EXPERIMENTAL CAMPAIGN ON SAN MICHELE BRIDGE

7-10 May 2024

PROJECT PLAN

Rev 04

REVISION DESCRIPTION

Date	Version	Description of the updating	
March 27th	00	First issue	Rosalba
April 29th	01	Sections 2.3.1, 3.1.1, 3.2 revised	Rosalba
April 30th	02	Section 2.3.1 added Section 3 revised	Rosalba/Maurizio
May 3rd	03	Time Schedule Sec. 2.3.2 revised	Rosalba/RFI
May 3rd	04	Time Schedule Sec. 2.3.2 revised	Rosalba/RFI
May 6th	05	Time Schedule Sec. 2.3.2 revised Measuring setup Sec. 3.2.1 revised	Rosalba/RFI

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

CONTENTS

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

1. GENERAL

The present document outlines:

- Fundamental insights into the geometric configuration of the bridge and its modal parameters (mode shape and natural frequencies) evaluated numerically (from a FEM model) and identified experimentally from previous campaigns (not conducted by the UniBg group of Mechanics of Solids and Structures);
- Available resources in terms of personnel and equipment;
- A proposal detailing the planned execution of the experimental tests.

2. PROJECT DESCRIPTION

2.1. GENERAL DESCRIPTION OF THE ACTIVITIES

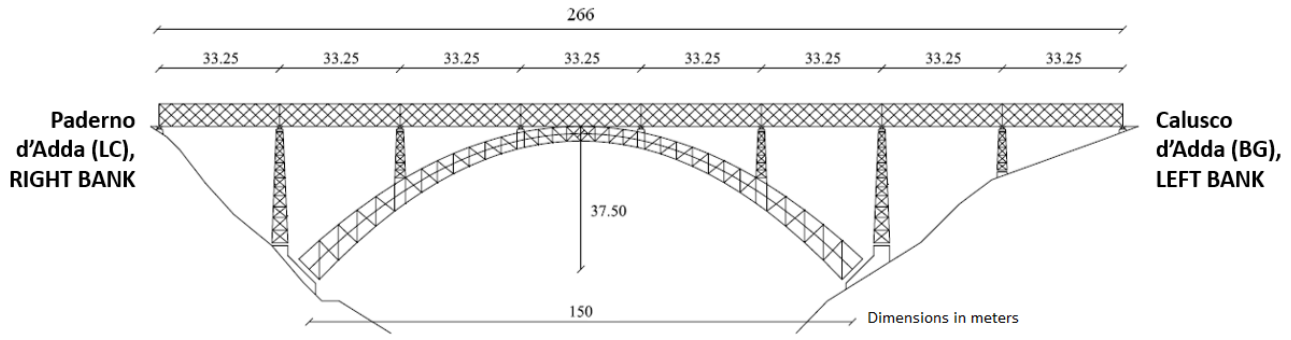
The activities concern the execution of vibration measurements induced by trains and vehicular traffic on San Michele bridge (built in 1889), which crosses the river Adda between Paderno d'Adda (LC) and Calusco d'Adda (BG) in the Lombardy region (Italy).

The experimental campaign will comprise two types of surveys:

1. **On-board measurements**: this involves capturing mechanical vibrations using instrumentation installed on test wagons as they travel across the bridge;

2. **Structure-mounted sensor measurements**: this involves using instrumentation fixed to the upper continuous box girder of the bridge, to directly monitor mechanical vibrations coming from the structure during the passage of test wagons and the ordinary (vehicle and railway) traffic.

2.2. GENERAL DESCRIPTION OF THE BRIDGE



San Michele bridge consists of a continuous box girder, 266 m long, supported by nine piers, four of which are supported by an arch with a 150 m span and a 37.5 m chord. It crosses the River Adda at a height of approximately 85 m. Photographic description in following Figure 1−Figure 5.

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

2.2.1. RAILWAY DECK (UPPER CONTINUOUS BOX GIRDER)

- Upper deck for pedestrian and automotive transit
- Inner railway
- Cross section:
  - Height 6.25 m
  - Width 5.00 m
  - Free passage for trains 4.60 m

2.2.2. MODAL PARAMETERS OF THE BRIDGE

Reported in following Figure 6 and Figure 7.

2.3. ACTIVITIES DESCRIPTION

The total duration of the experimental campaign is expected to be 4 days. Its development will consist of the following activities:

- Positioning and mounting of the measuring sensors;
- Lay out of the measuring chains and their verification;
- Performance of the vibration recordings;
- Preliminary analysis of the recorded signals in the time domain;
- Dismantling of the measuring chains and of the sensors.

