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INSPECTION, RECONSTRUCTION AND STRENGTHENING OF BUILDINGS

LECTURE NOTES

(for second (master's) level of higher education, full-time and part-time study in specialty 192 – Building Industry and Civil Engineering, educational program "Industrial and Civil Engineering")

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1 INTRODUCTION

The construction industry plays a vital role in the development of infrastructure and in ensuring the sustainability of urban and industrial facilities. Over time, buildings and structures undergo physical deterioration, while operational requirements evolve, often necessitating their adaptation to new uses or conditions. Therefore, building inspection, reconstruction, and structural strengthening are critical areas of modern construction practice.

This lecture compendium is intended for students pursuing the second (Master's) level of higher education, both full-time and part-time, in specialty 192 – Building Industry and Civil Engineering, within the academic program "Industrial and Civil Engineering". It covers the first thematic module of the course syllabus, including:

- вasic methods for assessing the technical condition of buildings;
- principles of reconstruction;
- modern techniques for strengthening load-bearing structures;
- regulatory and technical frameworks that govern these activities.

1.1 Purpose, Objectives, and Importance of the Course

The aim of this course is to provide students with both theoretical knowledge and practical skills required to perform surveys, reconstructions, and strengthening of buildings and structures. This ensures their safety, reliability, durability, and functional adequacy according to current standards.

The key objectives of the course are:

- to develop understanding of the fundamental methods for diagnosing the technical condition of buildings and structures, the causes of defects and damages, and the strategies and materials used for reconstruction and strengthening;
- to enhance skills in conducting visual and instrument-based surveys, preparing design solutions for reconstruction or strengthening, conducting cost-benefit

analysis of restoration work, and applying innovative technologies during the inspection and reconstruction process;

- to foster professional responsibility in ensuring safety compliance during inspections and reconstructions, considering environmental impacts, and adhering to legal and regulatory requirements.

This discipline is fundamental in training professionals engaged in the construction, restoration, reconstruction, operation, and technical maintenance of buildings and structures.

1.2 Regulatory Framework for Building Survey and Reconstruction

The regulatory framework for the inspection, reconstruction, and strengthening of buildings and structures defines the procedures, rules, and standards that must be followed during such works. It comprises national laws, state building codes (DBN), national standards (DSTU), and international guidelines and norms.

Key legislative acts of Ukraine:

- Law of Ukraine "On Regulation of Urban Planning Activities". Defines the general principles for construction and reconstruction works, and regulates the procedures for technical inspection prior to reconstruction;
- Law of Ukraine "On Architectural Activity". Establishes the legal and organizational framework for architectural practice and outlines the responsibilities of entities involved in reconstruction and inspection works;
- Law of Ukraine "On Occupational Safety". Defines safety requirements for workers during inspection, reconstruction, and strengthening activities;
- Civil Protection Code of Ukraine. Regulates emergency response and recovery activities in case of building damage.

State Building Codes (DBN):

- DBN V.1.2-14:2018 General Principles of Structural Reliability and Safety. Sets requirements for the safety and operational reliability of buildings and structures;

- DBN V.2.6-98:2009 Construction Structures. Reconstruction and Strengthening. Defines the design methods for structural strengthening and regulates the requirements for materials used in strengthening;
- DBN A.2.2-3:2014 Scope and Content of Scientific and Design Documentation for Reconstruction Projects. Establishes the procedure for development and approval of documentation for reconstruction;
- DBN V.3.2-2:2009 System of Technical Maintenance and Repair of Buildings and Structures. Regulates the process of technical maintenance and inspection;
- DBN V.1.1-12:2014 Protection of Buildings Against Progressive Collapse. Contains provisions for preventing catastrophic failures in structures.

National Standards of Ukraine (DSTU):

- DSTU-N B V.1.2-18:2016 Guidelines for Assessing the Technical Condition of Buildings and Structures. Provides a methodology for conducting surveys and assessing structural condition;
- DSTU B V.2.6-200:2014 Methods for Determining the Strength of Construction Materials. Provides instructions for laboratory testing of construction materials.

International Standards and Norms:

- ISO 13822:2010 Bases for Design of Structures – Assessment of Existing Structures. Specifies the international principles for assessing existing structures;
- Eurocodes (EN 1990 – EN 1999). A set of European standards governing the design, assessment, and strengthening of structures, widely used in EU and harmonized with national practice in Ukraine.

Other Regulatory Documents:

- methodological Guidelines for Technical Survey of Buildings and Structures (approved by the State Committee for Construction of Ukraine) Provide detailed guidance on organizing and conducting building surveys;
- sanitary Rules and Norms (SNiP). Regulate the sanitary and hygienic conditions for construction activities.

This comprehensive legal and normative base ensures that surveys and reconstruction works are conducted professionally and reliably, minimizing risks and maximizing structural safety and longevity. The use of harmonized standards streamlines the project approval process, aligns Ukrainian practice with international norms, and supports economically and technically justified construction decisions.

2 SURVEY OF THE TECHNICAL CONDITION OF BUILDINGS AND STRUCTURES

2.1 Objectives of the Survey

The assessment of the technical condition of buildings and structures is a critical phase in their life cycle. The main objective of the survey is to determine the actual load-bearing capacity and serviceability of structural elements and foundations.

Additionally, the survey aims to identify the most effective spatial and structural solutions, as well as suitable methods for strengthening the load-bearing structures, while ensuring:

- technical feasibility;
- minimal labor and material expenditures;
- and optimized execution time for reconstruction works.

When evaluating structures made of various materials – such as steel, masonry, reinforced concrete, or timber-appropriate limit state design methods must be applied in accordance with current codes and standards.

To establish normative and design load values, all calculations must conform to existing national building codes.

Upon completion of the primary phases of the survey, a comprehensive evaluation of the structural integrity and serviceability of the examined components must be performed. The results should be documented in a technical report or expert conclusion, which includes a summary of the current condition and the adequacy of the structure for further use.

2.2 Main Stages of Building Survey and Reconstruction

The process of surveying and reconstructing buildings follows a clearly defined sequence of stages to ensure the efficiency, safety, and quality of the works.

1. Preparatory Stage.

Involves collecting and analyzing all available documentation and information about the facility. Key activities:

- review of design documentation, technical passports, and results of previous inspections;
- study of operational conditions (load levels, environmental exposure);
- preliminary visual inspections;
- definition of the inspection objective (e.g., reconstruction, strengthening, technical expertise);
- development of a work plan and technical assignment for the survey.

2. Structural Condition Assessment.

Evaluation of the actual condition of structural elements, engineering systems, and the soil foundation. Key activities:

- visual inspection to detect defects and damages (e.g., cracks, corrosion, deformations);
- instrumental methods using specialized equipment (ultrasonic testing, thermal imaging, ground-penetrating radar);
- laboratory testing to assess material properties (strength, density);
- soil investigation to evaluate foundation conditions and geotechnical context;
- documentation: preparation of inspection reports, photographic and video evidence of observed conditions.

3. Analysis and Conclusions.

Interpreting the survey data to assess degradation and define the necessary intervention. Key activities:

- calculating the residual load-bearing capacity of structural members;

- assessing the severity of defects and structural safety risks;
- determining whether reconstruction or strengthening is justified;
- preparing a technical report with conclusions and recommendations for future actions.

4. Design of Reconstruction and Strengthening Measures.

Development of technical and architectural solutions based on the assessed condition. Key activities:

- preparation of architectural and structural design solutions;
- selection of materials and technologies for the required works;
- execution of engineering calculations;
- submission and approval of design documentation with relevant authorities.

5. Site Preparation.

Implementation of preparatory work to enable construction or repair interventions. Key activities:

- demolition of damaged or obsolete structural elements;
- organization of the construction site; ensuring access to all relevant zones;
- implementation of safety measures and environmental impact minimization.

6. Execution of Reconstruction and Strengthening Works.

On-site implementation of structural and technical interventions.

Key activities: Execution of works in accordance with design documentation:

- structural strengthening using advanced technologies (e.g., fiber-reinforced concrete, composite materials, steel overlays);
- replacement or modernization of engineering systems (e.g., plumbing, ventilation, electrical);
- continuous quality control throughout the process.

7. Quality Control and Completion.

Verification of the executed works' conformity to the approved design. Key activities:

- testing of altered structural elements and systems;
- preparation of completion reports;
- certification of materials and construction quality;
- final handover of the object to the client.

8. Post-Reconstruction Monitoring.

Ensuring continued reliability and functionality of the structure after intervention. Key activities:

- scheduled inspections of the reconstructed facility;
- identification and mitigation of potential issues;
- evaluation of the effectiveness of the performed interventions.

Strict adherence to these stages helps prevent emergencies, optimize reconstruction costs, and ensure long-term serviceability and safety of the building.

2.3 Methods for Assessing the Condition of Buildings and Structures

Groups of engineering and technical specialists with appropriate qualifications conduct inspections of buildings and structures. These teams must be trained and equipped with the necessary specialized instruments and devices. Inspection teams may include representatives of design and research institutes, engineering bureaus, building maintenance services, university research subdivisions, and student design bureaus of educational institutions.

These inspection groups must operate in accordance with applicable regulatory and procedural documents relating to building surveys and reconstruction, as well as current national standards for survey-design work, construction, and building operation.

Preparation for inspection includes studying the historical design and construction methods, structural systems, and building materials relevant to the construction and use period of the structure to be reconstructed.

