GERONTOLOGY OF ARCH BRIDGES

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SUMMARY

Gerontology is the field of medical science studying all aspects of human aging, but quite similar problems appear in the case of elderly bridge structures, including arch bridges. Similarities as well as differences between technical and medical gerontology challenges are presented and discussed. The paper is focused on comparison of bridge structure degradation mechanisms and human pathology, medical and technical diagnostic techniques as well as bridge defects and medical diseases.

Keywords: *Arch bridges, technical geriatrics, bridge gerontology, degradation processes, diagnostics, pathology.*

1. INTRODUCTION

One of the fundamental goals of medicine is extension of human life and similarly bridge engineering is focused on prolongation of service life of bridges – structures crucial for transportation systems. *Gerontology* is the field of medical science studying all aspects of human aging. Achievements of the gerontology are implemented in *geriatrics*, which is a branch of medicine focused on health care of elderly people. It aims to promote health by preventing and treating diseases and disabilities in older adults. There is no set age at which patients may be under the care of a geriatrician or geriatric physician, a physician who specializes in the care of elderly people. Rather, this decision is determined by the individual patient's needs, and the availability of a specialist.

Problems of *technical geriatrics* related to arch bridge structures seem to be very similar to medical challenges. Engineers taking care of old bridges have to do inspections and tests, to formulate diagnosis and to decide on the treatment of existing disease in bridge structure – scheme of the procedure is almost identical to medical practice. Scientific bases for technical bridge geriatrics are formed by the *bridge gerontology* – focused on degradation processes of bridge structures, engineering diagnostic and prevention techniques as well as bridge rehabilitation procedures.

2. HUMAN AND BRIDGE STRUCTURE PATHOLOGY

The medical term *pathology* itself may be used broadly to refer to the study of disease in general, incorporating a wide range of bioscience research fields and medical practices. *Human pathology* addresses four main components of disease [1]-[3]: cause (etiology), mechanisms of development (pathogenesis), structural alterations of cells (morphologic changes) and the consequences of changes (clinical manifestations).

Bridge structure pathology is trying to solve very similar problems related to identification [4]-[7]: stimulators of degradation initiation, pathways of degradation processes, defects caused by the processes and influence of the defects on condition of arch bridge structures.

Each bridge structure is influenced by degradation stimulators associated with environmental conditions, age of the structure, operational circumstances, maintenance quality, etc. Generally three main groups of the degradation mechanisms can be distinguished [7], [8]: physical, chemical and biological. Activated degradation mechanisms depend also on the structure material. In Tab. 1 basic degradation mechanisms specific to concrete, steel and masonry arch bridges are distinguished and compared with degradation mechanisms acting in medicine (pathogenesis). Relatively high level of conformity between technical and medical processes can be observed.

Table 1. *Activity of degradation mechanisms: arch bridges versus medicine.*

	Degradation mechanisms	Material of arch bridge			Medicine
		concrete	steel	masonry	
Physical	Accumulation of inorganic contamination	●	●	●	●
	Freeze/thaw actions	●	○	●	x
	Erosion	●	○	●	x
	Crystallization	●	x	○	○
	Extremal temperature influence	○	●	○	○
	Rheological processes	●	○	○	○
	Overloading	●	●	●	●
	Leaching	●	x	●	○
	Fatigue	○	●	○	●
	Changes of geotechnical conditions	●	●	●	x
Chemical	Carbonization	●	x	○	x
	Corrosion	●	●	x	x
	Aggressive environmental impact	●	●	●	●
	Reactions between material components	●	○	○	●
Biological	Accumulation of organic contamination	●	●	●	●
	Influence of microorganisms	●	●	●	●
	Influence of plants	●	○	●	●
	Influence of animals	○	●	○	●

● – basic mechanism; ○ – supplementary mechanism, , x – not applicable

Aims of human and bridge structure pathology are very tough because of high level of problem individualization regarding each human being as well as each bridge structure. Similarity of many problems should stimulate closer cooperation in the field of medical and technical gerontology.

