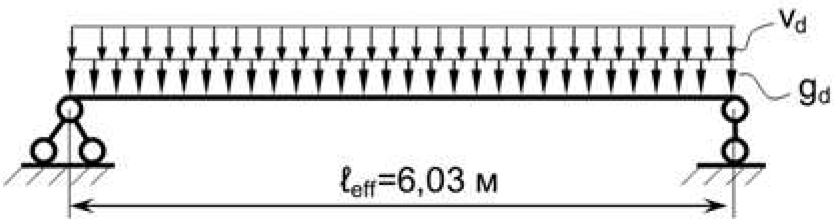
Loads and actions on the structure are determined in accordance with National Building Code B.1.2-2: 2006 «Loads and actions».

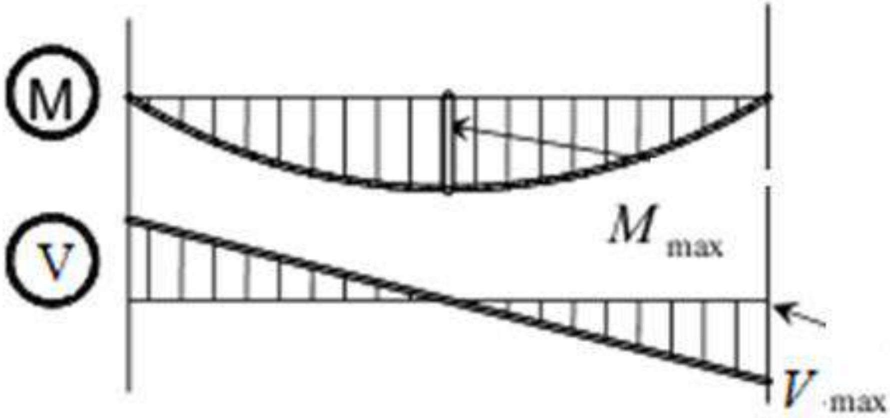
Efforts are determined by the methods of structural mechanics or by the limit equilibrium method on each external load separately, and then they are totted to get the most unfavorable combination.



Structural scheme of floor

Static analysis





Member section analysis of reinforced concrete structures is a determination

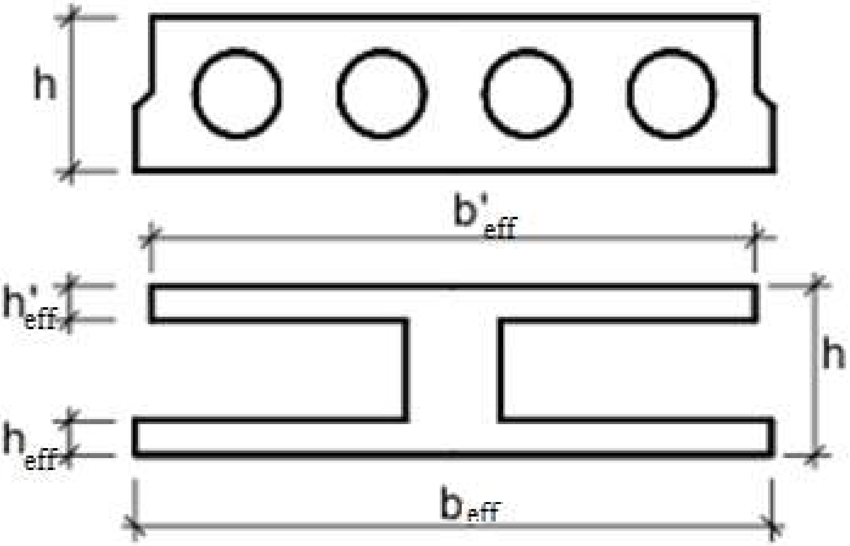
- of the rational shape and size of the normal sections, the optimum concrete class,
- the class and area of principal reinforcement and its configuration in plan with allowance for requisite crack resistance and member stiffness;
- or a verification of strength, crack resistance and deformability of members.

