Dynamics and damage in the Quisi steel truss bridge

Marianna Crognale[1], Vincenzo Gattulli[1], Salvador Ivorra[2], Francesco Potenza[3]

[1] *Department of Civil and Geotechnical Engineering, Sapienza University of Rome, Italy.*

E-mail: marianna.crognale@uniroma1.it

vincenzo.gattulli@uniroma1.it

[2] *DIC, University of Alicante, Spain.*

E-mail: sivorra@ua.es

[3] *DICEA, University of L'Aquila, Italy.*

E-mail: francesco.potenza@univaq.it

ABSTRACT

Quisi Bridge located in Benissa (Alicante) is an historic steel truss structure, which is investigated with different techniques to assess fatigue damages. A method based on vibration measurements, is illustrated to determine defect-induced reduction of stiffness, (combination of damage intensity and extension). Natural frequency change for a structural damage in a truss member is quantified through a classical FEM procedure in which a damaged truss element is defined and implemented. This model is used to produce pseudo-experimental response of a damaged truss which is dynamically excited by white noise. Stochastic Subspace Identification (SSI) has permitted to identify the main modal parameters related to both damaged and undamaged truss system. A damage index depending on Stiffness Reduction Factor (SRF) permits to determine the damage description based on measured quantities.

KEYWORDS: *Damage Identification, Steel Structures, Stochastic Subspace Identification.*

INTRODUCTION

Steel truss railway bridges are subject to potential damage, mainly due to fatigue phenomena and corrosion. Recently, vibration-based damage identification is proposed in conjunction with other techniques [1]. Classically, the use of vibration relies on the comparison between identified undamaged and damaged modal properties of simple structural elements. The knowledge of mechanical models which describe the damage effect on structural dynamics, is also used [2] [3]. The cited approach is followed in the case of steel truss structure such as the Quisi Bridge, in order to determine a damage identification methodology for a simple 2D truss model (Fig.1).

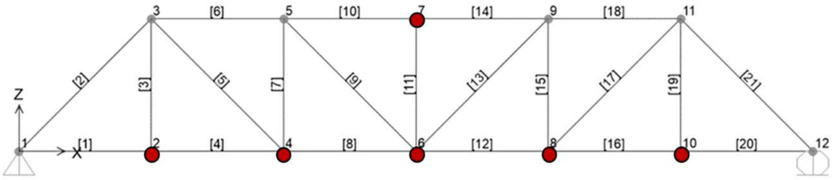

Figure 1: 2D truss simple model and sensor layout.

Damage is described as a cross-section area reduction of a truss member, through the introduction of the following damaged truss stiffness matrix:

$$\mathbf{K_d^e} = \frac{\mathrm{EA}}{\mathrm{L}} \cdot \frac{(1-\zeta)(1+\delta\zeta-\zeta)}{[(1-\zeta)(1-\delta)+\delta]^2} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} = \frac{\mathrm{EA}}{\mathrm{L}} (\mathrm{SRF}) \mathbf{K^e} \tag{1}$$

where the damage intensity ζ and extent δ have been represented in non-dimensional form as:

$$\zeta = \frac{\mathrm{EA}-\mathrm{EA_d}}{\mathrm{EA}},\ \delta = \frac{\mathrm{L_d}}{\mathrm{L}},\ 0 \leq \zeta \leq 1, 0 \leq \delta \leq 1 \tag{2}$$

SRF is the Stiffness Reduction Factor which is a combination of these two parameters affecting the stiffness and consequently the frequencies. Several damage scenarios were considered: the damage parameters ($\delta = 0.3, \zeta = 0.5$) were applied consecutively to truss element number 2, 5 and 6 in Fig. 1.

The dependence of the frequencies on the SRF is described by numerical evaluation FEM. The procedure uses pseudo-experimental response, generated from the numerical model under white noise. As sketched in Fig. 1, vertical accelerations of the bridge were evaluated in six nodes of the model (2, 4, 6, 7, 8 and 10). Based on these measurements a dynamic identification of the modal parameters was made by SSI in time domain (Fig. 3 shows the stabilization diagram). Fig. 2 shows pseudo-experimental response before and after damage.

