SPECIAL MOBILITY STRAND

SYSTEM IDENTIFICATION OF BRIDGES USING AMBIENT VIBRATION MEASUREMENTS AND NUMERICAL SIMULATIONS (CASE STUDIES)

Damir Zenunovic

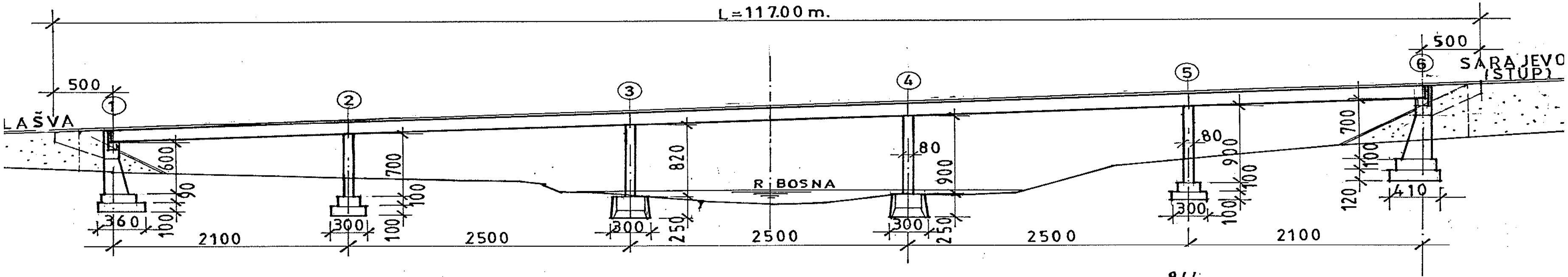
Tirana, April 2019

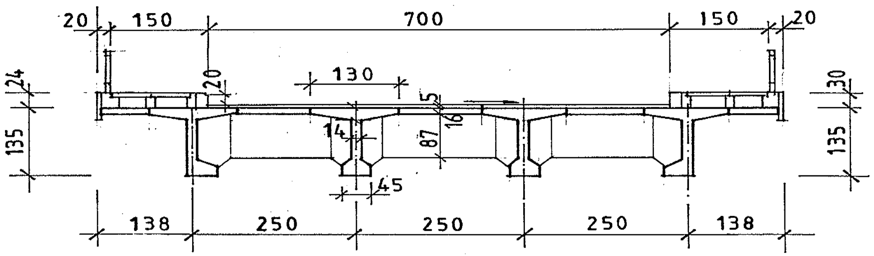
Damir Zenunovic
Full Profesor, University of Tuzla,
Faculty of Mining, Geology and Civil Engineering, Department of Civil Engineering

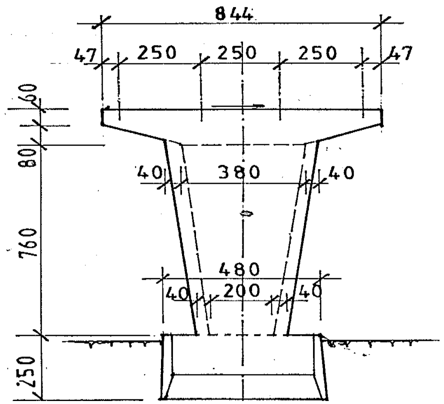
Co-funded by the Erasmus+ Programme of the European Union

CASE STUDY 1 – THE BRIDGE OVER RIVER BOSNIA IN SARAJEVO

Elevation and cross-sections of the bridge

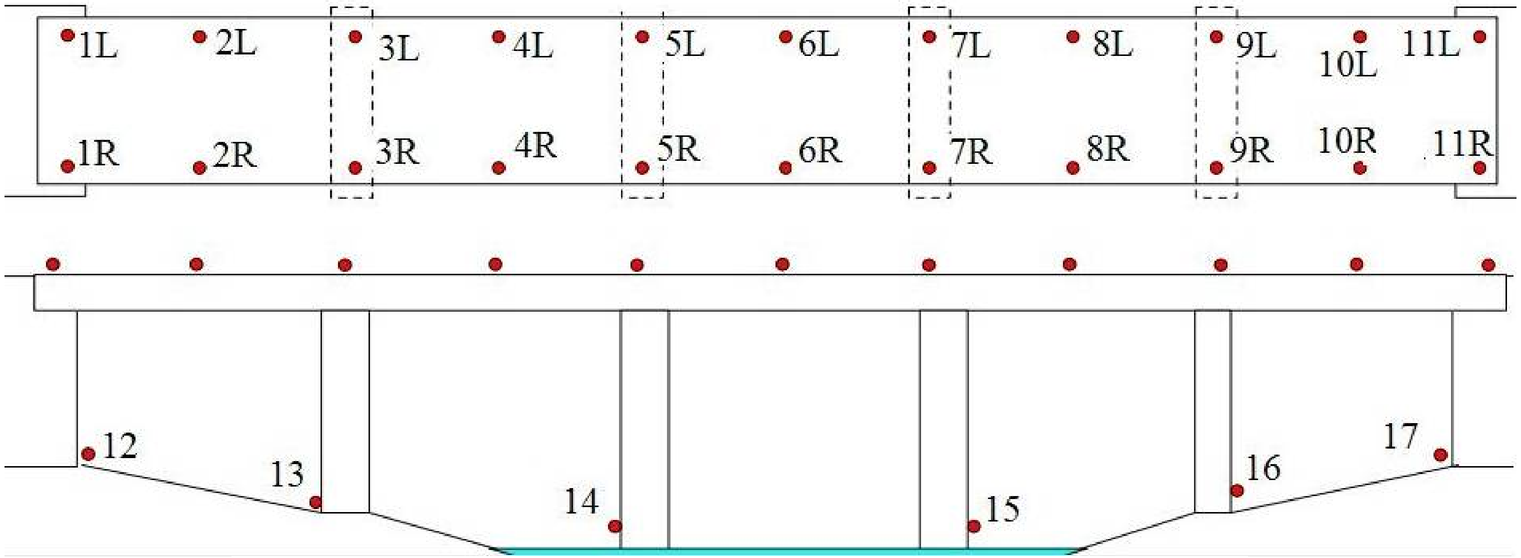







NATO
OTAN
This project is supported by: The NATO Science for Peace and Security Programme
(SfP Project Number 983828)
AMBIENT
VIBRATION
TEST
May 28th 2011
Sarajevo, B&H