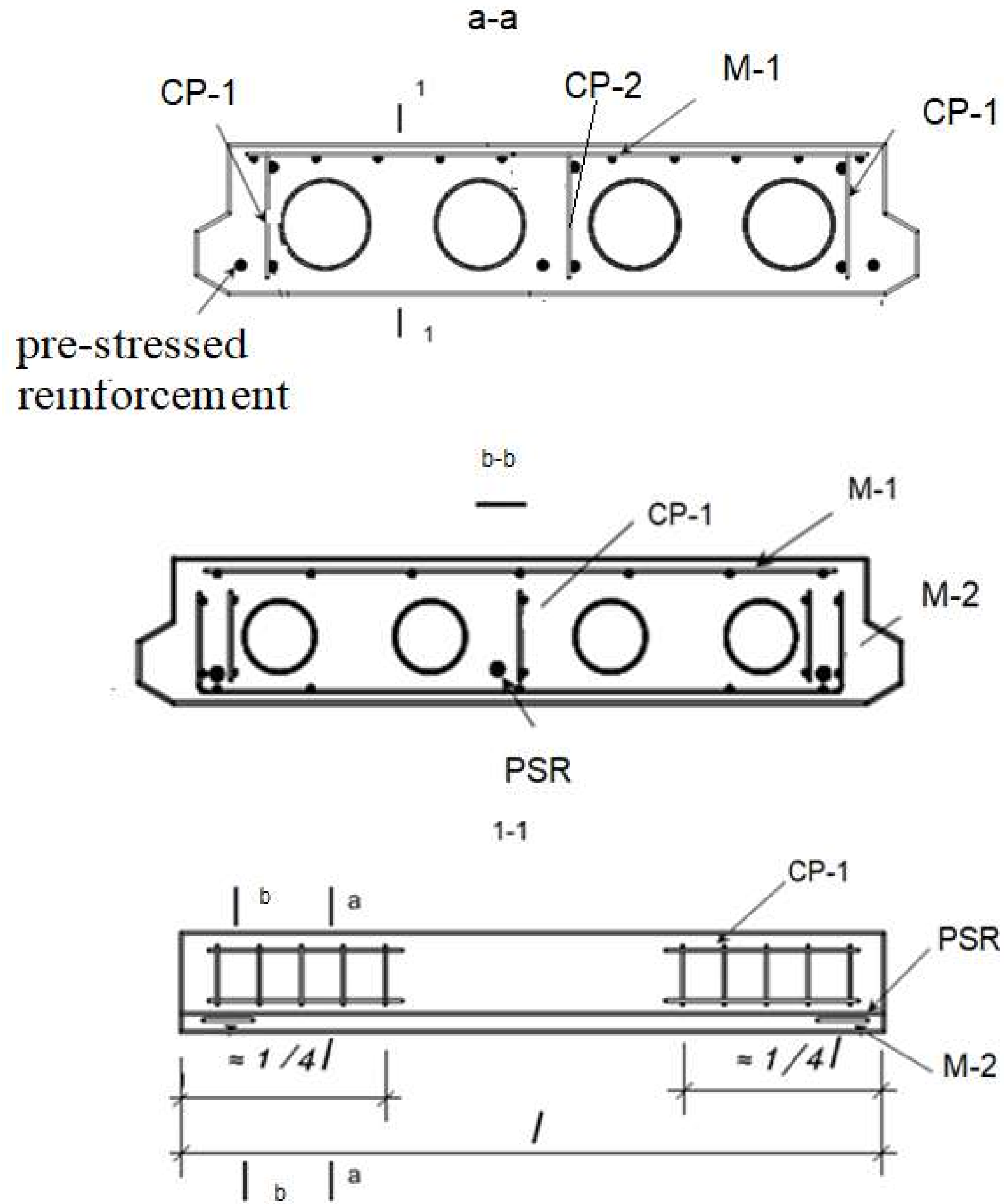
Section analysis is performed by methods of the reinforced concrete theory.

Detailing is

- the selection of structural solutions in general,
- rational scheme of principal and constructive reinforcement arrangement, formwork and reinforcement principal drawings,
- drawings of structural joins.