3. MEDICAL AND ENGINEERING DIAGNOSTICS

Very important challenges in medical and technical gerontology form efficient diagnostics, which enables detection and identification of degradation processes as well as their consequences. Diagnostic techniques applied in medicine and bridge engineering are quite similar and in the history successful innovations in one area stimulated developments also in the second field [9]-[16]. In both analysed areas of diagnostics three basic groups of technologies can be distinguished: physical, chemical and biological [4], [7], [8].

Among the physical technologies very extensive applications have various types of wave processes. In Tab. 2 the most popular testing methods based on wave processes are presented together with characteristic practicable wave frequencies. All methods taken into account in Tab. 2 are helpful both in medical and technical diagnostics, including all types of arch bridges.

Table 2. *Wave processes in technical and medical diagnostics.*

Testing method	Type of wave phenomenon	Frequency [Hz]	Arch bridges	Medi-cine
Mechanical vibrations	Low frequency waves	$10^{-1} – 10^{2}$	●	○
Impulse methods	Acoustic waves	$50 – 2·10^{4}$	●	●
Acoustic emission	Acoustic waves (inaudible)	$10^{4} – 10^{6}$	●	●
Ultrasonic methods	Ultrasonic waves	$2·10^{4} – 10^{8}$	●	●
Electromagnetic induction methods	High frequency waves	$10^{6} – 10^{8}$	●	●
Radar methods	Very high frequency waves	$10^{7} – 10^{10}$	●	●
	Microwaves	$10^{10} – 10^{12}$	●	●
Thermographic methods	Infrared radiation	$10^{12} – 4·10^{14}$	●	●
Visual inspection	Visible light	$4·10^{14} – 8·10^{14}$	●	●
Laser methods	Polarized light	$10^{12} – 10^{14}$	●	●
Magnetic methods	Ultraviolet radiation	$8·10^{14} – 5·10^{16}$	●	●
Radiological methods	X-radiation	$5·10^{16} – 10^{21}$	●	●
	γ-radiation	$10^{18} – 10^{22}$	●	●

● – basic method, ○ – supplementary method, X – not applicable

The basic preliminary diagnostic procedure in medicine [1]-[3] and bridge engineering [4], [7], [8], [14], [16] has usually a form of visual inspection, performed by means of simple tools (Fig. 1). To examine the interior of a bridge component or a hollow organ or cavity of the body an endoscope (Fig. 2) can be applied.

Fig. 1. *Basic tools used during visual inspection of bridges (left) and medical patients (right).*

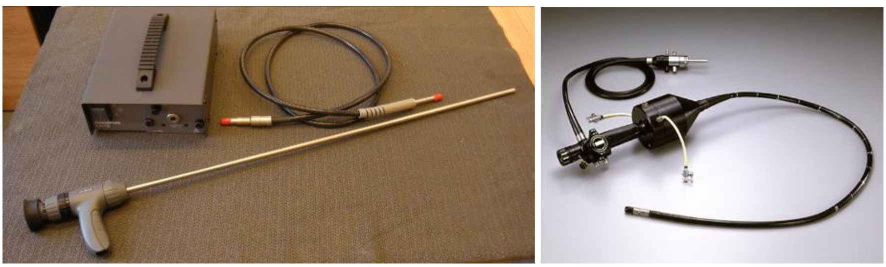

Fig. 2. *Endoscope for technical (left) and medical (right) tests [www.optyczne.pl].*

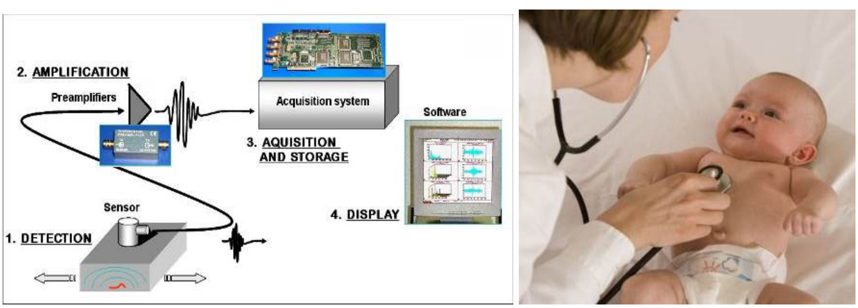

Fig. 3. *Scheme of system for analysis of technical acoustic emission (left) and direct medical analysis of acoustic emission (right) [www.epandt.com].*

