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VOLUME - SPATIAL DECISIONS OF BUILDINGS AND STRUCTURES

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The textbook outlines the principles of designing volume-spatial decisions for buildings and structures in Ukraine and creating and maintaining an artificial environment for humans that will provide the most favorable conditions for their existence, residence and production activities. Intended for students who study in the specialty G19 «Building and Civil Engineering» and are engaged in the study and implementation of modern technologies, structures in the construction industry.

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CONTENT

PREFACE

This educational manual outlines the purpose of volume-spatial decisions for buildings and structures [3, 5, 21], aimed at introducing modern scientific concepts [50], ideas, methods, and technologies for computer-aided design of buildings and their complexes [13, 20, 47, 48], in accordance with functional requirements, physical laws, and the principles of architectural aesthetics [32, 35].

The goal is to consolidate and systematize scientific and technical information in the field of design, to impart and develop skills and knowledge in designing buildings and complexes in compliance with functional requirements [7, 11, 14–18, 24] and Ukrainian legal regulations [1, 2], ensuring reliable and safe usage of buildings and structures [9, 42, 45, 46]. The manual is intended to create and maintain environments for humans that provide the most favorable conditions for their existence [6, 11, 19, 29, 32].

This guide is oriented toward the application of the latest design methods in accordance with existing norms and regulations in Ukraine [6–18, 22–26] and the organizational practices of the construction industry [34].

The primary objective is to study and develop housing decisions that ensure healthy and safe living and working environments. It addresses volume-spatial decisions for multi-apartment residential buildings, volume-spatial and engineering decisions for frame-monolithic high-rise residential buildings [55], as well as volume-spatial and structural decisions for industrial enterprises [33]. The manual emphasizes the rational use of zoning within production buildings [24], considering their possible integration within the building volume and the logical grouping of areas and zones according to various criteria (level of industrial hazards, fire and explosion risks [12, 36–38, 49], and the optimization of transport and human flows).

Preface and chapters 1, 2 are written by Bakulina V.M., chapters 3 and 4 are written by Kostyra N.O., chapters 5-10, 12-13 are written by Bakulin Y.A. and Bakulina V. M., chapter 11 are written by Bakulin Y.A. and Kostyra N.O.

CHAPTER 1. DEVELOPMENT OF THE ARCHITECTURAL AND CONSTRUCTION SECTOR IN UKRAINE

At the beginning of the 21st century, Ukraine's economy underwent processes that led to a significant reduction in social programs, including decreased state housing support.

In 1987, organizations in Ukraine commissioned 12.63 million m^2 of housing, compared to just 1.29 million m^2 in 1997. According to the State Statistics Committee of Ukraine, in 2003, the housing stock amounted to 1.35 billion m^2, with an average of 21.6 m^2 of housing per person. In European countries and the United States, this figure ranges from 50 to 100 m^2.

By Cabinet Resolution No. 1347 of August 27, 2000, a housing development plan was approved, which proposed funding for housing through the following sources:

- State budget – 2%;
- Local budgets – 9%;
- Mortgage lending – 20%;
- Individuals – 45%;
- Enterprises and organizations – 21%;
- Other sources – 3%.

Several programs aim to provide housing, including state housing programs such as "Affordable Housing," "Youth Housing Construction," and "My Own Home."

The State Specialized Financial Institution "State Fund for Youth Housing Assistance," funded by the state budget, provides preferential long-term state loans to young families and single young citizens. A total of UAH 37.8 million was allocated for housing construction and acquisition at an annual interest rate of 3%.

Budget programs are also implemented, such as:

- "Providing preferential long-term state loans to young families and single young citizens for housing construction and acquisition" (program classification code for state budget expenditures and lending PCCSB 2751390);
- "Providing loans for housing construction (acquisition) for scientific and pedagogical staff" (PCCSB 2201460).

As of April 1, 2012, 75 preferential long-term state loans totaling UAH 23.994 million were issued. As of 2012, the total number of families waiting for housing assistance through the fund was 19,809.

Within the framework of the President of Ukraine's social initiatives, the Ministry of Regional Policy oversees two budget programs aimed at providing affordable housing:

- "Providing state support for the construction (acquisition) of affordable housing" (PCCSB 2751190), implemented under Cabinet Resolutions No. 140 of February 11, 2009, and No. 193 of February 29, 2012;
- "Reducing the cost of mortgage loans for affordable housing for citizens in need of better housing conditions" (PCCSB 2751470), implemented under Cabinet Resolution No. 343 of April 25, 2012.

Changes to legislation initiated by the Ministry of Regional Policy have introduced tax benefits within affordable housing programs [2]. For instance, Article 165.1.34 of the Tax Code of Ukraine (hereinafter referred to as the Code) addresses the exclusion of state support amounts for affordable housing construction (acquisition) from taxable income.

Housing programs include:

- A comprehensive program to provide housing for military personnel and their families – 1.2 million m²;
- Housing program for discharged military personnel – 0.5 million m²;
- Youth housing program under Law No. 1659-IV of March 23, 2004 (for those under 35) – 1.2 million m²;
- "My Own Home" program (rural housing) – 1.2 million m²;
- Chernobyl housing construction program – 0.2 million m²;
- Construction of social housing – 0.8 million m²;
- Creation of a temporary housing fund – 0.1 million m²;
- Other regional programs – 0.5 million m².

1.1. Legal Regulation of Construction Activities in Ukraine

In 2019, changes were made to construction legislation [2]:

1. **"On Architectural Activities" (May 20, 1999, No. 687-XIV):**

The amendments specify that technical supervision duties can be assigned by the customer to a specialized organization, a technical supervision specialist, or a consulting engineer, as outlined in the contract. Standard forms of contracts for technical supervision and engineering consulting services in construction will be approved by the central executive authority responsible for state architectural policy. The changes took effect on December 1, 2019.

2. **"On Construction Norms" (May 11, 2009, No. 1704-VI):**

Key changes include the introduction of parametric, prescriptive, and target-based methods of regulation in construction. Texts of national and sectoral building norms must be published on official websites of relevant regulatory bodies, and access to them will be free. These changes took effect on October 19, 2019.

3. **"On Urban Development Regulation" (February 17, 2011, No. 3038-VI):**

Amendments stipulate that detailed plans of territories within populated areas will be reviewed and approved by local councils within 30 days. For state-owned lands allocated for public-private partnerships, approval is to be conducted by the relevant state administration within the same timeframe. The changes took effect on December 1, 2019.

The legislative assembly also adopted:

1. **The Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine to Stimulate Investment Activity in Ukraine"** (Bill No. 1059, September 20, 2019). Signed by the President on October 11, 2019, it came into force on October 17, 2019. This law regulates trust ownership rights and reduces or cancels certain participation fees.
2. **The Law of Ukraine "On Improving Administrative Services in Construction and Introducing a Unified Electronic System"** (Bill No. 1081, October 17, 2019). Signed by the President on November 14, 2019, and effective December 1, 2019, this law introduced electronic tools and a construction activity register.

Discussion and Self-Assessment Questions for Section 1:

1. List state housing programs in Ukraine and provide examples of their implementation.
2. What housing development plan was outlined by the Cabinet of Ministers of Ukraine? Provide examples of housing certificates for combat veterans and their families.
3. Enumerate changes in construction legislation over the past three years.
4. List the laws passed by the Verkhovna Rada in recent years.

Practical Work 1

Topic: Who and how can obtain housing loans in Ukraine? **Objective:** Learn how housing loans are regulated in Ukraine, whom to contact, and how state funding supports construction. **Tasks:** To consolidate the material covered in the practical work, consider:

1. The introduction of parametric, prescriptive, and target-based regulation methods in construction;
2. Detailed plans for territories within populated areas and their approval by local councils;
3. Changes regulating:

Construction conditions near aerodrome areas;
The implementation of electronic tools in construction;
The process and impact of these changes.

4. Requirements for technical supervision in construction.

CHAPTER 2. CLASSIFICATION OF BUILDINGS

2.1. Classification of Residential Buildings

In Ukraine, construction objects, referred to as structures, are classified in accordance with the provisions of the State Classifier NK-018-2023.

The classification objects in the "State Classifier of Buildings and Structures" include industrial and non-industrial buildings, residential houses, and engineering structures.

The "State Classifier of Buildings and Structures" (SC) is structured using a hierarchical classification method with a sequential coding system. Each position contains a five-digit numerical code and the name of the respective classification group. The structure of the SC numerical code corresponds to the following scheme: X – section; XX – subsection; XXX – group; XXXX – class. The numerical codes align with the classification of structure types established by the Statistical Commission of the European Union.

Residential buildings are categorized by functional purpose into single-family houses (individual houses), multi-family houses, and communal residences (dormitories, boarding houses, shelters) [21].

Depending on the number of floors, residential buildings are divided into:

- Low-rise (1–3 floors);
- Medium-rise (up to 5 floors);
- Multi-story (6–9 floors);
- High-rise (10–25 floors);
- Skyscrapers (25 floors and above) [62, 63].

By the building materials used, residential buildings are classified into:

- Reinforced concrete, concrete, stone, wooden, and metal structures.

By volume-spatial design, residential buildings are categorized as:

- Single-family, terraced (block), sectional, corridor-based, and gallery-type.

By structural design, they are categorized as:

- Load-bearing wall, volume-block, and with incomplete skeleton.

By apartment amenities, residential buildings are classified as:

- Fully equipped (elevators, water supply and sewage systems, garbage chutes, gas supply, heating);
- Partially equipped (water supply and sewage systems, stove heating, gas supply, pit latrines).

2.2. Classification of Public Buildings

Public buildings and structures can be categorized based on their functional purpose and usage characteristics into **specialized** and **universal** types (Table 2.1).

Specialized public buildings are designed for a specific purpose, which typically remains unchanged throughout their service life (e.g., kindergartens, schools, hospitals, theaters, etc.).

Specialized public buildings are further divided into:

- **Groups**, which encompass a broad range of public buildings sharing a general purpose;
- **Types**, which define the primary functional purpose;
- **Subtypes**, which indicate specific functional features.

Table 2.1. Classification of Public Buildings

Type	Subtype
1	2
Group I – Healthcare, Physical Fitness, and Social Welfare Facilities	
Healthcare and Preventive Institutions	Hospitals, dispensaries, outpatient clinics, maternity hospitals, sanatoriums, and others
Sanitary and Preventive Institutions	Sanitary and epidemiological stations, disinfection stations, and laboratories
Recreational Facilities	Boarding houses, recreational centers, summer camps for children, and tourist stations
Physical Fitness and Sports Organizations	Sports buildings (stadiums, swimming pools, and facilities of other purposes)

Continuation of Table. 2.1

Group II – Educational Institutions	
General Educational Schools and Childcare Institutions	Schools, kindergartens, orphanages
Educational Institutions for Professional Training	Universities, institutes, colleges, vocational and technical schools
Group III – Cultural Institutions	
Libraries	Libraries, reading rooms
Museums and Exhibitions	Museums of various purposes and permanent exhibitions
Club Facilities	Cultural centers, clubs, houses of folk art
Group IV – Art Institutions and Enterprises	
Entertainment Enterprises and Institutions	Theaters, circuses, cinemas, concert halls, studios, art workshops
Group V – Science Organizations and Institutions	
Institutions Engaged in Scientific Activities	Research institutes (R&D centers), computing centers, scientific laboratories
Design and Engineering Organizations	Design institutes, design bureaus, and others
State Archives	State archives engaged in research activities
Group VI – Administrative Organizations and Institutions	
State Institutions	Administrative buildings for various purposes (city council, district council)
Legal and Judicial Institutions	Courts, notary offices, legal consultations
Group VII – Consumer Service Enterprises	
Household Service Enterprises	Bathhouses, hair salons, repair workshops
Dry Cleaning Services	Mechanized dry cleaners and reception points

Service Providers	Utility offices, rental enterprises
Group VIII – Trade and Public Catering Enterprises	
Trade Enterprises	Department stores, markets
Pharmaceutical Institutions	Pharmacies and pharmacy shops
Public Catering Enterprises	Restaurants, cafes, and others

To provide cultural and domestic services to the population in small towns and villages, it is necessary to construct small multi-purpose facilities. Distributing them across multiple buildings is uneconomical and increases the length of roads and utility networks [29].

It is economically viable to place these facilities in a single relatively large building (integration of public facilities) and to arrange their cooperation, where shared spaces within the building are used by different facilities at various times of the day. The integration and cooperation of small public facilities in one building ensure more efficient operation and reduce operational costs. Universal public buildings can be of two types.

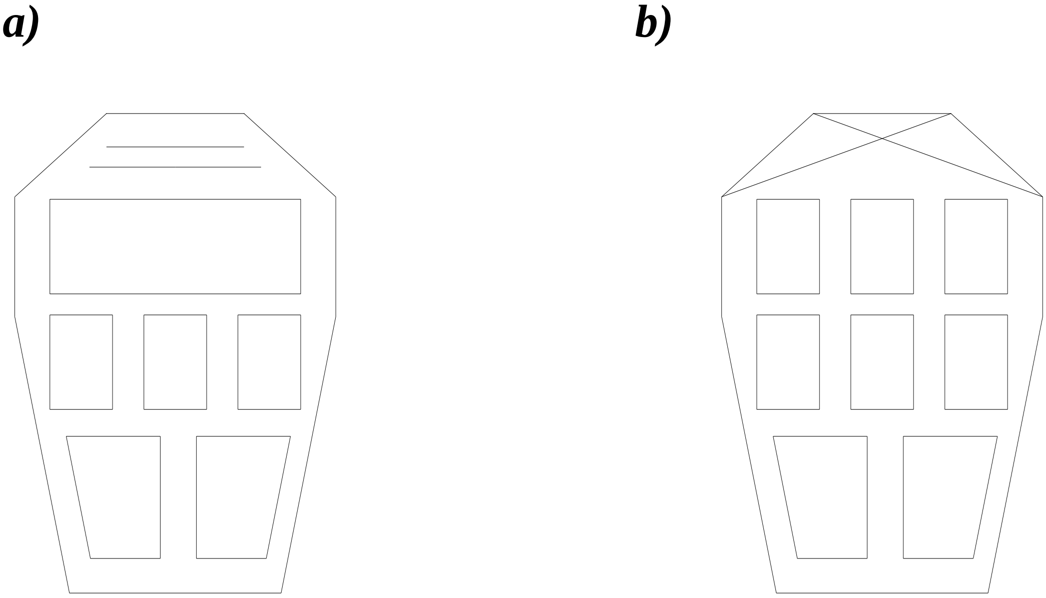


Fig. 2.1. Buildings of the first type: a – Tennis Hall; b – Cinema Hall

The first type includes multi-purpose buildings where spaces can be transformed for different uses within a few hours (fig. 2.1). The second type includes buildings where room sizes, layouts, and equipment placement can be periodically changed in accordance with functionality.

Both types of public buildings ensure cost-effective operation and correspond to modern forms of public activity. The first type of public buildings includes cinema and concert complexes and clubs.

The second type of public buildings includes administrative offices, design organizations, and large commercial enterprises. The functional processes in these buildings evolve and change, leading to equipment replacement and spatial reorganization. Such changes occur periodically over several months or years. Periodic transformations in universal public buildings are achieved through specific volumetric-spatial and structural solutions based on large spans and modular bearing structures.

Discussion and Self-Assessment Questions for Chapter 2

1. Describe and characterize the classification of residential buildings. What are the distinguishing features?
2. Describe and characterize the classification of public buildings. What are the distinguishing features?
3. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the first group of public buildings.
4. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the second group of public buildings.
5. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the third group of public buildings.
6. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the fourth group of public buildings.

7. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the fifth group of public buildings.

8. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the sixth group of public buildings.

9. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the seventh group of public buildings.

10. Define and characterize the concepts of "group," "type," and "subtype." Name facilities classified under the eighth group of public buildings.

11. Describe and characterize the main aspects of universal public buildings.

12. What are the differences between residential and public buildings? Justify your answer.

13. Provide a description of the State Classifier NK-018-2023. What sections are included in its structure?

Practical Work 2

Topic: Develop a volume-planning solution for an apartment in a multi-story residential building.

Objective: Learn to determine the class of the housing being designed and take into account all conditions in accordance with the requirements.

Tasks: To consolidate the material covered in the practical work, it is necessary to:

- Determine the class of the building being designed according to DBN B.2.2-15:2019. Buildings and Structures. Residential Buildings. General Provisions.
- Follow the design rules for people with limited physical abilities.
- Comply with state sanitary standards and rules for maintaining urban areas.
- Apply this knowledge to the design requirements for specific building elements.

CHAPTER 3. VOLUME-PLANNING AND STRUCTURAL DECISIONS OF BUILDINGS

3.1. Structural Schemes and Decisions of Public Buildings

The spatial solution of buildings depends on the adopted structural scheme. In the construction of public buildings of low-rise (up to 3 floors) and medium-rise (up to 9 floors) categories, panels, blocks, and bricks are used. Structural schemes are similar to those of residential buildings. In non-residential public buildings, frame structures are implemented using frame-braced systems (Fig. 3.1).

High-rise frame buildings are used for widths not exceeding 12–15 m. For wider designs, construction becomes uneconomical because ensuring the stability of the building against wind loads requires up to 50% of the total material expenditure.

Frame systems consist of columns rigidly connected to beams and slabs, forming a spatial structural system. Rigid connections with columns require 25–30% more metal than other schemes. The vertical elements of frame systems vary in thickness depending on the building height. Monolithic reinforced concrete frames provide greater spatial rigidity than prefabricated ones but are more labor-intensive. Steel frame structures demand substantial steel use and require special fire-resistant measures (e.g., concrete casing, ceramic cladding, or intumescent phosphate coatings), increasing the cost and limiting their application.

In skeleton type buildings, it is the skeleton that takes up the building loads, the wall panels serving merely as space-enclosing structures. Here, the skeleton consists of prefabricated reinforced concrete columns and girders. Load-bearing skeletons may be arranged longitudinally, transversely, or in both directions.

Horizontal load resistance in frame-braced systems is achieved through the interaction of braces in the form of vertical walls (diaphragms) and frames. Diaphragm walls are used throughout the building height, rigidly anchored in the foundation, and firmly connected (welded and subsequently monolithically sealed).

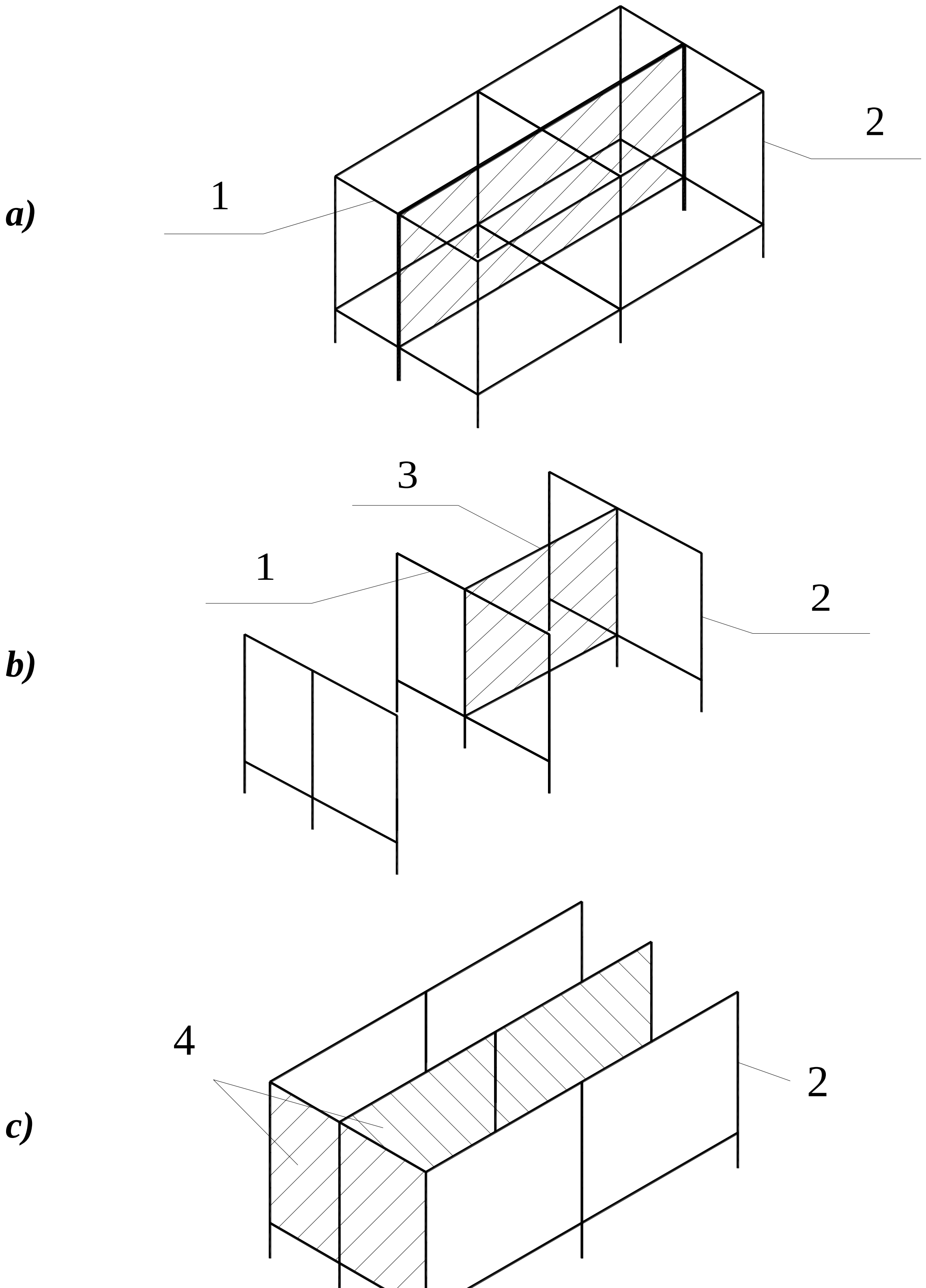


Fig. 3.1. Main structural schemes of public buildings: a – frame with frames located in mutually perpendicular directions; b – frame-braced; c – mixed; 1 – beam; 2 – column; 3 – diaphragm of rigidity; 4 – plane-braced element

Diaphragms are arranged perpendicularly to the frame direction and their plane. Transverse diaphragms must span the entire building width.

For multi-story public buildings, spatial braces or rigid spatial elements that extend throughout the building height and contain "rigidity cores" are essential. These spatial bracing elements are firmly fixed in the foundations and anchored by floor slabs and horizontal diaphragms.

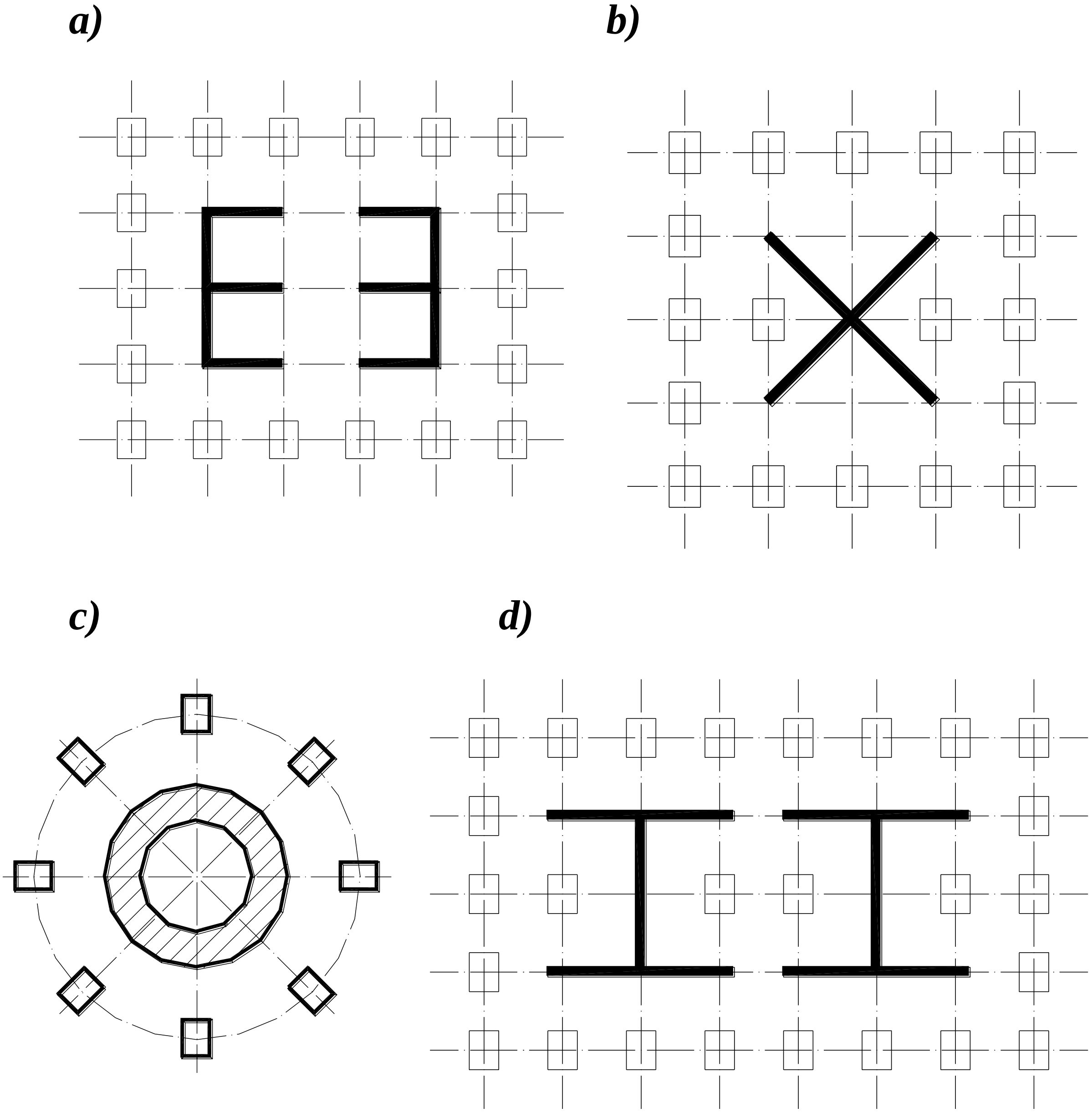


Fig. 3.2. Diaphragm wall arrangements:
a – box-like; b – X-shaped;
c – circular; d – I-shaped

Spatial bracing elements possess a high degree of rigidity, significantly exceeding the rigidity of other frame elements. They almost entirely bear horizontal loads and distribute them to the supporting elements of the frame. Using rigidity cores ensures the spatial rigidity of the building (Fig. 3.2).

Spatial bracing elements are typically located in the central part of high-rise buildings, utilizing elevator shaft enclosures. Such elements can be made of prefabricated reinforced concrete, monolithic reinforced concrete, or steel structures. However, monolithic reinforced concrete is significantly more economical. These are constructed prior to frame assembly using movable formwork, subsequently serving as a base for installation cranes.

3.1.1. Features of Spatial Decisions of Public Buildings

When designing public buildings, their specific features must be considered in accordance with [18]. The primary feature is the diversity of public buildings, with functional processes that can be complex and involve specialized equipment (e.g., mechanized stages in theaters, ice arenas).

Public buildings are characterized by high occupant density (e.g., the Olympic Sports Complex). Consequently, design must address the free movement of people and evacuation after events.

Certain types of public buildings require heightened fire safety measures (e.g., theater decorations, laboratory setups) [12]. Public buildings also adhere to sanitary and hygienic standards, influencing spatial planning, lighting and insolation, soundproofing, and engineering systems (heating, ventilation, air conditioning).

Public buildings are notable for combining spaces with various geometric parameters (area, height). Communication spaces (corridors, vestibules, lobbies) occupy up to 30% of the total area. The geometric parameters of these spaces dictate the use of different spans (small, medium, large). A critical feature of public buildings is their architectural and artistic design. Depending on their social and urban planning significance, public buildings can serve as central elements in major architectural city ensembles.

3.2. Volume-Planning Decisions of Residential Buildings

Multi-apartment buildings are classified by spatial and planning features into sectional, corridor, and gallery types, while small-apartment buildings include single- and two-apartment units as well as row houses. Each building type is formed by a combination of residential units (apartments, hotel rooms, dormitory living spaces), communication spaces (corridors, vestibules, stairwell-lift halls), and auxiliary facilities (stroller and bicycle rooms, etc.).

In residential construction, the most prevalent type, limiting the variety of primary dimensions (span, step, floor height) is crucial for conserving material resources, enabling unification of structural elements.

This goal is facilitated by the introduction of the Unified Modular System (UMS), where the module size is M = 100 mm. In residential construction, larger modules (3M = 300 mm, 6M = 600 mm, 12M = 1200 mm, 18M = 1800 mm) are used for spatial parameters, while vertical dimensions employ 2M (200 mm) and 3M (300 mm).

Each room in an apartment serves a specific function:

- A corridor facilitates removing outerwear and storing it in wardrobes.
- The kitchen is used for food preparation, consumption, and storage.
- The living room serves for family interaction and watching television.

Accurate spatial planning requires knowledge of human dimensions and furniture specifications to ensure effective equipment arrangement, functional zones, and compliance with normative areas.

Anthropometric and ergonomic data based on average statistics determine human dimensions considering gender and age.

Functional zone dimensions, equipment sizes, and passage norms between them are established per the Unified Modular System in multiples of the base module M = 100 mm or 0.5M = 50 mm.

Rooms with transverse wall or partition spacing of 2400 mm can accommodate single-person bedrooms, kitchens, sanitary facilities, and staircases; 3000–3600 mm widths suit double bedrooms; 3600–4200 mm widths are suitable for living rooms. Spans of 6000–7200 mm accommodate two adjacent rooms (e.g., a living room and kitchen). Spans of 4800–6000 mm provide the necessary apartment depth.

Apartment design aims for maximum comfort and space utilization. A critical condition for adequate housing includes considering climatic conditions, insolation, and establishing a rational thermal regime.

In residential complexes, integrating social and domestic service facilities is essential [32]. One aspect of resident service includes providing garage-parking facilities (Fig. 3.3).

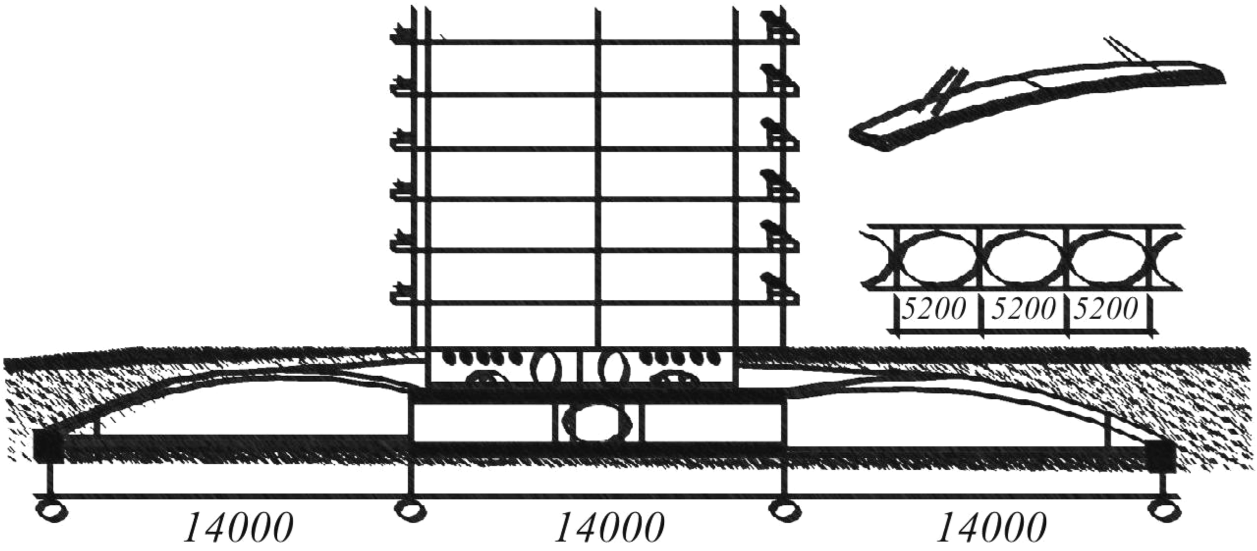


Fig. 3.3. Example of underground parking design

Developed solutions involve the use of underground building spaces or the overlapping of adjacent courtyard areas within the building’s dimensions. On the ground floors of large-panel residential buildings, small facilities, lightweight technical equipment, service enterprises, and auxiliary premises can be accommodated, as well as attached stores. In such cases, the structural design of the panel building needs to be modified (Fig. 3.4). A sufficiently wide range of facilities has been developed (libraries, pharmacy kiosks, video lounges, office premises) to be located on the ground floors of panel buildings.

When attaching trade halls on the street-facing facade, a communication corridor is created between the building and the hall, thereby separating the load-bearing structures of the hall from those of the building (Fig. 3.5). If non-residential premises with mass visitation (stores, administrative premises, etc.) are integrated into the ground floor of multi-apartment residential buildings, access routes and driveways to them must not obstruct access to every entrance of the residential building for fire, emergency, and utility vehicles.

Residential buildings for elderly people and families with disabled members should not exceed five stories. In other types of residential buildings, apartments for families with disabled members should be located on the ground floors.

When designing special buildings for the disabled and elderly, it is necessary to comply with accessibility requirements for people with limited mobility groups.

The requirements of DBN B.2.2–17 apply to the design and reconstruction of public buildings, taking into account the needs of people classified as limited mobility groups (hereinafter referred to as LMGs). These include functional and planning elements of the building, its land site, entrance nodes, communication paths, evacuation routes, living areas, service facilities, workplaces, and their informational and engineering equipment.

Limited mobility groups (LMGs) are people who face difficulties in independent movement, obtaining necessary services or information, or orienting themselves in space. These groups include disabled individuals, people with temporary health impairments, pregnant women, the elderly, and people with strollers, among others.

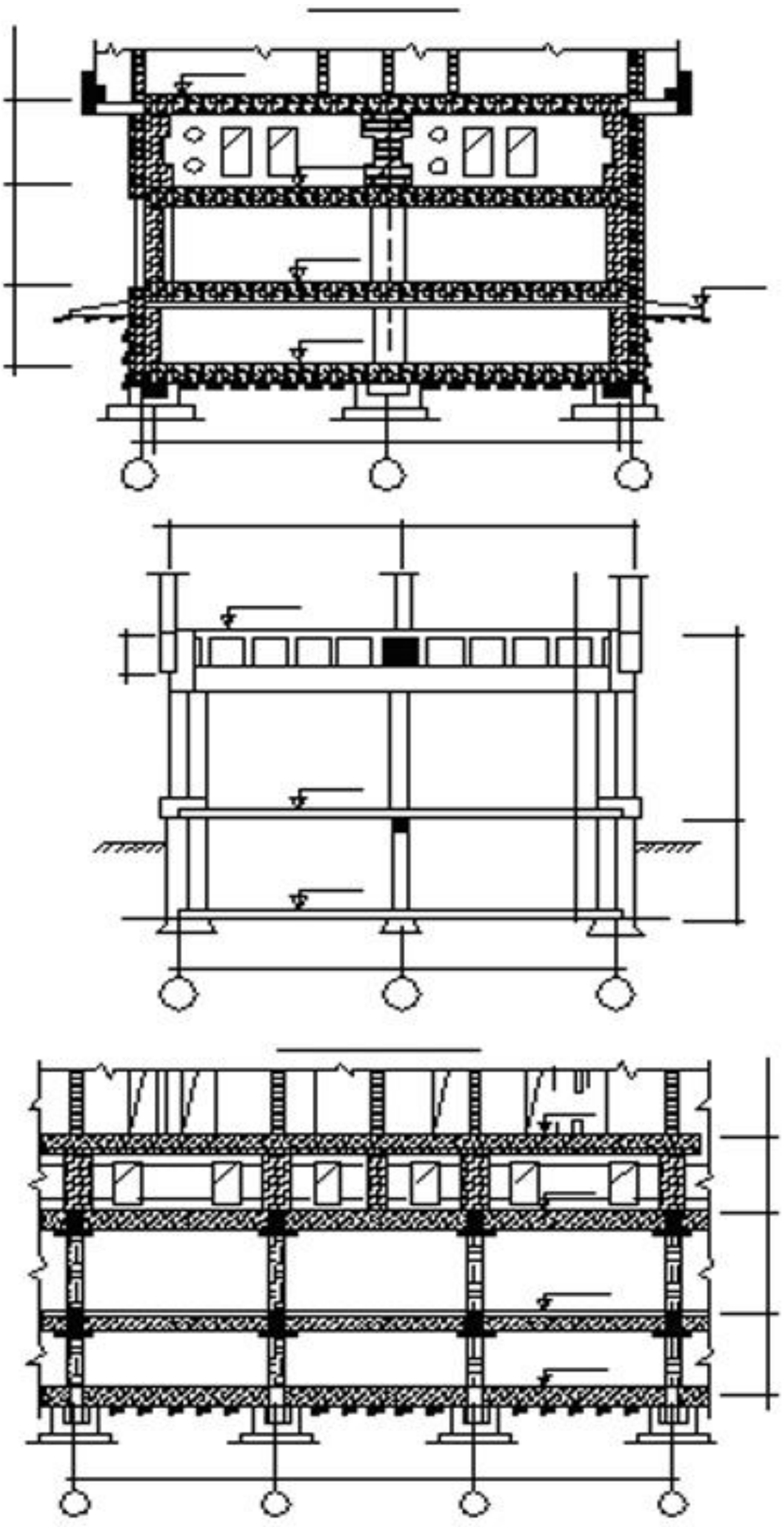


Fig. 3.4. Structural decisions for non-residential floors in panel buildings

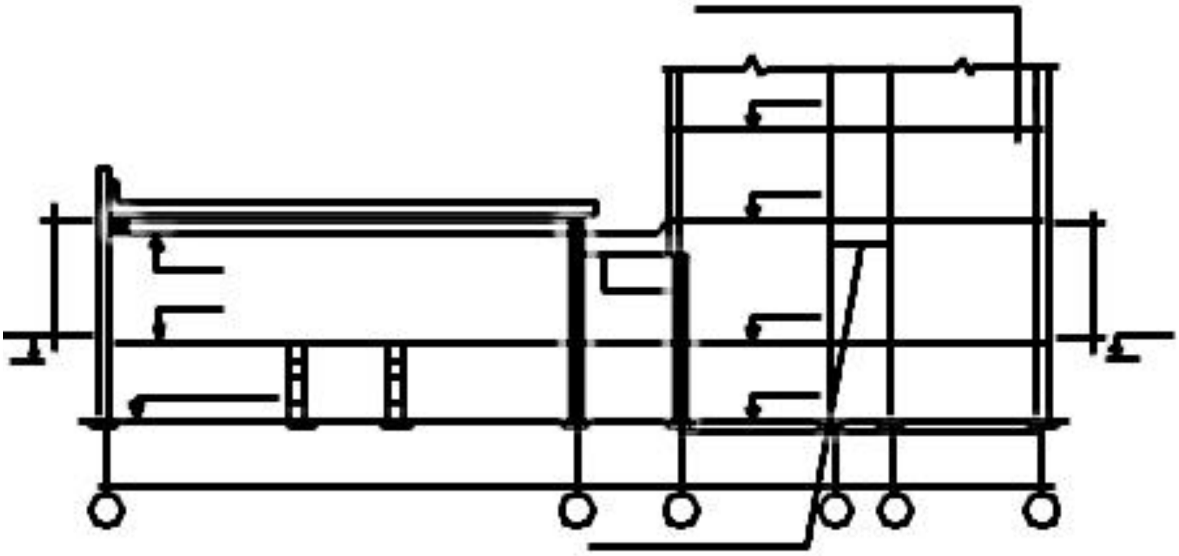


Fig. 3.5. Example of an attached store structure to a residential building

Accessible buildings and structures for LMGs are those where a complex of architectural-planning, engineering-technical, ergonomic, constructional, and organizational measures are implemented, meeting regulatory requirements to ensure accessibility and safety for LMGs.

Movement paths: pedestrian pathways used by LMGs, including wheelchair users, for movement around the site (walkways, sidewalks, ramps, etc.), as well as entrances to and inside buildings and structures (horizontal and vertical communications). When reconstructing public buildings [53, 64], conditions for the disabled and LMGs must be provided equivalent to those for other categories of the population.

The building must have at least one entrance adapted for LMGs from ground level and from each accessible underground or above-ground passage connected to the building. External stairs and ramps must have handrails designed according to technical requirements for stationary support devices as per applicable regulatory documents.

For open stairs on terrain level changes, the width of treads should not be less than 0.4 m, and the riser height should not exceed 0.12 m. All steps within a single staircase must be uniform in shape, width, and height. The transverse slope of external steps should range from 1% to 2%. Stairs must be complemented with ramps and, if necessary, other lifting devices, meeting the requirements of DBN B.2.3-5. For stairs with widths of 2.5 m or more on main approaches to the building, additional dividing handrails should be provided.

The entrance platform at LMG-accessible entrances must include a canopy and drainage system, depending on local climatic conditions, specified in the design task. The surfaces of entrance platforms and vestibules must be solid, non-slippery when wet, and have a transverse slope of 1% to 2%. Floor areas on LMG paths at a distance of 0.6 m before door openings and stair or ramp entrances, as well as before turning points in communication paths, must have warning ribbed or contrastingly colored surfaces. Light beacons may also be provided. The width of doorways and open wall openings, as well as exits from rooms and corridors to staircases, must be at least 0.9 m. If the door jamb depth exceeds 1.0 m, the doorway width should correspond to the communication path width but not be less than 1.2 m.

Doorways must not have thresholds or floor height differences. If thresholds are necessary, their height or the floor height difference must not exceed 0.025 m. Revolving doors and turnstiles with a width of less than 0.85 m are not allowed on LMG movement paths within buildings and structures. The maximum height of a single ramp rise must not exceed 0.8 m with a slope no steeper than 8%. For floor height differences of 0.2 m or less, the ramp slope may increase to 10%. In exceptional cases, spiral ramps may be designed.

The ramp width for one-way traffic must be at least 1.0 m; in other cases, it must correspond to the lane width per clause 6.2.1, which specifies that the width of stairs accessible to LMGs should be at least 1.35 m. For stairs with a calculated width of 2.5 m or more, additional dividing handrails should be included.

All steps within a staircase must have identical geometry and dimensions in terms of tread width and riser height. The pattern of the lower steps in the first staircase of external stairs may be altered. The platform at the horizontal segment of the ramp or turn must be at least 1.5 m deep.

Load-bearing ramp structures must be made of non-combustible materials with a fire resistance rating of at least R60, complying with DSTU B V.1.1–4 requirements. In buildings with the highest fire resistance level, load-bearing and enclosing structures of rooms with ramps must have fire resistance ratings of at least R150 (columns), REI150 (walls), EI150 (partitions), and for buildings of the second level of fire resistance – R120 (columns), REI120 (walls), EI120 (partitions), etc.

Guardrails with a height of at least 0.05 m should be provided along the longitudinal edges of ramp flights and horizontal surfaces with height differences exceeding 0.45 m to prevent cane or foot slippage.

Handrails must be installed along both sides of all stairs and ramps, as well as near height differences exceeding 0.45 m. Ramp handrails should be placed at heights of 0.7 m and 0.9 m; stair handrails at 0.9 m.

The inner side handrail of staircases must be continuous throughout their height. The ends of the handrails should extend beyond the staircase or ramp slope by 0.3 m.

The width (in clearance) of evacuation path sections used by LMGs must be at least:

→ 0.9 m for doors from rooms accommodating no more than 15 people;

→ 1.2 m for openings and doors in other cases, and for passages inside rooms;

→ 1.5 m for transitional loggias and balconies;

→ 1.8 m for corridors and ramps used for evacuation.

Materials used on evacuation routes (staircases, corridors, vestibules, ramps, etc.) must be non-combustible or have fire hazard indicators not exceeding: low combustibility (C1), non-flammable (F1), moderate smoke-forming ability (S2), moderate toxicity of combustion products (T2) for wall, ceiling finishes, and ceiling panel fillers in corridors, staircases, stairwells, vestibules, foyers, including elevator lobbies;

Fire-spread ability - do not spread (FS1), S2, T2 for floor coverings in corridors, staircases, stairwells, vestibules, foyers, including elevator lobbies.

Stairs and ramps should be designed following DBN B.2.3–22 and located within sidewalks and green areas, considering pedestrian flow directions and intensity. Stairways integrated into the first floors of buildings are permitted [DBN B.2.3–5].

For ramps, the width should not be less than 1.0 m, and the slope not more than 60‰. In particularly challenging conditions, the slope may increase to 80‰ with appropriate technical and economic justification.

For designing residential buildings [17] of significant length, driveways should be at least 3.5 m wide and 4.25 m high. Through-passages should be provided every 100 m. Residential spaces are not permitted in basement, semi-basement, or underground floors. The height of residential spaces from floor to floor should be at least 2.8 m; the height from floor to ceiling at least 2.5 m. In regions where the average monthly temperature is below 21°C, the height of residential floors is at least 3 m, and the height of residential spaces at least 2.74 m. The height of intra-apartment corridors, bathrooms, and utility rooms can be reduced to 2.1 m.

The number of risers in a single stair flight or level difference should be no fewer than three and no more than 18. The minimum width of the flight is 1.05–1.2 m. The maximum slope of flights is 1:1.5 for two-story buildings, 1:1.75 for multi-story buildings. For basement and semi-basement floors, the width of stairs can be 0.9 m with a slope of no more than 1:1.25. The width of the stair platform is designed to be at least the width of the flight [6].

During reconstruction, existing slopes and widths of stair flights and platforms may be retained. Floor levels at the building entrance should be at least +0.150 m above the sidewalk. When developing spatial solutions, requirements for access to all structural elements and equipment for periodic inspection and maintenance must be considered.

Apartment types (number of rooms and area) are determined based on the family’s size and composition, as well as the calculated living space per person. This section provides diagrams of typical apartment layouts for mass construction in sectional (Fig. 3.6), corridor (Fig. 3.7), gallery, and block buildings (Fig. 3.8).

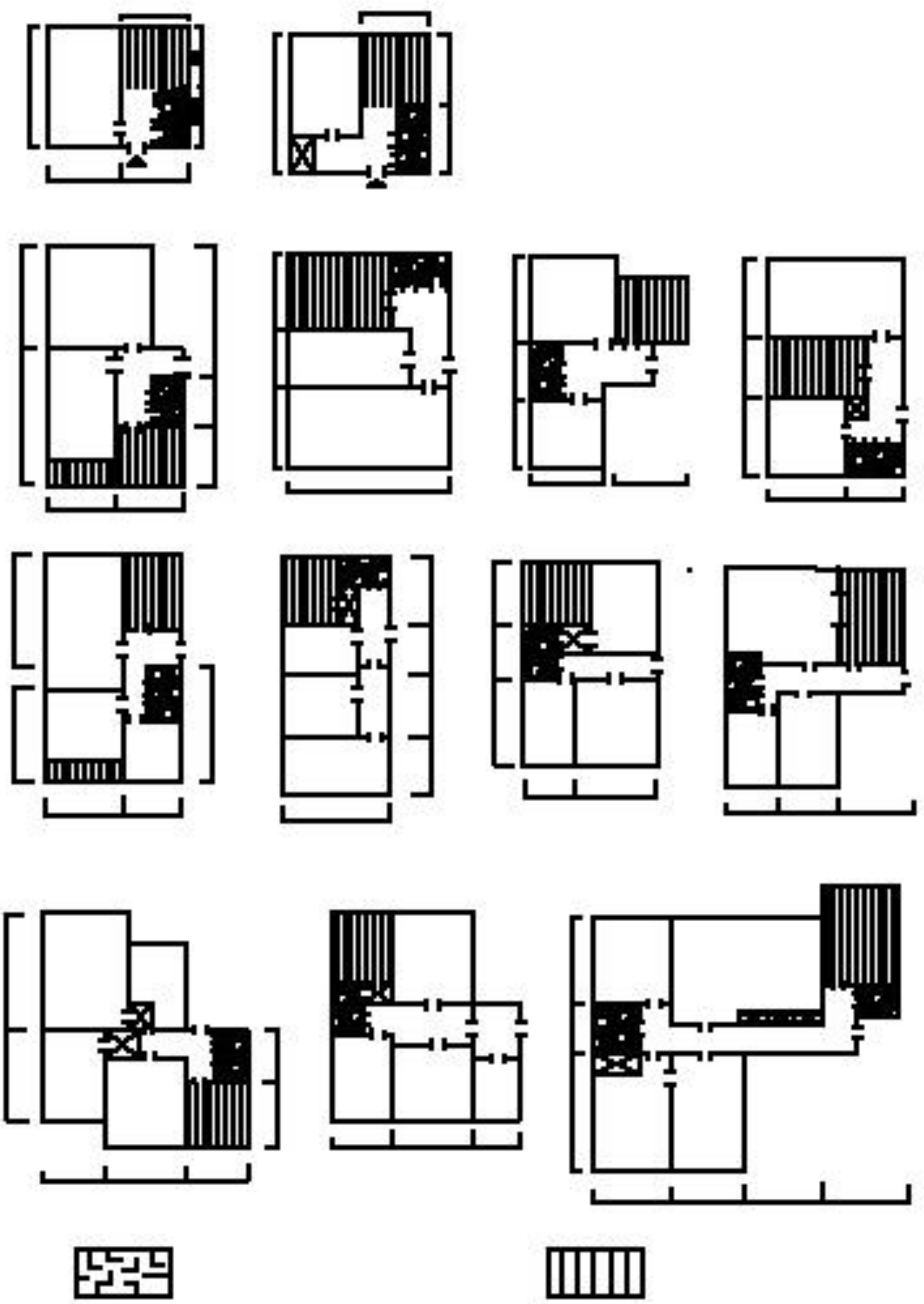


Fig. 3.6. Schemes of basic apartment types in sectional buildings

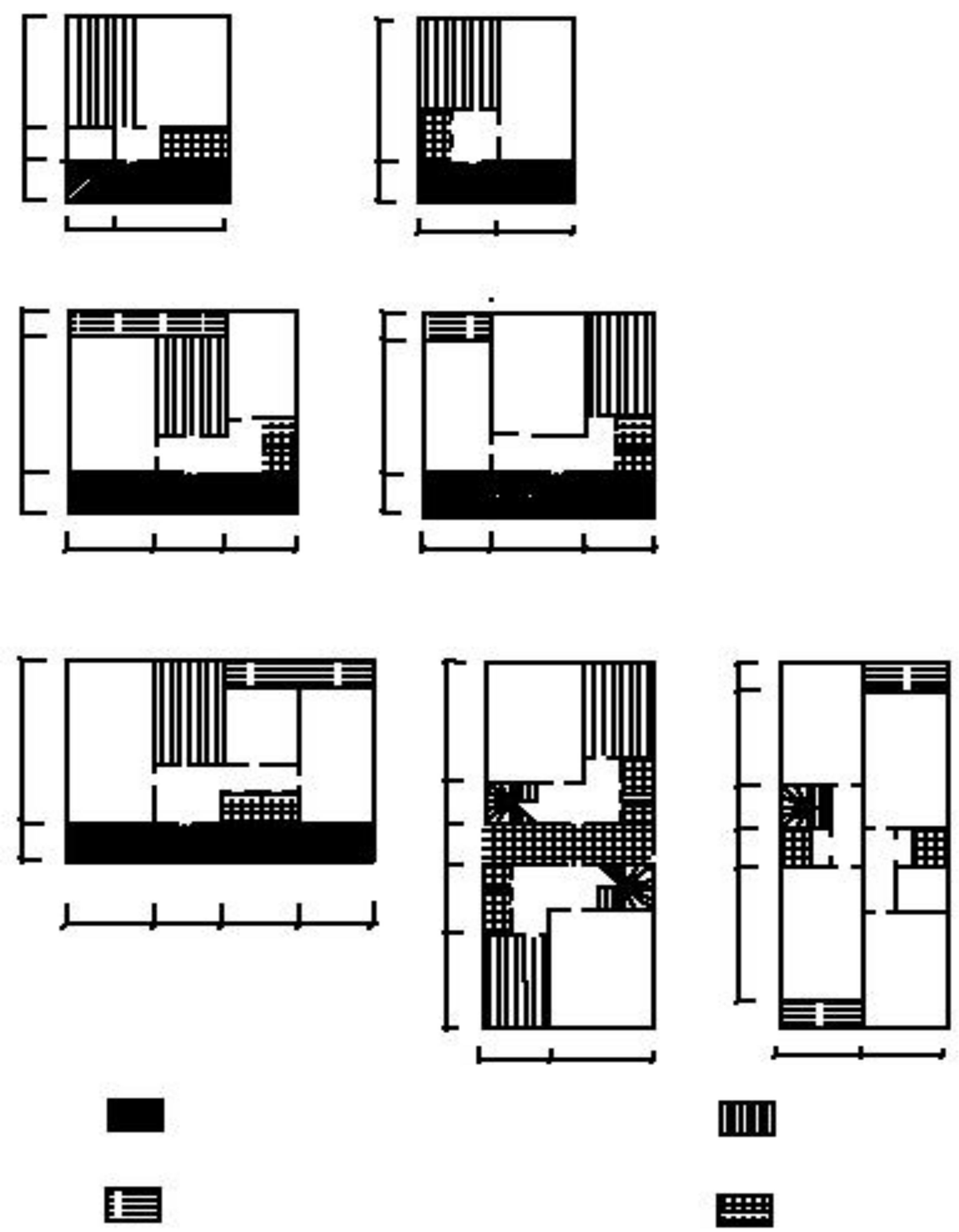


Fig. 3.7. Basic types of apartments in corridor-type sections

The planning design of an apartment is governed by the climatic conditions of the construction site, orientation, number of floors, type of apartment and building, its structural system, and the economic capacity of the country. General requirements for apartment planning are established. These include living rooms (such as a general room and one or more bedrooms) and auxiliary premises (toilet, bathroom or combined sanitary unit, storage or built-in wardrobes, corridor, or hall). Summer premises such as balconies, terraces, or verandas are also provided.

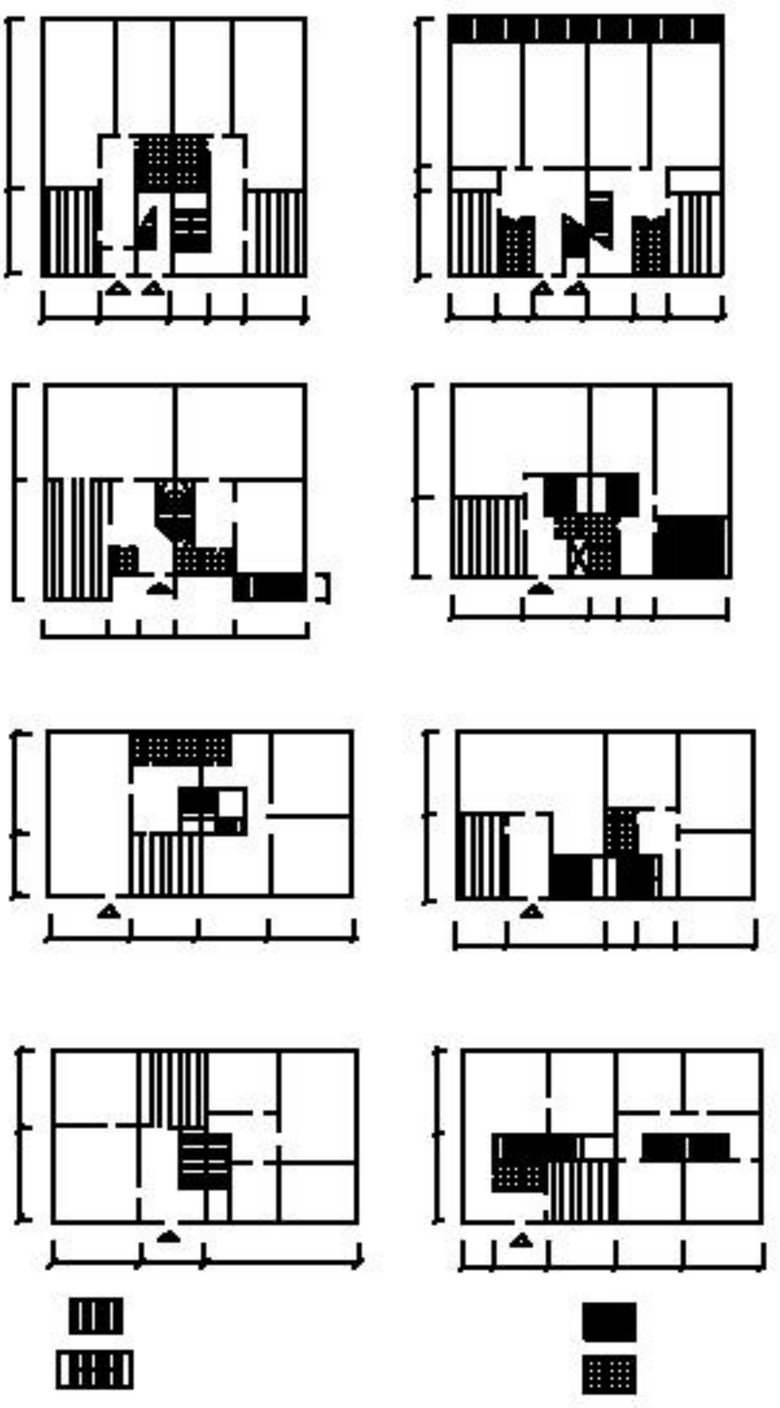


Fig. 3.8. Basic types of apartments in two-story row houses

The general room occupies a central place in the apartment, connects with the corridor, and should have access to the kitchen. Bedrooms are located deeper within the apartment and should have a direct connection to the sanitary unit. The minimum area of a bedroom for one person is 9.0 m², and for two people – 12.0 m².

It is noteworthy that even in two-room apartments, two sanitary units are now being designed. One is a “guest” unit located near the entrance and kitchen, while the other is in the intimate zone near the bedrooms. The "guest" sanitary unit is equipped with a toilet and sink.

Sanitary units can be either combined (bathroom and toilet in one block) or separate (bathroom, sink, bidet in one room, and toilet in another). Bathrooms with installed jacuzzies are also designed. It is important that general rooms should not include sleeping places. Children of the same gender can share a bedroom for two. In the parents' bedroom, a sleeping place for an infant may be included.

General rooms are designed with an aspect ratio of 1:1 or 1:2, provided the long side is parallel to the facade. Bedrooms have an aspect ratio from 1:1.5 to 1:2, with the short side perpendicular to the facade. Kitchens should have a working front length of no less than 2.7–3.0 m, positioned perpendicular to the facade. The minimum area for a kitchen in a one-room apartment is 8.0 m², and in a two-room apartment – 9.0 m².

Hallways are designed to be at least 1.4 m wide and equipped with built-in wardrobes for outerwear storage. Apartment areas depending on the number of living rooms are listed in Table 3.1.

For the unification of structural-spatial decisions in multi-apartment buildings, the area of certain apartment types can be increased by 5%. The area of the general room in a one-room apartment must be at least 15 m², and in other apartments not less than 17 m². The minimum bedroom area for one person is 8 m², and for two people – 10 m². The minimum kitchen area in a one-room apartment is up to 5 m², and in two-room or larger apartments – 8 m². The minimum area for a study or home office is 10 m².

Table 3.1. Types of apartments and their areas depending on the number of living rooms

Lower and upper area limits, *m*^{2}	**Number of living rooms**				
	1	2	3	4	5
	28,0–40,0	44,0–53,0	56,0–65,0	70,0–80,0	84,0–98,0

Living rooms in apartments must not be walk-through, except in 4th- and 5th-room apartments where access to one bedroom or study may pass through the general room.

In one-room apartments, combined sanitary units are allowed. The minimum dimensions of sanitary units are as follows: combined unit – 3.8 m^2; bathroom – 3.3 m^2; toilet with a sink – 1.5 m^2; toilet without a sink – 1.2 m^2.

It is not allowed to place bathrooms or toilets above living rooms or kitchens, but they may be designed above the kitchen in duplex apartments.

The width of auxiliary kitchen premises is 1.8 m, hallways 1.5 m, and corridors leading to living rooms – 1.1 m. The area of apartments for families with disabled members or elderly persons must be increased by 10–12 m^2.

In such buildings, there should be no steps or thresholds at the entrance, elevator entry, and garbage chute access. Ramps at least 1.2 m wide with a slope of 1:20 or lifts must be provided. The width of inter-apartment corridors must be at least 1.8 m, and doorways at least 0.9 m. The depth of vestibules in the building should be no less than 1.8 m. Loggias or balconies in such apartments are mandatory, with a minimum width of 1.5 m.

3.3. Modern Functional Requirements for Residential Buildings

Multi-story residential buildings are the primary type of urban development. Based on their planning structure, they are categorized into sectional, corridor, gallery types, or combinations of sectional structures with corridors and galleries. The number of apartments in a section is determined by economic, sociological, climatic, and demographic factors.

According to orientation requirements relative to cardinal directions, sections are divided into unlimited orientation (two-apartment), meridional (restricted orientation), and latitudinal (partially restricted orientation). Meridional sections accommodate the maximum number of apartments. However, the length of dead-end corridors (general apartment horizontal communications) must not exceed 12.0 meters. For small apartments (1–2 rooms), sections with 8–10 apartments can be designed.

Residential buildings are formed by combining sections in various configurations. Thus, the section acts as a compositional element of the building and requires a rhythmic facade appearance.

A dominant feature of residential development is "tower-type" buildings (single-section). These buildings offer the advantage of having light access from all four sides, allowing for apartments with dual orientation. Recently, buildings are being commissioned with fixed plumbing placement but without interior partitions. This enables the owners to execute their own interior layouts (free-layout apartments).

In our country, construction is predominantly conducted using industrial methods. Industrialization refers to the organization of construction production that transforms it into a mechanized and automated continuous construction process.

Industrialization can be achieved in two ways:

1. Maximizing the transfer of production processes to factory conditions using prefabricated elements.
2. Retaining all or most production operations on the construction site while reducing their labor intensity by utilizing mechanized equipment and new construction methods.

The panel system is the primary method of industrial construction. Buildings are assembled from pre-prefabricated industrial reinforced concrete elements, including external and internal walls, floor panels, roof panels, and elements of the underground cycle (foundation slabs and plinth panels).

Depending on the location of load-bearing walls, the following structural schemes are used in panel construction:

- Cross-wall system with small transverse wall spacing (up to 4.5 m);
- Transverse-wall system with mixed or wide spacing (up to 7.2 m);
- Longitudinal-wall system.

One advantage of the cross-wall structural scheme in large-panel construction is the possibility of using thin panels for apartment and interior apartment partitions, as well as for internal and external walls. These panels function as load-bearing structures, forming a stable structural system with room-sized floor slabs.

The cross-wall scheme features a rigid planning structure and evenly distributed loads.

Room-sized floor panels are supported on all four sides by load-bearing wall panels, enabling them to withstand significant loads despite their small thickness and minimal reinforcement.

Wall panels are room-sized and joined by welding corner reinforcement extensions.

The structural scheme with transverse load-bearing walls and wide spacing offers flexibility in interior planning. With a spacing of 7.2–6.0 meters, it is possible to accommodate either one large room or two rooms separated by a partition.

The dimensions of floor panels, determined by the size of the planning module, are 6.0×6.0 m or 6.0×7.2 m. Manufacturing such panels is challenging due to transportation and installation constraints. In these cases, reinforced concrete hollow-core panels with widths of 1.0, 1.2, 1.5, and 1.8 m, thicknesses of 220 mm, and lengths ranging from 2.1 to 7.2 m are used. Each room has one seam, which is easy to finish without plastering the entire ceiling.

The external longitudinal walls in this structural scheme are either non-load-bearing (the floor panels transfer their weight to the transverse load-bearing walls) or self-supporting (transferring their own weight directly to the foundation).

In the structural scheme with longitudinal load-bearing walls, the floor panels rest on the longitudinal walls, meaning their span equals the room length. Transverse walls and partitions rest on the floor panels, increasing their load. External walls in this scheme require high load-bearing capacity, leading to a three-layer structure.

Modern panel construction employs three-layer reinforced concrete panels for external walls with flexible connections. The inner reinforced concrete layer of the panel has a thickness of 90 mm (to support floor panels), and the outer layer is 70 mm thick. Between these layers is an effective insulating material, whose thickness is determined by thermal calculations in compliance with the requirements of **DBN V.2.6-31:2021** "Structures of Buildings and Facilities. Thermal Insulation of Buildings" [7]. When flammable insulation materials are used, they are protected along the perimeter with a layer of fire-resistant insulation 75 mm thick.

From an operational standpoint, sealing the horizontal and vertical joints of panel connections is critical. Joint seams are filled with efficient mineral-based insulators and sealing gaskets (e.g., polyurethane foam, porous rubber). These are coated with curing mastics (such as thiokol or butyl rubber).

An open joint design can include a water-repellent strip made of aluminum or plastic profiles, which acts as a compensator for temperature-induced changes in seam width.

The thickness of internal wall panels ranges from 160 to 200 mm, depending on the number of floors. All panels are one story in height and correspond to the planning module in length. They can be solid or feature door openings.

Floor slabs supported on four (or three) sides have thicknesses of 120, 140, or 160 mm. When supported on two sides by transverse load-bearing walls, hollow-core slabs with a thickness of 220 mm are used.

Housing Financing

Housing credit terms typically include an initial payment of 30% of the total apartment cost, with the remaining amount payable over

15–20 years at an annual interest rate of 4%. Favorable conditions for purchasing new housing have enabled buyers to acquire apartments with improved layouts in brick or frame-monolithic buildings.

This has driven the development of new architectural and structural decisions for multi-story residential buildings, including frame-monolithic designs with open apartment layouts. Notably, in the 1920s, French architect Le Corbusier proposed that free layouts are made possible by frame structures, allowing for varied partition arrangements on each floor. The separation of functions between the load-bearing frame and the external enclosing walls enables flexible façade designs.

High-Rise Buildings: Features and Considerations

In most European countries, prestigious residential buildings are located in city centers, with height limitations of up to 20 floors. In historical areas of France, building heights are restricted to seven stories. Medical experts note that living on high floors can negatively affect the mental health of certain groups, such as the elderly and children.

Negative aspects of living in buildings over 20 floors include:

- Increased aerodynamic and noise exposure.
- Potential air transfer between lower and upper floors.
- Fear of heights among some residents.

Despite this, high-rise buildings are being actively constructed, particularly in densely populated countries (e.g., China) or regions with limited space (e.g., Japan, Taiwan, Singapore) [63].

Maintenance Costs and Requirements

With increasing building height, operating costs rise significantly. Economists estimate maintenance costs at 50–100 UAH per square meter [5]. Designing new high-rise buildings must include provisions for parking spaces and landscaping at 12 m^2 per person.

Buildings over 75 m tall must adhere to individual technical requirements [7], with the maximum permissible height determined by municipal urban planning authorities.

Power Supply for High-Rise Buildings

Buildings exceeding 100 m in height must have three independent power sources, one of which must be a backup diesel generator with fuel reserves for at least 1.5 hours, located outside the building. Autonomous monitoring and control of engineering systems, as well as fire safety automation systems, should be located in a centralized control room on the first floor.

Fire Safety and Evacuation

High-rise buildings must be divided vertically by fire-resistant barriers of the first type, with floor fire resistance ratings of **REI 100** (R: load-bearing capacity, E: integrity, I: insulation). Horizontally, fire compartments should not exceed 50 m in height, with fire-resistant walls rated **REI 150** and compartment areas capped at 2,400 m^2.

For apartments up to 50 m high, firefighters can access them via aerial lifts and specialized ladders.

The design of staircase-lift communication nodes is critical, as they serve as primary evacuation routes in emergencies. For buildings over 10 stories, evacuation staircases must be smoke-free, achieved by pressurizing the stairwell during a fire or providing access through air zones (e.g., balconies, loggias, galleries, and other open pathways). Smoke-free stairwells must have exits at the ground level that led directly outdoors via entrance vestibules.

Distances between residential buildings and between residential and non-residential buildings are determined based on insolation and illumination calculations in accordance with DBN 360-92 "Urban Planning. Planning and Development of Urban and Rural Settlements." The placement and orientation of residential buildings must ensure at least 2.5 hours of insolation per day in residential premises during the period from March 22 to September 22 throughout Ukraine. In areas with buildings of nine or more floors, a single interruption of insolation in residential premises is allowed, provided that the total daily duration of insolation increases by 0.5 hours.

When placing residential buildings over nine stories high next to private houses, the distance between the single-family house and the multi-story building must be no less than the height of the building being constructed. Requirements or standards for multi-story residential buildings with improved living conditions include: ceiling heights of 2.7–3.0 m; functional planning; the presence of bay windows and French balconies to provide panoramic views from most apartments; mandatory availability of underground or attached above-ground parking near the residence; city transportation connections; improvement of the adjacent territory with a children's playground, a recreation area for elderly people, spaces for walking pets; and developed social infrastructure (kindergartens, schools, stores, clinics).

Compared to multi-section residential buildings, single-section buildings have increased light frontage, more diverse apartment layout options, better aeration, and insolation.

Single-section tower-type buildings feature compact layout decisions with a diameter or maximum dimension of 20–25 m. In multi-section frame-monolithic buildings, the width does not exceed 14.0–16.0 m because the building ends lack window openings, and the proportions of residential rooms with windows facing only the longitudinal facades are undesirable to design with a depth exceeding 1.5 m^2.

Free apartment layouts across the entire floor area are facilitated by the minimal number of vertical load-bearing supports (columns, pylons, walls). Elements that restrict free planning include:

- staircase-elevator units;
- sanitary-technical blocks (water supply, sewerage, ventilation);
- projections on monolithic reinforced concrete floor slabs for arranging balconies and bay windows;
- load-bearing walls, pylons, and columns.

Building designs must take into account energy-saving considerations.

It is necessary to provide for the following energy-saving measures: the introduction of supply and exhaust ventilation systems through automatically regulated air intake devices in window frames; the implementation of apartment-based heating systems with adjustable air temperature control in rooms; the use of new wall materials or wall structures with effective insulation, windows, and coverings with enhanced thermal insulation properties.

The concept of an energy-saving building includes not only the insulation of protective structures using thermal insulation materials but also spatial design decisions that determine the degree of solar energy utilization when setting parameters for the building’s internal microclimate, as well as engineering decisions for ventilation and heating systems.

When designing energy-efficient buildings, it is essential to address the influence of external climate, the thermal energy balance of rooms, and the thermal protection of external protective structures in a comprehensive manner.

The optimization of the thermal protection of external protective structures involves a series of measures, one of which is the method of calculating insulation thickness based on "minimizing the equivalent energy expenditures." This calculation considers the simultaneous costs of manufacturing structures, building construction technology, and operational expenses for their use.

External protective structures must meet several requirements, including:

- A high level of thermal insulation during the cold season;
- A high level of thermal resistance;
- Low energy intensity of the inner layers of materials when exposed to fluctuations in internal heat flow;
- Airtightness.

Insulating only the protective structures is insufficient for significantly reducing heat losses, as a substantial portion of losses occurs through "thermal bridges," areas of intense heat exchange with the external environment.

Modern insulation systems, therefore, include the creation of comprehensive protective envelopes around building structures. These envelopes integrate the insulation of foundation structures in contact with the ground, combined with roof insulation and the installation of ventilated facades, which shift the positive temperature zone closer to the exterior side of the load-bearing structures. This approach eliminates "thermal bridges," increases the thermal resistance of protective structures, and prevents condensation.

Special attention is paid to transparent protective structures during design, as they account for significant heat losses. To increase the overall thermal resistance of transparent structures, the following measures should be considered:

- Ensure reliable sealing of all joints and sashes, both within the window and between the window structure and the wall;
- Use low-emissivity coated glass and fill the inter-glass spaces in double-glazed units with argon or krypton to reduce heat loss by radiation;
- Employ spacer frames in window fillings with improved thermal insulation properties;
- Use multi-chamber profiles for PVC window frames and thermal inserts for aluminum-profile windows.

3.3.1. Examples of Volume-Planning and Structural Decisions of Existing Residential Buildings

Multi-Story Residential Building with Oshadbank Premises, 2-6/32 Yurkovska Street

Volume-Planning and Structural Design. The five-story residential building with a basement has a complex layout with overall dimensions of 44.0×108.0 m, and its total height is approximately 19.0 m. The building is located along the red line of development on Yurkovska and Kyrylivska (Frunze) streets (Figs. 3.10–3.13). The distance from the building to the "Ceramics blocks" factory territory is 35–40 m.

Constructed in early 1991 following a Czech design, the building has been in operation for about 25 years. During this time, localized repairs have been carried out. The building has a complex configuration in plan and is constructed with a longitudinal orientation: the main and courtyard facades face south and north, respectively (Fig. 3.9).

The building contains five residential apartment sections that open onto staircase platforms. Along axis "A" and between axes "17–19," a one-story premise for the Oshadbank was attached (underwent major repairs from January to May 2016). Along Yurkovska Street, in axes "1–5" and "A–G," there is a one-story premise for the "Fund for Business Support and Development" (formerly a milk kitchen). Over the Fund's one-story premise, a second-floor apartment was added during reconstruction.

The building's basement houses engineering networks for water supply, sewerage, and heating. Access to the residential premises of sections № 1, 2, and 5 is from the courtyard, while access to sections № 3 and 4 is from the building's main facade, located between axes "1–19" along Yurkovska Street. The height of the apartment premises is 2.8 m, the basement premises 1.9 m, and the attic premises 1.8 m.

The residential building is divided into two blocks by a deformation joint along axis "12," between axes "A–B."

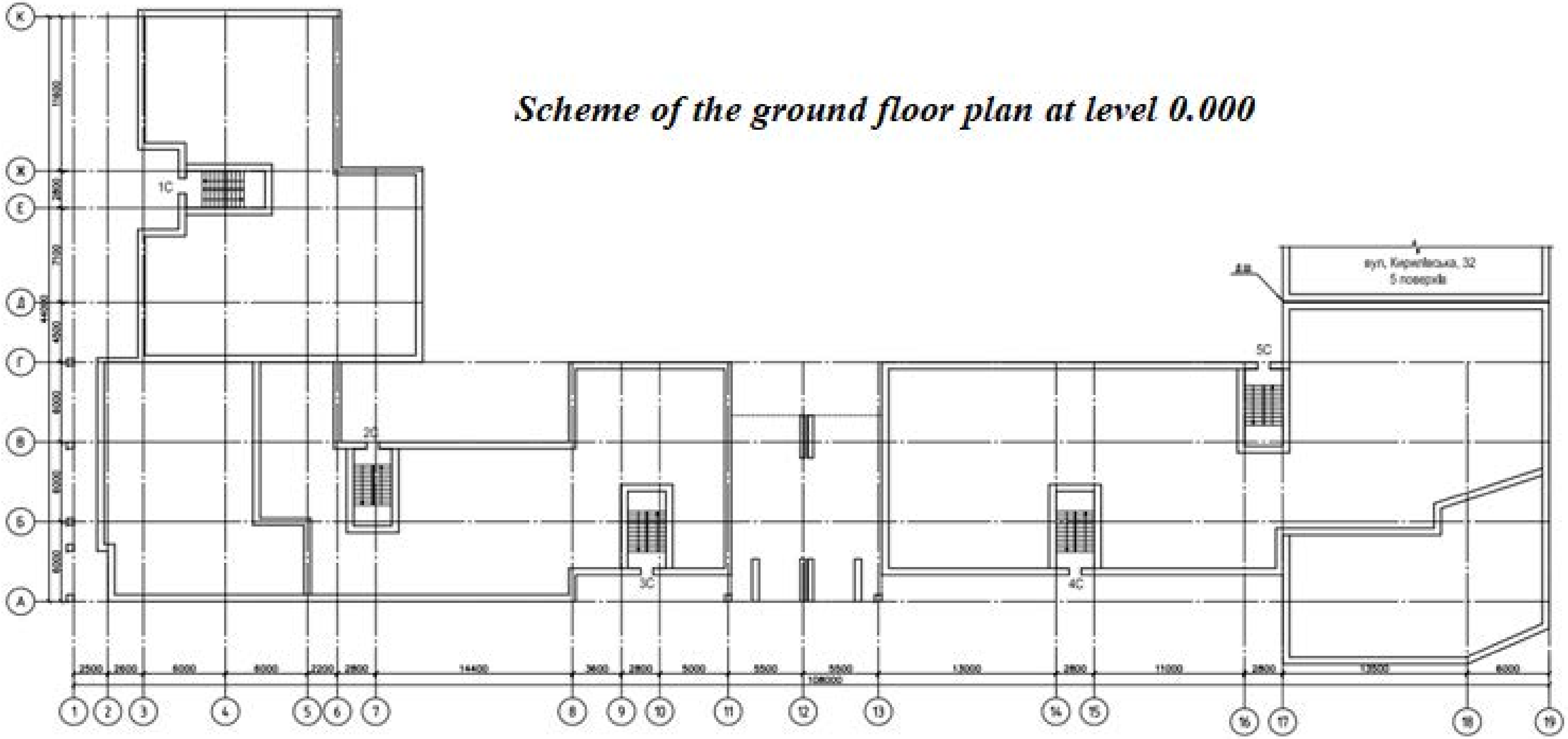


Fig. 3.9. Floor Plan Scheme of a Sectional Residential Building at 0.000 Level

Between axes "11–13," a driveway to the courtyard facade is designed.

The residential building is located on terrain with a gentle relief in a residential block of the historic Podil district of Kyiv.

The building's structural system is wall load-bearing system, with a combined arrangement of load-bearing brick walls. In the central part, between axes "A–G," "5–11," and "13–16," the longitudinal walls are load-bearing. In the side sections, between axes "G–K," "3–7," and "G–D," "17–19," the transverse walls serve as supports for the floors.

The staircase walls are self-supporting and contribute to the building’s spatial rigidity in conjunction with horizontal reinforced concrete floor slabs.

The building is equipped with engineering systems for cold and hot water supply, sewage, heating, gas supply, electricity, and waste disposal.