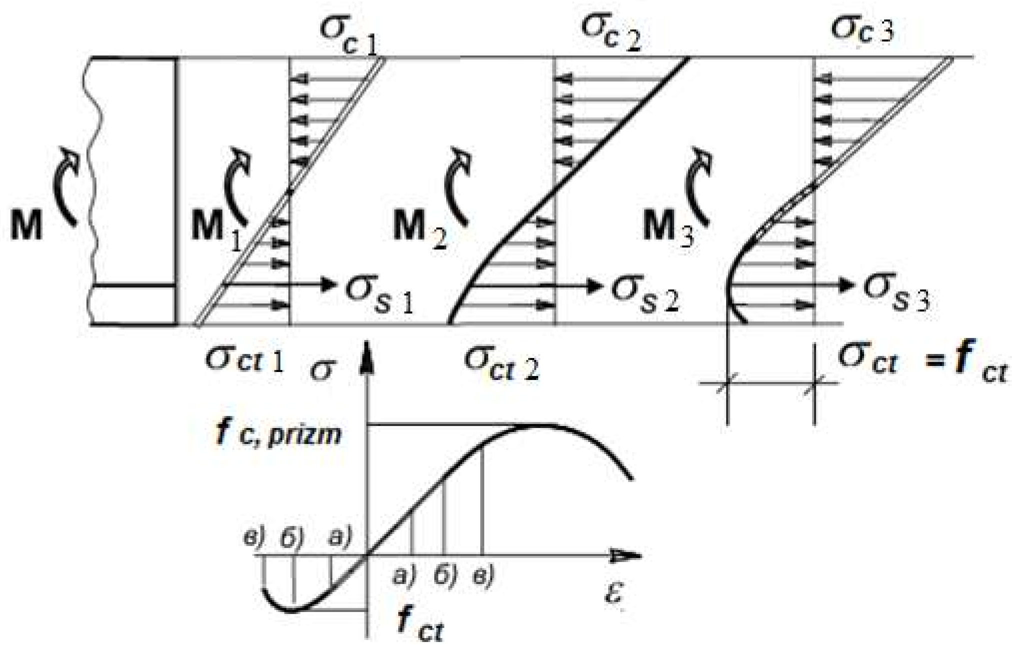
Member section analysis





6.2 The concept of stress-strain state (SSS) stages of reinforced concrete members

Reinforced concrete flexural members **without pre-strengsining**

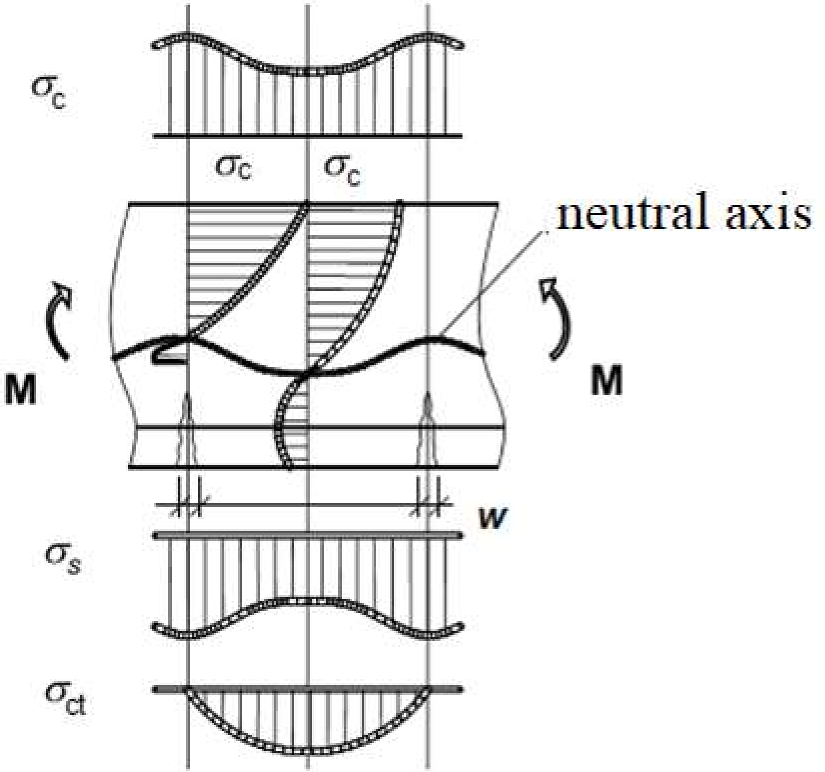


Stage I – the initial period of the members operation **till the cracking in concrete tensile zone**; when the loads are small, concrete strains are mainly of elastic character, and stress diagrams in compressive and tensile zones of elements can be taken as triangular.

With increasing of the load there is an intense development of plastic strains in the concrete tensile zone, the stress diagram here becomes curvilinear and its maximum values achieve the ultimate tensile strength; at the same time the concrete compressive zone is still mainly subjected to elastic strains, the stress diagram here is similar to triangle. Such condition characterizes the end of stage **I** or the end of ***member operation without cracks***. It is called stage ***Ia*** or ***the moment of the formation of the first normal crack***.

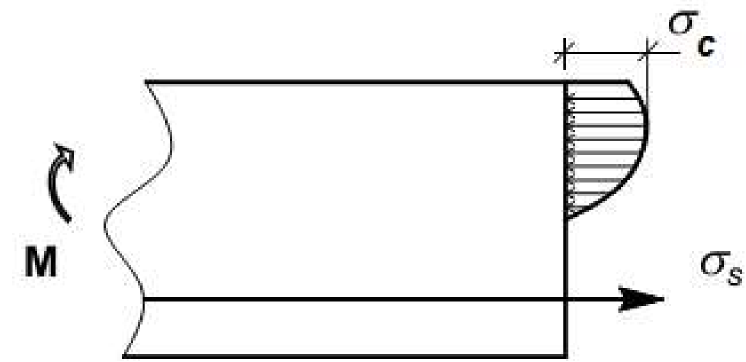
Most of reinforced concrete structures during operation are in ***stage II*** **(*the operation loads stage* or *the stage of reinforced concrete structures working with cracks*).**

Stage II becomes with further increase in the load immediately after the cracking in the concrete tensile zone, tensile forces at the crack areas are perceived by the reinforcement and concrete area above the crack, tensile forces between the cracks are perceived by the reinforcement and concrete jointly.



Strains in the concrete compressive zone have plastic-elastic character with a gradual dominance of plastic strains during increasing of the load (in flexural members the stress diagram is curvilinear). The maximum stress in the concrete compressive zone and in the tensile reinforcement is significant but doesn’t achieve limit values.

Stage III (failure)



It is characterized by a decrease in neutral axis depth and increase in stress and strain in compressed zone. The strains in reinforcement reach values corresponding to the beginning of the yield point, the crack opening width increases rapidly, the neutral axis depth decreases sharply, and the strains in concrete reach their limit values (at this moment, crushing of the compressed concrete occurs). it is **plastic** in character and it is called ***case I***. When the reinforcing of elements in the tensile zone with a high-strength wire with a small elongation at failure, while breaking of the wire there is crushing of the concrete compressive zone, and it is also classified as case I.

In *over reinforced* members (with unreasonably large amount of reinforcement in the tensile zone) the failure occurs at the concrete compressive zone. Stage II changes into stage III immediately. The failure has a **fragile** character. It is called ***case II***.

6.3 The main provisions of limit states design method

6.3.1 Essence of the method

Limit states design method was proposed by A. Gvozdev in 1955. To the present time it is normative.