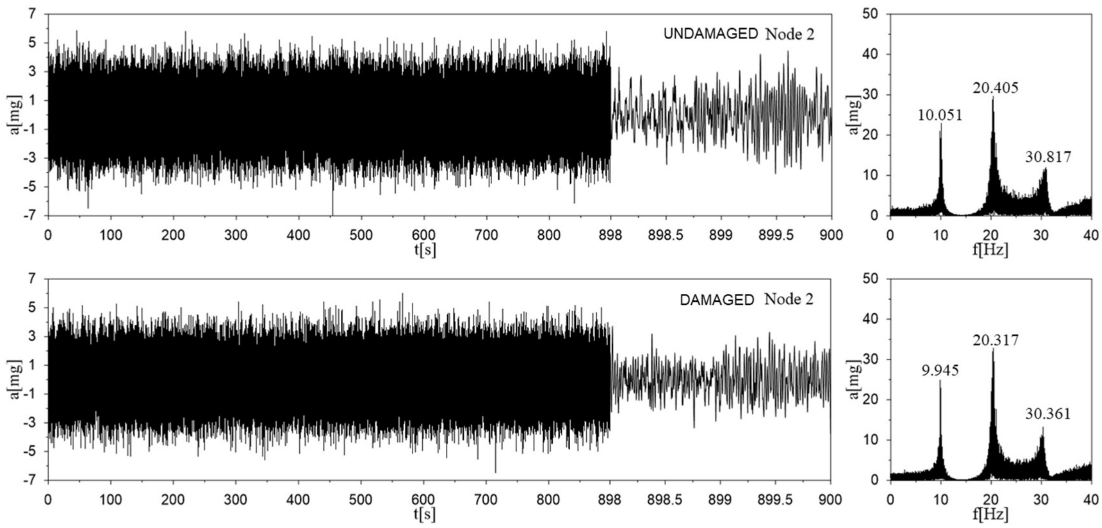

Figure 2: Time histories and FFT under white noise for node 2 - damaged truss member 6.

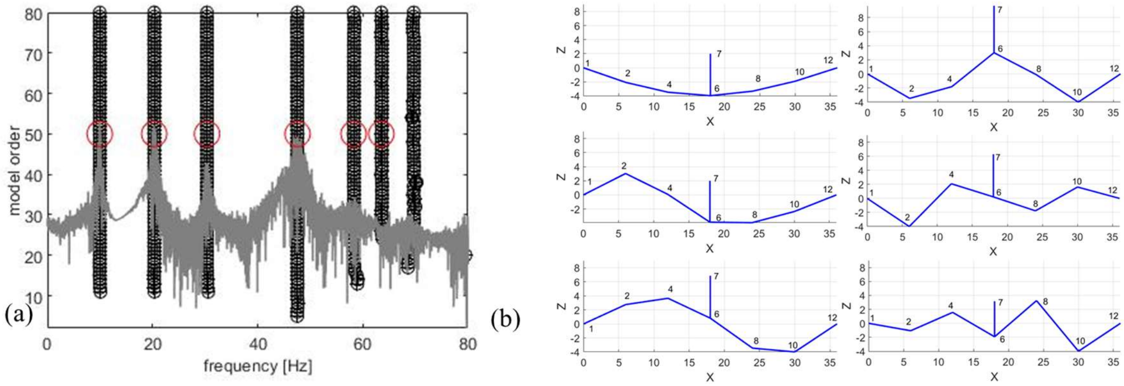

Figure 3: (a) Stabilization diagram obtained by the SSI-covariance driven procedure. (b) First six mode shapes identified from pseudo-experimental data.

MODAL AND DAMAGE IDENTIFICATION

The inverse problem of damage identification is addressed using a procedure based on comparison between the numerical and the experimentally measured dynamical response of the truss. Only an optimum number of modes are needed to be considered to univocally determine the curve SRF(δ,ζ) in the damage parameter plane (δ,ζ). The number of modes that are necessary to achieve a unique solution in the optimization problem depends on the position of the damaged element in the truss. The objective function $\mathcal{L}(\zeta,\delta)$ based on frequency measurements is defined as follows:

$$\mathcal{L}(\zeta,\delta)=\sum_{\mathrm{i}=1}^{\mathrm{k}}\left|\frac{\omega_{\mathrm{d,i}}^{\mathrm{EX}}-\omega_{\mathrm{d,i}}^{\mathrm{NM}}(\zeta,\delta)}{\omega_{\mathrm{u,i}}^{\mathrm{EX}}}\right|^2 \tag{3}$$

where $\omega_{\mathrm{d,i}}^{\mathrm{EX}}$ and $\omega_{\mathrm{d,i}}^{\mathrm{NM}}(\zeta,\delta)$ are the i-th experimental and numerical frequencies of the damaged element respectively, while $\omega_{\mathrm{u,i}}^{\mathrm{EX}}$ represents the corresponding frequency in the undamaged state. Thus, an optimal estimate of the damage is given by the parameter combination T$=(\bar{\zeta},\bar{\delta})$ corresponding to the SRF$(\bar{\zeta},\bar{\delta})$ that in the parameters space minimizes the objective function $\mathcal{L}(\zeta,\delta)\colon \Pi\rightarrow\mathbb{R}^{+}$ measuring the error between the experimental and the analytical frequencies. Fig. 4 shows results of the performance of index $\mathcal{L}$ in the detection of curve SRF (δ,ζ) varying the number of modes k.