2.3.1. PROPOSED TESTS

The following tests are proposed:

1. Normal conditions train traverse with the following characteristics:
   train speed: **15 km/h** (maximum operating speed)
   train set-up: Vag1 + 2 × Vag2 (66,4 t + 2 × 14 t + 30 t = **124,4 t**)
   train direction: from Calusco to Paderno
2. Return, from Paderno to Calusco
3. Slow train traverse with the following characteristics:
   train speed: **6-7 km/h** (half the maximum operating speed)
   train size: Vag1 + 2 × Vag2 (66,4 t + 2 × 14 t + 30 t = **124,4 t**)
   train direction: from Calusco to Paderno
4. Return, from Paderno to Calusco
5. Normal conditions train traverse with the following characteristics:
   train speed: **15 km/h** (maximum operating speed)
   train set-up: Vag1 (**66,4 t**)
   train direction: from Calusco to Paderno
6. Return, from Paderno to Calusco

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

7. Slow train traverse with the following characteristics:
   train speed: **6-7 km/h** (half the maximum operating speed)
   train size: Vag1 (**66,4 t**)
   train direction: from Calusco to Paderno
8. Return, from Paderno to Calusco

2.3.2. TIME SCHEDULE

1. **Tuesday 7th, 2 pm – 6 pm**
   a. Possible on-site inspection of the bridge and viewing of the test wagons at the Carnate depot, which is about 20' by car from the bridge [I]

2. **Wednesday 8th, 2 pm – Thursday 9th, 8 am**
   a. Installation of the measuring equipment on the wagons at the depot [D]
   b. Installation of the sensors (and supp. devices) on the railway beam [B]
   c. Verification of the measuring chains
   d. Performance of the vibration recordings from all the sensors during the passage of the wagons [R]
   e. Dismantling of the measuring equipment on wagons at the depot [d]
   f. Dismantling of the sensors (and supp. devices) mounted on the bridge [b]

3. **Thursday 9th, 7 pm – Friday 10th, 6 am**
   a. Installation of the measuring equipment on the wagons at the depot [D]
   b. Installation of the sensors (and supp. devices) on the railway beam [B]
   c. Performance of the vibration recordings from all the sensors during the passage of the wagons [R]
   d. Dismantling of the measuring equipment on wagons at the depot [d]
   e. Dismantling of the sensors (and supp. devices) mounted on the bridge [b]

	AM												PM											
Hour	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
Tue 7th															I	I	I							
Wed 8th									D/B	D/B	D/B	D/B	D/B											B
Thu 9th	B	R	R	R	b	d/b														?	?	?	D/B	B
Fri 10th	B	R	R	R	b	d/b																		

Hours of activity on the bridge or at the depot
Wagon route in the depot–bridge section
R Performance of the vibration recordings from all the sensors during the passage of the wagons
Downtime/sleep hours

3. PROJECT PLANNING

3.1. RESOURCES ORGANIZATION

3.1.1. STRUCTURE OF THE WORK TEAM

UniBg Team
Rosalba Ferrari, Associate Professor – UniBg Unit Project Responsible
Marco Bosio, PhD, Laboratory Staff UniBg
Daniele Di Marco, Dr, Laboratory Staff UniBg
Maurizio Zola, Engineer – Scientific Collaborator
Lorenzo Ermolli, Master Student – Collaborator

ETH Team
Vasilis Dertimanis, PhD – ETH Unit Project Responsible
Charikleia Stoura, PhD – Collaborator
Konstantinos Vlachas, PhD Student – Collaborator
Dominik Werne, Dr, Laboratory Manager ETH Zurich

RFI (Rete Ferroviaria Italiana, owner of the bridge)
Lorenzo Corti, Engineer – Administrative Interface
Emanuele Lizzori, Engineer – Administrative Interface
Alessandro Fiorilla, Head of Maintenance Unit

3.1.2. MEASURING EQUIPMENT

For the performance of the measurements the following equipment will be used.