The soil of foundations is made of marl clay, stiff plastic, and bluish-gray stiff plastic clay. There is strip foundations constructed from prefabricated concrete wall blocks, with footings approximately 1000 mm below the basement floor. Horizontal waterproofing is installed atop the foundations. The first-floor living spaces are elevated 0.9–1.0 m above the ground level at the main facade along Yurkovska Street. The socle of the facades is finished with concrete tiles.

The walls of the main and courtyard facades adjoin an asphalt paving area, a lawn, and a sidewalk.

The exterior walls are brick masonry, 510 mm thick, made of ceramic bricks on M50 cement-sand mortar. The facade surfaces of the external walls feature exposed joints with painting, while the internal surfaces are plastered with lime-sand mortar. The internal load-bearing walls are 380 mm thick.

Window openings are made with rebates, and window and door lintels are prefabricated reinforced concrete beams, with decorative finishes on the courtyard facades. The stairwells feature glazing in the form of bay windows with wooden frames, double-glazed with paired sashes.

Fig. 3.10. Fragment of the main facade of the building along axis "19" at the corner of Kyrylivska Street and Yurkivska Street, 2-6/32

Fig. 3.11. Fragment of the courtyard facade of the building between axes "13–11", expansion joint.

Fig. 3.12. Single-story premises of the "Enterprise Support and Development Fund" on Yurkivska Street between axes "1–5" and "A–H".

Fig. 3.13. Fragment of the courtyard facade of the building along axis "B", between axes "6–8", entrance to section No. 2.

In the apartments, the windows are made of PVC (polyvinyl chloride).

The partitions within the apartments are made of brick and gypsum blocks, 120 mm thick, plastered.

The over-basement, inter-floor, and attic floor slabs are prefabricated reinforced concrete hollow core slabs, 220 mm thick. The floors in the living areas are covered with linoleum and parquet; in the bathrooms, they are made of ceramic tiles on cement-sand screeds. In the basement, the floors are concrete.

The inter-floor staircases are made of prefabricated reinforced concrete flights and landings; the floors on the landings are made of terrazzo (mosaic concrete).

The load-bearing structures of the loggias along axis "B", between axes "6–8" are prefabricated reinforced concrete hollow core slabs.

The roof is flat with an attic. There are ventilation dormer windows in the attic. The roofing is rolled material (felt/bitumen) on a cement-sand leveling screed. The roof drainage is organized internally, and along axis "A" between axes "2–8" it is organized externally using a system of downspouts (rainwater pipes).

Residential Building at 34-38 Kyrylivska Street

The residential building, 4 to 5 stories high with a basement and a technical attic, is located at the corner of Kyrylivska and Olenivska Streets and has an L-shaped plan (Figs. 3.14–3.16). The building is situated on a site with a slight slope, and the distance from the building to the "Ceramic blocks" factory territory is 35–45 m.

The residential building was built in 1999 according to an individual design. It has been in operation for 16 years, during which time reconstructions and extensions of individual premises were carried out, and local repairs were performed. The building consists of 6 sections. The first section, located along axes "A-K" on Olenivska Street, has three apartments on each floor. The second section is a corner section. Sections 3 to 6, built along the red building line of Kyrylivska Street, have two apartments on each floor. Sections

1 to 5 of the building have 5 stories each, while the sixth section has 4 stories and is separated by an expansion joint. Entrances to the stairwells of the sections are from the courtyard.

Various technical auxiliary rooms are located in the basement, and in the basement of the fifth section, between axes "21–26, B–D", there are office premises of an insurance company. Office premises are also located in the fourth and fifth sections on the ground floor. Garbage chutes were originally planned in the stairwells, but they are currently not functioning. Various types of extensions have been built by the owners of some premises adjacent to the ground floor walls.

The height of the living spaces on floors 1–5 is 2.5 m (floor-to-floor height is 2.8 m). The basement premises have a height from 1.8 m to 3.3 m. The apartment layout is designed with all apartments oriented to both sides of the building. Each apartment has a balcony or a loggia. Inter-floor communication is provided by two-flight staircases.

The architectural design of the building is in the Postmodern style, using exposed exterior supporting columns, recessed elements, and bay windows in the composition.

The structural system of the building is a bearing-wall structural system with a combined arrangement of load-bearing vertical structures. The load-bearing elements are the longitudinal walls supporting the floor slabs; the internal transverse walls provide spatial rigidity to the building and are self-supporting.

The building foundations are made of prefabricated concrete blocks, assembled on a cement-sand mortar, and reinforced concrete bearing pads. Horizontal waterproofing made of roofing felt is installed on top of the foundations. The basement walls are faced with concrete tiles on cement-sand mortar; some sections are plastered with cement-sand mortar.

The asphalt pavement adjacent to the exterior walls has a width of 0.6–0.9 m. Adjacent to the wall of the courtyard facade of the fifth section along axis "D" between axes "17–21" are raised ground areas at elevation 0.000 to - 0.200 with brick retaining walls. Trees and bushes are located at an unacceptably short distance from the facade walls.

The exterior walls of the building are masonry, 510 mm thick, made of pink perforated ceramic bricks on cement-sand mortar. The facade surfaces of the walls have joint pointing, and the interior surfaces are plastered with cement-lime mortar. In some premises, thermal insulation layers are installed on the exterior surfaces. The internal load-bearing and self-supporting walls are masonry, 380 mm thick, made of pink perforated ceramic bricks on cement-sand mortar, and their surfaces are plastered with lime-sand mortar. The lintels of window and door openings are prefabricated reinforced concrete lintels, with brick decorative wedge-shaped elements on the exterior walls. The windows are wooden with double glazing and separate sashes.

The partitions within the apartments are brick, 120 mm thick, plastered; the partitions between apartments, as well as between apartments and common areas, are 250 mm thick to ensure sound insulation.

The inter-floor, basement, and attic floors are made of prefabricated reinforced concrete hollow core slabs, 220 mm thick. The balcony slabs are flat reinforced concrete.

The floors are made on cement-sand screeds with sound insulation layers. The floor coverings are made of engineered parquet and ceramic tiles in wet areas. The total thickness of the interstorey floor slabs is 300 mm. In the technical rooms of the basement, there are cement floors; in the basement office premises, there are ceramic tile floors. There is no floor installed on the attic above the insulation layer.

The interior staircases are made of prefabricated reinforced concrete slab flights and ribbed landings. The treads of the steps have applied polished concrete tiles.

The roofing is an attic roof. Over the part of the attic adjacent to the courtyard area, the roofing is made of prefabricated reinforced concrete slabs supported by the interior and exterior walls. It has a slight slope of approximately 5°. The roofing material is built-up roofing felt (bitumen). The roofing over the part of the building adjacent to the street facades is a wooden rafter system with a slope of approximately 45°, and the roofing material is galvanized metal.

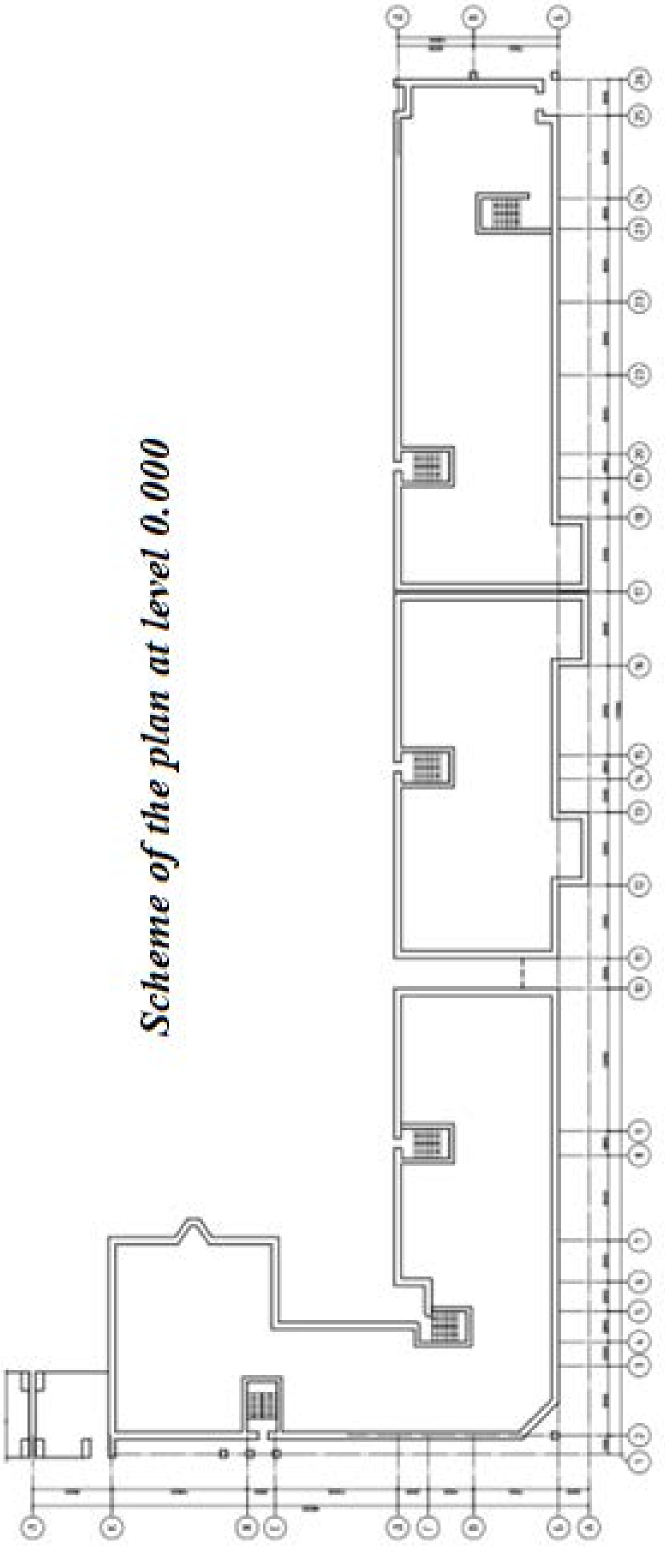


Fig. 3.14. Sectional Apartment Building Floor Plan at Level 0.000

Rainwater drainage from the roof is carried out via internal downspouts (rainwater pipes). On the surface of the attic floor, thermal insulation backfilling with expanded clay gravel is performed with a thickness of 70–150 mm.

Fig. 3.15. Fragment of the building facade on Kyrylivska Street between axes "B–D" and "17–25"

Fig. 3.16. Fragment of the facade on Olenivska Street between axes "D–L"

Residential dormitory building at 4 Nyzhnoiurkivska Street, Kyiv

The residential building was constructed in 1969, with partial reconstruction carried out in 2008 between axes "5–8" and "A–H".

The building is five stories high with basement and sub-basement (cellar) spaces, rectangular in plan, with a wall bearing structural system and longitudinal arrangement of brick load-bearing walls. The overall dimensions of the building between axes "1–8" and "A–H" are 73.0×13.6 m (Figs. 3.17–3.20).

The building footprint area is 992.8 m^2.

The spatial rigidity of the building is ensured by longitudinal masonry brick walls and floor slabs.

The building is divided along axis "5" by a thermal expansion joint.

The building's layout is corridor-type. Inter-floor connection is provided by two-flight staircases; the stairwells are located between axes "3–4" and "B–H", and "6–7" and "B–H".

The building accommodates: residential apartments; a medical center on the ground floor between axes "5–8" and "A–H"; and technical rooms, a heating point, and an electrical switchboard in the sub-basement (cellar) between axes "1–5" and "A–H".

The foundation base of the building is stiff clayey marl.

The foundations under the load-bearing walls are strip foundations made of large concrete blocks and a reinforced concrete slab.

The plinth along axis "A" between axes "5–8" is faced; the plinth along axis "H" between axes "5–8" is faced with ceramic tiles.

An asphalt pavement 800–1000 mm wide adjoins the plinth.

Reinforced concrete beams, 450 mm high and 400 mm wide, are installed on all floors along the transverse (numerical) axes "4" and "6".

The interstorey and basement floors are made of prefabricated reinforced concrete hollow core slabs with a length of 6.8 m.

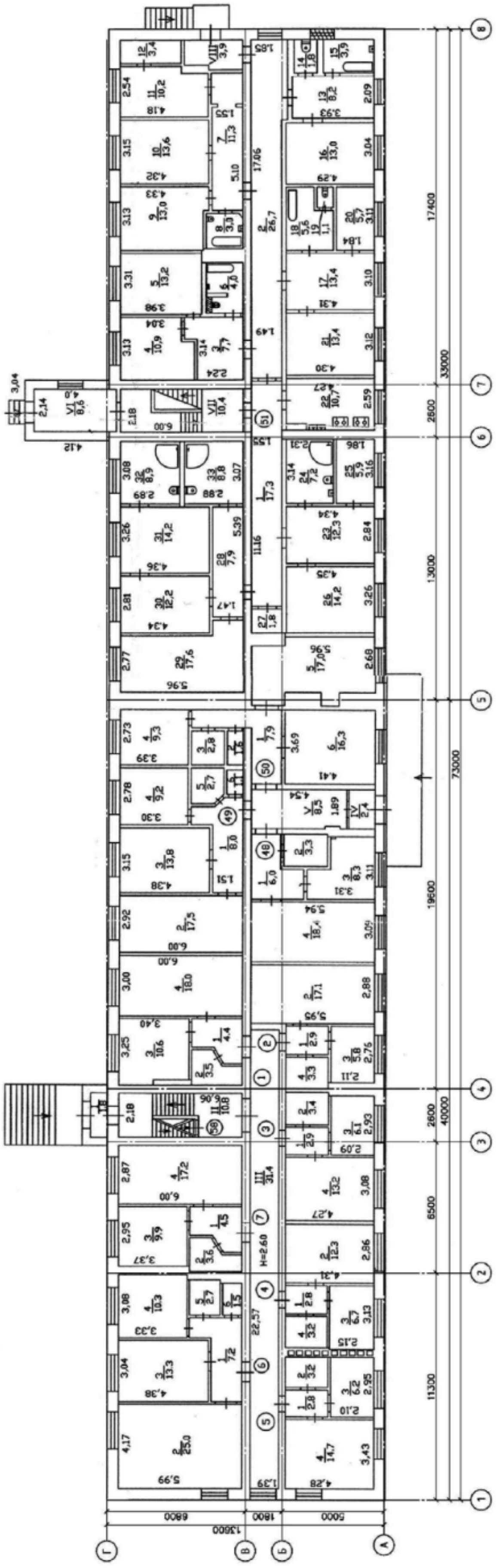


Fig. 3.17. Corridor-type dormitory building floor plan layout

Fig. 3.18. Fragment of the main facade of the building along axis "H" between axes "1–8"

Fig. 3.19. Fragment of the main facade along axis "A" between axes "1–6"

Reinforced concrete hollow core slabs with a width of 1.5 m. The thickness of the slabs is 220 mm. The reinforced concrete slabs and their connections are designed according to series 1.141–1 issue 60….64.

The roof is combined (flat) over reinforced concrete hollow core slabs with a thickness of 220 mm. The roofing is a multi-layer soft roof made of roofing felt over a layer of polymer insulation adhered with bitumen mastic over a 30 mm thick cement-sand screed. The roof has slopes of 3–8%. During the building's operation, the roof has been repaired several times. There is no internal or external drainage system.

The external longitudinal walls are load-bearing, and the end walls are self-supporting, made of ceramic bricks laid in cement-sand mortar with inserts of industrial brick blocks with a total thickness of 510 mm. The external surfaces of the first and ground floors

Fig. 3.20. Thermal expansion joint of the residential building along axis "5" between axes "A–H"

The external surfaces of the ground and first floors are faced with ceramic tiles on cement-sand mortar around the perimeter; from the second to the fifth floor, the brickwork is pointed (jointed). The internal wall surfaces are plastered with cement-lime mortar. The lintels of the wall openings are prefabricated reinforced concrete lintels according to series 1.138–10; a monolithic reinforced concrete ring beam (bond beam) is installed to support the roof slabs.

Partitions are made of brick laid in cement-sand mortar with a thickness of 120 mm and 250 mm, plastered with cement-lime mortar and finished with water-based emulsion paint.

The floors in the corridors of each floor and the ground floor are made of ceramic tiles; in the apartments, they are parquet, laminate, and roll materials; in the basement rooms – compacted soil.

The inter-floor staircases are made of prefabricated reinforced concrete ribbed flights and landings; the surfaces of the steps and landings are made of polished concrete.

The windows are wooden with double glazing and PVC windows.

The doors are wooden and metal, including armored (security) doors.

3.4. Volume-Planning Decisions for Specialized Residential Buildings

Specialized residential buildings include dormitories, boarding schools, and shelters. The features of such buildings, intended for temporary residence, are that, in addition to living rooms, they include premises necessary for servicing all residents of the building – lobbies with cloakrooms, dining rooms and restaurants with a complex of service premises, storage rooms, etc.

These types of buildings are usually designed according to a corridor layout. Collective service facilities can form a single volume with living quarters and are located on the first and second floors or adjoin the residential building, or are located in a separate volume connected to the residential building by walkways (Fig. 3.21).

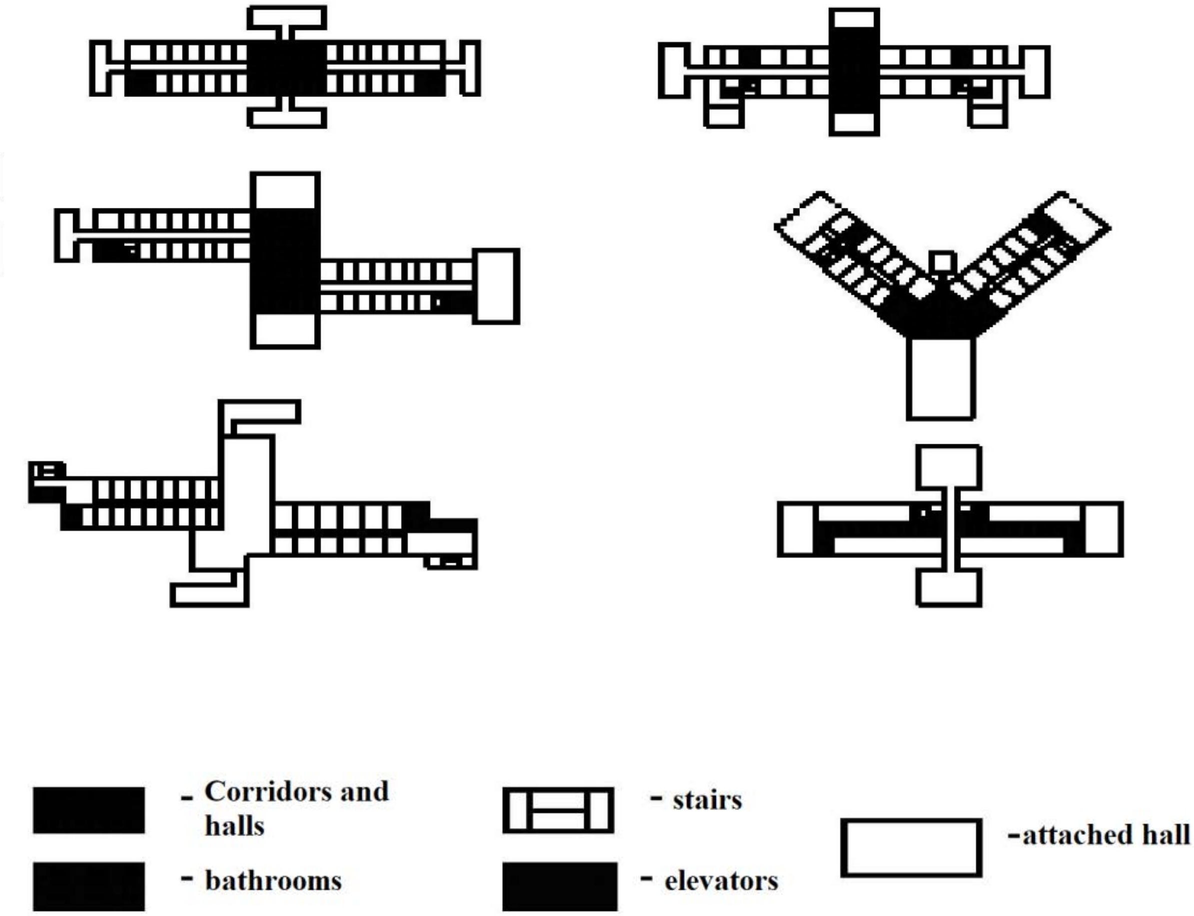


Fig. 3.21. Layout of corridor-type dormitory buildings

The plan of a typical floor of a hotel residential building has a corridor structure. Hotel rooms are designed for one, two, or three people. The room includes, in addition to the living room, bathrooms with a vestibule at least 1.05 m wide.

When designing dormitories, a corridor structure with living rooms designed for 3–6 people is used. The living area of the room is standardized at 6.0 m² per person, with no more than three people living in a room. Living rooms with areas of 12.0 and 18.0 m² are blocked in pairs with shared sanitary facilities. In dormitories for young families, a kitchen area can be included in the planning unit. Kitchens or kitchenettes are designed for one room with an area of at least 5.0 m².

Dormitories provide public areas for educational and sports activities, recreation and cultural events, including catering facilities, medical and household services, as well as administrative and utility areas.

Dormitories designed for young families include facilities for the temporary stay of children and strollers.

Residential buildings of dormitories are designed with two vertical evacuation staircases.

Premises intended for cultural and household services can be placed in separate blocks or located on the lower floors of the building. In dormitories for students of architectural and art institutes, studio spaces must be provided.

The total area of dormitories and specialized residential buildings for the elderly and disabled is determined as the sum of the areas of living rooms, utility rooms, public areas, as well as summer premises with certain coefficients.

The living area of dormitories is defined as the sum of the areas of living rooms, excluding built-in wardrobes.

The areas of public purpose premises must be no less than those specified in Table 3.2.

Specialized residential buildings for the elderly and families with independently mobile disabled people are built no higher than nine floors, and for families with wheelchair users – no higher than five floors.

Specific requirements are imposed on the utility rooms of apartments for families with wheelchair users, namely:

- the kitchen area should be at least 9.0 m^2;
- kitchens should have a width of at least 2.3 m – with one-sided and 2.9 m – with two-sided placement of equipment;
- the width of the vestibule is 1.6 m, and the corridors – 1.15 m;
- the dimensions of the bathroom in plan are 2.3×2.3 m, the toilet with a washbasin – 1.6×2.2 m, without a washbasin – 1.2×1.6 m;
- the depth of summer premises should be at least 1.4 m.

Table 3.2. Area of Public Spaces (per 1 person, m²)

Type dormitory	The number of residents of the dormitory							
for students of higher educational institutions and graduate students	25	50	100	200	400	600	800	1000
	3,0	2,6	2,5	2,5	2,5	2,4	2,4	2,3

In specialized apartment residential buildings, social service centers are provided: premises for cultural and mass events, premises for catering facilities, administrative and utility purposes, medical and household services. The requirements for the areas of public spaces are standardized according to Table 3.3.

Table 3.3. Public Areas in Accessible Housing

Types of specialized residential apartments houses	Number of residents			
	50	100	150	200
	Area of common premises destination for 1 person, m^2			
for the elderly	4,9	4,6	4,4	4,2
for families with disabilities	5,6	5,2	4,9	4,6

3.5. Features of Volume-Planning Decisions for Frame-Monolithic Residential Buildings

Monolithic reinforced concrete in the structures of mass-produced residential buildings is increasingly replacing the prefabricated construction method. The main advantage of constructing buildings from monolithic concrete using modern construction technologies is the virtually unlimited freedom of choice in the configuration of the building plan and its spatial planning decisions.

Such buildings stand out noticeably from the surrounding construction with original plasticity and non-standard decisions for facade planes, enriched by the structure of balconies and loggias.

3.5.1. Structural Decisions for Frame-Monolithic Residential Buildings

Frame-monolithic buildings are constructed in various versions of structural systems depending on the decisions of the main load-bearing structures: a wall system with a small spacing of load-bearing interior walls; a wall system with a large spacing of load-bearing interior walls; a frameless system with load-bearing columns; a frameless system with load-bearing pylons; a framed system with load-bearing columns.

Wall system with small (large) spacing of load-bearing walls. In such structural schemes, the load-bearing structures are transverse solid walls of monolithic concrete, located with a small (2.4–4.5 m) or a large spacing (up to 9.0 m).

The location of walls with a small spacing complicates the freedom of planning, especially in the case of apartment replanning.

Load-bearing interior walls are concrete slabs that work in eccentric compression. They are reinforced with two meshes connected by special reinforcing studs. A variant of reinforcement with vertical frames to which reinforcing meshes are attached is possible.

The frame structural system of the monolith provides freedom in the planning of residential premises, as well as the possibility of arranging non-residential premises (shops, cafes, restaurants) on the lower floors of buildings.

As in the wall system, the principle of continuous reinforcement is adhered to during the construction of load-bearing structures. Columns are reinforced with vertical bars with closed stirrups or vertical frames. Variants of the frame system are structural systems with flat pylons (Fig. 3.22).

They can be designed both with and without beams in the floor slab. Like frame systems, they offer freedom in planning decisions, but there are some disadvantages compared to the frame system: columns are replaced by flat wall sections, more developed compared to the cross-section of columns; in the beam system, beams appear in the interior of the premises.

It is worth noting that from the point of view of structural design, the beam system has advantages over the beamless one due to the simplification of slab reinforcement, which does not require strengthening of its column head area.

The dimensions of the pylons vary (200…300) × (900…1500) mm. The reinforcement of the pylons is determined by calculation.

For free planning of apartments, frame systems with a reduced number of internal supports are successful.

A feature of the static behavior of continuous monolithic reinforced concrete slabs is the presence of large support moments and shear forces. Therefore, the appropriate dimensions between vertical supports are 4.8 m or more, and for large loads on the slabs, monolithic reinforced concrete slabs of the following types are designed:

- ribbed, a slab with a thickness of 70–100 mm, which is monolithically connected to the main and secondary beams;
- beamless with a regular grid of columns and capitals that reduce the span dimensions and take up support moments.

Such structural decisions are also used for non-residential buildings. For modern high-rise residential buildings, a monolithic beamless frame with monolithic floor and roof slabs is a rational structural system. The design model of a frame-monolithic building includes the establishment of the space-planning parameters of a conditional multi-story frame. Multi-story frame-monolithic buildings are designed according to rigid structural schemes.

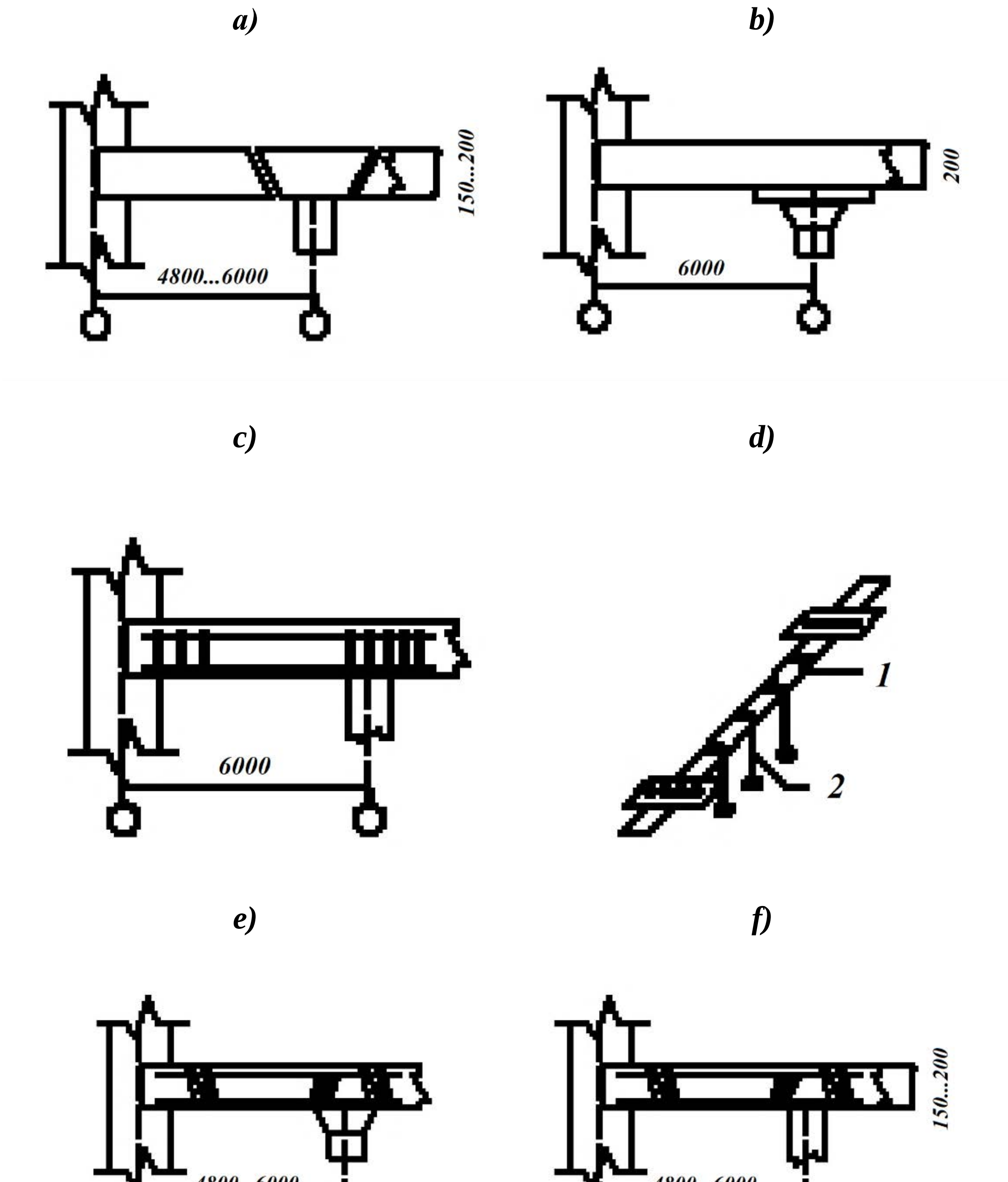


Fig. 3.22. Junction details of monolithic floor slabs with vertical supports:

a – punching shear scheme; *b* – column with a capital panel; *c* – column with a capital; *d* – plate; *e* – column with slab reinforcement using dowel plates; *f* – column without a capital; *1* – perforated plate; *2* – reinforcement and element with two heads

Designing buildings according to a rigid structural scheme involves combining their load-bearing elements into a single spatial system with the impossibility of displacement of individual elements of load-bearing structures during foundation deformations.

This requires: compactness of the building in plan; symmetrical and uniform arrangement of internal vertical load-bearing structures; arrangement of expansion joints in the building; increasing the spatial rigidity of the building using vertical diaphragms and stiffening cores; additional reinforcement of load-bearing structures; strengthening of foundations using monolithic solid slabs, cross beams, block walls, and pile foundations.

Balconies, Bay Windows, and Loggias:

Balconies: A balcony consists of a load-bearing structure, a floor, and a protective element or railing. The load-bearing parts of a balcony are made of precast reinforced concrete slabs (120 mm thick), cantilevered on one side into the wall and welded at the attachment point to metal anchors embedded in the wall (Fig. 3.23).

Bay Windows: A bay window is a part of a room enclosed by external walls that projects beyond the external plane of the facade and is illuminated by one or more windows. Bay windows can be trapezoidal, triangular, or semicircular in shape. A bay window increases the room area, improves lighting, and diversifies the facade.

Loggias: A loggia is a terrace built into the dimensions of the building, open on the facade side and enclosed on three sides by walls. They are designed in southern regions to protect rooms from insolation.

Stained Glass and Shop Windows (Display Windows): Stained glass is part of the external protection or enclosure of premises. Certain requirements are imposed on them: necessary light transmission and sound insulation, ensuring protection from atmospheric precipitation.

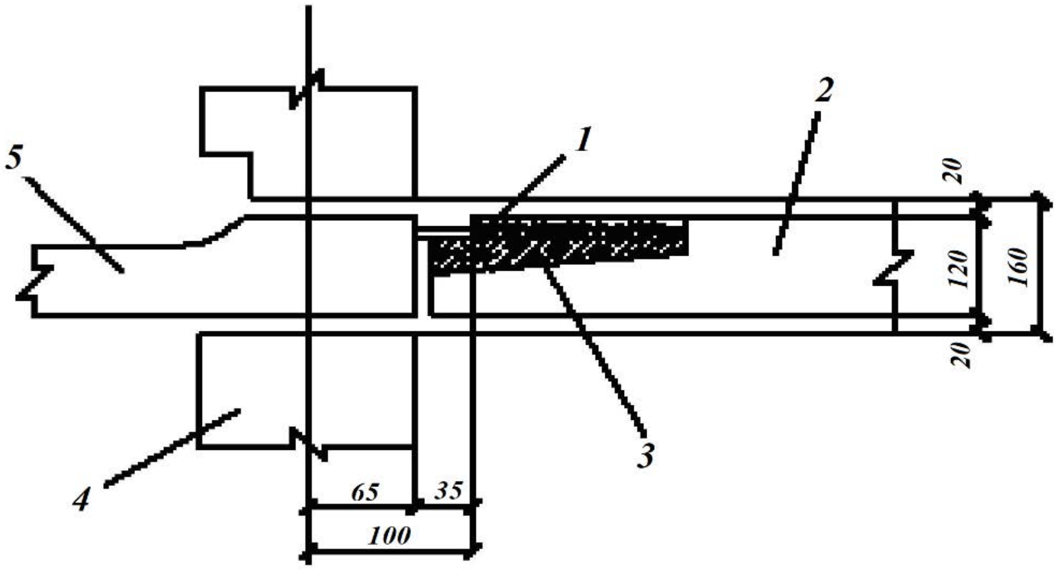


Fig. 3.23. Balcony slab connection detail in panel walls:
1 – reinforcement (rebar); *2* – floor slab; *3* – concrete class C8/10; *4* – external wall panel; *5* – balcony slab

Stained glass structures are subject to the following forces: wind loads, thermal loads, and self-weight (Fig. 3.24). The load-bearing structures of stained glass are made of aluminum alloys or metal.

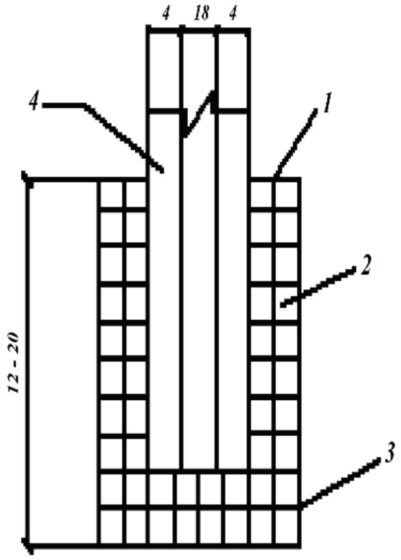


Fig. 3.24. Stained glass structure:
1 – grout; *2* – elastic rubber gasket; *3* – aluminum profile; *4* – window glass

Stained glass made of aluminum alloys offers several advantages, notably: they weigh 2.5–3 times less than metal (steel) counterparts, are strong, corrosion-resistant, benefit from a simple manufacturing process, and do not require additional painting. The disadvantages of aluminum-stained glass include: they are 8–10 times more expensive than metal (steel) counterparts and exhibit a high coefficient of thermal expansion. $\left(a = 2{,}3 \times 10^{-5} mm \cdot m/\ ^{0}C\right)$, at a temperature of 40°C, the elongation is 0.92 mm per linear meter), high thermal conductivity.

Different coefficients of linear expansion of glass and aluminum:$(0{,}95 \times 10^{-7})$ and$\left(a = 2{,}3 \times 10^{-5} mm \cdot m/\ ^{0}C\right)$ special elastic gaskets (or seals) and clearances (or gaps) are required at the points where the glass and frames are attached. This prevents damage from thermal deformations. Forces acting on the stained glass are absorbed by the mullions (or transoms) and frame members, which transfer the forces to the load-bearing frame and the building's floor slabs (or structural framework).

3.6. Features of Volume-Planning Decisions for Public Buildings

When designing public buildings, it is necessary to consider their specific characteristics.

The main feature is the diversity of types of public buildings and the functional processes within them, which in some cases are complex and involve the use of specialized equipment (e.g., mechanized stages in theaters, ice arenas).

A distinguishing feature of public buildings is the high concentration of people (e.g., the Olympic Sports Complex). Consequently, the design must address the issue of free movement of human traffic during evacuation after a performance or event.

Certain types of public buildings have increased fire safety requirements (e.g., stage scenery in theaters, laboratory installations). Public buildings are subject to sanitary and hygienic requirements. This influences the planning decisions (grouping of premises), the level of lighting and insolation of rooms, sound insulation requirements, as well as engineering equipment (heating, ventilation).

A characteristic feature of public buildings is the combination of rooms with different geometric parameters (area, height). In public buildings, up to 30% of the total area is occupied by circulation spaces (corridors, lobbies). The geometric parameters of the rooms in public buildings determine the use of different spans (small, medium, large).

An important feature of public buildings is their architectural and artistic design. Depending on their social and urban planning significance, public buildings can be centers of development, including large architectural urban ensembles.

3.7. Volume-Planning and Structural Decisions for Industrial Enterprises

The spatial and volume decisions of any industrial building depend on the technological process inside the building.

The technological process depends on the production and technological scheme, which establishes the sequence of operations, provides for technological equipment, type of transport, internal temperature and humidity conditions, and more.

The technological scheme is a decisive factor in choosing the number of floors in a building.

The complex of building planning issues includes ensuring operational qualities, which largely depends on the location of individual production areas.

For example: rooms with wet processes should be located inside the building (to avoid condensation on the walls), rooms with hot processes near the external walls, to improve ventilation.

All types of planning can be divided into 2 main types: separate and continuous (or integrated).

Separate planning is used in enterprises with low capacity. When all production facilities are located in small separate buildings with limited-size spans.

But such enterprises have disadvantages:

- large building area, which increases the length of engineering and transport networks and the amount of work on landscaping;
- lack of continuous production flow.

Modern practice shows that it is advisable to block productions with a similar technological process in one building.

For a significant number of industries, it is possible to place all main, auxiliary, ancillary, and storage facilities in a building under one roof.

Blocked buildings with multi-span large-area structures have continuous (or integrated) planning. Blocked buildings allow reducing the area of the factory site by 30-40%, reducing the perimeter of external walls by up to 50%, reducing construction costs by 10-15%, reducing the length of communications and operating costs of the building.

However, excessively large buildings have disadvantages:

- costs for lighting the premises;
- complications in roof drainage;
- complications in personnel movement and cargo transportation.

Therefore, blocked buildings should not be designed with an area larger than 30–35 thousand m².

It is advisable to block workshops when the production does not need to be separated by load-bearing walls and the difference in their height does not exceed 2 m, if the conditions of technological production and working conditions are not worsened (Fig. 3.25).

When blocking production in a building with continuous development (or integrated layout), zoning is used. Zoning involves, where possible, within the building volume, the rational grouping of areas and zones in accordance with certain characteristics (level of production hazards, fire and explosion safety, optimization of transport and human flows).

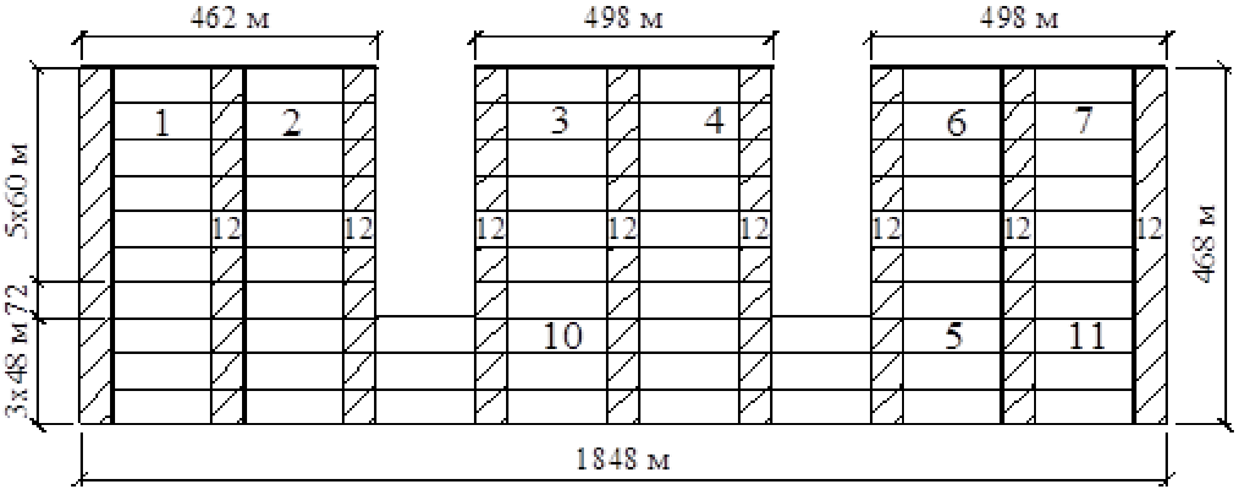


Fig. 3.25. Plan of the main building in Tolyatti:
1 – painting shop; *2* – body assembly shop; *3* – parts manufacturing area; *4* – engine assembly department; *5* – gearbox assembly; *6* – materials warehouse; *7* – machining department; *8* – maintenance area; *9* – wheel manufacturing; *10* – conveyor; *11* – testing and dispatch area; *12* – utility and support spaces

Zoning can be horizontal (on a floor) and vertical (in multi-story buildings). However, in single-story buildings, there can also be both horizontal and vertical zoning, as engineering utilities are placed above or below the working area within the space between trusses and in underground channels.

3.8. Improvement of Volume-Planning Decisions for Industrial Buildings

In modern foreign and domestic practice, technologies in various industries change every 2–3 to 10–12 years. At the same time, the dimensions of technological equipment and their placement often change.

As a result, industrial buildings are designed for a specific period (20–100 years or more).

With rapid technological updates, buildings that are easily reconstructed without disrupting the building's foundation are appropriate; such buildings are called flexible.

The principles of blocking different production facilities in one building, as well as the need to replace the technological process, initiated universal buildings.

Flexible buildings are characterized by different sizes of column grids. Depending on their size, they are divided into:

- low flexibility (3×3 to 18×12 m);
- medium flexibility (24×12 to 30×12 m);
- high flexibility (36×12 m and more).

Universal single-story buildings are characterized by a large column grid (24×12, 9×9, 12×12, 18×12 m, ...), a constant height of all spans, and the use of lifting and transport equipment in two mutually perpendicular directions (for this, overhead traveling cranes, suspended conveyors, gantry cranes, etc. are used).

In some cases, in universal buildings, instead of special foundations for equipment, a continuous foundation slab is used, on which equipment can be placed at any point.

The use of a large column grid allows saving 20% of the area in the middle of the building due to columns and internal walls.

In multi-story buildings, a large column grid is also used (9×9 m; 12×12 m; 18×12 m), Fig. 3.26.

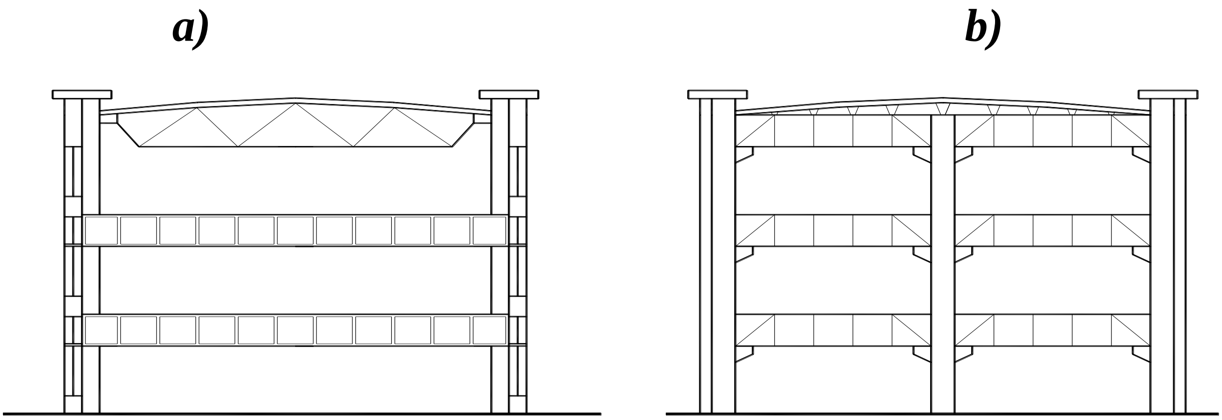


Fig. 3.26. Multi-story buildings with technical floors:
a – floor slabs on wall-beams;
b – floor trusses

However, this leads to more complex floor structures. Instead of simple solid cross-section transverse beams, more sophisticated structural decisions are employed.

The height of these floors’ ranges from 2 to 4 meters, making them suitable for technical and technological purposes. Technical floors accommodate utilities, engineering equipment, service areas, and storage.

In buildings with technical floors, the usable floor area decreases (by 10–16%), but their operational efficiency improves (by 16–20%). Furthermore, the presence of technical floors enhances hygienic and acoustic conditions.

In certain industries where technologically advanced equipment, complex in shape and volume, is employed, efforts are made to ensure independent installation of the equipment from the building's primary structural elements. In such production facilities, a pavilion-type building has evolved, Fig. 3.27.

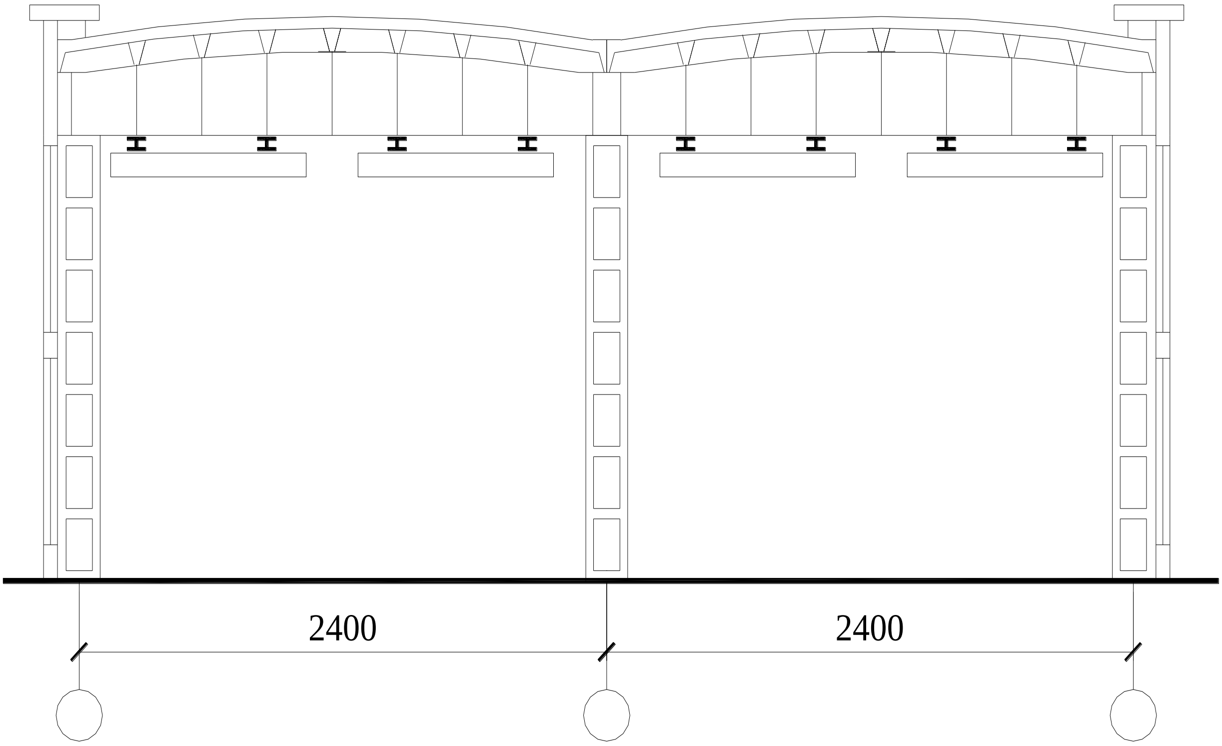


Fig. 3.27. Pavilion-type building

Such buildings are designed as single-story structures using large column grids (24×12 m; 30×12 m; 36×12 m and larger) and with heights ranging from 8 to 25 m.

3.9. Modeling Methods

The model method of equipment layout using models or templates simplifies the resolution of technical details, reduces errors and drawing preparation time, and provides a clear visualization of the technological process.

Model-based design involves creating scaled models (1:20–1:50) of machines, units, buildings, and structures.

The models are assembled on special tables with a coordinate grid. They should represent the object in miniature before its commissioning. When designing low-rise buildings with a large footprint, instead of the model method, a method of equipment layout using two coordinate templates made of cardboard, plywood, or sheet plastic is employed.

A model completed using the opaque template method is photographed, after which dimensions, labels, and scale are added to the photograph.

Nowadays, the model method is being replaced by computer modeling [13, 20, 48, 58, etc.]. Computer modeling reduces the labor intensity of the modeling process and offers greater visualization capabilities and the ability to generate drawings at any stage.

3.10. Selection of the Industrial Building Profile

The profile of an industrial building usually refers to its cross-section. The determining factors in choosing a profile are: technological conditions, lighting and air exchange, climatic features, and roof slope, Fig. 3.28.

Depending on these conditions, the building profile can have one or more spans of the same or different heights, Fig. 3.29.

Buildings with mechanical ventilation have a simple and regular profile; however, the building profile becomes significantly more complex with natural ventilation of the premises, when special skylights are provided on the roof. Buildings with an active aeration profile are more complex, with alternating high and low spans with skylights, Fig. 3.30.

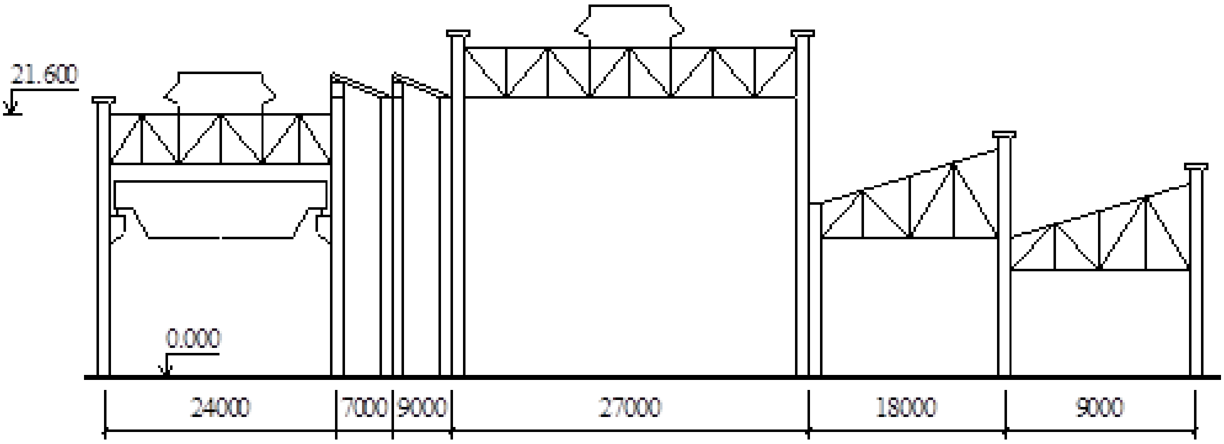


Fig. 3.28. Profiles of varying spans and heights

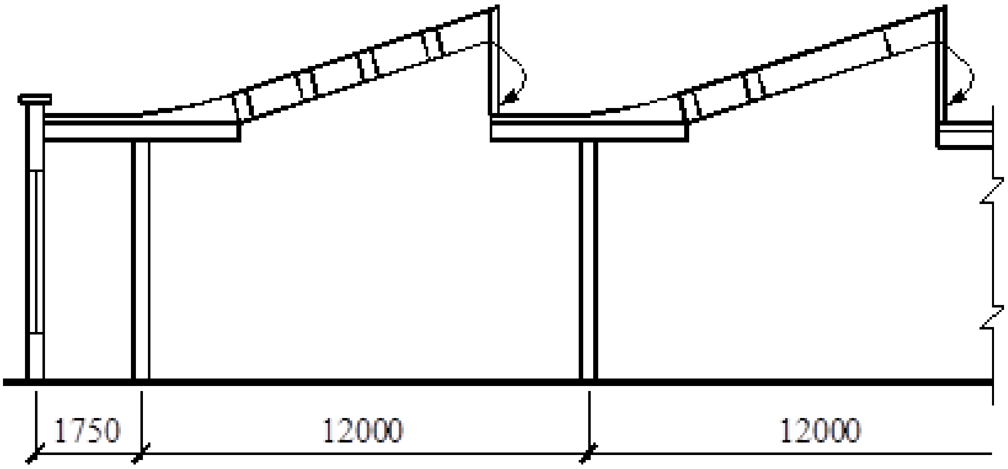


Fig. 3.29. Building with a sawtooth roof (or shed roof)

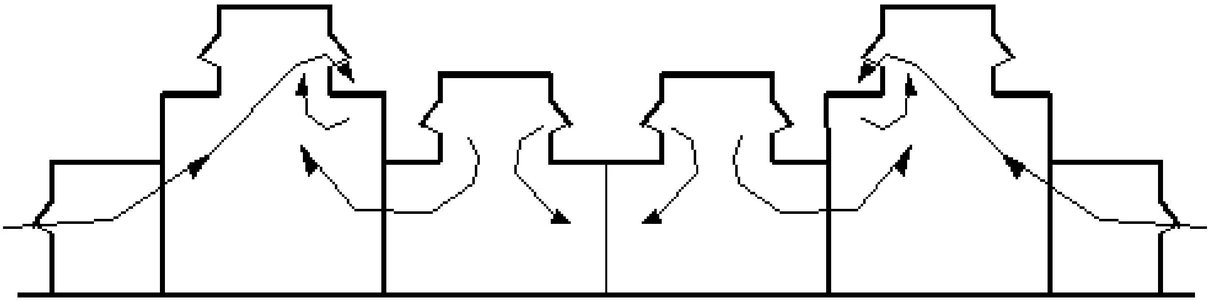


Fig. 3.30. Active aeration building profile

The climatic factors influencing a building's profile include wind, precipitation, temperature, solar radiation, and others. In the north, where there are more snow and a need to conserve heat, the form should be compact. In the south, flat roofs that cool down more quickly are practical. The slope depends on the amount of precipitation. The building profile depends on the roofing material: asbestos-cement roofs require a steeper slope than rolled roofs.

In industrial construction, coverings in the form of shells, folds, suspended systems, and other structures are used, which are sometimes close to natural forms.

3.11. Principles of Structural Decisions for Industrial Buildings

The structural solution of a building is determined at the design stage and consists of choosing a structural and building system and a structural scheme [3, 24, 33].

The structural system is a set of interconnected vertical and horizontal load-bearing structures of a building that ensure strength, stiffness, and stability.

The building system depends on the material of the structures and the method of its execution.

The structural scheme depends on the arrangement of load-bearing elements.

In frame buildings, 3 structural schemes are used:

→ frame;
→ frame-braced;
→ braced.

The scheme with transverse crossbars is more commonly used.

The structural scheme with longitudinal girders made of prefabricated elements provides less building stiffness. This scheme is used for complex planning and low loads.

Beamless schemes are used in buildings with special requirements for sanitation and microclimate.

3.12. General Fire Safety Measures for Buildings

In buildings, special measures are applied to reduce the possibility of fire occurrence, prevent its spread within the building, facilitate firefighting, maintain strength and stability, ensure rapid and safe evacuation of people, and eliminate the consequences of a fire [12].

To limit fire in public buildings, the space is divided by firewalls ("screens") into parts that extend above the building's roof by at least 0.6 m if the roof is made of materials of flammability groups G3, G4 (medium and increased flammability), and by 0.3 m if made of materials of flammability groups G1 and G2 (low and moderate flammability).

Firewalls may not extend above the roof if all covering elements, except for the roofing made of non-combustible materials.

It is allowed to place windows, doors, and gates with non-standardized fire resistance limits in the external part of the firewall at a distance of at least 8 m vertically above the roof and at least 4 m horizontally from the wall of the adjacent part of the building.

If the distance is less than 4 m, the openings must be filled with fire-resistant doors, windows, and gates of the 2nd type.

The total area of openings in a fire barrier, excluding elevator shafts and lobbies, should not exceed 25% of its area (the total area is determined separately within the floor).

An important fire safety measure in public buildings, which affects the space-planning solution, is ensuring reliable and rapid evacuation of people.

Exits are classified as evacuation exits if they lead from the premises:

a) from the 1st floor to the outside through a corridor, lobbies, or a staircase;

b) any above-ground floor, except the first: through a corridor, hall to a staircase of type C3 (see DBN V.2.2-28; DBN V.2.2-24);

c) an adjacent room on the same floor that is provided with exits;

d) basement, cellar, underground floors – to the outside through a corridor, a staircase that has an exit to the outside isolated from the floors above. Evacuation exits are not arranged through sliding and lifting-and-lowering doors and gates, revolving doors, turnstiles.

At least 2 evacuation exits should be provided from the building, except for cases provided by ND (normative documents).

It is allowed to provide one evacuation exit from:

a) room with no more than 50 people present, and the distance from the farthest point to the exit is 25 m;

b) room with an area of no more than 300 m^2, located in the basement, cellar, underground floors with the number of permanently present people – 5 people. If there are 6–15 people, a 2nd exit through a hatch with dimensions of 0.6×0.8 m with vertical metal stairs at least 0.45 m wide, or through a window with dimensions of at least 0.75×1.5 m is allowed. The exit through the pit must be equipped with metal stairs;

c) evacuation exits should be located dispersed. The minimum distance L (m) between evacuation exits is determined by the formula: $L = 1.5\sqrt{P}$, where P is the perimeter of the room (m)

The room is measured along the perimeter of the interior walls. The height of the exits must be at least 2.0 m, and the width is 0.8 m.

The height of doors and passages of basement, cellar, underground floors is allowed 1.9 m, and the height of doors leading to the attic is 1.5 m.

From technical floors intended for engineering equipment, doors of 0.75×1.5 m or hatches of 0.6×0.8 m equipped with metal vertical stairs are allowed. If the area of the technical floor is up to 300 m^2, one exit can be made, and for every 2000 m^2 at least one exit must be provided.

3.13. Structural Decisions for Stairs. General Provisions and Classification of Stairs

The placement of buildings with different floor heights one above the other or next to each other, for the purpose of providing connection, emergency operation, and transportation of objects using stairs and ramps. The level of the terrain around and the floor level in the building are usually also connected by stairs at the entrance to the building.

Modern stairs are not only vertical connecting elements of space but also interior decoration. Combining functionality with aesthetics, stairs are distinguished by a variety of architectural and structural decisions.

The classification of stairs is reduced to the following characteristics: by purpose, according to operational and aesthetic requirements, by location, in relation to the building's volume, by the degree of enclosure from the building's interior space, by the method of functioning, by material, by shape, by the number of flights, by the method of support of the steps, by the angle of inclination of the flights, as well as by fire-technical characteristics.

Depending on the purpose, stairs are divided into:

- main or principal, which provide communication between floors and evacuation;
- auxiliary, designed for communication with basements, attics, etc.;
- emergency, which are backup evacuation routes;
- fire escapes, which provide external access to floors, attic, roof during a fire.

According to the proposed operational and aesthetic requirements, the following stairs are distinguished: decorative-ceremonial; ceremonial (main); side (auxiliary); entrance.

Depending on the location relative to the building, stairs are internal and external.

Internal stairs in relation to the building's volume can be (Fig. 3.31): inside the building's volume; adjacent to the wall; partially protruding; fully protruding.

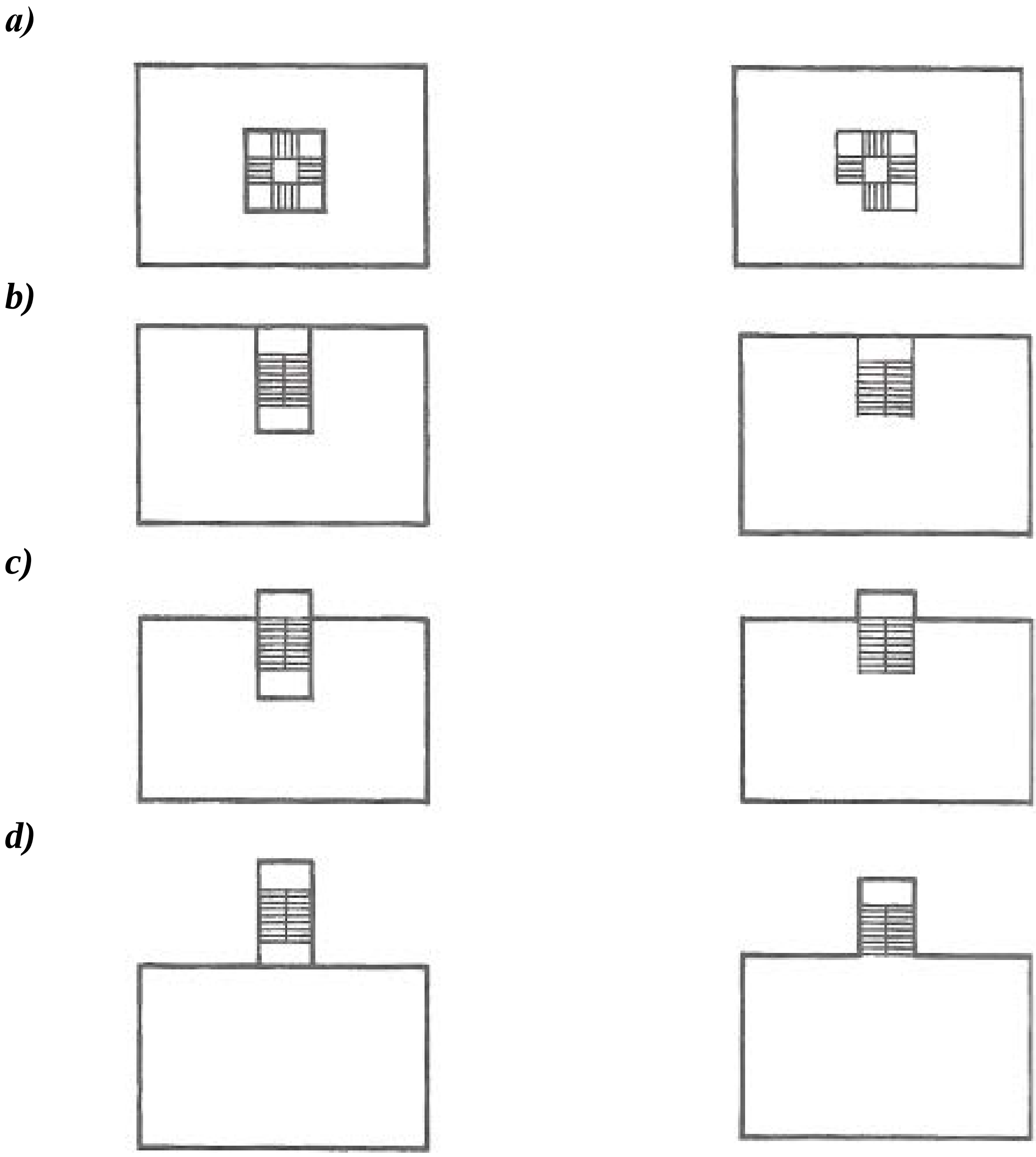


Fig. 3.31. Types of stairs (stairwells) depending on the degree of enclosure - openness and location in the building: *a* – inside the volume; *b* – adjacent to the wall; *c* – partially outstanding; *d* – fully outstanding

Internal stairs, according to the degree of their enclosure from the building's interior volume, are divided into (Fig. 3.31): enclosed, partially open, and open.

In Fig. 3.32, the following designations are introduced:

→ **Single-flight:** 1 – straight, 2 – with winder steps; 3, 4 – curvilinear;

→ **Double-flight:** 5 – straight; 6–10 – with a turn of 60°, 90°, 120°, 180°, 240°; 11–14 – with two outgoing flights; 15–18 – with two starting flights; 19–20 – with two starting and outgoing flights; 21–22 – curvilinear; 23 – circular;

→ **Triple-flight:** 24–29 – turning; 30–31 – with two intermediate and outgoing flights; 32 – with two starting and intermediate flights; 33 – curvilinear (oval);

→ **Quadruple-flight:** 34–36 – turning; 37–45 – with straight and winder steps; 46–53 – only winder steps; 54–55 – spiral with winder steps.

According to the method of functioning, stairs are divided into stationary, transforming, and portable.

According to the material of the main elements, stairs are: stone; concrete (reinforced concrete); metal; wooden; plastic; glass; combined.

According to the shape in plan (horizontal projection of movement on the stairs), all stairs are subdivided (Fig. 3.32) into: straight (rectilinear); with a turn of straight flights (broken); curvilinear; with a turn of curvilinear flights; circular; spiral.

According to the space-planning solution, stairs, depending on the number of flights and intermediate landings per floor height, are divided into: single-flight without intermediate landings, double-flight with one landing, triple-flight with two landings, quadruple-flight with three landings.

According to the method of supporting the stairs on load-bearing elements, stairs are divided (Fig. 3.33) into: on a solid base (slab, ground); on stringers; on carriages; cantilevered on walls or columns; cantilevered spiral on a central column; supported on walls; supported on columns; suspended (to handrails, floors, walls); chain prefabricated demountable; combined.

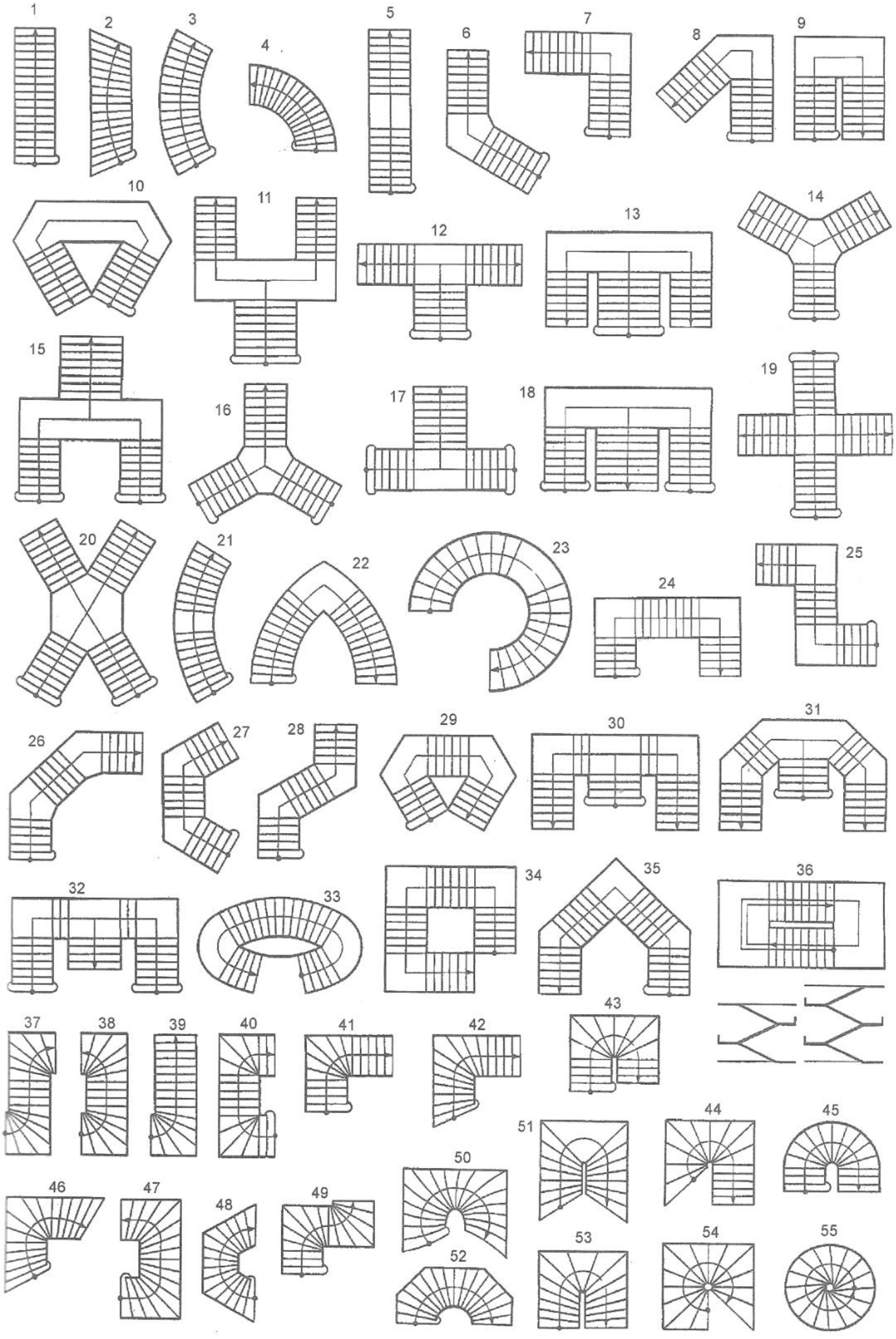


Fig. 3.32. Staircase variations by flight and landing shape, number of flights, and tread shape

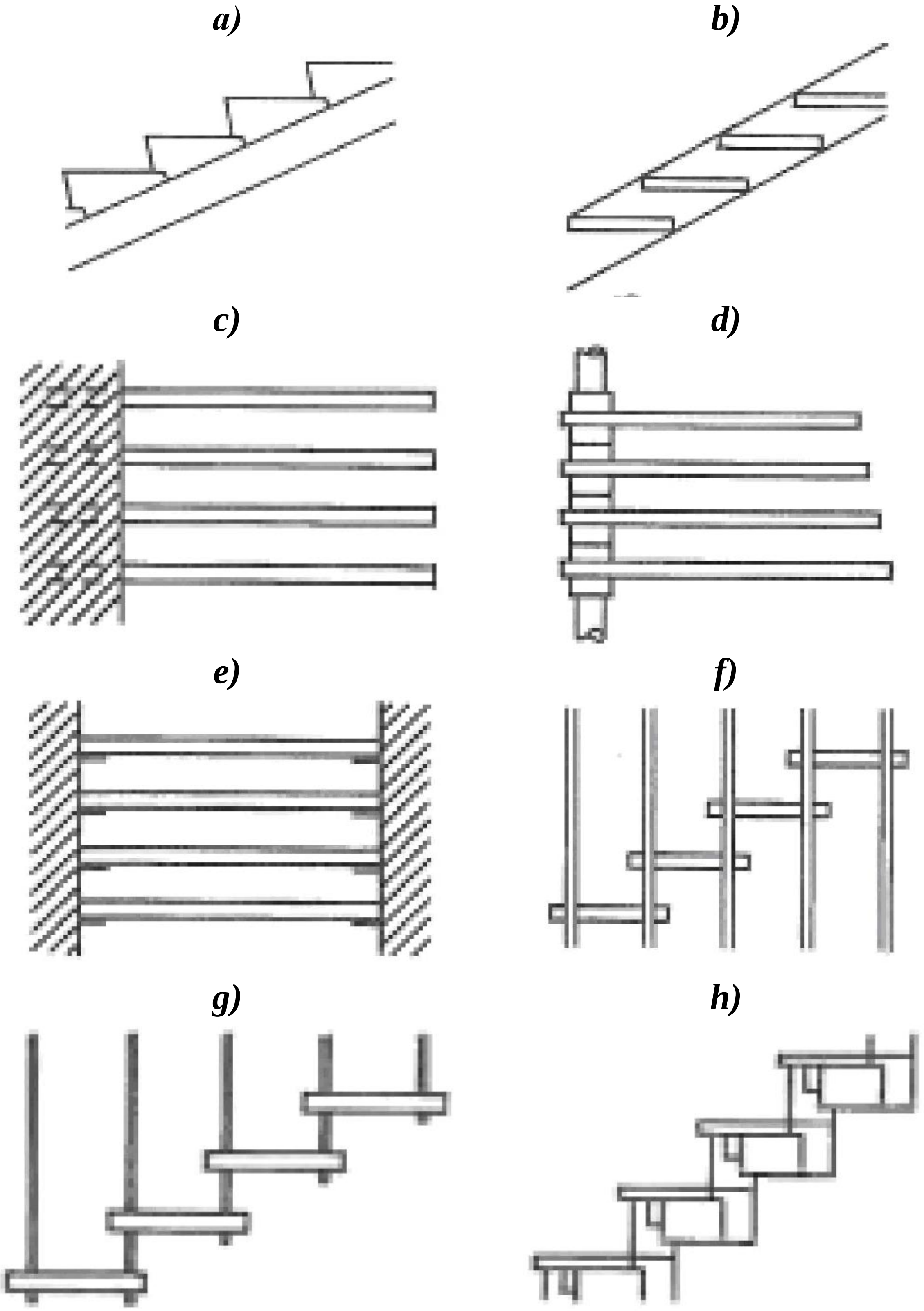


Fig. 3.33. Types of stairs according to support methods: *a* – on stringers; *b* – on carriages (string boards); *c* – cantilevered on the wall; *d* – cantilevered spiral on a central column; *e* – supported on the wall; *f* – supported on columns; *g* – suspended; *h* – chain prefabricated demountable

The classification of stairs by size is given in tables 3.4 and 3.5 and in Fig. 3.34.

Table 3.4. Slopes of stairs and ramps

Name	Slope	
	degrees	%
Main stairs	14 – 45	25 – 100
Auxiliary stairs	45 – 60	100 – 173
Auxiliary stairs	60 – 90	more than 173
Ramps	5 –14	9 – 25

Table 3.5. The slopes of the stairs depending on their purpose

Appointment, type of movement	Slope	
	degrees	%
Garden, terrace, external, entrance stairs	14 – 20	25 – 36
Stairs for mass movement of people	20 – 30	36 – 58
Stairs of residential buildings, general purpose for small mass movement	30 – 40	58 – 84
External and internal stairs of residential buildings	35 – 45	70 – 100
Stairs of residential buildings, apartments for temporary connection	45 – 60	100 – 175

According to fire classification, stairs and stairwells intended for evacuation are divided into:

→ stair types: 1 – internal, located within walls; 2 – internal open; 3 – external open;

→ ordinary stairwells of the following types: glazed or with open openings in the external walls on each floor; with natural lighting through glazed or open openings in the roof;

→ smoke-free stairwells of the following types: with entrance to the stairwell from the floor through an air zone via open walkways, while smoke-free conditions of the walkway must be ensured; with air pressurization to the stairwell during a fire; with exit to the stairwell from the floor through an airlock with air pressurization.

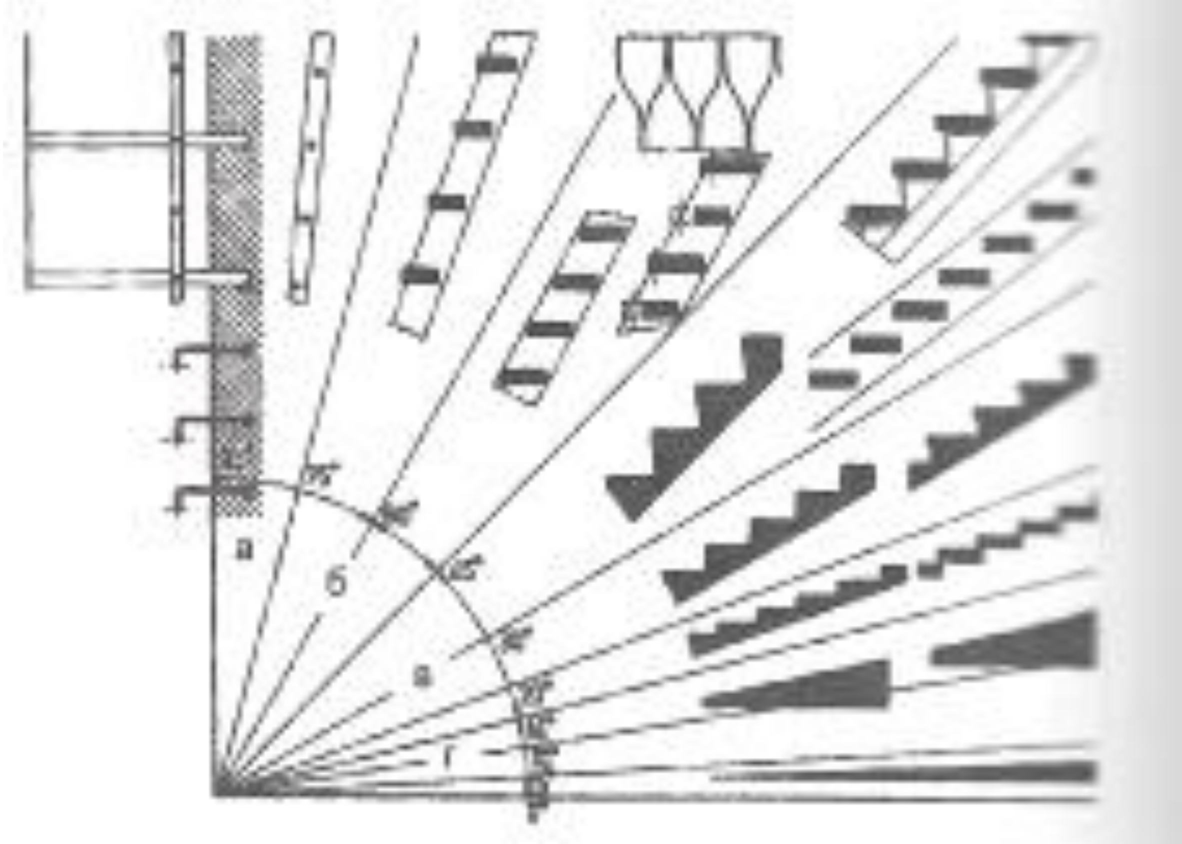


Fig. 3.34. Slopes of stairs and ramps: *a* – ladders; *b* – temporary stairs; *c* – main stairs; *d* – ramps

For fire extinguishing and rescue operations, the following types of fire ladders are provided: vertical; flight with a slope of no more than 6:1.

3.14. Requirements for stairs

Stairs are a high-risk area, therefore, when designing them, special attention must be paid to a number of issues that allow minimizing this risk.