A clearly defined inspection brief is essential – it should state the purpose of the reconstruction, the basic technical and structural requirements, anticipated technological loads and environmental effects, spatial planning objectives, and general post-reconstruction operating conditions. This brief forms the basis for the scope of the inspection. In addition, information about the technical capabilities of the contractor intended to carry out the strengthening work should be taken into account.

To review and approve technical solutions, the main inspection commission may include representatives of the enterprise—such as the chief architect's department, capital construction unit, and sometimes even representatives of general or specialized contracting companies.

In most cases, inspection is conducted in two stages:

- a preliminary inspection;
- a detailed inspection, although they may also be combined into a single-phase procedure.

During the inspection process, the following tasks are typically carried out:

- preliminary review of structures;
- study of design documentation;
- analysis of planned changes in function and load regimes;
- engineering-geodetic, geological, and hydrometeorological investigations;
- detailed visual inspections;
- geometric measurements of structures and defect identification;
- sampling and laboratory analysis of construction materials;
- determination of planned loads and environmental effects;
- creation of structural models and validation calculations.

If needed, full-scale testing of the structures may also be performed. It is important to note that certain types of work may be carried out during both the preliminary and detailed phases of inspection.

When initiating preliminary or general investigations, it is necessary to visually examine the building and its structural elements, as well as to study the available technical documentation and other materials that may help in understanding the object of investigation. At this stage, it is crucial to identify areas and specific structural elements that are in an emergency or critical condition, and to implement temporary strengthening measures accordingly.

The review of design and technical documentation must address a range of questions, including historical data such as the start and duration of construction, records of major or minor repairs, changes in layout, modifications in building usage or technological processes, and any measures undertaken to prevent emergencies or mitigate severe operational issues. Additionally, the review should include:

- spatial planning and structural solutions;
- working drawings;
- design loads and environmental actions;
- as well as geotechnical and geological conditions for both construction and operation phases.

To ensure comprehensive information about the construction and operational history of the structure, it is essential to supplement the original design and technical documentation provided by the design organization with additional sources, such as:

- commissioning certificates;
- concealed works records;
- material passports and conformity certificates;
- construction and maintenance journals;
- and documentation related to prior repairs, reconstructions, or other interventions.

Further insights into the construction and operational history of the facility may also be obtained through interviews with workers and engineering-technical staff at the inspected site.

Before commencing any works, a preliminary survey must be conducted to identify possible deviations from the original design data, especially in terms of:

- spatial layout and structural solutions;
- types and magnitudes of loads;
- including environmental and climatic effects.

In the absence of design and technical documentation, or where it is incomplete, it is mandatory to carry out preliminary geometric surveys and prepare basic drawings of the buildings and structures before proceeding with any physical interventions. During measurement works, the following parameters must be recorded:

- deviations of structural elements from permissible tolerances;
- cross-sectional dimensions and the spatial positioning of elements;
- quality of joints and connections;
- material strength characteristics;
- and observed material defects.

For convenience and systematic data organization, it is recommended to divide the structure into zones based on:

- the type of construction material;
- the structural system;
- and the functional purpose of the elements.

Preliminary or general surveys assist in providing a tentative assessment of the technical condition of structural components and in developing a detailed inspection program.

The latter is conducted in order to obtain the most accurate and reliable data for evaluating the technical condition of structural elements, which serves as the basis for selecting an appropriate structural solution during the reconstruction of buildings and facilities.

After a detailed structural survey, it is recommended to prepare accurate project and technical documentation, as well as measured drawings, which record the actual spatial position of structural elements in plan and elevation, taking into account:

- load-bearing components;
- displacements;
- shifts;
- and other deviations.

Subsequently, a set of tasks must be performed to determine the actual values of the physical and mechanical properties of materials, using destructive and laboratory testing methods.

The defects and damages of structural members, joints, and connections are to be precisely specified and systematically documented. In addition, data on the operational environment affecting the structures and foundations must be gathered. This includes the magnitude of static and dynamic loads, as well as other influencing factors, including vibration diagnostics.

Based on this information, a structural model of the load-bearing system is established, enabling the performance of final verification calculations for individual elements and the structure as a whole.

In the case of a detailed inspection, either a comprehensive or a selective survey may be conducted. A comprehensive (full-scale) survey must be carried out for buildings and structures with a reliability coefficient equal to one, as well as in situations where project documentation is missing, defects have been identified that reduce the load-bearing capacity of structural elements, or where material inconsistencies, loading conditions, or other dangerous operational factors are present.

When performing a comprehensive set of works aimed at determining the physical and mechanical or physico-chemical properties of structural materials, attention must be paid to elements that are operated under elevated and high temperatures, low and reduced temperatures, aggressive environments, and similar conditions. The analysis of the state of structural elements affected by high temperatures should take into account the source of heat release, the nature of the heating – whether it is convective or radiant, as well as the temperature regime, including the type of heating (cyclic or continuous), humidity, pressure, and other influencing factors.

During all types of structural surveys, it is essential to maintain strict records of the obtained data in dedicated journals, to issue inspection reports for each type of work, and to aim for the presentation and systematization of collected data in tabular form.

If during a full-scale inspection it is determined that not less than 20% of similar structural elements out of a total of more than twenty are in good technical condition, the remaining unchecked elements may be inspected selectively. The number of elements subject to selective inspection should be defined according to the specific conditions, but it must not be less than 10% of the total number of identical elements and in any case not fewer than three elements.

During detailed inspections and measurement procedures, engineering and geodetic surveys are carried out to enable the precise preparation of building and structure drawings and to determine the actual geometric parameters of load-bearing structures and their deformations in order to clarify and refine the calculation model. Engineering and geological surveys are recommended in the absence of working drawings for the foundations of the reconstructed structures, as well as when there is no execution documentation related to the construction of the foundations or insufficient data about the engineering and geological conditions of the construction site. This is especially important when the building is situated on foundations located in geologically complex areas.

Special engineering hydrogeological and hydrometeorological investigations are carried out during the reconstruction of buildings located in areas that are currently flooded or potentially flood-prone, as well as in cases where the operation of buildings and structures takes place under adverse physical-geological or hydrometeorological conditions.

The inspection of building structures is a vital component in ensuring the safety, durability, and functionality of facilities. The primary methods used for assessing the condition of structural elements can be classified into three main categories: visual methods, non-destructive methods, and destructive methods.

2.3.1 Visual Inspection Methods

This is the first stage of the inspection process, which allows for the assessment of structural conditions without the use of complex equipment. The main aspects include:

- examination of the external condition: checking for the presence of cracks, deformations, corrosion, plaster delamination, traces of moisture, or fungal growth;

- documentation: recording of identified defects using photo and video capture;
- assessment of geometric parameters: verification of verticality, horizontality, thickness of elements, and related dimensions.

2.3.2 Non-Destructive Testing Methods

These methods allow for obtaining detailed information about the condition of a structure without causing any damage to it:

- ultrasonic testing methods are used to detect cracks, voids, and inhomogeneities within materials. Their advantages include high accuracy and the ability to examine the internal structure;
- radiography (X-ray testing) is applied for the inspection of welded joints, steel structures, and reinforced concrete. It requires specialized equipment and compliance with radiation safety standards;
- acoustic emission testing is used to identify active defects by capturing sound signals generated during the material's internal fracturing process;
- rebar scanning employs magnetic or electromagnetic devices to detect the location of reinforcement within concrete;
- infrared thermographic inspection is used to identify heat loss, thermal insulation failures, and moisture penetration areas;
- endoscopy is applied to inspect hard-to-reach areas of structures using specialized video camera equipment.

2.3.3 Destructive Testing Method

These methods are used to determine the physical and mechanical properties of the materials that make up the structure. They involve partial or complete destruction of specimens. Specifically:

- strength testing – mechanical testing under tension, compression, or bending;
- core sampling (specimen extraction) – removal of portions of construction materials (such as concrete or steel) for laboratory analysis;
- chemical analysis of materials – used to detect corrosion, salt content, or other chemical impurities.

2.3.4 Other Survey Methods

Geodetic control involves the measurement of deformations and settlements in buildings.

Structural health monitoring refers to long-term observation of the condition of structures using sensors installed at critical locations.

Computer modeling entails the development of a digital model to assess the influence of loads or the effects of reconstruction interventions.

The choice of inspection method depends on: the type of structure (e.g., concrete, steel, timber); the identified defects; the objectives of the survey (e.g., repair, reconstruction, durability assessment).

The integrated application of visual, non-destructive, and destructive methods ensures a reliable and accurate evaluation of the structural condition and facilitates well-justified decisions regarding operation, repair, or reinforcement.

To determine the geometric characteristics of structural components, various laser-based instruments are used, such as laser levels, laser theodolites, and laser distance meters. These instruments enable measurements of lengths, distances, slopes, height differences, surface flatness, deflections, deformation magnitudes, and displacements.

To detect defects in structural materials, specialized flaw detection devices (defectoscopes) are used. These allow the identification of cracks, inclusions, corrosion damage, deformations, and similar issues. Such devices include magnetic flaw detectors, ultrasonic flaw detectors, X-ray flaw detectors, and thermal imagers (thermographs).

In addition, diagnostic procedures often involve instruments for measuring vibration levels, sound, illuminance, temperature, and other environmental or operational parameters that may affect the condition of the structures and facilities.

An important stage of structural diagnostics is the laboratory analysis of material samples, from which the elements of the structure are made. For this purpose, specialized equipment is used to determine the physical-mechanical and physico-chemical properties of the materials.

