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A systemic approach of bridge-environment interaction

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Summary

The article analyses interaction between construction and environment. The construction (a highway or railway bridge) is defined as a high complexity system consisting from three sub-systems: bridge, road and the obstacle (river, a valley, another transportation infrastructure etc.).

The inputs in the high complexity system "bridge-obstacle-road" are divided into actions and perturbations. Through actions (permanent, temporary, exceptional etc.) and perturbations (erosion, corrosion, scouring etc.) the answers are revealed and analyzed. The answer is materialized through the damage condition and deterioration, primary and direct effect of the environment on the constructed system.

KEYWORDS: bank protection, bridge, database, informatics system, river channel.

1. INTRODUCTION

In general terms, by realization of a construction (i.e. a bridge for this study) a connection between two independent systems, the bridge and the environment, is produced, generating reciprocal actions.

Photo 1. Interactions environment – "bridge-obstacle-roads" system

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In time, people erected different constructions (building, dams, bridges, roads etc.) in different surroundings (territorial complexes constituted from different geographic elements, geological structures, waters, climatic condition etc.). In literature, bridges are considered constructions of great technical complexity and social importance. Scientific analysis of such constructions warrants a broad, multidisciplinary approach of all problems emerging along their life span.

In this regard, the systemic approach is proposed as study methodology for bridge/environment interaction, consisting in use of principles, concepts and methods from General Systems Theory and System Engineering.

The bridge, as a system (Fig.1) is interpreted, in this approach, as consisting from two large sub-systems: superstructure and infrastructure, and each of the, at their turn, might be regarded as composed from other subsystems. The behavior of such a system is ascertained by indicating the inputs (actions) and outputs (answers).

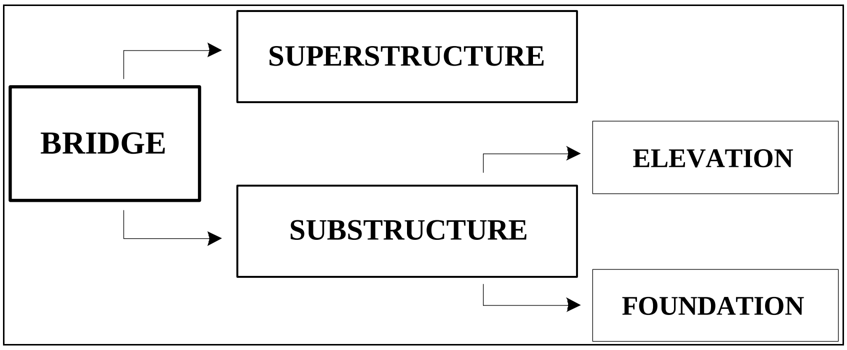

Fig.1. Sub-systems of the BRIDGE system

The system proposed for the study of the interaction bridge-environment is represented in Fig.2 and it is named, by abbreviation, “B.O.R.”. It consists from three large sub-systems: the bridge, the obstacle, and the road whose continuity is secured by the bridge over the obstacle. The bridge and the road are systems that enter in connection with the environment through the obstacle.

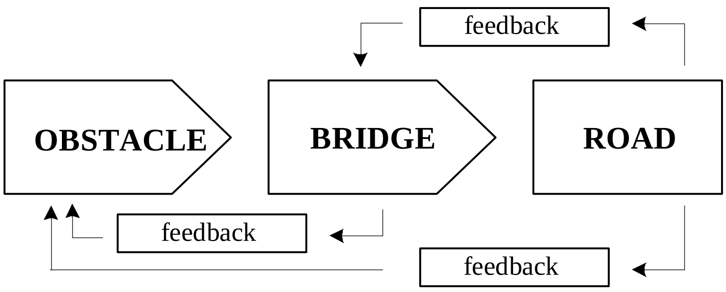

Fig.2. High complexity system “B.O.R.” (bridge-obstacle-road)

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As commonly known, the "obstacle" might be the channel of a running water (a river), a natural still water (lake), a pond or barrage lake obtained through construction of a dam which enters in the continent (lagoon, gulf).