Measurements setup

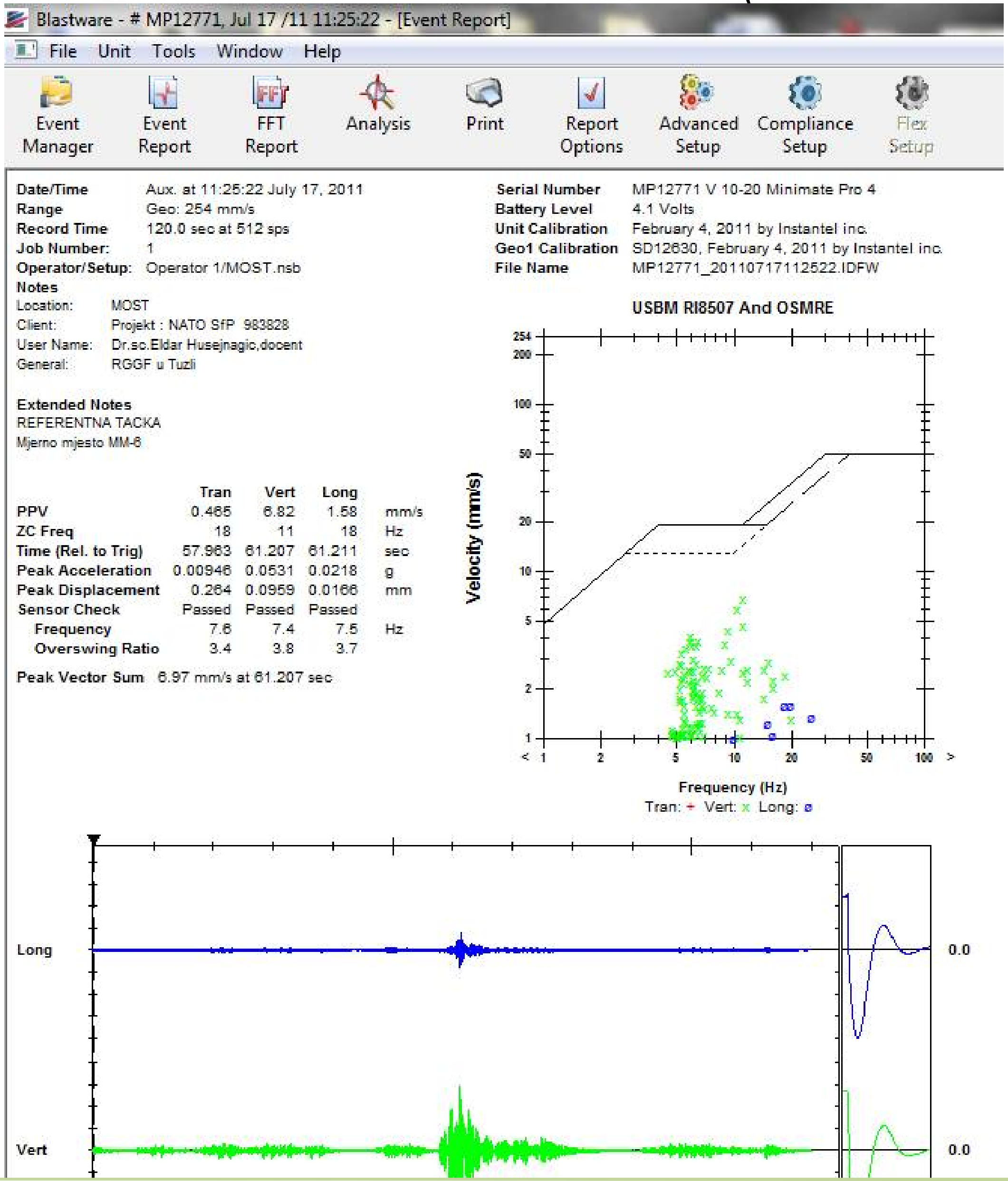


Setup	Moveable stations	Base stations
M1	4R, 5R, 7R, 8R	6R
M2	2R, 3R, 9R, 10R	6R
M3	1R, 2R, 10R, 11R	6R
M4	4L, 5L, 6L, 7L	6R
M5	3L, 4L, 8L, 9L	6R
M6	1L, 2L, 10L, 11L	6R
M7	12, 13, 16, 17	6R
M8	12, 13, 16, 17	6R

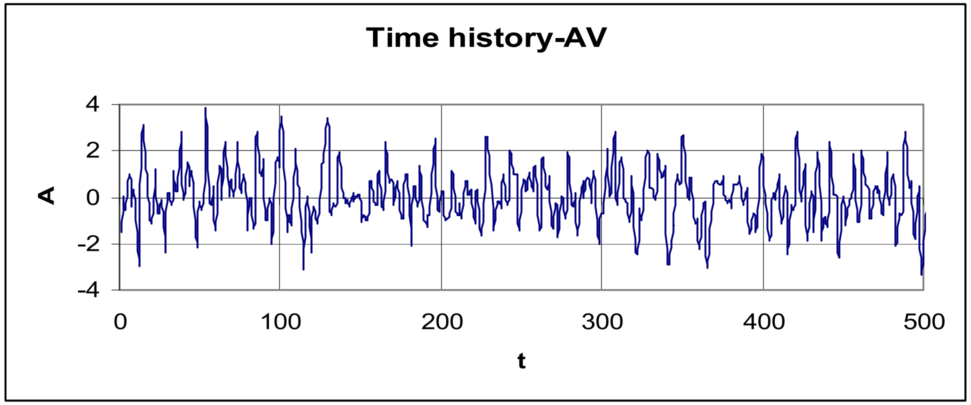
Test equipment

Test equipment

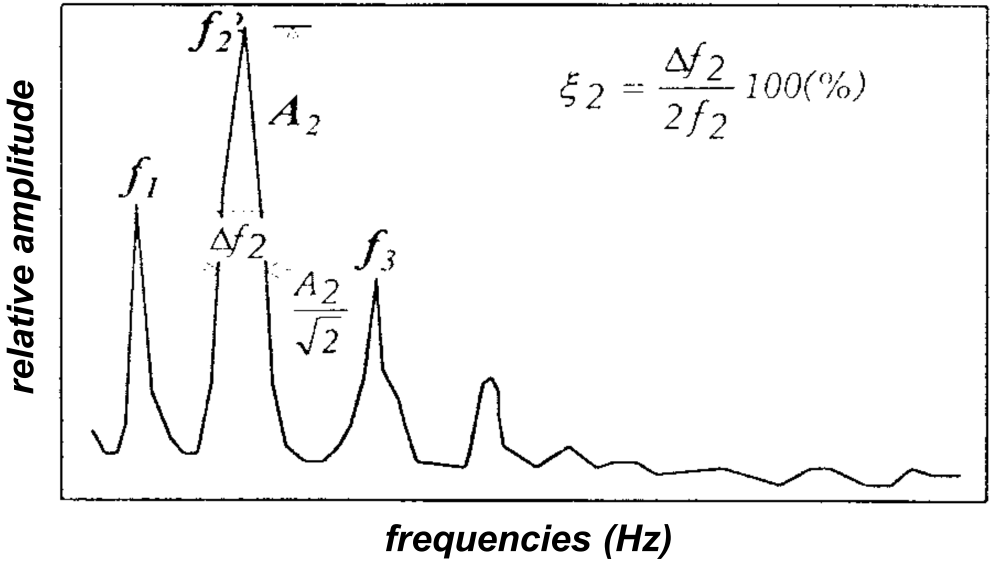
Measurement on base station 6R (middle of the span)



Ambient vibration testing procedure consists of real time recording of the vibrations and processing of the records by means of the Fast Fourier Transform , i. e. obtaining of Fourier Amplitude Spectra.