UniBg:

- **No. 15 seismic accelerometers** Model 731A and power amplifiers Model P31, Wilcoxon
  - Acceleration nominal sensitivity (selectable): 10 – 100 – 1000 V/g
  - Velocity nominal sensitivity (selectable): 0,1 – 1 – 10 V/(in/s)
  - transverse sensitivity (max): < 1%
  - frequency range: 0,08 ÷ 300 Hz
  - maximum acceleration: 0,5 g
  - mass: 670 grams
- **No. 4 analog input modules (x 4 channels)** – National Instruments, NI-9239
  - Output voltage: ± 10 V
  - resolution: 24 bit
  - sample rate: 50 kS/s/ch
  - Input signals on each channel are conditioned, filtered, buffered and then sampled by an ADC
- **8-Slot TSN-Enabled Ethernet CompactDAQ Chassis**, National Instruments
- **Shielded BNC cables** (no. 15 x 50 m + no. 25 x 20 m = **1250 m**)
- Honda EU10i 1 kW Inverter **Power Generator**

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

ETH:

- To be defined

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

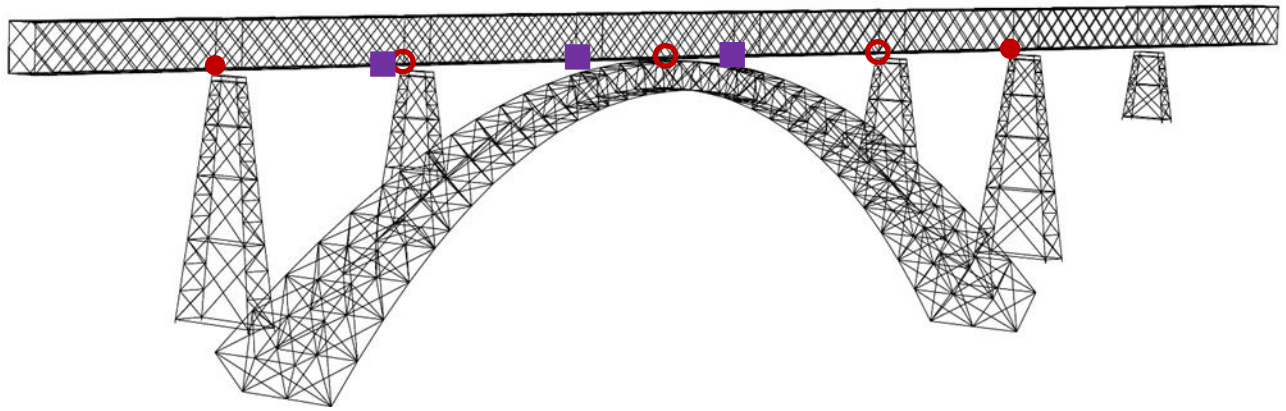
rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

3.2. MEASURING EQUIPMENT SET-UP

3.2.1. STRUCTURE-MOUNTED SENSOR MEASUREMENTS

During the passage of trains and vehicle traffic on the upper deck no. 8 transducers will be used in the following (no. 5) measuring points:

1	2	3	4	5	6	7	8



Paderno d'Adda (LC)
RIGHT BANK

Calusco d'Adda (BG)
LEFT BANK

	Sensor	Mounting Direction	No.	No. Tot.
●	Accelerometers 731A and power amplifiers P31, Wilcoxon	Transversal upstream	1	1
○	Accelerometers 731A and power amplifiers P31, Wilcoxon	Transversal upstream	1	2
	Accelerometers 731A and power amplifiers P31, Wilcoxon	Vertical upstream	1	
■	Accelerometers 731A and power amplifiers P31, Wilcoxon	Vertical upstream	1	1

Measurement points can be modified and/or added if other transducers are available by ETH Unit.

The following parameters should be used for the data acquisition for the measuring points on the bridge during all the operating conditions:

- sampling frequency: 600 Hz
- cut-off frequency for low-pass analogic filter: 300 Hz
- duration of each acquisition: the time for the train traverse
- pre and post-trigger for each acquisition: 10 seconds

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

3.2.2. ON-BOARD MEASUREMENTS

To be defined.

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

LIST OF FIGURES

Figure 1: View of San Michele bridge (1889) after the extraordinary maintenance works performed between 15 September 2018 and 14 September 2020.

Figure 2: Upper continuous box girder of San Michele bridge (pre-intervention state): upper deck for pedestrian and automotive transit, inner deck for the railway.

Figure 3: Interior part of the continuous box girder (pre-intervention state). It consists of two main reticular beams, connected by an orthotropic plate on the top, by transverse elements and St. Andrew's crosses at the bottom.

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379

Figure 4: Bottom view of the arch at the fixed-support on the Calusco bank (pre-intervention state).