Limit states design method establishes clear boundaries of structures limit states and introduces a system of design factors that prevents the occurrence of these states in the structures under the most adverse combination of loads and minimum strength of materials.

Designer has to ensure the structures, he designs are:

- *Fit for their purpose*
- *Safe*
- *Economical and durable*

Limit state is a **state of structure** in which it ceases to meet the requirements that are made to it, i.e**. loses its ability to resist to external influence** or **obtains abnormal deformations or local injuries**.

According to the causes that may lead to the loss of the required functional properties, there are **two groups of limit states** :

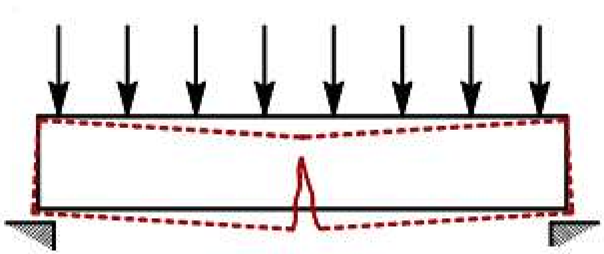
- the first group – ***ultimate limit state*** – for **unsuitability for further operation**;
- the second group – ***serviceability limit state*** – **for unsuitability to normal operation.**

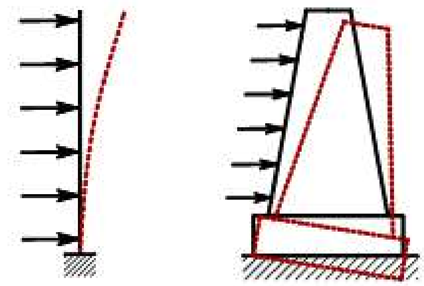
LIMIT STATES DESIGN

- "Limit States" are various conditions in which a structure would be considered to have failed to fulfil the purpose for which it was built.
- "Ultimate Limit States" are those catastrophic states,which require a larger reliability in order to reduce the probability of its occurrence to a very low level.
- "Serviceability Limit State" refers to the limits on acceptable performance of the structure during service.

The ultimate limit state includes the following limit states:

-fragile, binding and other failure (strength calculation);





– loss of shape stability (calculation of stability of thin-walled structures) or position (calculation at overturning and sliding retaining walls, the calculation of pivoting);

– fatigue failure (endurance calculation of structures that are under the influence of repetitive load – crane beams, railway sleepers, frame foundations and floors in some equipment, etc.);

– the failure of the joint influence of load factors and adverse environmental effects (intermittent or constant exposure of aggressive environment, the impact of alternate freezing and thawing, fire).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The serviceability limit state includes:

- abnormal movement (deflections, angles of inclination and rotation, oscillation);

- cracking, as well as short-term or long-term disclosure (if the operating conditions are acceptable).

All structures are calculated according to the first group, and the second one – calculation performed only when the following conditions may occur.

The main factors that determine the design achievement of a limit state are:

- loads that act on the structure;

- **strength characteristics of materials** of which they are made;

- the **conditions** under which structures work.

All these factors have a certain volatility and may differ from the intended standards. In the limit states design method it is taken into account by the introduction of *a system of partial safety factors*.