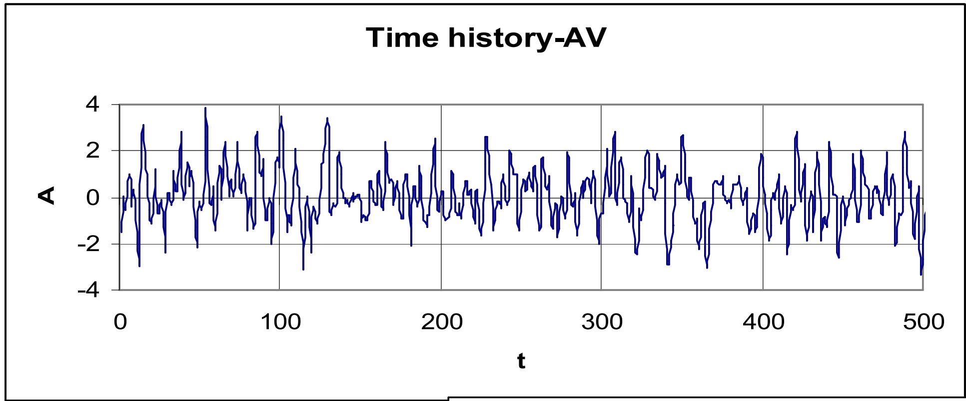
$$X(f) = \int_{-\infty}^{+\infty} x(t) e^{-2\pi i f} dt$$



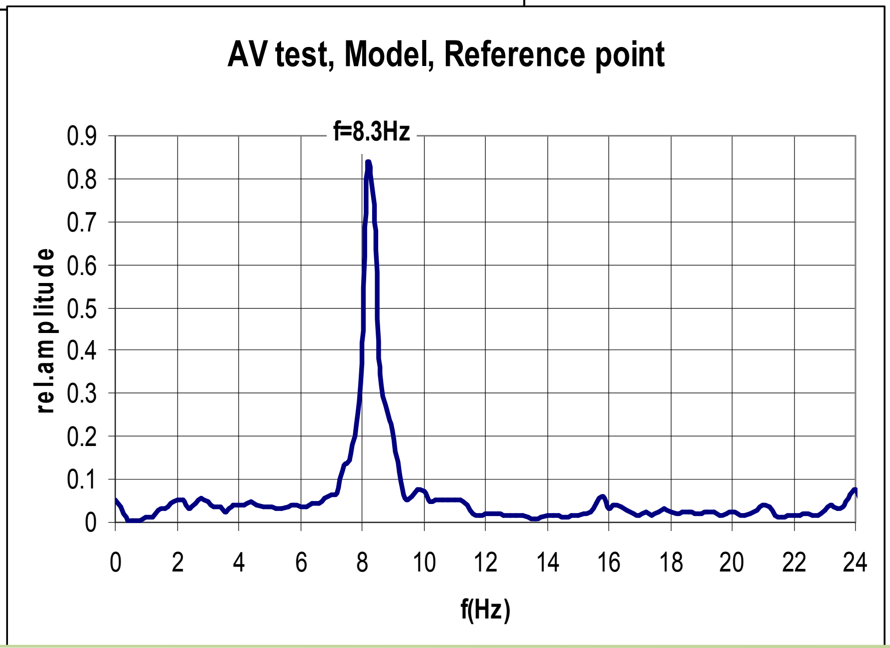
The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

The peaks of the amplitude spectrum occur at the predominant frequencies of the time function x(t), which due to the flat spectrum of the excitation represent the natural frequencies of the structure.