When selecting diagnostic equipment for assessing the technical condition of structures, it is essential to consider the accuracy, reliability, and applicability of the instruments in the specific working conditions. Compliance with occupational safety regulations must be ensured at all times, along with the proper storage and maintenance of all diagnostic equipment.

2.4 Advantages and Disadvantages of Survey Methods

Visual methods: dvantages: simplicity, low cost. Disadvantages: subjective assessment, inability to detect internal defects.

Instrumental methods: advantages: high accuracy, ability to detect internal defects. Disadvantages: require specialized equipment, higher costs.

The application of these methods ensures the safe operation of buildings, enables timely detection and elimination of defects, and extends the service life of structural elements.

2.5 Common Defects and Damages in Building Structures

Over time, building structures may be subject to various defects and damages caused by external factors, as well as errors in design, construction, or operation. Below we consider the main types of defects, their causes, and potential consequences.

Design-related defects refer to shortcomings in the design process, such as insufficient structural strength or stiffness, or the incorrect selection of materials and their properties.

Construction (technological) defects arise from errors during the construction process. These may include insufficient thickness of structural layers, poorly executed joints, or deviations from the approved design documentation.

Operational defects result from improper use of the facility, delayed maintenance, or the absence of timely repair and servicing.

Defects caused by external factors include climatic influences such as temperature fluctuations, moisture exposure, and aggressive environments, as well as mechanical damage from impacts or overloading. The main types of defects and their causes are presented in Table 1.

Table 1 – Main Types of Defects and Their Causes

Type of Defect	Causes	Consequences
Consequences	Heterogeneity of the foundation or settlement. Exceeding design loads. Thermo-hygrometric deformation.	Reduction in structural strength and durability. Loss of airtightness.
Corrosion of metal structures	Contact with moisture or aggressive environments. Poor quality or absence of protective coating.	Reduction in cross-sectional area of metal, leading to decreased load-bearing capacity.
Deformations and deflections	Insufficient stiffness of structural elements. Excessive loading.	Loss of structural stability. Possible collapse.
Shrinkage phenomena	Improper concrete placement techniques. Drying of concrete without proper curing.	Formation of fine cracks, which may propagate.
Efflorescence and staining	Penetration of moisture carrying salts to the surface.	Deterioration of aesthetic appearance. Surface degradation.
Delamination or failure of protective layers	Violation of protective layer application technology. Aggressive external influences (UV, frost).	Increased risk of corrosion or failure of the base structural material.

Causes of Structural Damage in Buildings: external natural or anthropogenic factors; internal factors related to the operation of engineering systems and utilities;

errors made during site investigation, design, or construction phases; violation of operational and maintenance rules.

Based on the degree of damage and the significance of the consequences, structural damage is classified into three categories:

category 1 – emergency-level damage caused by various factors;

category 2 – damage to primary structural elements that is not of an emergency nature and can be remedied through major repairs or reconstruction;

category 3 – damage to secondary structural elements, which can be addressed through routine maintenance or minor repairs.

Defect prevention can be implemented at the design stage (by using high-quality materials with appropriate properties, correctly defining loads and service conditions), during the construction stage (by following proper construction technologies, ensuring material quality control, and supervising construction works), and at the operational stage (through regular inspections and preventive maintenance, protecting structures from aggressive environmental exposure using waterproofing, anti-corrosion coatings, etc.).

Defects and damages in building structures represent a critical issue that directly impacts the safety and service life of buildings. Regular monitoring, proper maintenance, and timely remediation of damage contribute significantly to reducing the risk of structural failure and extending the lifespan of buildings and structures.

2.6 Assessment of the Residual Load-Bearing Capacity of Structures

The assessment of the residual load-bearing capacity (RLBC) of structures is the process of determining the ability of building structures to perform their intended functions under service loads, taking into account the effects of defects, damage, material aging, and changes in the original design conditions. This assessment is critical for ensuring the safety of buildings and structures, as well as for making informed decisions regarding their continued operation, repair, or reconstruction.

The purpose of RLBC assessment is to ensure the reliability and safety of the structure, to evaluate the extent of wear and the remaining service life of structural elements, to plan repair or reconstruction works, to determine the feasibility of continued operation, and to assess the compliance of the structures with current codes and standards.

The key factors influencing the residual load-bearing capacity include: physical aging of materials (e.g., reduction in the strength of concrete, steel, timber, or other materials due to natural degradation); defects and damage (such as cracks, delamination, corrosion, spalling of the protective layer, or structural settlement); overloading (permanent or temporary loads exceeding the design limits); environmental influences (aggressive chemical or moisture-laden environments, temperature fluctuations, seismic activity); operational conditions (violation of maintenance procedures or mismatch between actual usage and design assumptions).

The main criteria for evaluating residual load-bearing capacity are: strength (the ability of a structure to withstand the calculated loads); stiffness (absence of excessive deflections or deformations); stability (the structure’s ability to maintain equilibrium); durability (the expected duration of safe service life); serviceability (compliance with current standards and functional requirements).

2.7 Safety Requirements During Building Inspections

To ensure safety during the diagnostic assessment of buildings and structures, the following requirements must be observed: relevant authorities must be notified in advance regarding the scheduled inspection works; diagnostics must only be carried out by personnel with appropriate qualifications, knowledge, and experience; before starting work, potential risks must be assessed, hazardous factors identified, and measures taken to protect workers from these hazards; safety must be ensured when working in areas exposed to electromagnetic fields, and when using electrical devices and power tools; safety measures must be followed when working at height, in excavations, or in the presence of unstable structural components that may collapse or fall; protective equipment and devices must be used to minimize the risk of injury or danger; occupational safety instructions must be followed, and all applicable safety rules relevant to the specific type of work must be observed; appropriate medical assistance must be provided when necessary; compliance with these safety requirements will help ensure safe working conditions during building inspections, prevent adverse incidents, and protect workers' health.

2.8 Instrumentation and Equipment for Structural Inspection

To determine the geometric characteristics of structural components, various laser-based instruments are used, such as laser levels, laser theodolites, and laser rangefinders. These devices allow for the measurement of lengths, distances, slopes, elevations, surface flatness, deflections, deformation magnitudes, and displacements.

To identify material defects in structural elements, various flaw detection devices (defectoscopes) are employed. These devices can detect the presence of cracks, inclusions, corrosion damage, deformations, and other defects. Commonly used devices include magnetic, ultrasonic, and X-ray flaw detectors, as well as thermal imaging devices (thermographs).

During the diagnostic process, instruments are also used to measure vibration levels, noise, illuminance, temperature, and other parameters that may affect the structural condition of buildings and facilities.

An important stage of the diagnostic process involves laboratory testing of material samples taken from structural elements. For this purpose, specialized instruments are used to determine the physical-mechanical and physico-chemical properties of materials.

When selecting instruments for assessing the technical condition of structures, it is necessary to consider their accuracy, reliability, and applicability under specific field conditions. Compliance with safety regulations must be ensured, and proper storage and maintenance of the instruments must be provided.

Various testing instruments are used to determine the strength and deformation characteristics of the materials used in the construction of buildings and structures. The most reliable data are obtained through direct testing of material specimens selectively extracted from the structure. However, extracting specimens may be problematic in certain cases, so non-destructive testing methods are often preferred when assessing existing structures.

To measure the dynamic characteristics of structures, both mechanical and electrical instruments are used, such as vibrometers, dial indicators, strain gauges, and oscillographs.

In the course of flaw detection in building structures and materials, devices are employed to determine the concrete strength using physical (indirect) testing methods (see Table 2). To measure the width of crack openings, microscopes such as MPB-2 and MIR-2 are used.

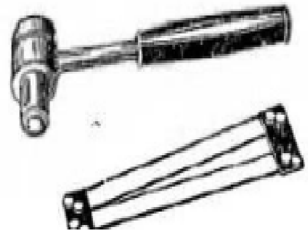
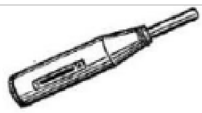
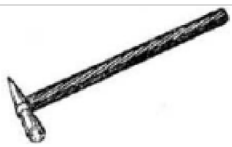
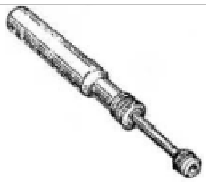
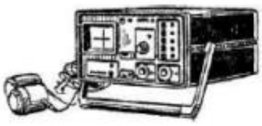
Physico-chemical parameters, which characterize the properties of construction materials and determine their resistance to chemical aggression, temperature, and humidity, are measured using specialized equipment and instruments in laboratory conditions based on tests of samples extracted from the structure.

During the inspection process, it may become necessary to conduct tests of existing structures in order to determine their stiffness and load-bearing capacity. For this purpose, conventional equipment and devices are used to perform static and dynamic tests of structural components in buildings and civil engineering facilities.

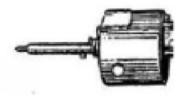
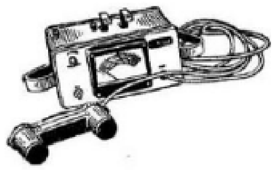
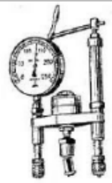
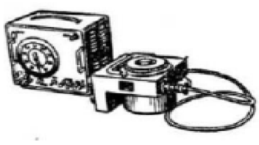
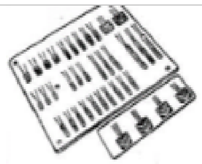
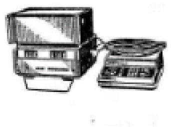
Various instruments are used to measure the forces transmitted to structures via jacks, winches, pulley systems, and similar devices. These include hydraulic and spring-type dynamometers, as well as devices for measuring displacements (deformations) such as deflectometers, comparators, dial-type indicators, and strain gauges (including those developed by Hugenberger and N.N. Aistov). Additionally, electrical strain gauges using various types of resistance strain elements, such as TCM, IDS, and oscillographs, are applied.

