Models of co-evolution of structural elements of building composites

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Abstract. It is shown that construction material changes its properties as a result of operational loads action. There are situations when construction leaves its working state with satisfactory material characteristics. This is due to the process of formation and development of cracks as structural elements. The article proposes to analyze history of the development process, which makes it possible to study mechanisms of its flow and to determine factors of process control. The analysis of the studies carried out on the effect of prescriptional and technological factors on the properties of materials and products, the phenomena of self-organization and the role of cracks in materials and products showed that the emergence of critical events cannot be foreseen when assessing properties accepted by averaged characteristics. The construction is considered to be a complex self-organizing system. This determined the work aim: to justify the choice of dynamic models, allowing to determine the structure elements, interaction of which ensures functional state of the structure. The qualitative method of verbal description of the structure of systems with the use of cognitive approaches was laid in basis of adopted methodology. Conservative, metastable and active elements are distinguished in the construction-system. It is emphasized that the active history of the system is determined by active elements, to which cracks refer to. Cracks are considered as some necessary structural elements, present at all scale levels. It is shown that the formation of cracks-systems, treated as parasitic systems, terminates the end of construction-system development and the beginning of parasite system development. Completion of crack-system life cycle removes the construction-system from its working state. To get constructions with a given set of structural elements, a creative community of materials and designers is needed, which will create a common terminology dictionary for both specializations.

1. Introduction
Construction products and structures in the period of operation perceive a complex of normalized and non-normalized power loads and loads connected with environmental effects (seasonal and diurnal changes in temperature and humidity). Under the influence of such influences, the properties of materials change, which inevitably affects the properties of products and structures. The level of change in the properties of materials is regulated by regulatory documents, which allows you to quantify the current state of the structure. The accumulated experience has shown that with satisfactory average values of the required material properties, a critical situation can arise in the design. As a rule, critical events are localized and are associated with the formation of a new component for the material and construction of the component – a crack. The process of crack development is initiated by external and internal factors and provokes structural rearrangements in the material and the redistribution of stress and strain in the structure, which can stimulate further deepening of the process of crack development to critical parameters. Any process, including the...
process of crack growth, cannot be analyzed by stopping it. Therefore, in order to establish the management factors, it is necessary to study the history of the development of the process, which will allow us to develop an idea of the mechanisms of its flow taking into account the time factor.

The compulsory presence of the history of development makes it possible to trace the structural transformation of the material and product taking into account that there are no "good" or "bad" elements – they are all parts of the whole. Representation of the material and construction in the form of an inseparable integrity allows us to consider the design as an open complex self-organizing system [1,2,3]. The system does not exist outside its structural design. Professor Solomatov V.I. and his followers emphasized the structural structure of composite building materials and products. The interrelation and mutual influence of different levels of structural components is noted in the works of Konokhov P.G., Krivenko P.V., Bolshakov V.I., Derevyanko V.N., Plugina A.N. and Plugin A.P., Runova R.F., Vandalovsky A.G., Bratchun V.I., I. Shtark, Fainer M.S., Shinkevich E.S. and many other native and foreign researchers.

The processes of self-organization during the formation of the structure of exploitation of building composites are devoted to the works of Korchakava M.D., Seynich L.A., Pushkareva E.K., Barabash I.V., Bobryshov A.N., Khrulev V.M., Chernyavsky V.L., S. Fits and others. The role of cracks in the formation of the properties of materials and structures is shown in the studies of Karpenko N.I., Piradov K.I., Zaitsev I.V., Dorofeev V.S., Bolotin V.V., Grushko I.M., Luchko I.I., Solodyk S. I., Leonovich S.N., R. Lermit. The influence of prescription and technological factors on the formation of the properties of building materials and products has been studied in the studies of Voznesensky V.A., Dvorkin L.I. and Dvorkin O.L., Koval S.V., Sheinin A.E., Akhverdov I.N., Sanytsky M.A., Gorchakov T.I. and many other researchers.

All of the above studies (and many others) are carried out, as a rule, within the framework of the current paradigm, which emphasizes that the level of the final properties of materials and products is determined by the initial composition and technological conditions for obtaining materials and their processing into a structure. In the final design, the material is considered as a kind of given outside the history of its formation and outside the specifics of its structural design. The mismatching of the terminology of technologists-materialists and designers does not contribute to the development of joint configurations of interactions. It is obvious that there are no products and structures outside their material filling, as there is no material without its constructive design. The system approach allows organically to combine material and construction into an inseparable whole – a system with a given objective function. In such a system, the principle of complicity of all structural elements in the functionally oriented behavior of the structure-system is realized. When analyzing a structurally structured system, it is possible to create a common terminological dictionary that will mutually expand the conceptual apparatus of materials scientists and designers and create the prerequisites for other basic models that shape our professional and scientific views and beliefs.