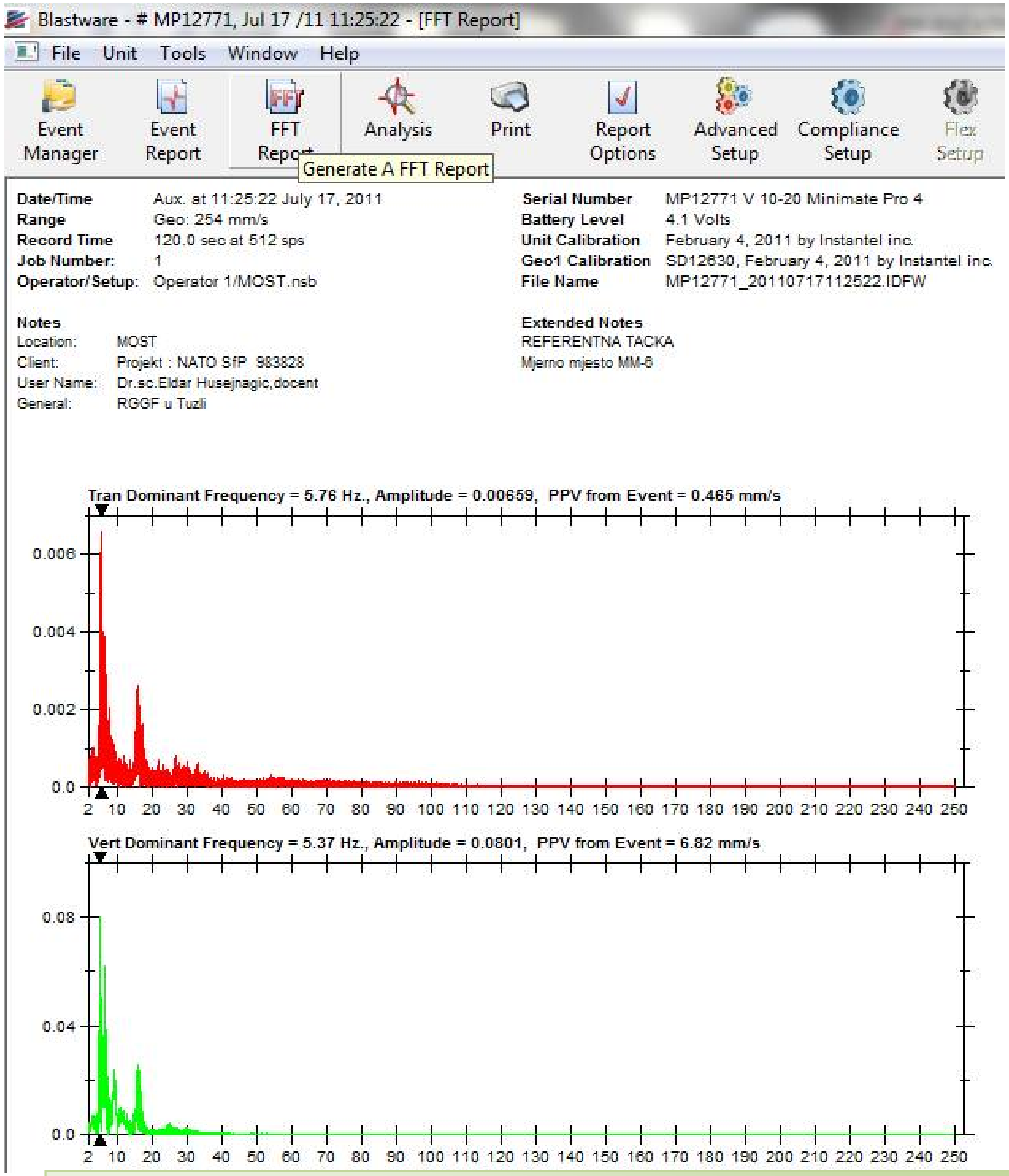


$$X(f)=\int_{-\infty}^{+\infty} x(t)e^{-2\pi i f}\,dt$$



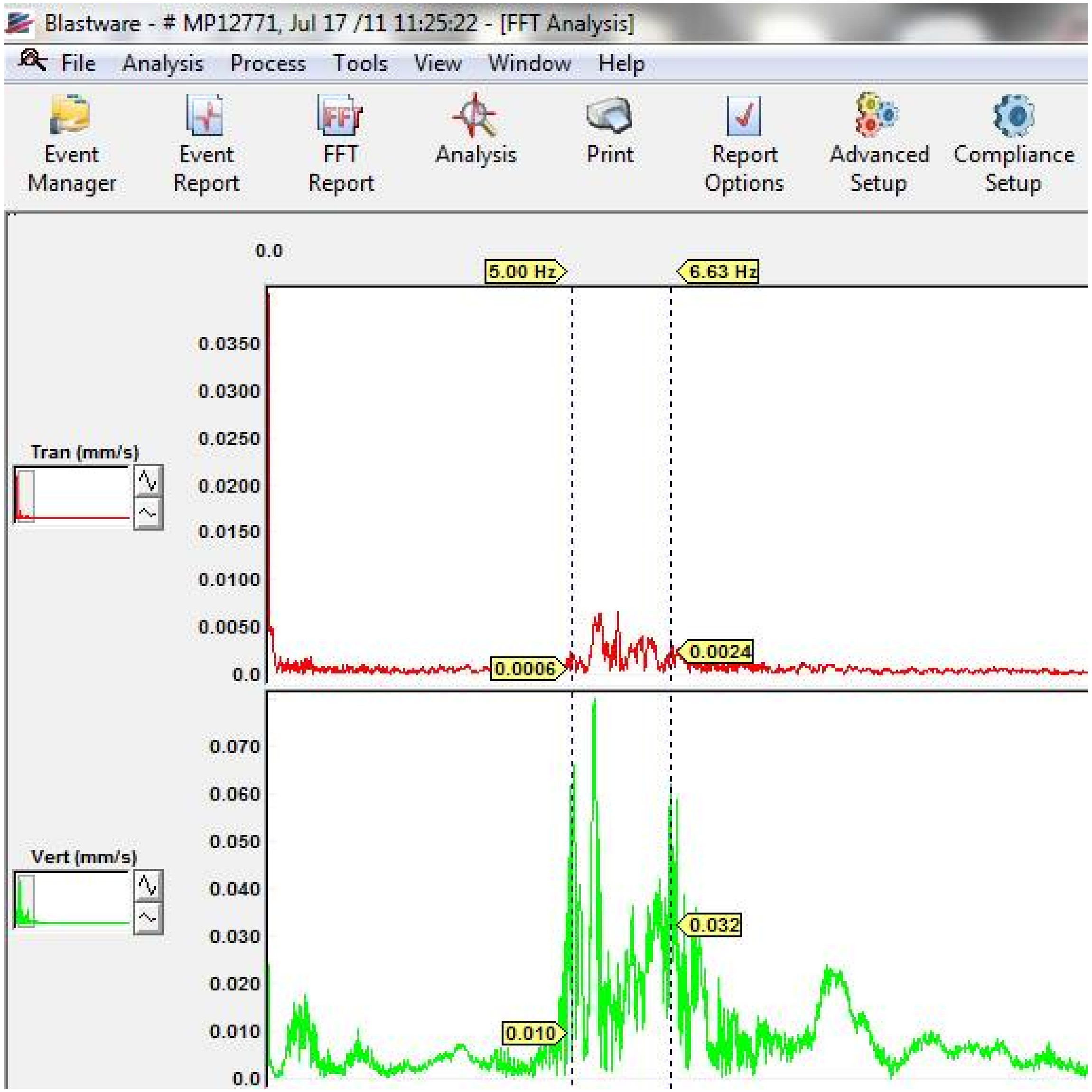
The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

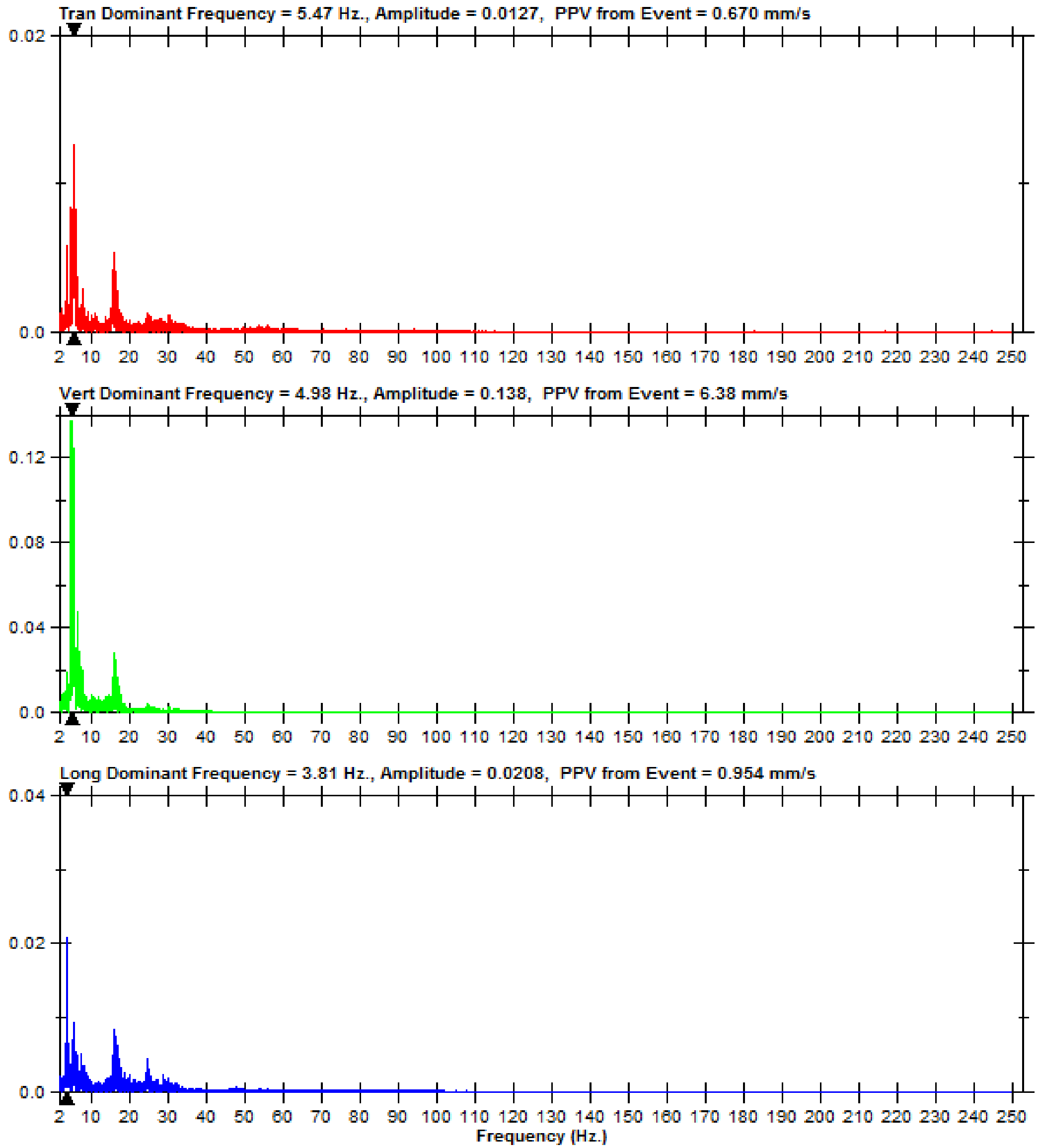


Measurement on base station 6R (middle of the span)