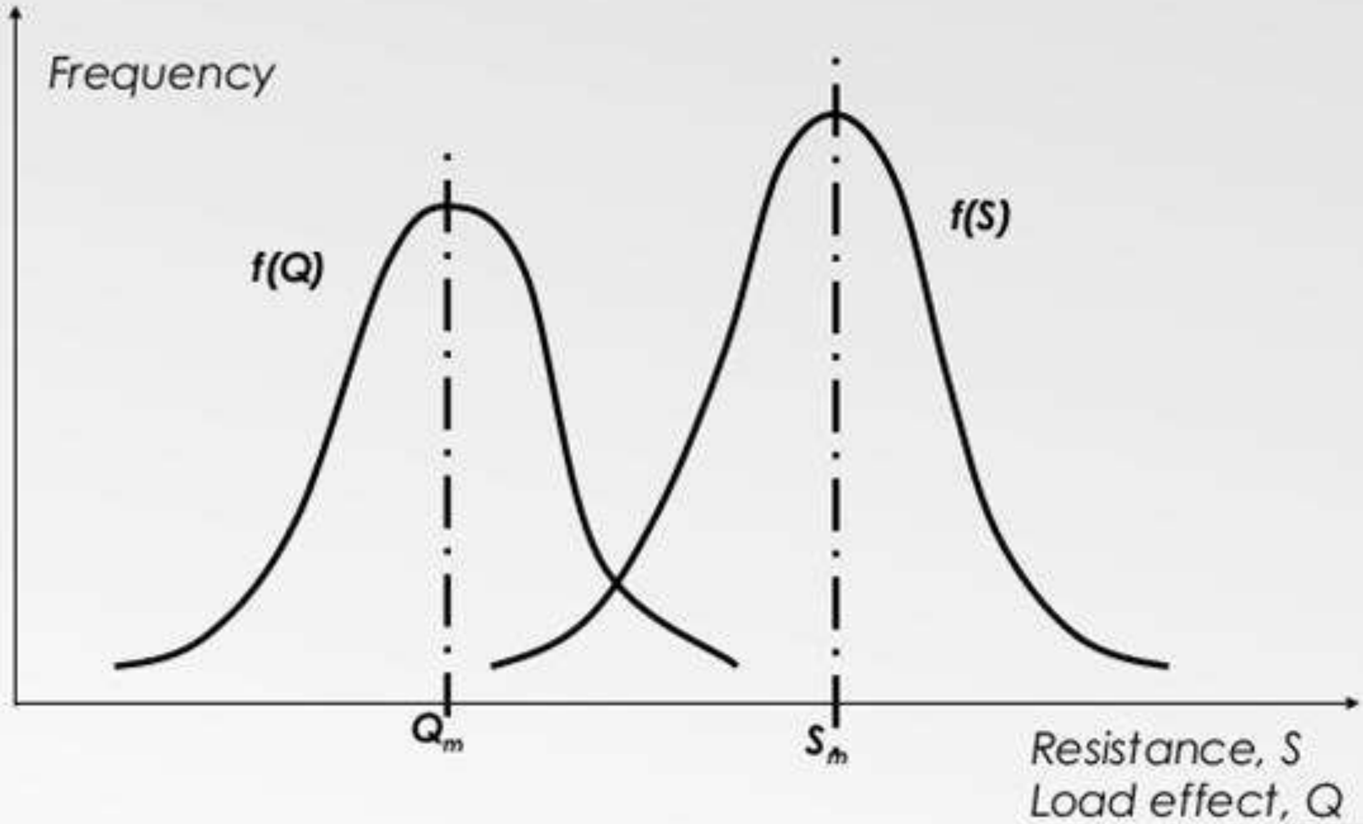
LIMIT STATE DESIGN

Limit State: State at which one of the conditions pertaining to the structure has reached a limiting value

Limit States

<u>*Limit States of Strength*</u>	<u>*Limit States of Serviceability*</u>
Strength as governed by material	*Deflection*
Buckling strength	*Vibration*
Stability against overturning, sway	*Fatigue cracks (reparable damage)*
Fatigue Fracture	*Corrosion*
Brittle Fracture	*Fire resistance*