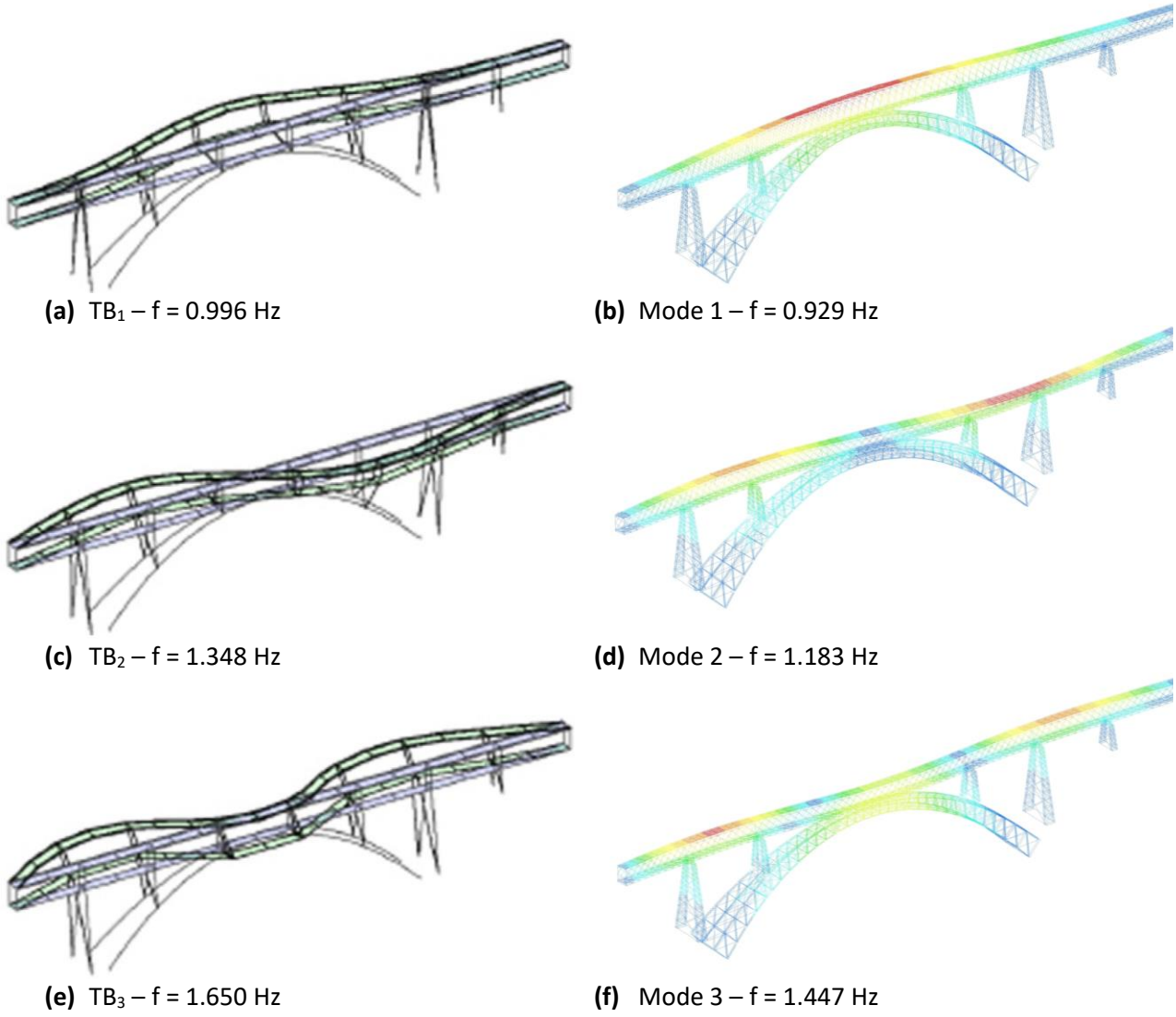
Figure 5: Overall view of the arch-pier-box girder assembly (pre-intervention state).