Clinometers are used to measure deflections and angular rotations of structural elements, while geodetic instruments are employed to measure overall displacements of the structure and its specific nodes.

Table 2 – Instruments for Determining Deformation and Strength Characteristics of Materials and Structures

Sketch	Instrument Name	Notes / Functionality
1	2	3
	Reference Hammer by Kaptsanov with Angular Scale	Used as a calibration device for impact-based strength measurements
	KM-Type Device	Typically used for evaluating surface hardness or local deformation
	Schmidt Hammer (Rebound Hammer)	Non-destructive testing device for estimating concrete compressive strength
	Fizdel Hammer	Mechanical tool for surface hardness testing
	PM-Type Device	Device for physical measurements; often customized for various dynamic tests
	Ultrasonic Device UK-10PM	For internal defect detection and measurement of ultrasonic pulse velocity in materials
	Dial Gauge Indicator	For measuring small linear deformations, deflections, or movements

Continue Table 2

1	2	3
	Microscope Type MPB-2	For measuring crack width and surface anomalies
	Vibrograph VR-1	Records vibration amplitude and frequency during structural diagnostics.
	Microscope Type MPB-2	Measures width and development of cracks in structural elements.
	IZS-2 Type Instrument	Device for measuring vibrations and deformations, often strain-related.
	Deflectometer PM-3 Type (by N.N. Maksimov)	Measures deflection and bending of structural members.
	Hugenberger Mechanical Strain Gauges	Measures strain in structures; used in field or lab tests.
	Deformation Gauge Type AID	Precision instrument for deformation measurements under load.
	Resistance Strain Gauges	Measures micro-deformations with high accuracy; electrical type.
	Same as above, Type CTM-5	A specific model of strain gauge for deformation analysis (typically more compact/digital).

Instruments for measuring the forces transmitted to structures enable the determination of: deflections, angles of rotation, and displacements of both the entire structure and its individual components

2.9 Methodology for Inspecting Buildings and Structures Damaged as a Result of Emergencies

The main regulatory document governing the methodology of inspections is the “Methodology for Inspecting Buildings and Structures Damaged as a Result of Emergencies, Military Operations, and Acts of Terrorism”, approved by the Order of the Ministry for Communities and Territories Development of Ukraine dated April 28, 2022, No. 65.

Inspections of damaged structures are conducted in accordance with the Procedure for Conducting Inspections of Commissioned Construction Sites, approved by the Resolution of the Cabinet of Ministers of Ukraine dated April 12, 2017, No. 257.

Inspection works must be organized by the client, who is responsible for engaging qualified specialists. Other professionals with relevant qualifications may be involved in the inspection process as necessary.

Financing of the inspection works shall be carried out at the expense of individuals or legal entities, or from the state and/or local budgets, as well as from other sources in accordance with applicable legislation.

The main stages of the inspection include: preparation for inspection, preliminary and/or detailed inspection, and the preparation of a report containing the inspection results and recommendations regarding further operation.

The number of stages and the scope of work performed at each stage shall be defined by the technical assignment, based on the objectives and scope of the inspection.

When conducting inspections of damaged structures, it is mandatory to observe fire safety regulations and occupational health and safety rules in accordance with applicable laws. If hazardous objects are discovered, such as unexploded ordnance, explosive devices, human remains, the smell of gas, or other unusual odors or if electric shock hazards are present, all work must be immediately stopped, and the relevant local authorities of the State Emergency Service (DSNS) and law enforcement agencies must be notified without delay.

The assessment of the technical condition of structures and the building as a whole shall be performed in accordance with Section 5 of DSTU-N B V.1.2-18:2016 “Guidelines for the Inspection of Buildings and Structures to Determine and Assess Their Technical Condition” (hereinafter DSTU-N B V.1.2-18:2016). This assessment must take into account existing emergency damage as well as other defects and damage that may have occurred during manufacturing, transportation, assembly, construction, or operation, which could reduce the performance of building structures and engineering systems. Such assessments must reflect the classification indicators of technical condition of structures in Appendix B of DSTU-N B V.1.2-18:2016, and for steel structures, also comply with DSTU B V.2.6-210:2016 “Assessment of the Technical Condition of Operated Steel Building Structures”.

To account for the sector-specific characteristics of engineering and transport infrastructure, inspections must also comply with the provisions of regulatory legal acts and construction standards and national standards relevant to the specific type of facility, including:

- DSTU 8954:2019 Assessment of Pavement Defect Level;
- DSTU 8745:2017 Methods for Measuring Irregularities of Subgrade and Pavement;
- DSTU 8746:2017 Methods for Measuring the Surface Skid Resistance of Pavement;
- DSTU B V.2.3-42:2016 Highways. Methods for Determining the Deformation Characteristics of Subgrade and Pavement — for the inspection of roads;
- DBN V.2.3-6:2009 Bridges and Culverts. Inspection and Testing;
- DSTU 9123:2021 Guidelines for Inspection and Testing of Bridges and Culverts;
- DSTU 8748:2017 Guidelines for Conducting Dynamic Testing of Road

Bridges;

- DSTU-N B V.2.3-23:2012 Guidelines for the Assessment and Forecasting of the Technical Condition of Road Bridges – for the inspection of bridges.

2.10 Definition and Categories of the Technical Condition of Structures

The technical condition of a building (or structure) refers to the combination of qualitative and quantitative indicators that characterize its serviceability and that of its components, relative to their allowable limit values. It is evaluated at a given moment in time and under specific environmental conditions based on performance parameters (serviceability indicators) established for the assessed structure.

The level of serviceability of individual structural components and the structure as a whole i.e., their reliability and safety for intended use is determined by their compliance with regulatory serviceability requirements.

The ratio between actual performance characteristics, obtained through inspection, and the corresponding design and normative values, accounting for limit states of structural elements and/or foundations, defines the degree of suitability of structures. This is expressed using the indicator "technical condition category."

Experience in the operation of buildings and engineering structures shows that the qualitative characteristics of structures deteriorate over time. As such, their technical condition is not constant but dynamic, and it may degrade to the point where the structure can no longer perform its intended functions.

The technical condition of structural elements is assessed through a comprehensive analysis of defects and damages, as well as verification calculations. According to normative documents, based on load-bearing capacity and serviceability, structural elements are classified into four categories of technical condition:

- normal (Category 1) – The actual internal forces in members and cross-sections do not exceed calculated allowable values. No defects or damage are present that would interfere with normal operation or reduce load-bearing capacity or durability;
- satisfactory (Category 2) – The structure meets the load-bearing and

serviceability criteria of Category 1. However, minor deviations from the design, defects, and damage are present that may reduce the service life or partially violate second-limit-state requirements. These do not restrict intended use under current operating conditions. Measures must be taken to protect the structure and comply with operating requirements;

- unsuitable for Normal Operation (Category 3) – The structure is overloaded or has defects and damage indicating reduced load-bearing capacity. However, based on calculations and damage analysis, structural integrity can be ensured for a limited time during strengthening. Repair, strengthening, or replacement is required. Until such measures are implemented, the facility must operate in a restricted-use mode with ongoing monitoring of structural condition, loads, and external impacts;
- emergency Condition (Category 4) – First-limit-state requirements are violated or cannot be guaranteed. Based on calculations and damage analysis, structural integrity cannot be assured, particularly where brittle failure is possible. Immediate evacuation is required, and emergency measures must be taken to prevent collapse until repairs, strengthening, replacement, or full decommissioning are completed.

According to DBN V.1.2-14:2009, depending on the potential consequences of failure, structures and their components are classified into responsibility categories:

- Category A – Structural components, the failure of which may lead to complete inoperability of the building or a substantial part of it;
- Category B – Structural components, the failure of which may cause operational difficulties or lead to the failure of other components not classified under Category A;
- Category C – Structural components, the failure of which does not impact the operation of other components or the facility as a whole.

Within Category A, a subgroup A1 is distinguished, which includes main load-bearing elements, whose reliability prevents full structural collapse under extreme impacts-even if further use is impossible without major repair. Elements in Category A1 include those, the failure of which could directly result in an emergency situation with danger to human life or the environment.

At present, there is no universally accepted approach to determining the number and naming of technical condition categories, nor to defining the criteria for assigning structures to a particular category. For example, DBN 362-92 Assessment of the Technical Condition of Steel Structures of Operating Industrial Buildings defines four technical conditions, but with different names:

- functional;
- operational;
- limited operability;
- emergency.

Previously, in design guidelines for strengthening steel structures, only three technical states were considered:

- operational;
- limited operability;
- emergency.

In scientific literature, based on the analysis of modern approaches to structural condition assessment, Klymenko Ye. V. proposed three technical condition categories with the following criteria:

- Category I – Satisfactory: All serviceability indicators meet both first and second limit state requirements;
- Category II – Unsuitable for normal operation: Some serviceability indicators exceed second-limit-state thresholds, but values for the first limit state remain within acceptable limits;
- Category III – Emergency: First-limit-state values exceed allowable limits; second-limit-state indicators may or may not exceed thresholds.

All indicators of the technical condition of structures, buildings, and facilities are defined at the design stage and constitute a comprehensive set of serviceability performance indicators (SPI), which together form the quality domain of the facility.