The slope and width of stair flights, the height of the stairs, the width of the stairs, the width of stair landings, and the headroom on the stairs must ensure comfortable and safe movement and the possibility of moving objects in the building.

The number of risers in one flight between stair landings (with the exception of curved auxiliary stairs) should be no less than 3 and no more than 18. In single-flight stairs, as well as in one flight of two- and three-flight stairs within the first floor, no more than 18 risers are allowed.

The use of stairs with different step heights is not allowed.

The width of stair landings should be no less than the width of the flight and no less than 1.2 m.

The width of stair flights in public buildings should be no less than: 1.35 m – for buildings with no more than 200 people on the most populated floor; 1.2 m – for buildings leading to premises not related to the presence of spectators; 0.9 m – in buildings leading to premises where no more than 5 people are simultaneously present.

The slope of stair flights in above-ground floors of general-purpose buildings should be no more than 1:2; for stairs leading to basements and ground floors, to the attic, a slope of 1:1.5 is allowed.

The smallest width and the largest slope of stair flights of residential buildings should be taken in accordance with Table 3.5.

The distance between two flights or between a flight and the ceiling should be at least 2 m vertically to ensure free movement of an adult.

The height of stair railings should be sufficient to prevent falls and be at least 0.9 m. The railings should be continuous, equipped with handrails and designed to withstand loads of at least 0.3–1.0 kN/m (30–100 kgf/m), depending on the building's purpose.

Stairwells are designed with **natural lighting** through openings in the external walls (except for basement stairs). The first and last steps should be particularly brightly lit. In some cases, an automated system that turns on artificial lighting for a short time, sufficient to go up or down the stairs, is convenient.

It is not recommended to provide spiral stairs and escape ladders on evacuation routes. When using curved ceremonial stairs, the width of the stairs in the narrow part should be at least 22 cm, and for service stairs – at least 12 cm.

One of the internal stairs in buildings of fire resistance degrees I and II up to 9 floors high can be open to the full height of the building, provided that the room where it is located is separated from the adjacent corridors and other rooms by fire partitions.

In buildings of fire resistance degrees I–III, the internal stairs from the lobby to the second floor can be open if the lobby is separated from the corridors and other rooms by fire partitions with ordinary doors.

In buildings 28 m high (10 above-ground floors) and higher, stairwells should be designed as smoke-free. One of the two stairwells must be a smoke-free type (with entrance from the floor through an air zone).

Stair components. The main elements of **stairs are steps**, which allow achieving the main goal – vertical movement. The first step in a **stair flight** is the entrance or **starting step**; **intermediate steps** are located between the starting and **ending step**; the ending step adjoins the landing of the opposite level.

According to the plan form (Fig. 3.35), stair steps are distinguished: straight (rectangular), beveled, wedge-shaped (winding), and arcuate.

According to the vertical cross-sectional shape, stair steps can be (Fig. 3.36): flat solid (closed); profiled solid (closed); open.

The upper horizontal platform of the stairs (working surface) is called a tread. The difference in levels between the horizontal platforms of the steps (treads) is called a riser.

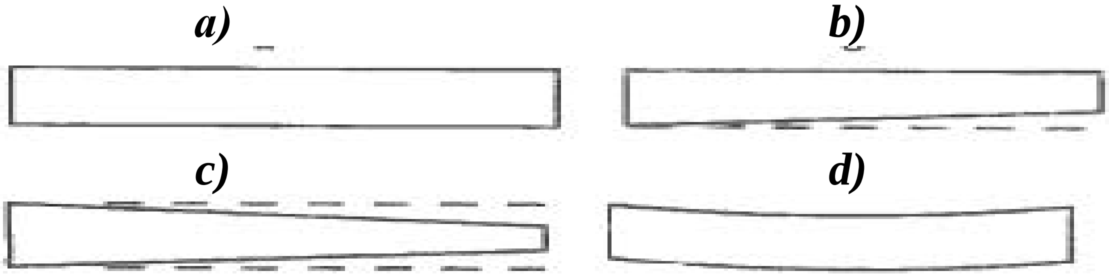


Fig. 3.35. Stair shapes in plan: *a* – straight; *b* – angled; *c* –winding; *d* – curved

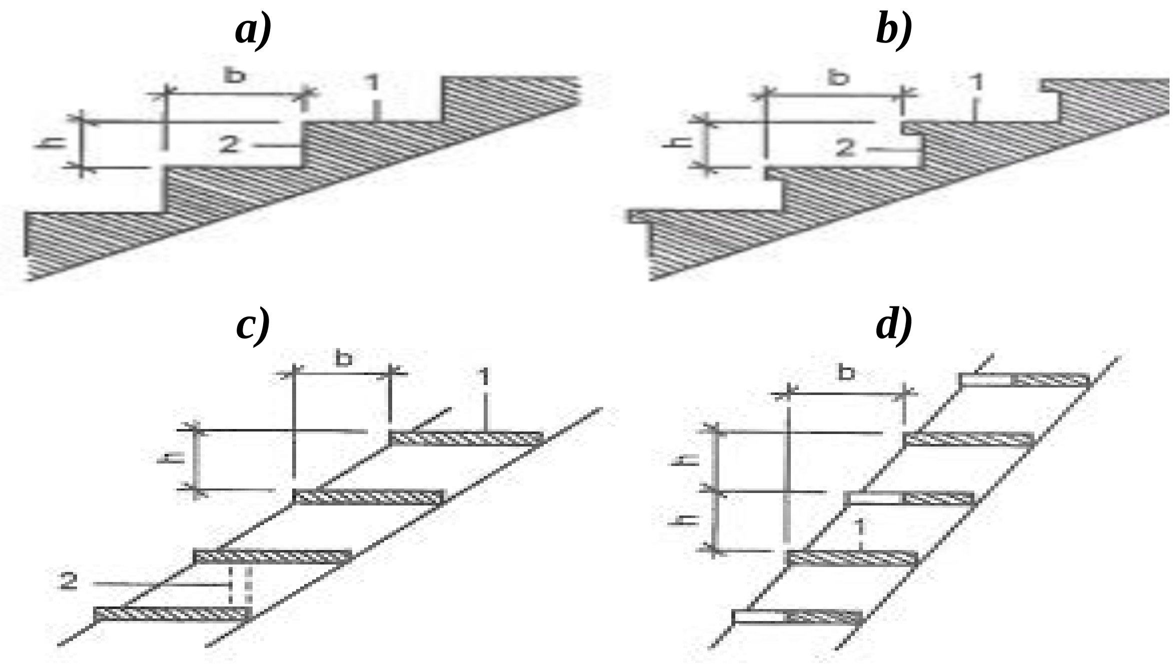


Fig. 3.36. Types of stairs: *a* – flat solid (closed); *b* – profiled solid (closed); *c* – open; *d* – butterfly type open; *1* – tread; *2* – riser; b – tread width; h – riser height

Depending on the structural and static characteristics of the stairs, their steps can have different support options (Fig. 3.37), the main ones being:

- embedding in a sloping slab (monolithic version);
- embedding in a stringer (monolithic version);
- support on a stringer;
- embedding in a string (monolithic version);
- support on a string;
- support on the wall from above;
- support on the wall from the side;
- support on a column;
- embedding in the wall;
- suspension (to handrails, floors, walls).

In this case, each step can be supported along its entire length (for example, on a slab in a monolithic concrete version), only on one side (in the case of a cantilever solution with embedding in a wall or column, with support on a column); in most cases, stairs are supported on two sides or, with a large width, on three supports (on walls, on stringers).

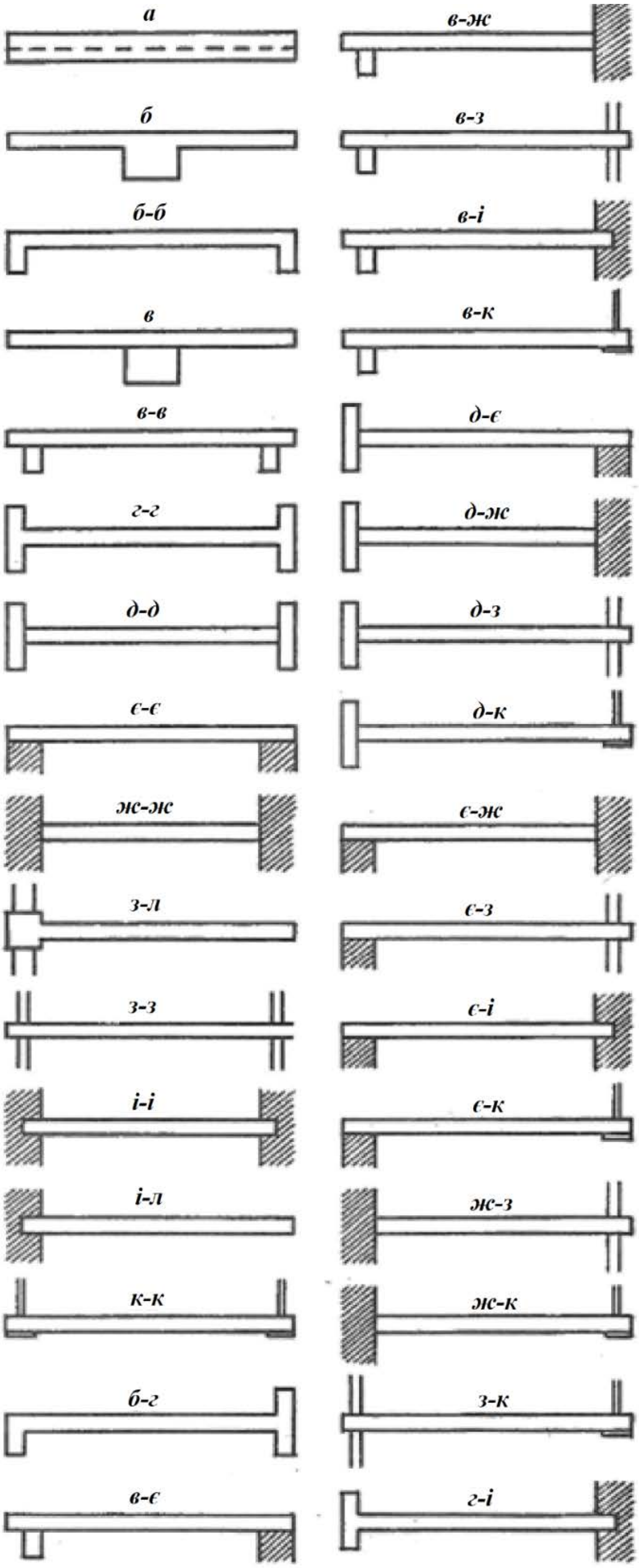


Fig. 3.37. Variants of step support in various stair designs

A continuous row of steps is called a **flight of stairs**. Depending on the configuration in plan, straight and curved (oblique) flights are distinguished.

In multi-flight stairs, according to the semantic meaning of their names, there are starting (initial), intermediate, and ending (final) flights.

The width of the **risers of the stairs** is determined (measured) along the line of travel – the line along which they go up or down the stairs. The line of travel of a stair flight is imaginary and passes through the middle of the flight for straight stairs.

In the case of a flight with a curved or broken guide, in which the edges of the stairs are not parallel, it passes at a distance of 25–35 cm (on average 30 cm) from the outer edge of the useful (working) width of the stair flight.

The tread width as a supporting surface for the foot is constant for stairs with straight flights; for stairs with curved flights (spiral), it is minimal near the central axis and maximal at the outer perimeter.

For spiral stairs, the tread width should be at least 100 mm at a distance of 150 mm from the edge of the step (or from the column).

The horizontal section connecting stair flights is called a landing. Starting and ending landings are distinguished – their levels coincide with the floor levels (floor landings), as well as intermediate (mid-floor) landings. Intermediate landings are arranged for ease of walking on stairs with a large number of steps (more than 15–18), as well as at the turning points of the stairs.

The shape of the landing depends on the relative position of the flights and can be rectangular, triangular, polygonal, or have a curved outline in plan. If the direction of the horizontal projections of two flights is perpendicular to each other, the landing can have the shape of a square or a quarter circle; if the direction of the flights in plan is parallel to each other, the shape of a rectangle or a semicircle.

A two-flight staircase, where the starting flight leads to an intermediate landing, from which two other flights diverge in different directions, is called a bifurcated staircase.

The shape formed when using radial stairs cantilevered to the central column of the stairs is called a spiral staircase.

Example of the spatial and structural decisions of stairs

Building of the "B" block of KNLU is located at 73 Velyka Vasylkivska Street, Pechersk district, has axial dimensions in plan 36.0×15.0 m, floor height 3.90 m, vestibule height in axes "2–5", "B–H" 5.0 m (Fig. 3.38–3.46).

The building has a frame structural system, with a grid of reinforced concrete columns 6.0×6.0 and 6.0×3.0 m.

The building is equipped with three passenger elevators with a lifting capacity of 500.0 kg and two stairwells in axes "1–2", "B–H" and "7–8", "B–H".

Fig. 3.38. Entrance area of building "B" in axes "3–5"

Monolithic reinforced concrete stairs with winders are located in the lobby between axes "2–4", "B–H", at elevation -1.100 (Figs. 3.41, 3.42).

According to the engineering-geological survey of this area, the soil of the construction site consists of layers:

- to a depth of 0.40 m, fill soil, represented by crushed stone and sand;

- below to a depth of 1.20 m, silty loamy sand yellowish-brown, layer 0.8 m;
- 9.50–12.50 m silty light gray, quartz sand;
- to a depth of 4.5 m, "brown" clay, yellow, yellowish-gray, light, of solid consistency, layer 3.30 m;
- to a depth of 21.40 m, light greenish-gray, brown, silty loam, of hard plastic consistency, with sand interlayers, layer 1.7 m.

Standard characteristics for the base under column foundations and a monolithic stair slab are density ρ=1.94 g/cm3, specific cohesion C=33.0 kPa, angle of internal friction φ=15°, deformation modulus E=22.0 MPa.

Fig. 3.39. Fragment of the facade of building "B" in axes "1–3"

Groundwater was found at a depth of 6.0 m from the ground surface. Seasonal fluctuations in groundwater level are within 0.8 m. Groundwater is non-aggressive to concrete and metal. The maximum freezing depth of the soil is 1.15 m.

The foundations under the stairs are a monolithic reinforced concrete slab with plan dimensions of 2.5×2.5 m, 500 mm thick, made of C20/25 concrete.

The supporting structure of the stairs is a curvilinear monolithic reinforced concrete beam made of C20/25 concrete, with a cross-section of 490×750 (h) mm, which rests on the foundation slab in axes "3–4", "B–H" at elevation -1.100 and a monolithic reinforced concrete longitudinal beam of the second floor slab at elevation +3.900. Monolithic reinforced concrete steps of trapezoidal shape in plan, with dimensions of 440×230 mm, a riser height of 140 mm, and a length of 1820 mm, rest on the curvilinear beam (Fig. 3.44), concrete class C20/25.

Fig. 3.40. Lobby area of the building in axes "3–5", "A–B" at elevation -1.100

Steps and landings are faced with marble slabs, 16 mm thick. Steel plates with dimensions of 490×150 mm and 280×150 mm are welded to the side surfaces of the steps, to which the railing posts are attached.

The lobby floor is mosaic concrete, 50 mm thick.

Fig. 3.41. Monolithic reinforced concrete stairs with winders in axes "2–4", "B–H", at elevation -1.100

Fig. 3.42. Monolithic reinforced concrete stairs designed to connect the lobby with the second floor between axes "B–H", "2–4" at elevation +3.900

Fig. 3.43. Support of the curvilinear supporting beam on the monolithic reinforced concrete slab between axes "3–4", "B–H", at elevation -1.100

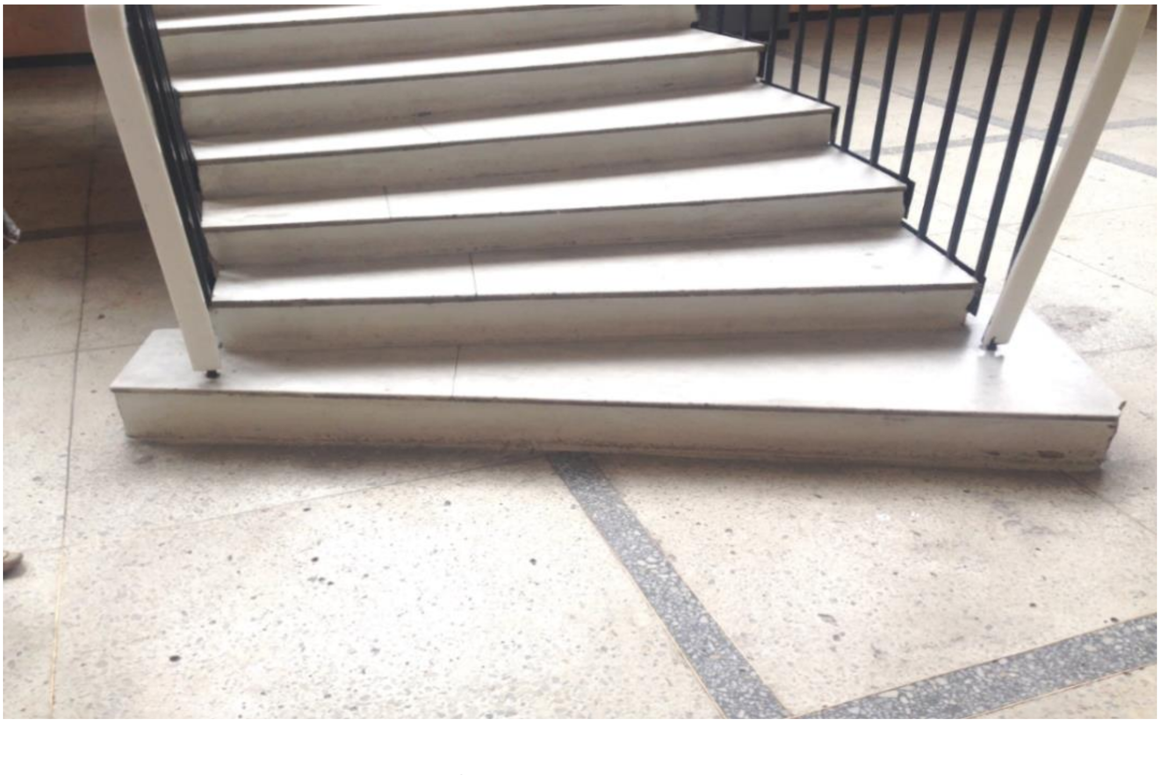


Fig. 3.44. Support of the bottom step on the monolithic reinforced concrete slab between axes "3–4", "B–H", at elevation -1.100

Fig. 3.45. Support of the curvilinear stair stringer beam on the monolithic reinforced concrete longitudinal floor beam of the second floor along axis "B", between axes "2–3", at elevation +3.900

Fig. 3.46. Support of monolithic reinforced concrete trapezoidal steps on the curvilinear beam between axes "2–4", "B–H", at elevation -1.100…0.000

Discussion and Self-Assessment Questions for Chapter 3

1. Enumerate the structural schemes and decisions for public buildings.
2. Present and characterize the features of space-planning decisions for public buildings.
3. Present and characterize the space-planning decisions for residential buildings.
4. Name the current functional requirements for residential buildings.
5. Present and characterize the space-planning decisions for specialized residential buildings.
6. Present and characterize the features of space-planning decisions for frame-monolithic residential buildings.
7. Enumerate the structural decisions for frame-monolithic residential buildings.
8. Present and characterize the space-planning and structural decisions for industrial enterprises.
9. How can the space-planning decisions for industrial buildings be improved?
10. What is the model method and how is it used?
11. Provide an example of selecting a profile for an industrial building. What parameters should be considered during the selection?
12. What principles govern the selection of structural decisions for industrial buildings?
13. Enumerate the general fire safety measures applicable to buildings.
14. What structural features are used to classify stairs in public buildings?
15. Present and characterize the requirements for stairs.
16. What types of stairs are used in design practice?
17. Present and characterize the options for stair flights and landings.
18. What parameters determine the choice of stair placement in buildings?

Practical Work 3

Topic: Design of Residential Premises with Consideration of Zoning Requirements: Planning Structures and Apartment Elements.

Objective: To learn how to determine the structural systems and schemes of the building being designed.

Tasks: To consolidate the material on the topic of the practical work, it is necessary to consider:

1. Space-planning decisions for specialized residential buildings;
2. Space-planning decisions for frame-monolithic residential buildings;
3. Space-planning and structural decisions for industrial enterprises;
4. Fire safety measures in design and requirements for structural elements;
5. Air exchange in the building in accordance with sanitary norms.

CHAPTER 4. STRUCTURAL ELEMENTS OF FRAMES AND ROOFS OF PUBLIC BUILDINGS

4.1. Structural Elements of Frames

Reinforced concrete frames of multi-story public buildings consist of foundations, columns, shear walls (diaphragms), beams (girders/lintels), floor slabs, and roof slabs [18].

Foundations for reinforced concrete column supports are of the cup (socket/caisson) type, and those for shear walls are strip (continuous/wall) foundations (cast-in-place/monolithic).

Reinforced concrete columns are designed for floor heights of 3.3; 3.6; 4.2; 4.8; and 6 m, and for basements, 2.9 and 2.4 m. In the column elements of the lower floors of buildings that bear loads up to 2000 tf (ton-force) per column, steel cores with a 6–8 cm concrete facing are used for protection against high temperatures in case of fire (Fig. 4.1).

Steel cores allow maintaining the same column dimensions as in the upper floors.

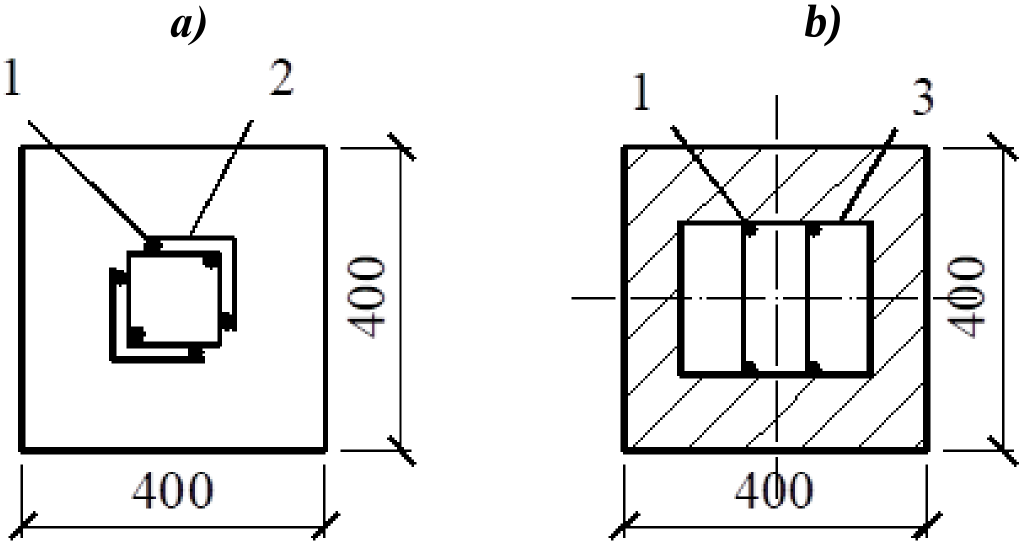


Fig. 4.1. Reinforced concrete columns with a steel core:
a – with an angle bar; *b* – with flat steel bar;
1 – weld; 2 – angle bar; 3 – flat steel bar

Joints of column elements along the height are made using metal heads at the ends of each element by welding and embedding with concrete over a mesh. A so-called "dry joint" is used with the transfer of forces to the concrete, with automatic welding of the reinforcement and caulking with rigid concrete of the gap between the column ends. The advantage is metal saving (Fig. 4.2). For ease of installation, this joint is made above the floor slab by 0.6–1 m.

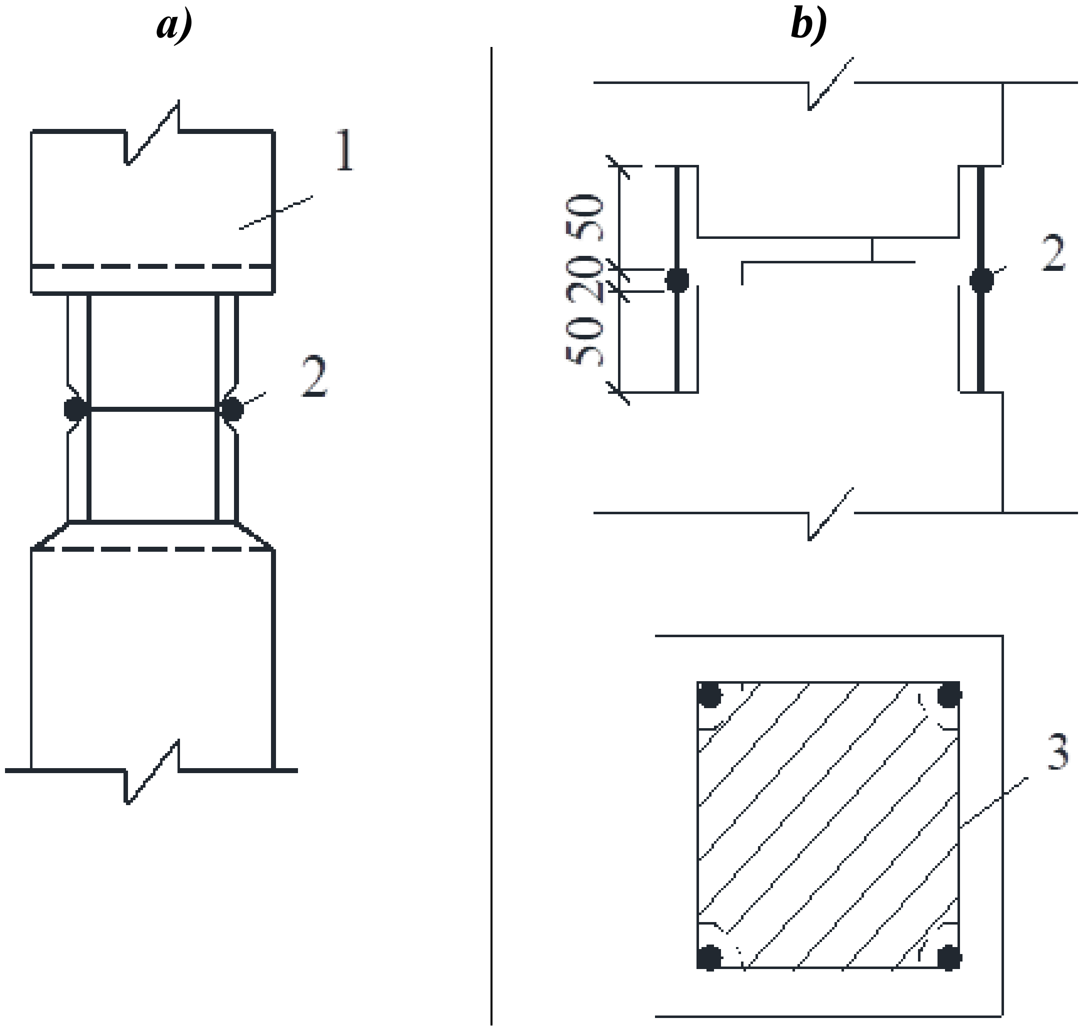


Fig. 4.2. Column connections:
a – reinforced concrete column splice/joint along the height;
b – dry joint of a reinforced concrete column;
1 – column; 2 – weld; 3 – rigid mortar/high-strength grout infill

Connecting (bracing/shear) diaphragms of unified frames are reinforced concrete walls rigidly connected to columns by welding and embedded (cast-in) elements.

The walls have cantilevers in their upper part, which allows increasing their stability, reducing metal consumption, and using the cantilevers to support floor slabs (Fig. 4.3). The thickness of the connecting walls, depending on the number of stories in the building, is 120, 140, and 180 mm.

Floor and roof slabs for public buildings are the same as those used for residential buildings.

The performance of roofing structures is characterized by the transfer of load from the upper enclosing elements of the roof (slabs, purlins) to the supporting structures (beams, trusses).

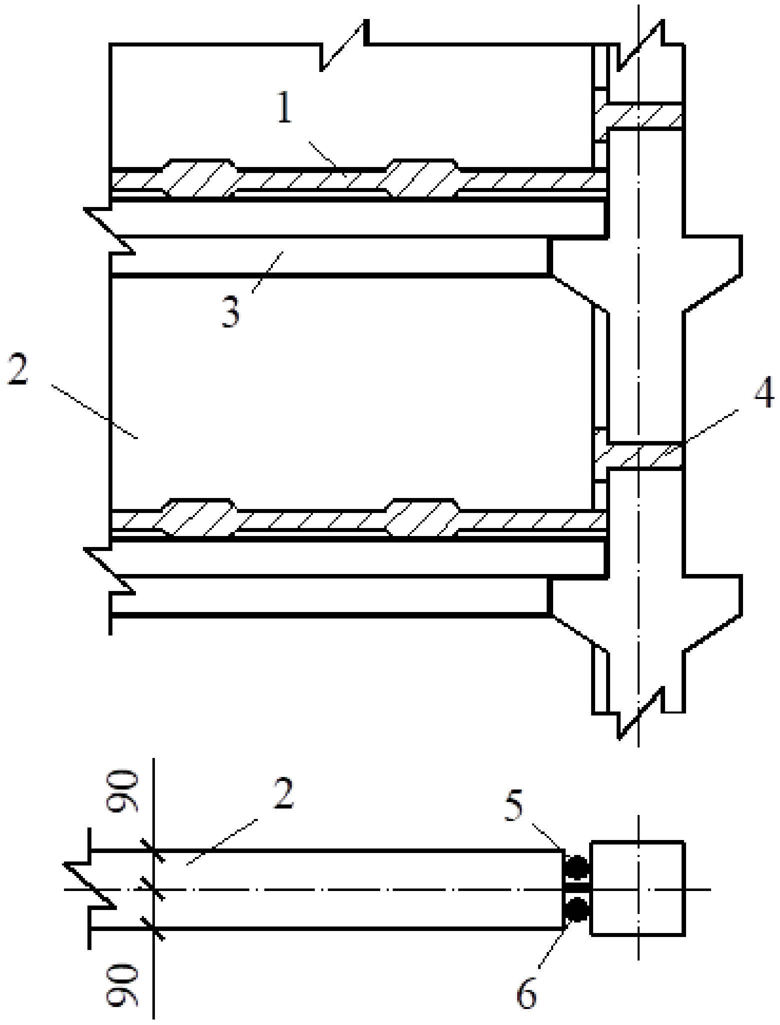


Fig. 4.3. Connection of connecting (bracing/shear) walls to columns:

1 – concrete; 2 – connecting (bracing/shear) wall; 3 – beam (girder/lintel); 4 – concrete infill/grout; 5 – weld; 6 – reinforcing bar extensions (starter bars) from the connecting wall

Wind load resistance and spatial rigidity of such a structural system are ensured by rigid connections using welding. If the roof is made in the form of decking (sheathing), spatial rigidity is ensured by horizontal bracing (ties) in the plane of the upper and lower chords of the trusses. In roofs of buildings with spans up to 30 m, prestressed reinforced concrete structures (beams, trusses) are used. For spans greater than 30.0 m, steel trusses are used.

In buildings with large spans, frame structures are used (Fig. 4.4). A feature of the static behavior of frames is the rigid connection of beams (girders/rafters) to columns (uprights/stanchions). Frames can have a horizontal or pitched (broken) beam, vertical or inclined columns.

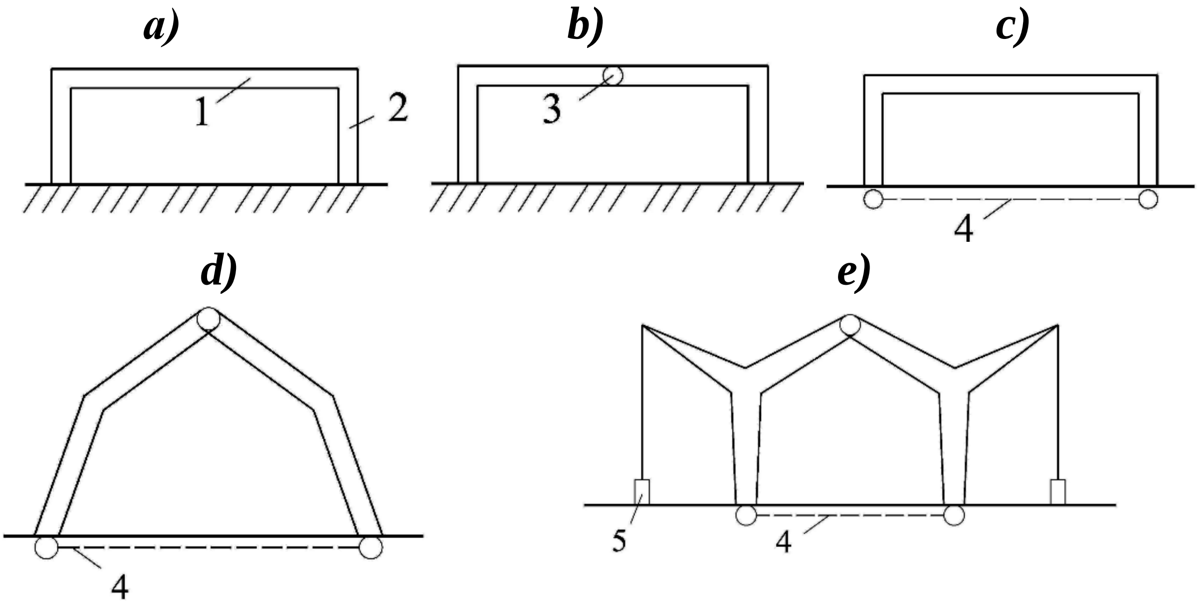


Fig. 4.4. Diagrams of large-span frames:
a – fixed (rigid/fixed-end); *b* – single-hinged (one-hinged /single-pinned); *c* – two-hinged (double-hinged/two-pinned); *d* – three-hinged (triple-hinged/three-pinned); *e* – three-hinged with cantilevers and tie rods (tiebacks);
1 – beam (girder); 2 – column (upright); 3 – hinge; 4 – tie rod; 5 – anchor foundation

Rigid Frames

Rigid frames are used in construction on dense soils and with reliable protection against differential settlement. Dividing these frames into prefabricated elements is complicated.

Single-hinged frames consist of two L-shaped elements connected by a hinge. These frames allow reducing the cross-sectional dimensions of the beam (girder), but require significant column dimensions.

Two-hinged frames have hinged supports of the columns on the foundations. Therefore, uneven settlement does not cause frame deformation. The cross-section of the columns can be small, as the moment near the support decreases, but the cross-section of the beam in the span will be large.

A three-jointed frame provides the ability to move in the plane of the frame without disturbing its overall operation. In such frames, static work consists in concentrating bending forces in rigid nodes and reducing their magnitude near the joints. The combination of prefabricated elements is easier than in other frames.

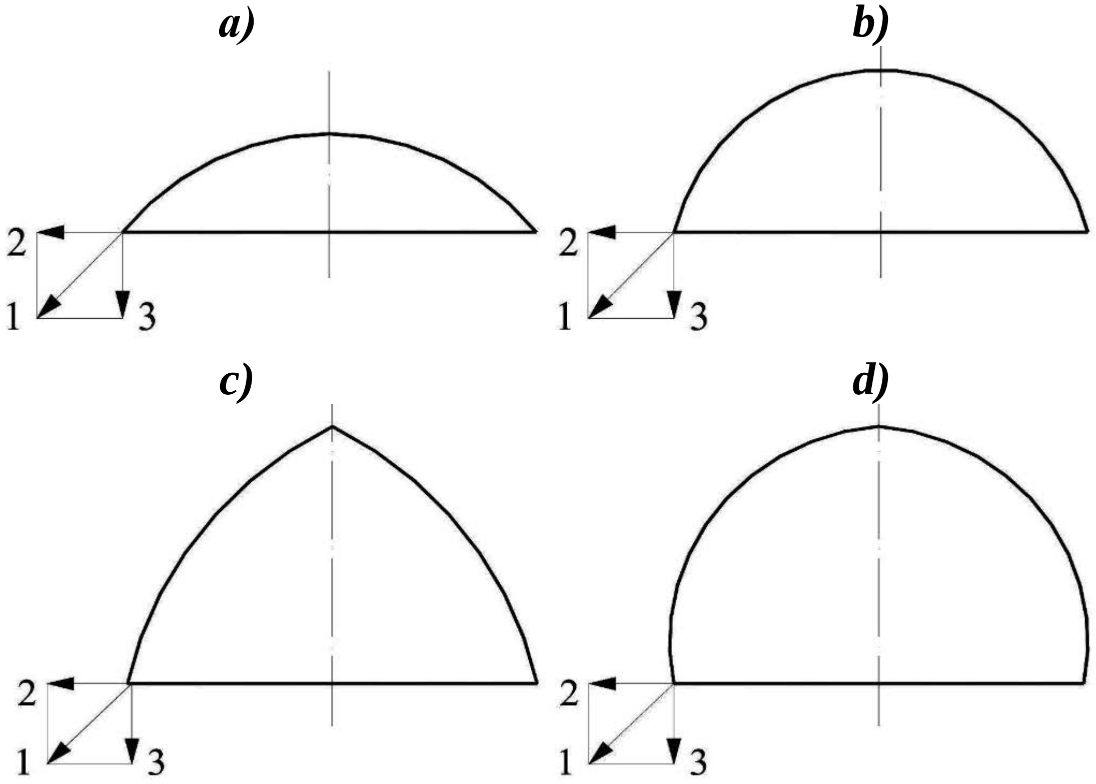


Fig. 4.5. Bearing structures of large-span arches:
a - round; *b* - semi-cylindrical;
c - arrow-shaped; *d* - parabolic;
1 - resultant; 2 - horizontal component of the support reaction;
3 - vertical component

In frame structures with cantilevers, the bending moment load in the transom span is reduced and the loads on the columns in the foundation are more uniform. The overhang of the consoles is 1/3-1/5 of the girder span. To reduce the bending moment in the girder span, the cantilever is raised to the cantilever by fences in the form of stained glass and lightweight panels or anchored at the base of a steel prestressed tie attached to the ends of the cantilevers.

The supporting structures of large-span roofs can be in the form of arches of circular, parabolic, elliptical and lancet outline, along which the slabs are laid, Fig. 4.5.

Due to their shape, the arches are primarily subjected to compression forces, which allows for efficient use of the material.

If the heels of the arches are placed at ground level, the bracing can be perceived by stretch marks below the floor level.

If the heel of the arch rests on columns or walls, the bracing can be taken up by tie-downs, supporting posts, transferring the forces to the foundation.

4.2. Design of Three-Hinged Frames in Single-Story Buildings

The main purpose of designing three-jointed frames is to ensure reliable and safe operation of the frame, reduce material consumption, labor costs during manufacturing and transportation.

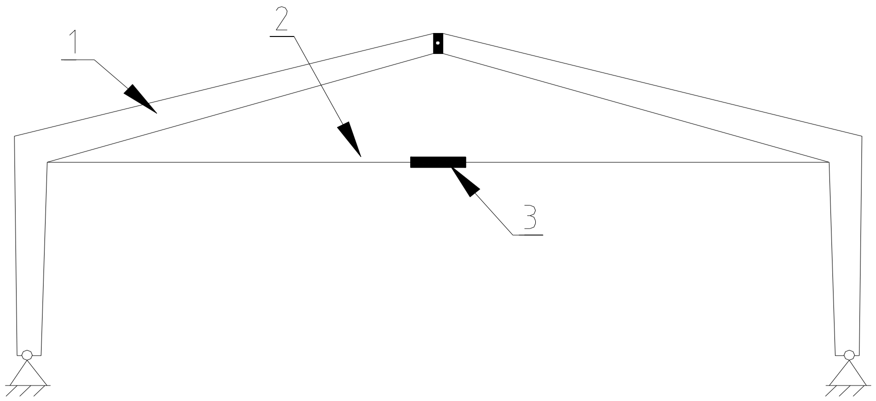


Fig. 4.6. Reinforced concrete frame with tie-in
in the presence of dynamic equipment:
1 - half-frame; 2 - tie-in of several metal rods;
3 - socket screw for connecting the rods

Such a frame allows you to adjust the rigidity of the structure and the frequency of its own vibrations so that they differ from the frequencies of the forced forces and moments of dynamic equipment (Fig. 4.6, 4.7, 4.8).

Wall panels have one or more window openings. Vertical ribs are located on the outer side of the wall panels and along the edges of the window opening and are made with a protrusion beyond the outer boundary of the panel with a cutout in the upper end.

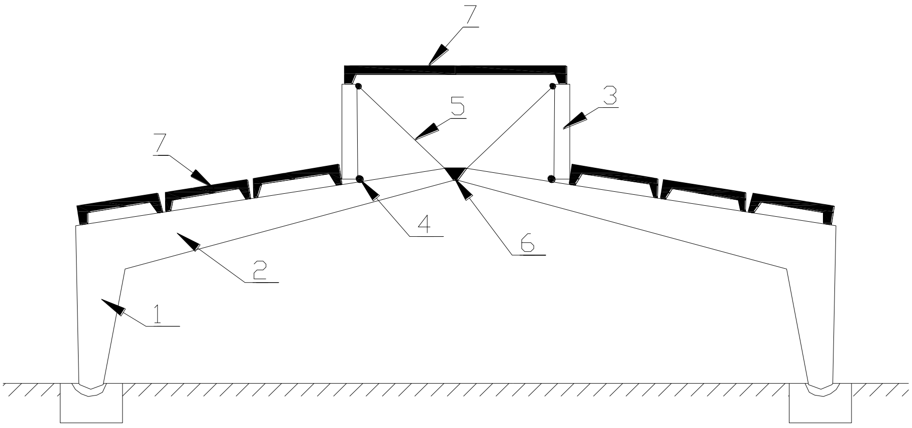


Fig. 4.7. Building frame with aeration lanterns:
1 - L-shaped half-frames; 2 - posts of aeration lanterns;
3 - lower end of the post; 4, 6 - hinged joint;
5 - metal ties; 7 – roof slabs

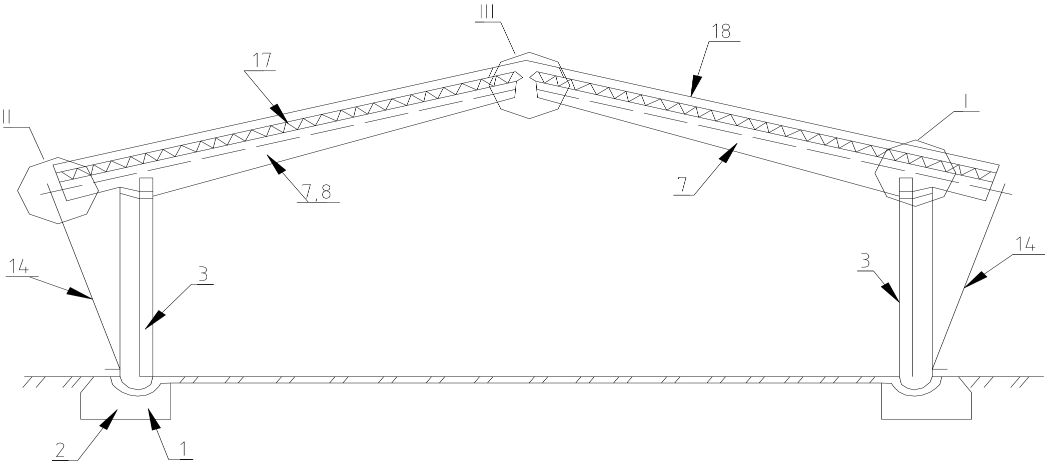


Fig. 4.8. One-story frame of prefabricated structures:
1 - foundation with a socket-type pedestal; 2 - projection of the foundation pedestal; 3 - wall panels with horizontal and vertical ribs; 7 - roof slabs

The wall panels are hinged to the foundations by installing projection of the foundation pedestal. The horizontal rib of the wall panels (3) is located along the central transverse axis of the panel between the vertical ribs and serves as a spacer. The floor slabs are made with one prestressed rib of variable cross-section along the length, located along the central axis, and transverse ribs. Roof slabs rest freely with a cantilever-longitudinal edge on the upper end of the vertical edge (6) of the wall panels (3) at the cutout.

The fastening of the roof slabs with the wall panels is carried out by means of inclined tighteners connecting the outer end of the longitudinal edges of the roof slabs with the vertical edge of the wall panels in its lower part.

The angle of inclination β of the ties to the vertical edge is equal to the angle of inclination α of the roof slabs to the horizontal. The junction of the ties with the longitudinal edge is located above the neutral axis of the roofing plates.

This frame design (Fig. 4.9) reduces the tightening forces and material consumption. In this frame, the transoms are made of different lengths. Short crossbars are installed on the middle post. The ridge assemblies of the frame are connected by a tie rod.

The prefabricated frame of a multi-bay building consists of posts on which the girders are supported. The short crossbars are supported by the middle posts of the two-bay sections. A tie connects the ridge assemblies of the two-bay section.

The optimal ratio of crossbar lengths is 1:2. A positive effect is achieved by reducing the force in the tie and reducing its length.

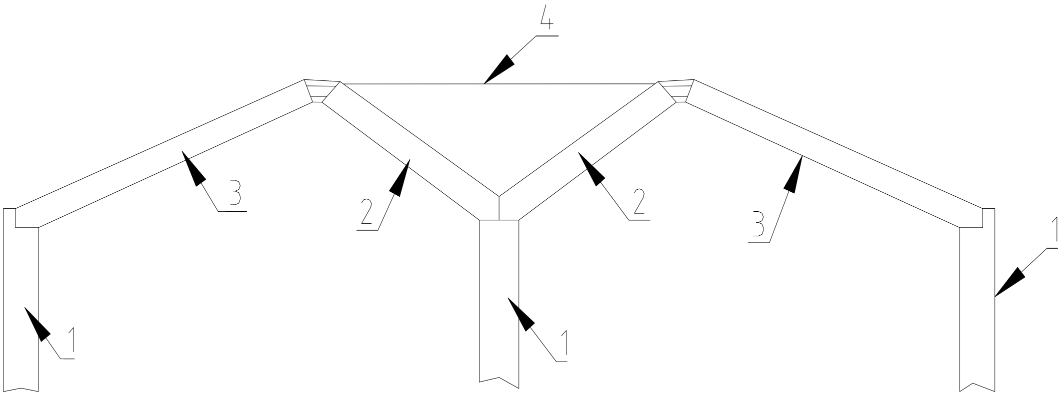


Fig. 4.9. Design of a prefabricated frame of a multi-span building with a tie-in: 1 - post; 2, 3 - crossbar; 4 - tie-in

The design of a prefabricated multi-span building with a tie-in (Fig. 4.10), which reduces manufacturing costs and increases the useful volume of the building.

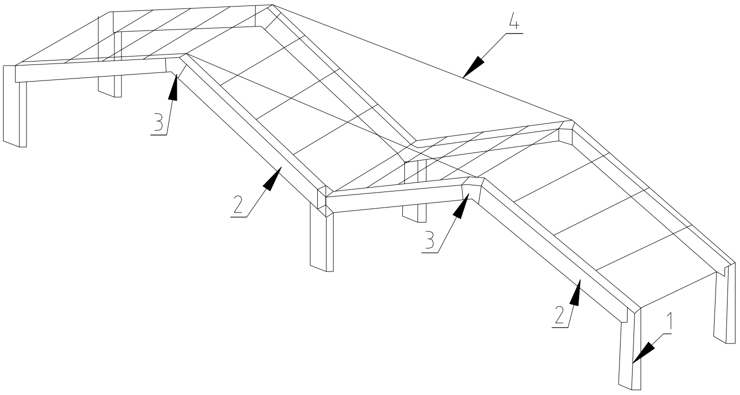


Fig. 4.10. Prefabricated multi-span building with a tie-in:
1 - post; 2 - crossbar; 3 - plates; 4 - tie-in

The prefabricated frame of a multi-span building consists of posts on which the crossbars rest. The joints of the crossbars with the posts can be rigid and hinged, while the joints of the posts with the foundations are hinged and rigid, respectively. The crossbars are connected to each other hinge with bolted plates. A tightener connects the ridge assemblies and is attached to the embedded parts of the transoms. When the posts are rigidly connected to the foundations and hinged to the girders, the tie bars are installed in the nodes eccentrically, below the neutral axis of the girders.

The economic effect is achieved through the use of standard forms for the manufacture of frames of greater height and the cross-section of the frame elements in the plane of bending moments, using the effect of prestressing.

This type of frame increases reliability during operation.

The frame structure consists of two half-frames hinged in the ridge, including crossbars and posts, a reinforced concrete lattice beam with parallel belts attached rigidly to the crossbar (Fig. 4.11). The structure of an additional rigid element in the form of a lattice beam at the level of the transom changes the nature of the distribution of moments in the frame and reduces their design values.

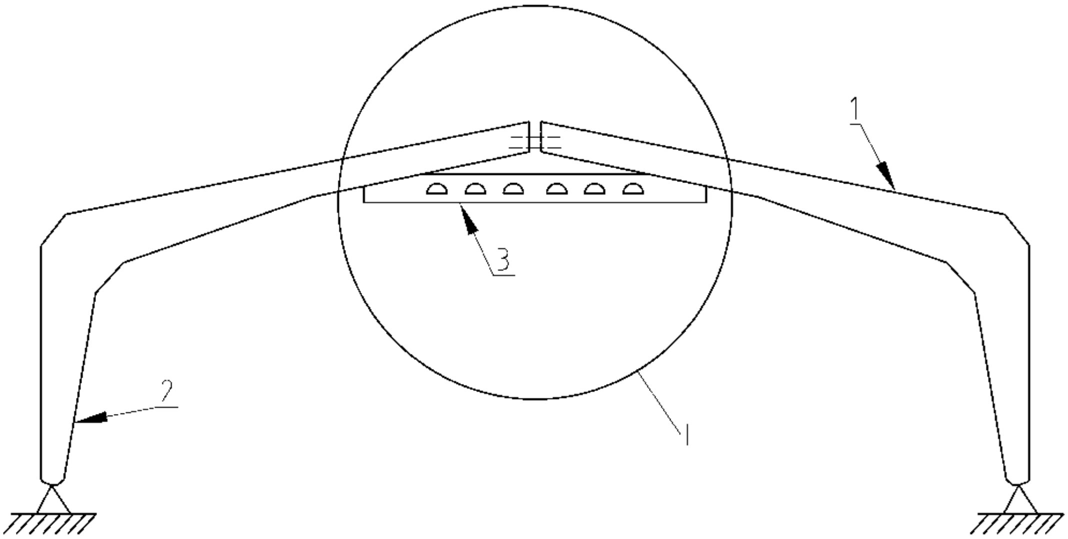


Fig. 4.11. Reinforced concrete frame structure:
1 - frame crossbar; 2 - post; 3 - reinforced concrete lattice beam

When an additional element is rigidly attached to the crossbar, it not only serves as a tightening element, but also works to absorb bending moment, longitudinal and transverse forces. Therefore, the use of reinforced concrete lattice beams is rational, since the middle layer of beam structures is not included in the work. The lower reinforced belt of the reinforced concrete beam absorbs tensile forces. Reinforcement consumption is less compared to metal ties. The stiffness of the frame increases and the maximum moment at the junction of the post with the crossbar is significantly reduced, and the corrosion resistance of the structure increases when used in livestock agricultural buildings.

The prefabricated reinforced concrete frame structure allows for an increase in building height (Fig. 4.12).

The frame includes L-shaped half-frames rigidly connected from the outside by strips with prestressed rod elements made separately. In the area of minimum bending moments, girder inserts and vertical brackets for attaching the crane rail of suspended equipment are attached to the half-frames. The prestressed tie rod is fixed in the eave’s nodes of the frame with a fracture of its axis in the sliding supports of the vertical brackets and is provided with suspensions.

The prestressed rod elements are manufactured separately in a special mold with the reinforcement tensioned on the stops and then attached to the L-shaped post with welds. The joint of the crossbar with the girder inserts and brackets is made at the assembly site with welds passing through the sliding supports of the metal tie bars and tensioning it with nuts at the ends of the frame.

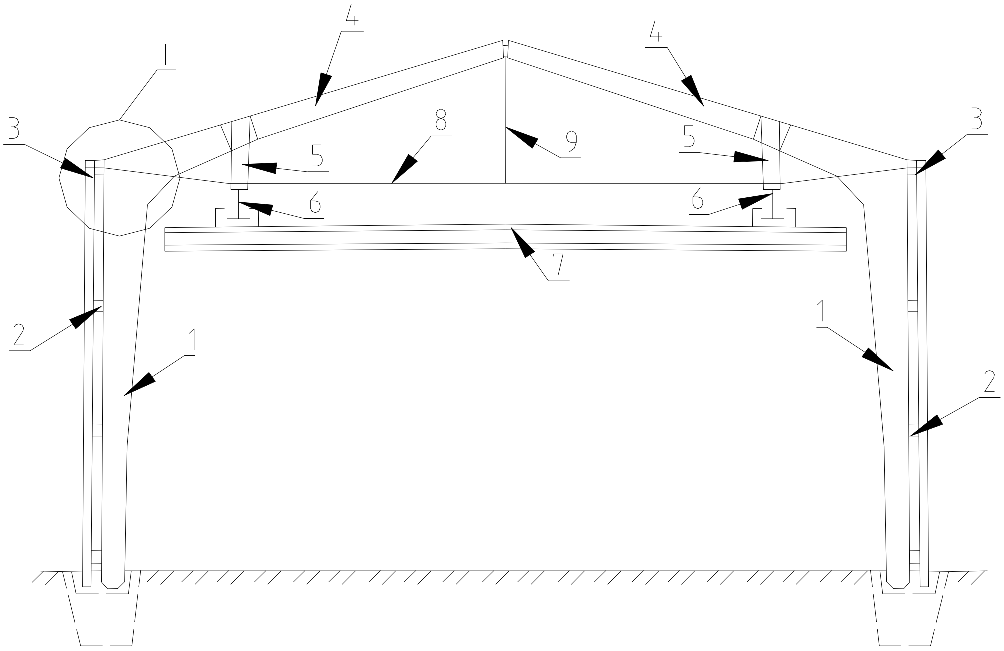


Fig. 4.12. Precast concrete frame structure:
1 - L-shaped half-frames; 2 - strips; 3 - rod element; 4 - span inserts; 5 - brackets; 6 - crane rails;
7 - suspension equipment; 8 - tightening; 9 - suspension

When performing such a frame, the design is simplified, the distance in the girders is increased due to a decrease in horizontal forces (Fig. 4.13).

The frame includes prefabricated three-jointed frames with tie-downs, girders, roof drainage trays, slabs, water distribution drainage ridge trays, and wall-mounted, short reinforced concrete supports. Each frame consists of two prefabricated half-frames, hinged in the ridge, which facilitates and simplifies their installation and ensures their transportability.

The posts of the two connected half-frames on the cantilever of one short cross-shaped reinforced concrete support are also hinged.

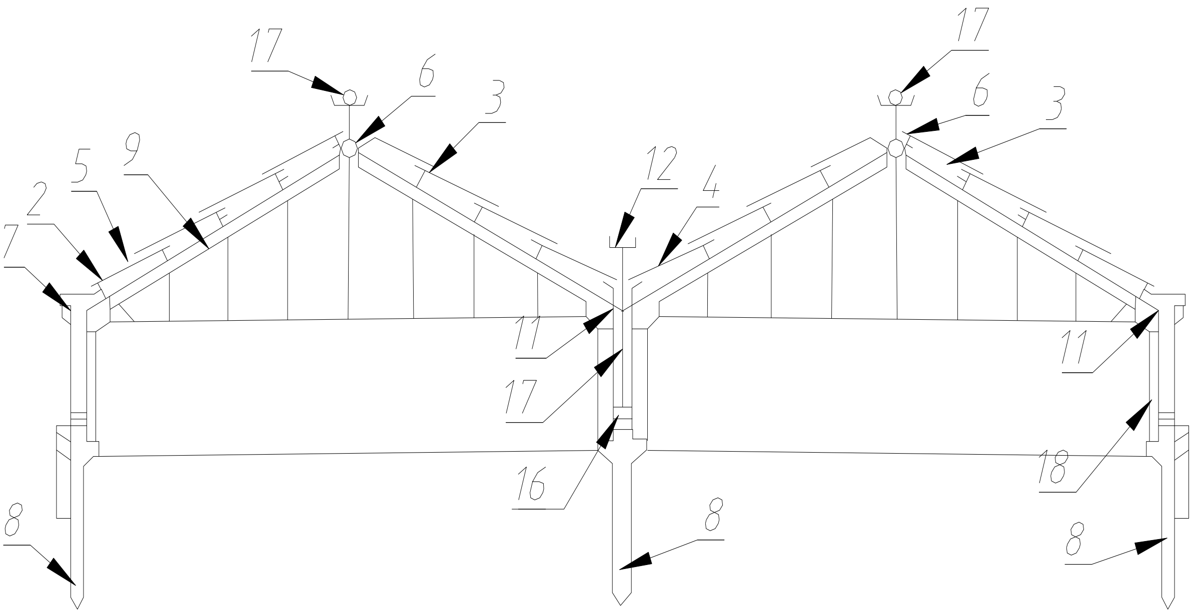


Fig. 4.13. Frame of load-bearing structures
of a multi-span building:
1 - three-hinged frames; 2 - tie-in; 3 - purlins;
4 - drainage trays; 5 - slabs;
6, 7 - water distribution drainage ridge and wall trays;
8 - short reinforced concrete supports; 9 - half-frames

When using a frame with a dimensional scheme (Fig. 4.14), the number of types of prefabricated elements is reduced while the overall dimensions of three-jointed frames increase.

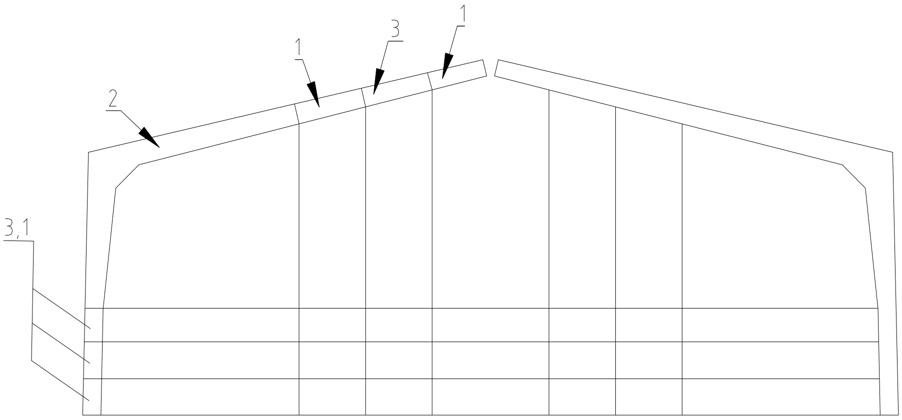


Fig. 4.14. Generalized dimensional diagram of three-hinged frames formed by half-frames with combined elements:
1 - girder element; 2 - L-shaped post;
3 – post, girder element

A semi-frame consists of a girder element, an L-shaped post and a post element. The girders and post elements are made of different lengths, and the dimensions of the girders and post elements are different (not the same and differ from each other). The ends of the girders and elements of the posts and the L-shaped post have the same dimensions and matching fastener details.

The post has the strength to ensure the operability of the half-frame when connected to girders or post elements of any length and to each of them from any of its ends.

The post includes a part of the length of the girder and a part of the height of the post, which can be changed in their places as intended when the post is rotated in its own plane, and when connected to elements 1, 3, they form the full length of the girder and the full height of the half-frame post, which can also be changed in places when assembled. The joints of the post with elements 1, 3 are made of the "dry" type by welding the embedded parts with the fasteners.

The same dimensions of the ends and matching embedded parts in all elements (1, 2 and 3) allow them to be replaced in various combinations, including turning the L-shaped post in its own plane, without preliminary adjustment, forming girders and half-frame posts and, by swapping them, posts and girders. It becomes possible to multiply the number of volume and spatial decisions for industrial and other buildings from a certain group of industrial elements, to mass-produce frames with "individual" dimensional parameters, to eliminate excess areas or volumes in mass-used versions, or to eliminate the compression of technological or functional processes in buildings due to full compliance with the required and "provided" volume and spatial parameters.

The three-hinged frame with cantilevers (Fig. 4.15) provides increased reliability due to the stability of the half-frames. The building includes a three-jointed frame of two half-frames with balanced cantilevers, a roof, and wall panels. The half-frames are supported by foundations. Wall panels are suspended from the cantilevers.

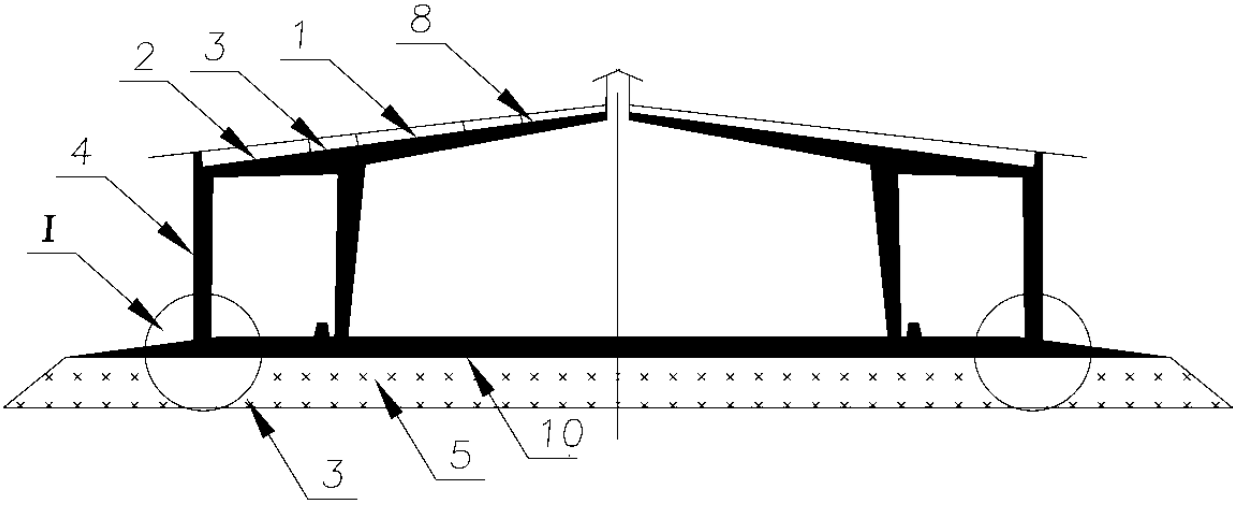


Fig. 4.15. Three-hinged frame with balanced cantilevers:
1 - semi-frames; 2 - balanced cantilevers; 3 – roof slabs;
3, I - foundations; 4 - wall panels; 5 – dense soil;
7 - gap; 8 - tightening bolts; 9 - support corners;

The building is equipped with large floor slabs located in the marginal girders and suspended from the wall panels with a gap using tie bolts anchored in the floor slabs and support angles (9) attached to the wall panels. The building structure works as follows. The load from the part of the roofing that is located on the girders of the half-frame is partially balanced by the load from the part of the flooring located on the cantilevers and the wall panels. The load from the floor slabs is balanced by the half-frame, eliminating the spreading forces in the foundations. The wall panels connected to the half-transoms and floor slabs form a closed system, ensuring the stability of the half-frames.

The three-hinged frame with cantilevers (Fig. 4.15) also simplifies the installation of the building.

Consider a building that includes three-jointed frames consisting of two half-frames with balanced cantilevers, wall panels and connected large-size floor slabs and roof coverings, Fig. 4.16.

Large-sized floor slabs and wall panels are rigidly connected to each other to form L- or inverted T-shaped blocks and are made with sockets for hinge support of cantilevers and posts, half-frames.

The length of the L- or inverted T-shaped blocks is equal to the spacing of the three-jointed frames, while the blocks can be installed between the transverse axes 10 of the buildings or with their axis 11 coinciding with the transverse axis 10 of the building.

The stability of the frames is ensured by the roof slabs and L- or inverted T-shaped blocks. Prior to the installation of the roof slabs, the frames are fastened along the ridge line with mounting ties.

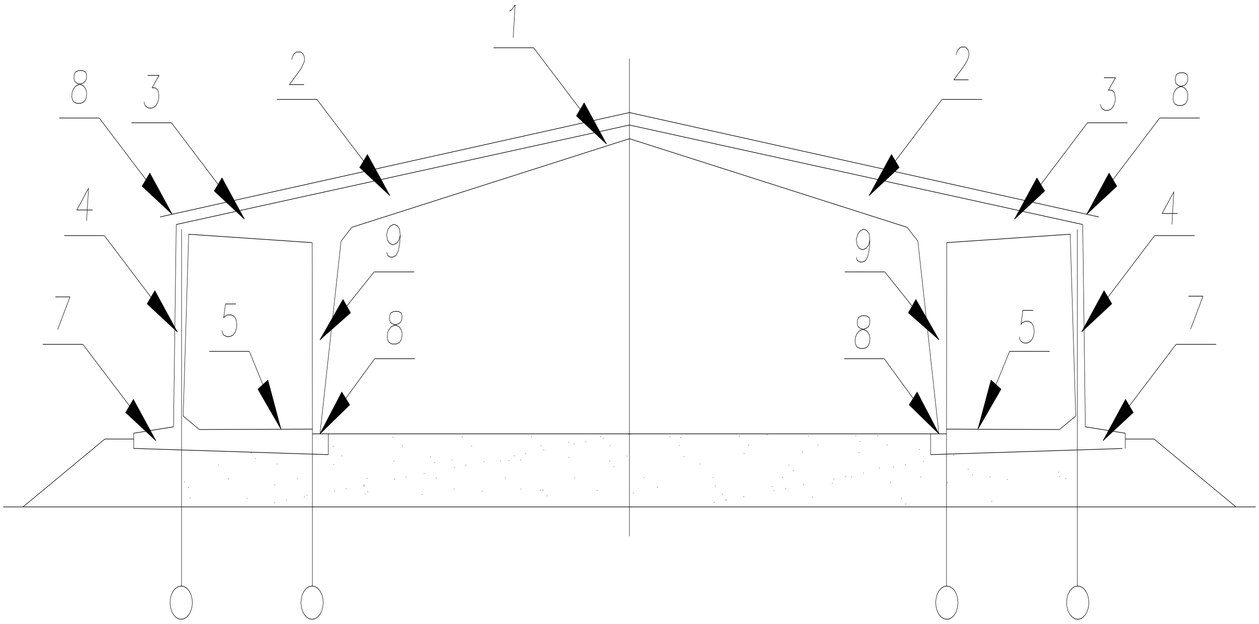


Fig. 4.16. Three-hinged frame with balanced cantilevers:
1 - three-jointed frame; 2 - half-frames; 3 - balanced cantilevers; 4 - wall panels; 5 - floor slabs; 6 - roofing;
7 - blocks; 8 - sockets; 9 - post; 10, 11 - transverse axes

A three-joint frame can be used to increase the seismic resistance of a building (Fig. 4.17).

The frame is formed by rigid post and girder fasteners, which are pin-connected to the foundations and to each other at the ridge assembly, and the girders. Half-frames are installed in the plan at an angle to the transverse axes of the frame and are rigidly connected by metal elements along the building in pairs with the ends of the crossbars and posts to form zigzag spatial half-frames.

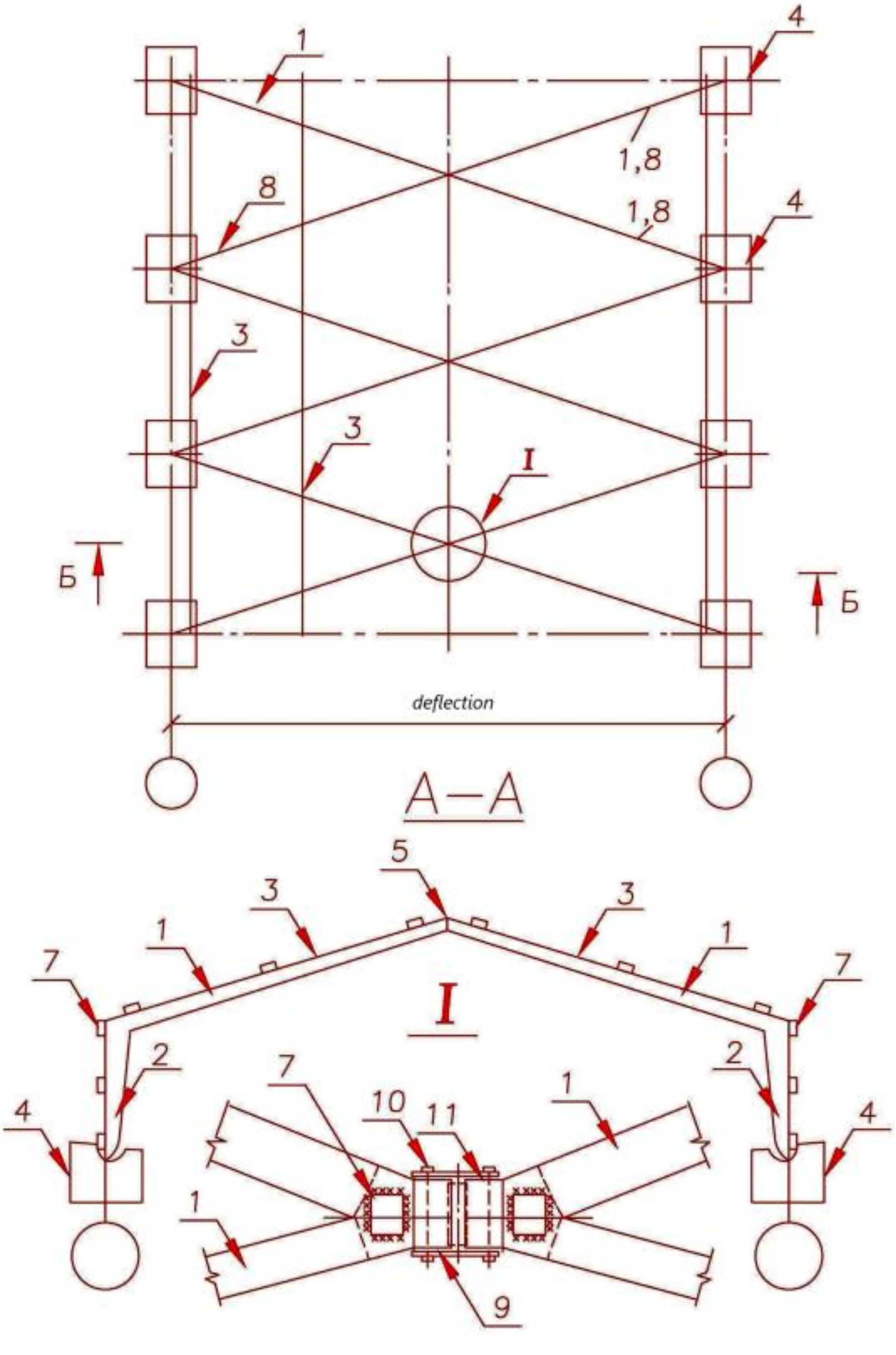


Fig. 4.17. Frame of a one-story earthquake-resistant agricultural building made of half-frames:
1 - frame; 2 - posts; 3 - girder; 4 - foundation; 5 - ridge assembly; 6 - purlins; 7 - metal elements; 8 - half-frame; 9 - metal plate; 10 - bolt; 11 - metal roller

The girders of the half-frames are connected to each other at the ridge assembly by means of connecting metal plates attached to the girders with bolts passing through holes in the ends of the girders and a cylindrical metal roller creating a hinged connection between the girders and the half-frames.

Vertical loads are taken up by the half-frames. When the building is subjected to horizontal seismic loads, the created frame of spatial half-frames works as a rigid structural scheme in the longitudinal and transverse directions of the building.

As a result of achieving high rigidity of the frame in the longitudinal direction of the building, there is no need to install metal connections along the upper belt of the half-frame girders, reinforce the girders and their attachment points to the girders.

The frame skeleton of an agricultural building (Fig. 4.18) is focused on reducing material consumption and increasing industrialization.

The frame of an agricultural building consists of a three-jointed frame made of L-shaped half-frames and connected by spacers.

The posts and girders of the half-frames are provided with transverse cantilever ribs and contour longitudinal ribs that connect the free ends of the transverse ribs to form the spatial structure of the frames.

The contour ribs of the semi-frame posts are connected to the lower end of the posts. The frames are supported by foundations.

The design of the wall enclosure can vary depending on the customer's needs and the availability of materials and can be made, for example, of corrugated asbestos-cement sheets (cold roofing) or slabs on a wooden frame made of asbestos-cement extrusions (warm roofing).

The single-span frame with gable roofing (Fig. 4.19) is also focused on reducing material consumption and increasing industrialization.

A gable-roofed building, consisting of a wall enclosure, rests on a foundation.

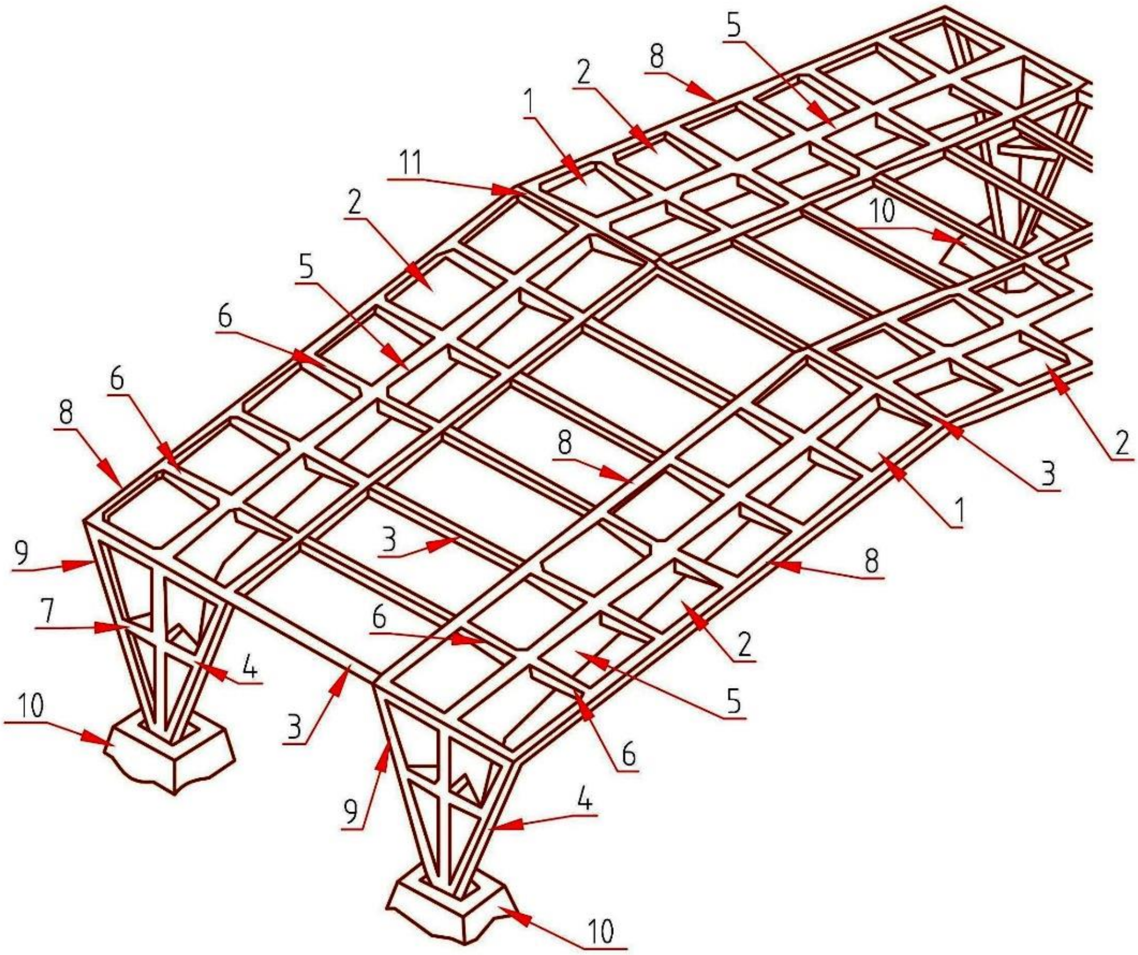


Figure 4.18. Frame of a one-story earthquake-resistant agricultural building made of half-frames:
1 - three-hinged frames, 2 - L-shaped half-frames; 3 - spacers;
4 - posts; 5 - girders; 6, 7 - transverse cantilever ribs;
8, 9 - contour longitudinal ribs; 10 – foundation

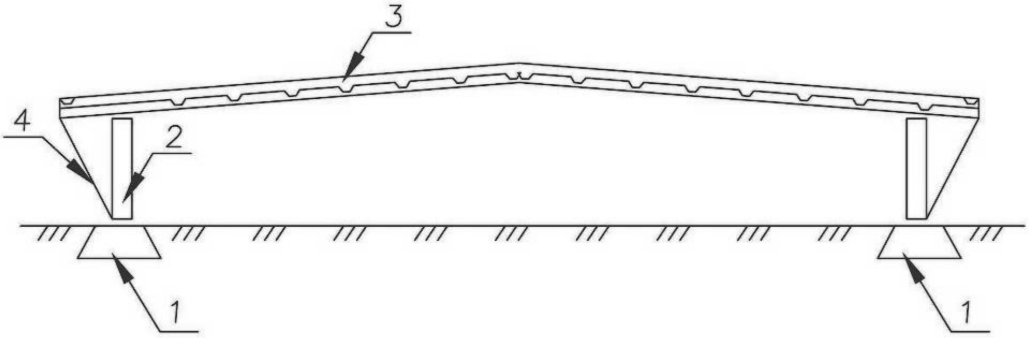


Figure 4.19. Single-bay building with a gable roof:
1 - foundation; 2 - wall panels;
3 - roof slabs; 4 - struts

The building is constructed of reinforced concrete ribbed slabs, struts, and the wall enclosure is made of ribbed slabs supported on the foundations by their longitudinal ribs, with the slabs placed across the building and resting at one end on the wall panels to form a cantilever of each slab connected to the foundation by struts.