To implement the declared approach, a task was identified on the justified choice of dynamic models, allowing to determine a set of elements of the structure, the presence, interaction and development of which ensures the operational functional state of the system design.

2. Research methodology
In the initial description and analysis of the construction-system, the verbal method of description [4] is appropriate. It allows to reveal the structure of the system at a qualitative level, to establish the basic processes of its development, to describe the mechanisms of interaction between different-scale structures. In turn, the verbal method is basic in the implementation of cognitive approaches, which aim to investigate the processes of perception, categorization, comprehension and explanation of objects, as well as the representation and storage of knowledge [5,6]. The cognitive approach is appropriate in cases: – if the interconnectedness of the processes leads to the need to consider individual phenomena in their totality; – in the absence of sufficient quantitative information on the dynamics of structural development; – with the development of self-organization processes, which
makes it difficult to build quantitative models. The use of methods of cognitive modeling, based on the conduct of thought experiments, allows, with the accumulation of relevant information, to move to quantitative models. In this paper, methods of qualitative description of the construction-system are used. Previous studies [3,7] allowed to propose a classification of structural components, based on the different "sensitivity" of different elements under the influence on the design-system of external and internal factors. In the general case, it is possible to distinguish conservative, metastable and active structural elements.

Conservative (from Latin conservation – preservation) structural elements include elements that change their parameters slowly enough during the period when the object performs its functions. As a rule, conservative elements belong to a scale level on which gravity dominates and on which phenomenological approaches to property evaluation are realized.

Elements of the structure that have relative stability under given conditions and that are capable of spontaneously transitioning to a stable or unstable state under the action of external or internal factors are referred to metastable (from the Greek meta – between, after, through) the elements of the structure.

A distinctive feature of active (from Latin activus – active) elements of the structure is their ability to respond adequately to the effects tested in a commensurate time interval (one tempo-rhythm).

The entire set of structural elements system in the form of building products and structures acquires in the technological period of obtaining concrete and its processing into products. At this stage all the initial elements actively participate in the processes of a different-scale structural design with the formation of new elements of the structure of the emerging system. Situations in which the emerging intermediate structural formations initiate the initiation and development of fundamentally different elements that are part of the structure of the final product are not ruled out. Characteristic manifestations of the effects of equifinality by which in our case we mean the implementation of various mechanisms of structural organization, which lead to the appearance of qualitatively identical elements of the structure. As examples, the origin of technological cracks is considered: – when discrete structures are formed at the level of products of neoplasms and at the level of interaction of the initial grains of mineral binders; – with the development of gradients of intrinsic deformations at interfaces between hardening matrix material and aggregates; – under the action of emerging gradients of deformation at the level of products or structures.

Thus, during the functioning of the system, the system enters with a certain set of structural elements, including the presence of technological (residual, initial, hereditary) local and integral deformations. Therefore, functioning should be considered as an uninterrupted structural drift in the direction in which the effects of adaptation of the system are manifested in the conditions of the permanent impact of the operational environment. In this regard, the life cycle of the structure is proposed to be described by the history of the evolution of the structural components, Fig.1.

The co-evolution of elements of the structure that are different in form and purpose presupposes their interaction, which is the primary basis of stability—the ability of the system to maintain a dynamic equilibrium through the manifestation of internal and external security.

Particular attention should be given to cracks. The term "crack" common to materials scientists and designers, initially carries a negative connotation. A crack is a localized structure element. The phenomenon of localization leads to the disintegration of a continuous medium into separate local structures. Therefore, when a "crack" appears in the construction, then automatically the paradigm of continuity loses its meaning. Our researches give grounds to assert that cracks are an inevitable and necessary structural component at all levels of structural heterogeneities. Cracks-builders contribute to strain relaxation, including critical retain properties of the whole by changing the parameters of its own, can be transformed into the inner surface section, include a work metastable and conserved structural elements.

Interaction and mutual influence of structural elements increases the diversity of structure, contributes to the development of interstructural links, thus providing a manifestation of the
phenomena of homeostasis, which ensures the viability of the system. To realize the self-movement of the structure towards the self-preservation of the system-design, it is necessary to determine the priority series of elements capable of influencing the periods of the onset of unfavorable situations. This priority number ranks first crack, which for some reason has moved from rank-creator-destroyer crack, thereby implementing the idea of self-organized criticality [8] and determine the start of a history of the life of the system period.

From the moment of formation of the crack-destroyer (point M, Fig. 2), it is necessary to consider two histories of development of two systems – the basic design-system and the newly formed crack-system. The crack-system, by virtue of its activity, which manifests itself through the redistribution of deformations with their concentration along the crack front, the release of surface energy as the area of the fracture edges increases, various-scale cracks and interfaces become involved in its development, reoriented the functions of the basic system to itself.