This quality domain may be represented as an n-dimensional space, whose vectors are serviceability indicators. Since structures are assessed with respect to two limit states for serviceability and for ultimate capacity the SPI set is also divided accordingly into two groups:

- first group of SPI (for ultimate limit state);
- second group of SPI (for serviceability limit state) (see Fig. 1).

The quality domains of structures A and B correspond to the requirements of their respective calculations according to the first and second limit states, respectively.

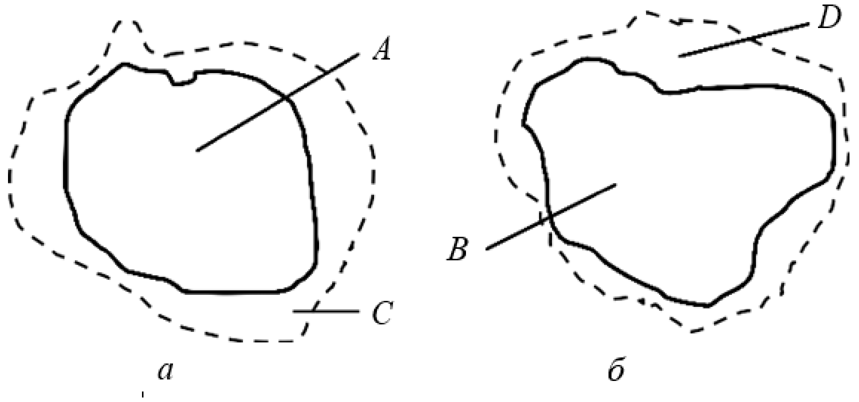


Figure 1 – Groups of Serviceability Performance Indicators (SPI):
a – first group of SPI (ultimate limit state); b – second group of SPI (serviceability limit state)

With regard to buildings and structures, Domain A includes serviceability performance indicators (SPI), the exceedance of which leads to complete unfitness for use. Domain B includes indicators, the exceedance of which results in impaired normal operation or reduced service life compared to the design lifespan specified in the technical documentation. Domains C and D are formed by sets of radius vectors, which represent individual serviceability performance indicators at any given time, determined respectively in accordance with the first and second limit state groups. Since these radius vectors in Domains C and D tend to change over time typically decreasing due to various factors (e.g., damage, physical aging) the boundaries of these domains gradually approach those of Domains A and B.

If the boundary of Domain D intersects the boundary of Domain B, it indicates that certain structural components or the building or facility as a whole can no longer be operated under normal conditions, i.e., they are unfit for normal operation (Technical Condition II). In cases where the boundary of Domain C intersects the boundary of Domain A, the structure as a whole is considered to be in an emergency condition (Technical Condition III).

Consequently, Domains A and B are associated with a satisfactory technical condition (Technical Condition I), in which all serviceability indicators comply with the values specified in the design and technical documentation.

2.11 Types of Technical Inspections of Building and Civil Engineering Structures

The control of the technical condition of buildings and structures is carried out by implementing a technical inspection system, which includes both scheduled (i.e., pre-planned and conducted at established intervals) and unscheduled inspections.

Technical inspections of buildings and structures enable the timely detection of malfunctions in structural components, identification of defects and damage, determination of their causes, and assessment of the necessary scope of current or major repair works.

Scheduled inspections assess the current technical condition of a facility and determine whether it can continue safe operation or whether there is a need to restore its performance characteristics.

Scheduled inspections are subdivided into general and preventive inspections.

General inspections are conducted based on an official order, typically twice per year, in spring and autumn. Their purpose is to determine the scope of works required for preparing buildings and structures for seasonal use and to assess their technical condition before major or current repairs.

Preventive inspections are part of the routine maintenance system for buildings and structures. They aim to detect and eliminate defects in structural components, determine their causes, prevent violations of sanitary and hygienic conditions within the premises, and check, adjust, and calibrate technical devices to ensure their reliable operation.

The inspection frequency for facilities operated under typical conditions for the given sector shall be adopted in accordance with Table 3.

Table 3 – Indicative Intervals for Scheduled Inspections of Structures

Type of Facility	Inspection Interval, Tb (years)
Residential and public buildings	6–7
Industrial, auxiliary, and warehouse buildings	5–6
Agricultural buildings	4–5
Mobile prefabricated and container-type buildings	3–4
Bridges, dams, tunnels	5–6
Water reservoirs	4–5
Oil product reservoirs	3–4
Chemical industry reservoirs	2–3
Bunkers, silos, towers, shafts, chimneys	3–4
Greenhouses	4–5

The average inspection interval (Tb) determined from Table 3 may be adjusted depending on the structural features of the specific facility, its current technical condition, the properties and condition of its foundations, the operational history of similar facilities, and other factors affecting its reliability and durability.

Unscheduled inspections of buildings and engineering structures shall be carried out when there is a need to restore serviceability or adapt the facility to new operating conditions, including: after extreme natural or man-made events; if it has been identified that the technical condition of the facility no longer meets serviceability requirements; when changes in the operating conditions of the facility have occurred or are anticipated, affecting design loads, external actions, geotechnical or hydrogeological conditions, or the structural system of the facility; during mothballing (conservation), recommissioning, or decommissioning of the facility.

A seasonal technical inspection is typically conducted twice a year, in spring and autumn, to assess the impact of seasonal factors (e.g., thawing, precipitation, freezing) on building elements, especially the roof, drainage systems, and facades.

A comprehensive (in-depth) technical inspection is performed when detailed information on the technical condition of structural components is required (e.g., for the development of a reconstruction or major repair project). This type of inspection includes instrument-based diagnostics, material testing, and laboratory analysis.

An expert inspection is carried out by specialized organizations or certified experts, often within the context of legal proceedings, insurance claims, or to verify the technical condition prior to the sale or lease of the property. The result is an expert report, which carries legal validity.

Normative documents also refer to:

- visual inspection – performed without dismantling or destructive method;
- instrumental inspection – conducted using devices, probes, and destructive/non-destructive testing methods.

3 REPAIR AND RECONSTRUCTION OF BUILDINGS

3.1 Concept of Building Repair and Reconstruction

Reconstruction of buildings and engineering structures is understood as a set of construction and repair activities associated with the reconfiguration of a building or structure as a whole, aimed at improving its comfort, capacity, and other characteristics. Reconstruction may also involve the redesign of individual parts of a facility and the construction of new ones.

Reconstruction is a process that begins with the assessment of a building’s condition and involves a set of construction and repair works aimed at reorganizing or restoring specific components or the entire facility, with the objective of improving or altering its functional purpose and extending its service life.

Restoration of buildings involves recovering the original strength, technical, architectural, and other properties of individual elements, assemblies, or the building as a whole.

Repair of an existing building refers to construction interventions intended to restore the required technical condition of the building’s structures.

Current (routine) repair includes construction and repair works that maintain the operational qualities of a building by adjusting systems, restoring protective coatings, and addressing minor damage.

Capital repair comprises a set of repair and restoration measures that are focused on improving performance indicators and increasing the reliability of building and structural elements. It may be selective or comprehensive in scope.

The purpose of reconstruction and repair is to improve the functional performance of a building and to enhance its reliability and comfort.

In the context of civil buildings, the objective of repair is to reorganize spatial layouts in order to improve planning solutions and raise the level of amenities and comfort in spaces of various functional purposes.

The directions of building and structure reconstruction include changes to functional purpose, improvement of planning layouts, and integration of extensions, inserted volumes, or vertical additions. In addition, certain tasks may address the restoration of physical and moral (functional) wear and obsolescence of the building or its elements.

Visual observation in any Ukrainian city demonstrates that the ground floors of buildings with various functions are being converted into service-sector spaces. A change in functional purpose involves a range of activities such as dismantling and demolition of structures, strengthening or replacing them, and installing new components or assemblies. When reconstruction is limited to internal reconfiguration, the associated works are usually limited in scope and may include demolition and installation of new partitions or interior walls, strengthening of floor slabs, replacement or repair of floor finishes and building services, and interior finishing works.

The addition, insertion, and vertical extension of buildings are also carried out quite frequently, and in each particular case involve varying sets of repair and construction-installation tasks.

An extension to an existing building, along with other new construction work, involves the installation of connection elements such as expansion joints, creation of openings for passage (doors, gates), and preparation of recesses or seats for supporting load-bearing structures.

Insertion of new buildings or spaces within existing structures requires an extensive range of work related to the reinforcement or replacement of structural elements, along with complete replacement of floors, utility systems, and interior finishes.

Vertical extension of buildings during reconstruction requires significant work on strengthening foundation soils, foundations, and load-bearing walls, as well as dismantling roof structures, replacing floors, and upgrading utility networks.

Efforts aimed at reducing physical deterioration of building structures typically focus on strengthening and repair, and in some cases, replacement of specific elements. This most often includes balconies, wall piers, cornices, parapets, and decorative components. Reducing moral obsolescence, just like addressing physical deterioration, lies at the core of any reconstruction approach.

3.2 Key Features and Classification of Reconstruction

Reconstruction encompasses all works aimed at modifying the physical parameters of a building or its functional purpose. The main objective of reconstruction is to ensure compliance with modern regulations, standards, and requirements applicable to buildings, as well as to extend their service life.

The main characteristics of reconstruction include: improvement of structural elements, systems, and technologies without demolishing the building; alteration of the building's configuration, spatial layout, or purpose; enhancement of reliability, safety, and aesthetic quality of the facility.