The use of a typical 3×12 m slab allows for the construction of an agricultural building with spans of up to 21 m. At the same time, the number of prefabricated building elements is reduced by 2 to 2.5 times compared to the known one.

The cantilevered frame structure of the building allows for rational use of the strength qualities of the material while increasing the rigidity of the structure and, accordingly, reducing the material consumption of the foundations by reducing the spacing.

The absence of a frame transom as a separate element reduces the height of the building by 10-17%, which reduces the material consumption of the wall envelope and the operating costs of heating and ventilation of the building.

Discussion and Self-Assessment Questions for Chapter 4

1. Give an example of a reinforced concrete column with a steel core.
2. Give an example of a long-span frame scheme. Hingeless frames.
3. Give an example of a long-span frame diagram. Single hinged frames.
4. Give an example of a long-span frame diagram. Double-hinged frames.
5. Give an example of a long-span frame diagram. Three- hinged frames.
6. Give an example of a reinforced concrete frame with a tightening in the presence of dynamic equipment.
7. Give an example of a building frame skeleton with aeration lights.
8. Give an example of a single-story precast frame.

9. Give an example of a prefabricated frame structure of a multi-span building with a tie-in.

10. Give an example of a reinforced concrete frame structure with a beam.

11. Give an example of a precast concrete frame structure that allows for an increase in building height.

12. Give an example of a frame of load-bearing structures of a multi-span building.

13. Give an example of a frame with a dimensional scheme.

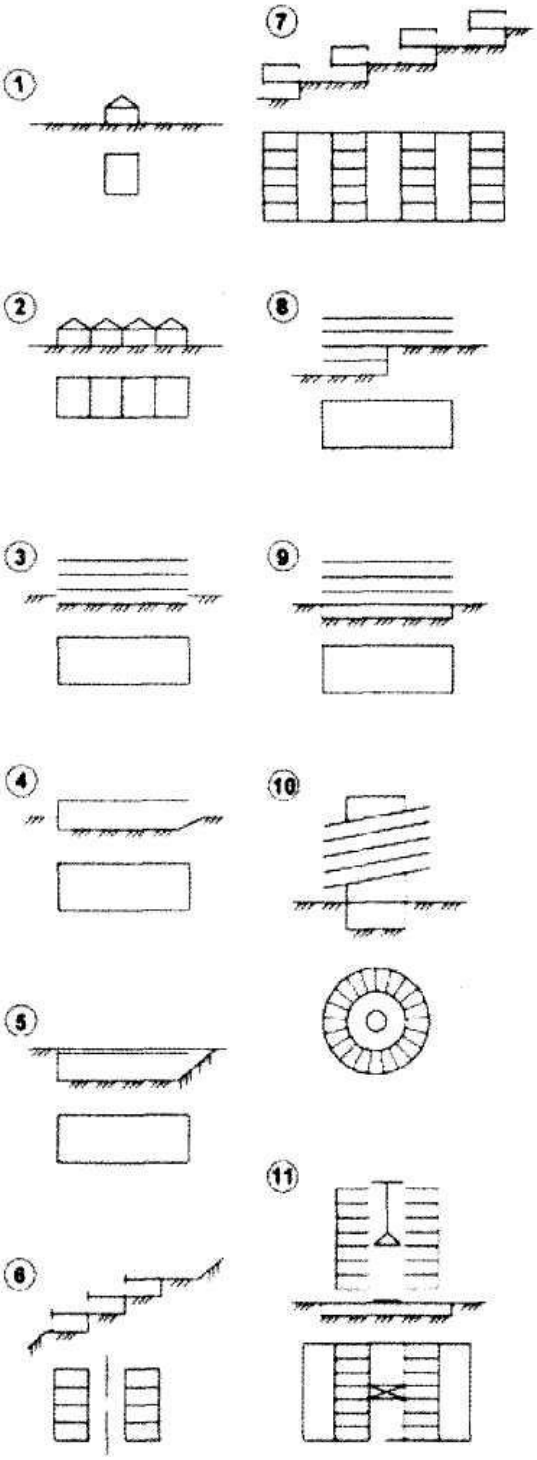
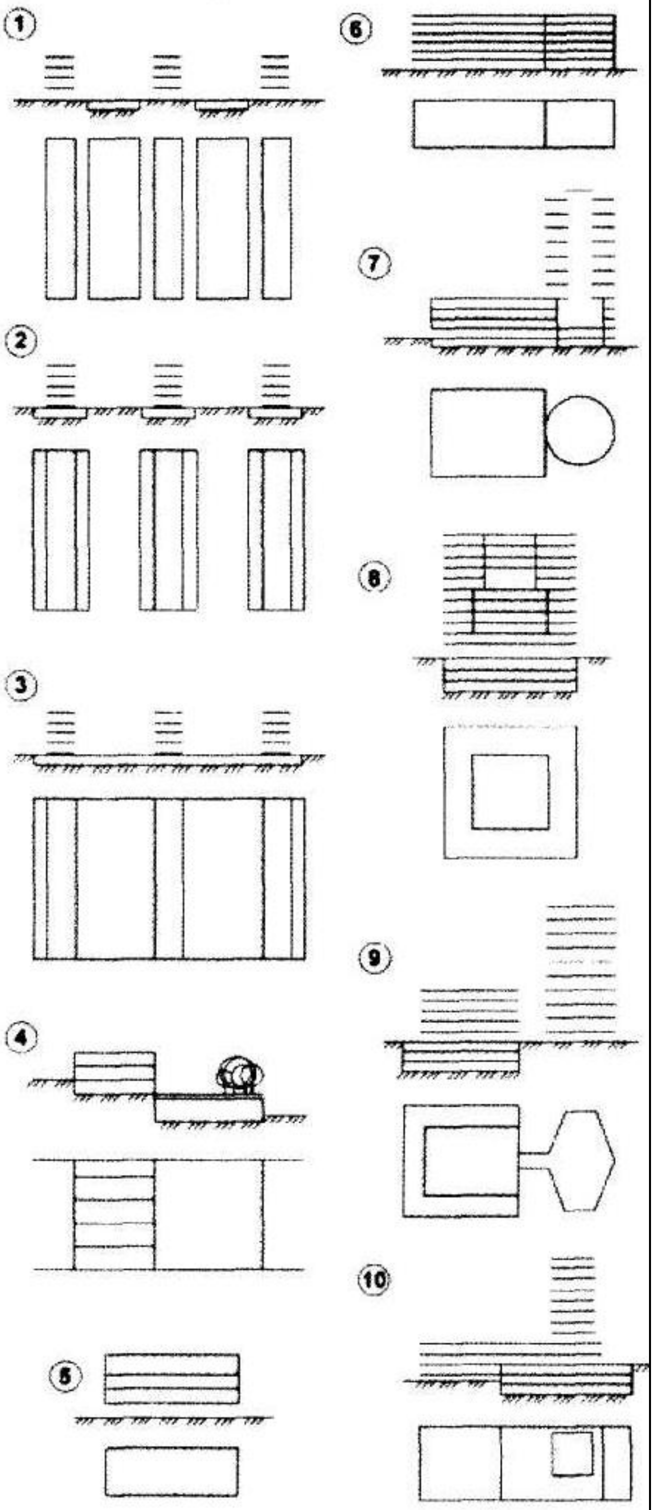
14. Give an example of a three-hinged frame with balanced cantilevers.

15. Give an example of a single-story earthquake-resistant agricultural building frame with half-frames.

CHAPTER 5. VOLUME PLANNING DECISIONS FOR TRANSPORT FACILITIES

5.1. Main Types of Transport Facilities

Types of transport facilities are conditionally divided into two categories.

A. Separately located	B. Built-in and attached
	

A. Separately located: 1, 2 - separate boxes and blocks of boxes; 3 - above-ground and underground; 4, 5 - semi-underground and underground; 6 - one-story terrace type; 7 - two-story terrace type; 8 - on relief differences; 9 - multi-storey ramp type; 10 - multi-storey with sloping floors; 11 - mechanized, automated.

B. Built-in and attached: 1 - between buildings; 2 - under buildings within their boundaries; 3 - under buildings and between them; 4 - on relief differences; 5 - in the upper floors or on the roof; 6, 7 - in attached volumes; 8 - in the courtyard; 9, 10 - in underground and semi-underground levels.

5.2. General Requirements for Transport Facilities

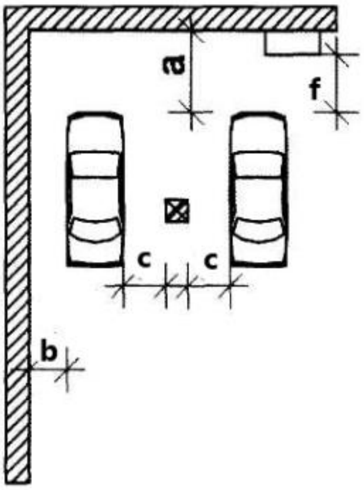
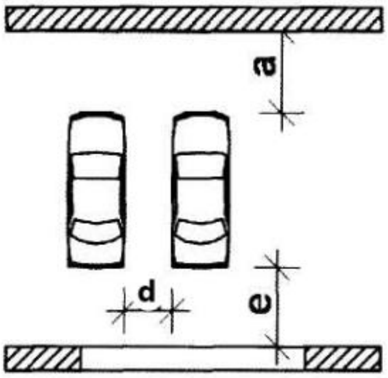
Above-ground garages may be provided with a height of no more than 9 floors, underground garages - no more than 5 floors. In transport facilities, in addition to car storage facilities, it is allowed to provide:

- service and storage premises;
- technical premises for the placement of engineering equipment (transformer substation, heating station, fire extinguishing pumps, sewage treatment plants, etc.);
- maintenance, repair and car washing stations, including self-service stations and places for vacuuming the car interior.

In underground structures, maintenance and repair stations, car washing stations, service and storage facilities, fire extinguishing and water supply pumps, transformer rooms with dry transformers may be located no lower than the first (upper) floor. The location of other technical premises is not regulated. The arrangement of maintenance and repair stations in buildings located under residential buildings is not allowed.

In ground-based multi-storey transport facilities, maintenance and repair facilities may be located only on the first and last floors without transit traffic of vehicles on the floors (with the arrangement of isolated ramps).

Table 5.1. Distances between vehicles and building elements of buildings and structures

Protected areas	designation	Distances to cars		Sketch
		on maintenance and repair posts	in places of storage	
From the end of the vehicle to the wall	a	1,2	0,5	 
Same for stationary process equipment	f	1,0	–	
From the longitudinal side of the vehicle to the wall	b	1,2	0,5	
Between the longitudinal sides of vehicles	d	1,6	0,6	
Between the car and the column	c	0,7	0,3	
From the end of the vehicle to the gate	e	1,5	0,5	
Between cars behind each other	–	1,2	0,4	

The parameters of vehicle storage areas, ramps (ramps), and internal passageways in structures are determined depending on the method of storage, class and dimensions of vehicles to be stored, their maneuverability and placement, as well as taking into account the technical equipment and planning solution in accordance with the requirements of the technological design standards for road transport enterprises.

The minimum dimensions of parking spaces in garages should be as follows: length of the parking space - 5.0 m, width - 2.5 m (for disabled persons using wheelchairs - 3.5 m).

In open-type structures, it is allowed to place cars bilaterally at an angle of 45-60º to the longitudinal axis of the passage, provided that the dimensions of storage areas and internal passages are not less than those given in the tables Table 5.1 and Table 5.2.

If the protective zones of the vehicle given in Table 5.1 are increased by 0.1, 0.2, 0.3 and 0.4 m (but not more), the width of the internal passage (Table 5.2) may be reduced by 0.15, 0.3, 0.45 and 0.6 m, respectively.

Wheel chocks with a height of not less than 0.12 m shall be provided along the walls against which cars are parked on the end and longitudinal sides.

In car storage facilities located under residential buildings, the design of wheel chocks shall exclude the transmission of noise and vibration to residential premises.

The height of car storage facilities from the floor to the bottom of protruding building structures and suspended equipment shall be at least 0.2 m higher than the height of the tallest car and shall be at least 2.0 m.

Garage buildings and car storage facilities are classified as category B in terms of explosion and fire hazard according to NAPB B.07.005.

Garages built into buildings for other purposes must have a fire resistance limit of the main building structures not lower than the fire resistance degree of the building into which they are built and be separated from the premises (floors) of these buildings by fire walls and floors of type 1.

When placing garages under residential buildings (in the underground or first ground floor), residential floors directly above the car storage rooms are not allowed (these rooms must be separated by a technical floor). In this case, the built-in garages must be separated by fireproof ceilings of type 2.

Table 5.2. Width of internal passage in vehicle storage facilities and at maintenance and repair stations

Types of cars - class	The width of the internal passage is determined taking into account the recommended approach of the moving vehicle to the structures of the building (structure), to equipment and vehicles in storage areas, m									
	in car storage facilities					in the premises maintenance and repair posts				
	when installing cars					ditches			outdoor	
	forward motion			in reverse		without additional maneuvering		with maneuver	without additional maneuver	with maneuver
	without additional maneuvering		with maneuver	without additional maneuver						
	Angle of installation of cars to the axis of travel					Angle of installation of cars to the axis of travel				
	45°	60°	90°	45°	60°	45°	60°	90°	60°	90°
cars - especially small class	2,7	4,5	6,1	3,5	4,0	4,3	5,3	6,4	2,9	4,8
cars small class	2,9	4,8	6,4	3,6	4,1	4,4	5,6	6,5	3,1	5,0
passenger cars - middle class	3,7	5,4	7,7	4,7	4,8	4,8	6,5	7,2	3,3	5,7
minibuses are especially small class	3,8	5,8	7,8	4,8	5,2	4,8	6,5	7,4	3,5	5,3

On the floor of the building under which the garage is located, it is allowed to place premises with a simultaneous stay of no more than 50 people. If more than 50 people are staying above the garage floor at the same time, a fireproof ceiling with a fire resistance rating of at least REI 180 must be installed.

Over the openings of the entry and exit gates of garages built into residential and public buildings, visors made of materials with a fire resistance rating of at least EI 60 and a width of at least 1 m should be provided. The distance from the edge of the canopy to the bottom of the window openings of these buildings should be at least 4 m. If the distance is less, the openings must be filled with fireproof windows of type 2.

Such requirements do not apply to garages of individual single-family houses, including blocked houses, with independent access to the site. The entrances and entrances to these premises must be isolated from the entrances and entrances to the garage.

5.3. Classification of Ramps

To move cars vertically in garages with two or more floors, it is necessary to provide isolated (attached) or non-isolated from the car storage premises (built-in) ramps or inclined interstorey floors, the classification and most commonly used types of which are shown in Table 5.3.

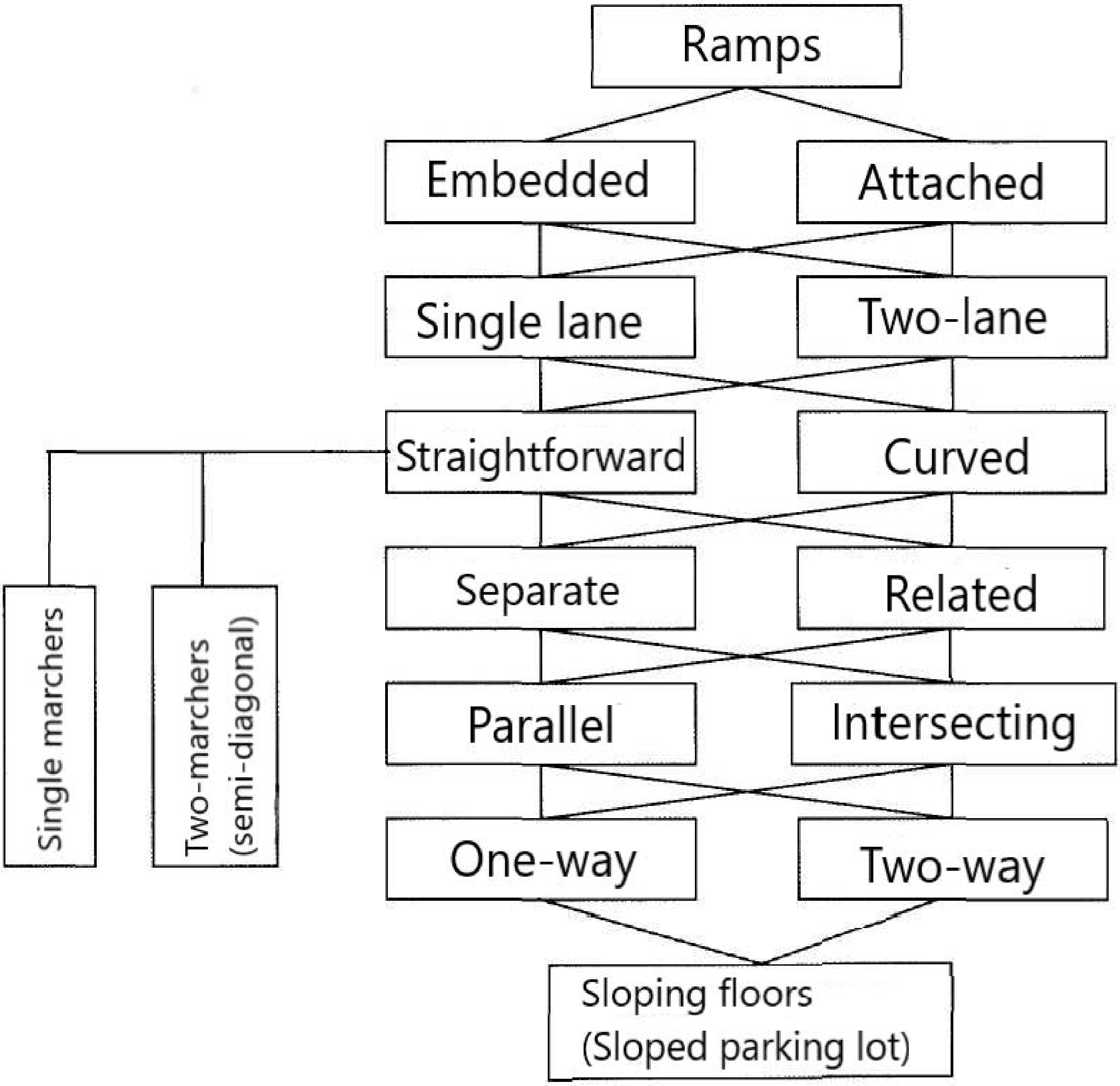
Isolated attached ramps of types “a”, “h”, “i” are the most common.

Built-in non-isolated ramps of type “b”, “c”, “d”, “e”, which provide for transit traffic through the garage floors, can be used in garages with no more than 3 floors and a total area of no more than 10400 m^2.

Semi-ramps of type “e” and “g” are used, as a rule, in open-air parking lots.

In garages with six or more floors, special lifts (elevators) may be used, subject to compliance with noise standards.

Table 5.3. Classification of ramps (ramps)



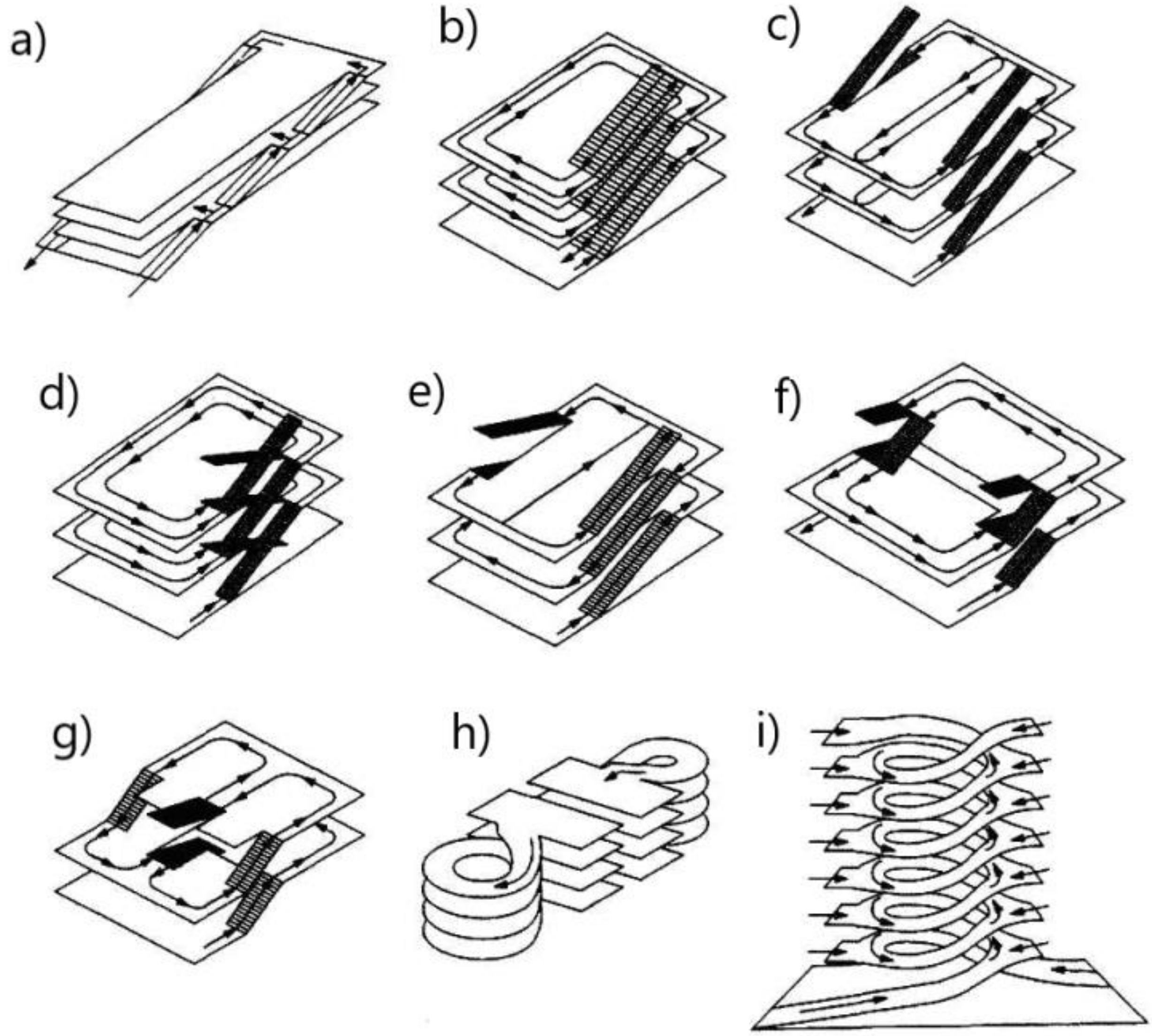


Fig. 5.1. Ramps that are most often
used in design:
a - attached rectilinear single-lane ramps;
b - built-in rectilinear two-lane ramps (two one-way screws); c -
same, single-lane ramps (two one-way screws);
d - same, intersecting ramps;
e - straight single-lane ramps (one two-motion screw);
f - single-lane half-ramps (two one-way screws);
g - the same, combined; h - attached curved single-lane ramps (two one-way screws); i - single-lane elliptical ramp (one two-motion screw)

5.4. Fire Resistance Requirements for Structures of Transport Facilities

For all floors of the garage structure, insulated ramps should be located near the outer wall of the building, have natural light and be separated on each floor from the car storage, washing, maintenance and repair facilities by fire barriers, gates and (or) fire vestibules-gateways with air support in case of fire in accordance with the requirements of Table 5.4.

Table 5.4. Fire resistance limit of structures, separating ramps

Garage	Fire resistance limit of structures separating ramps (fire barriers), min. not less than		Requirements for necessity arrangement vestibule-gateway
	walls (partitions)	gate	
Underground	REI 90 (EI 90)	EI 60	Fire door vestibules of type I with a depth that allows the gate to open, but not less than 1.5 m
Ground	REI 45 (EI 45)	EI 30	Optional

Doors and gates in fire barriers and vestibules-gateways shall be equipped with automatic devices for closing them in case of fire.

In one-story underground garages in front of the ramps, it is allowed not to provide a vestibule-gateway.

In isolated ramps, instead of fire gates, it is allowed to provide automatic devices that block the ramp openings on the floors by at least half their height (smoke screens) with a drainage curtain over the opening from the side of the storage room.

In ground garages, non-insulated ramps are allowed:

- in closed-type garages of I and II fire resistance classes with a total area of their floors (semi-floors) not exceeding 10400 m^2;

- in open-type garages.

The arrangement of a common non-insulated ramp between the underground and above-ground floors of the garage is not allowed.

The number and type of ramps and, accordingly, the number of required exits and entrances in the garage shall be determined by the number of cars located on all floors except the first floor (in underground garages - on all floors), taking into account the mode of use of the garage, the estimated traffic intensity and planning decisions on its organization, and shall be taken with the number of cars:

- up to 100 inclusive - one single-lane ramp;
- over 100 to 1000 - one two-lane or two one-lane ramps;
- over 1000 - two two-lane ramps.

When using a single-lane ramp that is used both for lifting and lowering vehicles (at different times), appropriate signaling must be provided.

The following requirements must be met when designing ramps:

→ the longitudinal slope of closed rectilinear ramps along the lane axis should not exceed 18%, curved ramps - no more than 13%, the longitudinal slope of open ramps not protected from precipitation - no more than 10%;

→ the transverse slope of curved and straight ramps should not exceed 6%; the connection of ramps with horizontal sections of the floor should be smooth, and the distance from the bottom of the vehicle to the floor should be at least 0.1 m;

→ wheel chocks (barriers) 0.1 m high and 0.2 m wide should be provided on both sides of the ramp carriageway; the middle barrier separating the carriageways of a two-lane ramp should be at least 0.3 m wide; on ramps with pedestrian traffic on one side, a sidewalk with a width of at least 0.8 m should be provided (on curved ramps, the sidewalk should be located on the inside);

→the pavement of ramps and pedestrian walkways on them should be electrically heated (switched on in winter) and prevent slipping; inclined interstorey floors should have a slope of no more than 6%.

The width of the ramp carriageway depends on the width of the largest vehicle using the ramp, according to Table 5.5.

Table 5.5. Ramp carriageway width

Types of ramps	Width of the ramp carriageway
Straight single-lane	The largest width of the vehicle plus 0.8 m, but not less than 2.5 m
Straight two-lane	Double the largest vehicle width plus 1.8 m, but not less than 5 m
Curved single-lane	The width of the largest vehicle plus 1 m, but not less than 3.1 m
Curved two-lane	Double the width of the largest vehicle plus 2.2 m, but not less than 6.2 m

Passenger elevators in garages are provided if the difference between the floor elevations of the first and upper floors is more than 12 meters. The dimensions of the cabin of one of the passenger elevators shall provide for the transportation of disabled persons using wheelchairs.

The number of elevators is taken at the rate of one stationary elevator for every 100 cars located on all floors except the first, and one mobile elevator for every further 200 cars, but in all cases not less than two elevators. The elevator car should exceed the dimensions of the car by 1.0 m in width (0.6 m if there is a dispatcher on duty); by 0.8 m in length; and by 0.2 m in height, taking into account the possible installation of a trunk and signaling and lighting devices.

In underground garages with more than two floors, and in above-ground garages with 5 floors or more, at least one elevator with the “firefighting unit transportation” mode of operation must be provided in each fire compartment. From each floor (section) of all types of garages, at least two dispersed evacuation exits to the outside or to stairwells should be provided. It is allowed to provide one of the emergencies exits to an isolated ramp. The passage along the sidewalks on the ramps to the stairwell is allowed to be considered an evacuation route. The distance from the most remote point of the car storage room to the nearest emergency exit is taken in accordance with Table 5.6.

Table 5.6. Distance from the farthest point of the vehicle storage facility to the nearest evacuation exit

Garage	Distance to the nearest evacuation exit, m, at the location of the storage place	
	Between the evacuation exits	In the dead-end part of the room
Underground	40	20
Above-ground	60	25

Stairs and escape routes should be at least 1 m wide.

For access to the ramp or to the adjacent fire compartment near the gate or in the gate, a fire door (gate) with a threshold height of no more than 0.1 m should be provided.

To allow for fire hoses to be laid, a hatch with a self-closing flap of 200×200 mm should be provided at the bottom of the gate.

The number of external gates for exit (entry) of vehicles from storage facilities, maintenance and repair stations in all types of garages should be taken in accordance with the presence of vehicles in the premises:

→ up to 25 inclusive - one gate;

→ more than 25 to 100 - two gates;

→ more than 100 - two gates and additionally one gate for each subsequent full or partial 100 cars.

The location of the gates in the storage rooms, maintenance and repair stations (if the number of gates is more than one) should be dispersed.

Entry (exit) of cars from the basement or ground floor of the garage through the storage room on the ground floor is not allowed.

Entrance and exit lanes shall be at least 3 meters wide; in curved areas, the lane width shall be increased to 3.5 meters.

External gates can be used as emergency exits in the construction of any type of gate, provided that there are gates without thresholds or with thresholds no more than 0.1 m high. The dimensions of the gates and their location must meet the requirements for emergency exits.

5.5. Fire Resistance Requirements for Transport Facilities

5.5.1. Ground Garages of Closed Type

The degree of fire resistance of ground-type closed garages depends on the number of floors and their compartment area and is taken according to Table 5.7.

Table 5.7. Degree of fire resistance of above-ground enclosed garages

Degree of garage fire resistance	Allowable number floors of the garage	The area of the floor within the fire protection limits compartment, no more than m^2	
		one-story	multi-storey
I. II	9	10400	5200
III	5	5200	2600
III a	2	3600	1200
IV	1	2600	–
V	1	1200	–

The degree of fire resistance of garages in an individual single-family, including blocked, residential building is not standardized.

In above-ground enclosed garages, fire compartments should be separated by fire walls and type 1 ceilings. Openings in fire walls and partitions should be protected by fire doors (gates) in accordance with DBN B.1.1-7.

In closed type garages of I and II degrees of fire resistance, it is allowed to provide separate boxes for the allocation of storage areas for cars owned by citizens. Partitions between the boxes should be solid (without openings) with a fire resistance rating of at least REI 45.

Gates in the boxes should be provided in the form of a mesh fence made of non-combustible materials or should have openings at a height of 1.4-1.6 m with a size of at least 300×300 mm for supplying extinguishing agents and monitoring the fire condition of the box.

If there is an exit from each bay directly to the outside, it is allowed to provide partitions made of non-combustible materials with a non-normalized fire resistance limit in one- or two-story garages of I, II and III fire resistance classes. At the same time, in two-story garages, the floors must be fireproof type 3.

The doors in these boxes must also have openings at a height of 1.4-1.6 m with a minimum size of 300×300 mm.

The installation of non-combustible mesh fences for each car storage space is allowed regardless of the capacity and number of floors of the ground garage.

5.5.2. Open-Type Ground Garages

The degree of fire resistance of open-type ground garages depends on the number of floors and their compartment area and is taken in accordance with Table 5.8.

The width of the enclosure in open-type garages should not exceed 40 m.

The structural scheme of open-type garages of the IIIa degree of fire resistance should be frame.

The height of parapets made of non-combustible materials on the floors should not exceed 1 m.

Mesh may be used to fill openings in external enclosing structures, and canopies made of non-combustible materials may be used to reduce the impact of precipitation over openings.

In this case, through ventilation of the floor should be provided. Ventilation in the direction of adjacent residential buildings is not allowed. Stairwells in open-type garages, regardless of their degree of fire resistance, must have a fire resistance limit and fire spread limits that correspond to the stairwells of buildings of the II degree of fire resistance. On the ground floor of open-type garages, heated rooms for service personnel, storage of fire-fighting equipment, etc. should be provided.

Table 5.8. Degree of fire resistance of above-ground garages

Degree of fire resistance	Allowable number of floors garage	Floor area within the fire compartment, *m*^{2}
I, II	9	5200
III	6	2600
IIIa	3	2000

5.5.3. Underground Garages

The degree of fire resistance of underground garages depends on the number of floors and their compartment area and is taken according to Table 5.9.

Table 5.9. Degree of fire resistance of underground garages

Degree of fire resistance	Permissible number of garage floors	Section area within the fire compartment, *m*^{2}
I,	1–2	3000
II	3–5	2600

The fire resistance limit of the floors and walls separating a garage built into or attached to an individual single-family dwelling, including a blocked dwelling, is not standardized.

Underground garages must be divided by type 1 blank fire walls into fire compartments (with the number of cars up to 200), and within a fire compartment by type 2 fire walls (with type 2 fire gates that automatically close in the event of a fire) into sections with a capacity of no more than 100 cars.

Solid fireproof floors of type 1 shall be arranged between the underground floors of the garages.

Each floor (section) in underground garages should have at least two dispersed exits and emergency exits. One of the exits may be provided through no more than one adjacent section.

Ramps can be connected to the outside environment through openings in the floors (walls) of the ramps with an area of at least 1 m, which are arranged at least every 60 m in length or in the ceiling above the central part of the screw ramps.

Exits to the ramps common to the floors should be arranged through vestibule gateways.

In residential buildings with built-in underground garages, the connection of stairwells and elevator shafts with the residential part is not allowed.

To ensure functional connection between the floors of an underground garage and the ground floor of a building for other purposes, it is allowed to arrange stairwells and elevator shafts, provided that the entrances in the underground part are arranged through fire vestibule gateways of type 1. With appropriate justification, in underground garages with no more than 2 floors, it is allowed to arrange exits to such stairwells and elevator shafts of the main part of the building through fire vestibule gateways of type 1 with air support in case of fire, subject to approval by the central body of state fire supervision.

The security room must be located on the upper underground floor of the garage or on the ground (basement) floor of the building, it must have direct access to the outside and be separated from other premises by fire partitions of type 1 and fire ceiling of type 3 (fire resistance class EI 45 and REI 45, respectively).

Entrances and exits from detached underground garages should be located at a distance of at least 15 meters from the windows of residential and work premises, areas of secondary schools, kindergartens, health care facilities, and recreation areas.

Discussion and Self-Assessment Questions for Chapter 5

1. What do you know about the types of transportation facilities?
2. List the general requirements for transport facilities.
3. Give an example of the classification of ramps.
4. Give an example of the most commonly used ramps.
5. List the requirements of fire resistance for structures of transport facilities.
6. List the fire resistance requirements for closed ground garages.
7. List the fire resistance requirements for open-air parking garages.
8. List the fire resistance requirements for underground garages.

CHAPTER 6. MATERIALS FOR SPATIAL STRUCTURES AND THEIR CLASSIFICATION

6.1. Development of Spatial Structures

With the advent of reinforced concrete capable of perceiving arbitrary shapes and absorbing compression, tension and bending forces in the early twentieth century, building structures began to be implemented that effectively used the qualities of a new material whose properties could be influenced.

Such structures were shells, in which a complex stress-strain state arises under the action of a load.

In the 30s of the nineteenth century, shells were characterized as three-dimensional load-bearing structures that differed in spatial work and consisted of one or two surfaces of curvature.

In the 40s of the nineteenth century, the concept of “thickness” appeared, which is very small relative to the size of the surface itself.

In the 50s of the nineteenth century, the concepts of “spatial constructions” and “spatial work” appeared. But spatial structures existed before the advent of thin-walled reinforced concrete shells.

First of all, these are metal core domes and vaults. The use of metal as a material for core systems made it possible not only to improve the design of gable trusses, but also to use lightweight core structures for domes and vaults. The development of building structures corresponded to the development of graphical and analytical methods of structural mechanics.

With the invention of the wire rope in 1834, a new structural element with the following properties appeared: high strength and flexibility at low weight. Working in tension, structures such as cable-stayed systems and membrane shells are among the most efficient types of building structures. Cable-stayed coatings first appeared in the late nineteenth century in the scientific works of V. Shukhov.

At the same time, the forming of shells was developing. Initially, simple forms were used - a sphere and a cylinder, and the next step was the invention of many structural forms of reinforced concrete in accordance with functional, architectural and artistic requirements.

As a result, fiber concrete and reinforced cement were produced.

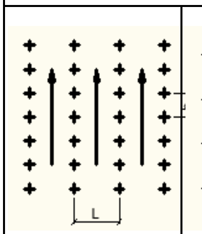
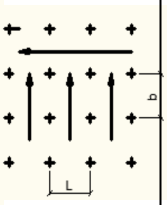
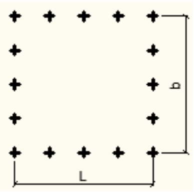
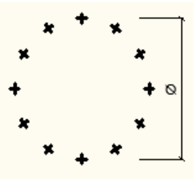
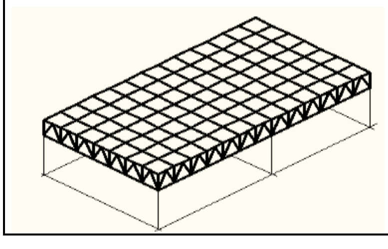
In the 60s and 70s of the nineteenth century, metal core spatial structures were developed, structures that are somewhat similar to solid slab structures. The principle of operation of the core-space structure has been known since ancient times. It was used in the Middle Ages and in our time when designing structures for cranes, airplanes, etc.)

6.2. Classification of Spatial Structures

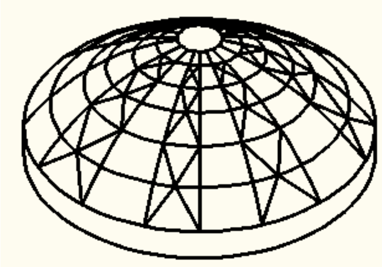
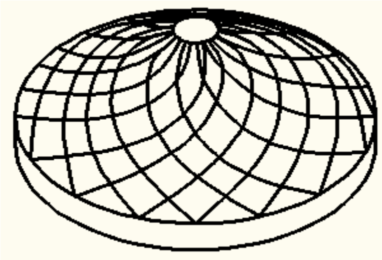
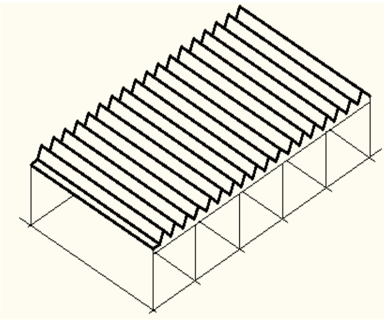
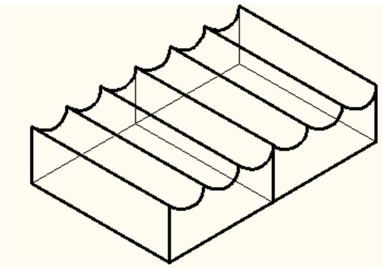
The types of spatial structures are distinguished by the static operation of the structure and the geometric shape of the median surface (Table 6.1).

The median surface is the geometric location of points in a spatial structure equidistant from its upper and lower surfaces.

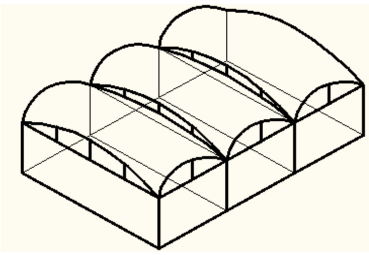
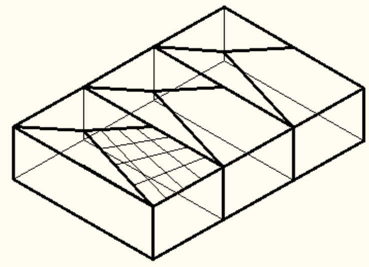
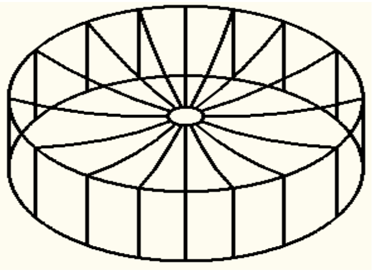
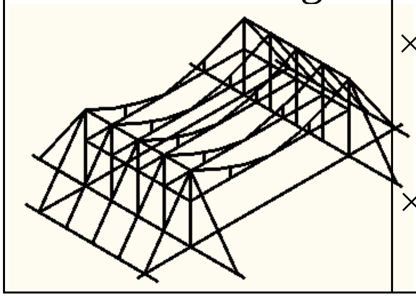
Table 6.1. Types of spatial structures

Types constructions	**Types of volume and spatial decisions and column grids, m**				**Materials**
					
1	**2**	**3**	**4**	**5**	**6**
Structures 	18×12 24×12 30×12	for 12×12 to 24×24	for 36×12 to 36×36	–	metal

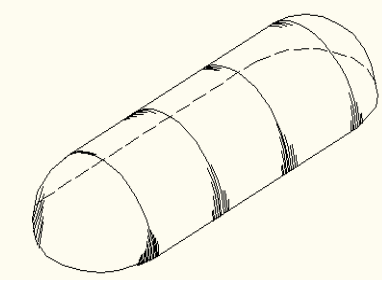
Continuation of Table. 6.1

1	2	3	4	5	6
radial-ring dome 	–	–	–	50…120	Metal, timber
mesh dome 	–	–	–	50…120	Metal, timber
folds 	18×6 24×6 18×12 24×12	–	–	–	reinforced concrete
shells in the form of hyperboloids of rotation 	18×6 24×6 30×6 18×12 24×12 30×12	–	–	–	reinforced concrete

Continuation of Table. 6.1

1	2	3	4	5	6
shells of positive Gaussian curvature 	–	18×18 24×24 24×36 36×36	36×36 42×42	–	reinforced concrete
shells in the form of hyperbolic paraboloids 	6×18 6×24 12×18 12×24	–	24×24 36×36 42×42	–	reinforced concrete
cable coverings, membranes 	–	–	–	up to 100 (for cable-stayed roofs)	reinforced concrete
	–	–	–	up to 150 (for membranes)	metal
cable coverings 	30× ×6..78×6 or 30× ×12…78 ×12	–	–	–	reinforced concrete

Continuation of Table. 6.1

1	2	3	4	5	6
pneumatic shells 	–	–	36× ×24…78× 48	–	synthetic materials

Note: b - column spacing; L - span; →- direction of technological flow.

The development of cross-beam spatial structures (CBS) systems is based on the following architectural and design principles: a single unified assortment of elements; use of rolled steel profiles that are optimal in shape; use of high-strength materials; complete industrialization of production; compactness of system elements and the ability to deliver by any type of transport; high reliability in terms of the speed of element installation; and wide possibilities for forming.

The object of standardization in the PSC systems is the core and the nodal element, which are optimized for load-bearing capacity with unified geometric dimensions. FRP have great forming properties. FRPs are designed from separate core and nodal elements.

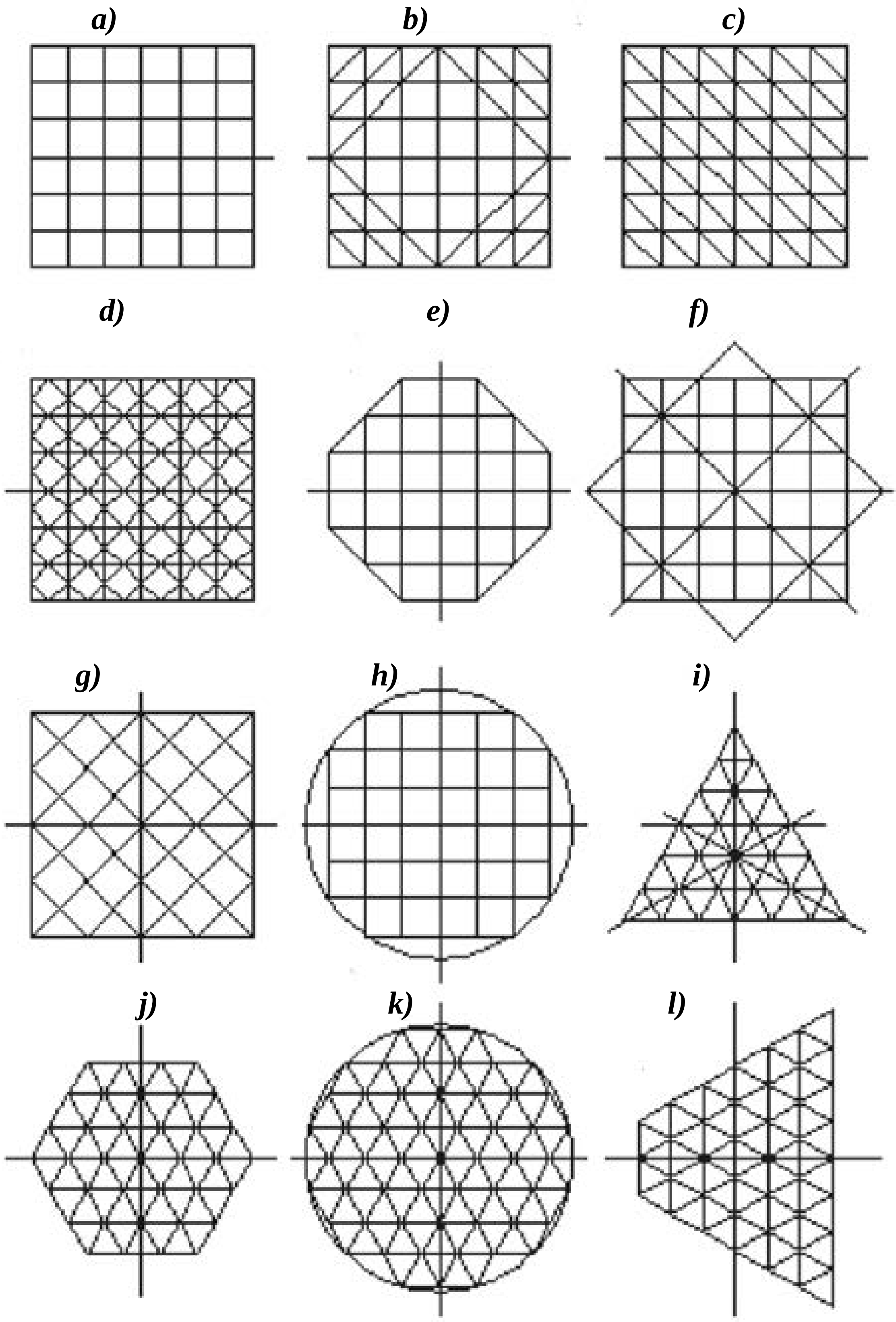


Fig. 6.1. The main schemes of roofing from cross beams and trusses

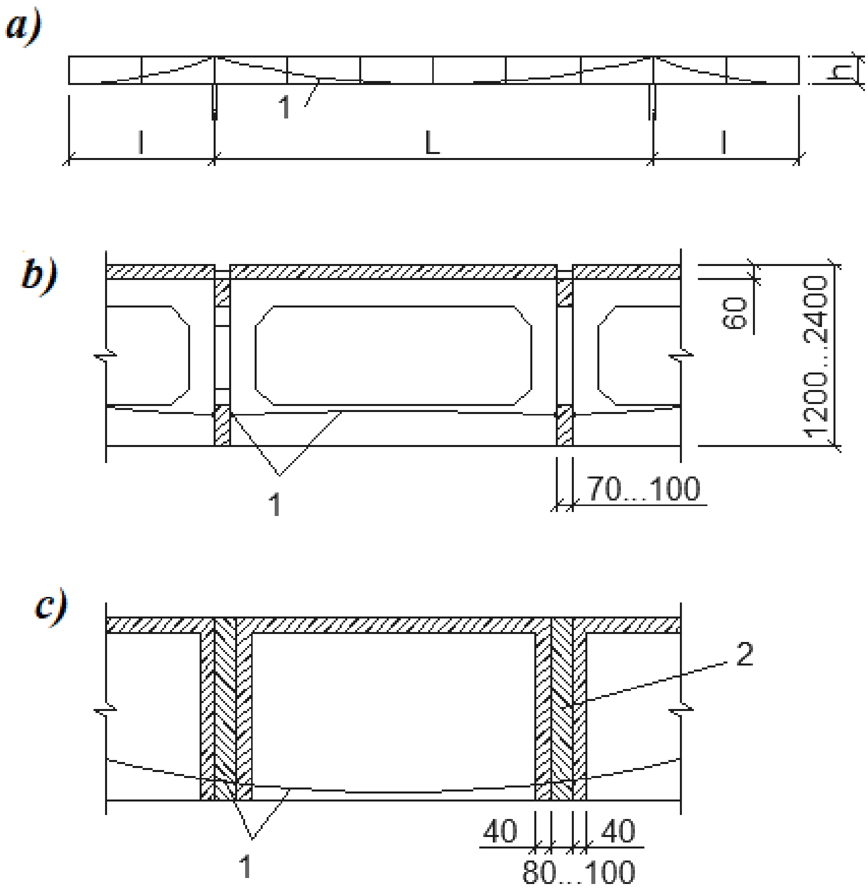


Fig. 6.2. Cross-ribbed reinforced concrete construction:
a – scheme of cross section; b – variant from planar elements;
c – from reinforced cement caissons; 1 – pre-stressed reinforcement;
2 – monolithic concrete C16/20

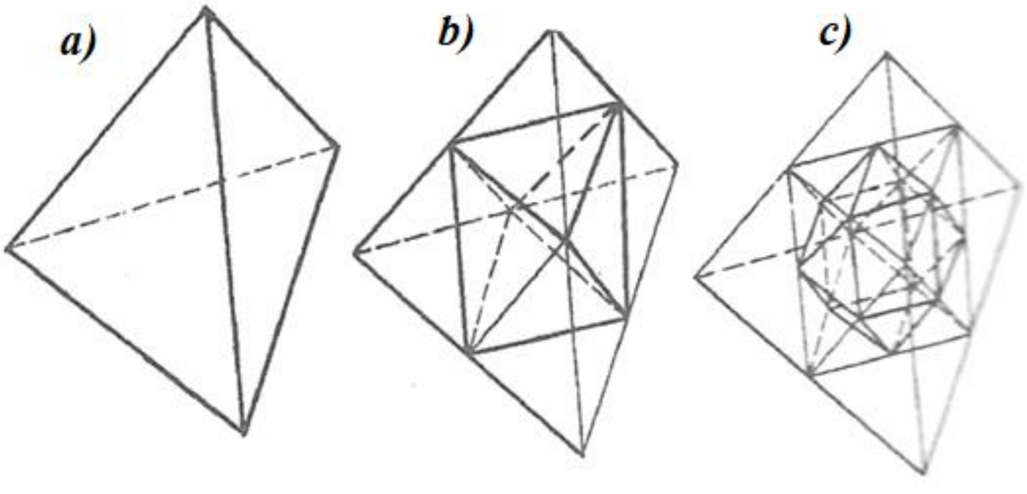


Fig. 6.3. Basic polyhedra:
a – tetrahedron; b – octahedron; c – octahedron cube

When designing spatial frames, structures based on elements of the tetra-cube-octahedral group are the most common. The main polyhedra are: tetrahedron, octahedron, cube octahedron (Fig. 6.3).

6.3. Schemes and Features of Cross-Core Spatial Structures (CCSS)

Features of CSCS:

- spatial stiffness and efficiency in case of unexpected partial destruction (internal redistribution of forces);
- low construction height;
- possibility of using as a roof and floor for long-span buildings with arbitrary plans;
- uniformity of prefabricated elements and their unification;
- use of roofing decisions without purlins.

The problems of suspended transport are solved in CCSS easier than in conventional coatings, as a frequent grid of nodes allows the suspension of crane rails in any area of the structure. Schemes of cross-core slabs are shown in Fig. 6.4.

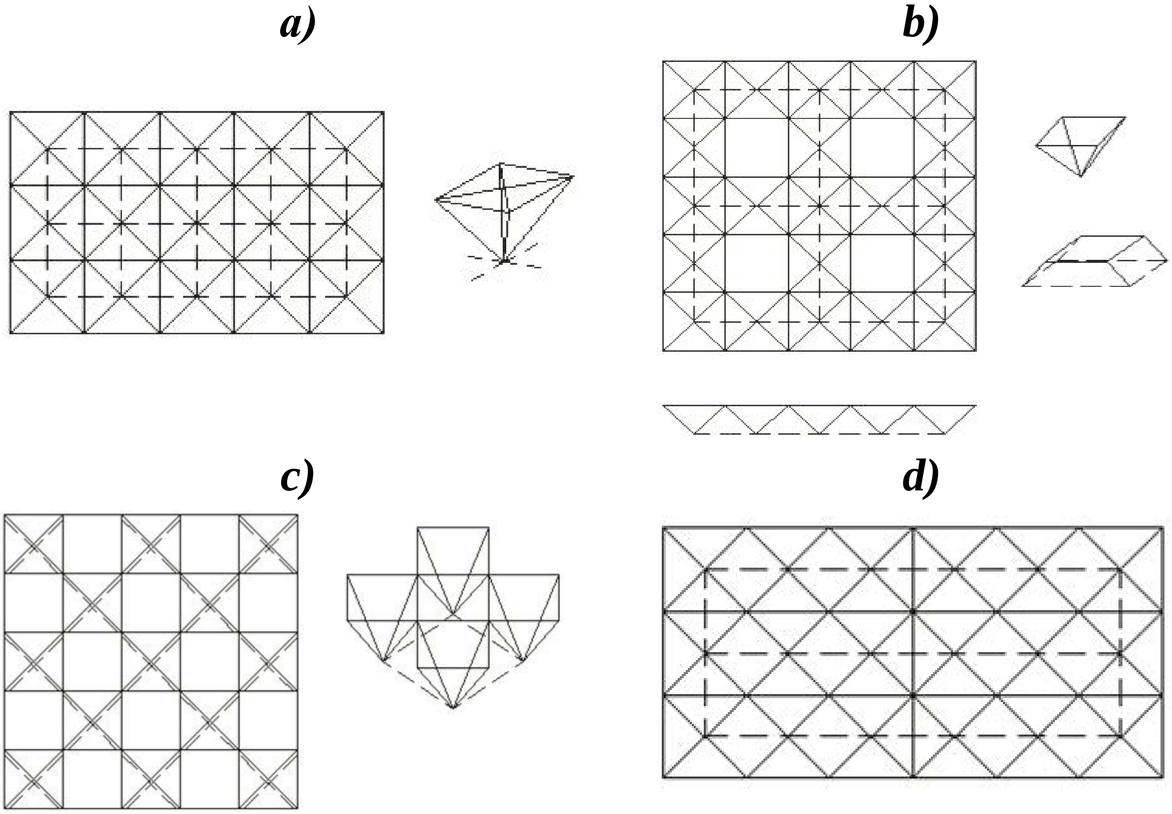
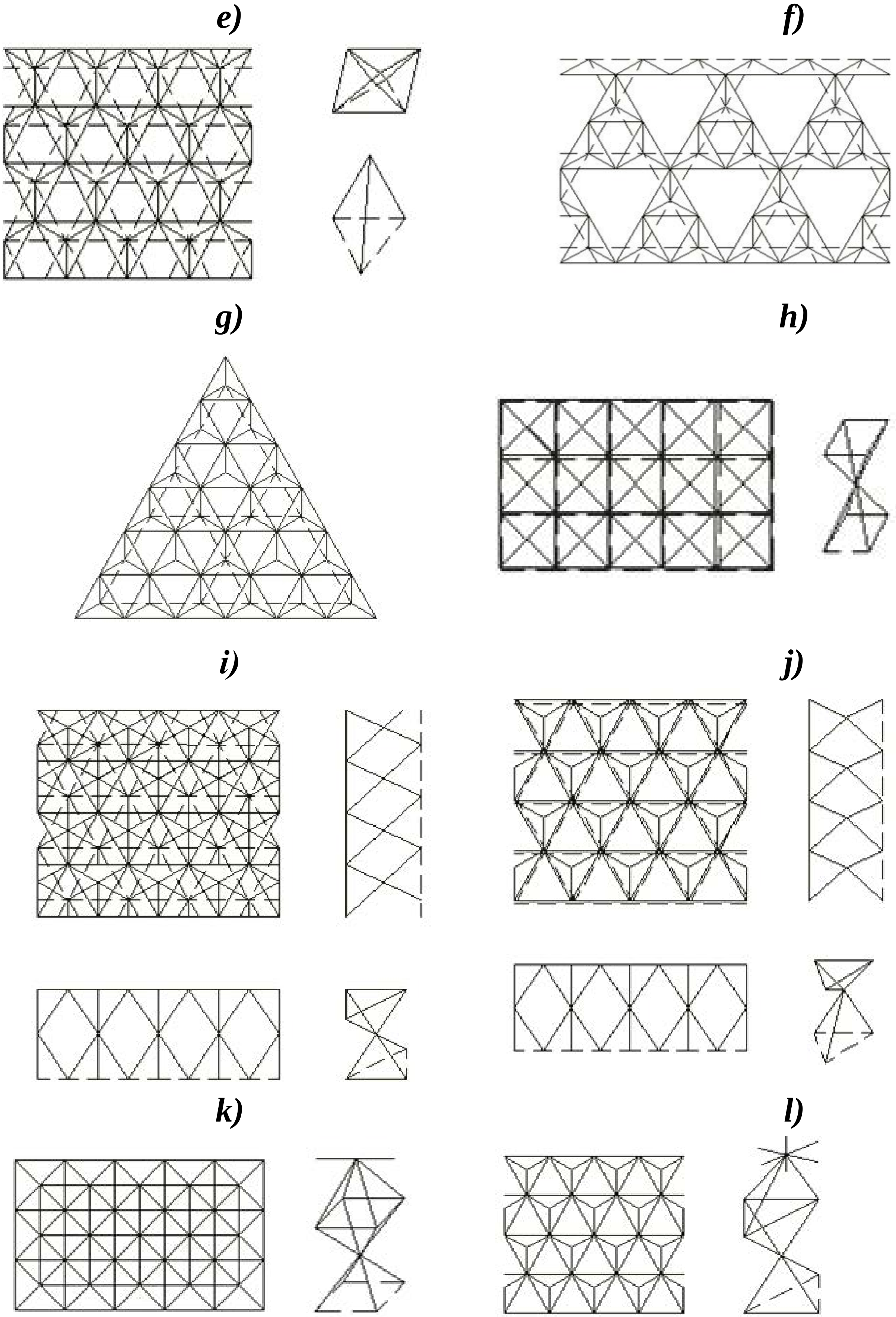


Fig. 6.4. Schemes of cross-bar plates



Continuation of Fig. 6.4. Schemes of cross-core spatial structures

Note. In Fig. 6. 4 the following notations are introduced: a - orthogonal grid of chord shifted by half a cell, chord cells can be supplemented by diagonals; b - same as scheme a, with a sparse grid of chords; c - orthogonal grid of chords with a 45^0 rotation relative to each other, sparse lattice d - pleated system, chords are located mainly in one direction and shifted by half a cell; e - grid of chords in three directions shifted by half a cell; f - the same as scheme e, with a sparse grid of chords and a sparse lattice; g - grid of chords in three directions shifted, the lower grid is sparse and forms hexagonal cells, the lattice is sparse.

Discussion and Self-Assessment Questions for Chapter 6

1. Describe and give examples of the evolution of spatial structures?
2. Give an example of the main types of spatial structures.
3. Give an example of the main schemes of roofs of cross beams and trusses.
4. Give an example of a cross-ribbed reinforced concrete structure.
5. Give an example of cross-core slab schemes.
6. Describe the features of cross-core spatial structures?

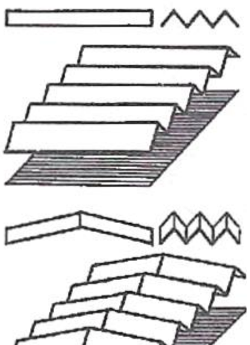
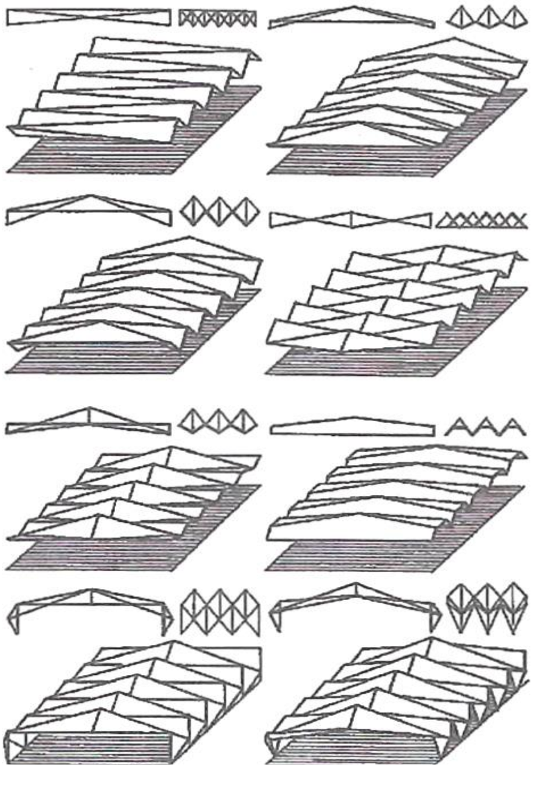
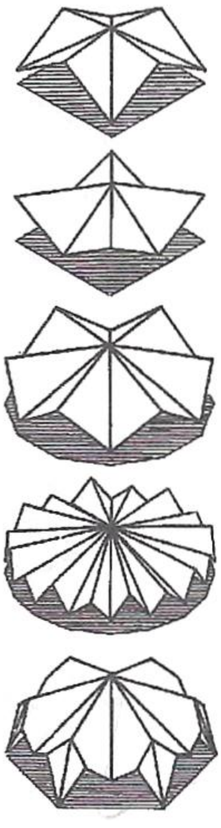
CHAPTER 7. FOLDS

7.1. Variety of Architectural and Structural Decisions for Folds in Construction

In the 50s and 60s of the twentieth century, the development of shell structures went in line with the industrialization of construction.

Folds are a system of flat plates inclined to the horizontal (at least 30°) with the connection of the lower and upper edges working together. According to their shape, folds are divided into: prismatic and pyramidal (counter and radial) (Table 7.1)

Table 7.1. Types of folds

prismatic	pyramidal	
	opposite	radial
		

The variety of architectural and structural decisions for folds is not exhausted. Flat rectangular, triangular and trapezoidal slabs in their various combinations have the ability to form a wide variety of structures and cover rectangular, polygonal and circular building plans.

7.2. Reinforced Concrete Folds

Reinforced concrete folds are made of reinforced concrete or reinforced cement. They are composed of slabs, side elements, and diaphragms, and are characterized by their triangular or trapezoidal cross-sectional shape, usually the same along the entire length.

Trapezoidal folds differ from cylindrical shells in that they replace the curved guide of the middle surface with a broken straight line.

The folds can be single and multi-span, as well as single and multi-wave. Prefabricated folds consist of slabs, prestressed side elements made of lattice or solid diaphragms. The upper horizontal shelves of the folds can be used to support prefabricated slabs when designing a flat roof, as well as to place lanterns.

The distance between the diaphragms, or the span of the folded structure, is taken to be 12-36 m, the wave length up to 12 m, the height of the fold of the span, the thickness of the precast concrete slab 50-60 mm, and the thickness of the reinforced concrete slab 20-30 mm.

To cover general-purpose halls, prefabricated large-sized single-span long folds are used to provide architectural expressiveness of the interiors (Fig. 7.1, a, d). Such folds can have one or two cantilevered overhangs.

To ensure the stiffness of the folds at the stages of manufacturing, transportation, and installation, as well as to absorb the forces arising in the transverse direction under the action of operational loads, in addition to the bearing loads, intermediate diaphragms are placed with a step of 3-6 m (Fig. 7.1, d).

Prefabricated folds are made of heavy concrete of at least C25/30 class, for reinforced cement folds at least C16/20. The main tensile reinforcement is recommended for the design of prestressed reinforcement made of high-strength rods of A400C, A500C class or K-7 and K-19 ropes.

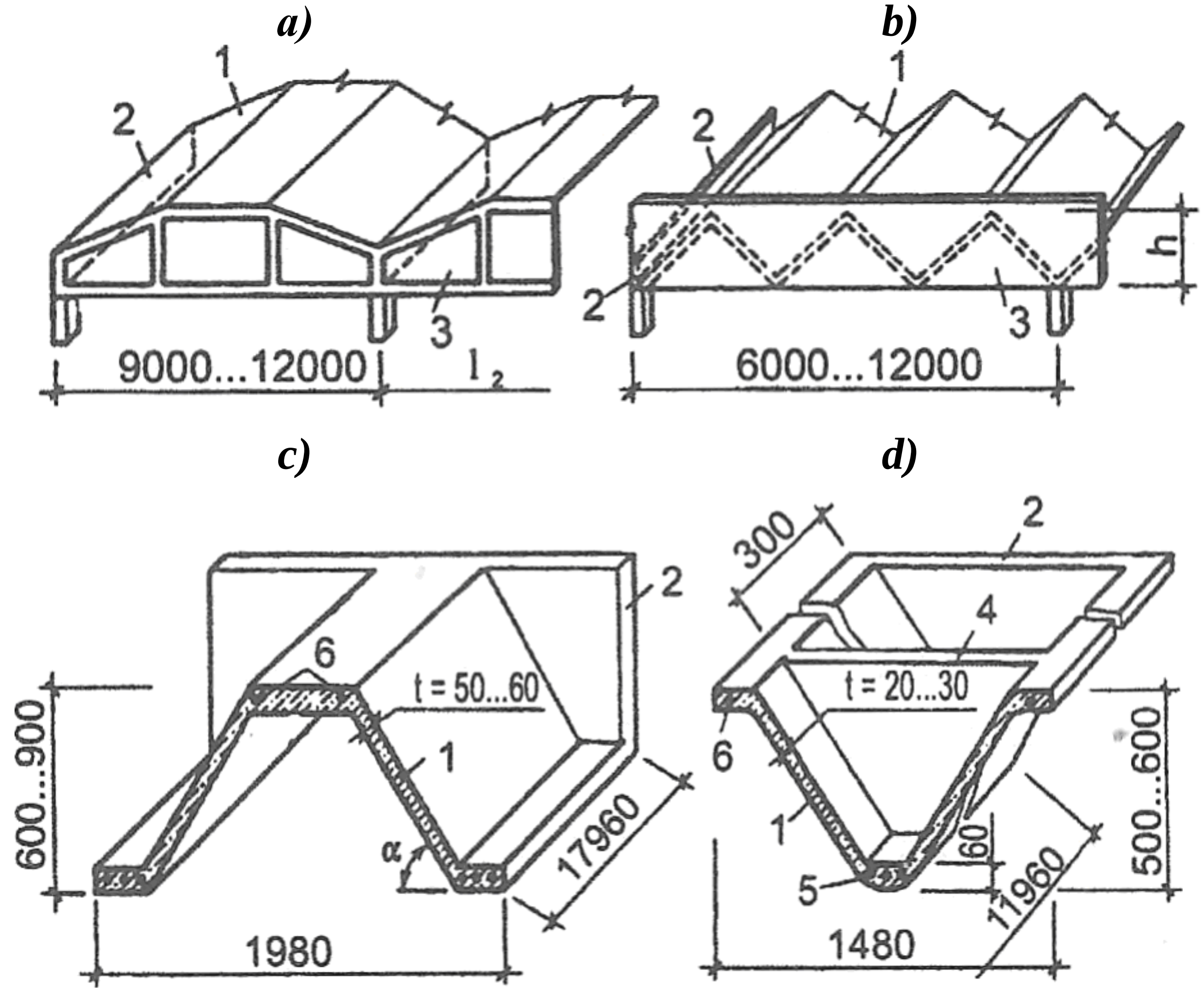


Fig. 7.1. Scheme of a roofing with trapezoidal (a) and triangular (b) multi-wave folds made of precast long elements, as well as the structure of a large-sized reinforced concrete (c) and reinforced cement (d) fold:
1 - slab; 2 - edge element; 3 - support diaphragm;
4 - intermediate diaphragm; 5 - working reinforcement;
6 - structural reinforcement

Reinforcement in the compression zone in the longitudinal direction is assigned structurally from rods Ø5-7 mm with a step of 20-25 cm.

The transverse reinforcement of the folds is performed by meshes with their bending along the line of contact of the edges.

7.3. Composite Reinforced Concrete Folds

Composite folds are constructed using flat slabs having in plan a rectangular, trapezoidal or triangular shape view shown in Fig. 7.2.

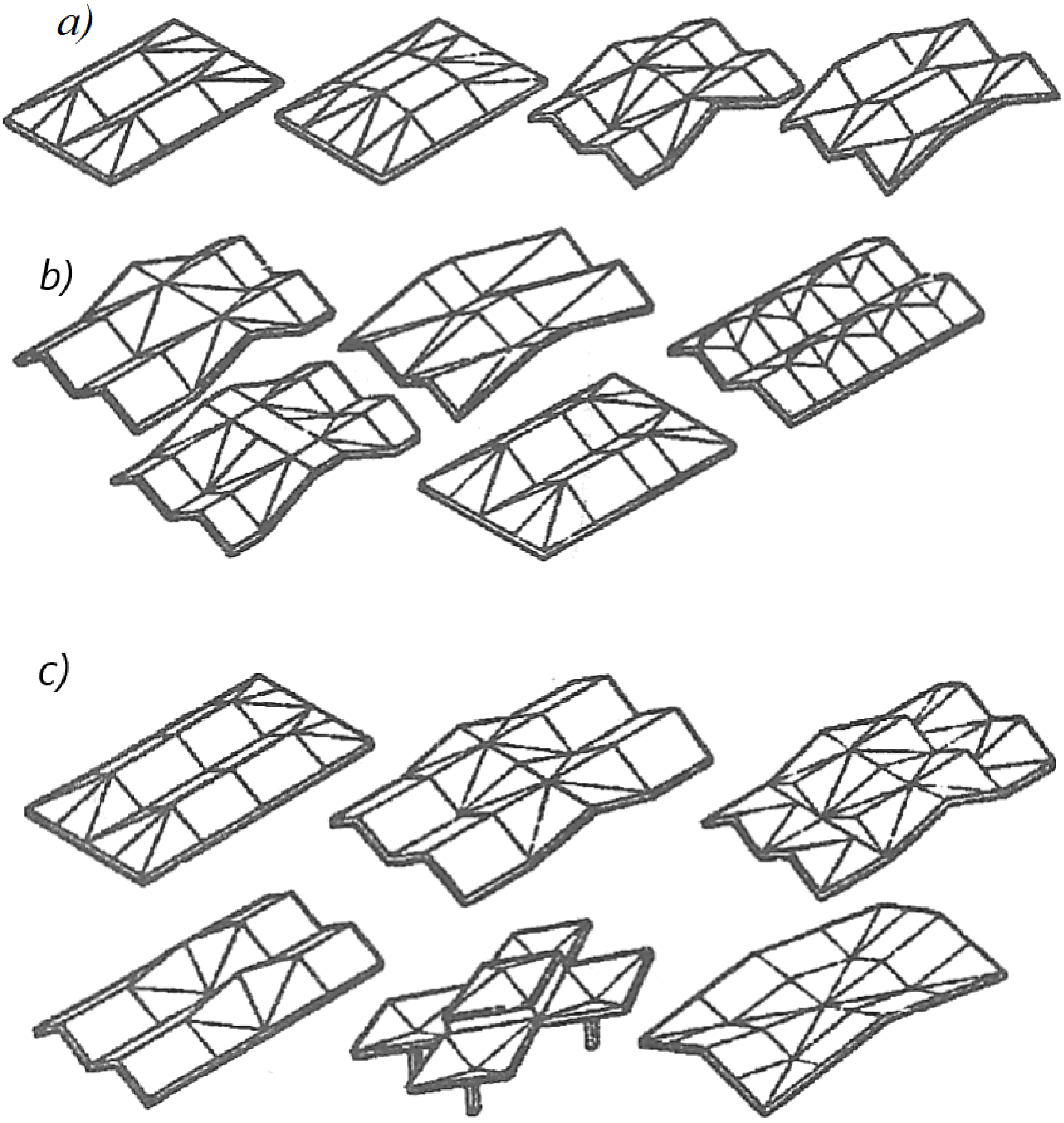


Figure 7.2. Variants of folds layout (fold spacing 6 and 12 m): a - 18 m spans; b - 21 m spans; c - 24 m spans

Varieties of composite folds are designed according to the principle of shells with central stiffeners. The roof is formed by separate folds that are interconnected. In the middle zone of the cover, openings are formed in the form of elongated polygons. The structure is equipped with multifaceted elements that hold the openings. The opposite corners of the openings are connected by rod elements (spacers, ties). Different variants of central elements in the form of polyhedra or with a surface of additional Gaussian curvature are used (Fig. 7.3, б).

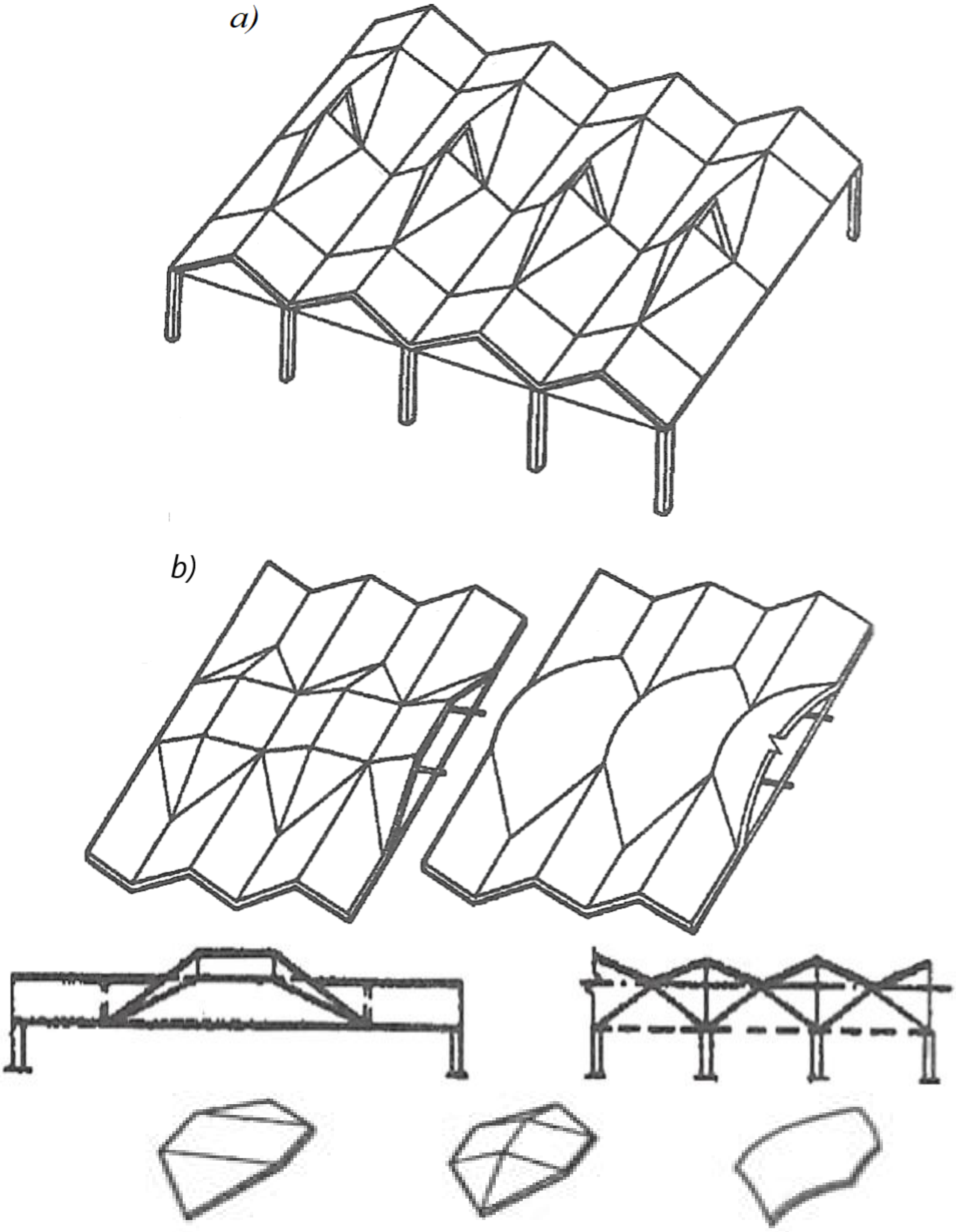


Fig. 7.3. Variants of composite folds with central stiffening elements in the form of polyhedral and curved plates: a - rod elements of spacers, ties; b - surface of positive Gaussian curvature

The purpose of the central element is to increase the spatial stiffness of the structure as a whole and reduce tension in the lower part of the fold. Pleated multi-wave roof (Fig. 7.4) consist of cylindrical (in some cases, flat) plates. They are joined together to form a pleated profile.

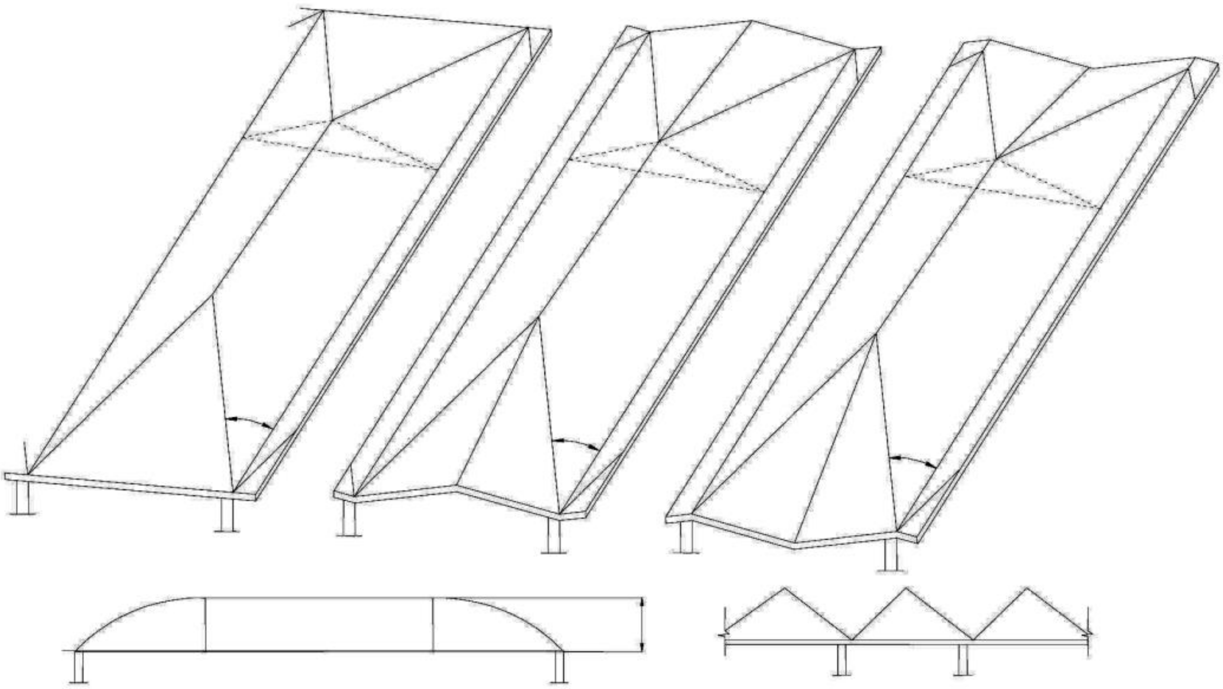


Figure 7.4. Composite folded shells without a central element

Each fold is made with a surface break along the lines connecting one of the corners of the structure with its longitudinal axis at an angle of α, thus forming triangular elements. Usually folds prestressed by tendons.