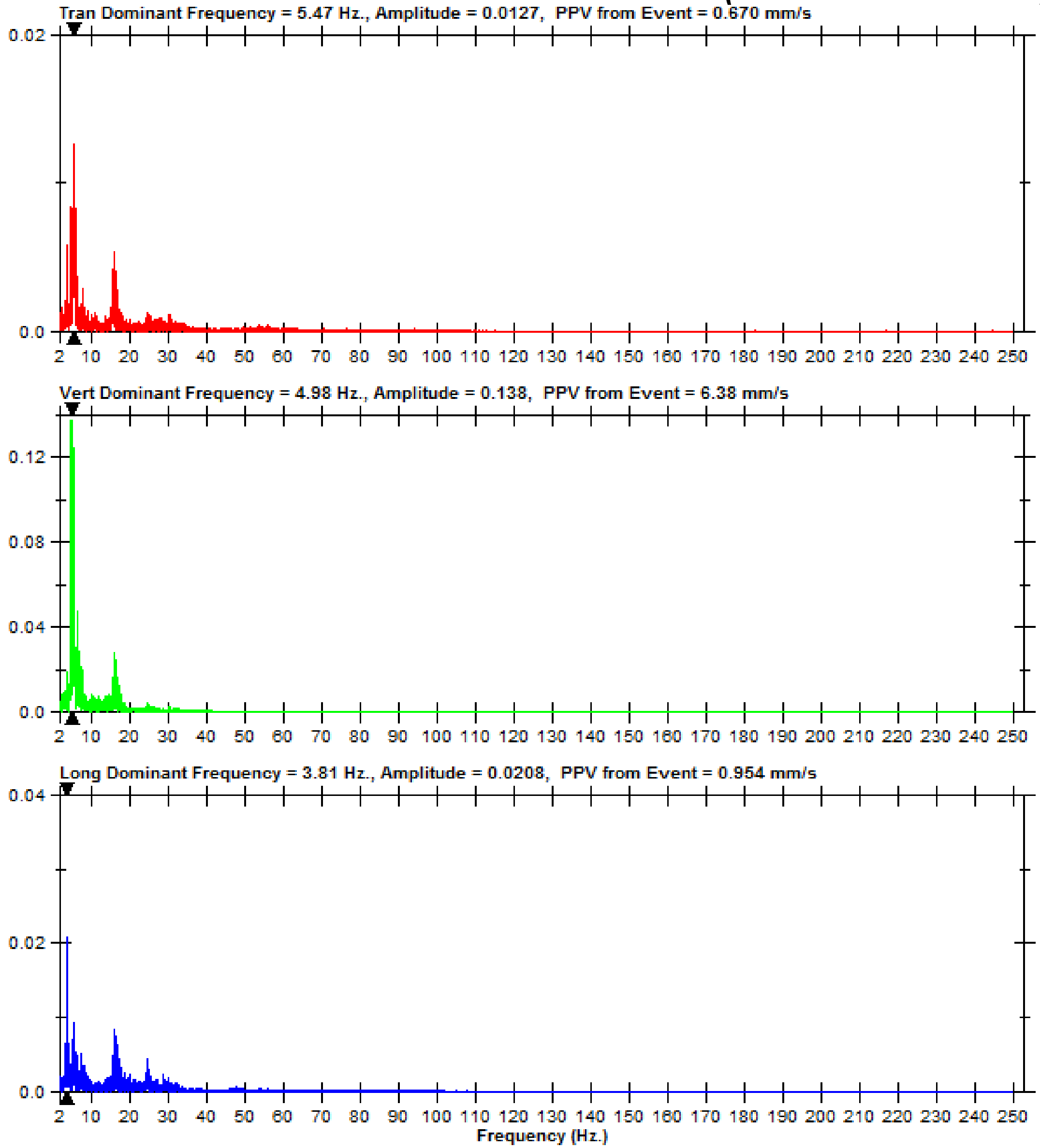
Measurement on base station 6R (middle of the span)



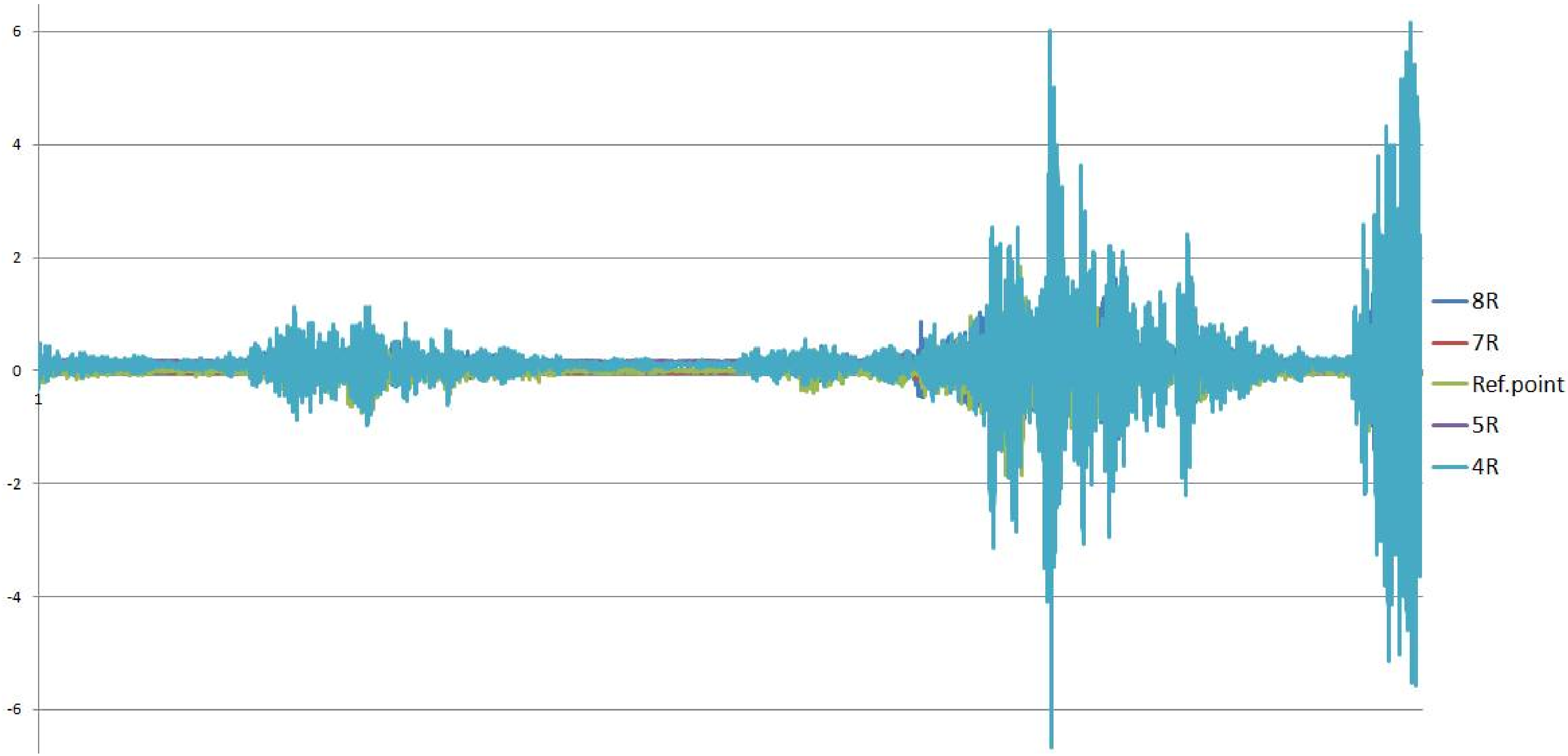
Measurement on base station 6R (middle of the span)