Reconstruction differs from major repair: while repair focuses on maintaining the original condition of the facility, reconstruction modifies its properties or intended function. Reconstruction is classified according to several criteria.

By scale of work.

Full reconstruction involves comprehensive replacement or improvement of all elements of the building (e.g., conversion of an industrial workshop into a business center).

Partial reconstruction includes changes to individual elements or parts of the facility (e.g., adding a floor or reconfiguring rooms).

By functional purpose.

Functional reconstruction involves the adaptation of a building to a new function (e.g., converting a warehouse into a shopping center).

Technical reconstruction focuses on improving the technical characteristics of structures and materials (e.g., foundation strengthening or roof replacement).

Economic reconstruction aims at reducing building operating costs (e.g., facade insulation to improve energy efficiency).

By type of structural change.

With extension, where the area or volume is increased by building upward or outward (e.g., creating a mansard floor).

Without extension, where work is carried out within the existing volume (e.g., wall reinforcement or reconfiguration of interior spaces).

With partial demolition, where obsolete or structurally deficient components are removed (e.g., demolition of a hazardous wing).

By reconstruction object.

Residential buildings, focusing on improved living conditions or conversion (e.g., into office space).

Public buildings, such as schools, hospitals, or theaters, reconstructed to meet current standards.

Industrial structures, restored or adapted for new production processes.

Engineering structures, including the reconstruction of bridges, tunnels, and overpasses.

By architectural value.

Reconstruction of modern buildings, aimed at improving functionality without regard to historic features.

Restoration of historical buildings, aimed at preserving and recovering architectural appearance with minimal structural intervention.

By method of execution.

Reconstruction with modernization, involving the use of modern materials and technologies.

Conservation-type reconstruction, maintaining the facility in its current condition to preserve future value.

Reconstruction with structural strengthening, including reinforcement of foundations, walls, or other load-bearing components.

3.3 Advantages and Disadvantages of Reconstruction

The advantages of reconstruction include resource savings compared to new construction, preservation of the existing structure (which is especially important for historical buildings), improved functionality, adaptation to modern requirements, and a reduced environmental impact.

The disadvantages of reconstruction include the potential presence of hidden defects that are difficult to detect during the design stage, high costs associated with strengthening structural or engineering systems, and limitations caused by the architectural or historical value of the building.

Reconstruction of building structures is an effective method for extending the service life of buildings and adapting them to modern needs. Through a wide range of methods and approaches, reconstruction enables the preservation of historical value, modernization of engineering systems, and improvement of building functionality, ensuring compliance with current standards and regulations.

3.4 Aspects of Reconstruction

The reconstruction of buildings and structures is a complex process that involves three key aspects: architectural, structural, and technological. These aspects are interrelated and contribute to achieving the main goal of reconstruction—extending the service life of the building, improving its functionality and safety, and ensuring its compliance with contemporary requirements.

3.4.1 Architectural Aspects of Reconstruction

The architectural aspect of reconstruction focuses on preserving or improving the visual appearance, aesthetic qualities, and functional purpose of the facility. The main objectives of the architectural aspect include:

- compliance with urban planning requirements (integration of the building into the surrounding environment; conformity with the master plan of the city or district);
- preservation of architectural identity (retention of façades, stylistic elements, and other features of historical or cultural value);
- functional adaptation (modification of internal layouts to suit new needs, for example, converting a residential building into an office center);
- aesthetic solutions (use of modern materials to enhance appearance; improvement of landscape design in the surrounding area).

Examples of architectural solutions include the restoration of historical façades using traditional materials, the addition of modern elements such as glass façades or terraces without compromising the overall stylistic integrity, and façade insulation and cladding while preserving decorative details.

3.4.2 Structural Aspects of Reconstruction

The structural aspect of reconstruction focuses on ensuring the strength, stability, and durability of the building through the analysis, strengthening, or replacement of specific structural elements. The main tasks of the structural aspect include:

- assessment of the technical condition of structures (identifying defects, deterioration, damage, cracks, or corrosion);
- strengthening of load-bearing elements (reinforcing foundations, columns, beams, floor slabs; using modern materials such as composites or high-strength steel);
- modification of the structural scheme (in cases of functional repurposing or increased load requirements);
- improvement of protective properties of structures (application of anti-corrosion coatings, waterproofing, and fireproofing materials);
- integration of new structural components (addition of floors, extensions, elevators, staircases, or inter-floor slabs).

Methods of structural reconstruction include:

- injection techniques: strengthening of cracks and voids in concrete using specialized grouts;
- replacement of structural elements: removal of damaged components and installation of new ones;
- frame extension: creation of additional frameworks to support added floors or superstructures.

3.4.3 Technological Aspects of Reconstruction

The technological aspect involves the use of modern methods, materials, and technical solutions to achieve the maximum effectiveness of reconstruction. The main tasks of the technological aspect include:

- selection of the optimal reconstruction technology (e.g., non-destructive testing such as ultrasonic inspection and laser scanning; digital modeling of structures using software such as BIM, SAP2000, LIRA);
- ensuring technological compatibility (use of materials that are compatible with the existing structure);
- improvement of energy efficiency (thermal insulation, window replacement, installation of energy-saving engineering systems);
- automation and modernization of engineering systems (installation of modern ventilation, heating, and air conditioning systems, as well as automated fire safety systems);
- organization of the construction process (phased execution of works to minimize impact on the surroundings; use of modern equipment for dismantling and assembling structures).

Reconstruction of buildings and structures is a multifaceted process that incorporates architectural, structural, and technological aspects. A balanced integration of these three dimensions ensures the preservation of historical value, improved functionality, durability, and aesthetic appeal of the structure. The use of modern technologies, materials, and tools allows reconstruction projects to be implemented at a high level, meeting current requirements and challenges.

3.5 Reasons for Repair and Reconstruction

Classification by characteristics.

The first group of reasons for repair and reconstruction includes deterioration of the physical condition of individual structural elements or the building as a whole, expiry of the service life, the properties of the construction materials used for specific elements and assemblies, operating conditions, and related factors.

The second group of reasons includes circumstances that justify changes in the functional use of the building or its adaptation to modern conditions, including comfort, aesthetics, or functional efficiency.

3.6 Physical and Moral Deterioration

Buildings and structures as well as their structural elements, engineering equipment, and interior finishes undergo both physical and moral (functional or aesthetic) deterioration during their operation.

Physical deterioration refers to the loss of original technical and operational characteristics of a structure, element, or building as a result of natural environmental factors and human activity. At the moment of assessment, physical deterioration is expressed as the ratio between the cost of objectively necessary repair works (to eliminate damage to the structure, element, system, or the building as a whole) and the restored value of the item.

For structures, elements, or systems with variable degrees of deterioration across different zones, physical deterioration is determined according to the following formula:

$$\mathrm{F_к} = \sum_{\mathrm{i}=1}^{\mathrm{i}=n} \frac{F_\mathrm{i}\mathrm{P_i}}{\mathrm{P_к}}, \qquad (1)$$

where $\mathrm{F_к}$ – physical deterioration of the structure, element, or system, %;

F_i – physical deterioration of the i-th damaged section;

$\mathrm{P_i}$ – size (area or length) of the iii-th damaged section, m^2 or m*;*

$\mathrm{P_к}$ – total size (area or length) of the structure, m^2 or m*;*

n – number of damaged sections..

Formula for Physical Deterioration of a Building:

$$F = \mathrm{i} = \sum_{\mathrm{i}=1}^{\mathrm{i}=n} F_{\mathrm{кi}} L_\mathrm{i}\,, \qquad (2)$$

where F – physical deterioration of the building, %;

$F_{к\mathrm{i}}$ – physical deterioration of the iii-th structural element or system, %.

L_i – weighting factor (cost proportion or significance) of the iii-th component in the total building value.

Table 4 – Cost Weight of Structural Elements in the Total Value of the Building

No.	Structural Elements	Weight, %
1	Foundations	7
2	Walls and partitions	40
3	Columns	4
4	Floor slabs and roofs	10
5	Roofing	3
6	Stairs	3
7	Floors	6
8	Windows and doors	4
9	Finishes (including plastering)	8
10	Engineering systems and utilities	12
11	Other elements	3
Total		100

Moral deterioration of a building refers to its functional and technological obsolescence caused by technological progress, as well as a decline in the building's qualities related to comfort, amenities, and suitability for modern needs. This type of deterioration often occurs earlier than physical deterioration—for example, due to changes in technological equipment.

Moral deterioration occurs independently of physical (material) deterioration and results in the loss or reduction of the building's functional performance due to changes in normative requirements concerning layout, amenities, or comfort standards. The combined degree of physical and moral deterioration defines the economic service life of buildings. This is an estimated time period after which full reconstruction or replacement of structures becomes necessary.

3.7 Service Life of Structural Elements

The service life of structural elements refers to the calendar time during which, under the influence of various factors, the elements reach a condition where further operation becomes impossible or restoration is no longer economically viable. The service life of a building is determined by the service life of its unchangeable structural components, such as foundations, walls, and frame elements.

The economic service life of a building is an approximate period after which complete reconstruction or replacement of structural elements is required. The minimum service life of individual structural elements is presented in Table 5.