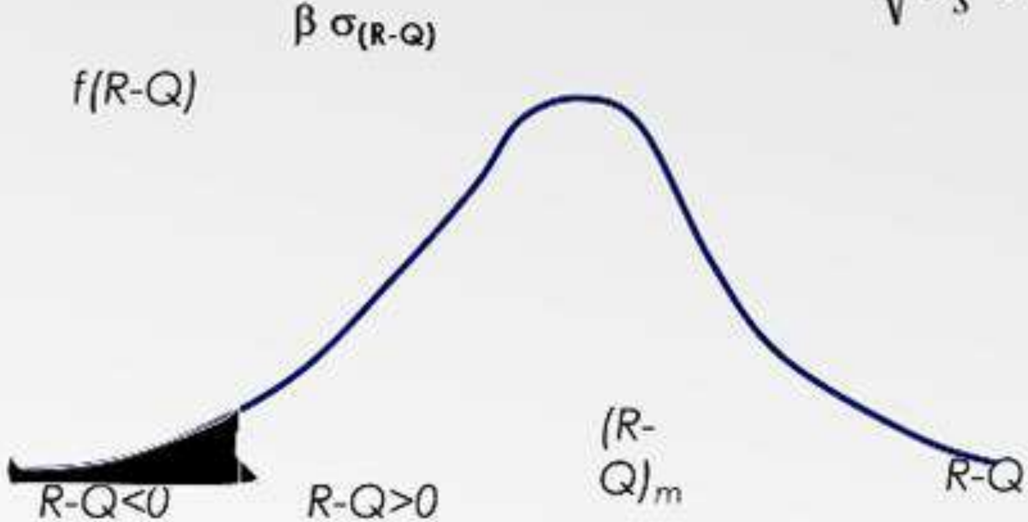
RANDOM VARIATIONS



Probability density functions for strength and load effect

- Basis of Limit States Design

$$\beta = \frac{S_m - Q_m}{\sqrt{\sigma_s^2 + \sigma_Q^2}}$$



Probability distribution of the safety margin

R-Q

PROBABILITY OF FAILURE

$$P_f = \Phi\left[-\frac{(R-Q)_m}{\sigma_{R-Q}}\right]$$

$$= \Phi\left[-\frac{R_m - Q_m}{\sqrt{\sigma_R^2 + \sigma_Q^2}}\right]$$

SAFETY INDEX

$$\beta = \frac{S_m - Q_m}{\sqrt{\sigma_S^2 + \sigma_Q^2}}$$

$$P_f = \Phi\ [-\ \beta]$$

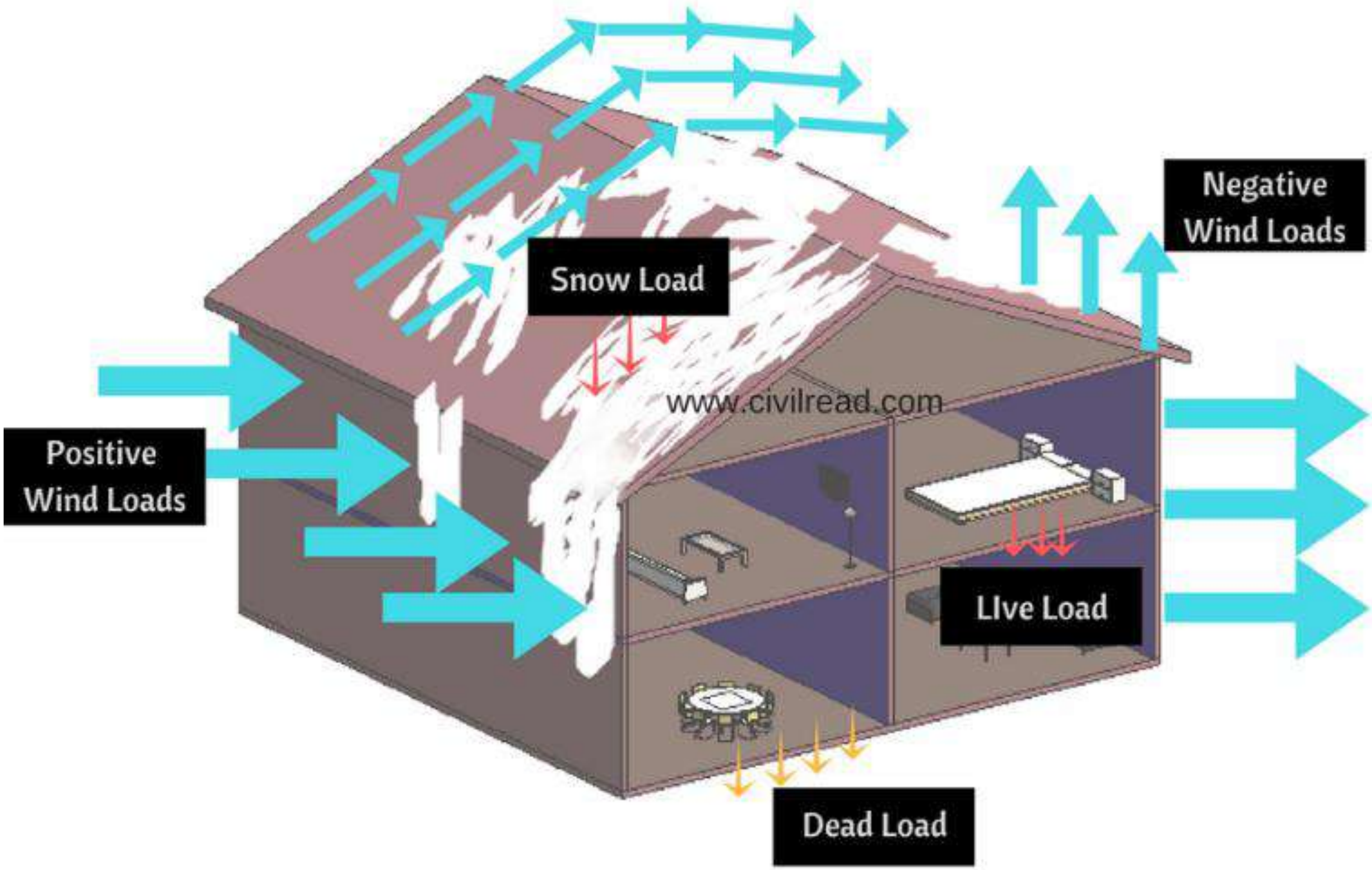
β	2.32	3.09	3.72	4.27	4.75	5.2	5.61
$P_f = \phi\ (-\beta)$	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}

6.3.2 Characteristic and design values of loads. The combination of loads

The loads are divided into **dead** and **variable** depending on the variability in time (**long, short and episodic**).

Dead loads include

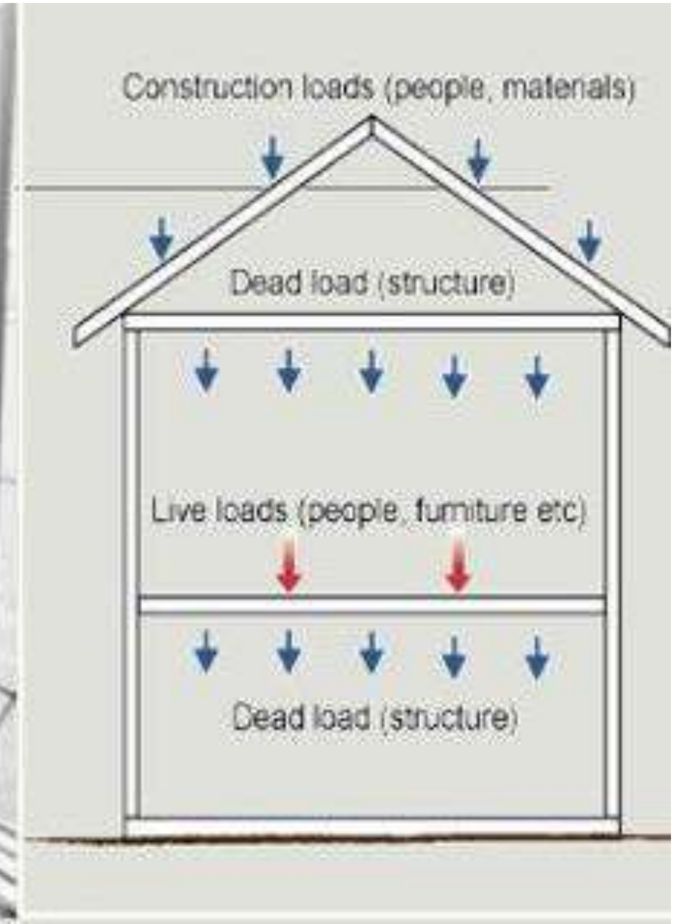
- the weight of bearing and enclosing structures of buildings and structures,
- weight and pressure of the soil,
- the pre-stressing of structures.



