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SERVICE LIFE AND DURABILITY OF ARCHITECTONIC STRUCTURES

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Abstract. *The paper is based on the analysis of bearing architectonic structures, properties of material, durability depending on the impacts they are exposed to. The research is aimed at defining the method of increase of durability of architectonic structure.*
The damage to the bearing structure concept would mean the damage to functionality, form and esthetics of the structure. The choice of materials and systems of bearing structure is important from the aspect of architectonic designing, formation and functionality, but also of safety and reliability. In that sense, structure durability is multiply important, both for the architectonic form and for the importance of the structure. The choice of materials and design of forms and connections in the structure is very important for improvement of durability.

Key words: *Architectonic structures, durability, contemporary materials, rehabilitation*

1. INTRODUCTION

Bearing architectonic structures have a very significant place in architecture. Recent research, accompanied with technical regulations, increasingly stress the importance of structure durability, so the choice of materials, static system, form of designed structure is performed depending on the chosen durability and importance of the structure. A new term has been introduced in designing of the structure according to durability, i.e. design according to the service life of a structure. Durability of structures is also important for the reasons of investment costs of building and maintenance of structures.

Durability of materials depends primarily on the type of material, its elasto-mechanical, physical and chemical properties, and also very important is the factor of the environment where the structure is situated. All the building materials in time lose their initial characteristics and material deterioration process begins. In an attempt to obtain and eternal structure, throughout history, oversized structures with very high safety

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coefficient were built. Nowadays, the safety coefficients both for materials and for loads are precisely defined, so there is no justification for construction of such structures. One of the ways to extend longevity of structures is the choice of materials which are very durable, or by increasing the cross section, i.e. the protective coating of concrete over the reinforcement bars, and anti-corrosion protection. proper design and construction of the structures is very important for durability. It must be emphasized that human care, monitoring, repairs, cleaning and maintenance is very important for durability of materials and structures.

Study of durability of materials in the structures is related to the study of the living environment and effects of the environment on the structure. Building of structures consumes a lot of natural resources, as well as energy, so it is a very important factor in this analysis.

Designing according to the service life, or durability is specified in contemporary technical regulations, with clear definitions, procedure and terminology. Structural durability comprises primarily the study of potential damage to the material of the structure depending on the purpose and living environment, i.e. climatic environment the structure. According to the analysis of the agents, the system of bearing structure, for the design working life of the structure is chose. The agents can be physical, chemical, biological and mechanical. Primarily, the paper analyses whether the structure is protected from or exposed to weather impacts, if the structures is exposed to the action of chemically aggressive matters, UV radiation, and the danger from the impact load by the vehicles, airplanes etc, and whether the structure is situated in soil, water or air.

The quality analysis of damage factor in designing can extend the structural life, by designing details with proper drainage, protective coating and insulations, proper shaping of details providing ventilation, and access for cleaning, inspections and interventions.

During the service life a structure sustains damage and for this reason monitoring of the structure is required, in order to react in good time and perform the necessary repairs. As a rule, there should be a well structures system of monitoring of all changes on the structure, identification of damage in order to reduce maintenance costs. The maintenance costs during the life time of a structure are very important segment of the total cost of a structure, because these costs can exceed the value of the newly built structure, so it is often more profitable to demolish an old one and construct the new structure. The inspection of the damage, mostly visual, identifies the damage. In case of large structures, there is an electronic monitoring of structural behavior and damage identification. Most frequently, what is identified is surface damage such as cracks, material wear, erosion, etc. The character of the damage, i.e. crack (crack morphology) frequently indicates the possible cause of the damage. It is very important to monitor the cracks throughout a long time interval. In case of serious damage, it is necessary to perform laboratory test. On the basis of that analysis the diagnostics of the condition of the bearing structure must be conducted, and perform rehabilitation.

Rehabilitation usually requires that the structure has the designed bearing capacity, but often it requires enhanced bearing capacity so it is necessary to design strengthening. In time, the material characteristics degrade, which complicates the problem. The strengthening of the structure can be performed by changing the static system by adding new bearing elements, by connecting the existing element with the new one by increasing the cross-section dimensions, and by using contemporary carbon and fiber-glass polymers for rehabilitation.

2. BASIC CONCEPT AND DEFINITION

Nowadays a new concept is increasingly discussed, and it is (service life design), which a novelty in design of bearing structures of buildings in the European technical regulations requirements. Durability in the provisions of this regulation is treated equally as bearing capacity – mechanical resistance or stability of the structure. The service life comprises the time period during which the planned properties and behavior of the structure are maintained. Durability of structures is nowadays paid great attention in the world, because insufficient durability of structures directly requires large financial investment. The consequences of executing construction works using materials which do not correspond to the design properties, irregular and improper maintenance, as well as the insufficient attention for the issues of durability in design of the structure, lead to the reduction of durability.