Table 5 – Minimum Service Life of Building Structures and Structural Systems

Building Elements	Service Life, years
1	2
Foundations	
Strip foundations on complex or cement mortar	50
Strip foundations on lime mortar and brick foundations	50
Strip concrete and reinforced concrete foundations	60
Rubble stone and concrete piers	40
Piles	80
Timber foundation structures	15
Large-panel walls with thermal insulation layer of mineral wool and fiber cement	50
Large-panel walls made of lightweight concrete	30
Load-bearing masonry (brick walls 2.5–3.5 bricks thick) and large-block masonry on complex or cement mortar	50
Standard masonry walls (brick walls 2.5–3.5 bricks thick)	40
Lightweight masonry made of brick, slag blocks, and shell limestone	30
Hand-hewn log walls and solid timber walls	30

Continuation of Table 5

1	2
Prefabricated panel and frame-infill timber walls	30
Rammed earth and adobe walls	15
Sealing Joints of External Wall Panels with Mastics	
non-hardening	8
hardening	15
Floor structures (ceilings)	
Reinforced concrete and monolithic slabs	80
Brick vaults or concrete infill over steel beams	80
Timber floors on timber beams with plaster, intermediate floors	60
Timber attic floors	30
Lightweight unplastered timber floors on timber beams	20
Timber floors on steel beams	80
Thermal insulation layers of attic floor structures	
Foam concrete	25
Foam glass	40
Fiber cement	15
Expanded clay and slag	40
Mineral wool	15
Mineral boards	15
Floors	
Ceramic tiles on concrete base	60
Cement floors	30
Cement floors with marble aggregate	40
Tongue-and-groove timber flooring on floor structure	30
Tongue-and-groove timber flooring on ground	20
Parquet	
Parquet – oak, nailed / glued	50\60
Parquet – beech, nailed / glued	40\50
Parquet – birch or aspen, nailed / glued	30\20
Parquet panels	20
Hardboard flooring	15
Mastic flooring on polyvinyl acetate mastic	30
Asphalt flooring	8
Linoleum	10
Linoleum on felt base	20
Polyvinyl chloride (PVC) tile flooring	10

End of Table 5

1	2
Stone flooring:	
Marble	50
Granite	80
Stairs	
RC landings, steps on steel or RC stringers	60
Overlay concrete steps with marble aggregate	40
Timber stairs	20
Balconies and Loggias	
on steel cantilever beams with monolithic RC infill or precast slabs	60
Balconies on RC cantilever beams and slab structures	80
Roofs	
precast RC rafters and battens	80
Timber rafters and battens	50
Insulation layers of flat ventilated/non-ventilated roofs:	
foam concrete / foam glass	40\30
Insulation layers: expanded clay	40
Insulation layers: mineral wool	15
Insulation layers: mineral boards	20
Roof covering:	
galvanized steel	15
Plain carbon steel	10
Roll materials	10
Ceramic roof tiles	60
Corrugated asbestos-cement sheets	30
Partitions	
slag concrete, concrete, or brick (plastered)	75
Gypsum or gypsum-fiber board partitions	60
Gypsum plasterboard partitions on timber frame	30

Practice shows that the service life values provided in Table 5 do not always correspond to the actual service durations of specific structural elements.

3.8 Classification of Buildings

According to their construction periods, the existing stock of public buildings can be conditionally divided into several groups:

- buildings constructed before the 19th century;
- buildings constructed in the late 19th to early 20th century;
- buildings constructed between the mid-1920s and the late 1950s;
- buildings constructed from the 1960s to the present day.

Depending on the wall and floor structure materials, buildings in Ukraine are classified into groups as listed in Table 6.

Table 6 – Classification of Public Buildings by Structural Capital Intensity

Building Group	Building Classification	Service Life (years)
1	Capital buildings with reinforced concrete or steel frames and masonry infill	175
2	Capital buildings with artificial stone or large-block walls; reinforced concrete or brick columns or piers; reinforced concrete or masonry floors; vaults over steel beams	150
3	Buildings with artificial stone or large-block walls; reinforced concrete or brick columns and piers; timber floors	125
4	Buildings with lightweight masonry walls; reinforced concrete or brick columns and piers; timber floors	100
5	Buildings with lightweight masonry walls; reinforced concrete or brick columns and piers; timber floors	80
6	Timber buildings made of logs or hand-hewn log walls	50
7	Timber frame and panel buildings	25
8	Buildings made of reed concrete and other lightweight materials	15
9	Tents, pavilions, kiosks, and other lightweight commercial buildings	10

3.9 Specific Features of the Repair and Reconstruction of Public Buildings

Repair and reconstruction works on public buildings involve a number of specific features that complicate construction processes and reduce efficiency. The main difficulties are due to the fact that such works are typically carried out in densely built-up urban environments with active infrastructure. This limits the possibility of using standard technologies and modern equipment, complicates logistics, and affects safety. Key features include:

1. Limited construction site space. Tight conditions hinder the placement of equipment and materials and complicate transport movement. The use of large-scale machinery is restricted. The sites may be: attached, integrated, combined, or volumetric (see Fig. 2).

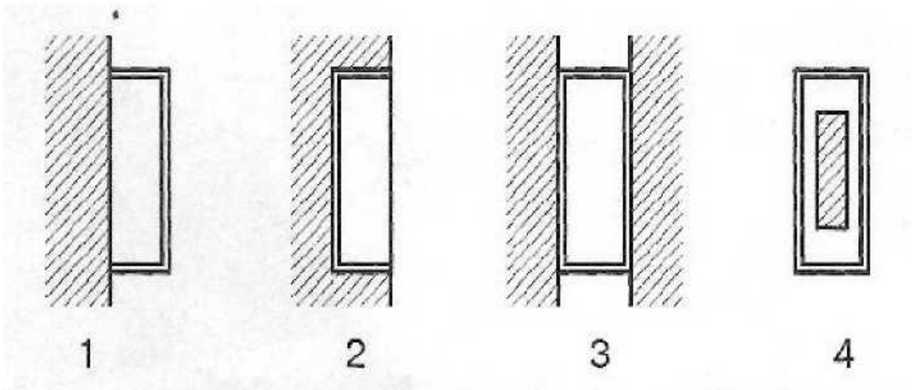


Figure 2 – Types of construction sites: 1 – Attached; 2 – Integrated;
3 – Combined; 4 – Volumetric

2. Complex configuration of the structure. Due to previous extensions or reconstructions, buildings often acquire an individual layout. A tailored approach is needed when choosing methods of work execution. Non-standard architectural and structural solutions are frequently encountered.

3. Limited accessibility of the facility. Facilities may be fully, partially, or completely inaccessible. Works are more difficult when the premises continue to operate during reconstruction.

4. Special operational conditions. It is necessary to account for ongoing transport, industrial, and domestic activities. Frequent work interruptions are caused by the building's operating schedule. Compliance with occupational safety and health regulations is mandatory.

5. Presence of additional works not typical for new construction. These include demolition, reinforcement, or replacement of existing structures. Structural stability must be ensured during operations. The mechanization of such tasks is limited; simple tools such as hoists, winches, and jacks are used. Due to the lack of complete information on the condition of the structures, unpredictable situations often arise during work that affect the scope and rhythm of execution.

3.10 Specific Features of the Repair and Reconstruction of Industrial Buildings

The development of industry demands increased intensity of technological flows, pressure, temperature, and the presence of aggressive environments. As a result, industrial buildings deteriorate more rapidly due to mechanical stress and exposure to harsh environmental conditions.

The physical wear and potential damage to the structures of industrial buildings and facilities can be classified according to several criteria: the causes of occurrence, the mechanisms of corrosive deterioration, the severity of consequences, and the difficulty of restoration.

Moral wear, i.e., the loss of economic efficiency of industrial buildings, can manifest in two ways. The first occurs due to the gradual reduction in the original value of a structure, caused by a decrease in the socially necessary labor required for constructing similar facilities over time. This affects the feasibility of maintaining the building and its functions, especially when considering its residual value.

Residual value is defined as the difference between the replacement cost and the amount of accumulated depreciation for its restoration. The second form of moral wear arises when the existing building no longer meets the requirements of reorganized production in comparison to more advanced reference buildings. This mismatch may be due to non-optimal column grid spacing, plan configuration, floor height, structural capacity, ventilation, air conditioning, and other factors.

During the reconstruction of industrial facilities, the following core objectives are addressed:

- adapting the building's spatial configuration to meet updated production requirements or, if its function changes, to the needs of new workshops or departments;
- enhancing the performance characteristics of existing load-bearing and enclosure structures in line with new production demands;
- modifying key building parameters (such as plan layout, height, and column spacing) to accommodate production developments and enable construction without halting technological processes;
- upgrading engineering systems to satisfy the needs of modernized production and provide adequate working conditions in compliance with regulations;
- improving the architectural and aesthetic qualities of the building and its interior, aligning with modern design standards and principles of industrial aesthetics.

In most cases, technical upgrades and reconstructions involve equipment replacement, space reorganization, and revised distribution of sections and departments. Reconfiguration may also be driven by updated sanitary and fire safety requirements. Additionally, enhancing production culture may require reorganizing interior layouts to achieve clear composition and well-defined functional zones within workshops.

Architectural design during reconstruction is shaped by several factors: implementation of new technological processes and equipment that improve productivity and require stable microclimate conditions in workshops; increased demands for engineering infrastructure; comprehensive mechanization and automation of production; the integration of automated production management systems; and the shift toward new spatial organizational concepts. These shifts result in changes to layout structures and functional zoning.

Construction works in active production environments differ significantly from new builds due to constraints uncommon to greenfield projects. The limited workspace and the need to coordinate with ongoing operations complicate the process. Furthermore, existing design and structural systems often limit the use of optimal construction machinery and sequencing, leading to increased labor intensity, unproductive time losses, inefficient equipment use, and financial losses that are not always offset by adjustment coefficients in cost estimates.