Types of loads on a structure

DEAD LOAD
- Dead loads are the forces incurred due to the weight of all the materials used in the construction of a building.
- The dead load, which includes its own weight, the weight of any permanent non-structural partitions, built-in cupboards, floor surfacing materials and other finishes.
- Dead loads have an effect on all structural members of a building. The loads are a constant over the life of the structure

LIVE LOAD
- Live loads are produced by the users of a building. These loads include the weight of people, their furniture, and their storage items.
- A live load is most applicable to floors, but it can apply to roofs during repair projects
- Live loads exert force on almost all of a building's framing components.
- The goal is to design floor systems that limit deflection and vibration.



Long-term variable loads include the weight of temporary partitions, grouting and base concrete for equipment; stationary equipment; pressure of gases, liquids, bulk; weight of specific load in warehouses, refrigerators, archives, libraries; quasi-dead design values of the load from people, animals, equipment on buildings floors, the vertical load from the bridge and underhung cranes, snow load; temperature climatic impacts.

Short-term variable loads include the weight of people, parts and materials in the areas of maintenance and repair of equipment; loads resulting from the manufacture, transportation and installation; snow and wind, crane and ice load with limit design or service values.

Episodic loads include seismic and explosive impact or loads caused by sharp disturbances of the technical process, base deformation.

medical equipment

production equipment

storage wall

An example of a water-filled floor covering a 55-story Marina Bay Sands hotel in Singapore

The basis for the assignment of loads is their *characteristic values*.

The design values of loads are determined by multiplying the **characteristic values** by the **load safety factor** γ_f.

Depending on the character of load and purpose of calculating the load **there are four types of design loads**:

- the limit;
- service;
- cyclical;
- quasi-dead.

To verification of the **first group limit states the limit design values of loads** should be used, the second group – depending on the operating conditions of the design.

Characteristic Actions Q_c

- Are those values of different actions that are not expected to be exceeded with more than 5 % probability during the life of the structure

Characteristic values of weight of precast structures should be defined by the standards, working drawings or passport data of suppliers, and other building structures and soils – the project sizes and density of materials. Characteristic values of equipment weight are determined by standards or directories, passport data or working drawings; characteristic value of snow load equals to the ground snow load and may be exceeded on average once every 50 years (depending on snow determining region); for wind pressure – equals to the average (static) pressure component of the wind at a height of 10 m above the ground, which can be exceeded on average once every 50 years (determined in accordance with the wind area).

Design Action Q_d

- $Q_d = \sum_{k} \gamma_{fk} Q_{ck}$

Depending on the composition of the load taken into account, there are:

- ***basic combinations*** that include dead, cyclic or quasi-dead values of variable loads;

- e***mergency combinations*** that consist of dead, variable and one episodic influences.

Low probability of simultaneous implementation of design values of multiple loads is taken into account by multiplying their design values by a ***combination factor*** $\psi \leq 1$.

6.3.3 Characteristic and design values of strength of materials

Different calculations require different strength security. As a result, there are two concepts that are used for concrete and reinforcement: the characteristic and design values of strength of materials.

There are the following ***characteristic values***:

– **concrete resistance to axial compression** $f_{ck,prizm}$;

– concrete resistance to axial tension $f_{ctk0,05}$ (if it is necessary, for emergency calculated situations concrete resistance values to axial tension $f_{ctk0,95}$ can be used).

These values are taken depending on the class of concrete to compression **C** in standards.

Design value of concrete compressive *strength* $f_{cd} = \alpha_{cc} f_{ck} / \gamma_c$

where γ_c **=** 1.3 – **the partial safety factor for concrete in compression** is assigned based on the coefficient of variation of concrete compressive strength of 13.5%;

α_{cc} – the coefficient taking account of long-term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied (the recommended value 1).

The value of the design tensile strength is defined as

$$f_{ctd} = \alpha_{ct} f_{ctk,0,05} / \gamma_{ct}$$

where γ_{ct} **= 1.5 – the partial safety factor of concrete in tension**, is assigned based on the variation coefficient of tensile strength of concrete at 15%;

α_{ct} – a coefficient taking account of long-term effects on the tensile strength and of unfavorable effects, resulting from the way the load is applied (the recommended value is 1).

Design Strength S_d

- $S_d = S_u / \gamma_m$

Design values of concrete compressive and tensile strength are taken depending on the class of concrete in compression C in standards.