Acoustic emission [4], [7], [10], [13], [16] is the phenomenon of radiation of acoustic waves in material and can be used to non-destructive detection of material defects (Fig. 3 left). Similar idea forms background to elementary medical auscultate tests (Fig. 3 right).

Very extensive diagnostic applications have ultrasounds [10], [12] i.e. sound waves with frequencies higher than the upper audible limit of human hearing. Examples of uses in bridge engineering and in medicine are presented in Fig. 4.

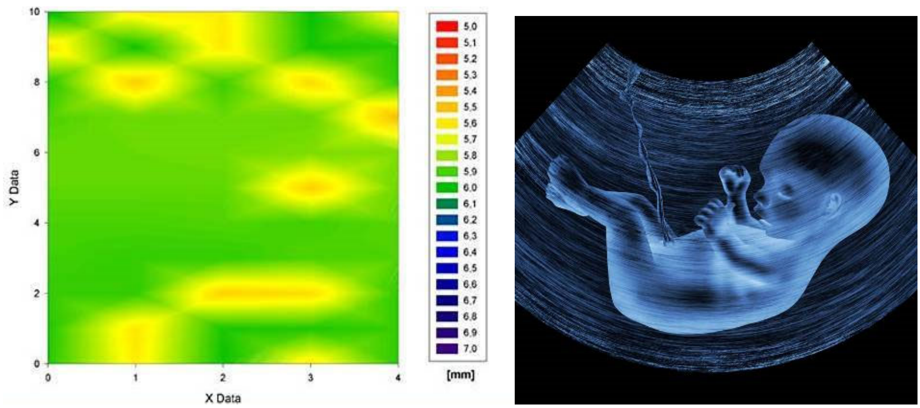

Fig. 4. *Ultrasonic techniques: thickness map of steel arch girder (left) and control of foetus condition (right) [www.megroup.pl].*

Since infrared radiation is emitted by all objects with a temperature above absolute zero thermography [4], [7], [8], [15] makes it possible to see one's environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature; therefore, thermography allows one to see variations in temperature what is very useful in engineering and medicine (Fig. 5).

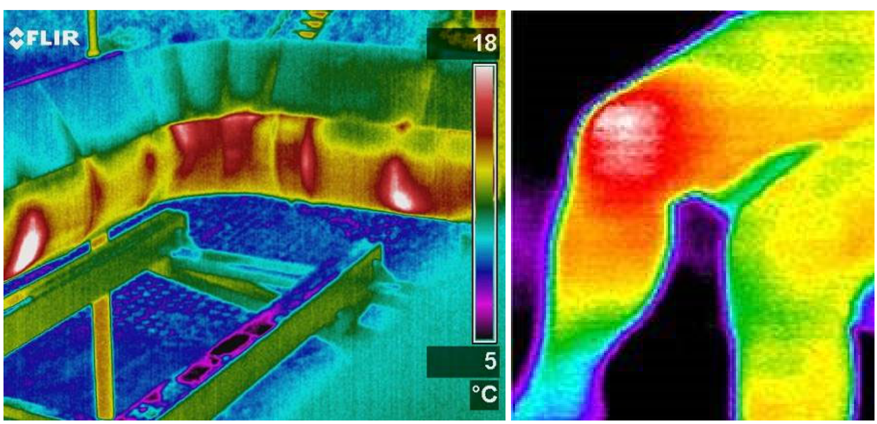

Fig. 5. *Thermograms: test of pipe insulation on arch bridge (left) and identification of knee infection [www.termocert.com.pl].*

One of the most advanced diagnostic techniques is tomography [1]-[4], [13], [16], which refers to imaging by sections, through the use of any kind of penetrating wave. Tomograms are derived using several different physical phenomena: X-rays (CT), γ-rays (SPECT), radio-frequency waves (MRI), Electrical Resistance (ERT), electron-positron annihilation (PET), electrons (3D TEM), etc. Tomography involve gathering projection data from multiple directions and feeding the data into a tomographic reconstruction software algorithm processed by a computer (Fig. 6).