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379



(a) TB_1 – f = 0.996 Hz

(b) Mode 1 – f = 0.929 Hz

(c) TB_2 – f = 1.348 Hz

(d) Mode 2 – f = 1.183 Hz

(e) TB_3 – f = 1.650 Hz

(f) Mode 3 – f = 1.447 Hz

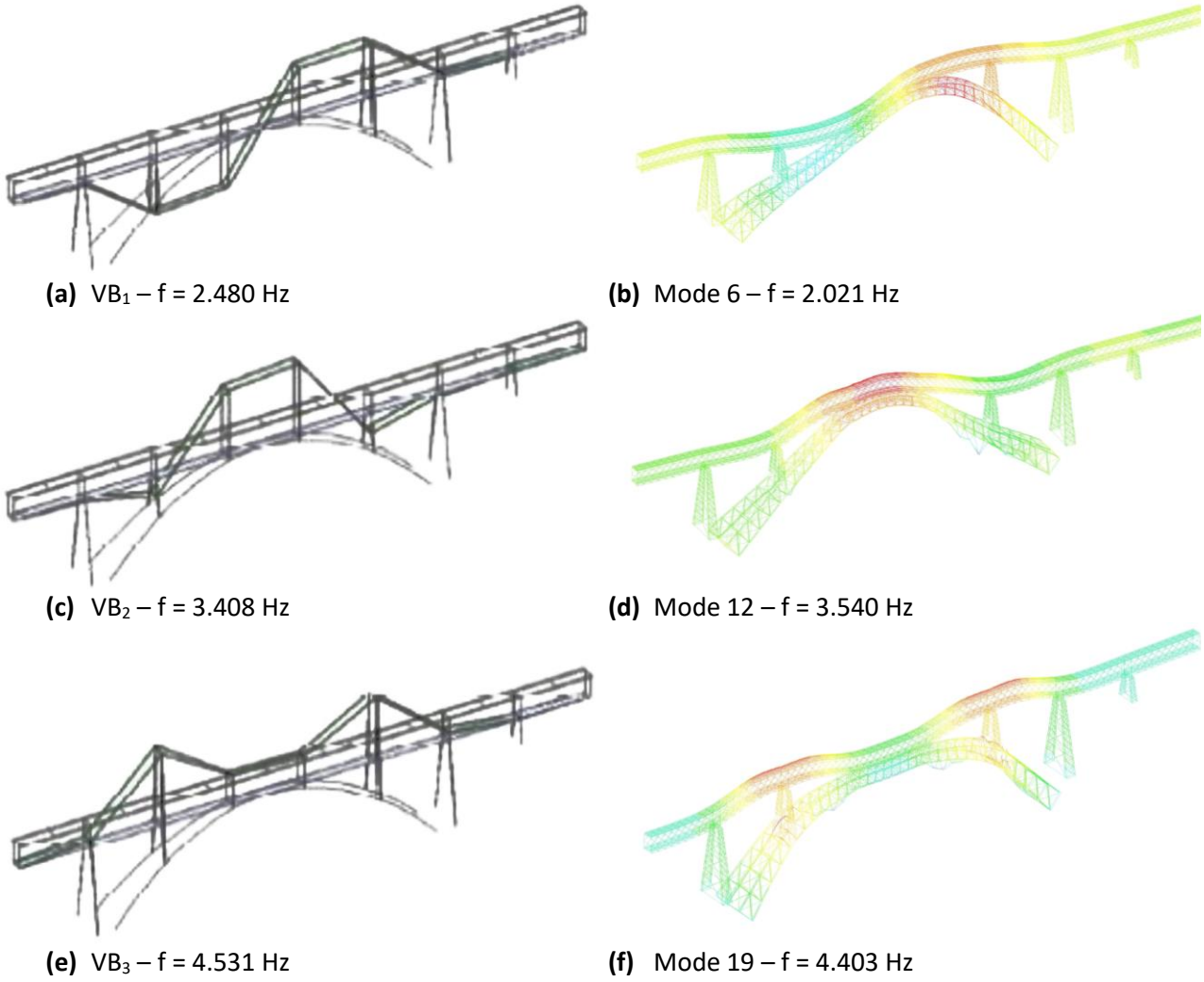
Figure 6: First three transverse dominant modes of the FEM model of San Michele bridge (b,d,f) compared with experimentally identified frequencies from previous measurement campaigns (a,c,e).

University of Bergamo
Department of Engineering and Applied Sciences

Group of Mechanics of Solids and Structures

G. Marconi 5
I-24044 Dalmine (BG), Italy

rosalba.ferrari@unibg.it
☎ +39 338 280 6840 / +39 035 2052379



(a) VB_1 – f = 2.480 Hz

(b) Mode 6 – f = 2.021 Hz

(c) VB_2 – f = 3.408 Hz

(d) Mode 12 – f = 3.540 Hz

(e) VB_3 – f = 4.531 Hz

(f) Mode 19 – f = 4.403 Hz

Figure 7: First three vertically dominant modes of the FEM model of San Michele bridge (b,d,f) compared with experimentally identified frequencies from previous measurement campaigns (a,c,e).