Design values of concrete strength decreases and sometimes increases by ***appropriate coefficients of concrete work conditions*** γ_{ci}, that take into account the peculiarities of its work in structure:

γ_{c1} – duration of static load (γ_{c1}= 1 – with short-term action load γ_{c1} = 0.9 – with its long-term action);

γ_{c2} – failure character of concrete structures (γ_{c2} = 0.9);

γ_{c3} – introduced for concrete and reinforced concrete structures that are concreted in a vertical position, at an altitude of more than 1.5 m γ_{c3} = 0.85).

The main characteristic of reinforcement strength is its characteristically value close to physical $f_{0,2k}$ ***or proof at 0.2 percent set*** f_{yk} ***yield strength,*** which is usually given in the relevant regulations for the reinforcement.

Design yield strength of reinforcement is given by $f_{yd} = f_{yk} / \gamma_s$ ***,*** where γ_s – ***the partial safety factor for reinforcement*** (depends on the type and class of reinforcement: A240C – 1.05; A400C – 1.10; A600 – A1000 – 1 2, B500 – 1.2; Br1200 – 1500 – 1.25; K1400 – 1500 – 1.2). ***Design values of compressive strength of reinforcement*** are equal to the ***design yield strength of reinforcement*** f_{yd} ***,*** but no more than those comply with the limits of concrete compressive strain, where the reinforcement is placed, in short-term or prolonged exposure of load.

Under certain conditions, **the *design yield strength of reinforcement*** in the calculations by the ultimate limit states is multiplied by ***a factor of reinforcement conditions*** γ_{si}**,** which allows

- character of loading,
- reinforcement purpose,
- welding seams presence etc.

Ultimate values of compression resistance of reinforcement with class B500 are adopted with a factor of safety – 0.9.

Design yield strength of shear reinforcement f_{ywd} is decreased compared to f_{yd} by multiplying by a factor of working conditions 0.8 and is taken not more than 300 MPa.

6.3.4 Safety factor for responsibility

Depending on the material damage and (or) social losses associated with the cessation of operation or the loss of integrity of the object the following ***classes of responsibility of buildings and structures*** **are determined**:

- *CC3* (significant consequences),
- *CC2* (secondary outcomes),
- *CC1* (minor consequences).

A tentative list of objects by classes of effects (liability) is given in standards. Depending on the effects that can be caused by the rejection, there are ***three categories of accountability of structures and their elements***:

– A – structures and elements which rejection can result in complete unsuitability to the operation of the building (construction) the whole or a substantial part there of;

– B – structures and elements which rejection may lead to complication of the normal operation of the building (construction) or failure of other structures that do not belong to the category A;

– C – structures which failure do not lead to the disruption of operation of other structures or elements.

Safety factor for responsibility γ_n is determined depending on

- the class of object effects (liability),

- category of construction liability and

- type of *design situations* as conditions complex that is taken into account in the calculations and determines the design requirements for the structure.

Design situation is characterized by

- the design model of structures,

- types of loads,

- the values of the coefficients of working conditions and safety factor, the list of limit conditions that should be considered in this situation. Design values of bearing capacity, the design values of resistance, design values of deformations, or crack opening width are divided by this coefficient or the design values of loads and efforts are multiplied by it.

treatment facilities

potable water storage tank

headwork

pipeline system

6.3.5 The essence of calculation for various limit states

Condition that ensure the bearing capacity of structures, i.e. impossibility of realization of ultimate limit states in general, is written as

$$\Phi_{\max}\left(g_k; v_k; \gamma_f; \gamma_n; c\right) \leq \Phi\left(f_{ck}; \gamma_c; \gamma_{ci}, f_{ctk}; \gamma_{ct}; f_{yk}; \gamma_s; \gamma_{si}; s\right)$$

where Φ_{max} – design efforts;

Φ – design bearing capacity;

c – design scheme of structure (members);

s – shape and sizes of the section.

The same equation can be written in reduced form as

$$\Phi_{\max}\left(g; v; \gamma_n; c\right) \leq \Phi\left(f_{cd}; f_{ct}; \gamma_{ci}; f_{yd}; \gamma_{si}; s\right)$$

LIMIT STATES DESIGN

$$\Sigma(\text{Load} * \text{Load Factor}) \leq \frac{(\text{Resistance})}{(\text{Resistance Factor})}$$

∀ γ_m takes account;

- Possible deviation of the material in the structure from that assumed in design
- Possible reduction in the strength of the material from its characteristic value
- Manufacturing tolerances.
- Mode of failure (ductile or brittle)

Conditions for calculating of crack resistance in general terms can be written depending on whether cracking in the structure is permitted:

– in the case when the cracks are not allowed, the condition should be fulfilled in the calculations of their formation (for flexural member)

$$M \le M_{crc}$$

where M – moment of maximum external load; M_{crc} – cracking moment (the moment at which cracks in structures may cause);

- in the case when the width limited cracks are admitted, i.e. for the calculations for crack opening

$$w_k \le w_{k,u},$$

where w_k – the largest crack opening width calculated theoretically; $w_{k,u}$– ultimate value of width of the crack opening imposed standards.

Condition for calculation by deformations is in form $f \le f_u$,

where f – deformation which calculated theoretically; f_u – ultimate value of deformation imposed standards.

The main advantage of the method of calculation by the limit states is that the introduction of design coefficients system allows a more differentiated assess of the impact of all determinants on structures operation, and thus more accurately reflect its actual stress state.