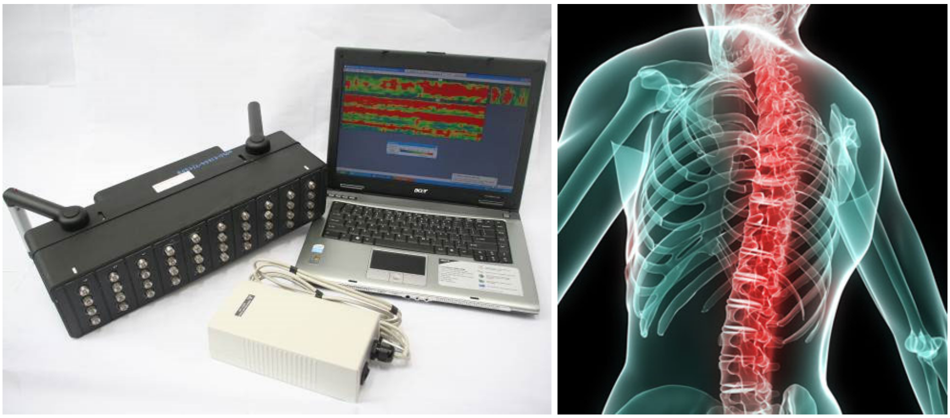

Fig. 6. *Tomography: equipment for ultrasonic tomography of engineering structures (left) and medical tomography (right) [www.fit.pl].*

Important diagnostic tool is radiographic analysis [1]-[3], [4], [7], [8], [12] − a non-destructive testing (NDT) method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The method is broadly used in engineering and in medicine (Fig. 7).

Fig. 7. *Conventional radiological tests: defects of welds in steel bridge arch (left) and broken bone (right) [www.zsm.com.pl].*

Apart of presented above non-destructive testing methods technical and medical diagnostics require laboratory tests performed on specimens taken from structure or human body (Fig. 8). Such samples are used for various types of physical, chemical or biological tests [1]-[4], [7], [8], [14], [16].

Fig. 8. *Samples for laboratory tests: specimen of masonry arch bridge (left) and sample of patient's blood (right).*

Chemical diagnostic techniques, very important in engineering and medical analyses [1]-[4], [7]- [9], enable determination which chemicals are present in the object in question. Qualitative analysis identifies substance, while quantitative analysis determines the numerical amount or concentration of components. Analytical chemistry involved in technical and medical applications consists of classical, wet chemical methods (Fig. 9 left) and instrumental methods (Fig. 9 right), including spectrometry, chromatography, electrophoresis or field flow fractionation.

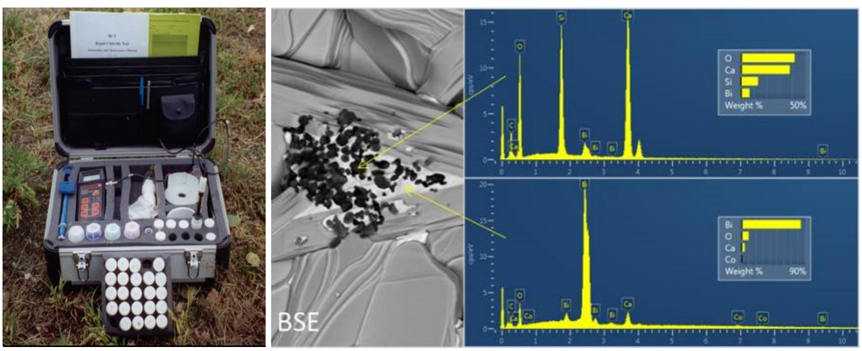

Fig. 9. *Chemical techniques: diagnostic kit for field tests of bridge structures (left) and example of results of quantitative instrumental analysis (right).*

Basic biological techniques applied in engineering as well as in medical diagnostics can be classified as follows [1]-[4], [7]-[9]:

- macroscopic methods – when objects or phenomena are large enough to be visible practically with the naked eye,
- microscopic methods – performed by means of optical, electron (transmission or scanning) or other type of microscopes,
- *in vitro* studies – performed with microorganisms, cells or biological molecules outside their normal biological context.

