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COMPLEXITY THEORY ANALYSIS OF BRIDGE STRUCTURE SYSTEM

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ABSTRACT—This paper explores the complexity of the bridge structure system, and proposes definition of bridge structure system's complexity and theoretical research methods about characteristics of bridge structure system's complexity. The features of bridge structure system's complexity include: openness, giant, emergence, uncertainty, hierarchy. And bridge structure has nonlinear complexity, such as dissipation, chaos, and fractal. Thus, a state evolution model for bridge structure system can be established through dimensionality reduction, entropy reduction, chaotic bifurcation, self-similarity dimension, solitary, then implementing assessment of in-service bridges' condition based on Complex System theory

Keywords: Complex System; Bridge Structure; Dissipation; Chaos; Fractal; Solitary

1. INTRODUCTION

Science of "Complexity" began in 1928, proposed by an Austrian biologist, Bertalanffy, in his "living organism". The paper first proposed the concept of "complexity". Then Prigogine in the Dissipative Structure Theory, Haken in the Synergetics have made a breakthrough. Complex System theory is still improving and developing. Theory of Complex System includes: modern system theory, nonlinear and complex[1] (Figure 1).

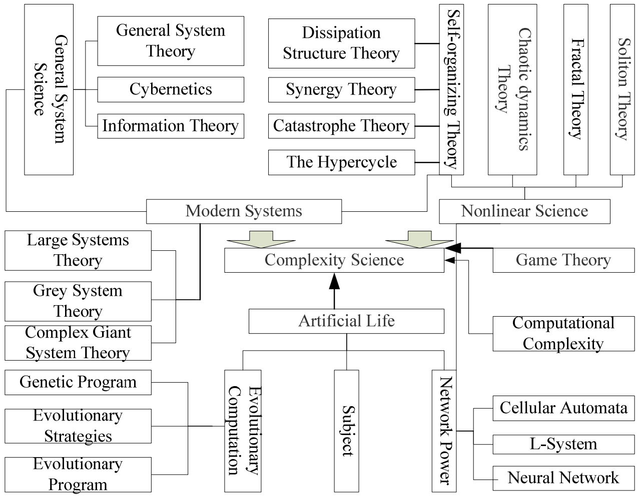

Figure 1. Complex Scientific Theories

The research of Complex System has been deeply into the practical engineering[2-5]. Rock and Concrete exchange with environment by energy, material and information. The formation of small cracks and micro-fracture zone and crack propagation all have characteristics of Dissipative Structures; crack propagation in concrete box Girder Bridge, and slope instability can be explained using fractal theory; nonlinear chaotic dynamics theory in the analysis of existing bridge state proves that the bridge structure dynamic characteristics have chaotic character.

2. BRIDGE STRUCTURE SYSTEM COMPLEXITY

2.1 Bridge Structure System

Bridge structure system comprises a variety of materials and different structures. Bridge structure system constitutes various of lower levels of subsystems. Elements of basic components also constitute various systems. This system has its own elements, structure, function and environment (Figure 2).Bridge structure system as a whole is not equal to sum of the parts[15].

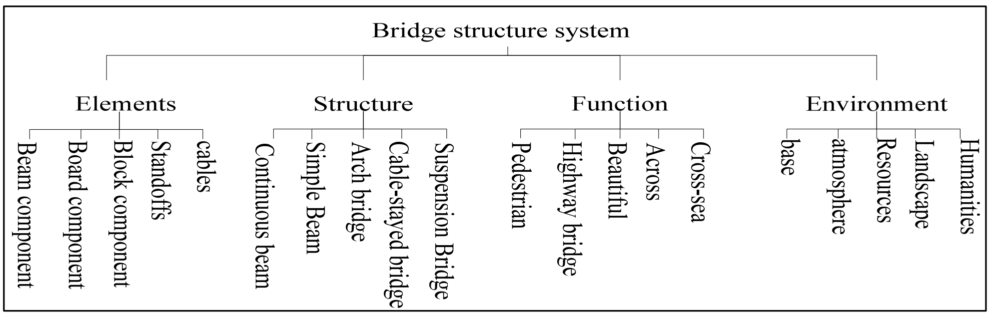

Figure 2. Bridge Structure System Schematic

2.2 The Complexity Features of Bridge Structure System

Bridge structure system has the following features: high dimensional nonlinearity, material nonlinearity, geometric nonlinearity, boundary conditions uncertainty and a series of behavior of complex system. And its dynamical behavior of structural damage response of time series also contains structural nonlinear information. Considering various definitions of complex system on different areas[7-11], the paper proposes its definition: the overall behavior or characteristic of a system cannot only be analyzed through that of the components; the overall behavior of the system also cannot be established in advance on a large scale; large amount of subsystems which interact or separate each other are coupled together in a nonlinear way; and the system is open, there exists exchange of information, energy and material among subsystems, between the system and environment.