Measurement on moveable station 4R (middle of the span)



Comparison of vertical channels

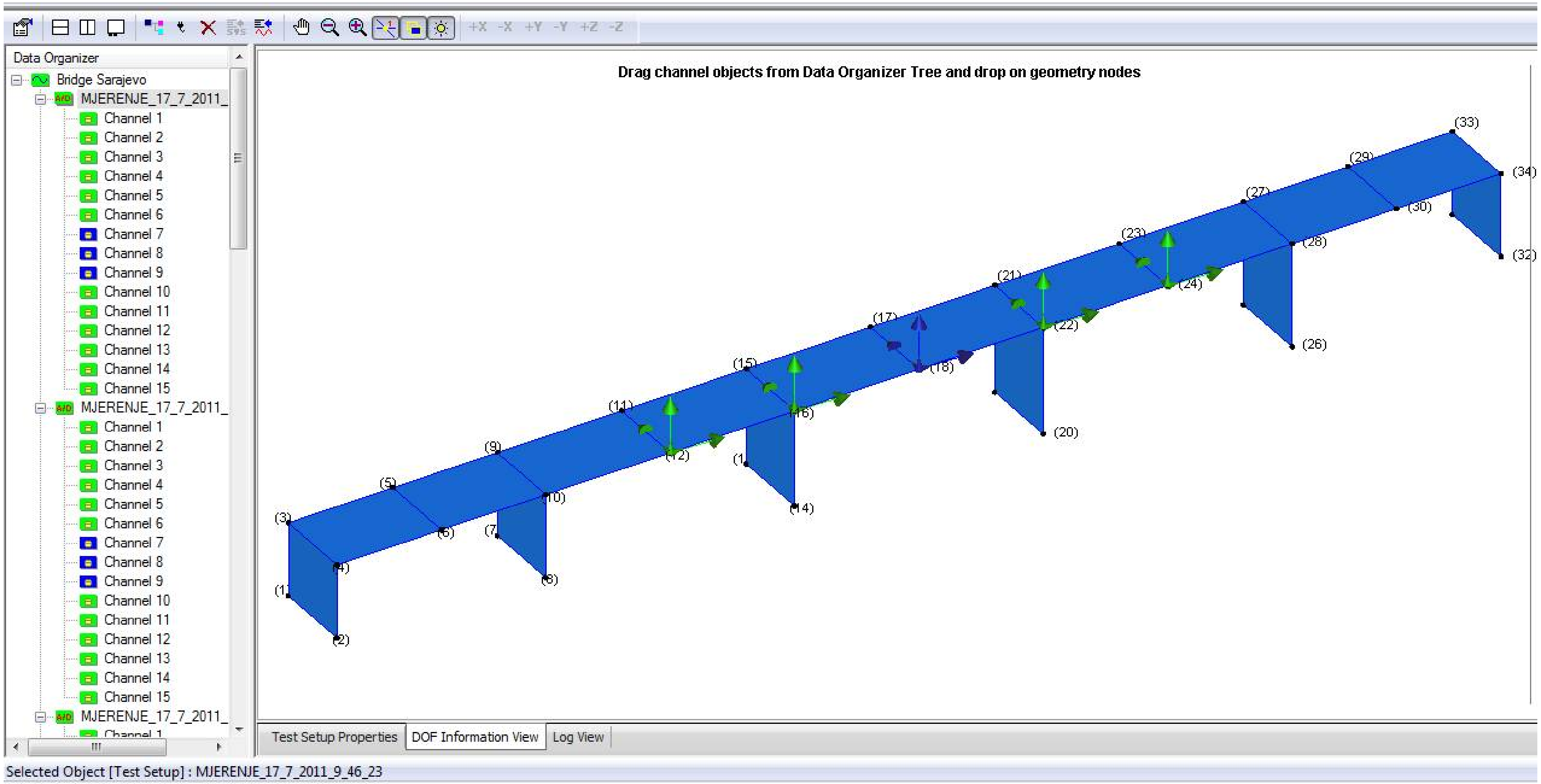


The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

Measured dominant frequency

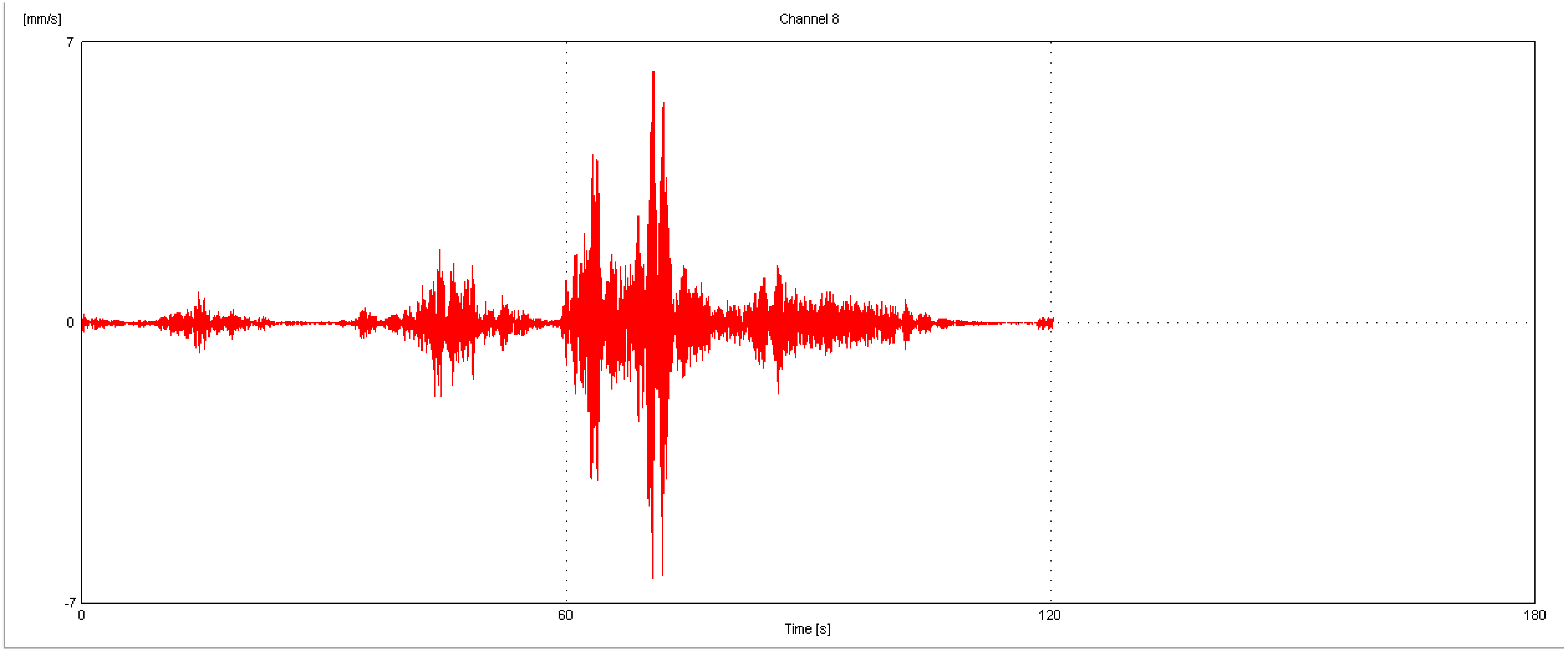
Measuring points	Trans. Freq. (Hz)	Vert. Freq. (Hz)	Long. Freq. (Hz)
M1 4R, 5R, 6R, 7R, 8R	5.62, 5.63, 5.47, 5.62, 5.63	5.45, 5.60, 4.98, 3.81, 5.61	5.61, 5.60, 3.81, 3.81, 3.81
M2 2R, 3R, 6R, 9R, 10R	5.77, 5.97, 16.4, 5.97, 6.00	7.69, 5.50, 4.97, 5.43, 7.58	19.6, 5.43, 3.73, 5.43, 6.16
M3 1R, 2R, 6R, 10R, 11R	5.76, 5.75, 5.57, 5.75, 5.75	7.85, 7.86, 4.95, 5.73, 5.73	21.7, 5.56, 3.85, 5.56, 5.56
M4 6R, 4L, 5L, 6L, 7L	5.76, 5.76, 5.76, 5.49, 5.76	5.38, 5.74, 5.76, 5.36, 17.2	5.48, 5.48, 5.48, 5.48, 3.88
M5 6R, 3L, 4L, 8L, 9L	5.54, 6.48, 5.75, 7.74, 5.02	5.02, 5.54, 5.78, 5.02, 5.54	3.86, 5.54, 5.54, 17.2, 5.54
M6 6R, 1L, 2L, 10L, 11L	16.3, 6.70, 19.3, 5.67, 8.24	6.85, 20.3, 6.70, 8.17, 20.9	3.92, 7.95, 19.50, 6.29, 6.29
M7 6R, 12, 13, 16, 17	4.95, 14.1, 4.99, 2.01, 2.00	4.99, 2.27, 4.99, 2.00, 2.01	16.1, 5.50, 5.50, 2.01, 2.02
M8 6R, 12, 13, 16, 17	6.84, 16.6, 5.84, 2.00, 2.00	6.84, 2.39, 17.1, 2.00, 2.00	3.91, 6.28, 6.37, 2.00, 2.00