Also, "obstacle" may be represented by a valley (no water) or transportation infrastructure (road, motorway, or railway) inside or outside a town.

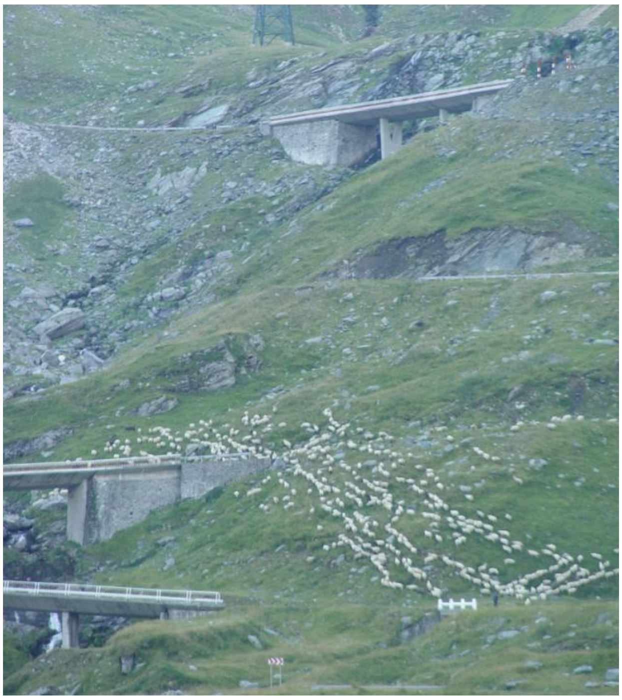

Photo 2. Bridges over valleys in mountainous area

The zone where is placed the obstacle crossed by the bridge is of great importance in the interaction phenomenon from the high complexity system "B.O.R.". In this regard one can identify: mountainous area, hilly area, field area, inhabited area (towns, villages).

The construction (bridge) influences the behavior in time of the high complexity system "B.O.R." both through the material used in the realization process and through the structural system.

In the realization of the bridges, with respect to the importance and extend, the following materials are used: wood (used less often due to short service life), stone (needs a high quantity of work and securing small spans), metal, reinforced concrete, and pre-stress concrete.

With regard to the constructive system one may enumerate beams, frames, arches, cable stayed or suspended bridges.
The interaction system "B.O.R." – high complexity system can be characterized by the following properties:

- It is composed from the set of sub-systems S_i (i=1,2,….,n):

$$S_i = \{U_i, W_i, X_i, Y_i, \varphi_i, g_i, h_i, T; \qquad (1)$$

- Dimension of the system S, expresses the fact that the dimension of the state vector $x \in X$ exceeds a certain limit;
- Structure of interaction between the S_i sub-systems has a high degree of complexity;
- The processes involved in the system S are non-linear;
- Behavior of the system S falls under the principles of uncertainty.

In the preview definition (1): the symbols U_i, W_i, X_i, Y_i denotes, respectively, the input, perturbation, state, and output sub-systems; T is the set of time variables; φ_i, g_i, h_i represents the transition, interaction and output functions.
Expression "a certain limit" used in connection with the dimension of the system, which induces itself an uncertainty (fuzzy in nature), must be specified for each subsystem.
The principle of uncertainty in high complexity systems has been expressed as follows: "state x_i of a subsystem from a system, composed by *n* interconnected subsystems and its interaction with all the other *n*-1 subsystems might be determined only up to degree of accuracy".
This principle has an important impact on modeling, simulation and control of the big systems (as the "B.O.R." bridge-obstacle-road system).
Uncertainty in the systems might be studied, due to its stochastic nature, using probabilistic mathematical models. Also, the transition of the system from a state to other can be described using Markov chains.

2. INPUT, STATE AND OUTPUT SPACES

It is known from Theory of Systems that the inputs of the system can be represented by as a space with as many dimensions as variables. A unique state variable is represented as a line, two variables as a plane etc.
Generally, for a system with *m* inputs, *n* states and *p* outputs, the set of possible inputs, states, and outputs which can be represented as spaces with *m*, *n*, and *p* dimensions.