Combined with the definition of Complex System, bridge structure system is part of Complex System that can also be studied on Complex System theory. Complexity of bridge structure system can be as follows:

(1) Bridge structure system is an open system, there exists exchange with the external environment by energy, information and material, for example, structural vibration, concrete carbonation, corrosion of steel components, earthquakes, external load energy transfer.

(2) The overall behavior (characteristic) of bridge structure system cannot be completely determined by its component behavior (characteristic), for example, damage of a subsystem in bridge structure system cannot be fully determined by the security situation in the bridge.

(3) The overall behavior of bridge structure system cannot be determined on a large scale in advance, for example, bridge damage accumulation is an uncertain quantity. Therefore, it is impossible to predict their overall behavior for long time.

(4) Bridge structure system has a large number of interacting and separating subsystems that are coupled together in a nonlinear way. Its overall behavior cannot be linearly superimposed. For example, the bridge structure system has many subsystems. Macro: beam bridge pier, pile, the upper structure; Cable-stayed bridge with cable, beam, main tower and so on. Micro: a component of reinforced concrete, steel between which nonlinear coupling are made. And bridge structure system has high-dimensional nonlinear[8].

Thus, bridge structure system complexity characteristics are summarized as follows:

(1) Openness. Bridge structure system is an open system contacting with the external environment and loads bridge structure system between subsystems. Between the system and the environment there are material, energy and information exchange.

(2) Giant. The number of bridge structure system basic units and subsystems are enormous.

(3) Emergence. Bridge structure system overall behavior cannot be used to represent the behavior of its subsystems. The overall function is greater than its parts.

(4) Uncertainty. Environmental loads nonlinear coupling effect, cumulative damage of randomness, as well as materials, geometric nonlinearity result in the conclusion that the overall behavior cannot be determined on a large scale in advance.

(5) Hierarchy. There is high-dimensional nonlinear interacting between the individuals of bridge structural system, leading to that the system in time, space and forms of organization have different dynamic evolution.

3. ANALYSIS OF THE THEORY AND METHODS OF BRIDGE STRUCTURE SYSTEM COMPLEXITY

Due to structural material nonlinearity, geometric nonlinearity, boundary conditions of uncertainty and a series of non-linear behavior affect, nonlinear structural decay show more complex features than linear. Nonlinearity is the source of Complex System[12], so the bridge structure system decay mechanism also shows uncertainty on a large scale, and appears chaotic fractal and fractal dimension, self-organization, mutation, bifurcation and a series of Complex System characteristics.

3.1 Complexity Mechanism of Bridge Structure System Based on the Dissipative Structure Theory

Dissipative structure system is an open system far from equilibrium, the system by constantly exchanging energy with the outside world, information and material from the original state of disorder to a time, space or function order state.

Bridge structure system is an open system and closely linked with environment. Due to the internal or external environment caused by the accumulation of structure damage, systems far from equilibrium gradually go into the plastic deformation stage. When the damage reaches a certain threshold value, the bridge structure mutates, thus forming dissipative structure. Dissipation function[13]:

$$\Phi = T\sigma \tag{1}$$

σ : is the Entropy production. It can be used to measure the free energy dissipation rate caused by the irreversible process. Thus, residual carrying capacity of structure can be calculated, so the system can be timely reinforced.

With the bridge span increasing, pylon towering, box girders thinner and the application of high-strength materials, structural stiffness declining globally and locally, it appears stability problems. The system is unstable and may form a dissipative structure. Some studies have shown that. Rock instability is a dimensionality reduce process and an entropy reduce process[16]. Dimensionality reduction and entropy reduction process indicate that the system has a dynamic characteristic developing process from disorder to order, indicating that system constraints become increasingly strong. It shows some critical behavior. Orderliness often means that the system is unstable, such as entropy and fractal dimension is low, degree of order is large, stability of the system is poor. In non-equilibrium nonlinear zone, if the boundary conditions are independent of time, there are[13]:

$$\frac{d_x\varphi}{dt} \le 0 \tag{2}$$

$d_x\varphi$ is a system Lyapounov function. Time-varying portion of the force is always negative or zero contribution to the Time-varying entropy production. You can find out that structural stability characteristics of the system development over time.

Dissipative structure theory in geotechnical, slope and concrete has achieved some results. Combining the dissipative structure theory of entropy reduction, dimensionality reduction, minimum entropy principle, mutation, stability, and bifurcation, we can know the bridge system damage and instability of a new sub-drama form.

3.2 Complexity Mechanism of Bridge Structure System based on the Fractal Theory

Fractal refers to a class without rules, confusing and complicated, but there are similarities between the components and the whole system. Morphology (structure), information, functionality and time with a self-similar object are called the generalized fractal[14,17]. Research shows that the degree of cracking girder can be expressed by the fractal dimension. Fractal Theory is also used in slope stability analysis. Dynamic response has shown similar multi-fractal characteristics such as span ratio, beam pier stiffness ratio and bearing stiffness[18]. P. S.

