Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

On possible applications of smart structures controlled by self-stress

W. Gilewski *, A. Al Sabouni-Zawadzka

Faculty of Civil Engineering, Warsaw University of Technology, Al. Armii Ludowej 16, 00-637 Warsaw, Poland

ARTICLE INFO

Article history:
Received 2 April 2014
Accepted 25 August 2014
Available online 16 September 2014

Keywords:
Smart structure
Structural control
Tensegrity
Self-stress

ABSTRACT

Civil Engineering (CE) is one of the many fields of possible implementation of smart or intelligent technologies. The present paper is an attempt to specify and estimate problems and areas of CE suitable for the application of such technologies, with the focus on Bridge Engineering (BE). Precise definitions, explanations and classifications of terms used in smart technique are introduced and components of smart systems are defined. Analogies between smart systems and biological ones are indicated. The paper presents some of the research projects carried out in the field of CE, according to the current state-of-the-art. Concepts of smart bridges are proposed and several examples of structural control performed on space trusses and tensegrity structures with self-stress are introduced.

Examples of structural control presented in the paper show that characteristic displacements of the analysed structures may be reduced by changing the prestressing force applied to the single modules, which are a part of the structure. Results of the performed analysis indicate that tensegrity structures are much more prone to the changes in the value of prestressing force than truss structures, which makes them a promising solution as far as structural control is concerned.

1. Introduction

Engineering structures, such as buildings or bridges, are subject to various actions, among which the most dangerous ones are accidental loads. It may be a challenge for an engineer to design a structure that would react to such accidental loading by modifying its own properties. It is possible with the use of smart technologies. Such intelligent technologies apply to both materials and structures. However, considering the immense costs of implementing smart materials into structural elements, the authors focus on structural smartness rather than material one.

The present paper discusses possible applications of smart technologies in the field of CE, with the focus on BE. The concepts of smart structures, materials and systems, as well as other terms used in smart technique are precisely defined and classified. The study introduces principal elements which make the system smart and it indicates analogies with biological systems. Several applications in CE are presented and a concept of a smart bridge is proposed.

* *Corresponding author*. Tel.: +48 22 2345753.
E-mail address: w.gilewski@il.pw.edu.pl (W. Gilewski).

http://dx.doi.org/10.1016/j.acme.2014.08.006

Buildings or bridges can be regarded as smart or intelligent due to the advanced structural health monitoring (SHM) systems, which are very often installed on the existing and newly built structures. However, the authors suggest a slightly different approach to the topic of smart structures. According to the authors, ''smartness'' should regard a structure itself, not the advanced technologies, with which buildings or bridges are equipped. Intelligent systems, understood in such way, may have various applications: vibration damping, reduction of displacements, acoustic isolation, damage localization and repair, stress reduction, etc.

According to the authors' opinion, one of the most interesting possibilities of structural control lies in a control of truss and tensegrity elements through self-stress state adjustment [1–3]. Such structural elements may be used as parts of bigger structures, for example decks or pylons of lightweight footbridges. Results of the performed analyses indicate that the structural displacements might be significantly reduced by adjusting the initial self-stress state in such elements. The paper introduces examples of structural control performed on a space truss with self-stress and a plate based on tensegrity modules. An influence of several self-stress states on displacements is analysed.

2. General characteristics of smart structures

The topic of smart structures is relatively new [4]. It commenced to be qualified as a distinct field of applied science in the 1980s, when, thanks to the technological progress, scientists joined together in small groups working on the subject. At the beginning, all the research carried out in the area of smart technologies were funded by the government. In the early 1990s private companies started to invest money in this field, providing necessary funding and application possibilities. The cooperation between government research organizations, scientists and companies resulted in several multi-year programs dedicated to the development of smart products and their implementation.

The definition of smart structures has been a disputable issue for as long as the topic exists. There are numerous methods of approaching to this subject. Each author [5,6] defines and classifies smart structures in a different way. These differences arise from distinct ways of perceiving work of such structures and methods of their analyses. Some examine a whole structure, while others focus on a specific part of it – a single structural element.

Another reason of such differences is the fact that the word ''smart'' itself has various meanings. According to the dictionary, its original significance was ''stinging, sharp''. The present meaning of the word ''smart'' – ''clever, intelligent'' – has taken over from its original definition the element of quick energetic movement and sharp thought. This original meaning characterizes perfectly the idea of smart structures. In relation to the structures, the word ''smart'' means: capable of acting in a quick way and making corrections that resemble human decisions, particularly in response to changeable conditions. The present significance, ''intelligent'', is also applied to the structures, but it is not fully adequate. Intelligence is a human feature and should be reserved for humans. Although the classification distinguishes a group of very smart structures, calling them intelligent, it does not mean that those structures possess intelligence. The only attribute, which makes them resemble humans, is the ability to learn.

There are various types of ''smartness''. A smart building, for example, can be understood in many different ways. For an occupant of the building it will signify high-tech equipment, such as electronics controlling ambient environment, air conditioning systems, lighting and alarm installations. For an engineer designing the structure, it will indicate that the building is equipped with a smart monitoring and damping system.

There are three concepts related to the topic of smart structures (Fig. 1).

Smart structures are the structures with the ability to sense and respond adaptively to changes in their environment. This feature distinguishes them from the conventional ones. Whereas the main purpose of the traditional structures is to provide strength and carry loads acting on them, the smart ones adapt in a pre-designed manner to a functional need, modifying their shape, stiffness or damping characteristics in order to minimize deflection and possible damage.

Smart materials are the materials which are able to convert one form of energy (mechanical, magnetic, electrical, etc.) into another in a reversible and repeatable process. They are capable of sensing changes in the environmental conditions, responding to them in a predetermined manner, in an appropriate time and returning to their original shape as soon as the stimulus is removed. Smart materials are often used in actuation systems of smart structures, stimulating them to adapt to the variable conditions.

Smart systems are the systems composed of a smart material, a smart structure and an expert data processing. Smart systems ensure that during normal conditions, the structure carries all the loads without any help of smart components and on the other hand, it uses specific actuation systems to tackle abnormal load cases.

An important concept related to the topic of smart structures is learning control [7]. The point of this phenomenon, also known as a case-based reasoning, is that the structure has a base, in which variable possible cases and

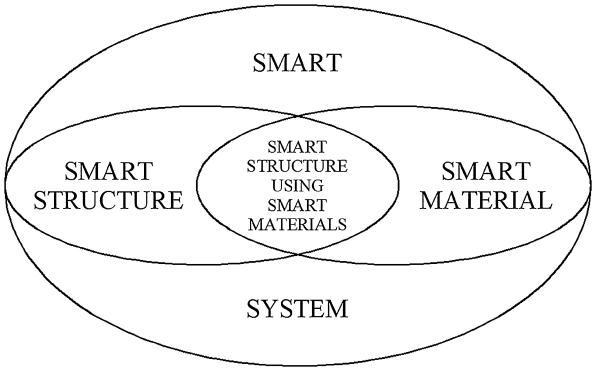

Fig. 1 – Schematic diagram showing a smart concept. The diagram presents three concepts related to the topic of smart technologies that can be implemented in the field of CE: smart structures, smart materials and smart systems.