2.1. Service life and life cycle of structures

Terms and definitions (For the purposes of EN 1990, the terms and definitions are derived from ISO 2394 and ISO 3898)

Design working life assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary.

Maintenance set of activities performed during the working life of the structure in order to enable it to fulfill the requirements for reliability

Technical service life is the period for which a structure can actually perform according to the structural requirements based on its intended purpose (possibly with necessary maintenance but without major repair).

Functional working life is the period for which a structure can still meet the demands of its (possibly changing) users (may be with repairs and or adaptations).

Economic service life – is the period for which structure is in use until its replacement becomes economically more profitable than maintenance cost.

Reliability, ability of a structure or a structural member to fulfill the specified requirements, including the design working life, for which it has been designed. Reliability is usually expressed in probabilistic terms

In calculation, the service life is determined by:

- Defining the relevant limit state,
- Time period expressed in years and
- Degree of reliability that the limit state will not be reached during that period.

This includes design and construction cost analysis, structural failure costs, inspection, management and rehabilitation works costs, etc. The moment of intervention – repair, in terms of stopping the structural degradation process, and if necessary strengthening of the structure is very important from the aspect of bearing capacity, functionality, economy and esthetics. Preconditions of the required durability are proper planning and designing, construction of buildings, as well as regular maintenance. In order to achieve durability, it is very important to study: purpose and function of the building, micro-location conditions, and analysis of environment impact and selection of actions on the structure, choice of the bearing system of the structure, proper building material, quality of building and regular and adequate maintenance.

The research method based on the data of time monitoring of damage and ageing of bearing structure materials are based on the mathematical status prediction of the observed time period. For the designed, new and the structures in good condition, with the known characteristics of material and geometry, the probabilistic safety methods for the structures, materials and impacts are dealt with in detail, on the basis of the stochastic models known in literature, which are specified in the documents of „The Joint Committee on Structural Safety"(JCSS).

There are no stochastic models for assessment of structural limit bearing capacity for evaluation of those structures in which, in the course of time, material and geometry change due to damage and aging. Status assessments using visual methods, which are used around the world, are subjective and often unreliable, and depend on the experience and expertise of the investigating engineer. In order to obtain as realistic data as possible in case of visual methods, it is possible to develop a number of measures and procedures for improvement of objectivity and quality of results. Reliability relates to the bearing capacity, serviceability and durability of the structure.

Durability is in the standard ISO 2394:2015 defined through the design working life, and in EN 1990: 2002 the table 1: Indicative design working life is provided.

Table 1 Indicative design working life

Design working life category	Design working Examples Indicative life (years)	Examples
1	1 to 5	Temporary structures (1)
2	25	Replacement structural parts, e.g. gantry girders, bearings
3	15 to 30	Agricultural and similar structures
4	50	Building structures and other common structures, not listed elsewhere in this table
5	100 or more	Monumental building structures, highway and railway bridges, and other civil engineering structures

(1) Structures or parts of structures that can be dismantled with a view of being re-used should not be considered as temporary

Reliability includes:

- **Bearing capacity (safety)** (to actions, loads)
- **Serviceability** (for deformations, vibrations and damage) and
- **Durability of the structure**

Basic structural requirements according to EN 1990: 2002

- Limit states with partial safety coefficients
- Actions in compliance with EC-1:EN 1991
- Calculation of bearing capacity, serviceability and durability in accordance with EC for structures

3. Environment – Structure Interaction

The choice of building materials can be made based on the analysis of the service life of the structure, on one hand taking into account the durability of material, its mechanical characteristics, resistance to aggressive environment and choice of material with minimum negative impact on the living environment. On the other hand, the price of material as well as social requirements, such as the heat comfort, esthetic characteristics and constructions rate also influence the choice. The choice of materials is made by optimizing the environmental, economical and social factors (local materials). The choice of materials aimed at the least negative impact on the living environment is a part of LEED system (Leadership in Energy and Environment Design). The requirement is for the renewable material, whose production has low energy demand, and causing small pollution of the environment, that is low emission of hazardous substances during production and service.

The most important aspects of the environment are:

1. Consumption of material and energy and
2. Their emission into environment during the entire cycle of production and duration, which includes:
   - Usage and transport of raw material,
   - Industrial processing of products,
   - Transport to the place of usage,
   - Construction or fitting process,
   - Service and maintenance of structures and
   - Waste management.

Production of building materials and construction itself requires high consumption of energy and water, creation of waste, increase of global emission of gasses and greenhouse effect, external and internal pollution and exhaustion of natural resources. Annually, for construction of buildings: 25% of felled timber, 40% of stone, sand and gravel and 16% of water are used. As a result of their action, 50% of greenhouse gasses and acid rain agencies are generated. For production and construction of buildings, almost 3 billion tons of raw materials are consumed. Also, the energy is used for excavation, transport, processing of construction materials and construction of buildings.