By varying the angle α, it is possible to design a roofing in which, in the zone of high bending moments, the cross section will have a maximum surface fracture in the part under resistance, which will allow the formation of various facades.

Discussion and Self-Assessment Questions for Chapter 7

1. What is a “fold” and what architectural decisions of folds do you know?
2. Give an example of a trapezoidal multi-wave folds covering scheme.
3. Give an example of a coverage scheme for triangular multi-wave folds.
4. How is the stiffness of the folds?
5. Give an example of composite reinforced concrete folds.
6. Give an example of composite folded shells without a central element.

CHAPTER 8. VAULTS

8.1. Types of Vaults

Vaults are spacer shells of single and double curvature, in which the spans are four or more times their width (wave length). In the case of such coincidences, the shell works mainly in the direction of its span. Depending on the conditions of support, the following types of vaults are distinguished: vaults with support on two opposite sides; vaults with support along the contour (closed); vaults with point support in the corners (cross, sail).

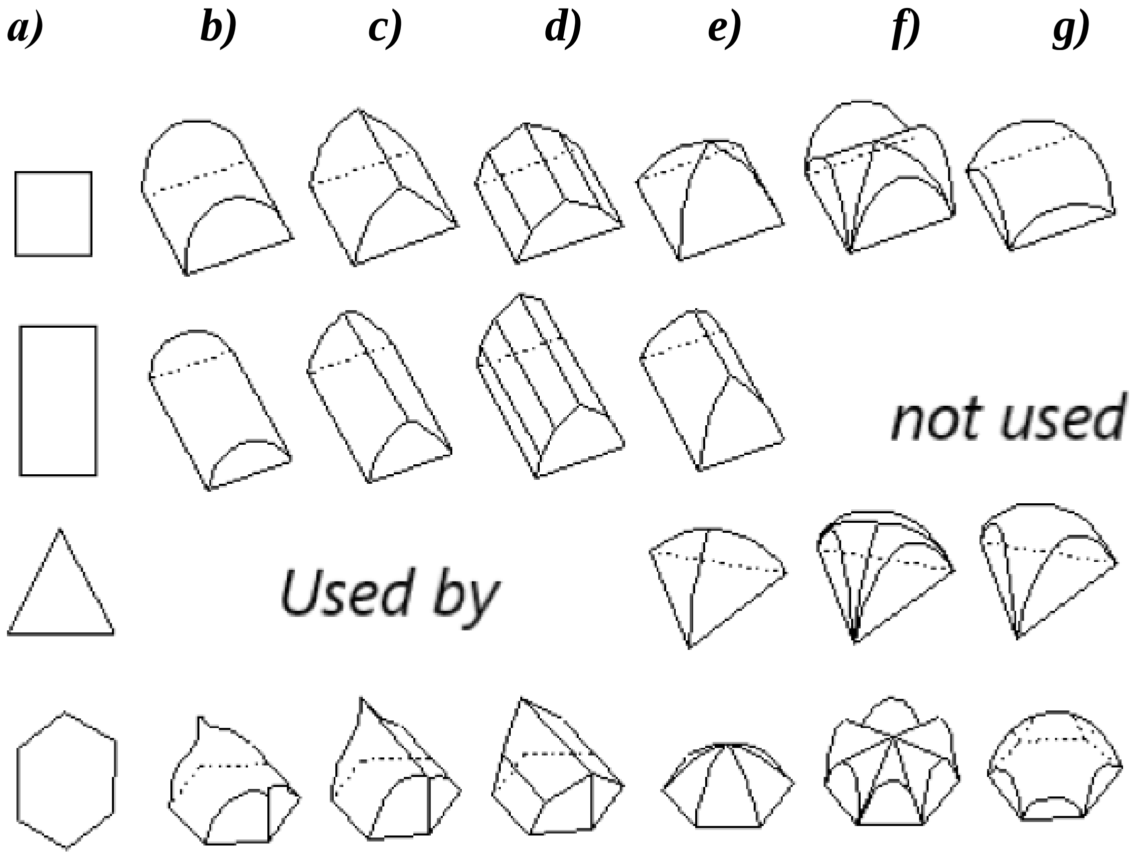


Fig. 8.1. Types of vaults:
a - shape in plan; b - cylindrical; c - lancet;
d - polygonal (prismatic); e - closed;
f - cross; g - sail

A cylindrical vault is the surface of a straight line transferred along the contour or other curve.

A lancet vault is formed from two cylindrical surfaces with an intersection forming a ridge on top.

A polygonal vault has a cross section in the form of a broken line inscribed along the contour of a circle or other curve.

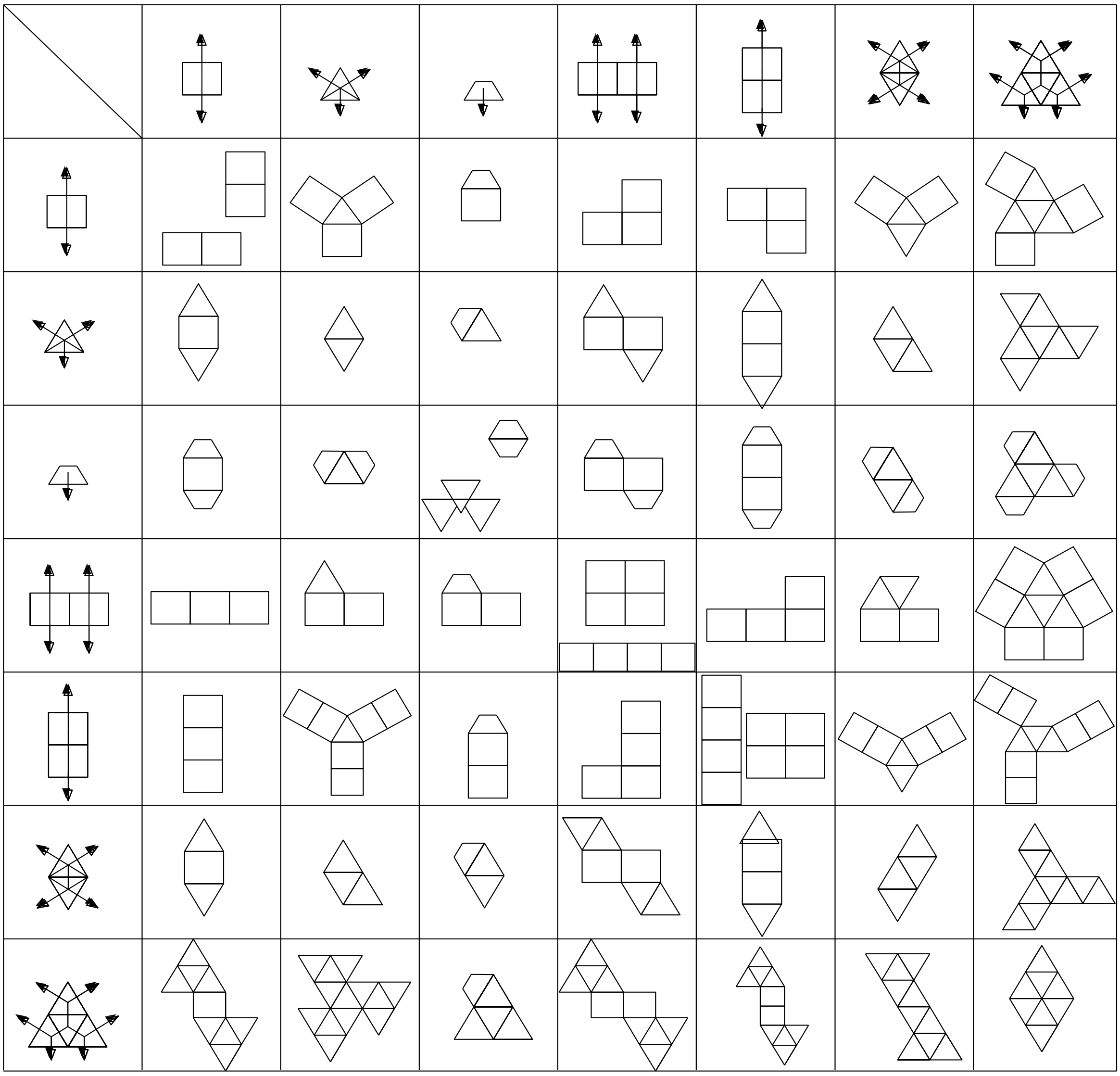


Fig. 8.2. Layout of vaults in the plan

A closed vault is formed by cylindrical surfaces that intersect and form vertices.

Cross vaults are formed at the intersection of two or three cylinders open to the outside.

A sail vault is a surface of double curvature (a transitional form to domes) that has a segmental section cut off in the plan view.

When combining different forms of vaulting (as part of the roof), it is possible to obtain components of shell vaults on different forms of building plans (Fig. 8.2).

In the transverse direction, it is recommended to take the shape of the vaults according to one of the following curves: arc of a circle, parabolas, chain lines or similar curves and broken lines inscribed in curves (Fig. 8.3):

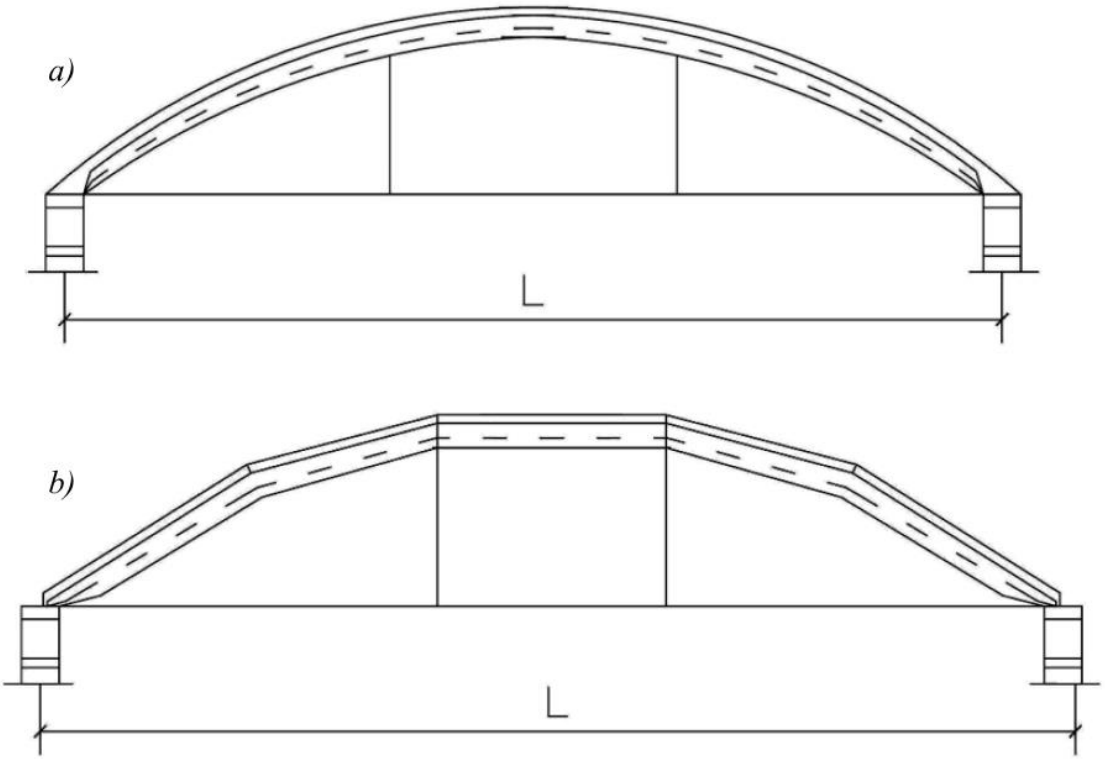


Fig. 8.3. Types of vault structure shapes in the transverse direction:

a – curved; b – prismatic

For vaults made of precast concrete elements; in order to improve the number of their standard sizes, the shape of the vault should be taken along the arc of a circle or a broken arc inscribed in it (polygonal vaults).

The most typical cross sections of an open profile are (Fig. 8.4):

- wavy, having a smooth connection of two equivalent curves (positive and negative curvature), a section describing a sinusoid, etc;
- folded sections, formed by the intersection of a series of rectangular lines representing a broken line in the cross section of the coating;
- a section that has an unambiguous curvature: positive or negative (barrel vaults).

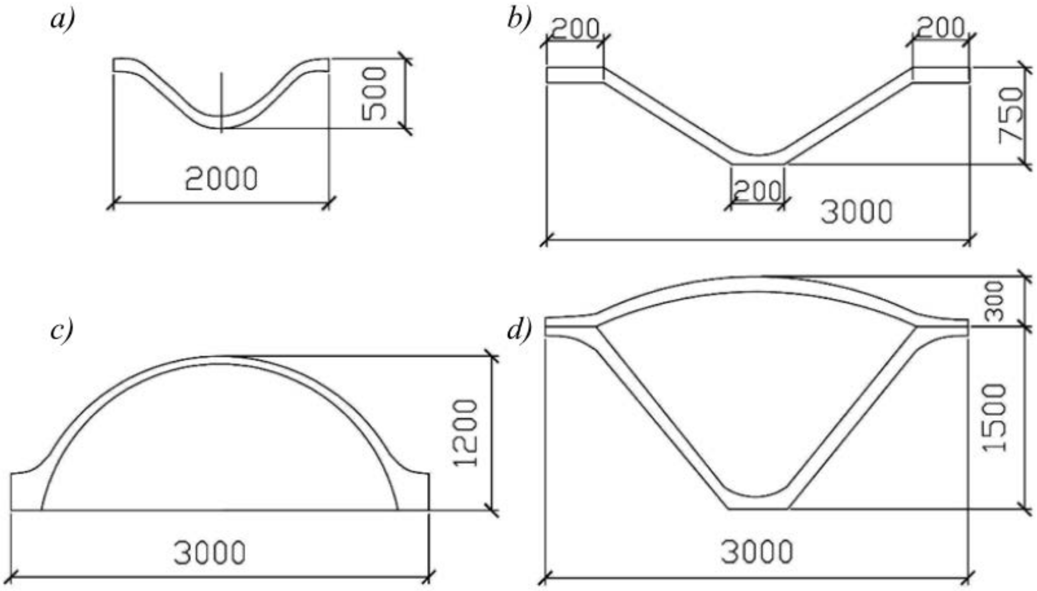


Fig. 8.4. Section of the vault structures:

a – wavy; b – folded; c – barrel; d – closed profile

Cross-sections with a closed cross-sectional profile are also used. The cross-sectional dimensions of the vault elements significantly affect the structural rigidity. The ratio of section height to width is taken within 1/4...1/5.

The roof of the vault is designed as a single or multi-span. At the ends, the vaults can be supported by columns, frames, diaphragms, or foundations. When resting on columns, a spacer occurs in the vaults, which is perceived by the puffs, which are load-bearing structures.

The vault supports are designed to be reinforced concrete, reinforced cement, steel-reinforced concrete and wooden.

8.2. Reinforced Concrete Vaults

It is recommended to perform in a prefabricated version from separate unified thin-walled elements manufactured at the factory. It is possible to manufacture vaults from monolithic reinforced concrete. Vault ties are made of reinforced concrete (with conventional and prestressed reinforcement) or steel. Sometimes it is effective to use steel contour arches installed along the length of the span to be covered, with the inclusion of the top arch chords in the load-bearing system of the top chords of the vault.

Two main sections of vaults for precast slabs are used - longitudinal and transverse. In Fig. 8.5. shows a variant of a barrel vault with a longitudinal cut into slabs. The design with transverse cutting is shown in Fig. 8.6.

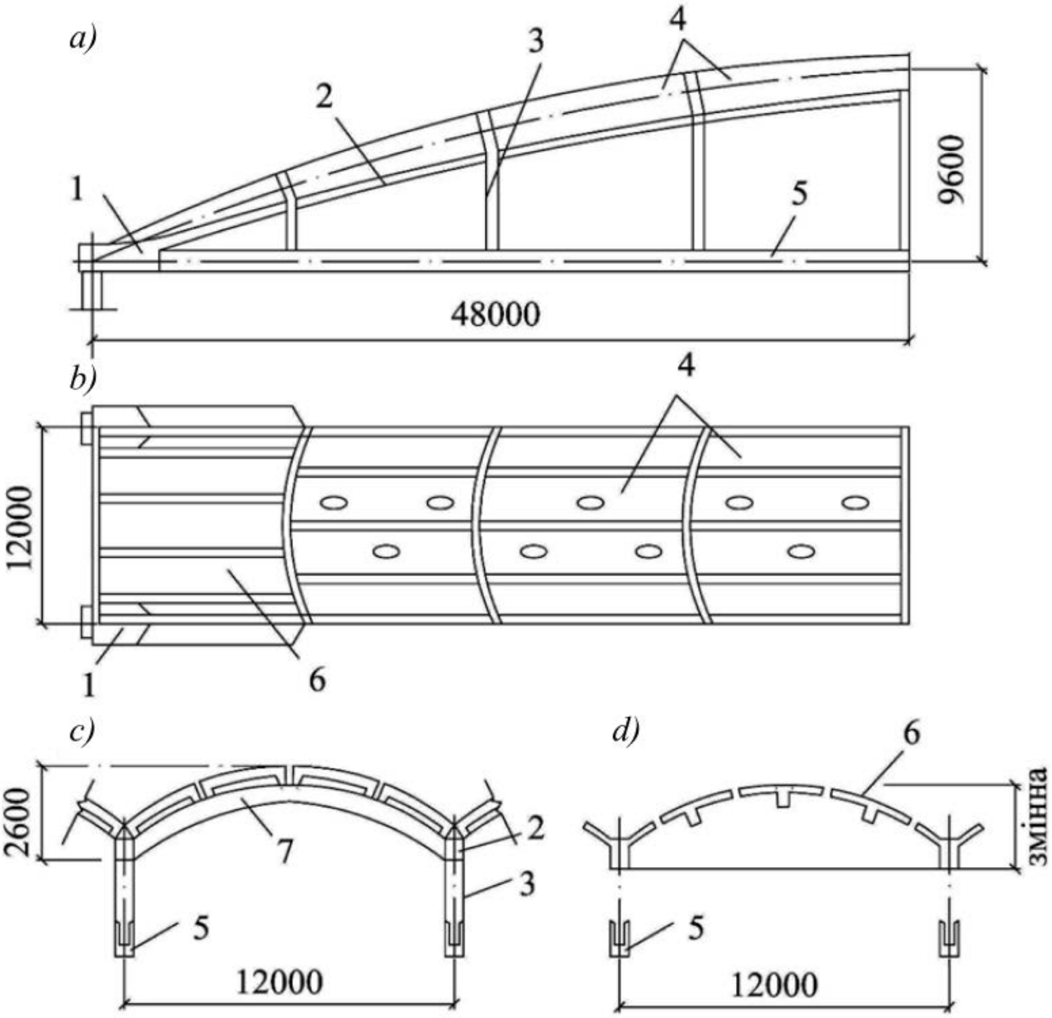


Fig. 8.5. Scheme of a barrel vault:
a - longitudinal section; b - slab layout plan;
c - cross-section along the middle span; d - the same for the support zone;
1 - bearing node; 2 - side element;
3 - steel suspension; 4 - middle slab with openings;
5 - tightening unit; 6 - support zone slab; 7 - diaphragm beam

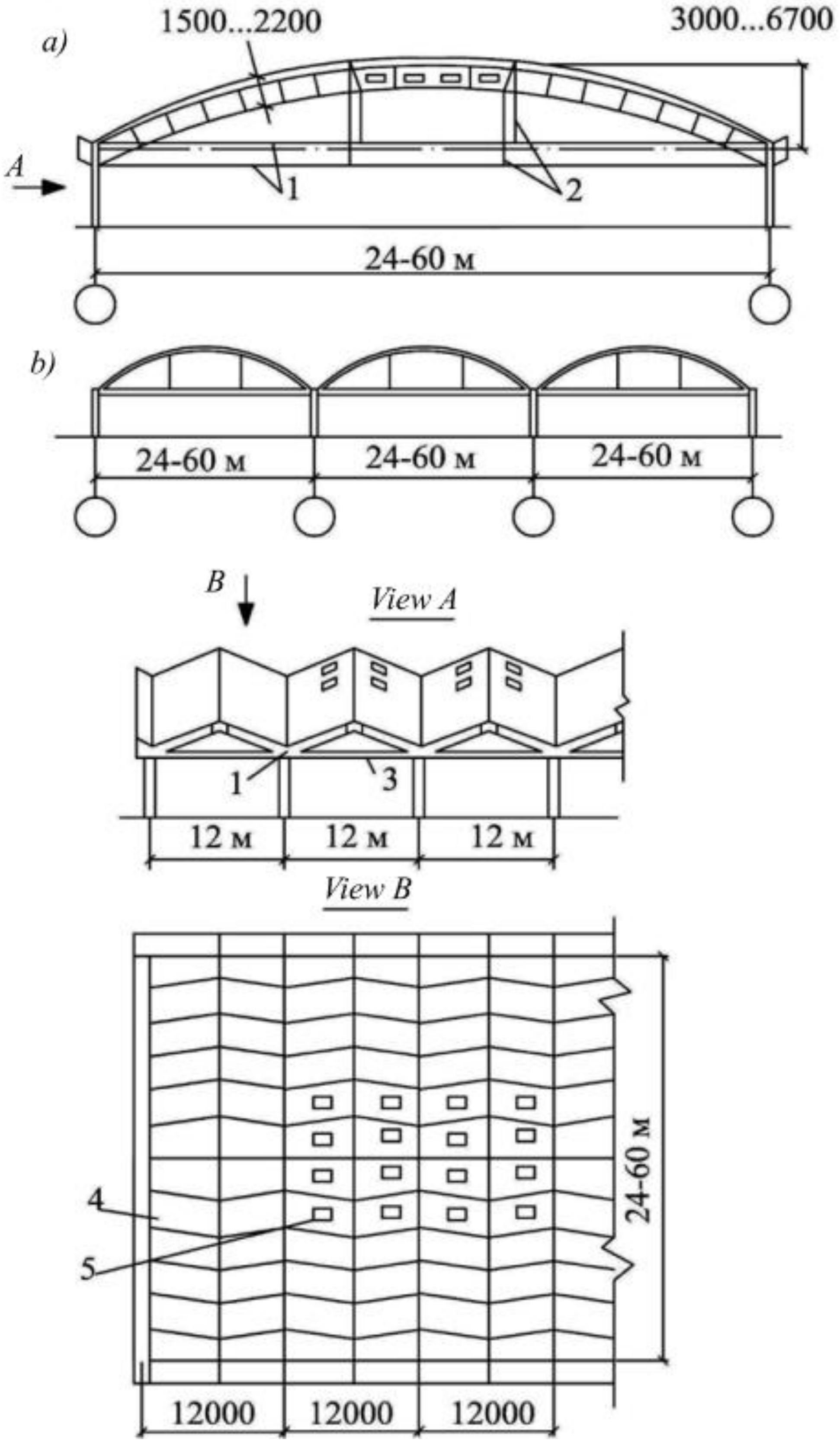


Fig. 8.6. Folded vault of flat slabs:
a - single-span variant; b - multi-span variant;
1 - tendon; 2 - suspension; 3 - support truss;
4 - slab; 5 - lantern

It is recommended to take the raise of the longitudinal axis of the vault within 1/2...1/4 of the span. Larger values are accepted for vaults supported by foundations, smaller values - for vaults with tendons supported by columns.

Fig. 8.7 shows the design of the upper and lower joints for a three-jointed vault. Insulation of the roof covering is carried out with monolithic (polystyrene foam) or lightweight insulation directly on the surface of the entire roof covering.

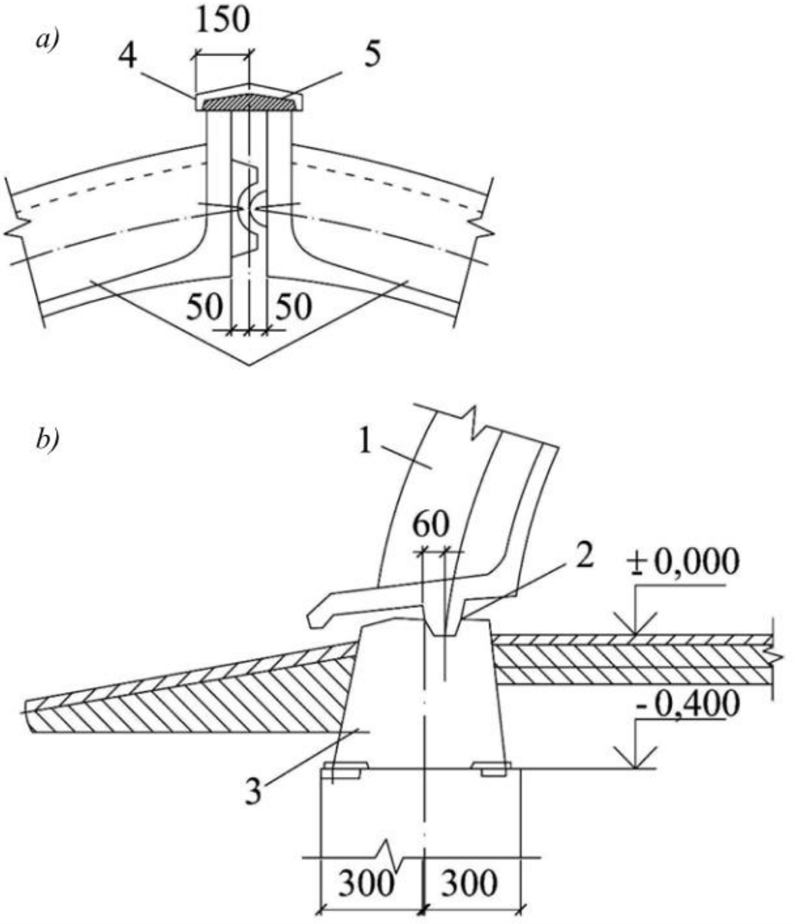


Fig. 8.7. Upper and lower hinges in a building with a vault:
a – the upper assembly of the vault with a concrete hinge;
b – support of the vault on the foundation beam;
1 – roofing element; 2 – rubber mastic;
3 – foundation beam; 4 – galvanized iron; 5 – gasket

Vault ties can be made with prestressing and without prestressing.

Prestressed tendons are designed as reinforced concrete or metal. Rod reinforcement and high-strength reinforcement in the form of harnesses and ropes are used as stressed elements (Fig. 8.8).

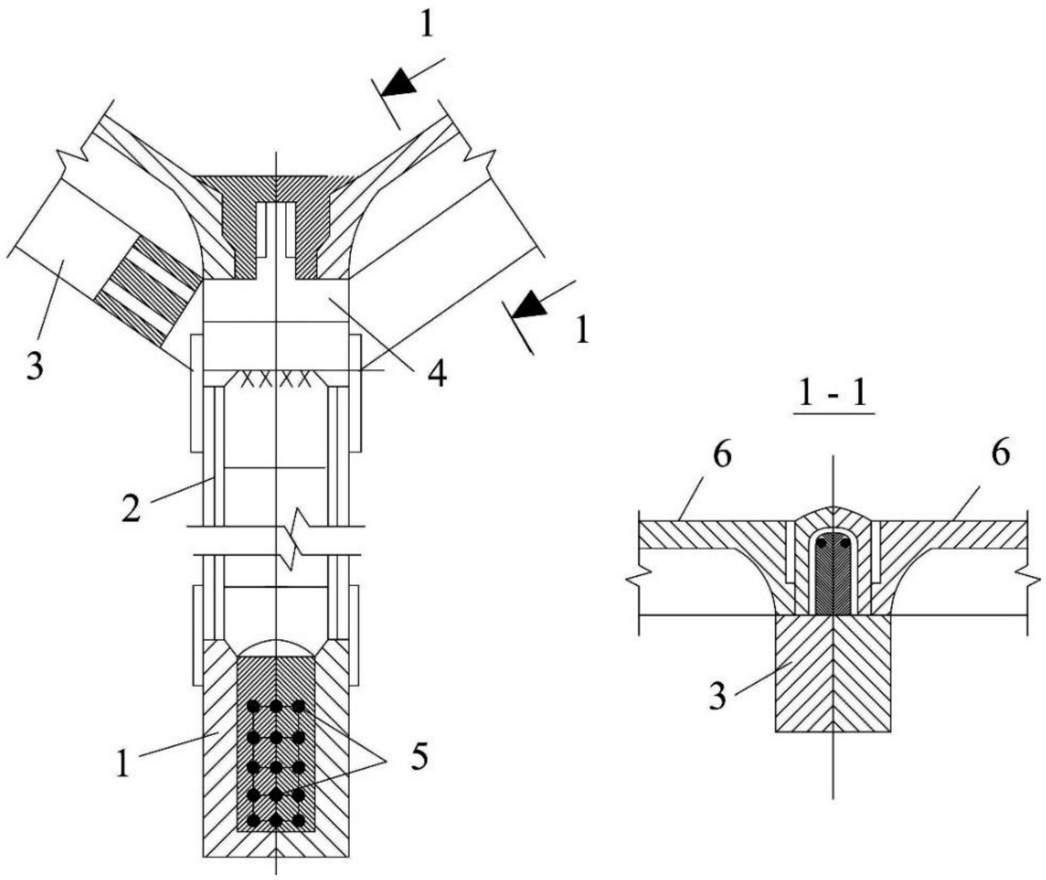


Fig. 8.8. Detail of the connection of barrel vaults:
1 - tendon node; 2 - steel suspension;
3 - diaphragm beam; 4 - side element;
5 - tendon reinforcement; 6 - middle slab

Tendons take up the vault bracing, are attached directly to the support beams, and take up vertical and horizontal loads.

Design schemes of thin-walled vaults are determined by the presence of hinged support of elements or their clamping in the supporting structures. Therefore, vault coverings are divided into clamped (hingeless), two- or three-jointed. A simplified calculation of such structures is reduced to the calculation of flat arches with a curved or broken cross section.

8.3. Folded and Wavy Vaults

The design of a folded vault is capable of covering spans from 24 to 60 m, consisting of interconnected folded arches 12 m wide, mounted from flat reinforced concrete slabs with dimensions of 3x6 m (Fig. 8.9).

Slabs of folded arches are designed similarly to flat slabs. The thickness of the slab plate is 30-40 mm, and 50-60 mm in the bearing zones.

The height of the longitudinal and end ribs is 150-200 mm, and the transverse ribs are 120-150 mm, spaced at 600-800 mm intervals. Recesses are made on the side surfaces of the slabs to form keyways. The vault support slabs are designed with continuous thickening.

The reinforcement of thin-walled vault structures is performed in accordance with the diagrams of normal and transverse forces, as well as bending moments. Bending moments are absorbed by rod reinforcement in the form of flat frames laid in the longitudinal rib along the length of the structure. Normal and transverse forces are absorbed by reinforcing meshes made of wire with a mesh size of 150x150 mm or 200x200 mm with a diameter of 3-6 mm. The supporting parts of the elements, which are reinforced concrete slabs or beams, are reinforced with core spatial frames.

Woven mesh is used to reinforce the vaults, which are laid over the entire surface of the structure.

Barrel vaults. For barrel vaults with a span of 48-100 m, it is recommended to take the raise 1/10 ... 1/12 of the span. The wave width of the vaults in the transverse direction should be 6 - 12 m. For spans of 60 - 100 m, the most rational width is 12 m. The height of the cross-section of the vault wave is within 1/4...1/10 of its width, Fig. 8.9.

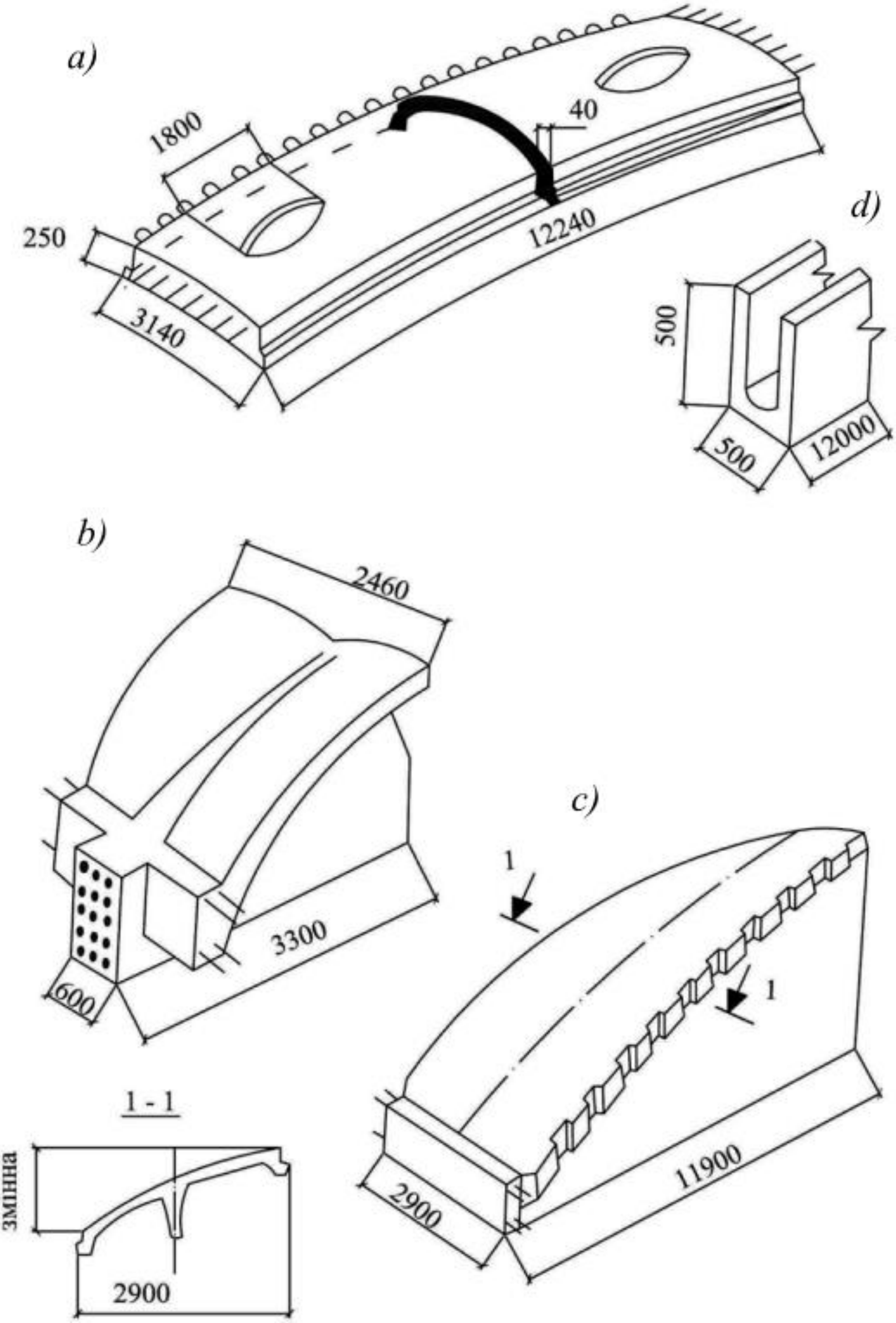


Fig. 8.9. Cylindrical slabs of barrel vaults:
a - middle slab with openings;
b - bearing node; *c* - tightening block

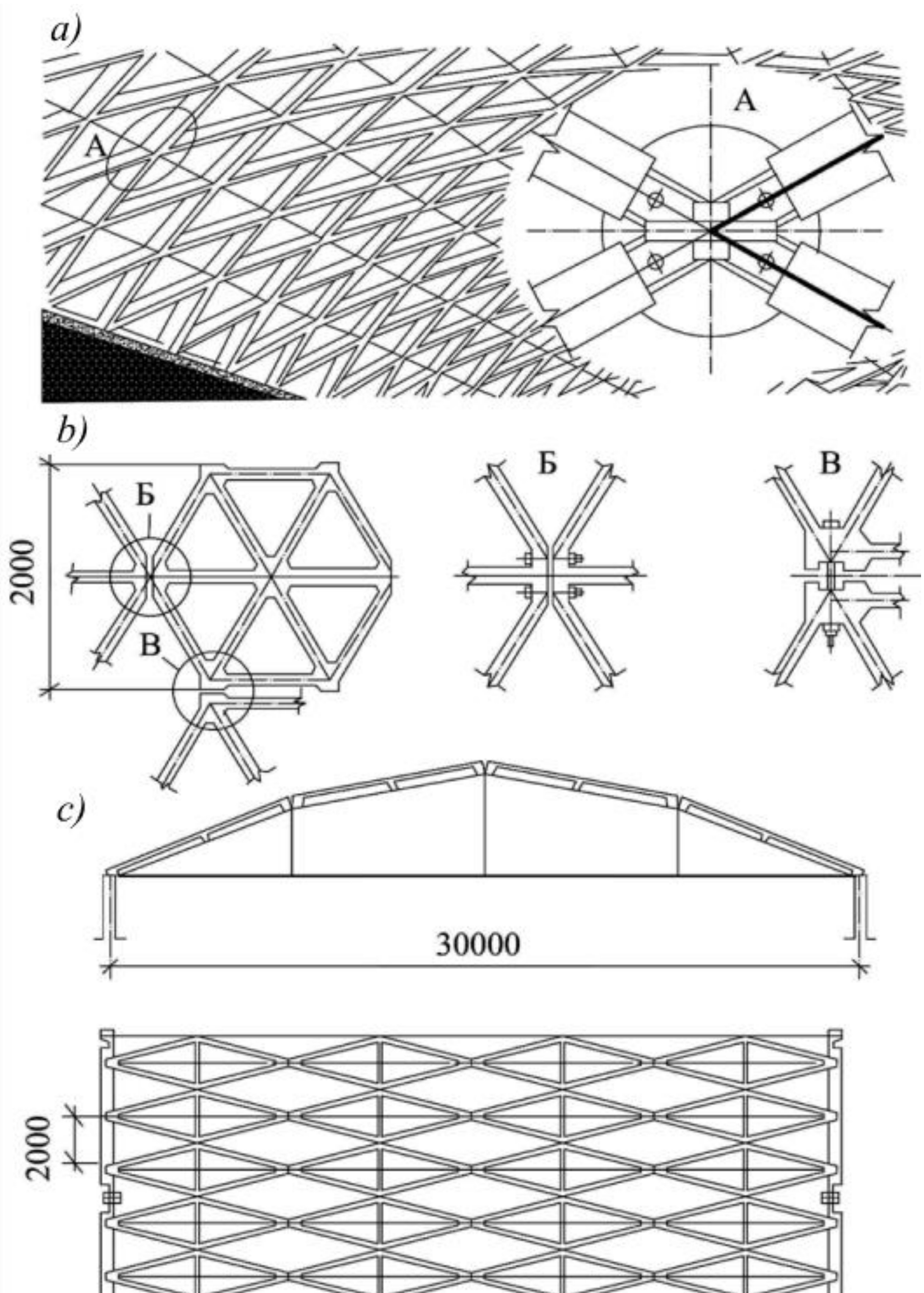


Fig. 8.10. Prefabricated lattice vaults
of reinforced concrete elements:
a - from two-meter-long rods; *b* - from hexagonal modules;
c - from rhombic elements

The surface of a barrel vault is formed by moving a certain curve (arc, circle, parabola) or broken line along the axis so that the plane of the generic remains perpendicular to the axis of the vault, the end or support zones of the vaults must be designed in one of the following ways:

1 - the bearing zone is toroidal (the vault has a constant cross-sectional shape along its entire length);

2 - the bearing zone has a conoidal shape or close to it (variable height of the profile of the middle zone to the straight line on the line of supports.

Prefabricated slabs of the barrel vault are recommended to be made in sizes of 3×6 m and 3×12 m. The minimum thickness of the slab plate is 30-35 mm. The slabs are framed around the perimeter with ribs 150-250 mm high. In the longitudinal cutting scheme, slabs with a cylindrical surface shape with a span of up to 12 m are recommended (Fig. 8.9); slabs with a broken surface shape can be accepted.

The edge surfaces of the ribs are made with keyways to ensure the transmission of shear forces. The slabs are connected to each other by welding embedded parts or reinforcement stick-outs.

Reinforced concrete lattice vaults are made in a prefabricated variants and are assembled from flat grids of polygonal or rhombic shape (Fig. 8.10). The span of the girders is 18-36 m.

Discussion and Self-Assessment Questions for Chapter 8

1. Describe the concept of the term “vault”.
2. List the existing types of vaults.
3. Give an example of vaults in the plan.
4. Give an example of the types of trusses vault structures.
5. How are vault coverings designed and what forces occur in such structures?
6. Give an example of a barrel vault.
7. Give an example of a folded vault made of flat slabs.
8. Design the upper and lower hinge joints of a vaulted building.
9. Design a detail of a barrel vault connection.
10. Provide an example of cylindrical slabs of barrel vaults.

CHAPTER 9. DOMES

9.1. Spatial Dome Structures

The classification of domes according to the structural scheme, the features of the technological process in the manufacture of domes are presented. The advantages and disadvantages of monolithic domes are presented. Reinforcement with a support ring and connection points are considered.

Domes are a spatial structure with a curved (circle) or polygonal plan and a curved or polygonal frame in the vertical plane (Fig. 9.1).

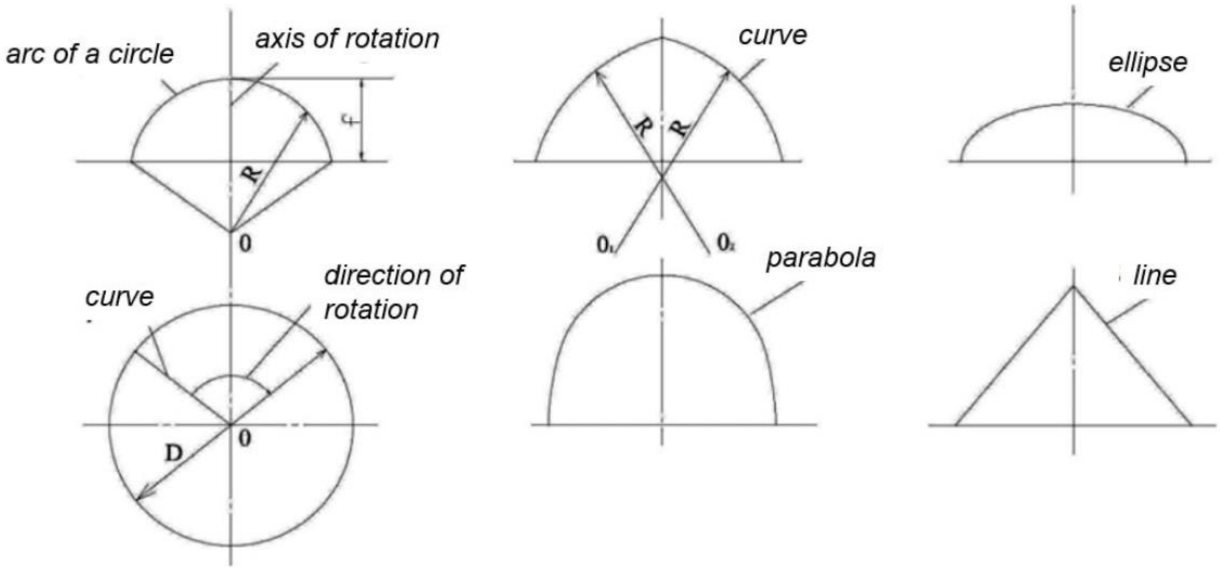


Fig. 9.1. Formation of domes

According to the design schemes, they are divided into shell domes (smooth or ribbed), ribbed, ribbed-ring and folded (Fig. 9.2).

Shell domes (Fig. 9.2, a) have a surface formed by the rotation of a curve (arc of a circle, ellipse, parabola, cycloid) around a vertical axis. The elements of the dome are a thin-walled shell and a stretched support ring. The upper ring of the lantern can be made in compression. The shell of the dome can be made wavy or pleated. The shell domes are mainly constructed of reinforced concrete.

Ribbed domes (Fig. 9.2, b) consist of individual flat ribs in the radial direction. The ribs are joined together at the top and supported by supports at the bottom. Conical and pyramidal domes are formed with straight edges. The dome also consists of a lower support ring, ribs, and an upper ring. Ribbed domes are a spacer system in which the spacer can be perceived as a special support ring or a foundation.

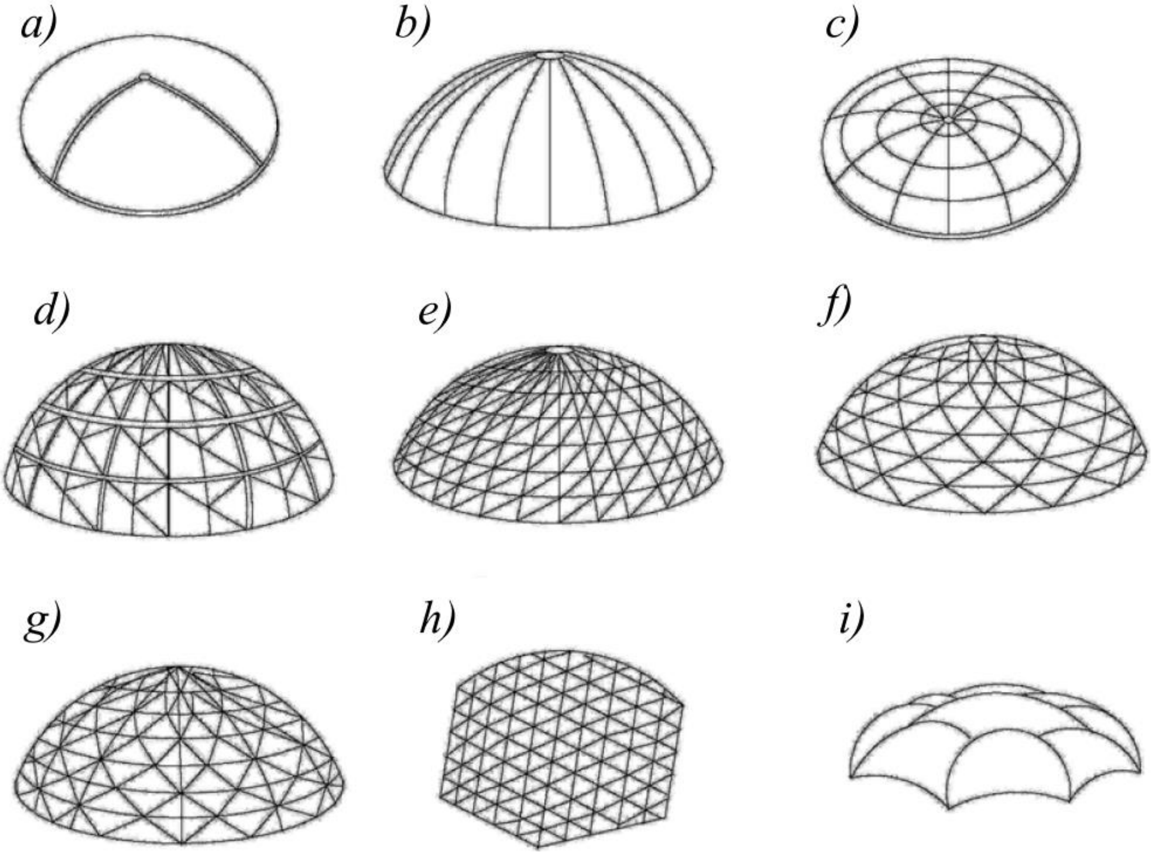


Fig. 9.2. Schemes (a - i) and shapes of domes:
a - smooth dome-shell; b - ribbed; c - ribbed-ring; d - ribbed-ring with connections; e - lattice dome of Schwedler; f - the same, Feppl; g - the same, Civitta; h - the same, Chabyshev; i - composite shell-dome;
1, 4, 7 - spherical; 2, 9 - lancet; 6 - conical;
3, 8 - paraboloidal; 5 - ellipsoidal; 10 - tent; 11 - closed;
12 - folded; 13 - multifaceted; 14 - umbrella; 15 – sail

Ribbed domes can be made of reinforced concrete, metal, and wood.

If thin-walled slabs can be laid on the ribbed frame, the ribbed dome turns into a shell dome, provided that the slabs and ribs work together.

Ribbed-ring domes (Fig. 9.1, c) consist of flat radial plates connected in the annular direction of the girders, which together form a rigid spatial system.

The purlins can be used as a dome tendon.

Ribbed-ring domes with lattice connections (Fig. 9.2, d) consist of radial and annular ribs with braces between them. The presence of braces reduces the forces in the ribs. The radial ribs are connected at the top into a ring, which is also used to form a skylight. Such rib-ring domes are made of metal or timber structures.

Lattice domes (Fig. 9.2, e-h) are polyhedra inscribed in a spherical or other surface of rotation consisting of a single layer of structural elements.

Lattice domes are designed mainly in metal and timber structures.

Domes can be composed of shells of double curvature or cylindrical shells (zero curvature) that intersect in the medial planes to form a surface fracture angle. Such structures are called composite dome-folded shells (Fig. 9.2, i).

9.2. Reinforced Concrete Domes

Reinforced concrete domes are designed mainly as monolithic or precast-monolithic shells.

Monolithic domes can be smooth or prefabricated monolithic domes can be made of ribbed cylindrical or flat plates.

9.2.1. Monolithic Domes

Monolithic domes with a span of up to 120 m are made in most cases with smooth walls (shell), wavy or folded shape, describing the surface of rotation in general, Fig. 9.3.

Depending on the ratio of the raiser f to the diameter D of the supporting contour, the following domes are distinguished:

- gently sloping $\frac{f}{D} = \frac{1}{5} \div \frac{1}{10}$;
- high $\frac{f}{D} \geq \frac{1}{5}$.

The most economical effect is at $\frac{f}{D} = \frac{1}{3} \div \frac{1}{5}$, however, in order to reduce the roofing surface, it is recommended to take $\frac{f}{D} = \frac{1}{6} \div \frac{1}{7}$.

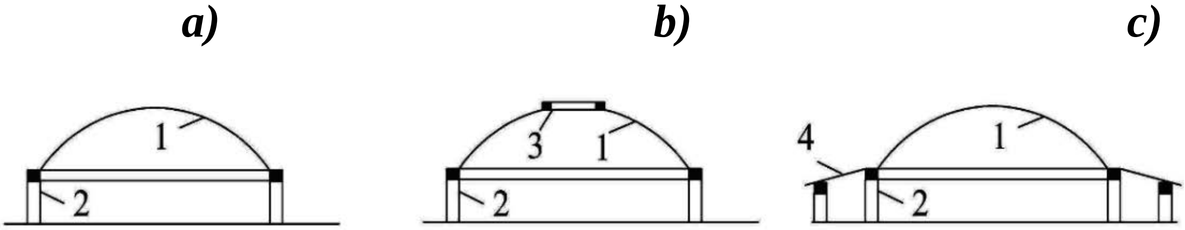


Fig. 9.3. Structural schemes of thin-walled dome roofings:

a - with a full dome; *b* - with a dome truncated for the central opening; *c* - with a dome connected to the flat ring roofing of the extension;

1 - dome shell; 2 - support ring; 3 - ring of the central opening; 4 - flat ring roofing

The thickness of the slab of monolithic domes is taken within $\frac{1}{600} \div \frac{1}{800}$ the radius of curvature at the top. A curved smooth slab of a monolithic dome is reinforced structurally: with a thickness of up to 70 *mm* - with a 200x200 *mm* mesh, with a rod diameter of 4-6 *mm*, with a greater thickness, a double mesh is used.

A smooth transition is made at the junction of the casing with the lower support ring with mandatory double reinforcement of the casing and the launch of reinforcement into the support ring (Fig. 9.4). The ring is designed for tensile forces from the split and is recommended to be prestressed.

A significant disadvantage of monolithic concrete domes is the complexity of the formwork and its cost, which can be as high as the cost of the dome itself. For domes with small spans (up to 30 meters), pneumatic formwork can be used.

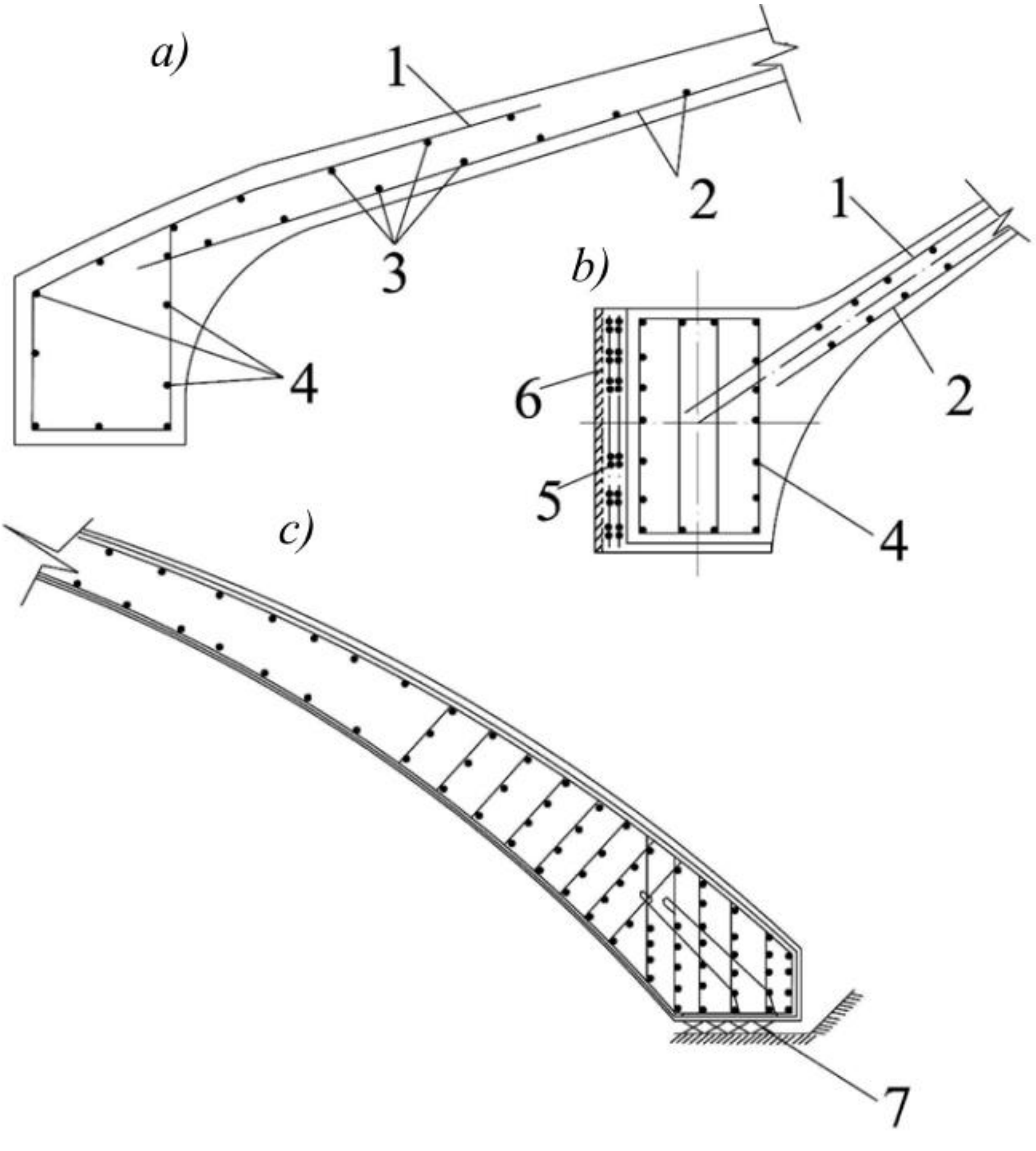


Fig. 9.4. Reinforcement of the connection zone of monolithic dome shells with support rings:
a - a ring with standard reinforcement; *b* - with prestressing reinforcement;
c - formation of a support ring by thickening the shell;
1 - additional rods; 2 - structural reinforcement mesh;
3 - ring reinforcement; 4 - unstressed reinforcement of the support ring;
5 - stressed reinforcement; 6 - monolithic concrete;
7 - support rollers

9.2.2. Domes Made of Large Slabs

Domes made of large-sized cylindrical slabs (Fig. 9.5) are recommended to be designed with a rise of at least 1/10 of the shell span. all slabs are made meridional and therefore the circles on the plan are the same for domes. The trapezoidal slab has a cylindrical surface; the length of the slab is approximately equal to the radius of the dome (up to 20 meters). The width of the slabs at the lower ring can be up to 3.7 meters. The longitudinal ribs of the slabs are directed along the meridians. Transverse ribs are made in the slabs every 2-3 meters.

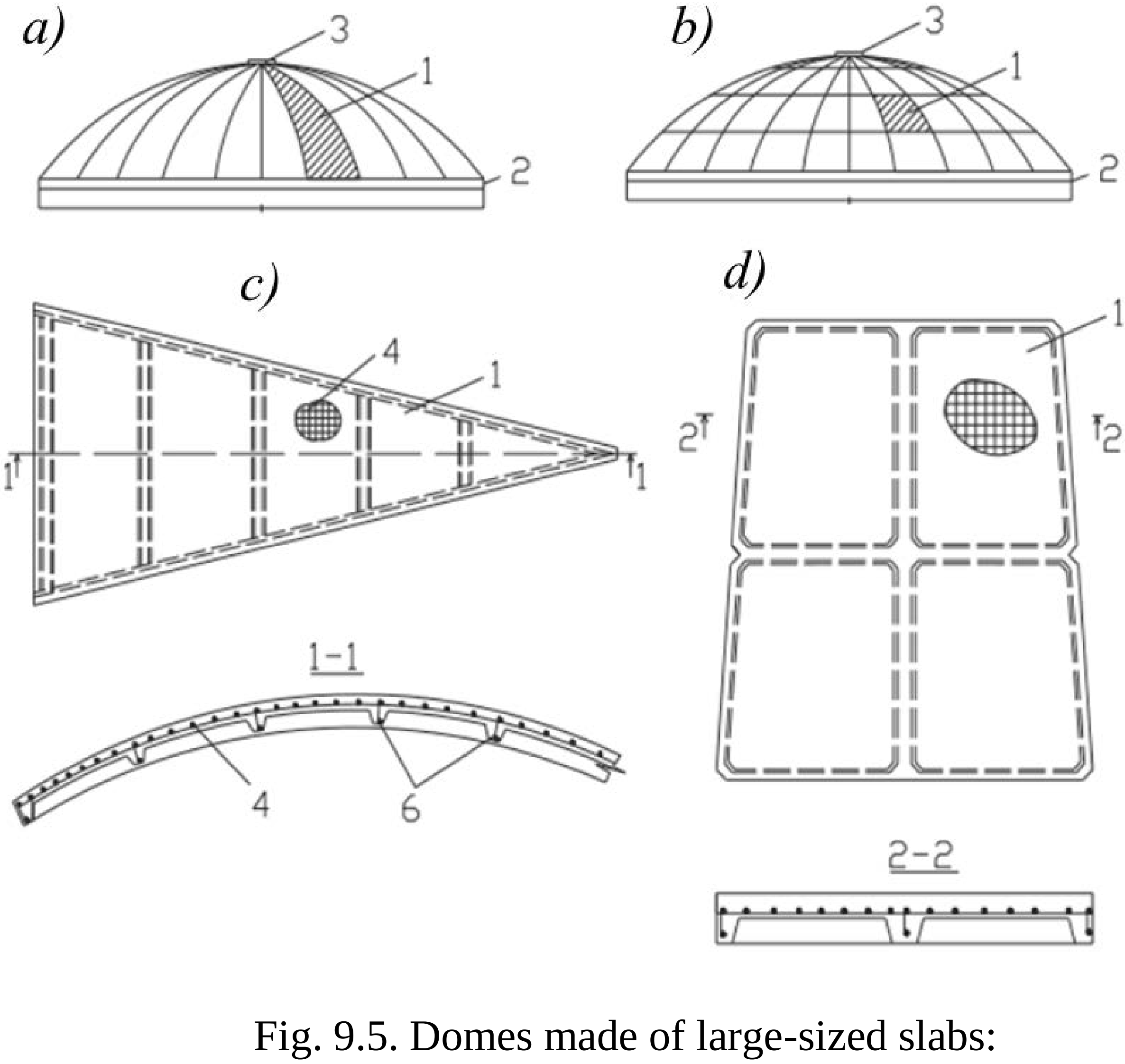


Fig. 9.5. Domes made of large-sized slabs:
a, b - cutting into prefabricated elements;
c, d - ribbed panels - sectoral and trapezoidal

The nodes for connecting the elements to each other and to the rings are shown in Fig. 9.6. The upper ring is made of reinforced concrete L-shaped section or metal with a special table for supporting the upper part of the slab.

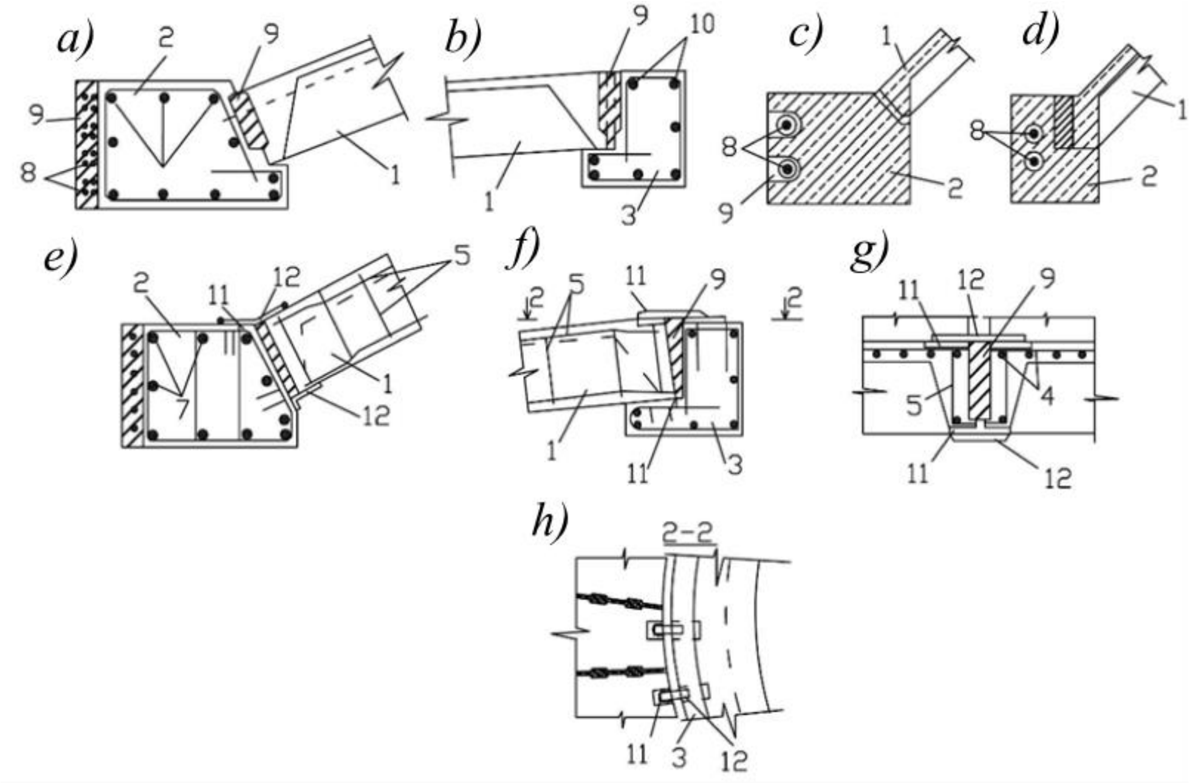


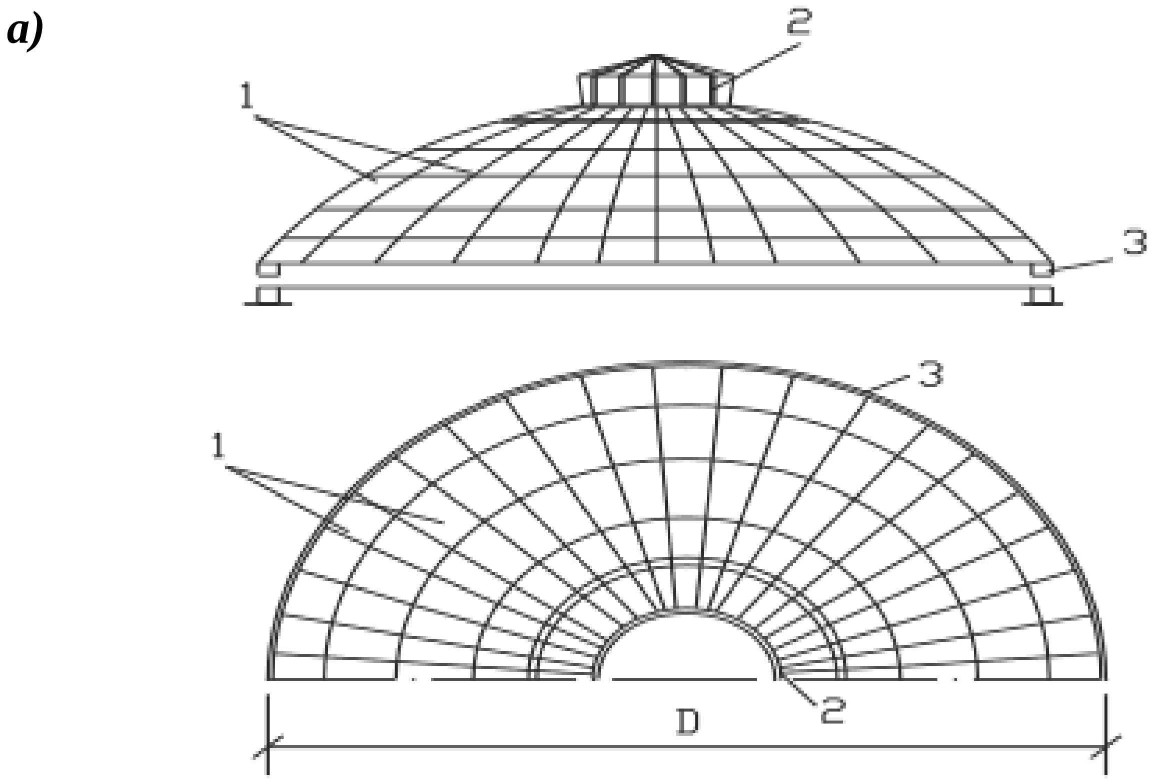
Fig. 9.6. Nodes of elements' connections:
a - hinged connection of the panel with the lower support ring; b - the same with the upper one; c, d - options for installing tensioned beam reinforcement in external gutters and channels; e - rigid connection of the panel with the lower ring; f - the same, with the upper one; g - panel joint;
1 - panel; 2 - lower support ring; 3 - upper ring; 4 - panel reinforcing mesh;
5, 6 - welded frames of the longitudinal and transverse ribs of the panel;
7 - conventional reinforcement of the lower ring; 8 - prestressed reinforcement of the lower ring; 9 - concrete monolithic; 10 - reinforcement of the upper ring;
11 - metal embedded parts; 12 - welding overlay

The support ring can be made of individual reinforced concrete elements that are placed on the support; the reinforcement stick-outs are joined and the joints between them are filled with monolithic concrete. After the concrete has strengthened, the joints of the ring are crimped with prestressed reinforcement, which is fixed and protected with concrete.

The joints between the edges of the plates are cast in-situ, and the reinforcement at the junctions of the edges is joined by welding. At the junctions of the shell plates with the reinforcement support ring, the rib rods are welded to the embedded parts or reinforcement releases in the support ring.

9.2.3. Domes Made of Flat Slabs

Domes made of flat plates are obtained by cutting the shell with medial and annular incisions, Fig. 9.7. In this case, each tier is assembled from slabs of the same size.



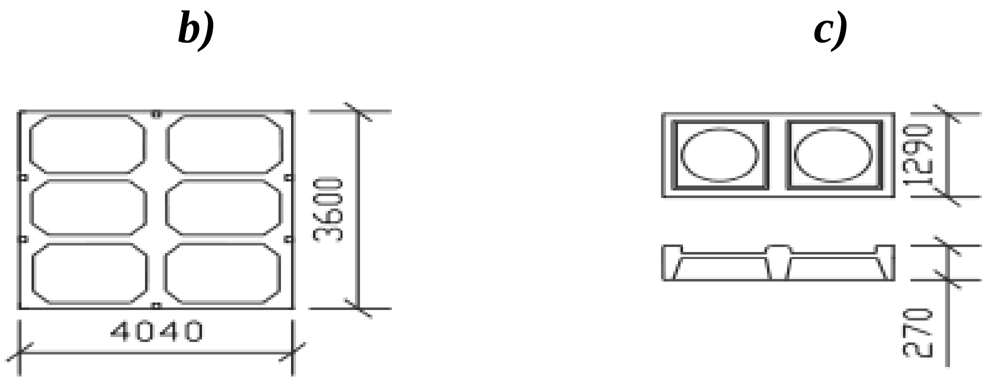


Fig. 9.7. Domes made of flat slabs:
a – general view and plan; b – flat ribbed slab
for the lower tiers; c – heavy, for the upper tier;
1 – slab; 2 – upper ring; 3 – lower support ring

The slabs are cut relatively small, their surface can be assumed flat, and the structural shape of the dome as a whole takes the form of a polyhedron inscribed in a sphere, cone, or other surface of rotation.

A variation is the slabs that have minor fractures in the middle of the lower tier. The slab plan can be rectangular or trapezoidal, with ribs 240-270 mm high along the contour, and intermediate ribs dividing the slab into several caissons. The outer and intermediate ribs of the slabs are joined by welding to form the medial and annular ribs of the dome. These ribs are located at the bottom of the slab (at the bottom of the dome), but sometimes, for structural reasons, the ribs are located at the top.

9.2.4. Domes Assembled Using Suspended Methods

Consider domes that are mounted with a hinged assembly (Fig. 9.8), divided into ring and meridian tiers.

The slab is a two-tiered structure (located in two tiers of the dome). The prefabricated ribbed slabs have a trapezoidal plan and are installed by hinged assembly between the cantilevered sections of the lower tier slabs.

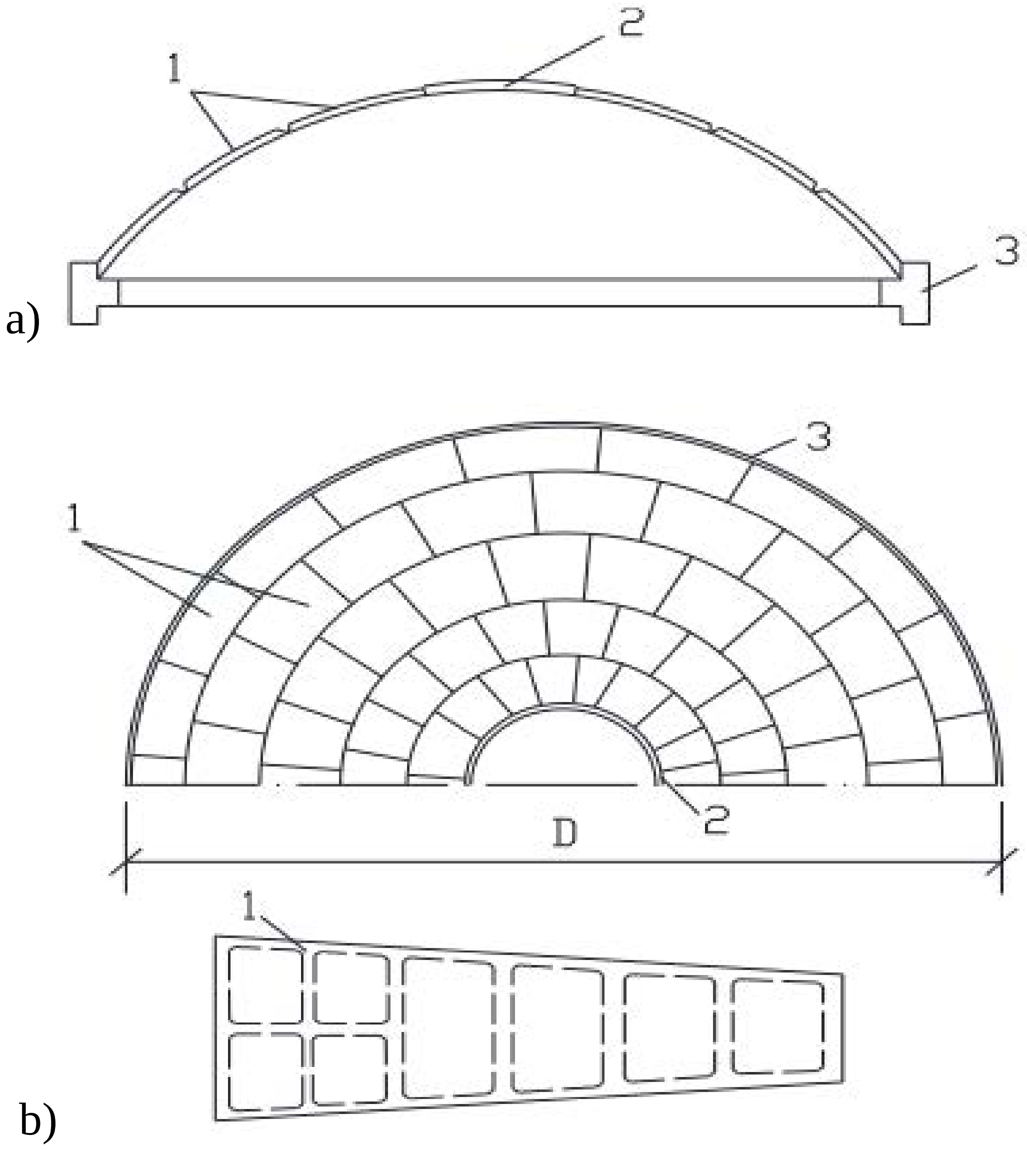


Fig. 9.8. Domes mounted with a hinged assembly:
a - section; b - plan; 1- slab; 2 - top ring; 3 - bottom ring

9.2.5. Ribbed-Ring Domes

Ribbed-ring domes (Fig. 9.9), including those with lattice connections, are formed by ribs - half-rings resting on the lower ring.

The ribs are connected in height by horizontal ring beams (ribs). Curved insulated slabs or steel decking can be laid along the load-bearing ribs. In ribbed-ring domes, in order to ensure the stability of the cross-section of the medial ribs, they are made I-beams. All ring ribs are recommended to be of rectangular or square cross-section.

The shape of the dome support ring is polygonal in plan and rectangular in cross-section with a cut corner for the ribs to rest on.

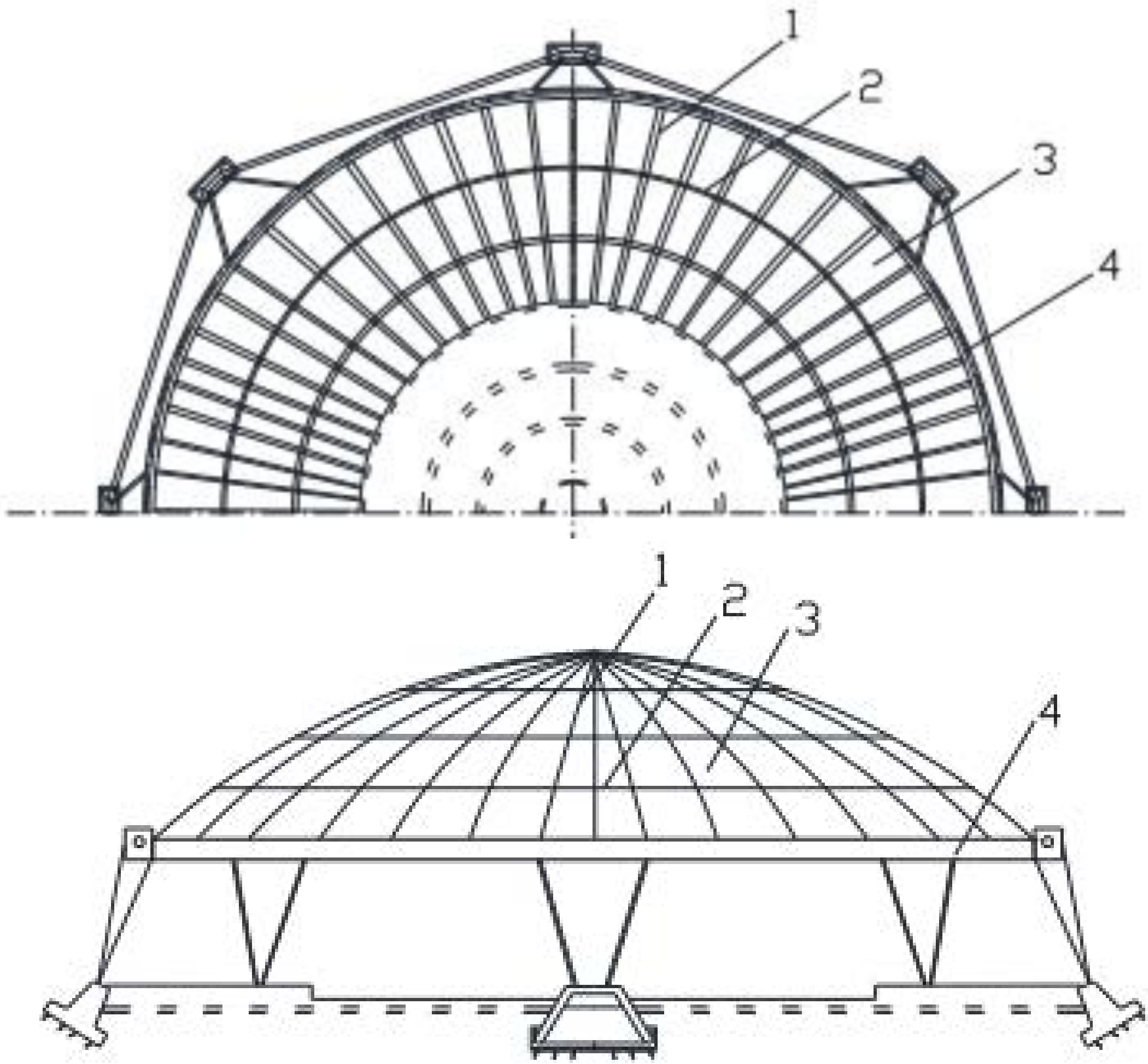


Fig. 9.9. Ribbed-ring dome:
1 - ribs semi-arches; 2 - horizontal ring beams;
3 - curved plates; 4 - support ring

It is recommended to connect the ribs with the rings (support and upper) by welding the embedded parts with subsequent concrete grouting on fine-grained aggregate. The dome supports are made in the form of cylindrical rollers to ensure free horizontal movement.