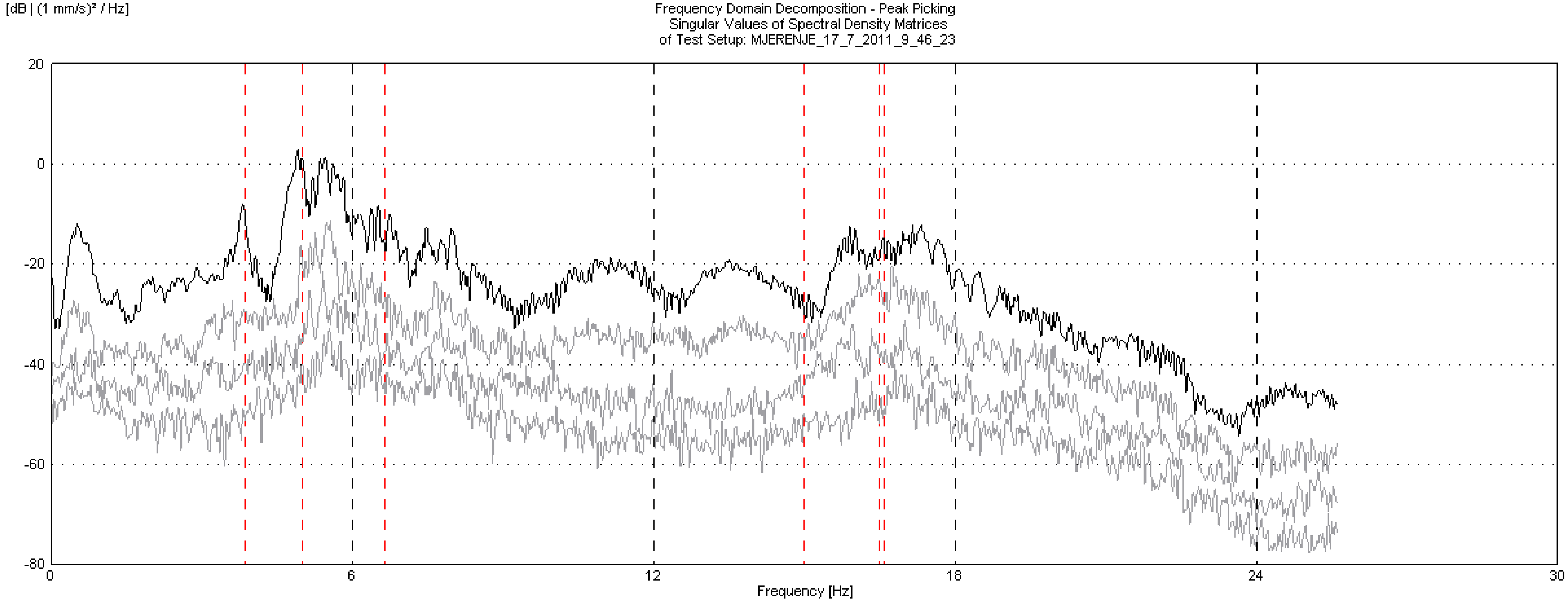
The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