This is particularly relevant to dismantling and installing structural components. Reconstruction often involves tasks unnecessary in new builds, such as dismantling, reinforcement, replacement of individual elements, and demolition. These activities require maintaining the stability of retained structures, and mechanization is difficult in working environments. Simple lifting tools such as winches, pulleys, and jacks are typically used, leading to increased setup costs and greater labor input.

These operations are technologically complex and require special methods, advanced techniques, and highly qualified personnel. They often necessitate tailored solutions, raising costs and extending timelines. Such tasks might include reconfiguring industrial equipment, rebuilding partitions, or replacing flooring. Due to their difficulty and potential hazards, such works require appropriate safety equipment and procedures.

In today's environment of rapid industrial development in Ukraine and abroad, the pace of technological change far exceeds the lifespan of industrial buildings. While buildings and structures may remain in use for 50 to 100 years, technologies in machinery are updated every 10–15 years, in chemical industries every 6–8 years, and in electronics every 5 years. Thus, buildings may undergo several technological upgrades during their service life, requiring repeated modernization.

To perform such reconstructions, comprehensive investigations must be carried out to determine optimal parameters in line with the concept of renewing core assets.

Reconstruction must also comply with occupational health and fire safety standards. In addition to structural updates, energy efficiency and operational cost reduction must be addressed. Reconstruction and modernization of industrial facilities is a complex and costly undertaking, requiring resource-efficient strategies and sound management.

The environmental performance of reconstructed buildings must meet relevant ecological and sustainability standards. Prior to reconstruction, a full analysis must be carried out to define the renewal parameters for core facilities (see Figure 3).

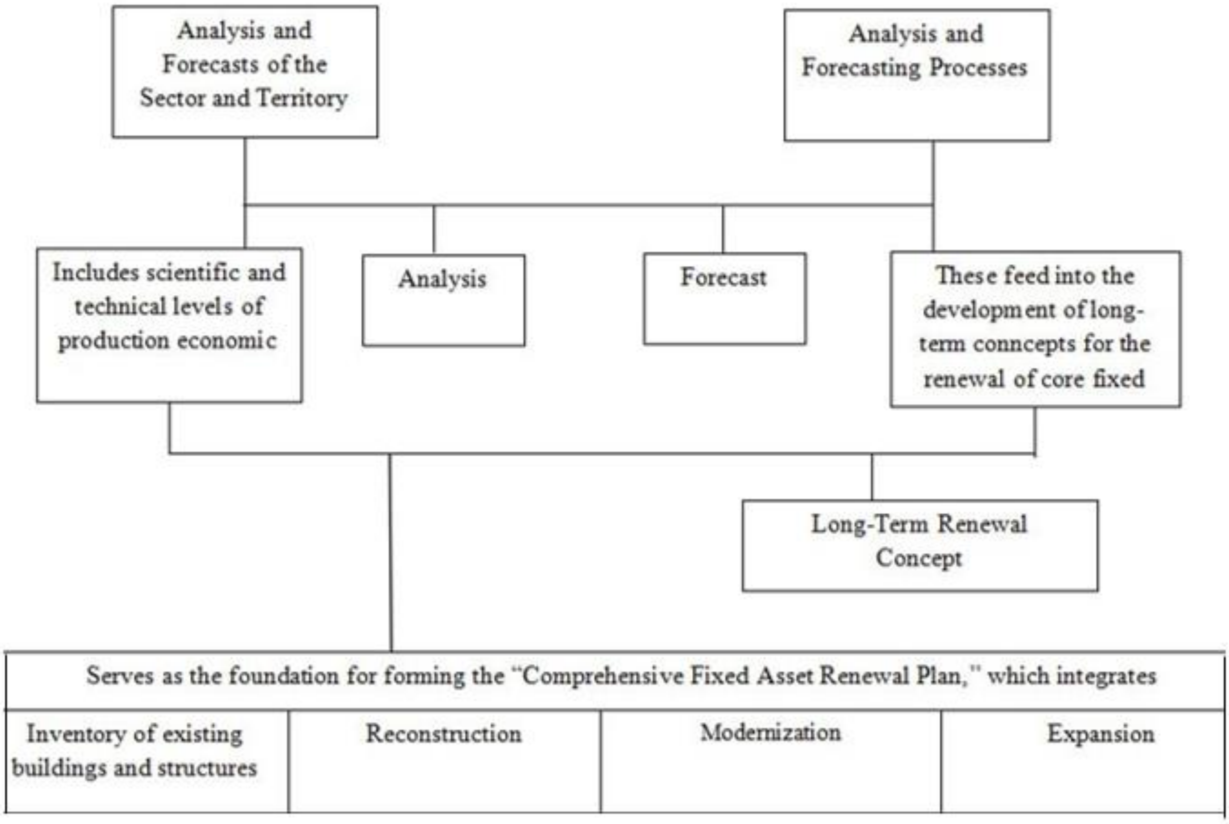


Figure 3 – Concept of General Renewal of Fixed Assets

The implementation of the proposed strategy for planning reconstruction works at industrial enterprises has the potential to address several issues related to resource efficiency and productivity improvement:

- analyzing reconstruction costs and their impact on existing infrastructure allows for a better understanding of the necessary changes to maximize production efficiency;
- development of optimal technological solutions can enhance production conditions and the overall operational environment, leading to reduced costs for repairs and maintenance;

- engineering preparation and planning help lower reconstruction expenses and improve work productivity through better resource allocation and scheduling.

In conclusion, applying this strategy can significantly increase production efficiency, enhance profitability, and reduce maintenance and reconstruction costs for industrial enterprises.

4 MODERN TECHNOLOGIES AND INNOVATIONS IN THE FIELD

4.1 Use of BIM Technologies in the Reconstruction and Inspection of Building Structures

BIM (Building Information Modeling) is a technology for creating, managing, and analyzing a digital model of a building throughout its entire life cycle. The use of BIM technologies in the reconstruction and inspection of building structures provides increased accuracy, efficiency, and cost reduction at every stage of the work. It allows for risk mitigation, improved design and reconstruction quality, and more rational use of resources.

The process of inspecting building structures traditionally requires the collection of a large volume of data on existing structural elements, their condition, materials, and properties. With BIM technologies, this process becomes significantly more efficient. Specifically:

Accurate scanning – The use of laser scanning or photogrammetry enables the creation of precise 3D models of existing structures. These models can be imported into BIM systems for further analysis and processing.

Data integration – Data from various sources (scanning, inspection, laboratory tests) can be integrated into a unified model, allowing for a complete overview of the structural condition.

4.2 Structural Condition Modeling

BIM models allow the creation of interactive 3D exhibits of the building, where the condition of various structural elements can be assessed in detail, such as.

Cracks and deformations – Problematic areas are easily detected thanks to the ability to overlay various types of data onto the model (e.g., loads, displacements).

Material wear – The model can be used to visualize material damage (concrete, steel, wood) and analyze their condition based on the results of inspections.

4.3 Inspection Planning and Monitoring

BIM enables effective planning of structural inspection stages, ensuring:

- **team coordination** – all participants in the inspection process (engineers, architects, designers) can work within a single information environment, reducing the likelihood of errors;
- **change monitoring** – all changes in the condition of structures recorded during the inspection can be saved and displayed in real-time within the BIM model.

The use of BIM technologies in the reconstruction and inspection of building structures significantly enhances the efficiency and accuracy of operations. From the creation of precise models of existing structures to the optimization of the reconstruction process and subsequent maintenance, BIM technologies become an indispensable tool for ensuring high quality, reducing costs, and minimizing risks. This not only improves the design and reconstruction processes but also lays the foundation for more sustainable and long-term use of buildings.

Self-Assessment Questions for Section 1

1. What requirements are imposed on buildings and structures?
2. What factors determine the durability of buildings?
3. What are the structural characteristics of residential buildings from the pre-revolutionary and pre-war periods?
4. What circumstances must be considered when assessing historical buildings?
5. How many categories of durability (capitality) exist for residential buildings, and what do they represent?
6. How many durability categories exist for public buildings, and what are their characteristics?
7. Under what conditions are service life terms for buildings established?
8. How is the physical deterioration of buildings assessed?
9. How is the moral (functional) deterioration of buildings determined?
10. What factors indicate the durability and degree of deterioration of industrial buildings?
11. What criteria are used to classify possible structural damages?
12. What can be said about the categories of damage?
13. How are the main groups of reliability and durability requirements for structures characterized?
14. What measures should be taken to extend the preservation of operational performance in structures?
15. What aspects are most important when assessing the technical condition of buildings, structures, and their structural elements?
16. What forms the basis for conducting structural surveys?
17. What types of work are carried out during a structural inspection?
18. What do comprehensive and selective inspections involve?
19. What technical tools and devices are used during building structure inspections?

20. What are local and general deformations of buildings?

21. What is the purpose of structural defectoscopy?

22. What are the main defects in metal and timber structures?

23. What are the main defects in reinforced concrete structures?

24. What is the essence of the impulse ultrasonic testing method?

25. What does a scheduled preventive maintenance system for buildings and structures include?

26. What is the difference between routine and capital repairs of buildings?

27. How is the frequency of maintenance for residential and industrial buildings determined?

28. What documentation is maintained by maintenance services?

29. What types of inspections are performed for residential and industrial buildings, and at what intervals?

30. What is the purpose of building reconstruction and modernization?

31. What are the features of building maintenance? What typical damages affect the failure of residential buildings?

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