9.2.6 Composite Dome-folded Shells

Composite dome-folded shells (Fig. 9.10) are distinguished by the fact that at the intersection of the folded shells a cavity is formed, at which a thickening called a valley occurs, together, this gives spatial stiffness to the entire cover, similar to a stiffener. These elements are made in the form of metal arches (Fig. 9.10, g) or reinforced concrete ribs. For the organization of radial light openings, double metal radial arches of I-section are arranged, the pieces of which are connected by ties.

Structural elements are made in the form of steel arches with ties or precast concrete crossbars hinged on columns. Ties can be metal or reinforced concrete.

In the center of the roofing, an inner ring is made to support the radial elements. The central-radial “frame” of the roofing improves the static performance of the shell and improves the construction process. In composite shells, the cross-sectional height of radial arches is taken within $\left(\frac{1}{60} \dots \frac{1}{80}\right)$ the limits of the shell span, and contour arches are not less than $\frac{1}{100}$ the arch span.

Dome-folded shells are made of the same type of main plates (rectangular in plan) and additional plates (triangular or trapezoidal in plan). The plates are connected to each other by means of metal sheet plates that are welded to the embedded parts of the plates installed in the places of the ribs. All joints and seams between the slabs are filled with concrete, the concrete class is not lower than the concrete class of the supporting structures.

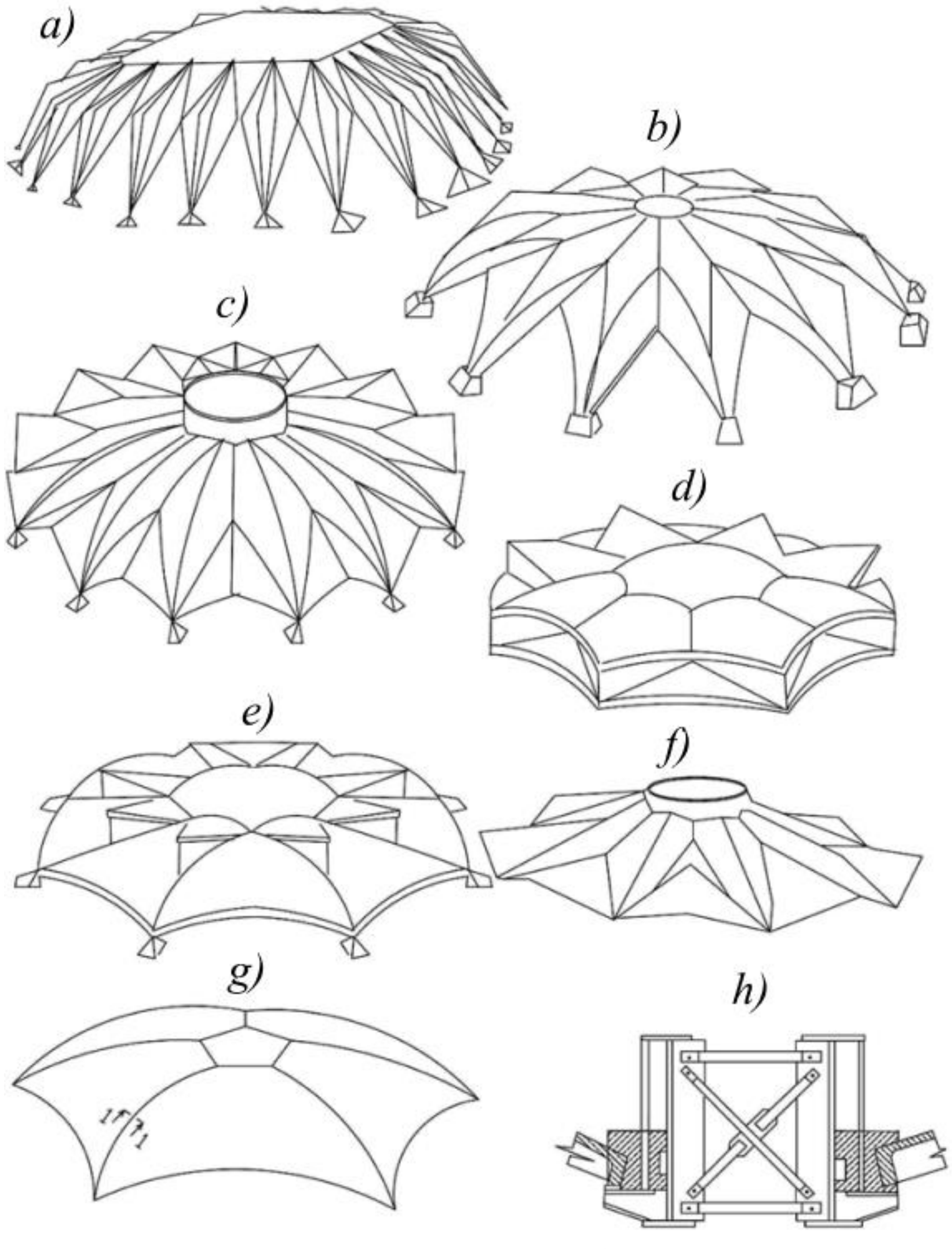


Fig. 9.10. Composite dome-folded shells:
a - ribbed; b - ribbed-ring; c - e - mesh
(Schweller, Fepel, Civitt)

Discussion and Self-Assessment Questions for Chapter 9

1. Give definition the spatial structure of the dome.
2. Give examples of reinforced concrete structures of domes.
3. Describe the schemes and forms of domes.
4. How does the diameter of the dome depend on its thickness?
5. Give an example of the reinforcement of the zone of connection of monolithic reinforced concrete dome shells with support rings.
6. Give an example of a node for connecting dome elements to each other and to the support rings.
7. Give an example of a dome made of flat slabs.
8. Describe the technology of mounting domes.
9. Give an example of a ribbed-ring dome.
10. Describe the types of composite dome-folded shells.
11. Describe the design schemes of thin-walled dome roofings.
12. Give examples of domes types.

CHAPTER 10. SHELLS

The chapter discusses the use of shells in construction. The features of the static operation of cover shells, types of flat and cylindrical shells, methods of their calculation, and methods of manufacturing are presented. Joints of reinforced concrete shells of zero, positive and negative Gaussian curvature are presented.

10.1. Flat Shells

Gently sloping shell structures are designed for roofs with plans close to the shape of a square. First of all, these are shells of positive curvature with a small rise above the supports compared to the dome (Fig. 10.1).

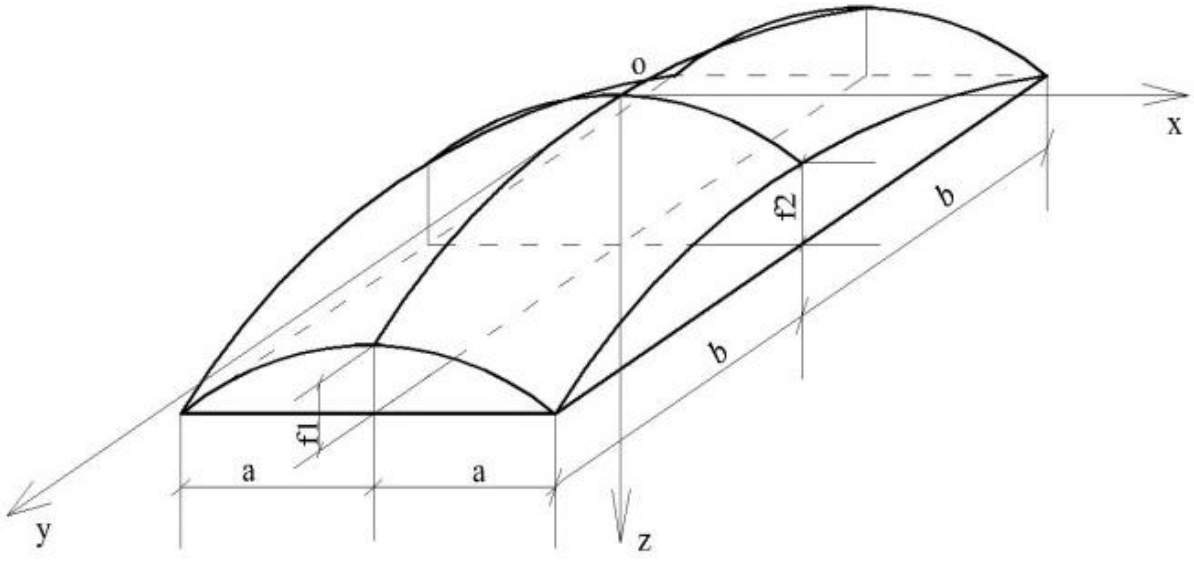


Fig. 10.1. The surface of a shell of rectangular shape in plan with positive Gaussian curvature

The shells are considered gentle if the ratio of the raiser to the corresponding size of the shell side is within 1/5-1/10.

Taking into account the static and architectural requirements, flat shells with a raiser in the center of no more than 1⁄5 of the length of the diagonal connecting the corners of the shell are used. For prefabricated shells with a rectangular plan, it is recommended to take the part of the longitudinal surface that has an additional curvature and a horizontal axis of rotation as the middle one.

The meridional-ring system of cutting the shells into plates is performed by a system of radial cutting surfaces passing through the axis of rotation and a system of vertical planes perpendicular to the axis plane (Fig. 10.2).

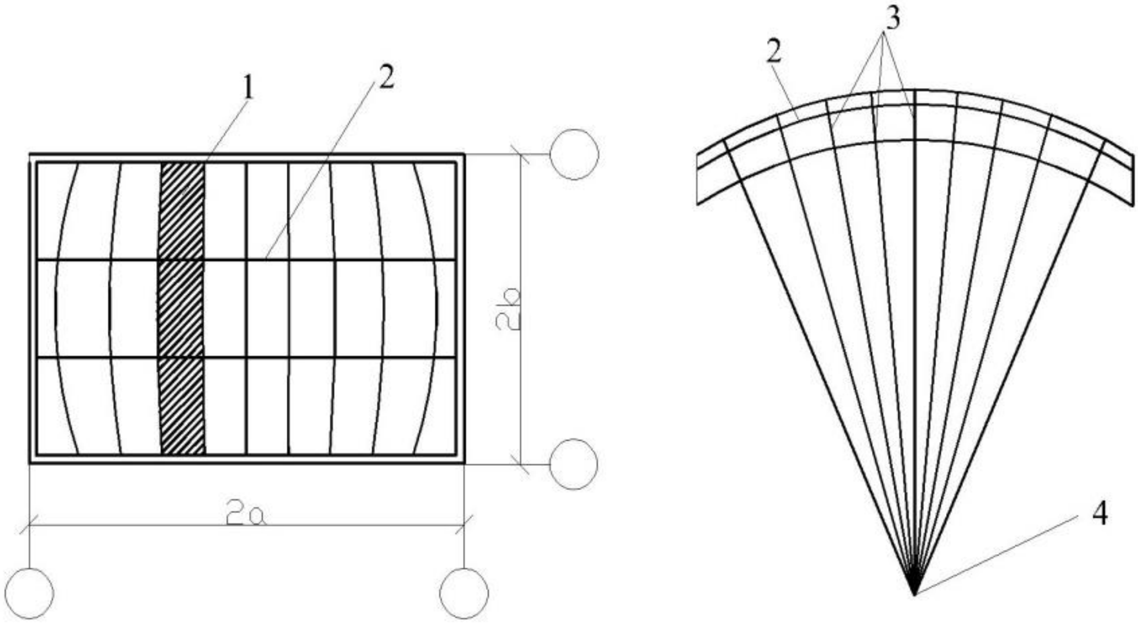


Fig. 10.2. Principle of meridional-ring cutting of the shell:
1 - cutting element; 2, 3 - vertical and radial cutting surfaces;
4 - rotational axis of the cutting surface

This cut allows for a minimum size of precast slabs. A spherical surface is recommended for shells with a square plan. The surface shape of the slabs can be flat, cylindrical or double curvature. Cylindrical plates are recommended for shells, as double curvature plates are difficult to manufacture, and flat plates increase material consumption. The shells are supported along the contour by diaphragms, which are made in the form of beams, trusses, arches, as well as curved bars laid on the wall or column.

Contour beams (Fig. 10.3, a, b) are used in free-standing shells with frequent placement of columns around the perimeter of the building.

In other cases, trusses (Fig. 10.3, c, d) or arches are used. The use of trusses, as more rigid elements in the vertical plane, has an advantage over arches.

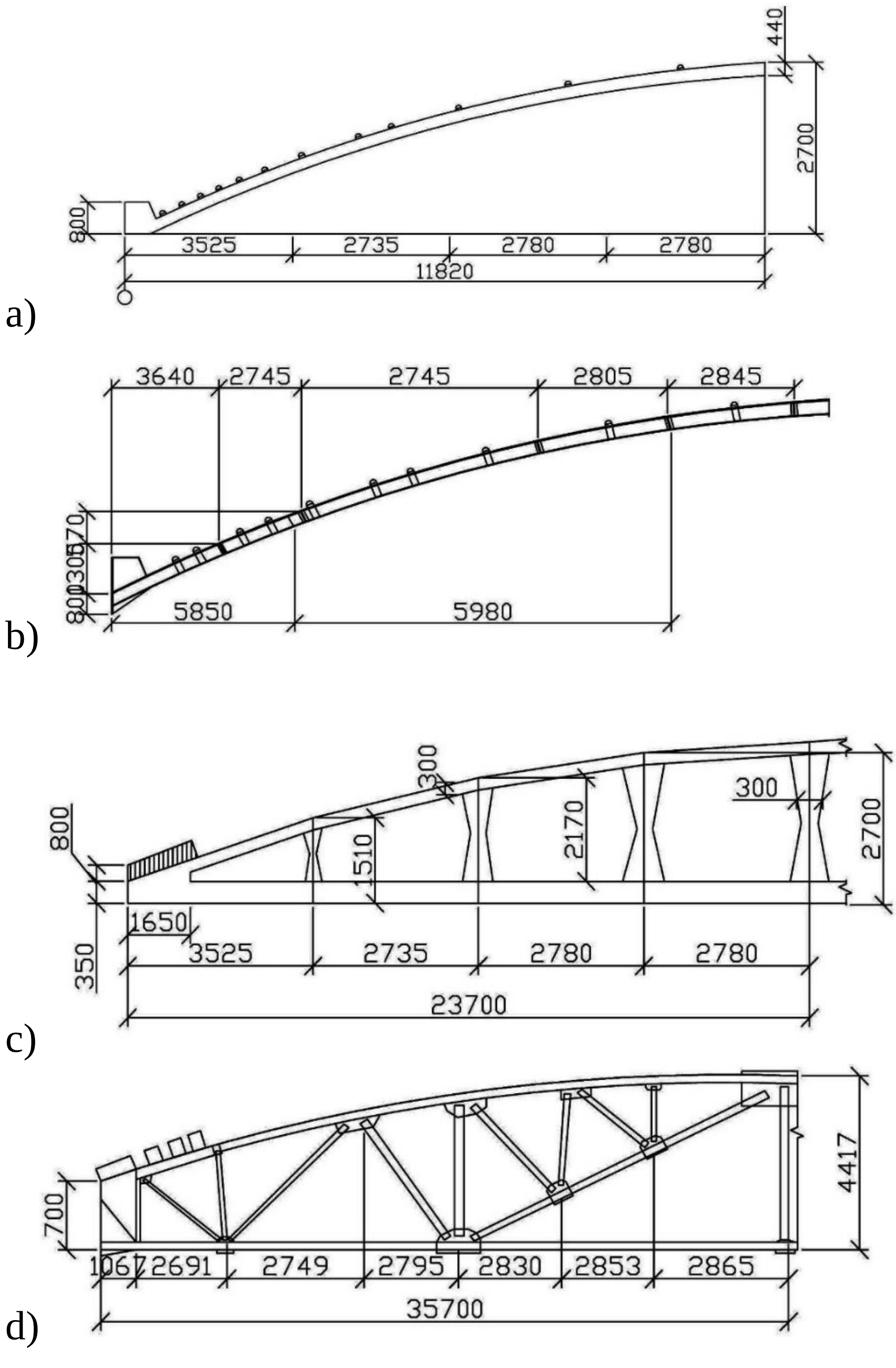


Fig. 10.3. Contour elements of diaphragms of shallow shells:
a – reinforced concrete beam; b – metal beam;
c – reinforced concrete truss; d – metal truss

Depending on the number and location of the column grid, the building envelopes can be designed as free-standing (one-wave) and multi-wave in one or two directions. Multiwave shells are designed as "simple" and "continuous".

Prefabricated hollow shells are recommended to be designed simple, which ensures their more favorable static operation.

Hollow shells made of monolithic concrete are designed smooth. The thickness and reinforcement of the middle zone of smooth shells, where only compressive forces occur, is assigned constructively with a check of the stability calculation. In the contour and corner zones, the shell plate is thickened in order to accommodate additional reinforcement and to absorb the existing forces, which are increased compared to the central zone.

Reinforcements for the perception of tensile forces are made in the form of individual rods or grids. For prefabricated shells, the introduction of a new standard size of plates with a thickened shelf and reinforced reinforcement is economically impractical.

In this case, the thickening of the shell plate is carried out with the help of a concrete block - monolithic concrete, made on top of prefabricated plates.

Additional reinforcement is placed within the concrete slab at an angle of 45^0 to the contour and laid in accordance with the calculation of the main tensile forces acting on it.

10.2. Precast Reinforced Concrete Shells

Precast reinforced concrete shells are divided into groups: typical shells for industrial buildings with an enlarged grid of columns (18x24 *m*) and slabs 3x6 *m* (Fig. 10.4, a); shell span up to102 *m* from 3×12 *m* slabs with contoured support beams (Fig. 10.4, b, c) shell with a span up to 42 *m* from 3×6 *m* slabs mounted by hinged method (Fig. 10.4, d) shell up to 60 *m* from unified slabs 3 ×6 *m*, including with a column spicing of 18 and 24 *m* (Fig. 10.4, e).

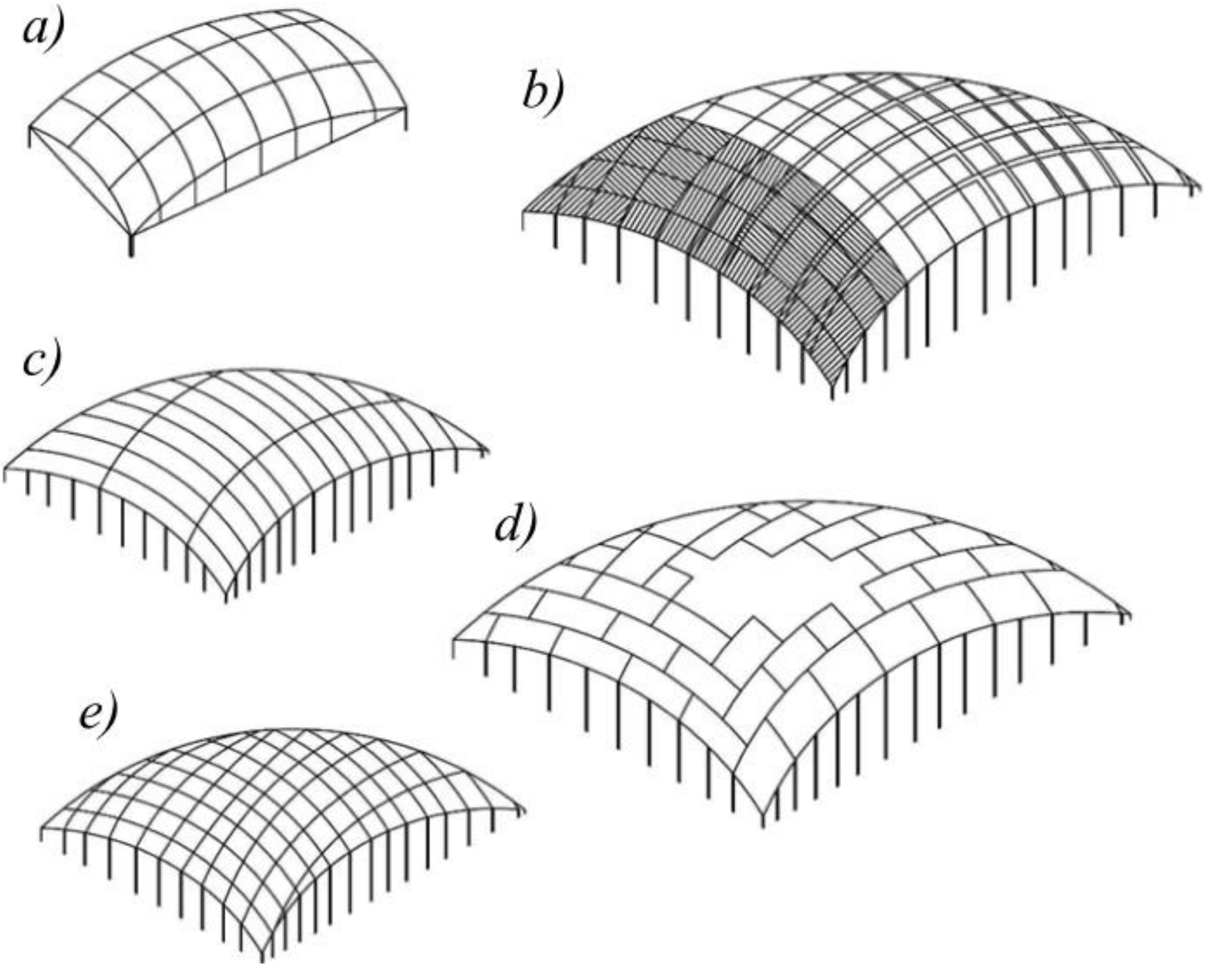


Fig. 10.4. Structural forms of
prefabricated reinforced concrete hollow shells:
a – with an enlarged grid of columns; b – with intermediate beams;
c – without intermediate beams; d – mounted by a hinged method;
e – type of curvilinear polyhedron

Cylindrical plates measuring 3×6 *m* (Fig. 10.5) and 3×12 *m* are used for flat shells.

Floor slabs are made with contour and additional transverse ribs. In slabs 3×6 *m*, one transverse rib is projected, in slabs 3×12 *m* three transverse ribs. The height of the ribs is 250–300 *mm*, the thickness of the flange is 30–50 *mm*.

The rib system provides strength, rigidity of plates during transportation and installation, strength and stability during operation.

Grooves are provided on the outer side faces of the ribs of the plates for the formation of dowels that absorb shear forces after the seams are monolithic. Plates are reinforced with welded meshes and frames.

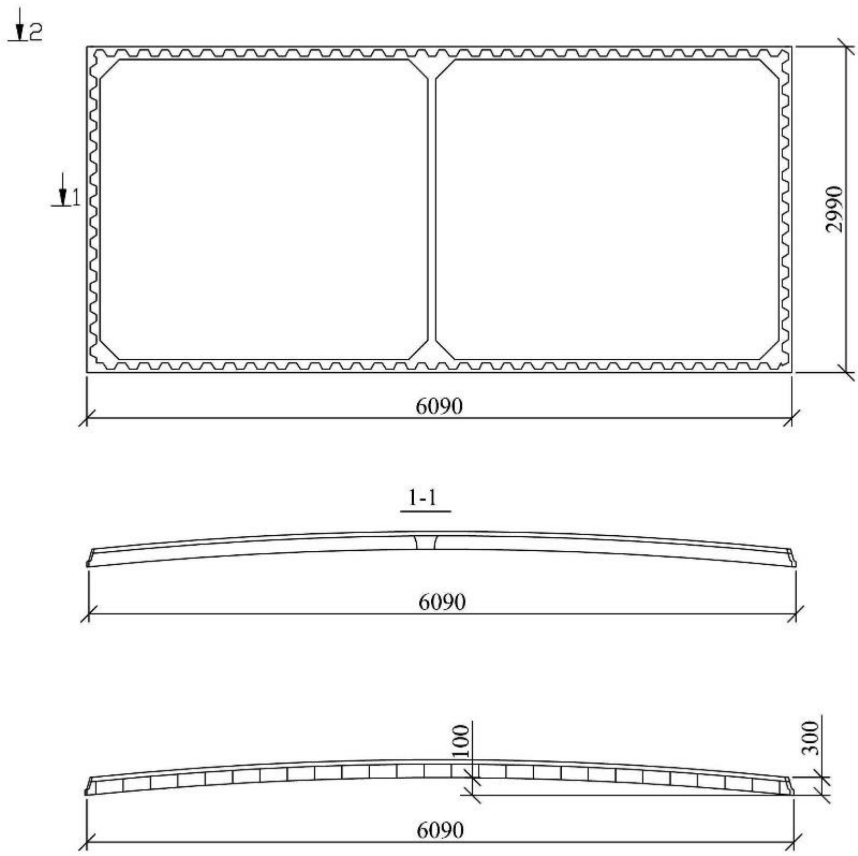


Fig. 10.5. Cylindrical reinforced concrete slab 3.0×6.0 *m*

In long-span shells, additional stiffeners are needed to ensure the strength and stability of the structure. Thus, in a shell of 102x102 m (Fig. 10.4, b), its stability is ensured by a system of prestressed beams-stiffness ribs, with a step of 12x12 m, which during the installation period is a support for supporting the slabs. The slabs are connected to the beams by means of welding of embedded parts and casting of joints.

In shell plates, it is possible to use light-aeration slots of various shapes between the ribs; placement of slots is recommended no closer than 4–6 *m* from the support contour.

The outer plates of the shell rest on contour elements from above or at the same level (Fig. 10.6). For this purpose, they provide embedded parts and supporting tables.

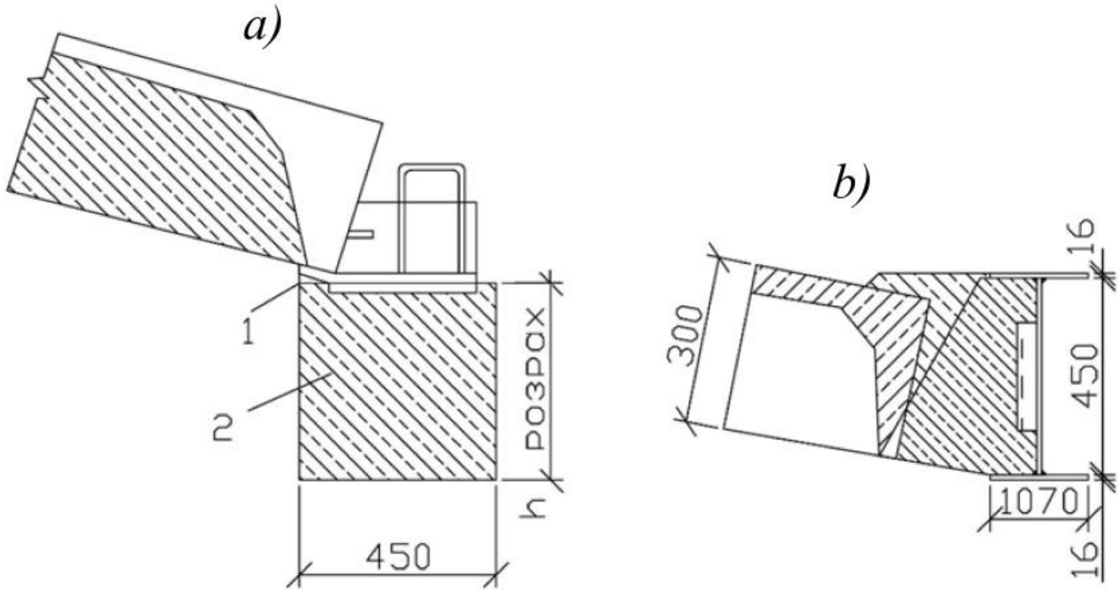


Fig. 10.6. Nodes supporting the plates on the contour beam:
a – floor connection; b – connection at the same level;
1– support steel sheet; 2 – contour beam (calculated height)

10.3. Cylindrical Shells

Have a median surface formed by parallel sliding of a straight line along a curvilinear contour - a circle, parabola, ellipse, or other curve (Fig. 10.7). For prefabricated shells, the circular outline of the guide is simpler.

Designated folds of the type of short cylindrical shells (Fig. 10.8) differ from cylindrical shells in that the curvilinear guide is replaced by a broken line.

The distance between the supports of the shell is the span (l_1), and the distance between the longitudinal edges (l_2) is the wave length or the width of the shell.

Cylindrical shells rest on supporting columns through rigid end diaphragms. On the edges of the shell, there are side elements that reduce the deformation of the edges of the curved plate. Longitudinal edges in the run can remain free or rest on columns or walls. Side elements for shells with free edges are taken in the form of beams located below the edges of the shell.

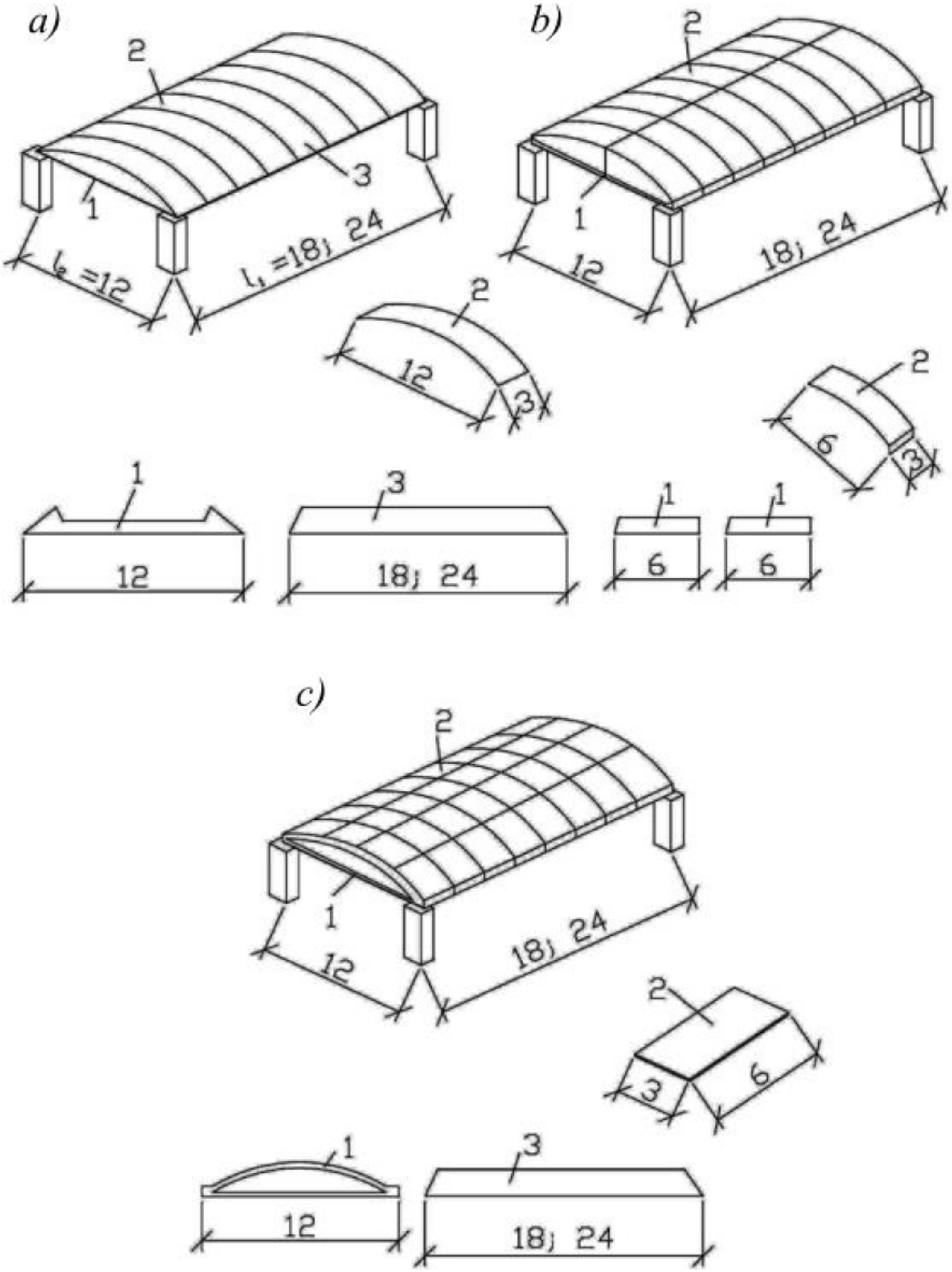


Fig. 10.7. Structural forms of long cylindrical shells:
a – with side elements in the form of prefabricated beams;
b – with side elements those are part of the slab;
c – with a longitudinal cut into slabs;
1 – diaphragm element; 2 – slabs; 3 – side plates

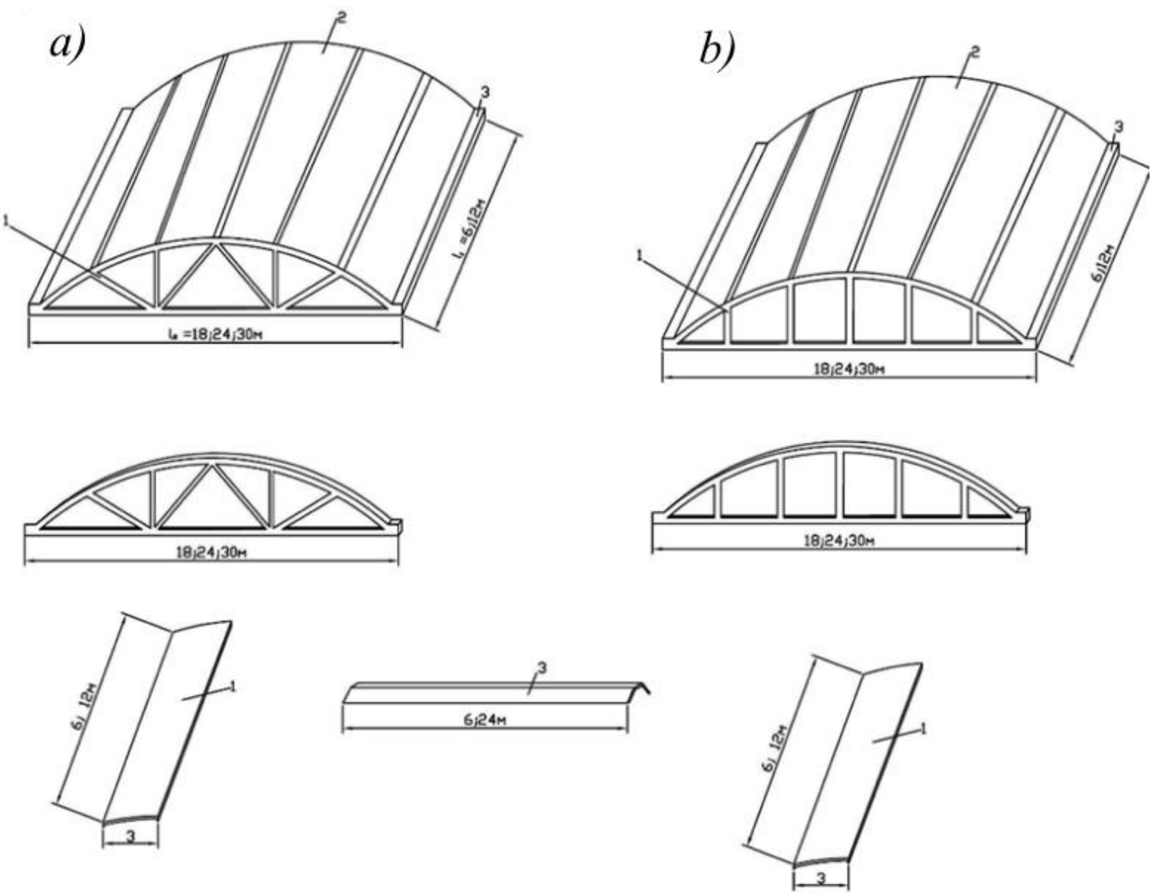


Fig. 10.8. Prismatic type folds of short cylindrical shells:
a – with edge elements; b – without edge elements;
1– truss-diaphragm; 2 – plate; 3 – edge element

For precast shells, the beams are cut with two-ply beams in order to reduce mass.

Side elements can be located above the edge of the shell, then they are made in the form of an L-shaped section, if the edges of the shell are supported in the vertical and horizontal directions, then the side elements are made in the form of plates. The cross-sectional height of the side elements is accepted within 1/20–1/30 of the span L.

Shells can be single-pass, multi-pass (continuous) and cantilever. There are single- and multi-wave shells, interconnected by side elements. At the same time, extreme and average (additional) waves are distinguished. Accordingly, supporting diaphragms can be single- or multi-span, and their design can be beam, truss, arch or frame (Fig. 10.9).

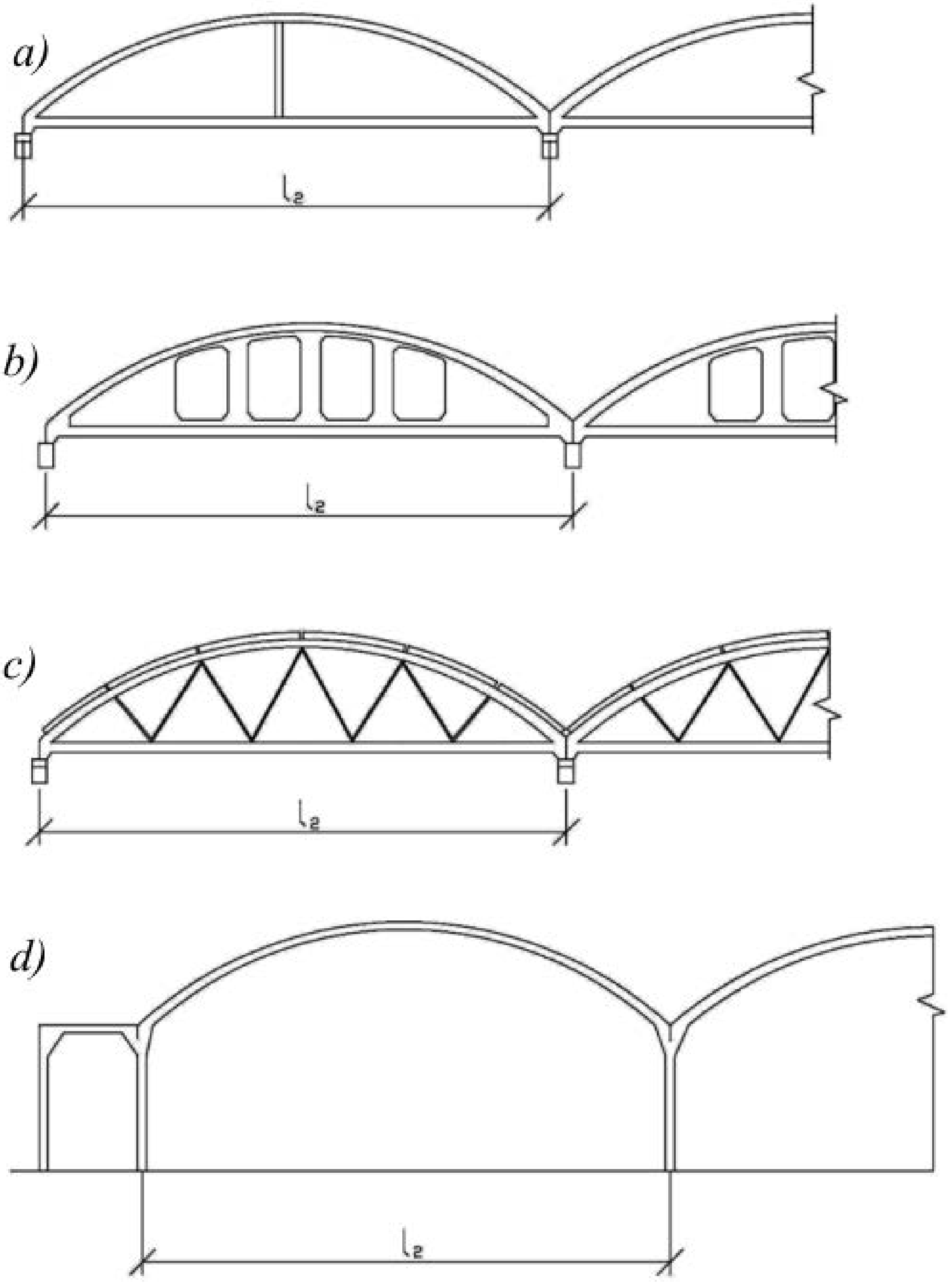


Fig. 10.9. Diaphragms and edge elements:
a – in the form of an arch; *b* – in the form of a non-braced truss;
c– in the form of a truss with a brace; *d* – side elements – beams

Depending on the ratio of the shell span to its wavelength, cylindrical shells are divided into types: long $\ell_1/\ell_2 \geq 4$; average at $1<\ell_1$

$/\ell_2 < 4$; are short when $\ell_1 / \ell_2 \geq 1$. The first two types are called long cylindrical shells. Monolithic reinforced concrete shells are made smooth with a thickness of 50–80 *mm*. For spans of 18 *m* and more, the reinforcement is pre-tensioned. Prefabricated and prefabricated monolithic shells are mounted from plates 30–50 *mm* thick with ribs along the contour of the side elements and diaphragms (Fig. 10.7).

Long cylindrical shells. The height of the shell *h* includes the section of the side beam, which is equal to (1/10–1/15) ℓ_1, and the raiser *f* is equal to (1/6–1/8) ℓ_2. Shells in fig. 10.7, a are assembled from cylindrical plates of two standard sizes in the plan of 3×12 *m* (Fig. 10.10). The middle plates (P-1) have a thickness of 40 *mm* with some thickening towards the outer edges. The height of the contour ribs is variable: at the supports – 250 *mm*, in the middle – 400 *mm*. The end plates (P-2) have a thickness of 50 *mm*, and their end edge has a larger rib, which is an element of the end arched diaphragm of the shell.

Side elements are made in the form of reinforced concrete I-beams (CE-1). The beams have a curvilinear framing of the upper belt with an increase in height to the middle of the span. The height of the beams is 800 *mm* on the supports, and 1200 *mm* in the middle of the span, thus increasing the bearing capacity of the beam and solving the slope for drainage of atmospheric precipitation.

In fig. 10.7, *b* long cylindrical shells are divided into plates of two types - middle and end plates. Each plate in section has half a cylindrical shell with a side member along the outer edge. On three other sides, the slab has contoured edges. Channels are provided in the side elements of all plates, through which bundles of high-strength wire pass. In the upper contour ribs, one channel is also provided for the passage of bundles of wire, which tightens the plates of the shell in the upper zone to ensure its operation together, fig. 10.10.

In the middle part of the shell, the joint of the seams is casted with concrete with the formation of concrete keys, in this zone there are bending forces and small shifts (Fig. 10.11, a). When using longitudinal joints, plates are connected by welding overlays to embedded parts of plates.

In the corner zones of the shells, where mainly the tensile forces are connected according to the design solution (Fig. 10.11, c, d).

10.3.1. Short Cylindrical Shells

Short cylindrical shells are found in practice with a diaphragm step (ℓ_1) in the range of 6–12 *m*, when the ratio $\ell_1 / \ell_2 < 0.5$, the raiser is assigned (1/8) ℓ_2. The height of the side elements without prestressing is taken to be at least (1/15) ℓ_1, and the width – (1/15–1/2) of the height. For short cylindrical shells, flat ribbed plates measuring 8×12 *m* are often used, which are laid along diaphragms-trusses (Fig. 10.9, c), the end and transverse ribs of the plates are made unstressed (Fig. 10.12), the height of the longitudinal ribs is taken within (1/ 30–1/35) ℓ_1.

The step of the transverse ribs is taken within 1–2 *m*, and their height is within (1/15–1/20) of the calculated span, equal to the distance between the inner faces of the longitudinal ribs.

Grooves are formed on the outer faces of the longitudinal and end ribs for further concreting of the seams of the concrete keys.

The operation of these elements ensures the strength of the concrete keys in the grooves of the end ribs of the plates, the concrete on the upper belt of the truss-diaphragms and the reinforcing frames in the longitudinal seams between the plates above the diaphragms, which ensures the upper connection of the rod reinforcement of the plates after installation, thanks to which their indistinguishability is achieved (Fig. 10.13).

10.3.2. Long Cylindrical Shells

The designs of long cylindrical shells made of plates 3.0×12.0 *m* are considered below, fig. 10.10. Also graphically illustrated nodes and details of long cylindrical shells, fig. 10.11. The structures of long cylindrical shells made of 3.0×12.0 *m* slabs are considered below, fig. 10.10. Also graphically illustrated nodes and details of long cylindrical shells, fig. 10.11.

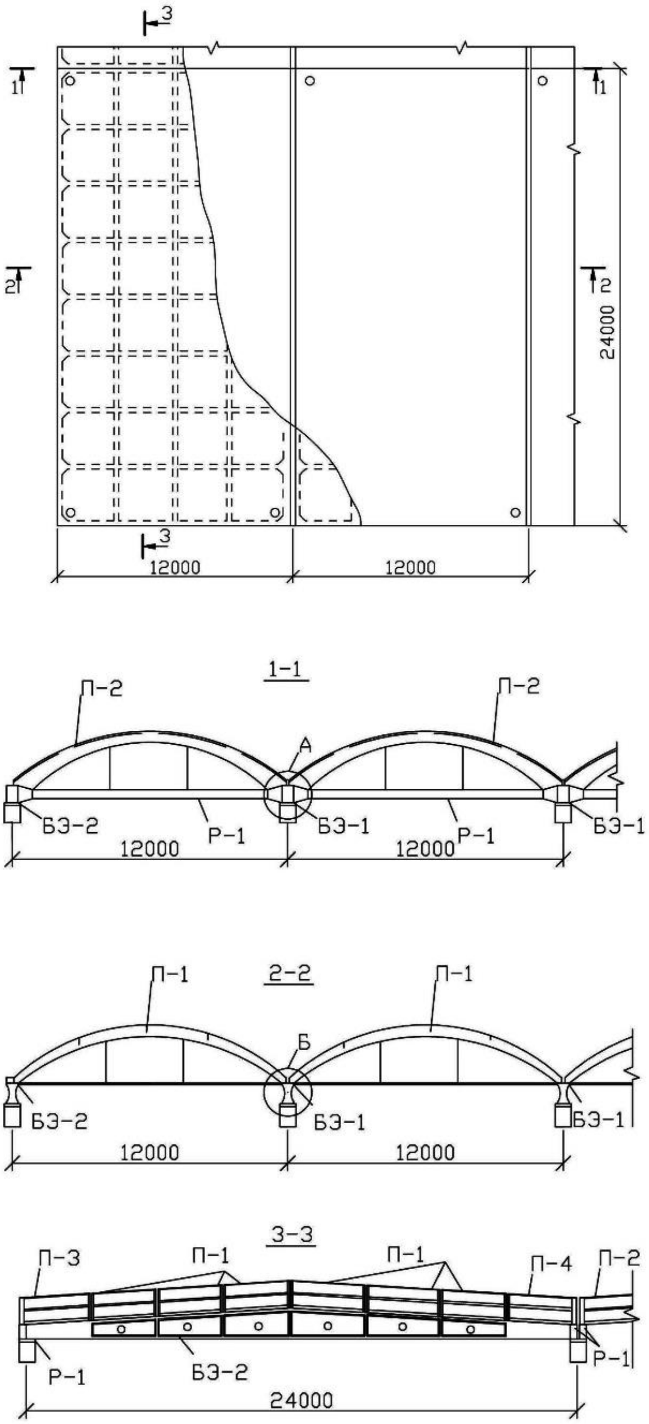
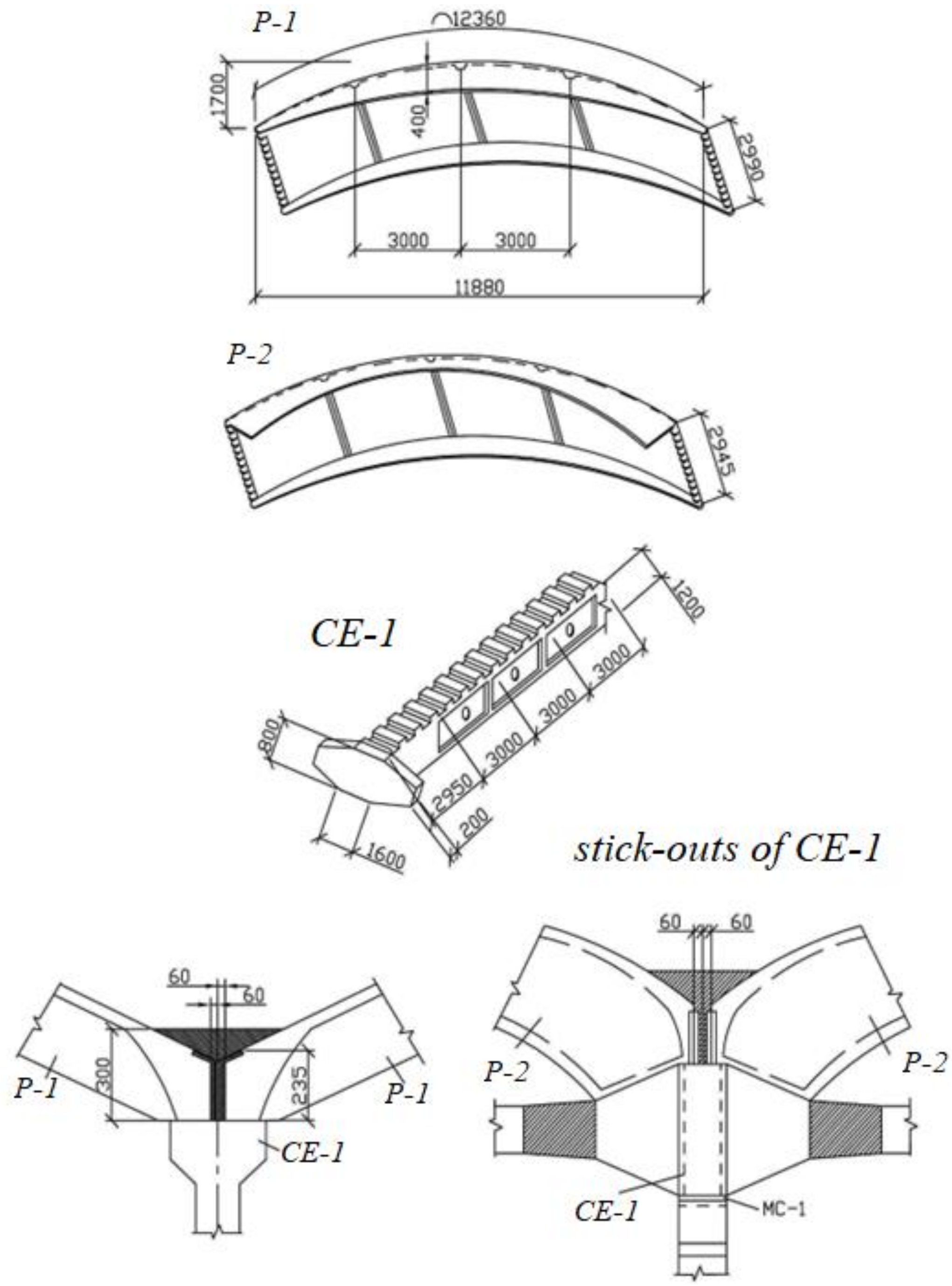


Fig. 10.10. Long cylindrical shells made of plates 3.0×12.0 *m*



stick-outs of CE-1

Continuation of fig. 10.10.

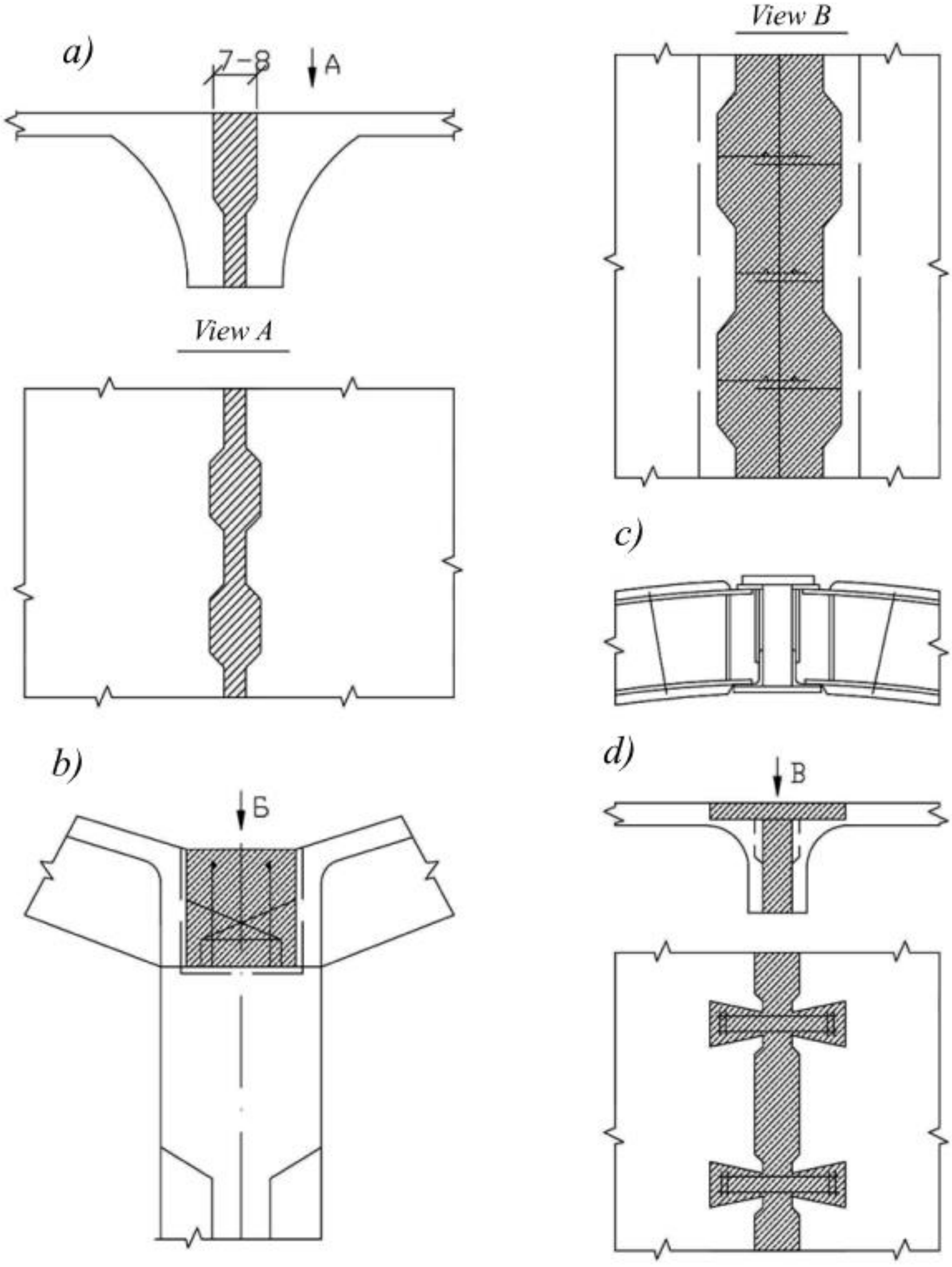


Fig. 10.11. Nodes and details of long cylindrical shells:
a – plate joint in the compressed zone of the shell;
b – joining of plate edges;
c – connection of plates with side elements;
d – plate joint in the zone of action of the main tensile forces

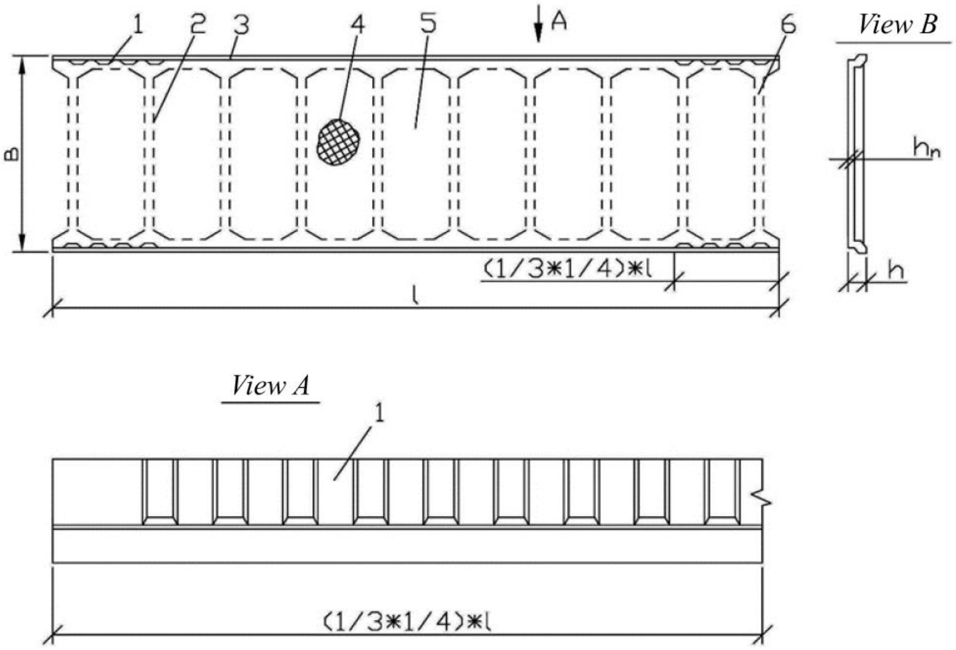


Fig. 10.12. A plate of a short cylindrical shell:
1, 3 – longitudinal rib; 2 – transverse rib;
4 – reinforcement; 5 – plate shelf; 6 – end rib

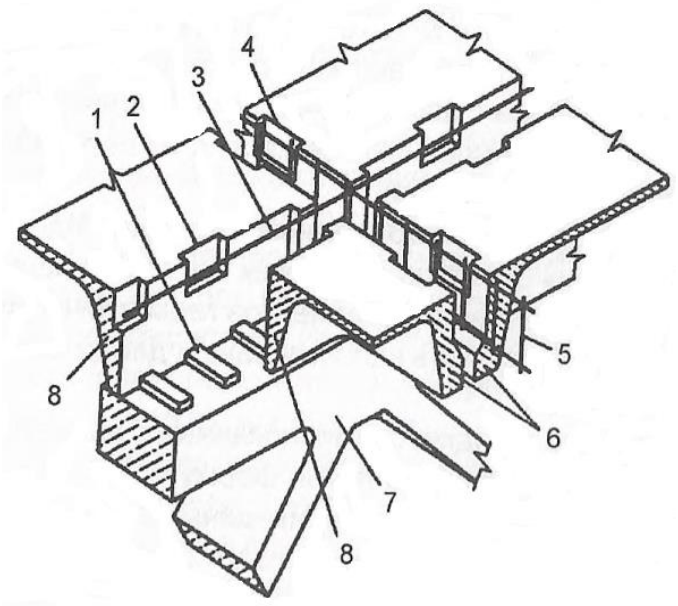


Fig. 10.13. The joint of plates and diaphragm of a short cylindrical shell:
1 – "thorns"; 2 – key sockets; 3 – longitudinal reinforcement of the monolithic seam between the plates; 4 – key sockets of the longitudinal ribs of the plates; 5 – monolithic seam frame; 6 – slab edges; 7 – truss-diaphragm; 8 – end rib

Questions for Discussion and Self-Assessment for Chapter 10

1. Give the definition and give an example of a hollow shell.

2. Give an example of a meridional-annular section of the shell.

3. Describe the existing elements of flat shells. Give an example.

4. How are prefabricated reinforced concrete shells divided?

5. What structural elements of the roofing are used for hollow shells?

6. Give an example of a plate support unit on a contour beam.

7. What forms of long cylindrical shells do you know and give an example?

8. Give an example of short cylindrical shells.

9. How are shells distinguished?

10. What are shells connected to each other and how are they divided according to the work of the structures?

11. Give an example of a node and parts of long cylindrical shells.

12. Give an example of connecting plates and a diaphragm of a short cylindrical shell.

CHAPTER 11. METAL THIN-WALLED ROOF STRUCTURES

11.1. Metal Spatial Structures of Cross-Braced Lattice Systems

A separate group of spatial structures consists of cross-bar spatial lattice systems, in which, in order to save metal, part of the elements are made of non-metallic materials (wood and lightweight reinforced concrete).

The inclusion of such materials allows the use of structural roofings for buildings with an average aggressive environment under the condition of protection of metal structures.

A lightweight roof is laid over structural slabs. The load-bearing element is metal profiled flooring along the spans (Fig. 11.1).

In this case, the upper belt works on longitudinal forces for local bending (Fig. 11.1).

11.2. Metal Lattice Folded Structures

Metal lattice folds are used for spans of 18–40 *m*. They are supported on metal or reinforced concrete columns with pulls on the ends, on rafter metal trusses or walls of the building.

Rafter trusses increase the pitch of the columns of the corrugated coating and allow for a more flexible planning solution. The height of the folds is taken within 1/10 - 1/15 of the span.

Triangular folds, which are easier to make, are most commonly used.

Regarding the borders of thin folds, different lattices (Fig. 11.2) with geometrically unchanged cells (as in trusses) are used.

The most practical is a cross lattice (Fig. 11.1, c), in which the elements work only in tension, which allows them to be designed from flexible, high-strength steel profiles.

Metal folds are mainly designed in the form of single-pass systems, if necessary, they can be made multi-pass and cantilever.

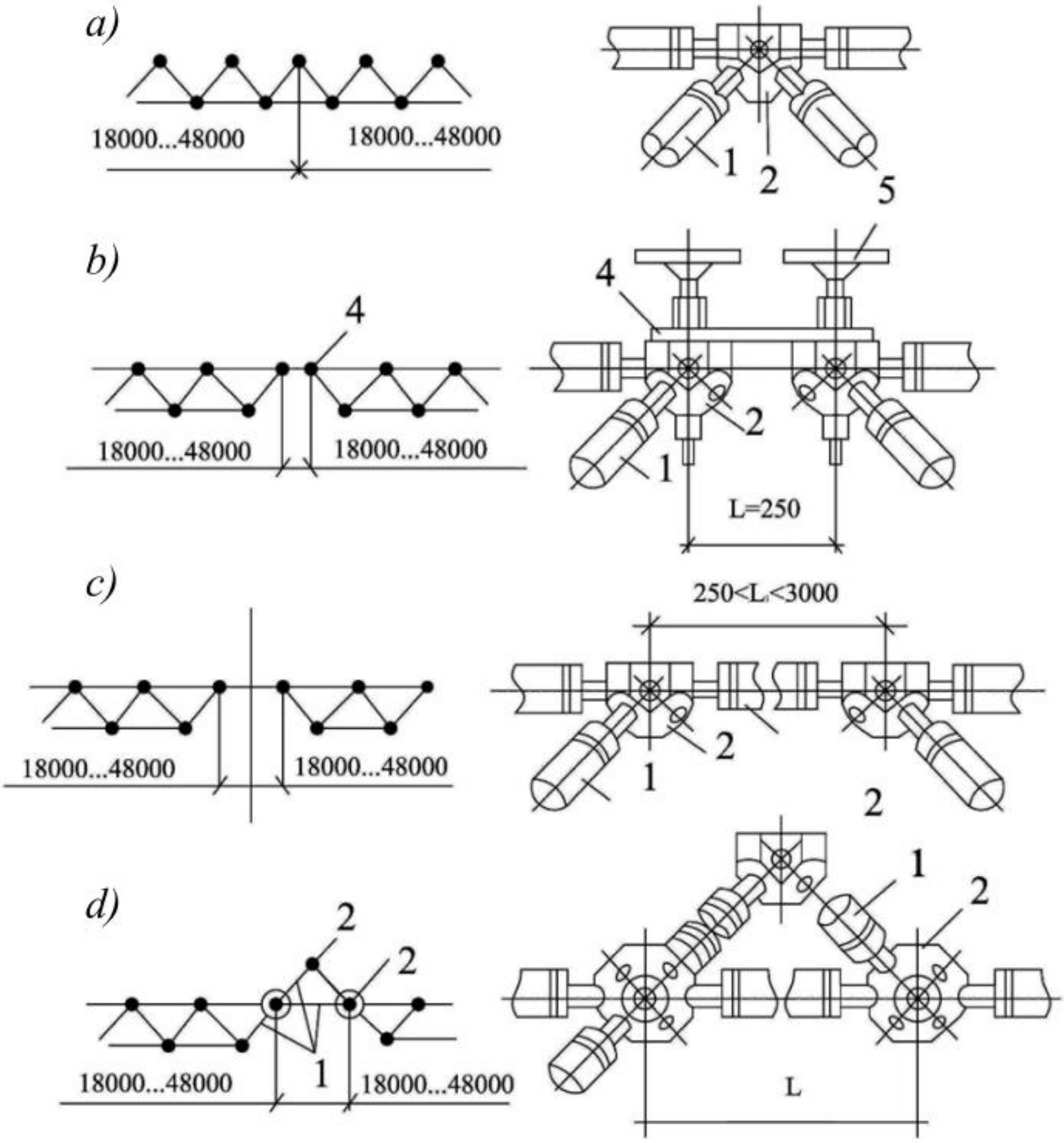


Fig 11.1. Options for connecting structured plates in multi -span buildings:

a – inseparable; b – with a connecting plate; c– with an additional rod;
d – with a lantern superstructure;
1, 2 – rod and nodal elements;
3 – additional element; 4 – butt plate;
5 – support table

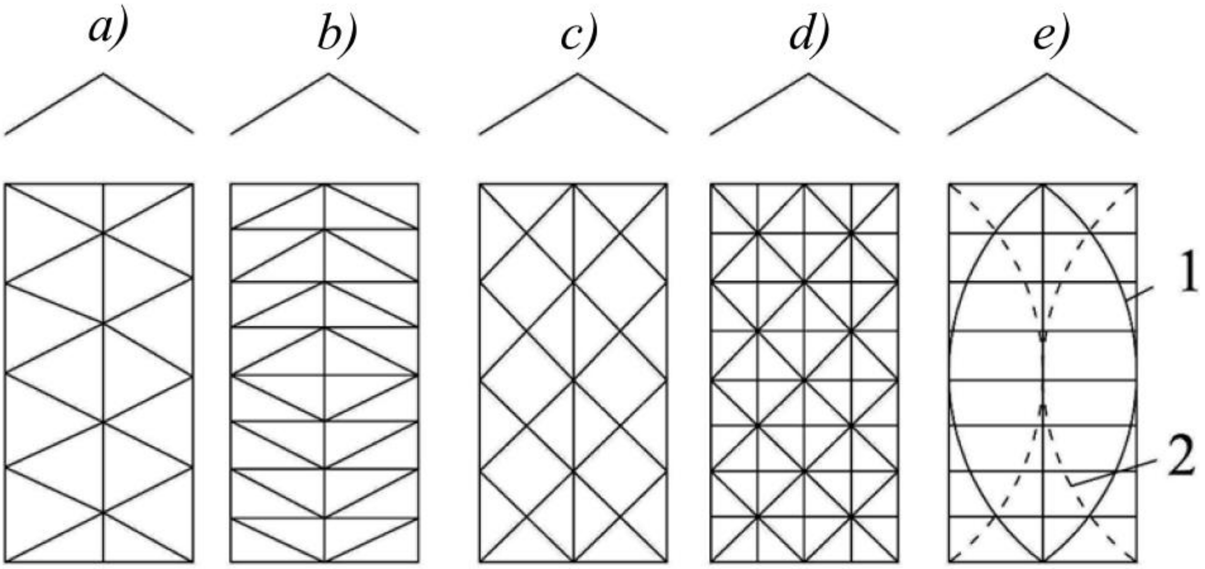


Fig. 11.2. Schemes of metal grids for corrugated roofings:
a – with triangular cells; b – with braces; c – with double braces (X-shaped); d – with incomplete filling of braces of square cells;
e – with built-in arches;
1 – stretched arches; 2 – compressed arches

Folds with a span of up to 18 *m* are made from flat lattice trusses that are fully factory ready. For larger runs, folds are mounted from two half-trusses along the length of the run. From the installation conditions, pleat belts are taken from paired corners or pipes (Fig. 11.3).

Twin elements along the length of the belt are connected on bolts (Fig. 11.3, *a*) or steel fishplates (Fig. 11.3, *b*), which ensure the operation of the elements without displacement in relation to each other. The fold elements are attached to the cross-section of the chord with high-strength bolts with the help of inclined flanges welded to the chord elements (Fig. 11.3, *c* - *d*).

11.3. Metal Vaults

Metal lattice vaults can be single-span and double-span. Vaults of a single grid structure with a span of up to 30 *m* are made with triangular and square shells. For large spans, two-grid structures are used.

The main elements of single-lattice cylindrical vaults resting on walls or foundations are a lattice shell and end lattice diaphragms.

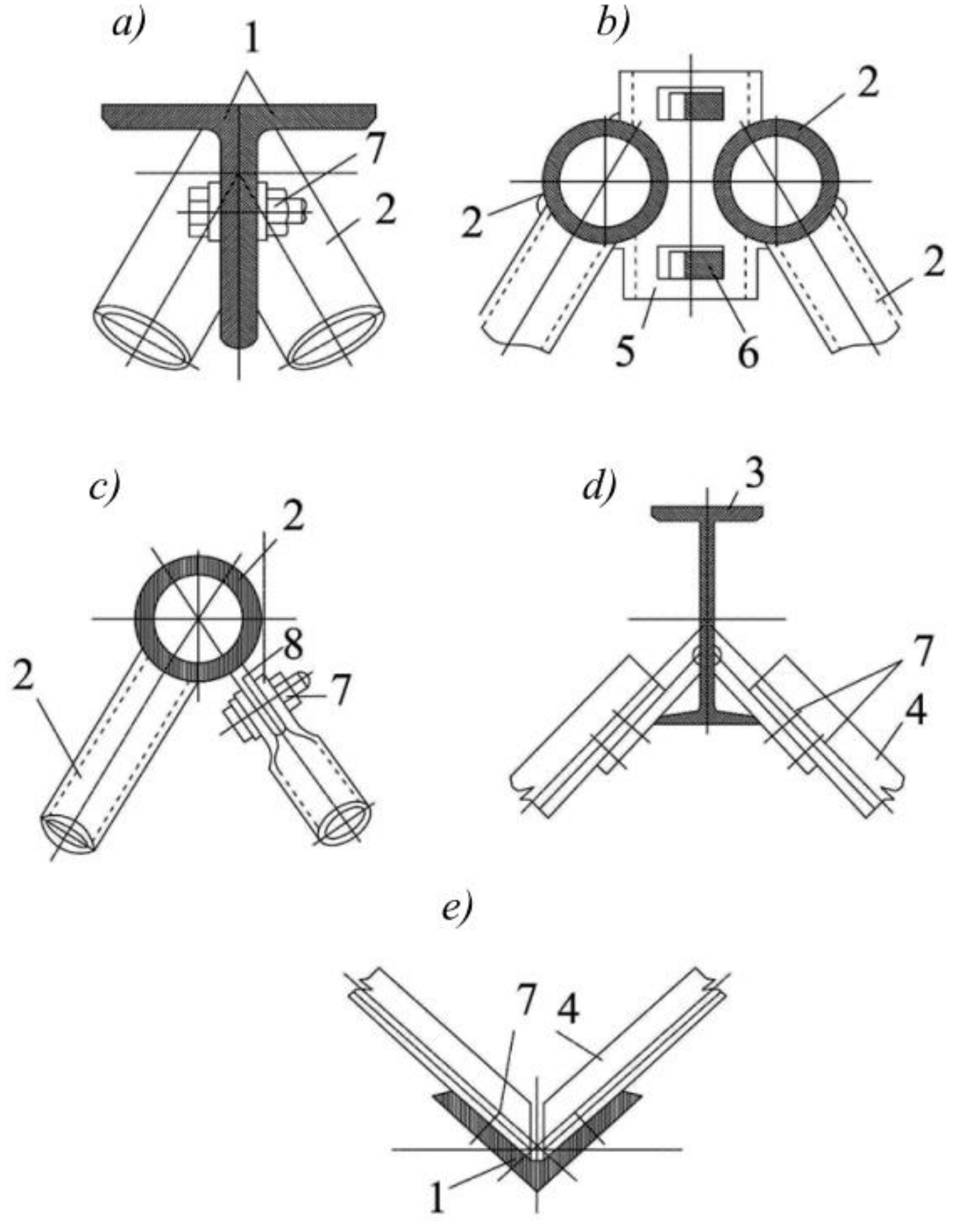


Fig. 11.3. Nodal connections of lattice folds:
a – with chord from twin angles; b – from pipes;
c – with a combined pipe chord; d – with a double-breasted chord;
e – with a single angle:
1 – an angle of the chord; 2 – pipe; 3 – gable; 4 – angle of the grid;
5 – locking device; 6 – fishplate; 7 – bolt; 8 – flange

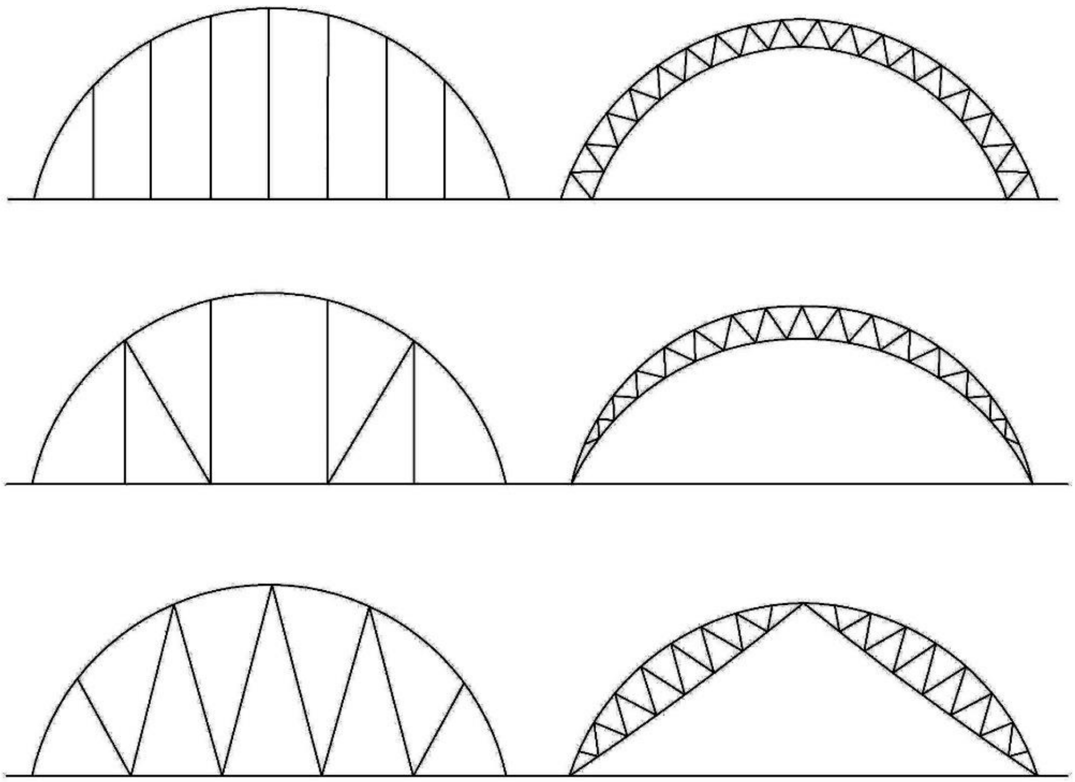


Fig. 11.4. Schemes of end diaphragms of lattice vaults

The span of a single-lattice vault is the distance across the wave, which is taken to be 24-80 *m*, and when the flooring is included in the work together with the lattice - up to 100 *m*.

The beam of the lift, lattice vault is assigned to $\left(\frac{1}{6}\ldots\frac{1}{8}\right)$ the girder. The height of the cross-section of the rod elements of the lattice is taken $\left(\frac{1}{80}\ldots\frac{1}{200}\right)$ as a span.

Metal lattice vaults can be assembled from special stamped elements (Fig. 11.5) that form a diamond grid. By changing the angles between the axes of the elements and the shape of the rhombus, you can change the radius of curvature of the vault profile and its bearing capacity. The "dense" the mesh is, the higher its bearing capacity.

The grid of rhombuses decreases geometrically, so additional ties, which are roof purlins, are necessary.

Other systems of single-layer latticed metal vaults using pipes (Fig. 11.6) and a section in the form of a hat (Fig. 11.6, *b*) are used abroad.