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These spaces have the name of input space, state space and output space. Related to state space the notion of trajectory may be introduced. Trajectory of the system represents the set, order after time, of the all states the system passes through within a time interval (t_o, t_f).

Schematic representation of the high complexity system "bridge – obstacle – road" is presented in Fig.3. Input space is represented by actions and perturbations manifesting over the whole life span of the system. The output space includes the answers of the system to the exterior answers.

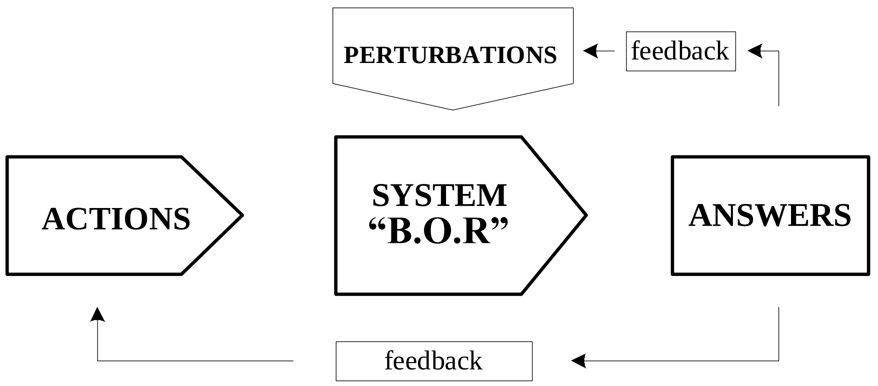

Fig.3. Inputs (actions) and outputs (answers) of the "bridge - obstacle - road" system

2.1 Actions – answers

The loads induced in the bridge in operation might be classified as: permanent, temporary, and exceptional actions.

From the point of view of environment – bridge interactions two permanent actions are associated with the environment: weight of the subsystems (elements) and the weight and pressure of the earth and backfill. The cause of these actions is gravitation.

In the bridge system a state of stress and deformation is induced under the permanent loads (weight of the structure, weight and pressure of the earth) and the answer of the construction can be measured through displacements, deformations, and tension.

When the deformation and stress state exceeds certain limits (i.e. – concrete resistance) fissures and cracks may appear in the elements of concrete, reinforced concrete or pre-stressed concrete.

Temporary actions, which are caused by the environment, are classified as follows: wind load, temperature variations, ice pressure, loads from waves caused by wind.

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Action of ice at wood bridges may result in total or partial destruction of fenders and dolphins through: tear out of planking, destruction of ridge or destruction of resistance structure.

Concrete infrastructures of bridges can experience a process of local destruction named concrete wearing. This process is caused by permanent action of floating ice, water waves (especially on coastline) and winds (mainly where there are predominant directions).

From the category of *exceptional actions*, seismic action of tectonic or volcanic nature has extremely important influence on the behavior of constructions. Bridge answers to seismic actions are localized at the level of infrastructures, bearing equipments, or superstructures in form of damages.

The most usual damages in infrastructures are: cracking or destruction of backwalls due to hits from superstructure in earthquake; settlement or inclination of abutments due to exceeding of the bearing capacity of the soil, use of improper foundation type or pushing of earth from abutment backfill.

Reinforced concrete superstructures suffered, due to seismic actions, the following damages: falling of superstructure from the bearings due to failure of bridge infrastructure; cracking of main girders or floor beams etc.

2.2 Perturbations – answers

Realization of a bridge, in a certain environment, characterized through a variety of obstacles (river bed, another way of communication etc.), triggers a series of complex processes of interaction between environment and bridge system.

The processes of interaction environment – system will be quantified through perturbations which will induce in the “B.O.R.” system a series of states, represented trough answers, especially through degradation state. In the space of perturbations which action over “B.O.R.” system some elements are included: infiltrations; wood rot; concrete, reinforcement and metal elements corrosion; landslide; modification of the hydraulic regime of the river; displacement of the waterway etc.
Infiltrations - Answer. Infiltrations represent the penetration of water between the bridge elements and/or in the concrete mass under the influence of gravity, capillary forces, due to existence of pores, fissures and cracks etc. The answer to this type of perturbation appears as: humid spots on concrete surface, efflorescence, stalactites and drapes (whenever the process is associated with corrosion).