4. ARCH BRIDGE DEFECTS AND HEALTH PROBLEMS

Highlighted above similarities of degradation mechanisms and diagnostic techniques present in bridge engineering and medicine are also observed in the field of bridge defects and effects of medical diseases [1]-[4], [6], [7], [8], [16]. Technical defects are provoked by degradation mechanisms occurring in bridge structures and, by analogy, health problems are caused by illnesses.

Taking into account effects of degradation mechanisms and medical diseases, the following six basic types of defects/health problems can be distinguished:

- deformations – in engineering: changes of the structure geometry, incompatible with the project, with changes of mutual distances of structure points; in medicine: deviations in geometry of human body parts, e.g. curvature of the spine;
- material destruction – in engineering: deterioration of physical and/or chemical features of structural material with relation to designed values: in medicine: worsening of physical/chemical parameters of human body components, e.g. blood parameters, reduction of bone strength because of osteoporosis;
- material losses – in engineering: decrease of designed amount of structural material; in medicine: missing components of human body, e.g. absent tooth after resection;
- material discontinuity – in engineering: inconsistent with a project discontinuity of a structure material; in medicine: abnormal discontinuities in human body, e.g. broken bone;
- contaminations – in engineering: appearance of any type of an organic or inorganic dirtiness or non-designed plant or other organisms existence on the structure; in medicine: impurities appearing on the external parts of human body (e.g. on the skin) as well as inside of the organism (e.g. in alimentary canal);
- position changes – in engineering: dislocation of a structure or its part incompatible with the project, also restrictions in designed displacement capabilities; in medicine: abnormal displacement of a part of human body (e.g. dislocation of bones) as well as constraints in normal movement possibilities (e.g. in body joints).

In the hierarchical classification presented in Tab. 3 for each basic type of arch bridge defects also a few sub-types are defined. The proposed classification of technical defects is compared with taxonomy of body harms caused by medical diseases − consistency is very high.

Table 3. Classification of arch bridge defects versus health problems.

Defect type	Defect sub-type	Arch bridges	Medicine
Deformation	Changes of element (body component) axes geometry	●	●
	Changes of geometry along the element (body component)	●	●
Material destruction	Changes of chemical features	●	●
	Changes of physical features	●	●
Material losses	Losses of structural material (internal body components)	●	●
	Losses of protective material (external body components)	●	●
Material discontinuity	Scratch	●	●
	Crack	●	●
	Delamination	●	●
Contaminations	Inorganic	●	●
	Organic	●	●
Position changes	Abnormal position of elements (body components)	●	○
	Abnormal movement of elements (body components)	●	○
	Limitations in movement possibilities	●	●

● – frequent defect, ○ – rare defect, x – not applicable

5. CONCLUSIONS

Similarities as well as differences between technical and medical gerontology problems are presented on the example of arch bridges. The following basic aspects are considered and discussed:

- physical, chemical and biological processes of arch bridge degradation and their equivalents in medicine,
- comparison of bridge structure and human pathologies,
- technical and medical diagnostic tools and procedures,
- classification of arch bridge defects versus health problems.

On the example of arch bridges more general strong interactions between bridge engineering and medicine are presented, including medical and technical problems of pathology, diagnostics and gerontology. The main existing connections are underlined and illustrated by examples. Solid mutual influences are expected also in the future, focused mainly on improvement of diagnostic techniques and procedures as well as development of new advanced diagnostic tools using physical, chemical and biological technologies.

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