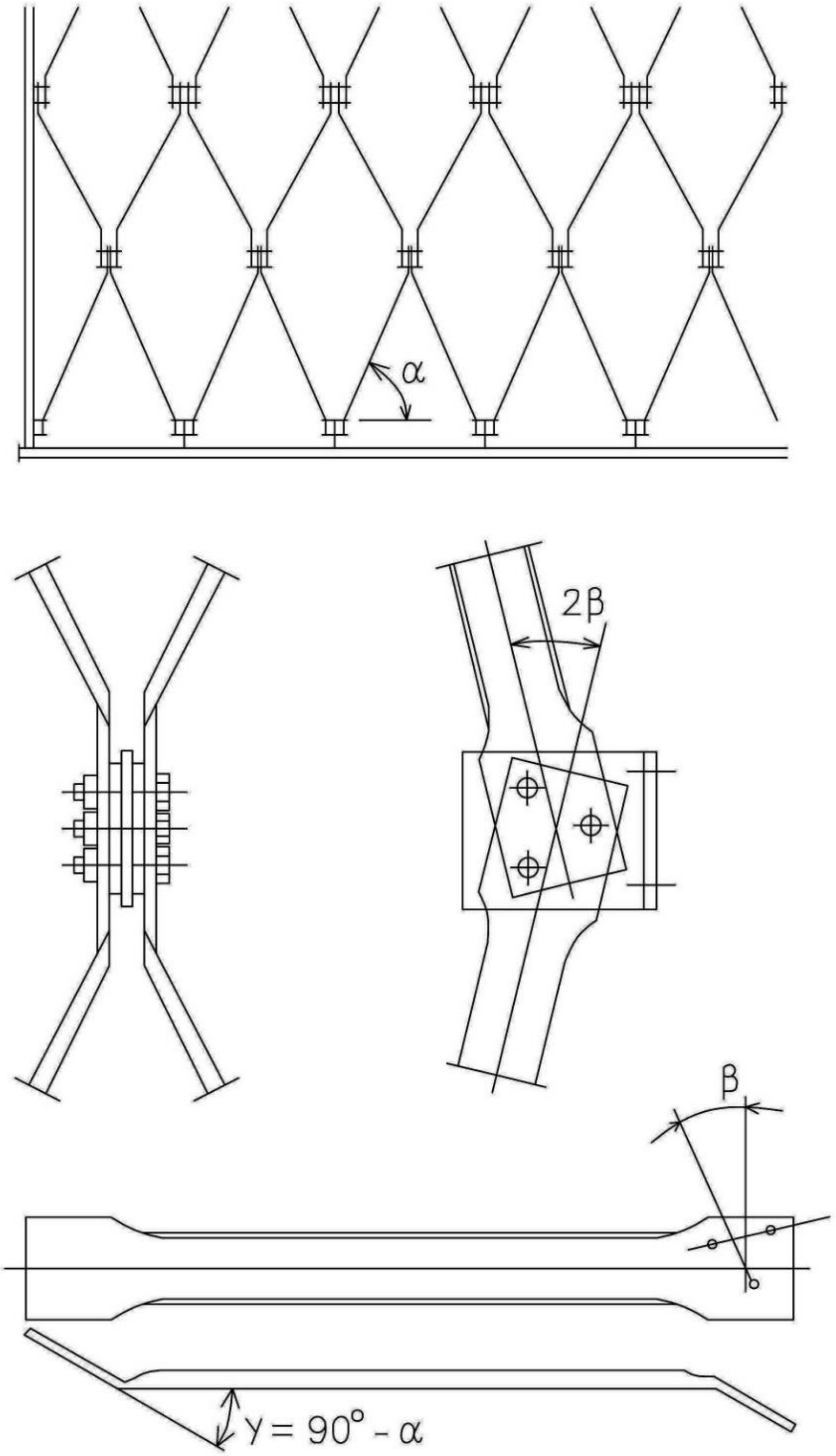


Fig. 11.5. Metal lattice vaults from stamped elements

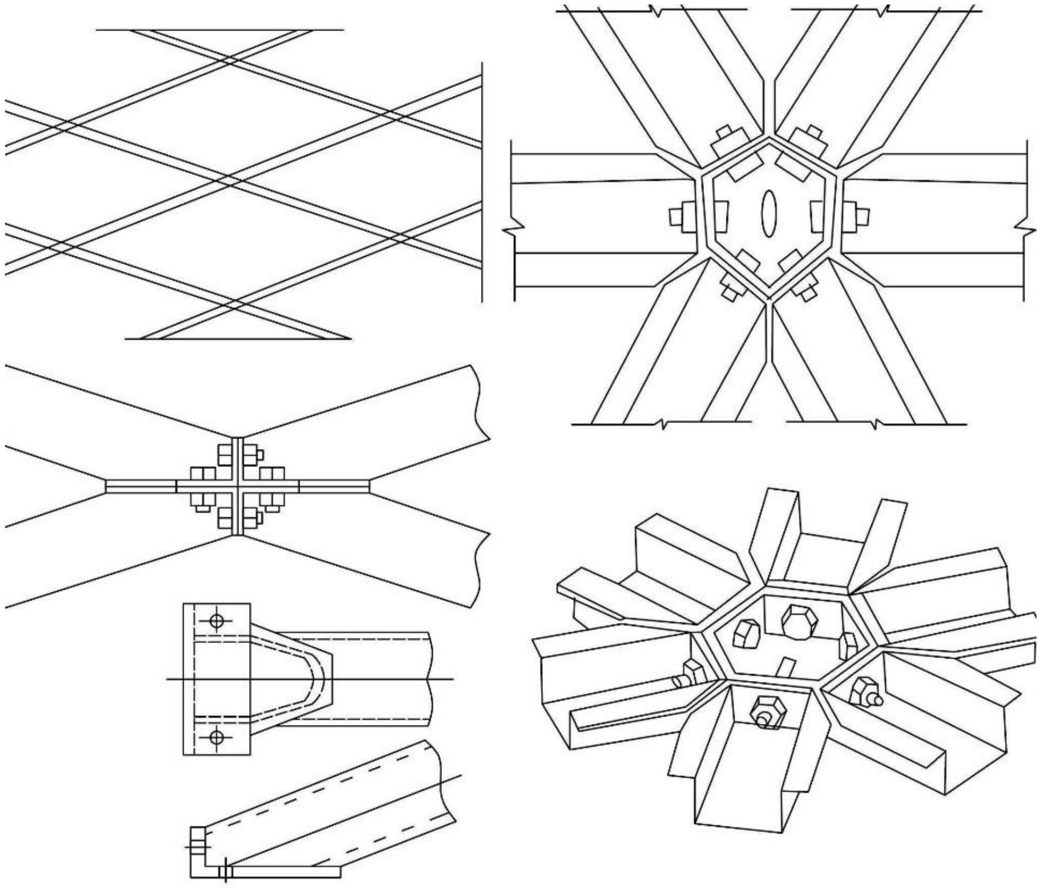


Fig 11.6. Nodal connections of single-girdle, metal, lattice vaults:

a – with knotted patterns (Czech Republic);
b – with cast nodes, "Wupperman" (Germany)

Double-girdle lattice vaults, compared to single-girdle shells, are stiffer and have a greater bearing capacity. They can cover spans up to 500 m, with the ratio of the boom to the span within $\left(\frac{1}{6}\dots\frac{1}{10}\right)$, and the ratio of the cross-section height to the average radius of curvature$\left(\frac{1}{20}\dots\frac{1}{100}\right)$.

Double-lattice vaults (Fig. 11.7) are formed by a system of crossed trusses of arches in two or three directions. The main load-bearing function is performed by the transverse lattice arches, which transmit the main forces to the foundation, and the longitudinal straight trusses help redistribute the forces between the transverse arches and significantly increase the rigidity of the shell.

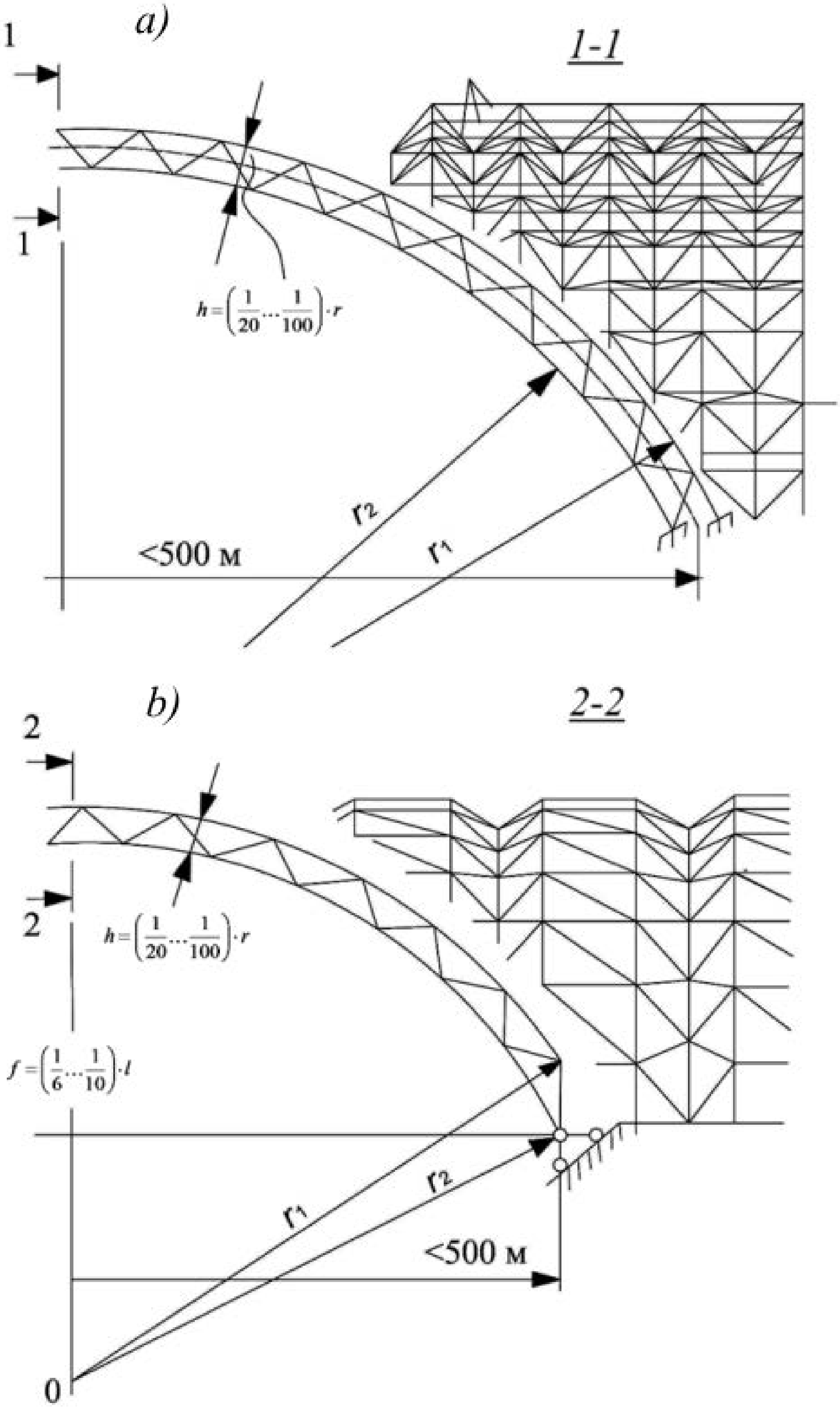


Fig.11.7. Form of two-grid metal vaults:
a – folded; *b* – prismatic

11.4. Metal Domes

Design schemes of metal domes are divided into types: ribbed, ribbed - ring and lattice (Fig. 11.8).

A ribbed dome is a system of radial ribs - semi-arches, which are connected to each other with the help of an upper ring, which perceives the force of the spacer from the semi-arches (Fig. 11.8, *a*). The spans of ribbed metal domes reach up to 125 m, the ratio of the height of the dome to the diameter is from 1/4 to 1/7.

When designing long-span dome coverings, cross-section structures are used - each load-bearing element is a truss with parallel belts connected by a grid.

The purlins of ribbed domes work only in bending as auxiliary beams, taking the load from the roof and transferring it to the ribs. By combining the purlins with rings and including them in the spatial work, we will get the scheme of the rib-ring dome

The ribbed-ring dome has a more rational design scheme. The rings significantly reduce the bending moment in the meridional ribs, which provides greater spatial rigidity.

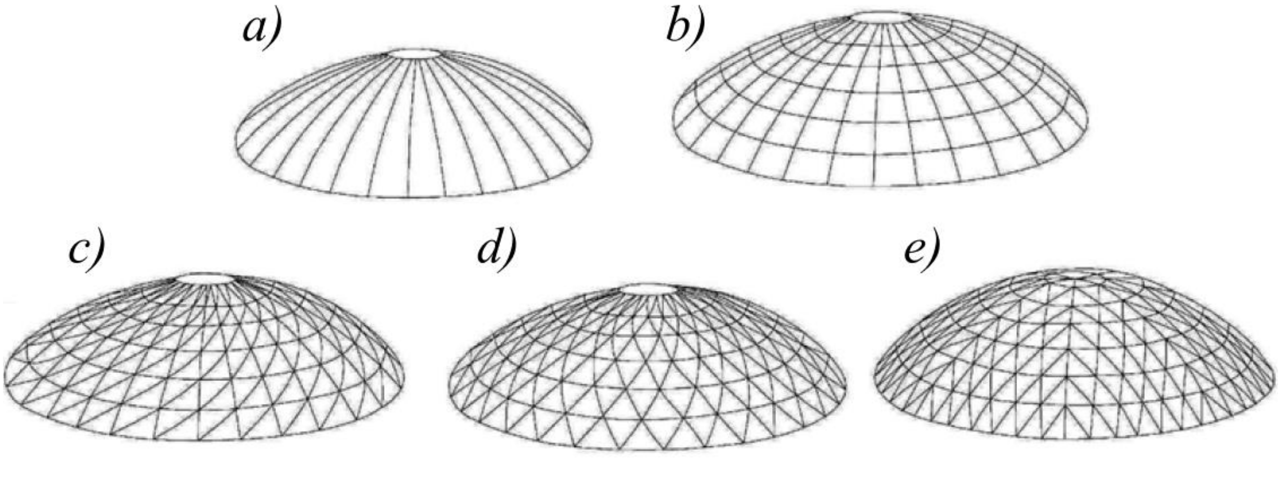


Fig. 11.8. Types of metal rod domes:
a – ribbed; b – rib-ring;
c, d, e – lattice (Schwedler, Civitt, Feppl)

Lattice domes consist of one or two layers of structural elements that form a triangular, diamond-shaped, pentagonal, and hexagonal grid. Lattice domes have only the lower support ring.

The main spatial schemes:

- ribbed - annular with ligaments in each cell (Fig. 11.8, *c*);
- star (Fig. 11.8, *d*);
- Civitt scheme (Fig. 11.8, *e*);
- "Rhomb" scheme (Fig. 11.9).

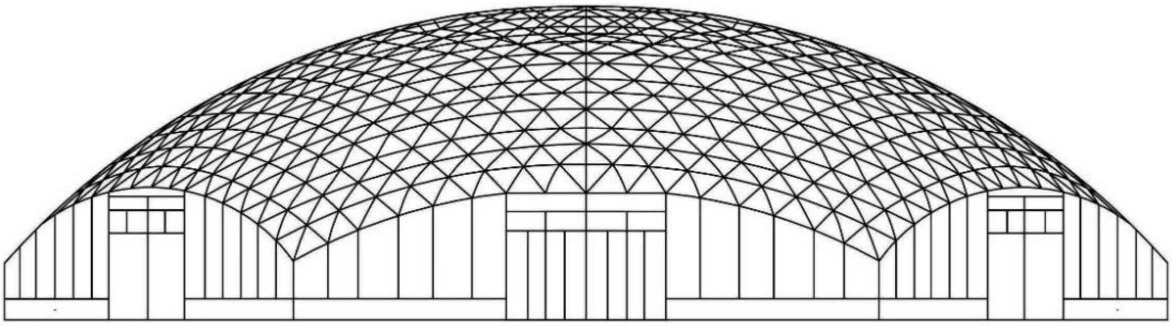


Fig. 11.9. Lattice dome "Rhomb" scheme, diameter 65 *m*

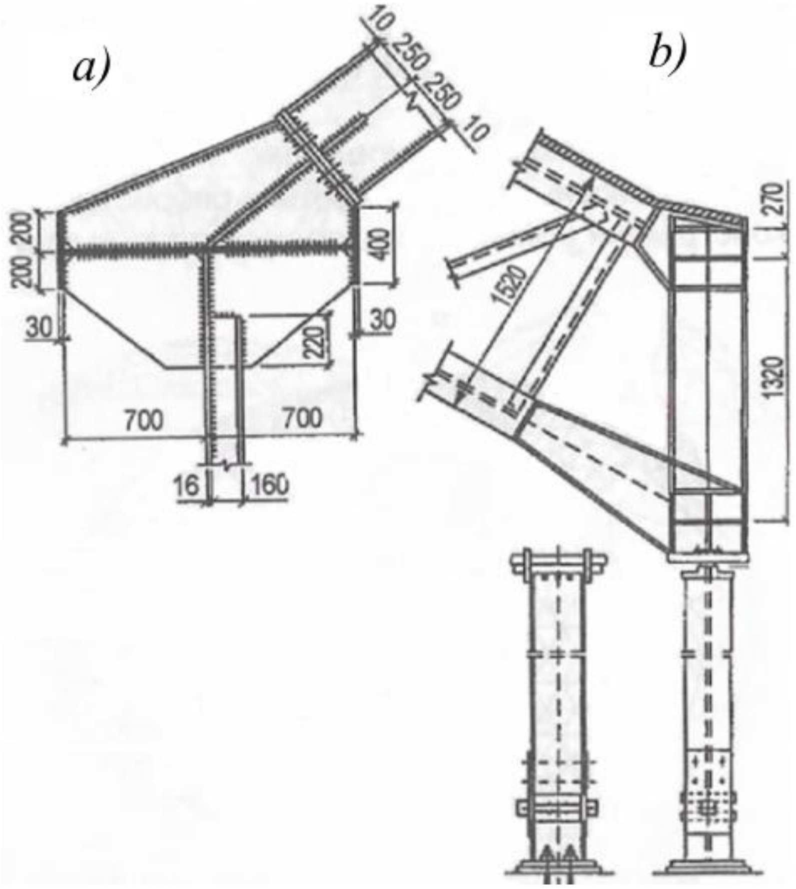


Fig. 11.10. Support nodes of metal domes:
a – rib-ring dome; *b* – double-reticulated dome

11.5. Metal Hypars

The surface of a hyperbolic paraboloid (hypar) refers to the surface of a negative Gaussian curve.

Metal hypars are designed with mesh. They are single-belted (single-grid) and double-belted (double-grid). Runs of single-girdle girders up to 60 m due to the possibility of loss of general stability. The grid structure of the hypar is framed by side elements, the horizontal size of the section of which is taken from $\left(\frac{1}{50}\dots\frac{1}{60}\right)$, and a vertical $\left(\frac{1}{100}\right)$ span. The two-belt grid structure of hypar is used for spans of more than 60 m. Ratio of height to span $\left(\frac{1}{100}\dots\frac{1}{150}\right)$. Metal and aluminum profiles can be used as the rods for mesh hypars.

The tape roofing is mounted from separate tapes that are not connected to each other.

In fig. 11.11 shows an example of covering an industrial building, which consists of 12 grid-connected shells in the form of hypars: 4 square and 8 triangular, made of aluminum pipes.

Two-belt roofing systems include systems in which one or two chords of running structures are made in the form of a membrane. The chords are joined by spacers or a grid.

The material for the manufacture of membrane roofings can be:

– C245 steel in sheets and rolls up to 6 mm thick;

– low-alloy steel of the C345 grade and weatherproof steel of the C345K grade, up to 4 mm thick;

– low-alloy steel of the C390 grade in rolls up to 5 mm thick.

The use of aluminum sheets in rolls with a thickness of 1–3 mm of the $AlMn_1$ grade is allowed. In buildings with an aggressive environment, stainless steel with a thickness of up to 2–4 *mm* is used.

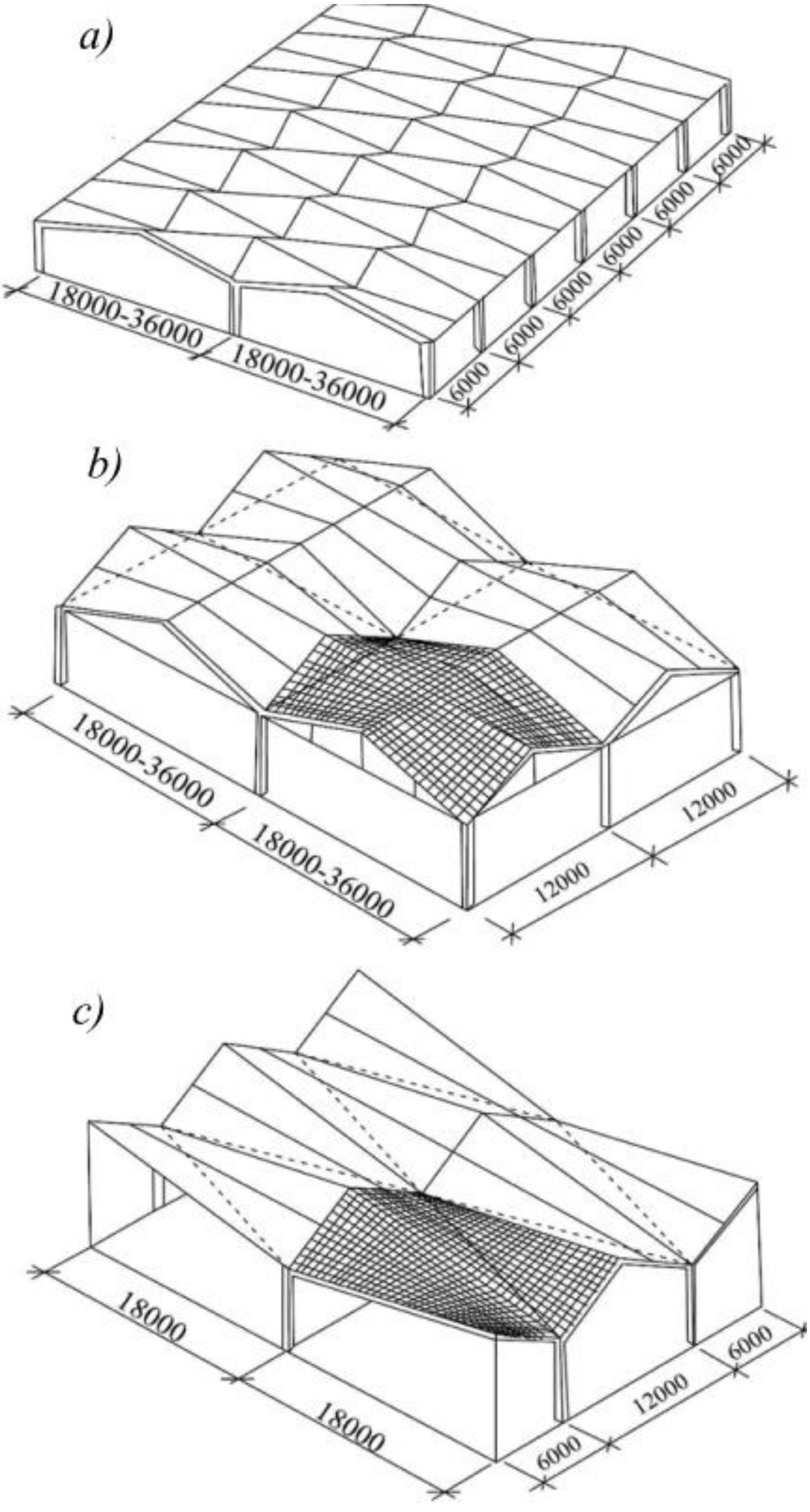


Fig. 11.11. Schemes of coverings with a rectangular plan consisting of hyperbolic paraboloids:
a – from hypars of two types; *b* – "cross-shaped roofing" type;
c – with diagonal tendons

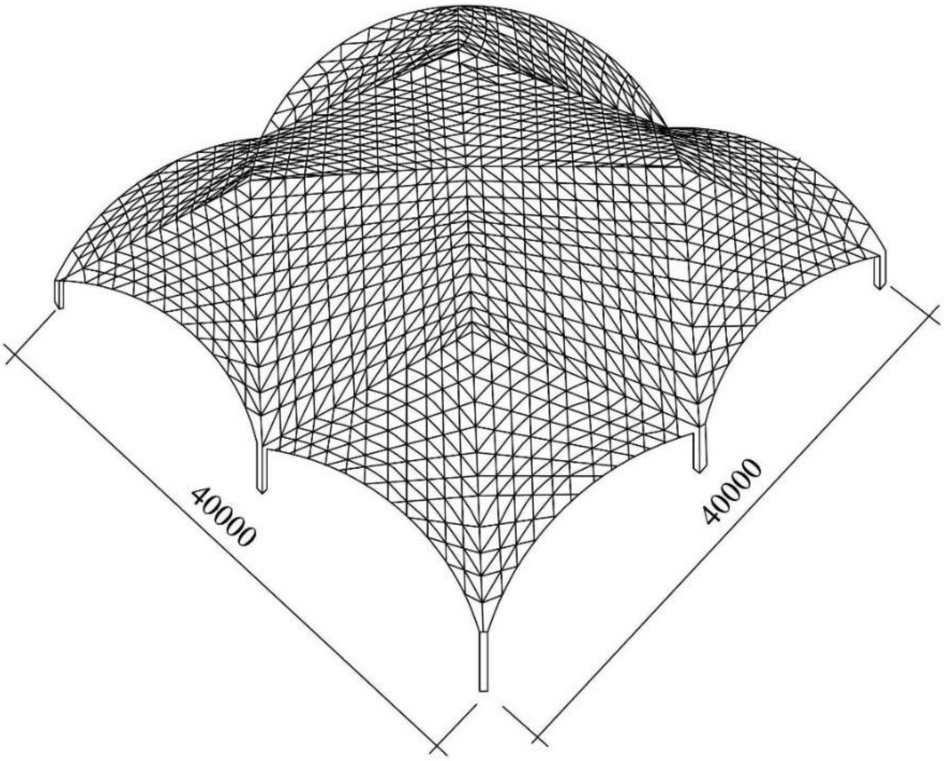


Fig. 11.12. Metal shell in the form of several hypars

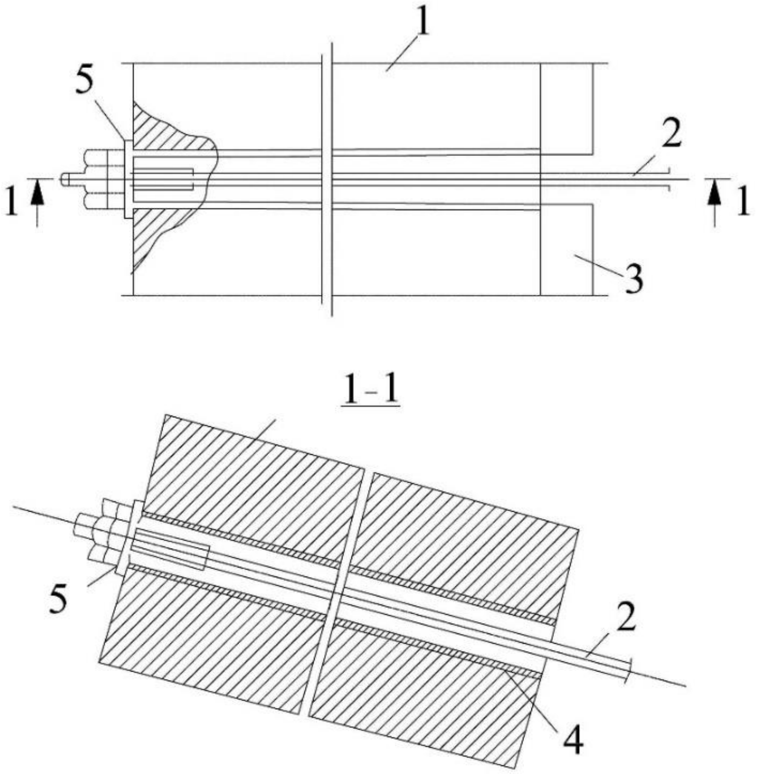


Fig. 11.13. Node of connection anchor rods to the contour
1 – strip steel; 2 – anchor rod of the "bed" element;
3 – support table for fastening the membrane;
4 – steel sleeve; 5 – rest

Nodes for attaching guides to the contour should ensure the geometry of the bed. To do this, a shank is made at one of the ends of the guide connections, which is tightened to the stops on the contour to ensure the adjustment of the length of the guides (Fig. 11.13, 11.14).

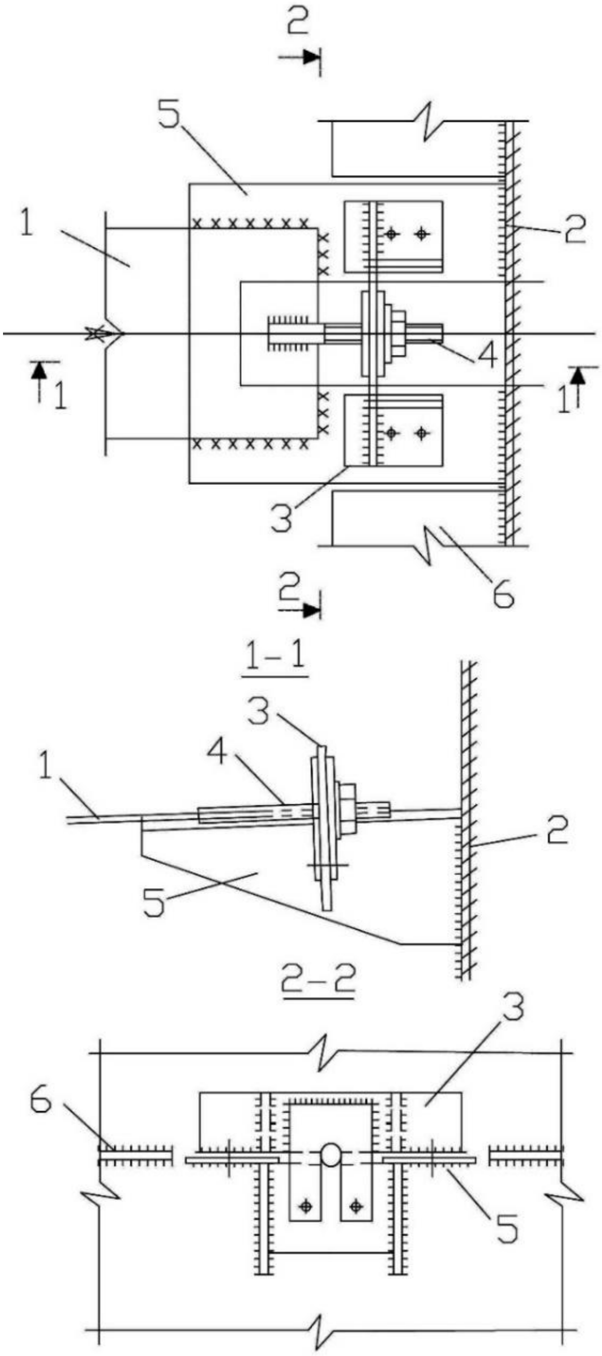


Fig. 11.14. The node that regulates the fastening of the guiding elements of the bed to the contour:
1 – guiding element of the bed;
2 – contour; 3 – stop (removed after welding the guide element to the table); 4 – shank; 5 – support table;
6 – the same, for fixing the membrane

11.6. Membrane Roofs

The main elements of membrane coatings are a thin-sheet running structure-membrane, the membrane perceives the forces from the running structure. According to structural features, membrane systems are divided into: continuous membrane shells; on tape coating; on two-belt combined thin-sheet coverings.

Membrane shells are made of individual thin sheets, which are combined during installation into a continuous spatial system. They can have a different shape of the surface of individual coatings (Fig. 11.15) or a surface consisting of combinations of shells with the same or different geometric surfaces (Fig. 11.16).

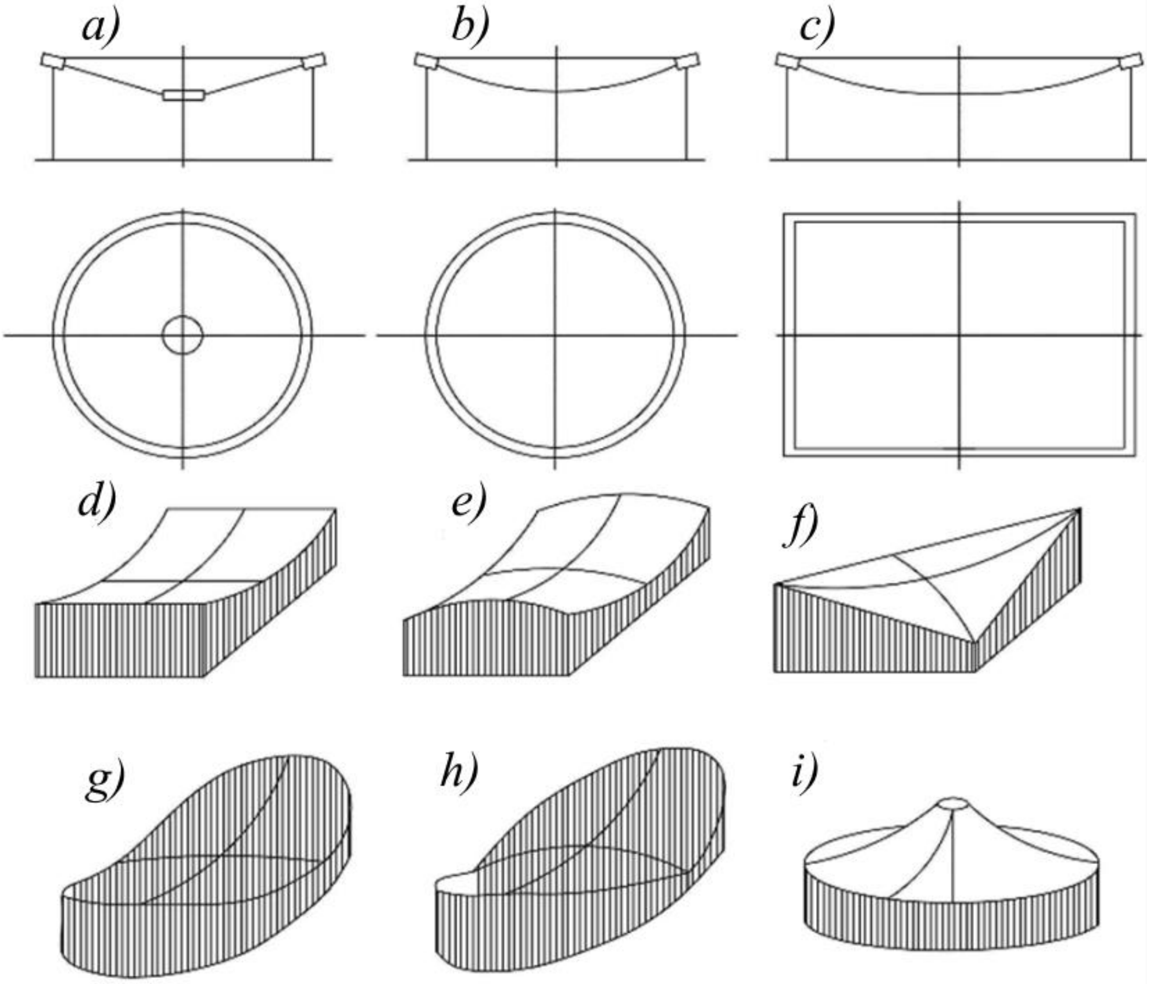


Fig. 11.15. Forms of the surfaces of membrane coatings: *a, d* – zero Gaussian curvature; *b, c* – positive Gaussian curvature; *d, i* – negative Gaussian curvature

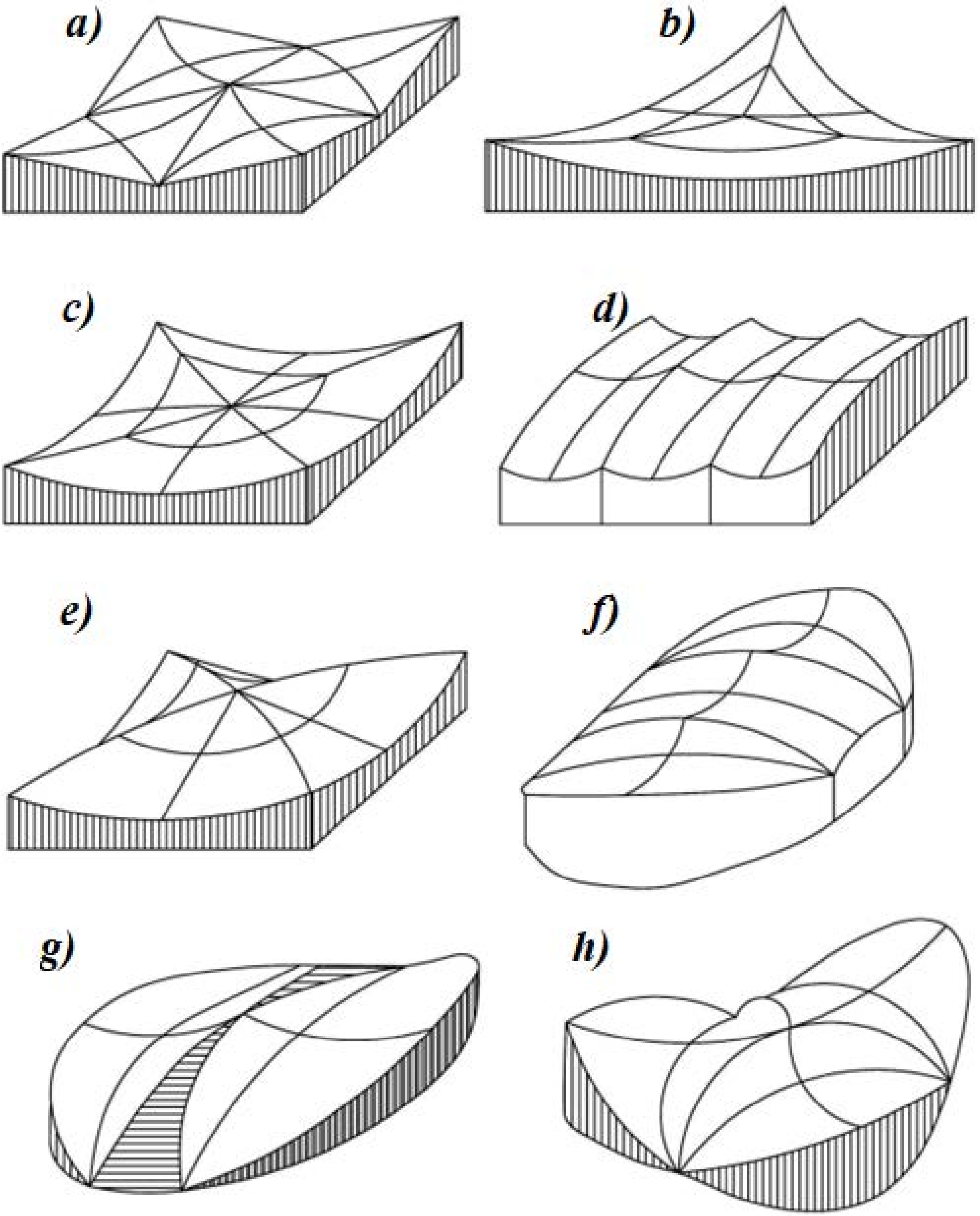


Fig. 11.16. Shapes of composite membrane roofing surfaces:
a, *d*, *f*, *g*, *h* – negative Gaussian curvature;
b, *c*, *e* – zero Gaussian curvature

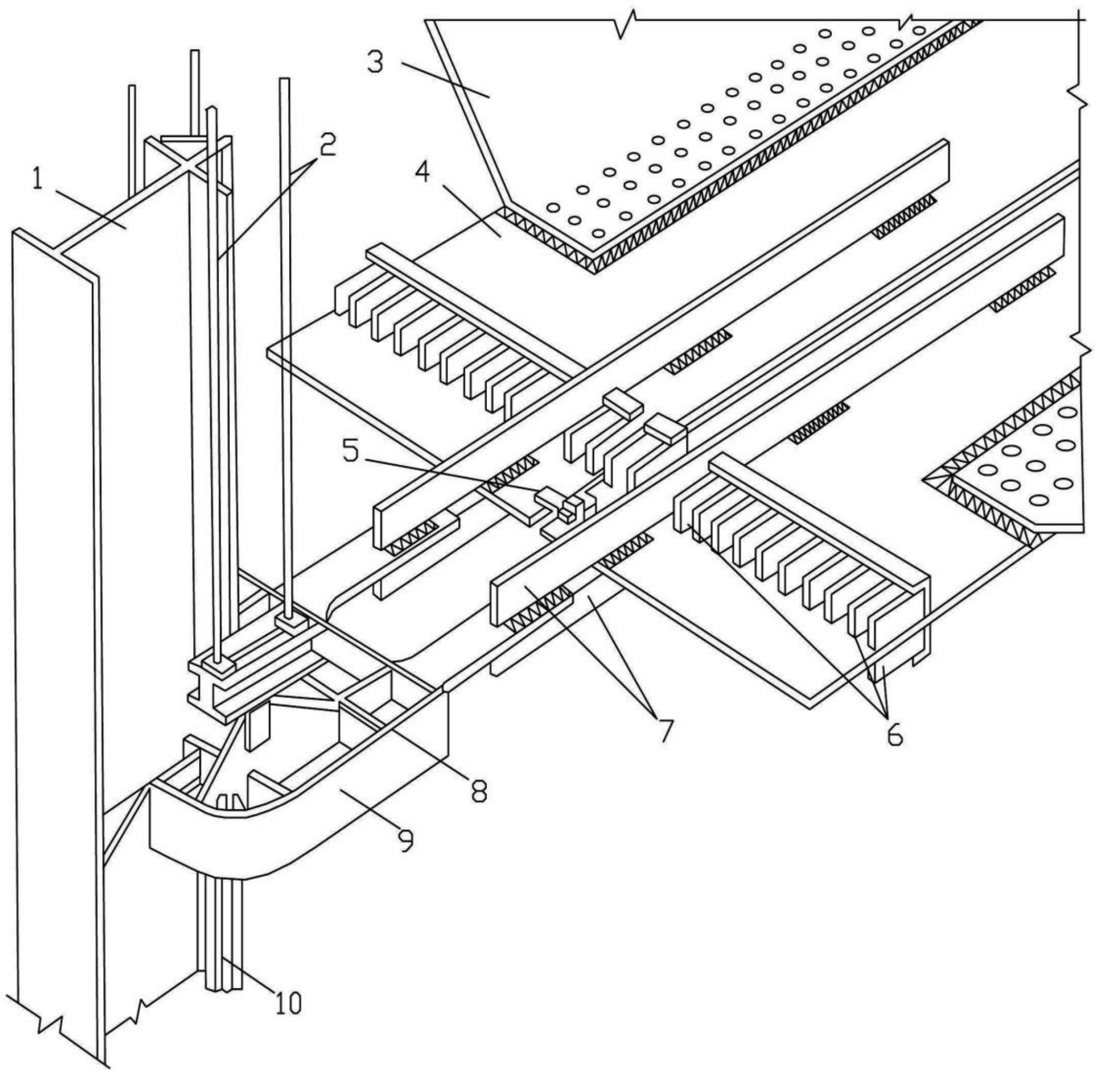


Fig. 11.17. Diagram of membrane attachment during lifting: *1* – installation column for membrane lifting; *2* – screw traction lifter; *3* – membrane tape; *4* – diagonal supporting elements of the membrane; *5* – gap fixator between diagonal elements; *6* –«sprocket» for fastening diagonal elements to the support contour; *7* – connecting elements of diagonal strips and brackets; *8* –balancing traverser; *9* – axles with a slider block; *10* – guide rail CR–70

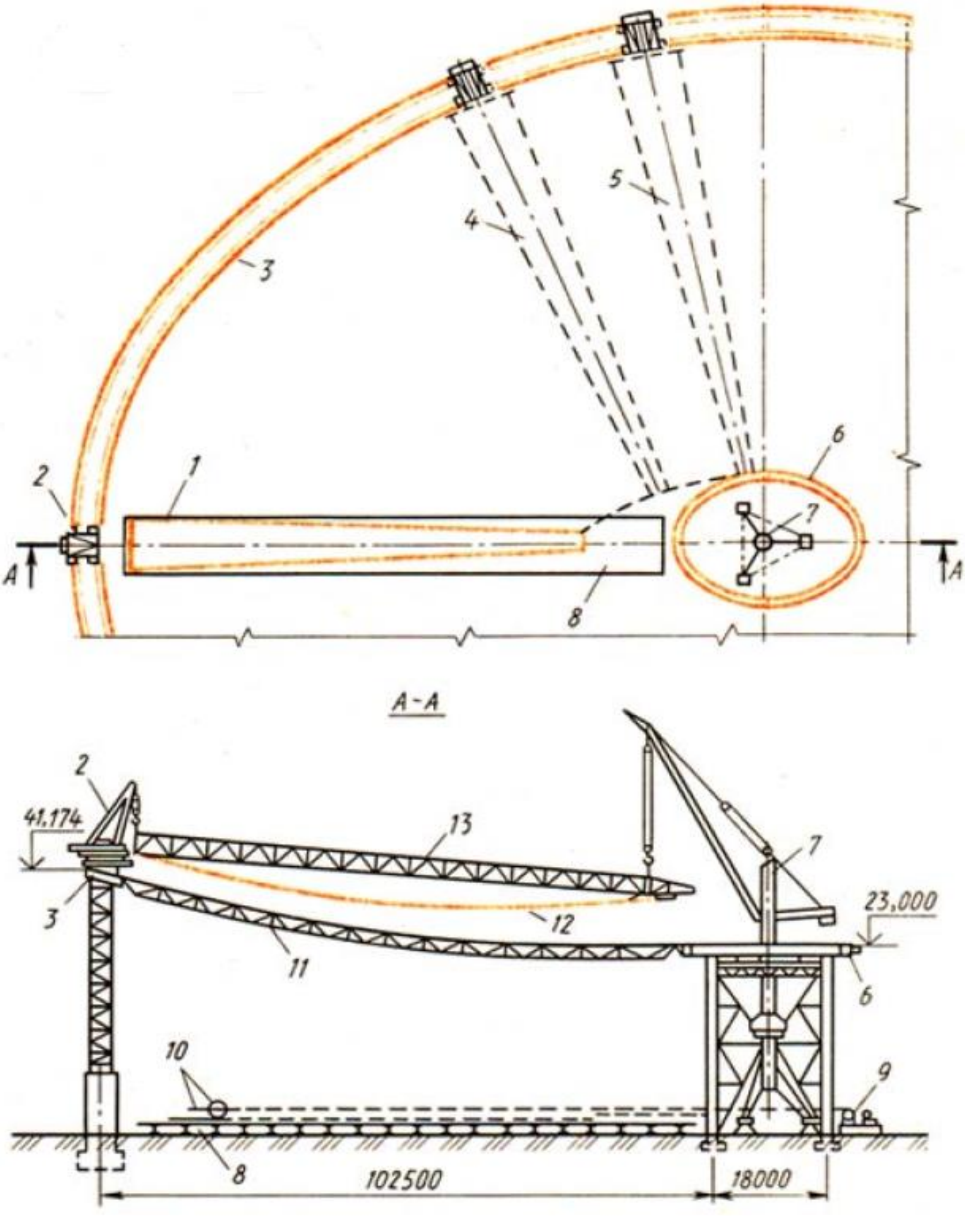


Fig. 11.18. Assembly diagram of membrane elements:
1 – the position of the membrane element before lifting;
2 – lifter; *3* – external support contour; *4* – intermediate position during installation; *5* – design position of the membrane;
6 – inner steel support ring; *7* – tower crane; *8* – stand for roll deployment; *9* – telpher; *10* – deployment diagram; *11* – mounted block; *12* – mounted element of diagram; *13* – traverse-brace

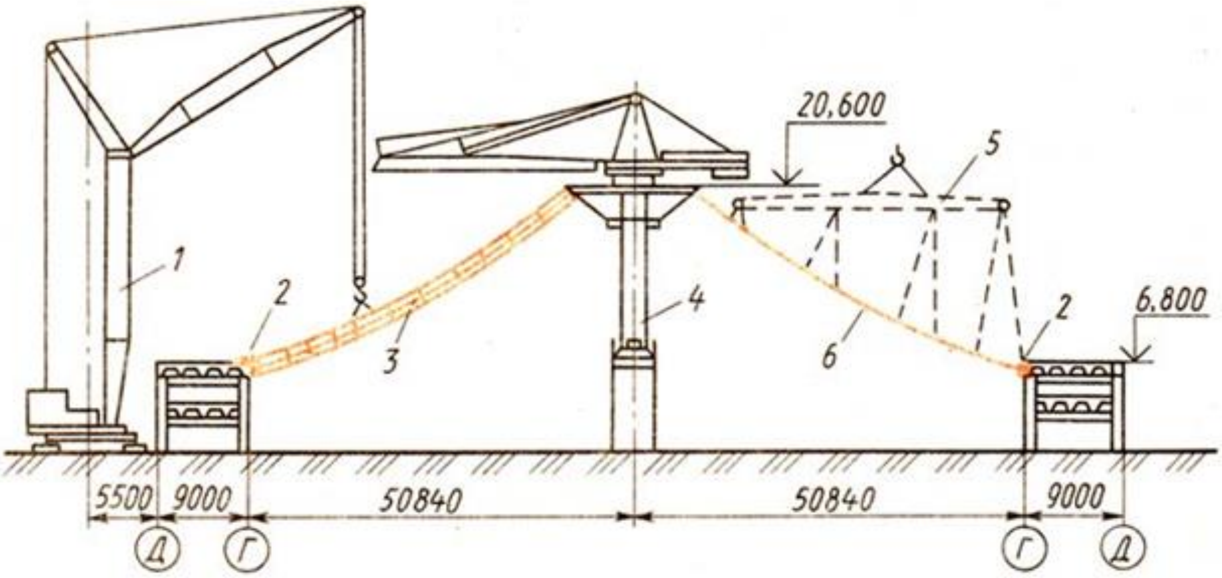


Fig. 11.19. Tent-type hanging coating installation diagram:

1 – tower crane; *2* – outer ring; *3* – covering slab; *4* – the central support; *5* – cross-arm for lifting of ropes; *6* – cable-stayed which is mounted

Questions for Discussion and Self-Assessment for Chapter 11

1. Give examples of metal mesh schemes for folded coatings.
2. Give examples of lattice fold joints.
3. Describe the metal lattice vaults and give an example of end diaphragm diagrams.
4. Give an example of a metal lattice vault assembly of stamped elements.
5. Give an example of an assembly for connecting single-girdle metal lattice vaults.
6. Describe the properties of two-grid metal vaults and their shapes.
7. What is a ribbed dome and what types of metal rod domes do you know?
8. Provide an example of a dome with a lattice scheme "rhombus" and name the structural elements of which.

CHAPTER 12. CABLE-SUPPORTED ROOFS

12.1. Classification of Cable-Supported Roofs

Cable-stayed roofs is one of the main groups of spatial hanging roofings, where the main bearing elements are sagging cables, which work mainly in tension. Cables can be bent and rigid, perceiving bending moment.

The cable-stayed cover consists of three parts: a bearing structure of stretched guy ropes, an enclosing plate and a support contour. The forces transmitted to the support contour are horizontal tensile forces reaching significant values.

Advantages of hanging type roofs:

– full use of bearing capacity of high-strength steels;

– low weight of the structure itself;

– variety of forms and architectural expressiveness;

– high self-stability;

Disadvantages of hanging type roofs:

– increased deformability (design nonlinearity);

– it is necessary to install additional structures for the taking up thrust efforts;

– the relative complexity of the drainage system.

Hanging roofs - coatings in which the main supporting structure overlaps the span and works on tension.

Cable cover - a cover, part of the span of which is formed by a grid of bearing flexible guy ropes with the following enclosing elements laid on it, to ensure their compatible work between themselves and the support contour.

The support contour is a rigid structure (steel, reinforced concrete, pipe concrete), which perceives the thrust force from the span part of the roofing, and is capable of working for compression, bending and torsion.

The guy is a flexible sagging rod that perceives tension and carries a transverse force from the span.

Flexible guy - the rope works only on tension.

Rigid guy – the rope that works on tension but can also withstand a small bending moment.

Cable-stayed structures can be classified based on:

By Type of Load-Bearing Structures:

- – single-layer systems (made of flexible elements and combined);
- – cable-stayed grids;
- – rigid cables;
- – suspended (including cantilever-cable);
- – combined systems.

By Surface Curvature:

- – zero Gaussian curvature;
- – positive Gaussian curvature;
- – negative Gaussian curvature.

By Type of Thrust Distribution:

- – externally thrust-resistant (thrust forces are transferred to the foundation level and carried by special foundations or anchors);
- – externally thrust-free (thrust forces are supported at the level where the flexible elements of the structure are fixed to the corresponding closed support contours).

By Thrust Absorption Method:

- – with a closed support contour;
- – with tie rods or thrust members;
- – with an open support contour combined with struts and stays;
- – with struts and stays only.

By Stabilization Method:

- – with additional loading.

By Surface Shape:

- – with additional elements;
- – with inherent rigidity and bending resistance;
- – with prestressing.

For cable stays made of ropes, the following fastening methods are used: a loop with a thimble secured by clamps, or a loop with a thimble and the end of the rope pressed using aluminum or steel oval-section sleeves (Fig. 12.1, a–d). The strength of such ropes is not fully realized, so they are used as temporary fastening for stays during construction.

More reliable are poured socket end fittings for ropes (Fig. 12.1, e–g). The supporting component of such a fastening a socket can have various designs and is attached to the support contour.

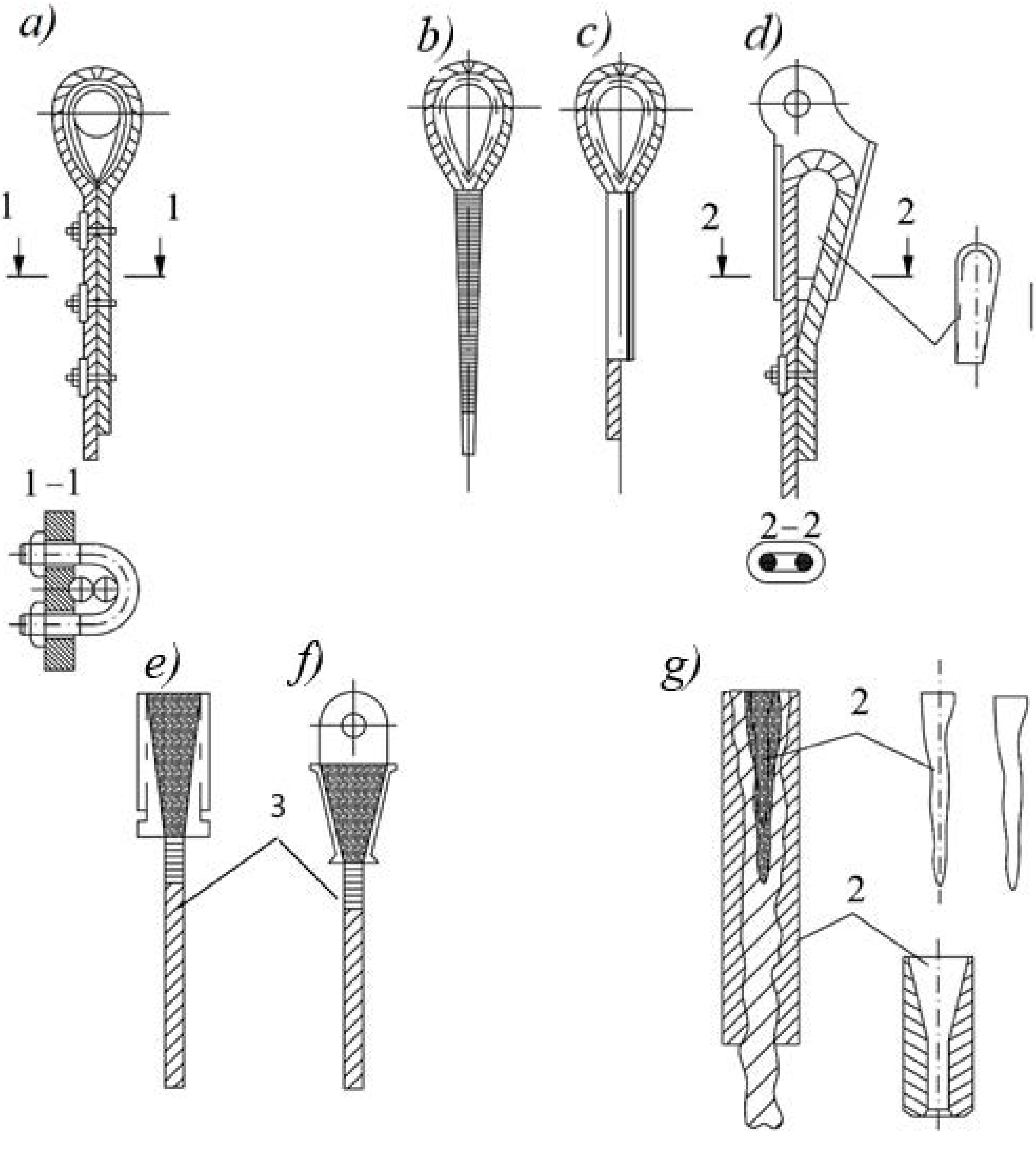


Fig. 12.1. End fittings for cable stays made of steel ropes**:**
1 – movable wedge; 2 – wedge; 3 – sleeve

For cable stays made of high-strength flexible wire, the end fittings are formed through friction forces, bending, and wedging.

In anchors (Fig. 12.2, a–d), the wires are secured by pressing sleeves. Cone-shaped fastenings, such as the “block with plug” type (Fig. 12.2, e–g), are used in prestressed trusses and shells.

For strong reinforcing bundles (stays), anchors are used with cast-in-place fixation, where the pre-bent wire ends are embedded in a metal socket and filled with fine-aggregate concrete.

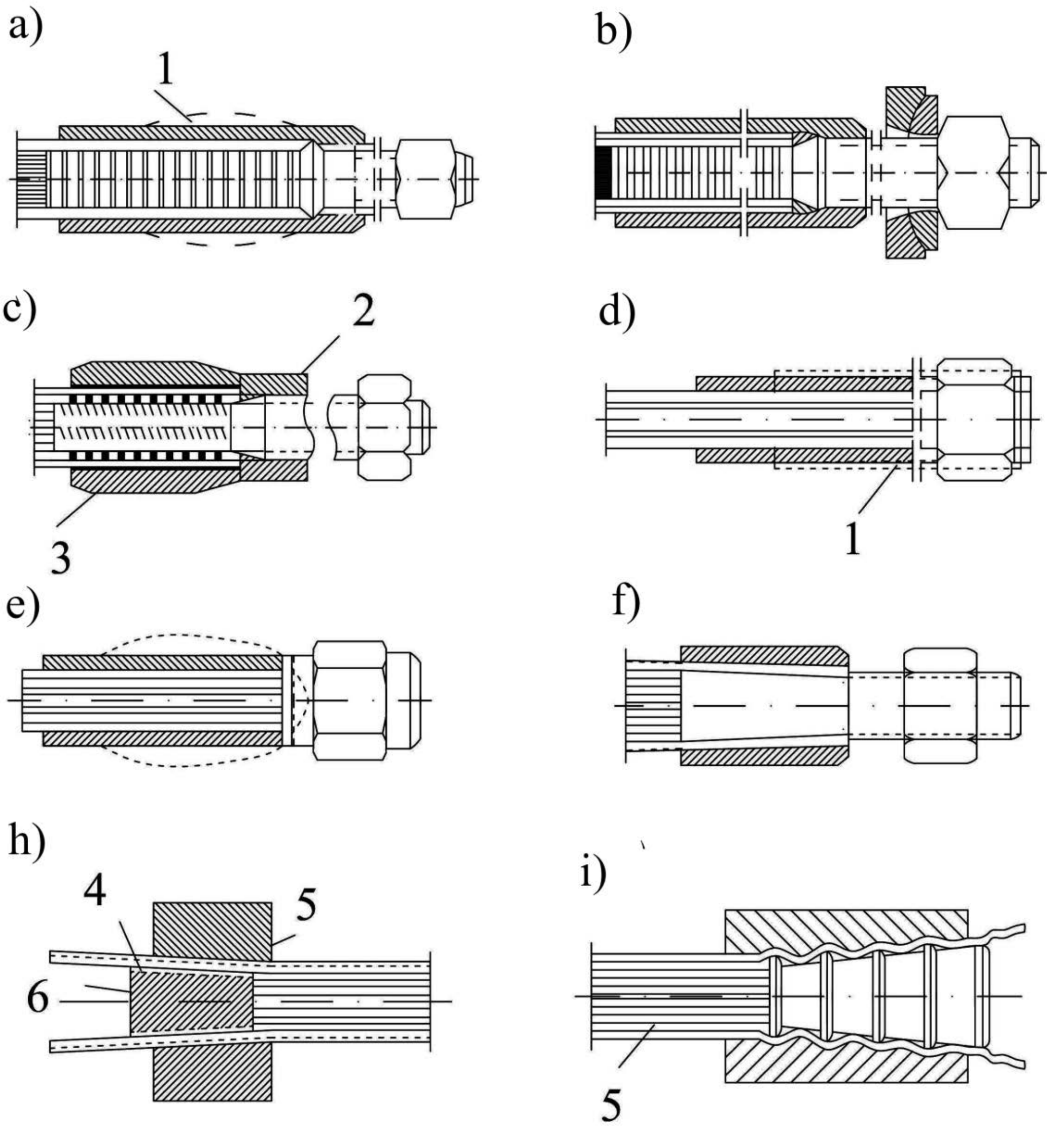


Fig. 12.2. End anchor fastening for cable stays made of wire bundles: 1 – sleeve contour for compression; 2 – rod; 3 – spiral; 4 – thread; 5 – block; 6 – plug

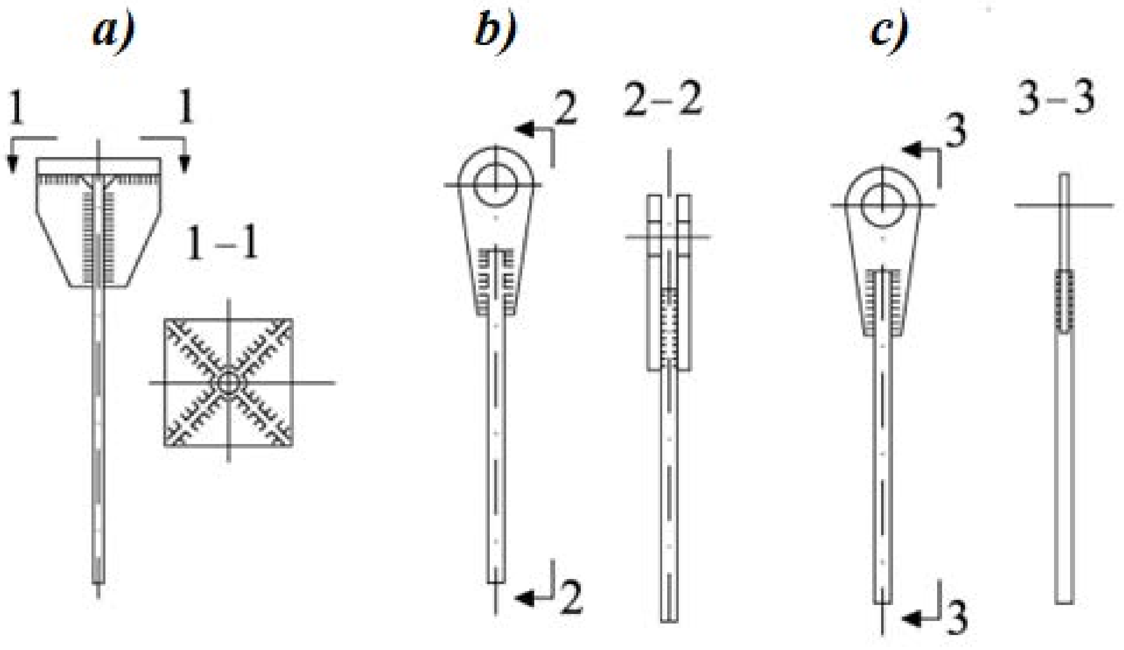


Fig. 12.3. End fittings for cable stays made of reinforcing bars

End fittings for cable stays made of reinforcing bars: in most cases, end fittings for stays made of reinforcing bars allow for welding of components (Fig. 12.3). A bearing washer with stiffening ribs (a) is used to anchor the bar in edge elements of monolithic reinforced concrete. For hinged fastening of bars, single or paired gusset plates with holes are used (Fig. 12.3, b, c).

12.2. Supporting Structures

Support structures in suspended roofs, the thrust of the cables is transferred to the support structures. These structures must accommodate the anchor fastenings of the cables, taken the tensile forces in the cables, transfer them to the building’s foundation, and form a rigid support contour to limit the deformation of the suspended system. The external support ring (Fig. 12.4, a) allows the thrust to be neutralized within the roof structure, creating an internally balanced system that transfers only vertical forces to the foundation. In other cases, the foundation also receives additional thrust forces. The external support ring operates in compression, which is why it is typically made of reinforced concrete. In suspended roofs with double curvature, a successful solution is a support structure in the form of two inclined arches (Fig. 12.4, b). The arches work in compression, and the thrust can be transferred to the foundation using compressed columns and tensioned ties.

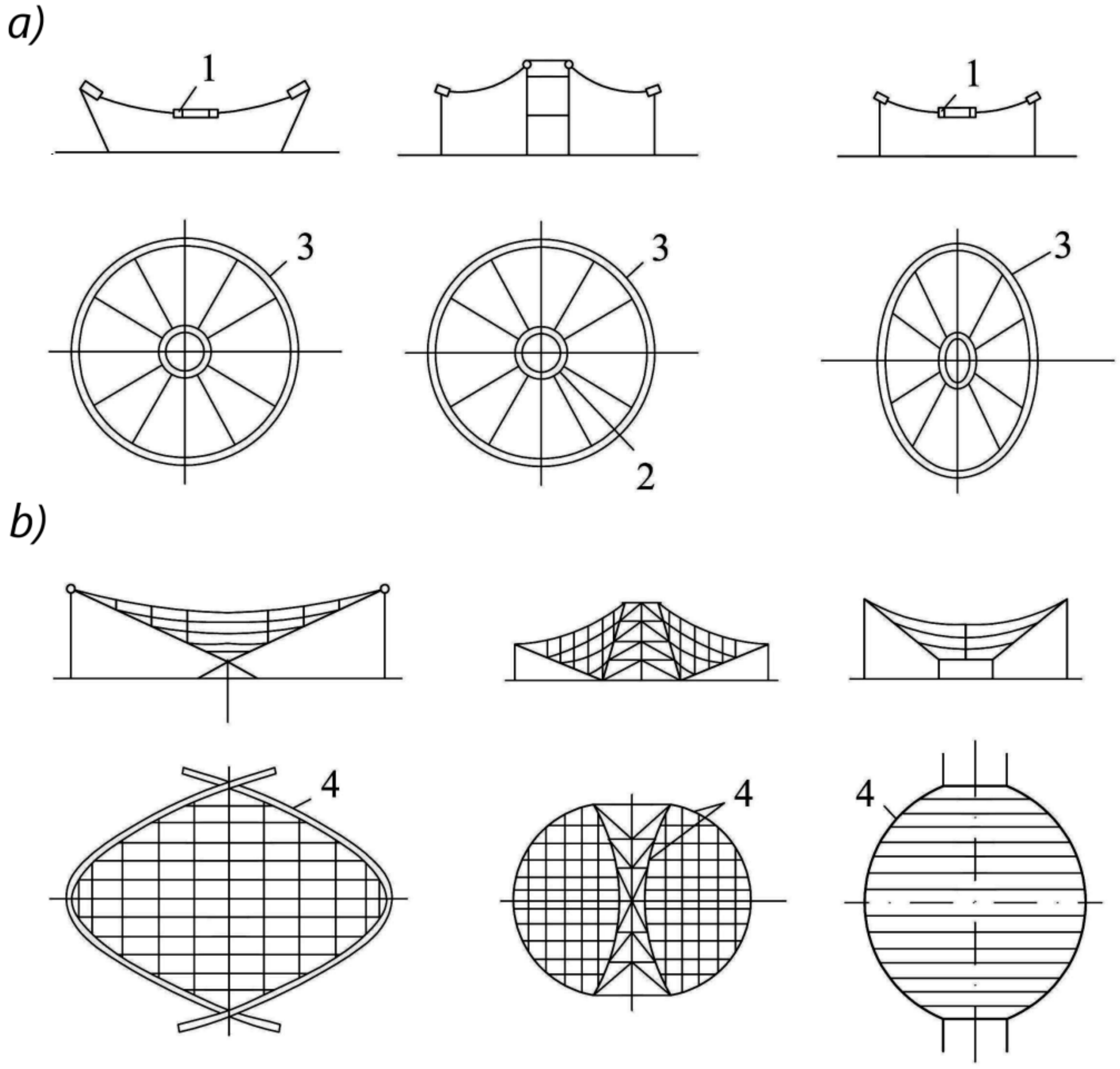


Fig. 12.4. Schemes of circular and arched support structures:
a – circular; *b* – arched; 1 – inner ring; 2 – inner support ring;
3 – external support ring; 4 – support arches

The guy cables are attached only at the points where the beams rest on the columns. Additionally, multiple guy cables can be anchored to a single foundation (Fig. 12.5, a). The thrust can be transferred through beams located in the plane of the roof to end diaphragms in the form of solid walls (Fig. 12.5, b). The thrust on diaphragms can also be transferred via curved walls (Fig. 12.5, c). If necessary for the building’s functionality (e.g., stadium stands), rigid frames can also be used to absorb the thrust forces (Fig. 12.5, d).

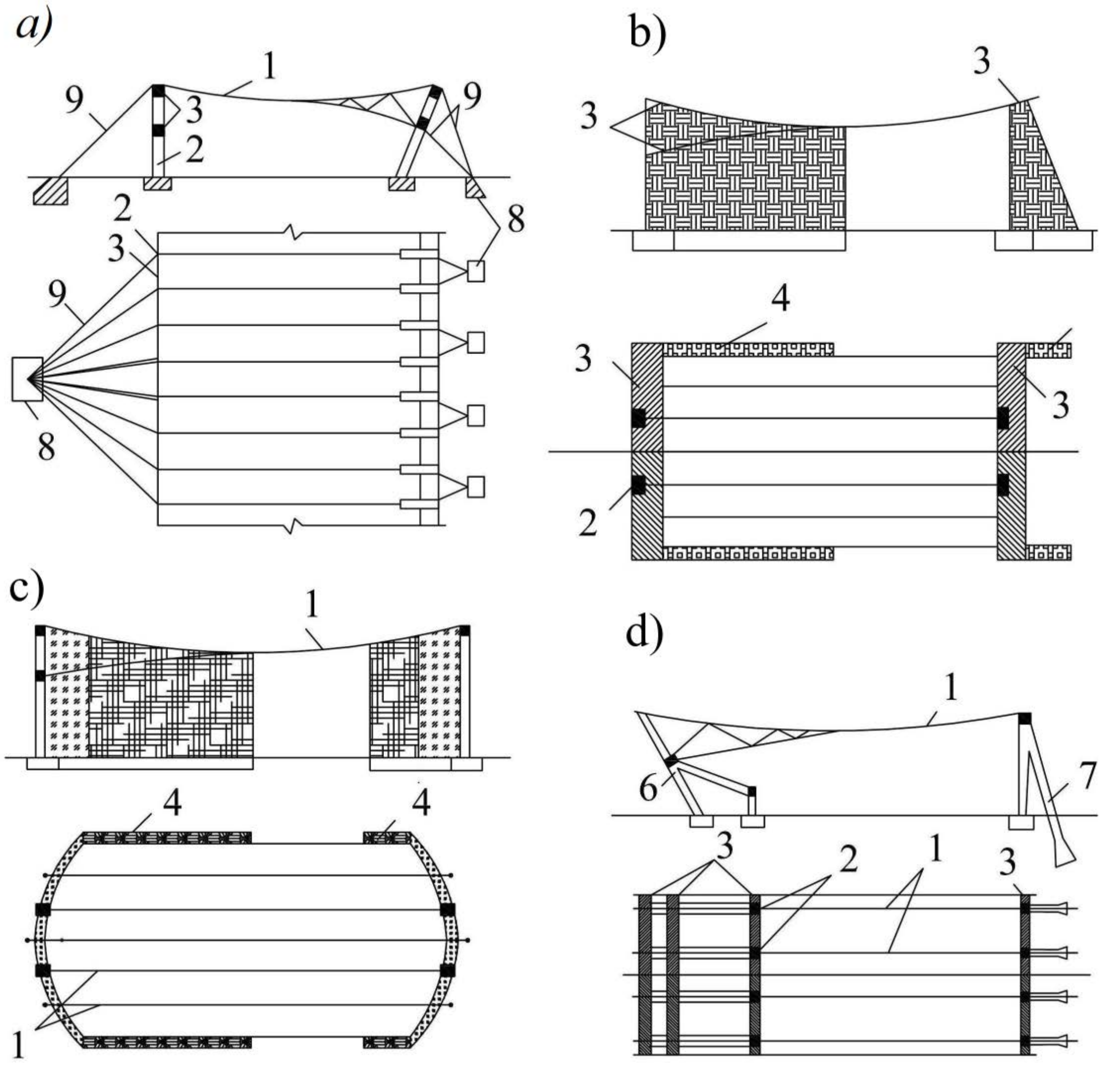


Fig. 12.5. Types of support structures:
a – with thrust transferred to guy cables;
b – with thrust transferred to end diaphragms; c – with thrust transferred to curved walls; d – with thrust transferred to frames.
1 – cables (cable trusses); 2 – columns; 3 – rigid beams; 4 – end diaphragms; 5 – buttresses; 6 – transverse frames; 7 – tensioned struts; 8 – anchor foundations; 9 – guy cables

12.3. Roofs Made of Cables and Beams

Such cable-stayed roof structures should be designed using a system of cables and beams (Fig. 12.6). At the intersections of beams and cables, they are connected to each other.