Photo 3. Stalactites (bridge over Bârsa River, at Ghimbav, Braşov County – Romania)

Photo 4. Infiltration, humid spots, stalactites (bridge over Sovata River, at Sacadat de Jos, Mureş County – Romania)

Corrosion of concrete – answer. Main factors to trigger and maintain the process of corrosion of concrete (cement stone) might be grouped in three categories: physical, chemical, and biochemical. Corrosion is a complex deterioration of the concrete followed by a reduction in mechanical and penetration resistance.

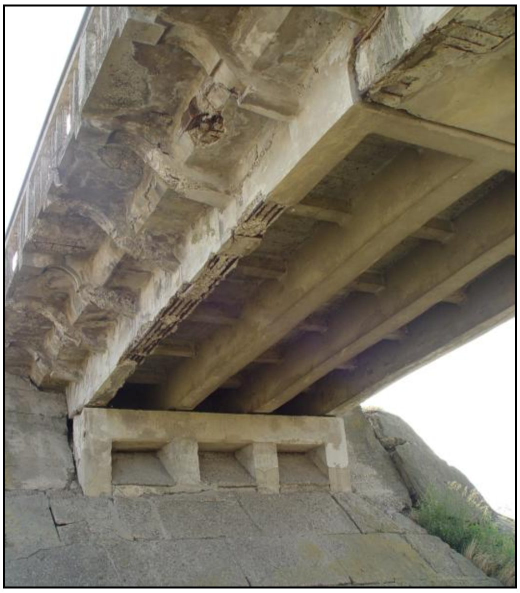

Photo 5. Reinforced concrete bridge superstructure: corrosion of concrete with spallings (bridge over Jijia River, Iaşi County – Romania)

For reinforced or pre-stressed concrete elements, the elements in the answer space are: friable concrete, alligator cracking, fissures and structural cracking, delamination and spalling.

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Timber Rot – answer. In case of timber bridges, one can encounter rotten of wood, decay, and the decomposition of wood under bacterial action (together with oxidation of organic compounds).

Modification of the hydraulic regime of the water channel - answer. It is produced due to hydro-technical works upstream, regularization of water channel without considering the influence of the bridge itself.

Photo 6. Modification of the hydraulic regime of the water channel (bridge over Siret River, at Ion Creangă, Bacău County – Romania)

State of degradation consists, in this case, from: deepening of the talweg associated with the lowering of the terrain level; deposit of solid material in the channel; decrease of low-water mark (phenomenon leaving in air the elevation-foundation joint) etc.

Photo 7. Modification of talweg Bridge; bridge over Viştea River at Viştea (Romania)

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Erosion of the channel – Answer. As answer to the erosion of the river bed one may observe rupture of banks displacement of channel.

Scouring - Answer. The process of erosion of the soil around the infrastructure of the bridge positioned in the water channel. This would result in degradations such as: displacement of wingwalls, displacement of infrastructure elements from initial position. All these damages induce further secondary degradations to the level of superstructure.

Photo 8. Damage of the superstructure due to infrastructure failure; bridge over Buzău River at Mărăcineni (Romania)

3. CONCLUSIONS

Introduction of the concept of high complexity system "bridge – obstacle – road" reveals the required premises for the study of the interactions between environment and constructed system from at least two aspects: actions of the environment on construction and influence of the construction on environment.

During and after realization the constructed system will influence the environment. Also, the environment will generate phenomena, actions, situations which influence technical condition of the constructed system, reducing its normal life span. This last aspect is considered in the present article.

Separation of the inputs of high complexity system "bridge – obstacle – road" in two: actions and perturbations, allows to better understanding the influence of environment on the bridge.

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The article analyzes, using original examples, the correlation between inputs (actions and perturbations) and the answers of the system, especially by studying the state of deterioration of the bridge system.

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