Measurement 85 (2016) 210–221

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Structural damage detectability using modal and ultrasonic approaches

B. Blachowski [a,*], A. Swiercz [a], P. Gutkiewicz [a], J. Szelążek [a], W. Gutkowski [b]

[a] Institute of Fundamental Technological Research, Warsaw, Poland
[b] Institute of Mechanized Construction and Rock Mining, Warsaw, Poland

ARTICLE INFO

Article history:
Received 2 December 2015
Received in revised form 15 January 2016
Accepted 19 February 2016
Available online 27 February 2016

Keywords:
Detectable damages
Bolted connections
Experimental modal analysis
Ultrasonic measurements
Steel frames
Analytical dynamics

ABSTRACT

An experimental and analytical study of the relation between local defect, in a steel structure, and its higher frequencies and higher modes is discussed. The structure is a plane steel frame, assembled of beams, joined together with bolted connections. Removing some bolts from a given connection simulates the damage. In the experiment, an impulse force induced structural vibrations. Effects of vibrations were shown by data from gages, measuring accelerations with a high accuracy. From the data, it could be observed, that mode shapes, for the healthy and damaged structures didn't show any differences for low frequencies. Only modes around thirteen showed significant gap between picks of Frequency Response Functions, for healthy and damaged frame. Moreover, looking at mode shapes, it could be observed that structural configuration may have some influence on defects to be observable. This aspect is discussed in a separate section. The experiment performed on the whole structure allows finding the place where the defect is localized. However, it can't give detailed information on the defect itself, here defect of a bolt. For finding it, an ultrasonic measurement of pre-tensioning forces in bolts was applied. It allowed not only to determine stresses in the bolt, but also to verify, if in the process of assembling the structure was not pre-stressed.

1. Introduction

In recent years, Structural Health Monitoring (SHM) and damage detection techniques have attracted much attention from both the scientific and the engineering community [1,2]. The main reasons are safety requirements, which should be satisfied by the civil infrastructure and observed by the automotive and aviation industry. Many methods of damage detection have been proposed in the last two decades, examples of which are provided in [3–5]. These methods can localize and estimate damage sustained by a structure, especially the one to structural members [4]. However, there is still a need for algorithms which can reliably identify damage in structural connections. This paper aims to address this issue using two different measurement techniques, namely vibration-based and ultrasonic approaches.

The influence of joint flexibility on the dynamic response of a whole structure has been investigated by Swiercz et al. [6], Blachowski and Gutkowski [7]. Neglecting the influence of joint compliance on the dynamic response of a real engineering structure can lead to catastrophic failures as in the case of the I-35 bridge in Minneapolis [8]. The development of an adequate model of a structural system under investigation is also a critical issue when dealing with control forces,

* Corresponding author.
E-mail addresses: bblach@ippt.pan.pl (B. Blachowski), aswiercz@ippt.pan.pl (A. Swiercz), pgutkie@ippt.pan.pl (P. Gutkiewicz), jszela@ippt.pan.pl (J. Szelążek), wgutkow@ippt.pan.pl (W. Gutkowski).

http://dx.doi.org/10.1016/j.measurement.2016.02.033
0263-2241/

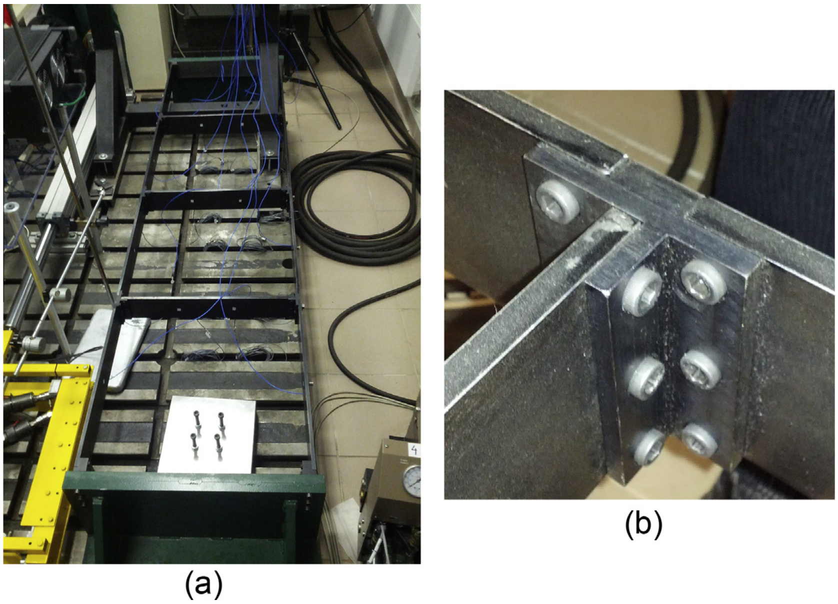

Fig. 1. View of the tested frame and the connecting element.

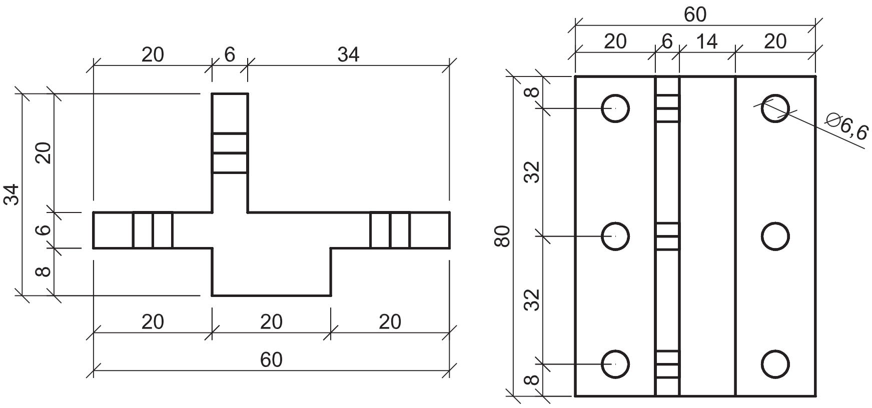

Fig. 2. Detailed view of the connecting element.

which are applied to reduce excessive and adverse vibrations. An example of a control system intended to reduce displacements of a tall steel tower was presented by Blachowski [9].

Because of the above reasons, researchers started to closely analyze the dynamics of structures with semi-rigid joints. The methods for identifying mechanical parameters of structural connections can be classified into three groups. These are modal, frequency and time domain methods, respectively.

One of the methods of the first group is presented in the paper by Wong and Mak [10]. They proposed to use experimental modal analysis to identify parameters of three types of connections: T-stub, web-seat angle and web-T. A more recent approach, using natural frequencies of healthy and damaged structures, was proposed by Zhu and He [11]. They used optimization techniques in conjunction with modal analysis to localize a damaged bolted connection in a spatial frame.

The second group of methods uses frequency domain in identifying the stiffness and damping parameters of a structural connection. A representative paper is the one by Hwang [12]. The author used Frequency Response Functions, instead of using only natural frequencies and modal shapes, to identify connection properties more accurately. An FRF-based method for identifying joint parameters was also proposed by Yang et al. [13]. The authors not only successfully identified the rotational stiffness of a connection, but also analyzed the coupling between the rotational and translational stiffness. Another FRF-based method was investigated by Celic and Boltezar [14]. The authors combined the FRF approach with the substructuring technique to identify the mass, stiffness and damping of a real bolted connection.