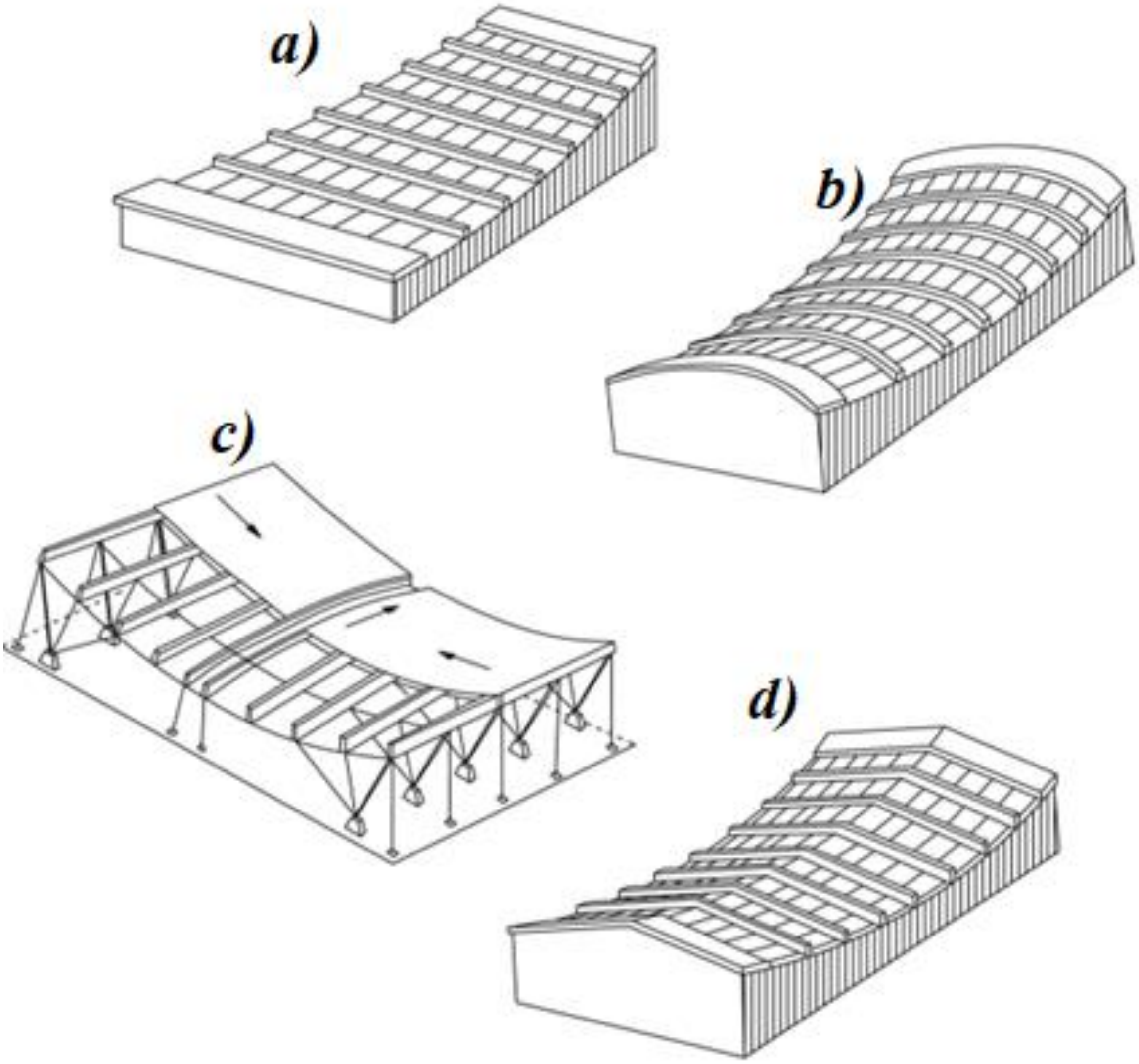


Fig. 12.6. Cable-beam roof system:

a – rectangular spans of 24–30 m;

b – with a curved closed contour, beam spans up to 48 m

c – cables are placed within the span$\left(\frac{1}{10}\dots\frac{1}{4}\right)$ range; d – beam height is from$\left(\frac{1}{20}\dots\frac{1}{4}\right)$

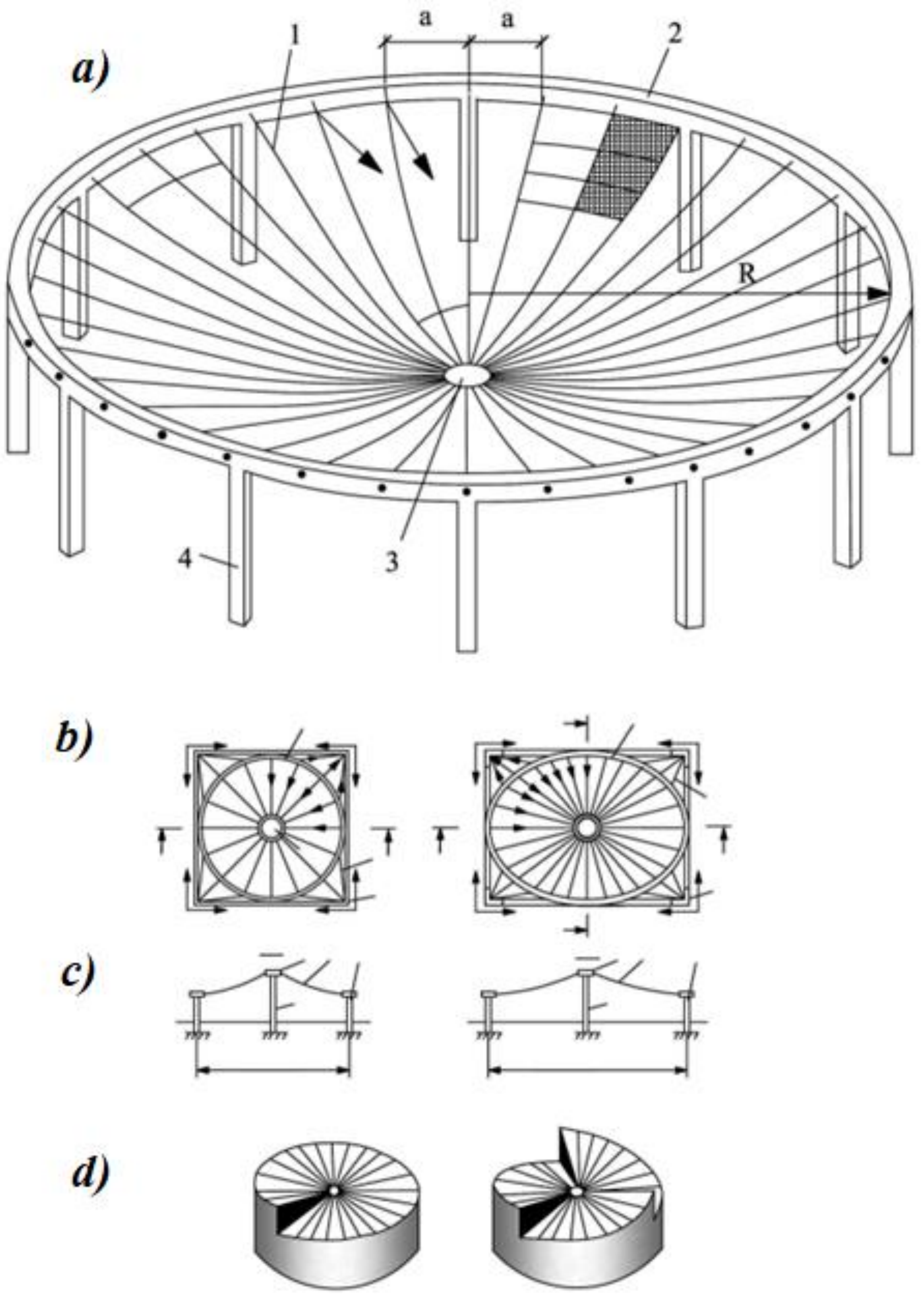


Fig. 12.7. Schemes of single-tier roofs with radial cables:
a – concave with a circular plan;
b, c – tent-like with square and rectangular plans;
d – spiral-shaped
1 – load-bearing cable; 2 – external compressed ring; 3 – internal tensioned ring; 4 – column; 5 – corner support; 6 – additional cable

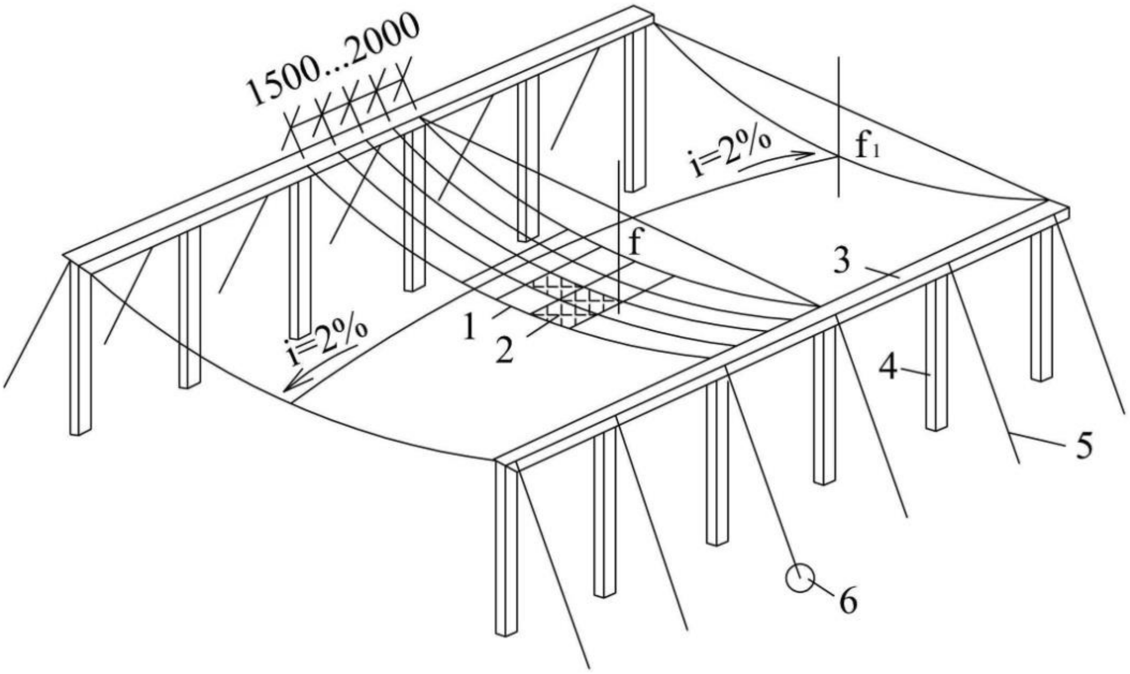


Fig. 12.8. Suspended roof of a building with rectangular chords:
f– sagging of the cable in the middle of the building;
f_1– same at the ends.
1 – load-bearing cables; 2 – roof slabs; 3 – edge element; 4 – column; 5 – guy cable; 6 – anchor foundation

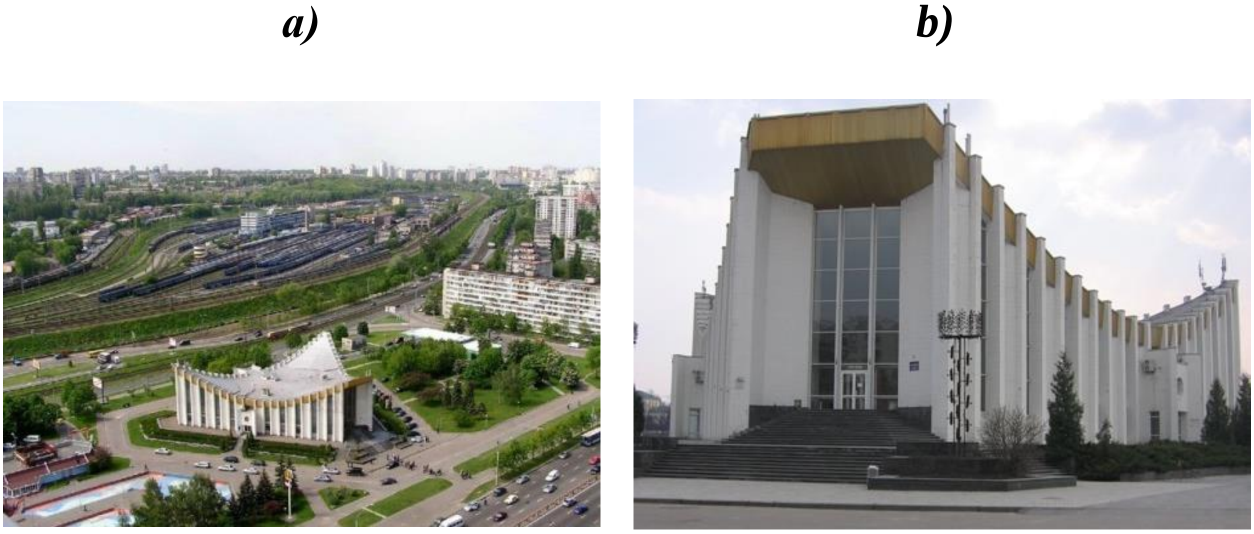


Fig. 12.9. Example of a building with a suspended shell roof of negative gaussian curvature**:**
Central Wedding Palace, Kyiv, 1980,
Kyivproekt, Architects: V.I. Hopkalo, V.M. Grechina,
Engineer: N.M. Yurchenko

Fig. 12.10. Example of a building with a suspended roof system for a hall with a diameter of 51.8 m and radially arranged cables: shopping mall in Pechersk, Kyiv, 1982, Architect: A.M. Anishchenko

Fig. 12.11. Example of a building with a suspended roof using rigid cables: Furniture Exhibition Store, Kyiv, 1975, Architects: N.B. Chmutina, Yu.A. Chekanyuk, Building dimensions: 63.0 × 63.0 m

Questions for Discussion and Self-Assessment for Chapter 12

1. What is cable-stayed roofs?
2. What structural elements make up a cable-stayed roof?
3. List the main advantages of cable-stayed roofing.
4. How are cable-stayed roofs classified by type of load-bearing structures?
5. How are cable-stayed roofs classified by surface shape?
6. How are cable-stayed roofs classified by stabilization method?
7. How are cable-stayed roofs classified by type of thrust distribution?
8. How are cable-stayed roofs classified by surface curvature?
9. How are cable-stayed roofs classified by type of load-bearing structures?
10. Provide an example of an end anchorage for cables made of steel ropes.
11. List the schemes of circular and arched support structures.
12. Provide an example of support structures for guy cables.
13. Provide an example of single-tier roof schemes with radial cables.

CHAPTER 13. FLEXIBLE SHELLS

13.1. Pneumatic Structures

Soft shells are a group of spatial structures made from materials that have high tensile strength but are not capable of resisting other types of stresses. Such materials (such as fabrics and films) are thinned to a degree that they cannot withstand compression, bending, or shear.

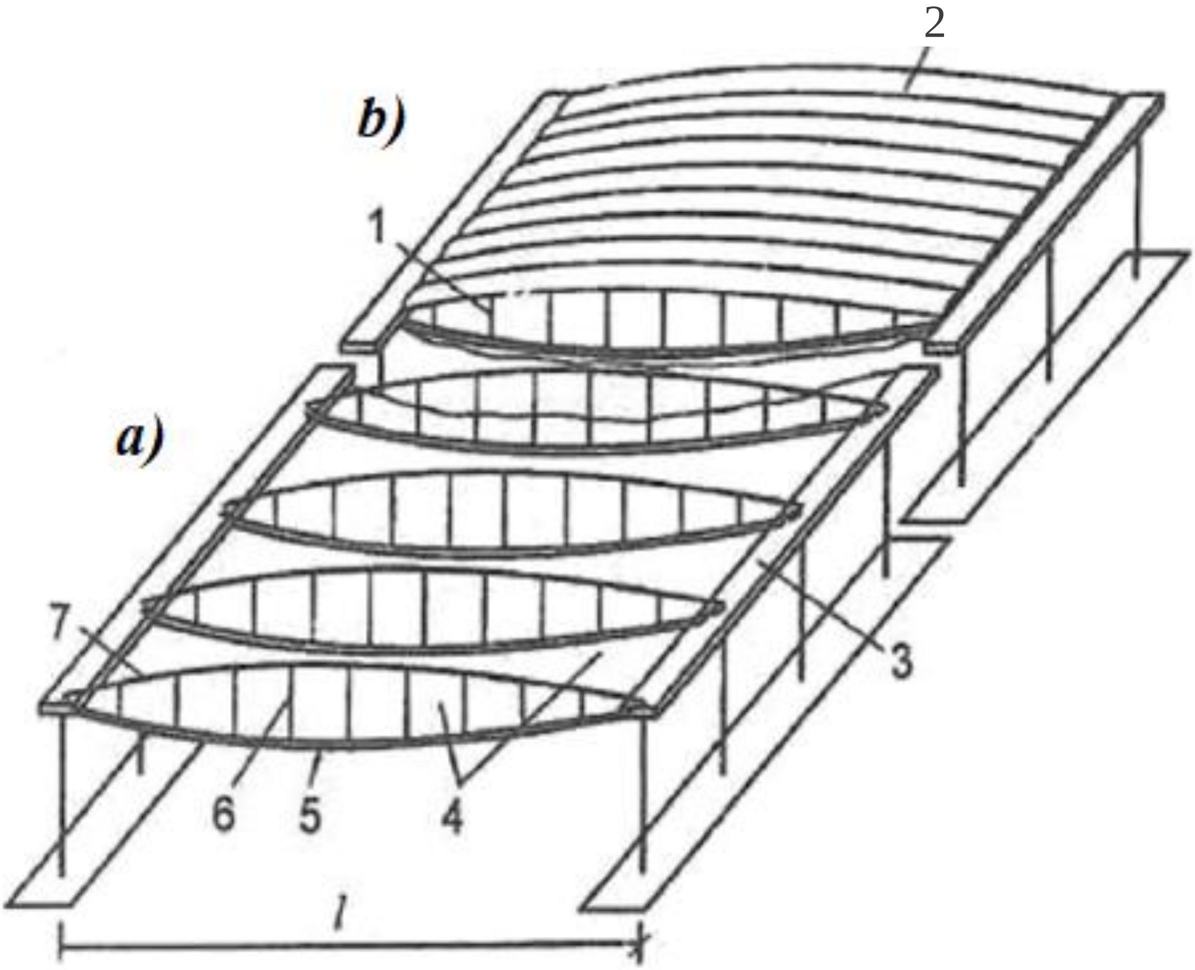


Fig. 13.1. Double-tier cylindrical shells on a rectangular plan:
a – membrane-arch roof; b – membrane-vault roof;
1 – columns; 2 – vault elements; 3 – support contour;
4 – membrane; 5 – reinforcing element; 6 – strut; 7 – arch

The ability of soft shells to carry loads arises from their pre-stressing, which is achieved through two main methods: aerostatic (pneumatic) and mechanical. According to the method of pre-stressing, shells are divided into pneumatic and tent structures.

Pneumatic construction structures are divided into two main types: those that resist air pressure and those that contain air (see table 13.1).

Structures that resist air pressure are buildings where the wall and roof parts are combined. After securing the shell's contour and filling it with air, these structures are ready for operation, which is supported by centrifugal or axial fans with operating pressures ranging from 400 to 1000 Pa. Continuous air supply eliminates the need for high-level sealing.

Structures that contain air consist of rod elements (columns, beams, arches, etc.) or panel elements.

The air pressure in their shells, ranging from 50 to 700 kPa, is generated by compressors during either single-time or periodic filling. This requires a high level of sealing in the shell.

The functional difference between structures that resist air pressure and those that contain air is that the former are operated under additional pressure, while the latter are operated under atmospheric pressure.

13.2. Pneumatic Lenses

Pneumatic lenses are a type of pneumatic structure that combines characteristics of the two previous types. In terms of static operation, they resist air pressure, and in terms of function, they serve as a structural element, such as a roof or wall panel.

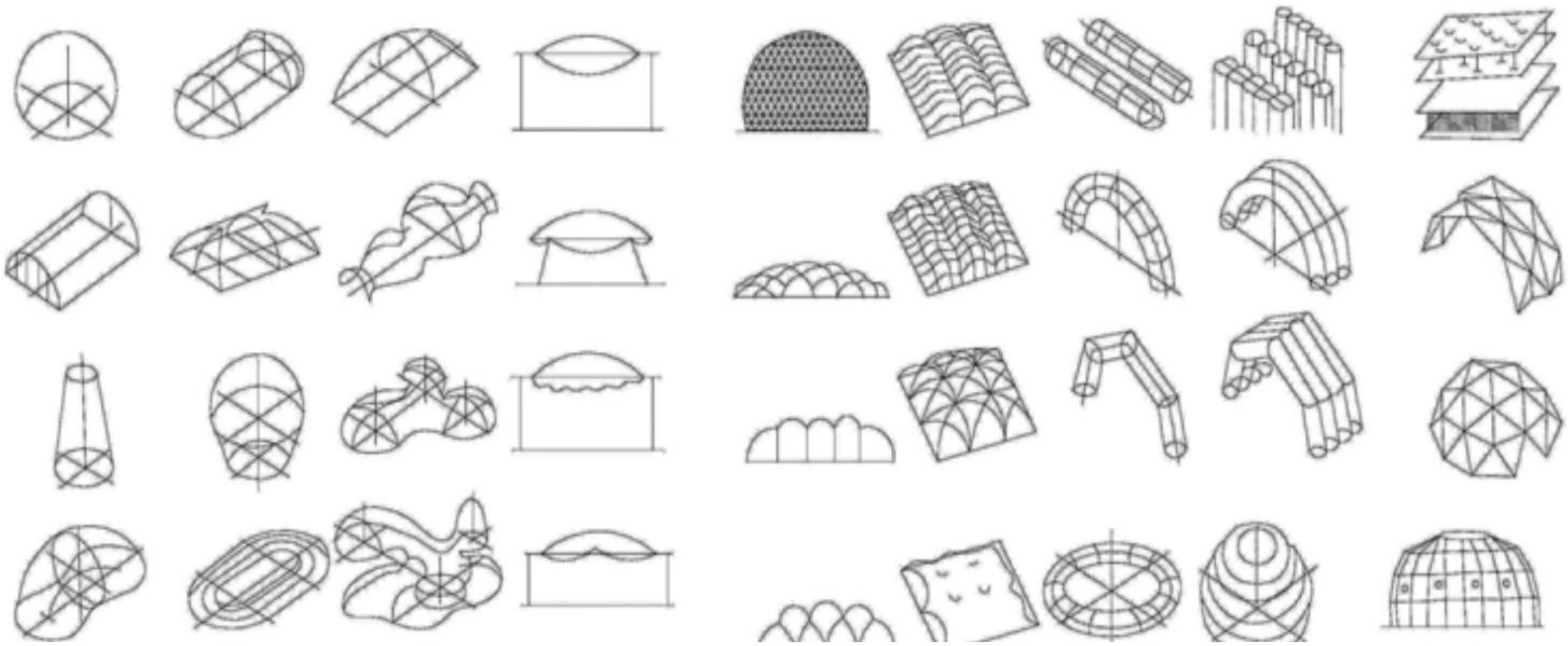
Materials. For soft shells, materials such as fabrics, reinforced films, homogeneous films, and thin steel sheets are used.

Key requirements for soft shell materials:

– tensile strength – the material must be strong under tension to maintain the structural integrity of the soft shell;

Table 13.1 Classification of Pneumatic Structures

Air-supported structures						Air-inflated structures		
Geometric shape			Lenses (cushions)	Reinforced with cables or meshes		Struts	Panels	
Simple	Composite	Complex		Single-span	Multi-span		Orthotropic	Isotropic



– tensile strength under excessive stretching and after local ruptures appear;

– water and air impermeability;

– durability;

– resistance to atmospheric influences and mechanical damage;

– light transmittance of fabrics (up to 5% for reinforcing films, up to 90% for fabrics);

– fire resistance;

– ease of joining fabric (sewing, electric welding, gluing).

When choosing materials, it is important to consider changes in their physical and mechanical properties due to aging, creep, and fatigue.

Aging is caused by the combined action of heat, moisture, ozone, and ultraviolet rays from sunlight. The more transparent the fabric cover, the more intense the aging process.

Creep is the gradual accumulation of deformation under the influence of prolonged loads, leading to strength loss. It is evaluated by the long-term resistance coefficient.

Fatigue refers to the phenomenon of repeated increases and decreases in tensile forces in soft shell materials, which is not yet fully studied.

For high-pressure pneumatic arches, the material used is sealed, single-piece fabric sleeves with diameters ranging from 200 to 900 mm, featuring an inner airtight layer (rubber chamber or coating). The fabric of the sleeves, made from nylon fibers, has high tensile strength, elasticity, and resistance to external influences.

Thin steel sheets made from stainless steel or aluminum alloys used for soft shells have advantages: high strength, durability, and air impermeability. However, they also have certain disadvantages, such as the lack of "softness" in the pre-operational process (manufacturing, transportation, installation, and difficulties in joining thin sheets).

13.3. Pneumatic Structures with Air-Supported Roofs

The main structural elements of such buildings include the shell, supporting structure, and air supply system (see Fig. 13.2).

Assembled shells are a combination of connected shell fragments of rotation (see Fig. 13.3).

The forms of assembled shells are not ideal for pneumatic structures, as the condition for the compatibility of stresses and deformations is not fulfilled along the line of their connection. The most characteristic load for pneumatic structures is the excess air pressure. The pressure level must be such that the stress generated in the shell completely or partially counteracts the compressive forces within the shell, which are created by the action of the structure's own weight and external loads (such as snow, wind, and technological loads).

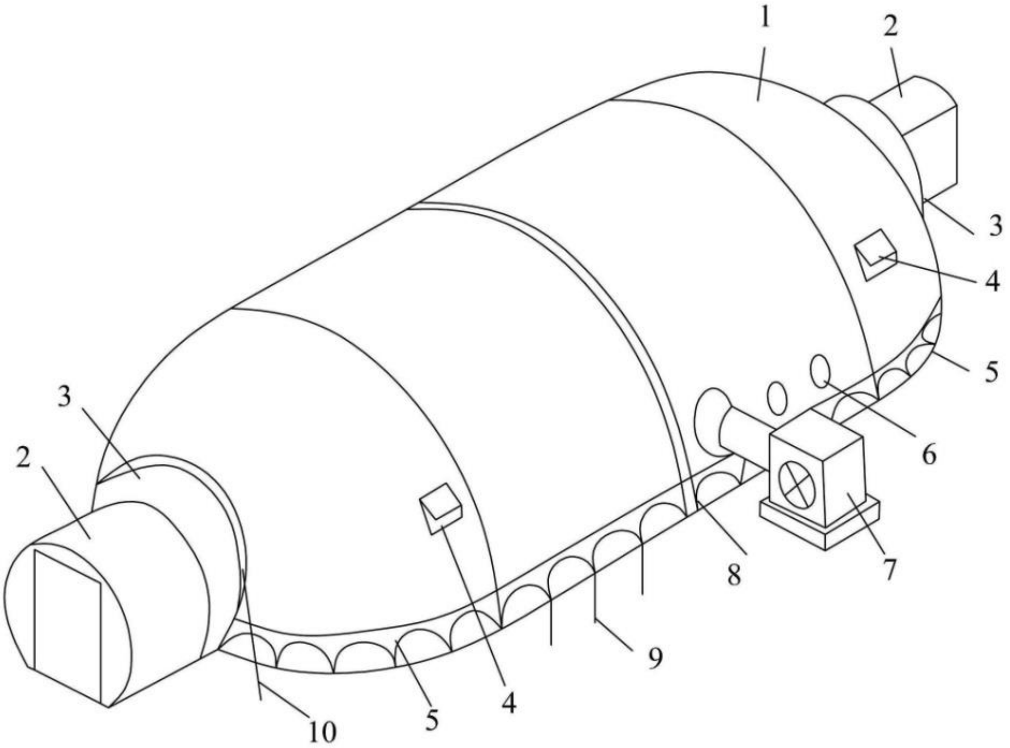


Fig. 13.2. Air-support shells:

1 – shell; 2 – gate tent; 3 – adapter; 4 – vent valve; 5 – power belt; 6 – soft air inlet pipe; 7 – air supply unit; 8 – installation seam; 9 – screw anchor; 10 – unloading cable

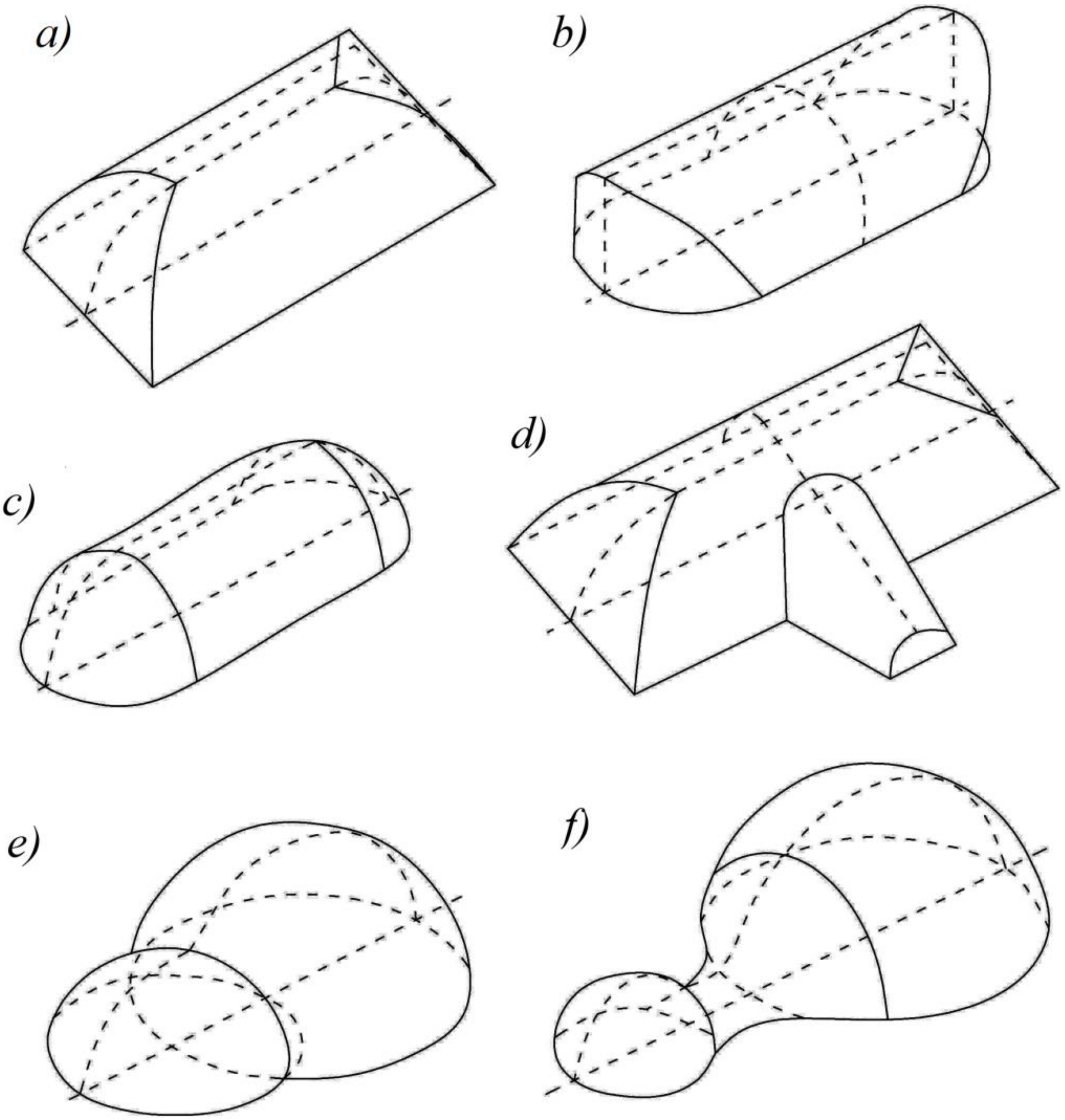


Fig. 13.3. Composite air-resistant shells:

a, b – cylinder-cylinder; c – cylinder-sphere;
d – cylinder-cylinder-cone; e – sphere-sphere;
f – sphere-hyper-sphere.

The own weight of the shells is small and is balanced by an air pressure of 10-20 Pa. In calculations, it is not considered, or if it is, it is accounted together with the snow load.

The snow load is significantly less (than according to Building Code) on the smooth surface of the structure's cover, so snow does not accumulate.

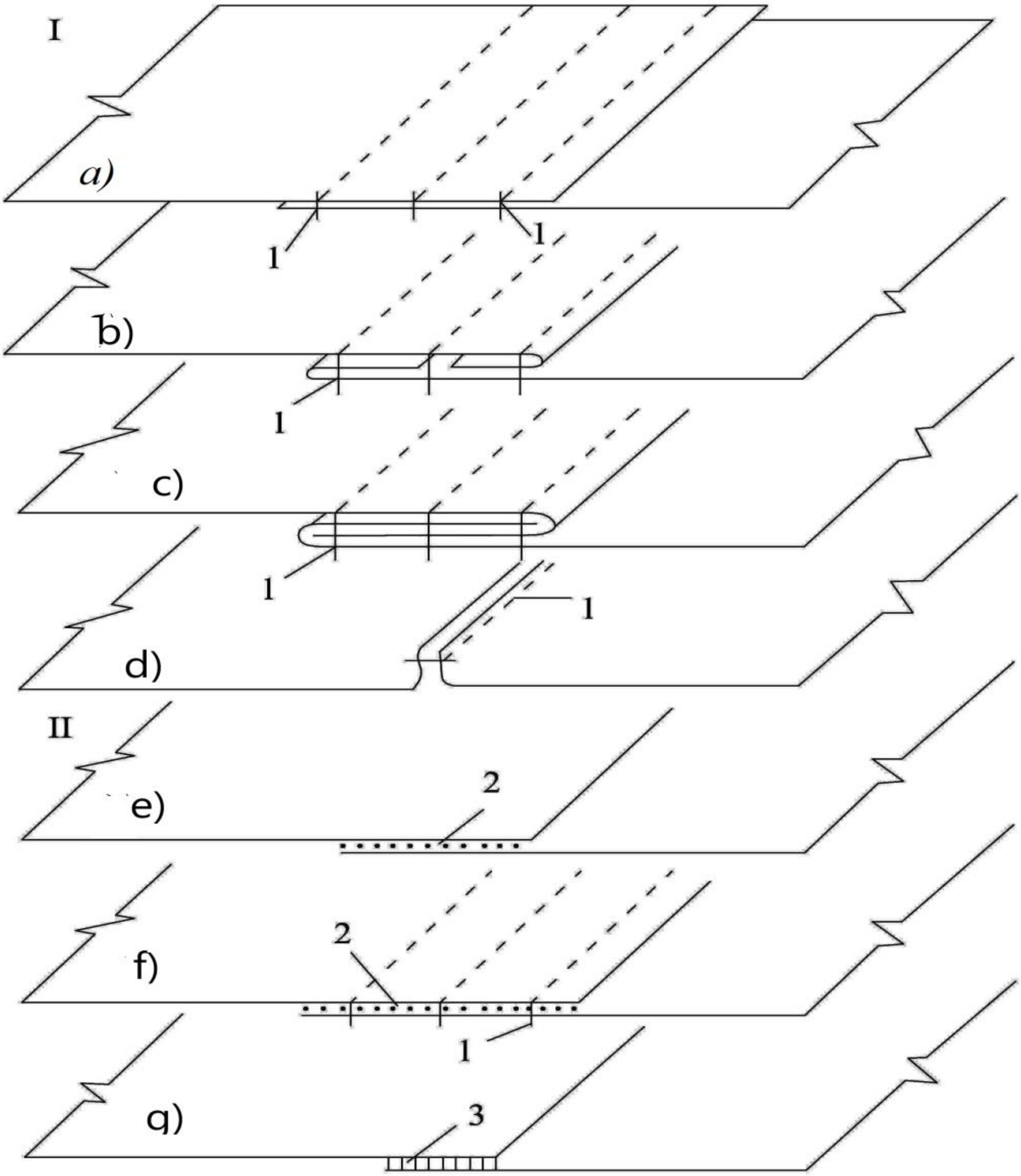


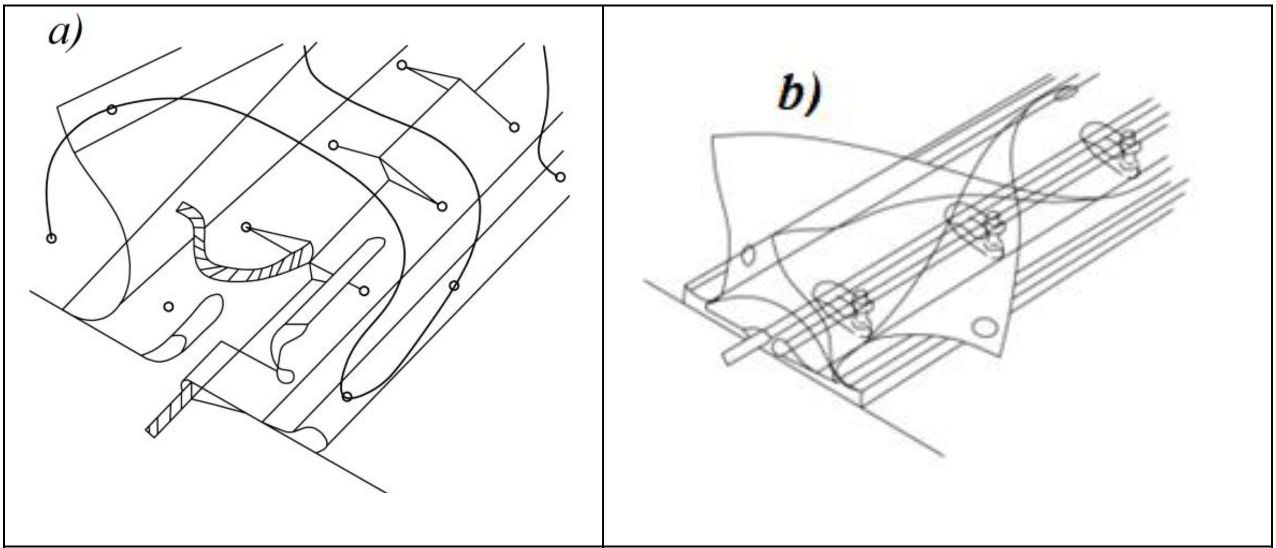
Fig. 13.4. Factory joints: I – sewn joints; II – glued joints;

a – overlapping joints; b – overlapping joints with closed edges; c – interlocking joints; d – straight stitched joints; e – overlapping joints; f – glued-and-sewn joints; g – welded joints;
1 – sewn joint; 2 – glued joint; 3 – welded joint

Wind load is the primary type of load for air-supported membranes [10]. The most dangerous situation for these membranes occurs when there is insufficient air pressure beneath them [30], which can lead to failure. The connection of fabric sheets and membrane sections can be divided into two types of joints: factory seams and assembly joints.

Factory joints can be welded, sewn, glued, or combined (Fig. 13.4). Their strength does not reach the strength of the material itself and amounts to 60-80%.

Assembly joints (Fig. 13.5), compared to factory joints, are more complex and have lower strength. Whenever possible, they should be avoided, and if necessary, placed in areas with the lowest stresses. Assembly joints are sealed with flaps, secured with cord stitching or fasteners.



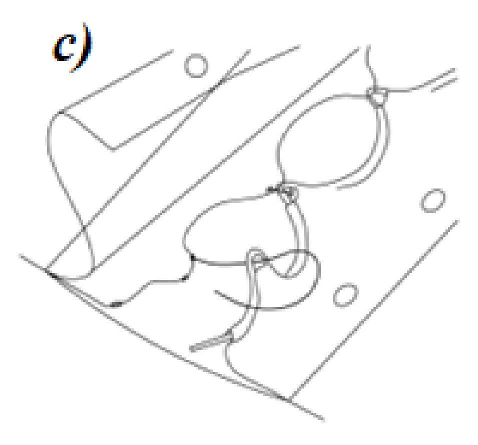


Fig. 13.5. Assembly joints:
a – double edge joint;
b – clamp joint;
c – boat joint

13.4. Supporting Devices

Negative support reactions of the shell, which arise along the support contour due to the internal air pressure, are counteracted by the force of massive foundations or the resistance forces of anchor rods, screw piles, and other elements.

Support devices are designed to withstand the forces that occur along the shell contour (Fig. 13.6).

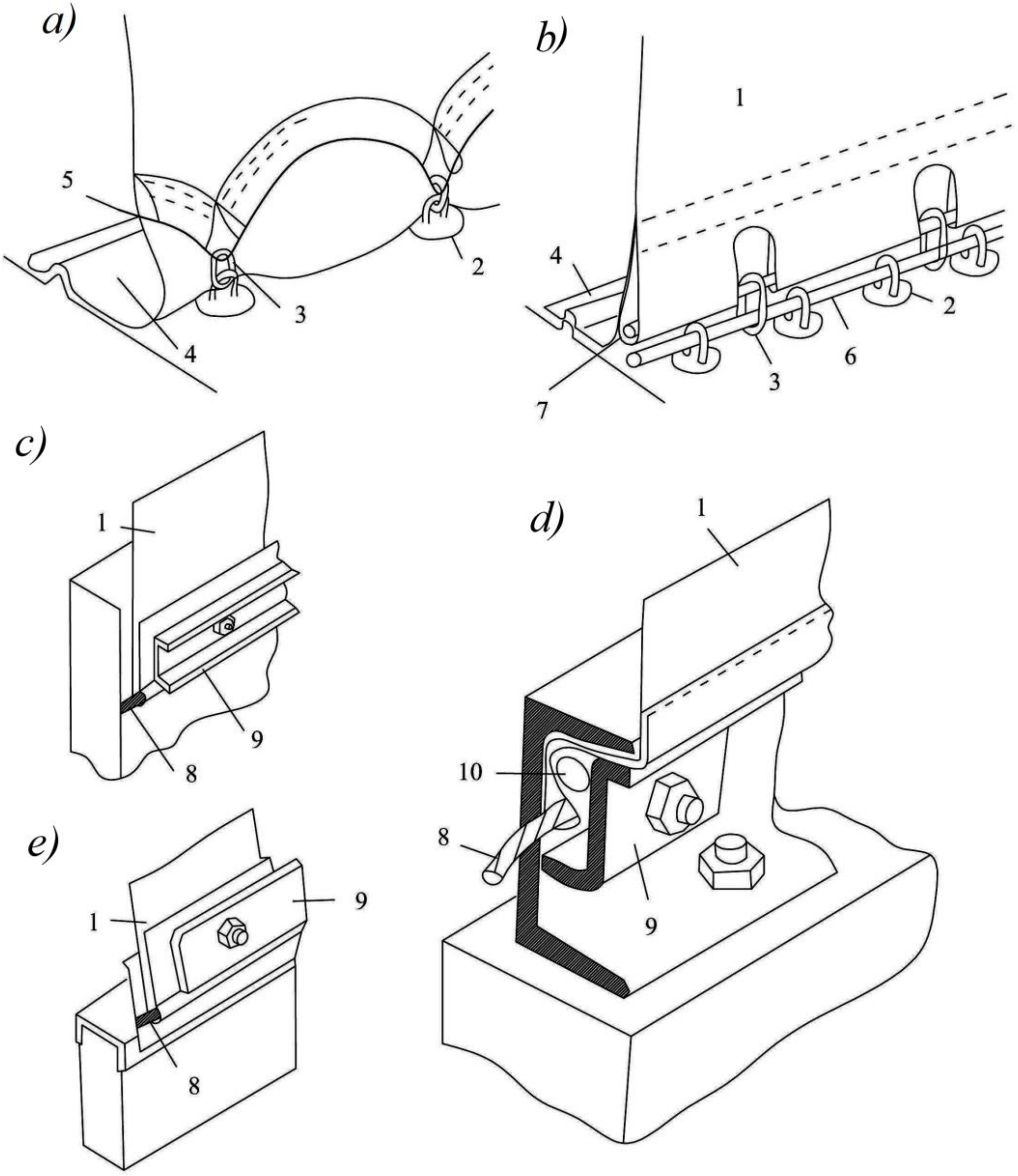


Fig. 13.6. Fastening of the shell support contour:
a, b – to screw piles; c, d – to strip foundations;
1 – shell; 2 – anchor; 3 – connecting element;
4 – inner (sealing) apron; 5 – boat rope;
6 – lower pipe; 7 – upper pipe;
8 – edge rope; 9 – overlay; 10 – rod

To transfer anchor forces into the shell, boat chords and edge chords are used (Fig. 13.6, a, b). When connecting the shell to a continuous (strip) structural chord, the folded shell edge is reinforced with a rope threaded through it (Fig. 13.6, c–d).

Structural connections to the shell can be either point or linear. Point connections should be avoided in pneumatic structures. Linear connections are necessary when using diaphragms and when reinforcing ropes are placed under the shell.

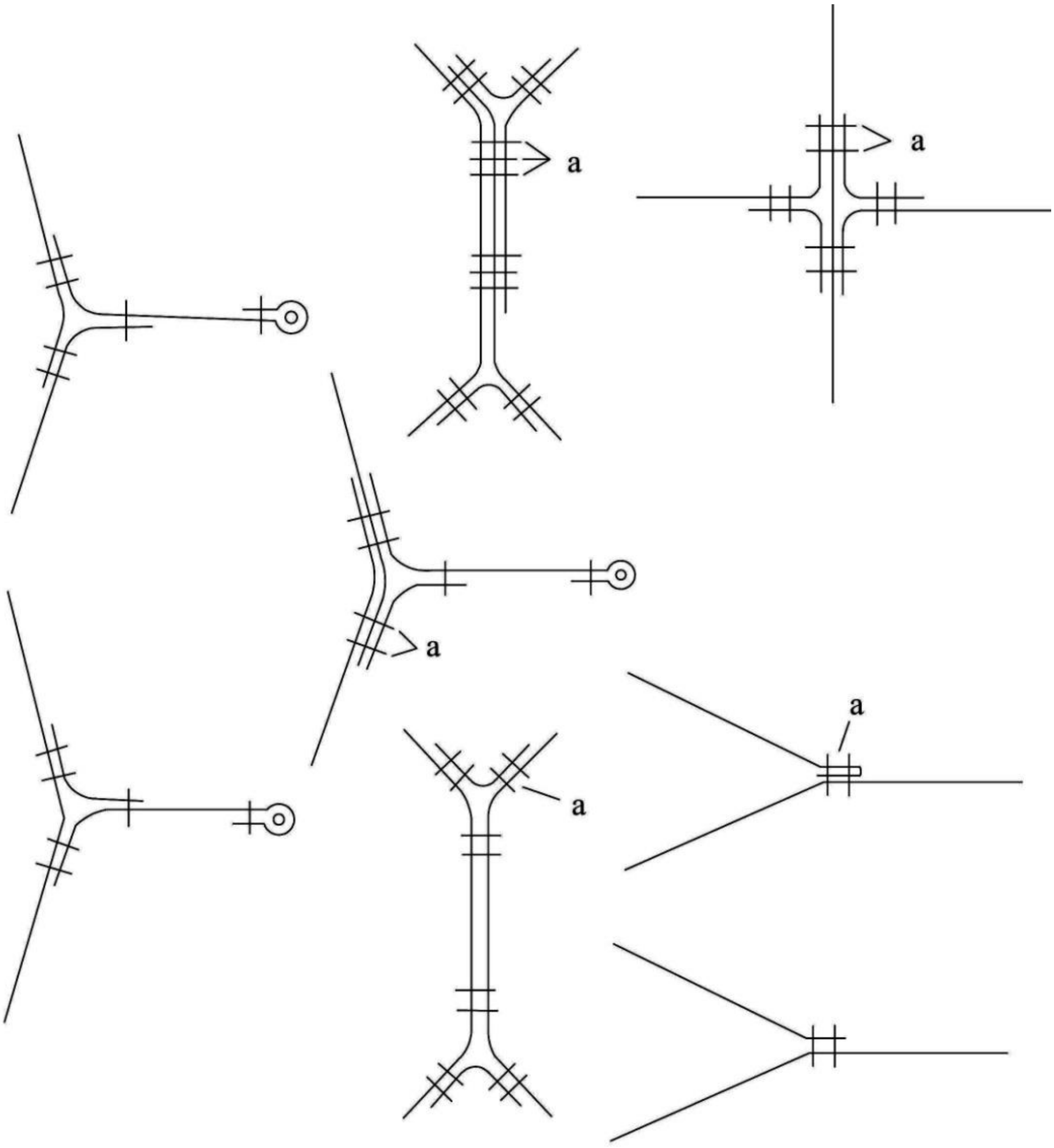


Fig. 13.7. Arrangement of soft-shell connection nodes

13.5. Pneumatic Shells Reinforced with Cables and Mesh

Cables bear the primary loads, while the shell functions as a membrane within the area framed by the cables (Fig. 13.8). The combined performance of the shell and cables is possible if their tensile stiffness is approximately equal.

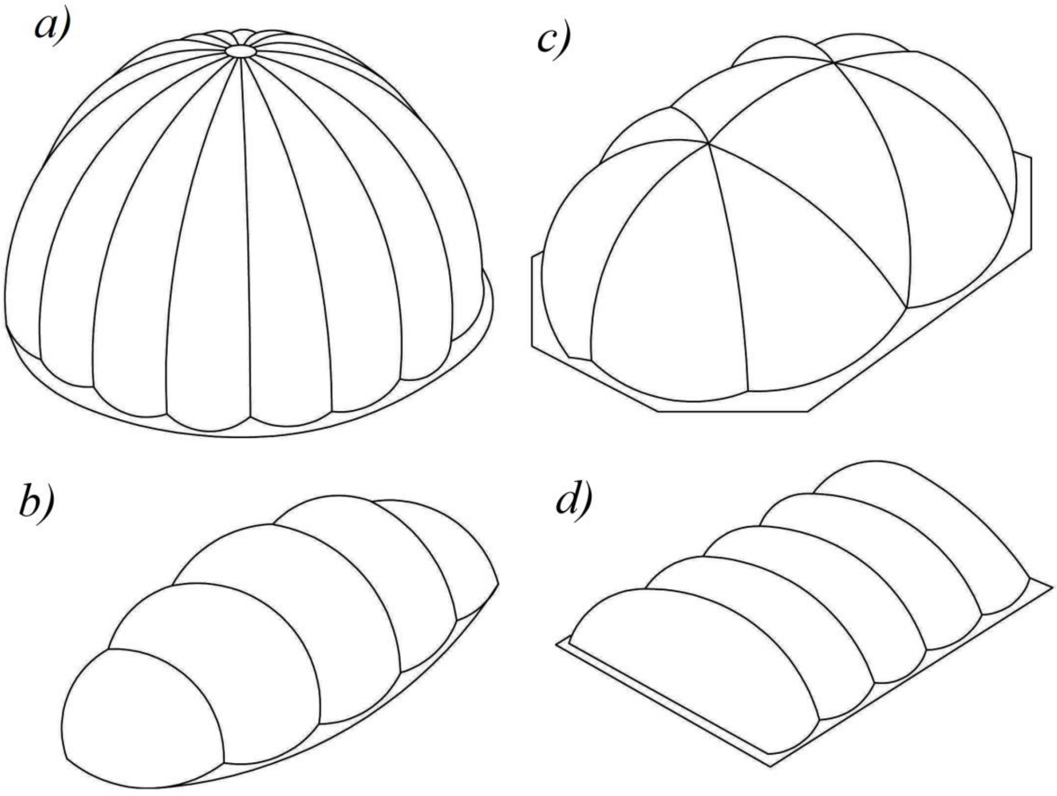


Fig. 13.8. Shells reinforced with cables and nets in plans**:**
a – circular; b – elliptical; c – polygonal; d – rectangular

Three groups of reinforced pneumatic shells are used:

1. **First group** – used with a fine mesh, where the shape of the structure is determined by the mesh layout. The thin shell has low strength and serves only to ensure air tightness.
2. **Second group** – used with a small (up to 1 m) spacing of cables, where the overall surface of the structure is designed to be smooth. Local curvatures of the shell between the cables arise due to the elastic deformations of the material. The cables are not attached to the shell, allowing free mutual movement.

3. **Third group** – used with a large (several meters) spacing of cables, where the overall surface of the structure is divided into curvatures by the cables. Specially cut sections of the shell are designed to fit these curvatures.

Shallow shells with large spans on oval and rectangular plans are designed with an elevation $\left(\frac{1}{7}\dots\frac{1}{12}\right)$ of the span (see Fig. 13.9). The cables are arranged parallel to the diagonals of the plan with a spacing of 6–12 meters.

The support ring is positioned in such a way that, in the event of a drop in air pressure under the shell, the shell does not reach within 2–3 meters of the floor.

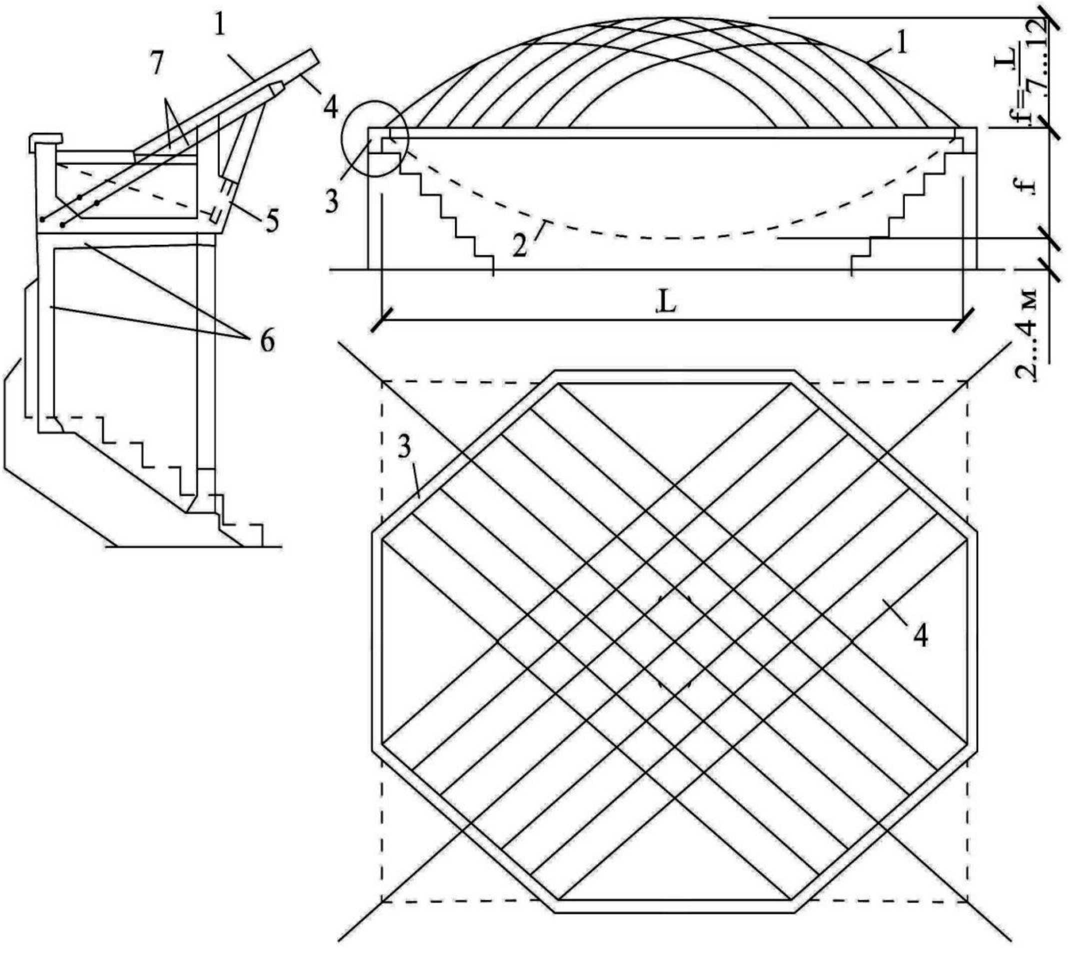


Fig. 13.9. Shallow shell resisting air pressure and reinforced with crossed cables:
1 – shell layout during operation; 2 – sagged shell line;
3 – support contour; 4 – cables; 5 – beam;
6 – metal frame; 7 – cable anchoring elements

13.6. Pneumatic Structures Supported by Air

Pneumatic structures supported by air include flexible shells whose load-bearing capacity is ensured by prestressing created by air pressure within the enclosed volume of individual elements. These structures consist of components such as struts, beams, arches, and frames (Fig. 13.10), as well as vault and dome panels.

Pneumatic arches are classified into two types: low-pressure and high-pressure. Low-pressure arches (40–100 kPa) are constructed as a series of short cylindrical shells made from roll materials. The cross-sectional diameter of the arch $\left(\frac{1}{6}\dots\frac{1}{10}\right)$ corresponds to the radius of curvature of the axis.

High-pressure arches (up to 700 kPa) are made from rubberized or fabric-reinforced tubes with internal chambers. The cross-sectional diameter is typically within the range of $\left(\frac{1}{25}\dots\frac{1}{35}\right)$ ...the radius of curvature of the axis.

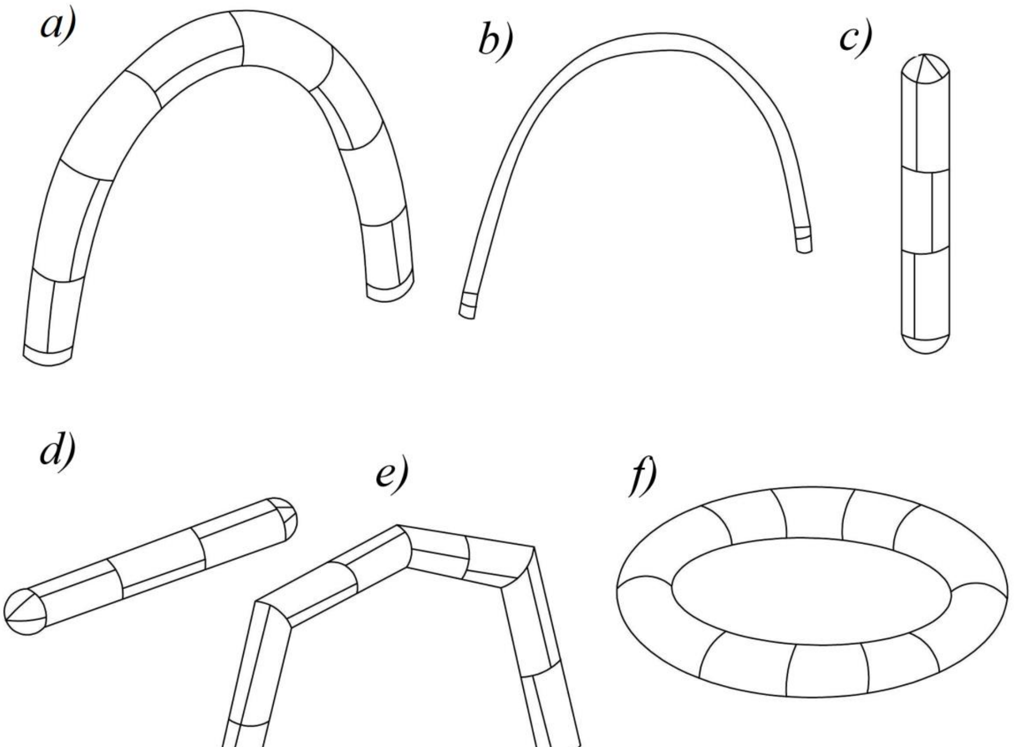


Fig. 13.10. Pneumatic rod structures:
a – low-pressure arch; b – high-pressure arch;
c – strut; d – beam; e – frame; f – ring (torus)

Pneumatic arches are used as load-bearing elements in the spatial framework of vaults or tent structures (Fig. 13.11).

Pneumatic panels are structures consisting of two fabric layers connected by linear or point stitches, forming vault or dome coverings. Pneumatic panels can be classified as orthotropic or isotropic (Fig. 13.12).

Orthotropic panels (Fig. 13.12, a–d) are made from shell materials that resist air pressure. Isotropic panels consist of two fabric layers connected by threads (2–15 per cm²) (Fig. 13.12, e, f, g).

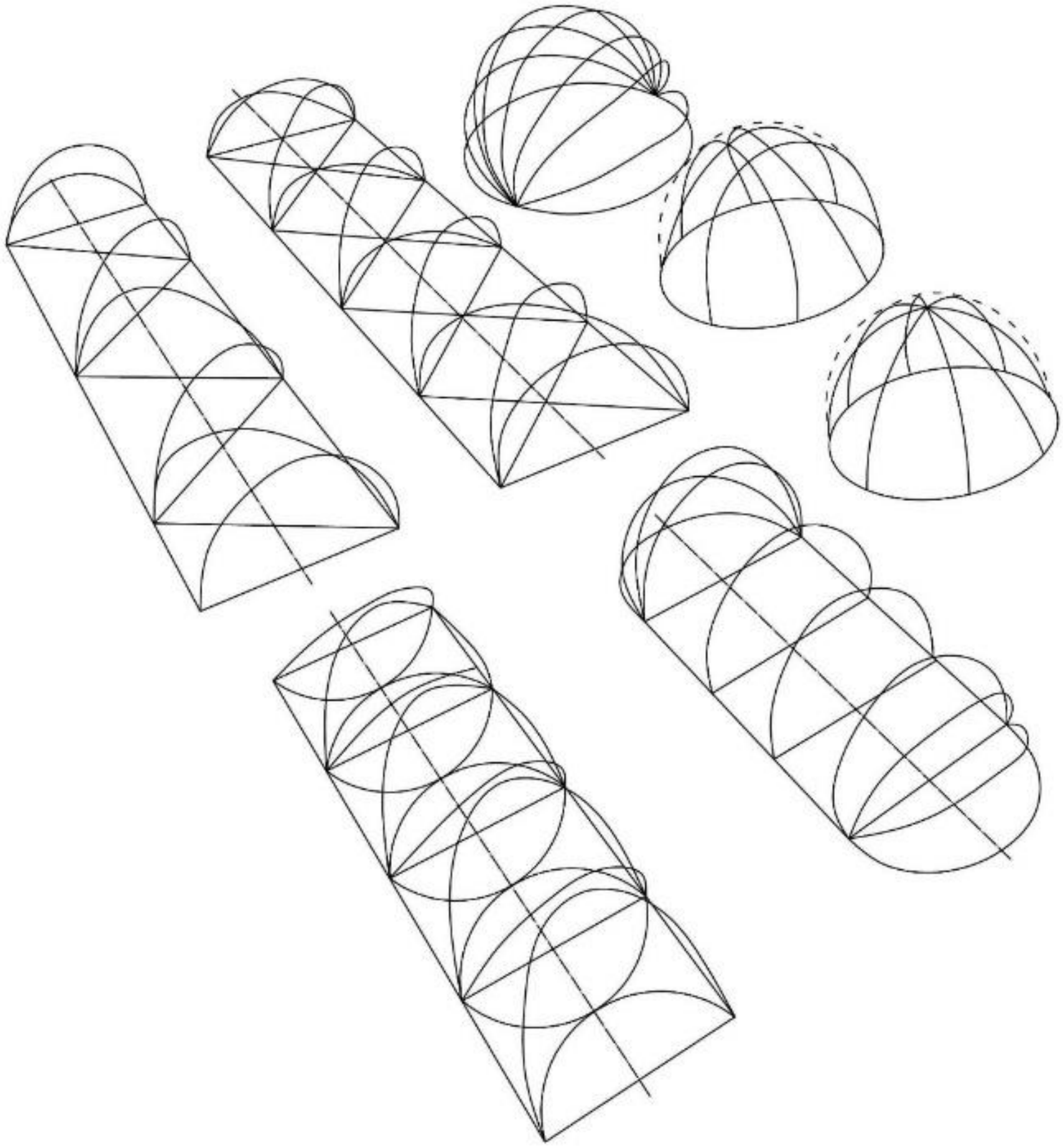


Fig. 13.11. Variants of dome and vault frameworks made from pneumatic shells

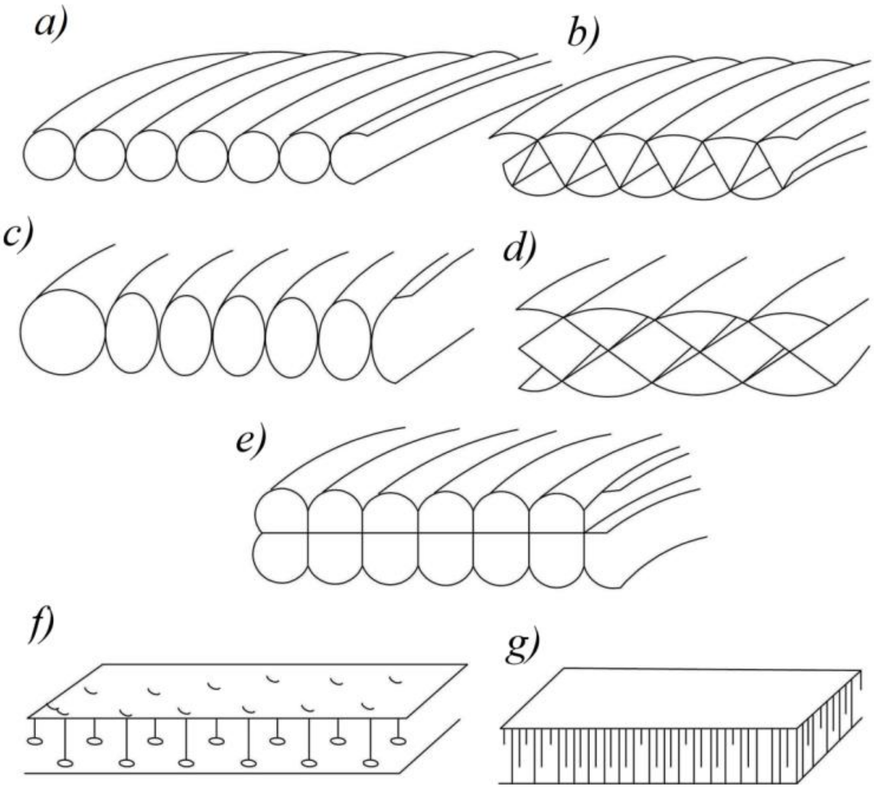


Fig. 13.12. Pneumatic panels:
a – d – orthotropic; e – g – isotropic

Tent coverings in construction are used for spans of no more than 30 meters.

A tent covering is a prestressed structure. The tensioning of the tent membrane is carried out mechanically by pulling the corners, raising the support columns, stretching intermediate points of the tent to the ground or upwards, curving the rigid support contour, and other methods.

The shape of the tent surface must meet two main requirements:

1- ensuring an even distribution of tension across the entire membrane surface.

2- achieving a "rigid form" after the membrane has been prestressed.

The rigidity of the surface shape, mainly with negative Gaussian curvature, is characterized by the fact that the centers of its principal curvatures are located on opposite sides of the surface, and therefore, the radius have different signs. The principle of shaping tent membranes is implemented in two cases:

- The initial conditions define only the membrane's contour.
- The initial conditions, in addition to the contour, also define the position of certain internal points.

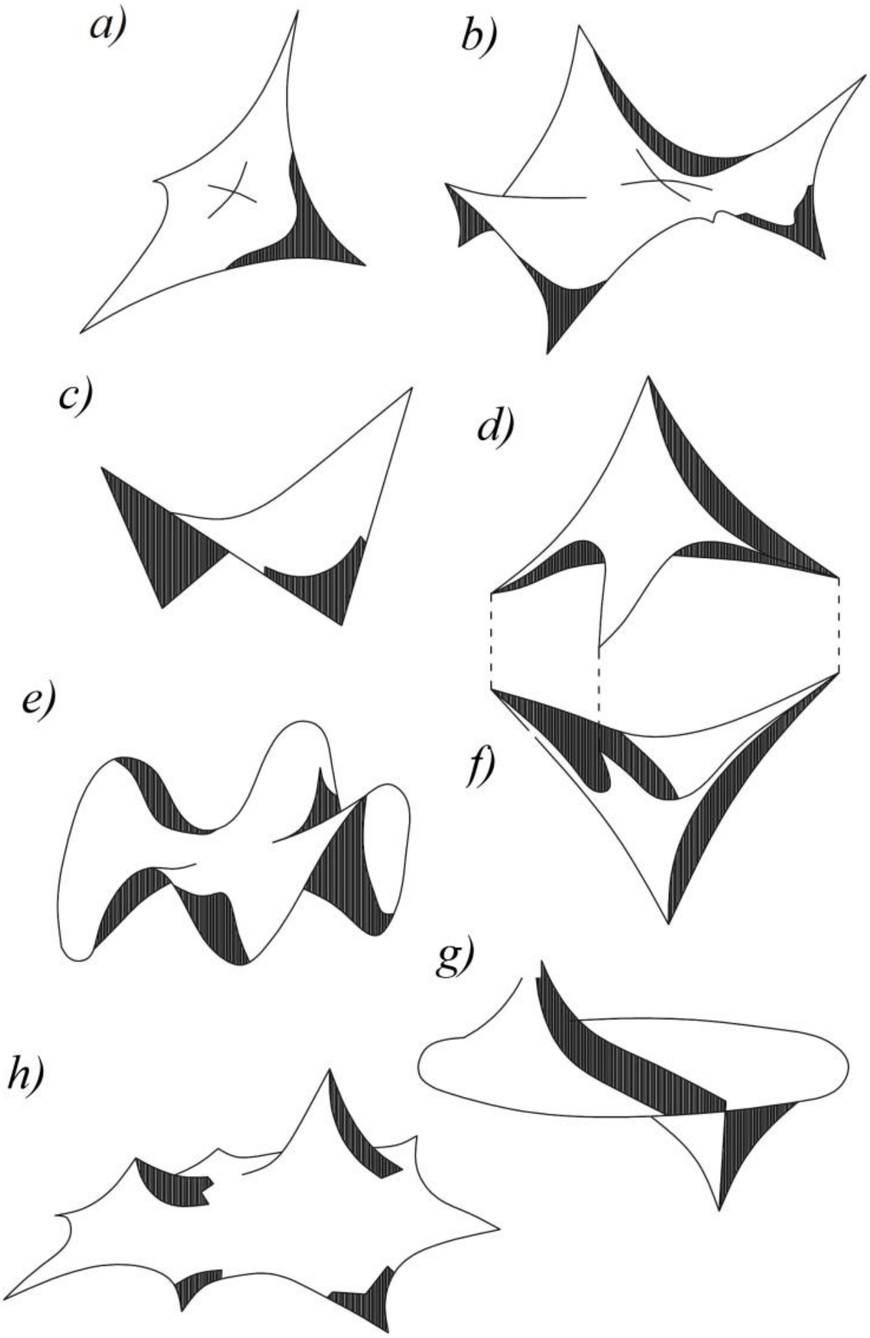


Fig. 13.13. Methods of forming a stable shape of tent membranes: a – fixing the contour at four points; b – the same, at multiple points; c – fixing on a rigid non-flat contour; d – the same, on a curvilinear contour; e – raising inner contour points to the contour plane upwards; f – the same, downwards; g – the same, in one direction; h – the same, in different directions

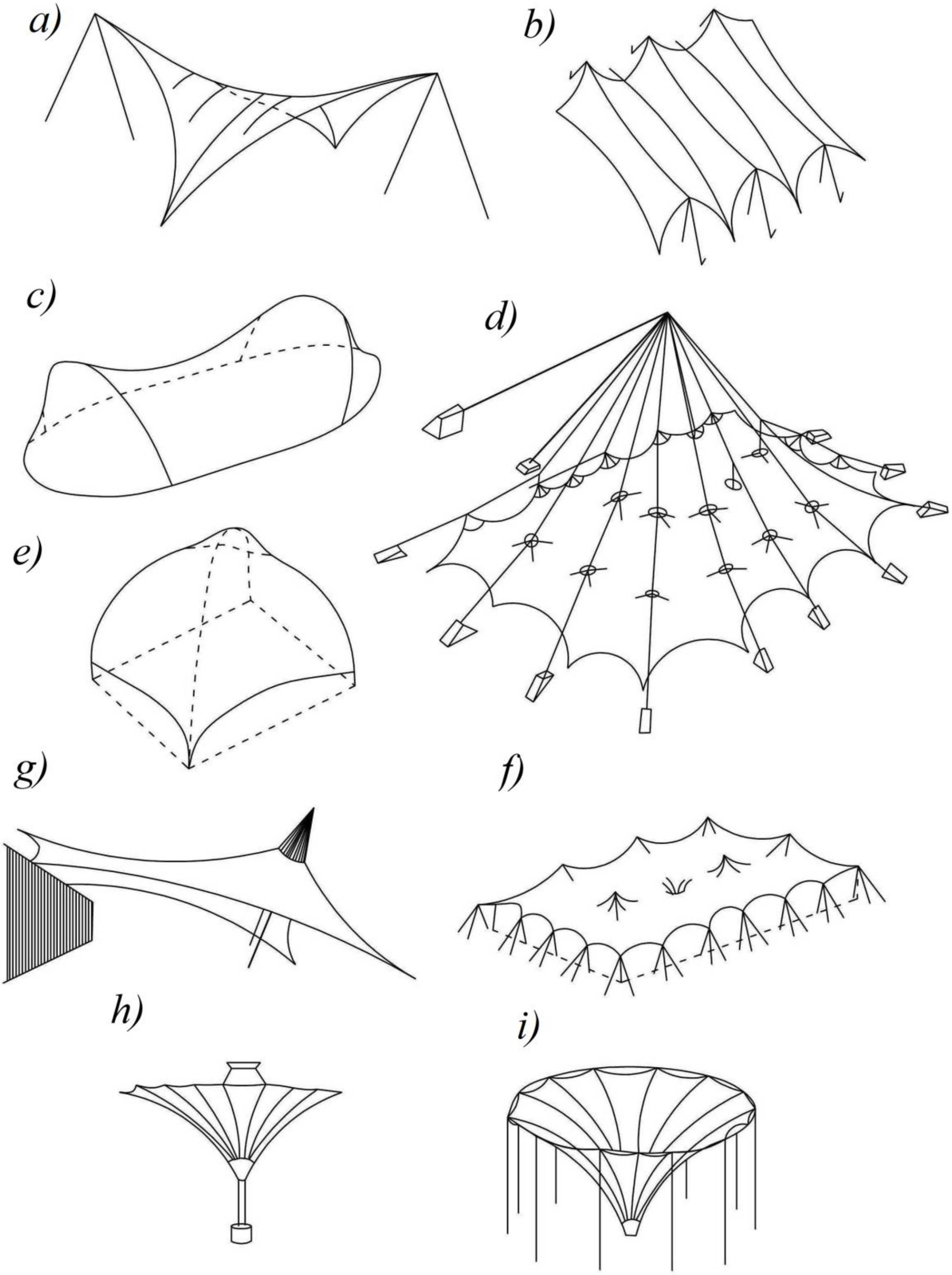


Fig. 13.14. Examples of design decisions tent coverings

Structurally, this is achieved in four ways (two for the first case and two for the second case).

The first method involves shaping the membrane by securing specific contour points at different levels (Fig. 13.13, a, b) when using a flexible contour.

The second method consists of fixing the membrane onto a curvilinear or rigid-bent, non-flat contour (Fig. 13.13, c, d).

The third and fourth methods ensure the stability of the tent's shape by displacing internal contour points from the imaginary plane defined by the fixed contour points.

Within a single membrane, both methods can be implemented simultaneously (Fig. 13.13, e–h).

Examples of tent coverings based on the method of forming a stable shape are shown in Fig. 13.14.

Questions for Discussion and Self-Assessment for Chapter 13

1. Characterize the principles of operation of pneumatic structures resisting air pressure. Provide an appropriate example.
2. How are pneumatic structures classified?
3. Justify the concept of "pneumatic lenses." Describe their static behavior and material requirements.
4. Define and provide an example of composite shells.
5. What loads are considered in the calculations of air-supported structures?
6. Provide an example of factory seams used for connecting pneumatic structures.
7. Provide an example of assembly joint connections in pneumatic structures.
8. Provide an example of fixing the support contour for pneumatic structures.
9. Provide an example of the placement of connection nodes in flexible membranes**.**
10. Define shells reinforced with ropes and nets. Into what groups are they divided?

11. Provide an example of shallow shells resistant to air, reinforced with cross ropes.

12. Define pneumatic structures that support air and provide an example.

13. Provide examples of dome and vault frame options made from pneumatic shells.

14. Justify the concept of "pneumatic panels." Provide a classification and describe their differences.

15. Justify the concept of "tent covering." List the requirements they must meet.

16. Provide examples of structural decisions for tent coverings.

17. Describe the methods of forming tent shells.

TERMS AND DEFINITIONS

The textbook uses terms established in the listed regulatory documents and structural elements of buildings:

Flying Buttress – An external supporting stone arch that transfers the thrust of a vault to external supports called buttresses. It is a characteristic element of Gothic architecture.

Bus Terminal, Automobile Station – A complex of buildings and structures designed to serve passengers at major transport hubs. The bus terminal building includes ticket offices, passenger waiting areas, a dispatch center, luggage storage, a café, a drivers' rest room, and other facilities.

Ambulatory Clinic – A small medical facility, usually located in rural areas or at enterprises, intended for providing outpatient medical care in primary medical fields such as therapy, surgery, obstetrics, and pediatrics.

Structural Reinforcement – A construction element in the form of separate rods, either welded or tied together in the form of frames, meshes, or clamps. Reinforcement can be made of metal, plastic, or fiberglass. It is used in the manufacturing of building structures and components.

Atrium:

1- A space with overhead lighting in an ancient Roman house.
2- An inner courtyard with a central pool (impluvium) and an opening (compluvium) in the roof or ceiling above it to collect rainwater.

Beam – A solid or composite structural element in the form of a bar, usually with a prismatic cross-section, used for floor structures. Depending on the number of supports, beams can be classified as single-span, multi-span, cantilevered, or simply supported.

Balcony – A fenced platform projecting from a wall on the facade or inside a building. The railing can be solid, latticed, or in the form of a balustrade. In theaters and concert halls, balconies are equipped with seating for spectators.

Sports Swimming Pool – A facility designed to serve athletes during swimming competitions and training. The building includes pools for swimming and water polo (50×21 m, depth 1.8–2.3 m), diving from trampolines and platforms (18–20×14–21 m, depth 3.5–5.5 m), as well as pools for swimming instruction. Additionally, various service areas for athletes and visitors are provided.

Garage – A separate building or complex of buildings and structures for storing, maintaining, and repairing vehicles (cars, tractors, self-propelled machines, etc.).

Latticed Structures – In construction, these are load-bearing structures (trusses, columns, frames, arches, etc.) made of steel, reinforced concrete, wood, or composite materials, formed by straight rods connected at nodes using bolts, rivets, or electric welding.

Hotel – A building designed for the accommodation and short-term stay of travelers. The largest part consists of guest rooms, while the public areas include service facilities, dining establishments, sometimes an auditorium, and various utility rooms.

Impost –

1. An architectural detail, a molding in the form of a cornice that separates an arch from its support (a column or wall). The impost serves as a base for the arch's springing and transfers the load to the supporting wall, column, or capital below.
2. A vertical element that separates a window or door opening.

Industrialization of Construction – A direction of technical progress characterized by the transformation of construction into a mechanized, continuous process of erecting buildings using large prefabricated components and structures.

Building Frame – The main load-bearing structure of a building, consisting of vertical supports (such as columns, pylons, or short load-bearing walls) and horizontal beams, girders, spans, trusses, and other structural elements that rest on them. The frame bears the main load and ensures the strength and stability of the structure. It is typically made of reinforced concrete or metal structures.

Buttress – A vertical transverse wall or a projection on a wall that counteracts lateral thrust and strengthens the main load-bearing structure.

Corridor-type Residential Building – A building where residential apartments are located along a corridor that connects them to vertical communication elements such as staircases or elevators.

Stringer – An inclined beam that connects stair landings and on which stair steps are mounted.

Smoke-free Stairwell – A stairwell designed with engineering or structural decisions that prevent the entry of combustion products in case of fire.

Rib (Ribbed Vaulting) – An arch made of precisely cut wedge-shaped stones that reinforce a vault. In Gothic architecture, ribs form the framework of vaults covering the naves.

Fire Support Point – A room designated for storing protective equipment necessary for fire suppression.

Sports Palace – An architectural building designed for competitions and training in various sports, as well as for entertainment and public events. The sports palace complex includes a main sports hall with spectator seating and several service and utility rooms.

Ramp – A gently sloped surface that replaces stairs inside or outside a building. Ramps are used for pedestrian movement, vehicle access in multi-level garages, etc. The slope of a ramp ranges from 1/6 to 1/8.

Pendentives – In architectural structures, a triangular-shaped construction that facilitates the transition from a rectangular base to a dome covering.

Passage (Arcade Mall) – A type of building where workspaces are arranged in tiers along the sides of a spacious corridor covered with glass. Tiered galleries connect to this corridor. Passage-type buildings are widely used for commercial enterprises, office buildings, and other purposes.

Fire Separation Distance – A regulated distance between buildings to prevent fire spread.

Fire Compartment – A section of a building that is separated from other sections to prevent fire spread.

Fire Section – A part of a fire compartment.

Fire Tambour-Lock – A volumetric element of a space, separated from other rooms and located at the entrance (exit) of a room. It is designed to prevent the spread of fire.

Unvaulting – A part of a cylindrical vault’s surface that appears as an elevated triangle. It is formed by the intersection of two cylindrical vaults or by the ribs of a Gothic ribbed cross vault.

Solid Building Structure – A building structure without openings.

Conditional Building Height – The height determined as the difference between the lowest level of a fire truck access road and the floor of the top story, excluding upper technical floors.

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