Fig. 1. Co-evolution of the elements of the structure in the period of functioning of the construction-system

I – stage of formation of the system-design (¹₁); II – period of functioning of the system-design (¹₁…²₂); III – the stage of the output of the structure-system from the safe functioning (²₂…³₂)

\( S_A, S_M, S_M, S_D \) – structural components of the construction-system;

\( S_{A1}, S_{M1}, S_{K1}, S_{D1} \) – initial set of active (A₁), metastable (M₁), conservative (K₁) elements and technological deformations (\( S_{D1} \));

\( S_{A1} \ldots S_{A2} \) – change the parameters of active elements;

\( S_{M1} \ldots S_{M2} \) – change the parameters of metastable elements;

\( S_{K1} \ldots S_{K2} \) – change of parameters of conservative elements;

\( S_{D1} \ldots S_{D2} \) – change of local and integral residual deformations;

\( S_{A3} \) – change in the structural parameters of the self-developing parasitic system.
With an increase in the degree of structural diversity of the design, the level of its safe functioning decreases. During this period, the behavior of the design-system is determined by the dynamics of the development of the new system, which is referred to as the parasitic system.

This definition is legitimate in our view, since the fracture self-generated in the basic structure and draws energy for its own development from its environment – the material of the system design.

Fig. 2. Dynamic model of changing structural diversity over the lifecycle of the design-system

O – the minimum acceptable level of safe operation;
A – the necessary set of structural elements, ensuring the safe functioning of the structure-system;
(A-B) – structural transformations in the period of functioning;
B – spontaneous generation in the construction-system of the parasite system;
(B-C) – integral structural changes of the base system;
M – reorientation of the objective function of the structure-system to the goal of the self-generated system;
(C-D) – reducing the level of safe operation of the system-design;
(M-N) – active functioning of the parasite system;
N – completion of the life cycle of the parasitic system;
D – completion of the life cycle of the construction-system.

The purpose of the existence and development of a parasitic system in the complete passage of its own stages of its life cycle – from spontaneous generation through development to the completion of its existence. The completion of the existence of a crack-system is the exit of its front line to the surface of the base system. This concludes the life cycle of the parasite system, which causes the inevitable completion of the life history of the structure-system. Thus, the inflation of the structural-system structure through degeneration of the whole variety of structural components before the emergence of a new relatively simple parasite system leads to a violation of its external security and a complete exit from the functional state.
3. Summary

3.1 The presentation of building products and structures in the form of structurally organized systems at this stage of research should be regarded as a peculiar beginning of the explanation of the mechanisms of the functioning of structured objects.

3.2 This structural approach is based on an entrenched scientific ideology based on ideas and methods of systemic thinking and synergetics, for which the concept of "structure" is dominant.

3.3 The inevitable shift of paradigms towards structured objects will be greatly accelerated when creating a joint vocabulary of technologists and designers and developing a common strategic direction for obtaining system designs with the required set of necessary structure elements.

The analysis performed allows to conclude that building constructions should be considered as an independent research object due to their individual structural design, which is defining for the manifestation of the required properties. Special attention should be paid to active elements since a change of their parameters causes change of parameters of the construction structure. All stages of the construction life cycle are accompanied by the manifestation of deformations, included as an element in the general network of the processes of its creation and functioning. The propagation of deformations in the material is carried out in the form of returnable deformation waves, which are transmitted from one level of heterogeneities to another through the surfaces of partition between them. That promotes to the spontaneous generation and self-development of active elements – the technological cracks and inner surfaces of partition that determine material damage. Experimental researches allowed recommending methods for controlling the formation and propagation of deformations in the structure of the material of construction at various levels of heterogeneities. That provided the possibility of the predicted damage change as set of the active elements which define maintaining integrity and manifestation of material properties in the construction.

References

[1] Vyrovoy V, Dorofeev V, Sukhanov V 2010 Composite Building Materials and Constructions. Structure, Self-organization, Properties (TESS, Odessa)
[2] Prangishvili I 2000 System Approach and System-wide Regularities (SINTEG, Moscow)
[3] Sukhanov V, Vyrovoy V, Korobko O 2016 Structure of Material in Structure of Construction (POLYGRAPH, Odessa)
[4] Solomatov V, Vyrovoy V, Bobryshev F and others 1991 The Polystructural Theory of Composite Building Materials (FAN, Tashkent)
[5] Cherniavsky V 2008 Adaptation of Abiotic Systems: Concrete and Reinforced Concrete (DNURT, Dnepropetrovsk)
[6] Dorofeev V, Vyrovoy V 1998 Technological Damage of Building Materials and Constructions (Gorod Masterov, Odessa)