When producing materials for bearing structures, the consumed energy can be represented by the relative energy consumption index, where consumption of energy for production of timber is interactively assumed to be:

Table 2 Index of relative energy consumption

	Structural material	Index of relative energy consumption
1	Timber	1
2	Concrete	3
3	Steel	17
4	Aluminum	70

Table 3 Index of relative carbon emission

	Structural material	Index of relative carbon emission
1	Timber	1
2	Concrete	8
3	Steel	21
4	Aluminum	264

Bearing structures of buildings, according to the current European Regulations for the structures are designed so as to satisfy the requirements of BEARING CAPACITY, SERVICEABILITY AND DURABILITY. A fourth requirement should be added to this, and that is: the impact of interaction, construction and living environment which should be in range of some given criteria, valid for all the phases of the life cycle of the structure. These impacts are expressed through the following categories:

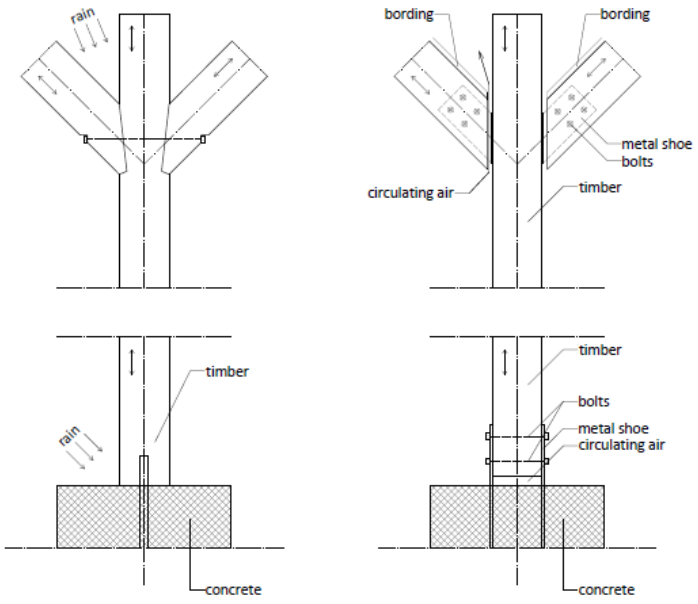
- Global warming
- Acidification
- Eutrophication
- Photo-chemical formation of ozone
- Reduction of non-renewable resources (stone, sand, iron)
- Reduction of non-renewable energy sources (oil, coal)
- Waste disposal
- Noise, dust, vibrations

The hazardous effects of concrete are small, in comparison to other building materials, but due to the massive production, the cumulative effect of concrete structures on the environment is considerable. After water, it is the second most used material on the planet. Each year, concrete industry in the world consumes 1.6 billion tons of cement, 10 billion tons of rock and sand and 1 billion tons of water. Each ton of cement requires 1.5 tons of limestone and usage of energy obtained from fossil fuels. In addition, it is estimated that its consumption will be doubled in the following 30 years. Nowadays, great attention is paid to designing of concrete structures regarding their impact on the environment, with an aim to minimize, as possible, its impact during the entire life cycle.

4. Designing Preventive Protection of Structures

Designing of protective covers of a structure exposed to wetting, (especially in timber and steel structures), where the protective cover is both esthetic and protective element, to be replaced at certain intervals, and the structure has a longer service life (Fig. 1).

Designing of bearing structural details based on the analysis of adverse effects on the vulnerable contacts of tie or bearing elements where dampness or impurities tend to accumulate (Fig. 2). Skilful structural measures can provide ventilation and access for cleaning and inspection of those spots.