Symonds has studied two degrees of freedom for a beam component model fractal dimension in the transient shock loads under the elastic response. Then its self-similarity dimension calculated is 0.78[19]. However, in the process of bridge damage, injury, before and after damage on the structural dynamic response, the surrounding environment changes caused by damage are all have self-similarity. Structural damage within certain parameters appears scale-free zone; local damage and partial damage, injury and overall injury are all have self-similarity; bridge system damage in the structure, morphology, information, functionality and time also has a self-similarity. Therefore, Studying of self-similar structure damage, and looking for structural damage response characteristics of fractal dimension indicator can reveal the structural damage condition in depth.

3.3 Complexity Mechanism of Bridge Structure System based on the Chaos Theory

Chaos is seemingly random movement state that appears in dynamical system. It describes a complex, unpredictable and disordered state. Chaotic motion is always confined to a limited area and the track never repeats, and has complex motion behavior and sensitive dependence on initial conditions, with rich gradation and self-similar structure, with strange attractor. It is sometimes described as having infinite cycle of periodic motion and seemingly random movement.

Based on the characteristics of chaotic system, chaotic parameters are used to evaluate the performance of engineering system with time-varying, nonlinear and non-stationary characteristics. Researchers take more and more attention to it, and it has been widely used in many fields. O'Reilly[20] uses stainless steel wire with 0.64m long, 0.61 mm diameter as the suspension model and the normal excitation at the end portion. Build two degrees of freedom model, theoretical and experimental study of the suspension of non-linearity, non-planar, non-periodic vibrations. In 2000, Alaggio and Rega[21] observed quasi-periodic steady-state movement, lock phenomena and chaotic attractors. Subsequently, Rega and Alaggio[22] analyzed suspension for almost periodic motion to chaos regional bifurcation mechanisms. In 1979, Moon and Holmes[23], in order to verify the irregular response and the presence of chaotic motion, used magneto-elastic system to form a forced Duffing oscillator model, and found that buckling beam excitation slightly was mainly as periodic motion for fixed damping and frequency through experiments. But for a substantial movement, beam jumps from one equilibrium point to another equilibrium point, and the experiment proves that Mechanical System exists strange attractors.

Through the preliminary study of chaos theory, during the process of bridge structure damage, certain parameters, status, function, response shall go through[6] double period bifurcation approach, paroxysmal way, quasi-periodic motion bifurcation approach. These ways can be made the structure into chaotic state. It has broad application prospects by using Chaotic dynamics to solve bridge damage Problem and assessment of structural safety state.

3.4 Complexity Mechanism of Bridge Structure System based on the Soliton Theory

As early as 1834, the famous British scientist J. Scott Russel found a solitary wave phenomenon. Kruska and NJ Zabusky named "Soliton". The soliton has penetrated into many natural sciences since the soliton was founded[24], such as fiber soliton transmission, plasma and magnetic nonlinear problems.

Nonlinearity of structural damage and structural dynamic behavior relates to damage evolution of complexity. Constructing injury-related finite-dimensional and infinite-dimensional nonlinear evolution equations[25], for damage finite dimensional nonlinear evolution equations, it is studied to know the dispersion, nonlinearity, volatility; solution attenuation; smoothness and solitary. For damage infinite dimensional nonlinear equations, the chaos in space, singularity set, global attractor, the existence of inertial manifolds, and their Hausdorff dimension, fractal dimension of the upper and lower bound estimates. Attractor dynamic structure, approximate inertial manifold, nonlinear Galerkin method, inertia sets and other characteristics are studied.

Identify the nature of these nonlinear evolution equations associated with the inherent structural damage, while building evaluation of characteristics of the injury indicators.

4. CONCLUSION

As regarding safety assessment for the locality of the bridge structure, static resistance, and over-reliance on the limitations of in-service bridge inspection, this paper proposes a method of Complex System to study the existing bridge structure system security status based on system theory and reductionism. This paper qualitatively proves that bridge structure system has complexity by the theory of Complex System. Bridge structure system complexity characteristics include: openness, giant, emergence, uncertainty, and hierarchy. Complex system characteristic index can reflect the evolution of structural damage condition, such as dimensionality reduction, entropy reduction, chaotic bifurcation, self-similarity dimension, solitary solution.

From the perspective of Complex System, this paper combines Complex System theory with nonlinearity of bridge structure theory to analyze behavior of nonlinear dynamical of existing Bridge Structure System and provides a new idea to reveal the evolutionary status of the bridge structure and predict the remaining capacity of bridge structure system. Theoretical assessment of bridge structure system state of Complex System is the future direction of development.

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