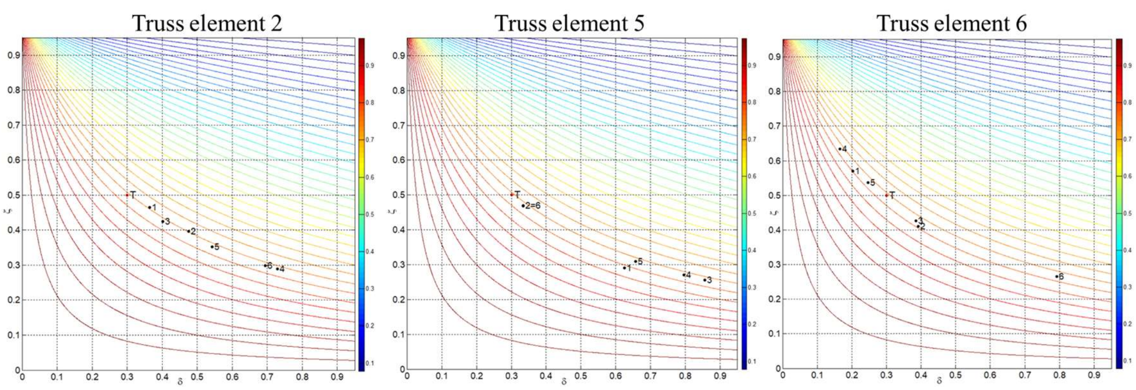

Figure 4: Effects of number of modes in the detection of SRF$(\boldsymbol{\delta},\boldsymbol{\zeta})$ curve.

QUISI BRIDGE CASE STUDY

The Quisi Bridge is located in Benissa (Alicante) was built in 1914 and it is part of the 9th FGV Railway Line. The structure consists in a top-bearing Pratt type truss. It is 170 m long with six spans of different length (Fig. 5). A 3D FE model of the main span permits to evaluate frequencies variation due to damage affecting an element with SRF = 0.76923. The frequency variation for the first four modes in percentage are $(f_{iu}-f_{id})/f_{iu}$ = [0.15, 0.02, 0.14, 0.09]. In the real case the damage affecting one single element influences the natural frequencies with quite small variation.

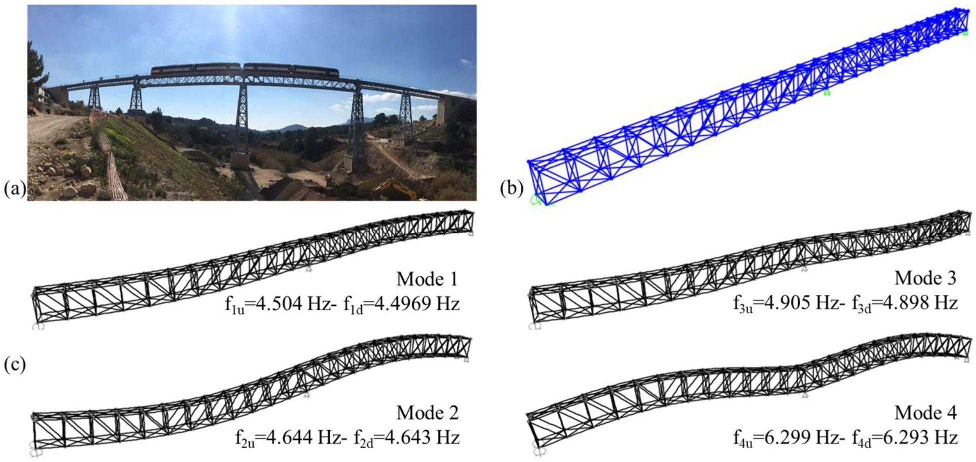

Figure 5: (a) Quisi Bridge; (b) FE model of Quisi Bridge main spans; (c) First modes of vibration.

CONCLUSIONS

A procedure to identify the overall stiffness reduction factor produced by damage in truss element has been proposed. The results obtained through pseudo-dynamic testing and FEM analysis for a simple truss evidences the obtainable resolutions in damage indicator with the increase of a number of modes. For the main span of the Quisi Bridge the frequency variation produced by damage appears to be quite low evidencing the needs of introducing also other sources of data to assess the damage identification.

ACKNOWLEDGMENTS

This paper is a part of a project that has received funding from the Research Fund for Coal and Steel under grant agreement No 800687.

REFERENCES

[1] Potenza F, Castelli G, Gattulli V, Ottaviano E. Integrated process of image and acceleration measurements for damage detection, EURODYN 2017.

[2] Vestroni F, Cerri MN. Detection of damage in beams subjected to diffuse cracking, *Journal of Sound and Vibration*, 2000.

[3] Lepidi M, Gattulli V. Static and dynamic response of elastic suspended cables with thermal effects, *Internation Journal of Solid and Structures*, 2012.