a)Wrong solutions b) Correct solutions

Fig. 1 Details of constructive ties

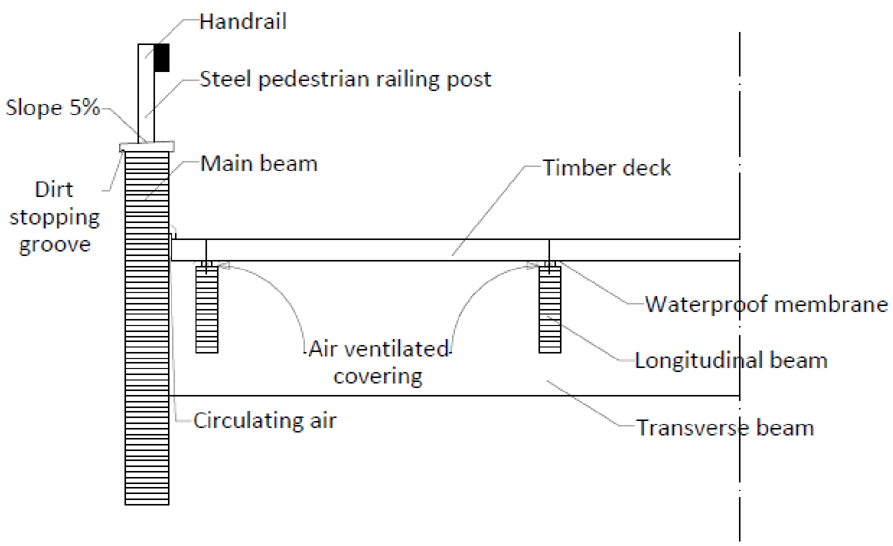


Fig. 2 Examples of ties exposed to wetting - correct solution

- Contact surfaces are pressed against each other, and moisture is retained there and its the vulnerable spot.
- Contact surfaces are separated by distancers, providing ventilation and drying of element joints

Design of tie details exposed to weather, at the example of the timber strut, instead of the classical joint which deteriorates rapidly because of water absorption at the contact spot, a tie with profiled sheet metal which facilitates total distancing of timber elements and proper ventilation (rapid drying) of the joint is recommended.

Detail of proper design of facade draining with an overhang preventing wetting of lower elements is illustrated in (Fig..3)

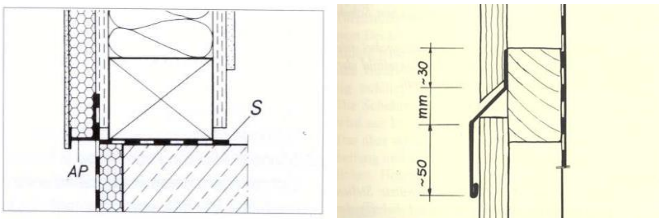


Fig. 3 Detail of facade draining

4.1. Preventive measures

Preventive measures for protection of roof structure or bearing façade elements can be at the same time repair of the roof cover or façade cladding. Proper design of supports (Fig. 4.), where the timber is not resting directly on the foundations, but via profiled metal footing or special support. Such joints are good for ventilation, control and maintenance.

Fig. 4 Details of supports-correct solution

- Preventive measure of protection of reinforced-concrete structure exposed to weathering and chlorides is construction or repair of hydro-insulation, proper draining, proper fitting of downspouts and covers.
- Preventive measure of protection of a steel structure is anti-corrosive protection and its repair in the course of time.
- In case of metal structures, details with recesses where water can accumulate are avoided, and usually those places are perforated for drainage and drying.
- Other preventions, monitoring of the structure, regular control, testing, status diagnostics, and timely repair of damaged parts of structures.

5. CONCLUSION

Formation of the structure form, retention of its esthetic values and function, preservation of property and human lives, in service, is a task of the bearing structure of the buildings. For years in designing, care was taken of bearing capacity, i.e. the issues of balance, load and stability on one hand, and deformation and vibrations on the other hand. The concept of durability is a new concept of structural design according to the service life. This is a large improvement of regulations, where in addition to the two already mentioned criteria, behavior and monitoring of structures in time is introduced, until the service life is reached. This facilitates monitoring and interventions on the structure, in order to retain basic purpose and function and retain necessary safety of the structure. The principles of sustainable architecture pose new requirements in terms of applied materials, and primarily, it is demanded that the building material is renewable, and that production of the material has low energy demand and that it causes low emission of dangerous matter during production and operation.

Durability, bearing capacity, functionality and serviceability of bearing structures primarily depend on the durability of materials they are made of. Durability of materials is directly related to the environment conditions of the structure. All building materials are corrosive, so it is necessary to adequately protect them. The protection is performed starting from the design of the structure, to the final treatment of surfaces after construction. The structural durability requires regular inspection and maintenance. For that purpose, a plan for inspection, control and maintenance must be made and the planned activities must be conducted. Design of the structures according to the service life is a contemporary designing concept which has been widely implemented.

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UPOTREBNI VEK I TRAJNOST ARHITEKTONSKIH KONSTRUKCIJA

Rad je baziran na analizi nosećih arhitektonskih konstrukcija, svojstava materijala, trajnosti u zavisnosti od dejstava kojima su izložene. Istraživanje je usmereno ka definisanju metoda povećanja trajnosti arhitektonskih konstrukcija.

Oštećenje koncepta noseće konstrukcije, značilo bi i povredu funkcionalnosti, forme i estetike objekta. Izbor materijala i sistema noseće konstrukcije je važan sa aspekta arhitektonskog projektovanja, oblikovanja i funkcionalnosti, ali i sigurnosti i pouzdanosti. U tom smislu, trajnost konstrukcije višestruko je važna, kako za arhitektonsku formu tako i za značaj objekta. Izbor materijala i projektovanje oblika i veza konstrukcije je veoma važno za povećenje trajnosti.

Ključne reči: *Arhitektonske konstrukcije, trajnost, savremeni materijali, sanacija*