ARTeMIS



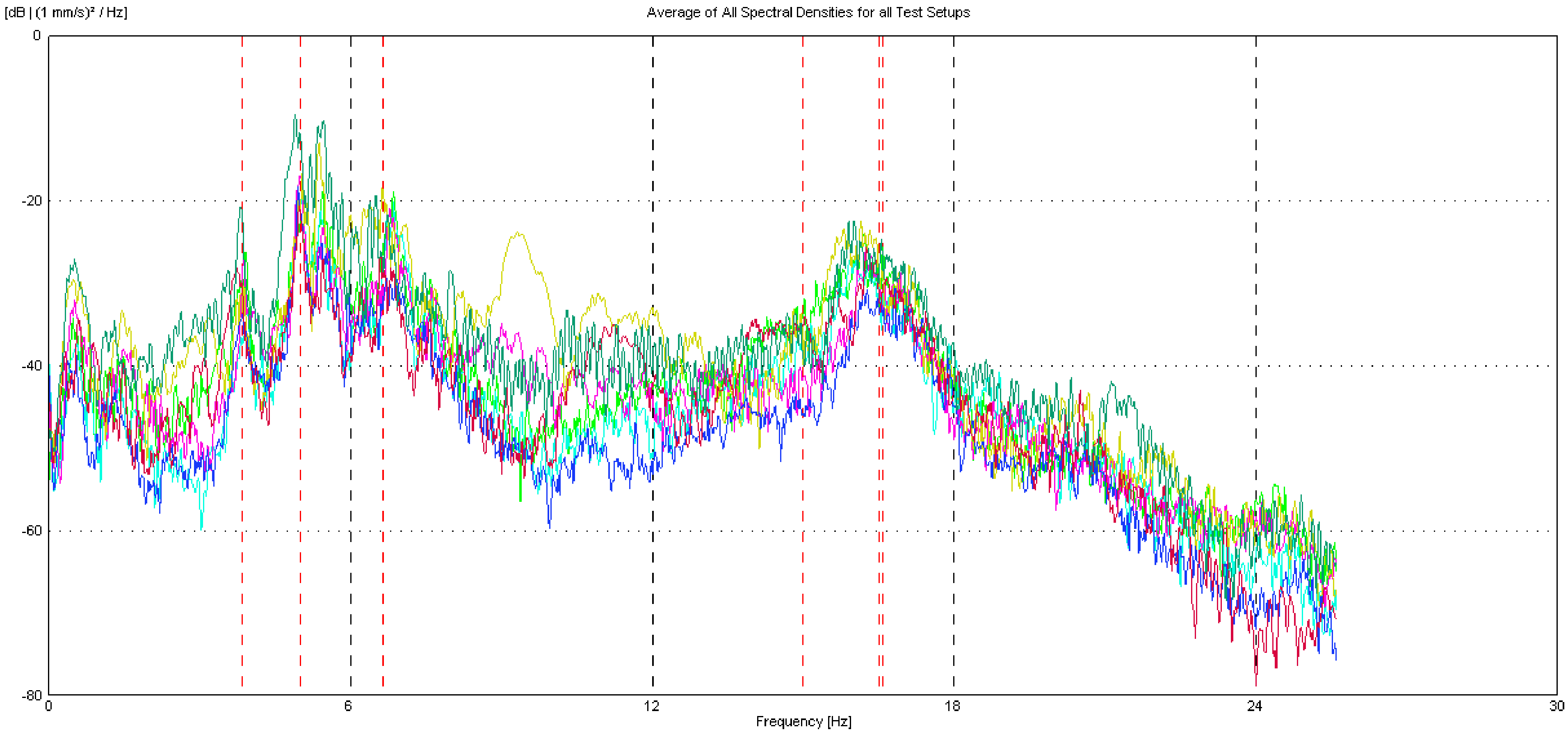
ARTeMIS



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

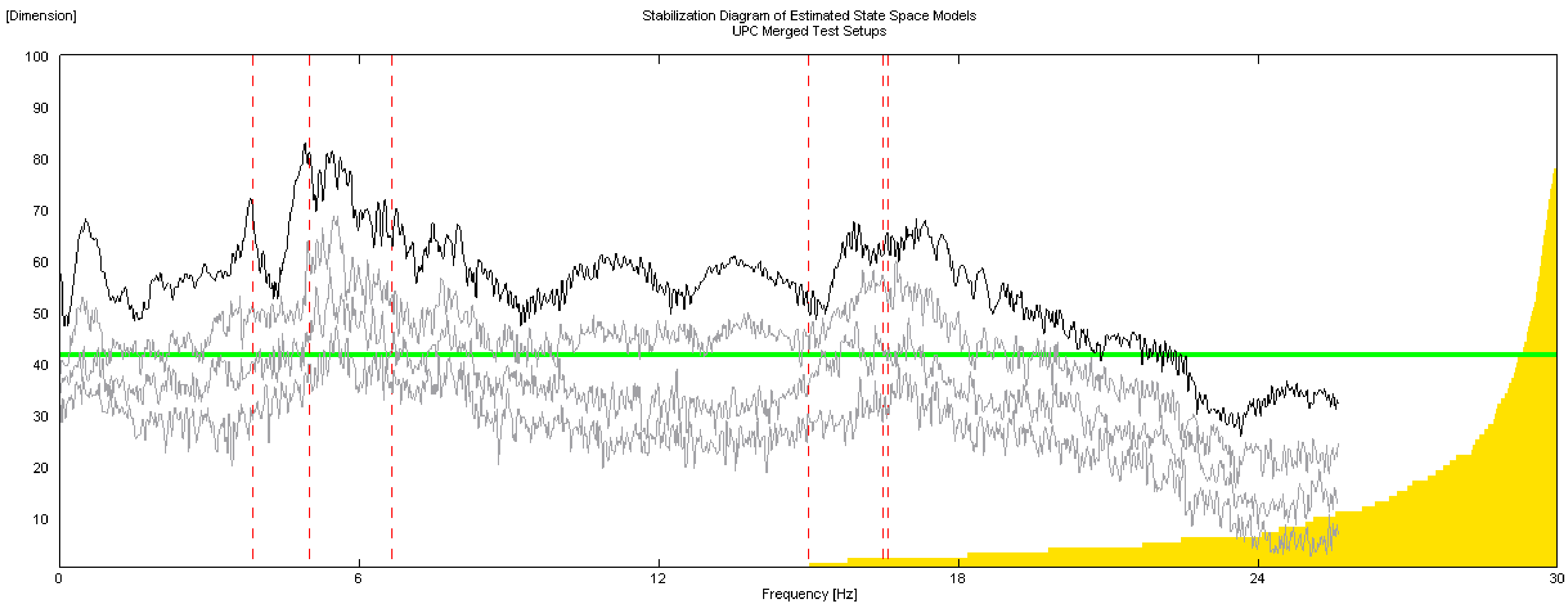
ARTeMIS



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

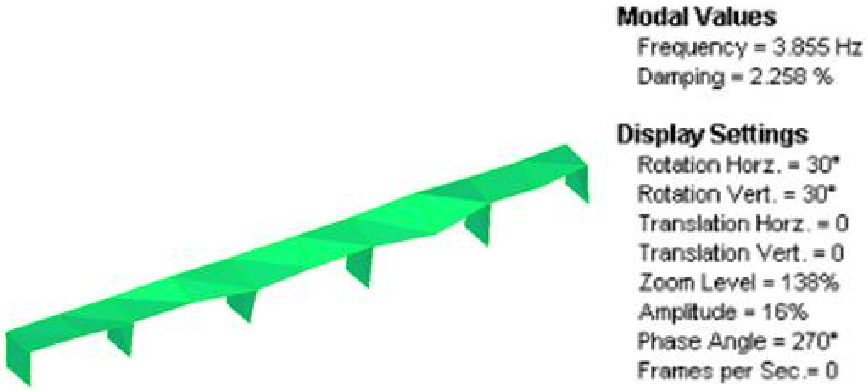
Co-funded by the Erasmus+ Programme of the European Union

ARTeMIS

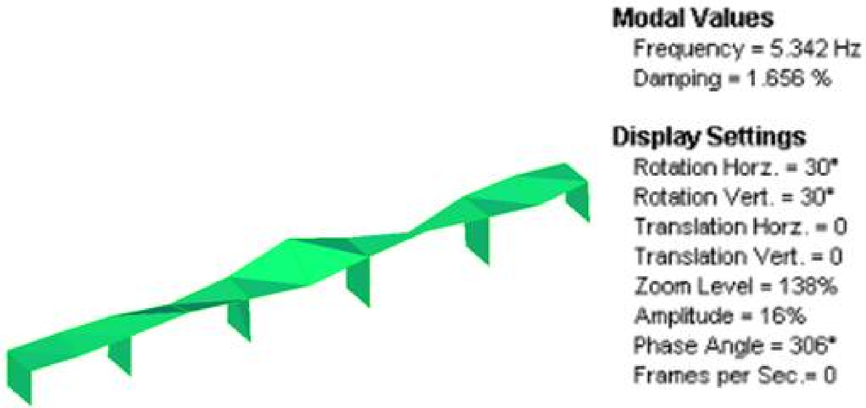


[Dimension]
Stabilization Diagram of Estimated State Space Models
UPC Merged Test Setups
100
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
Frequency [Hz]

ARTeMIS

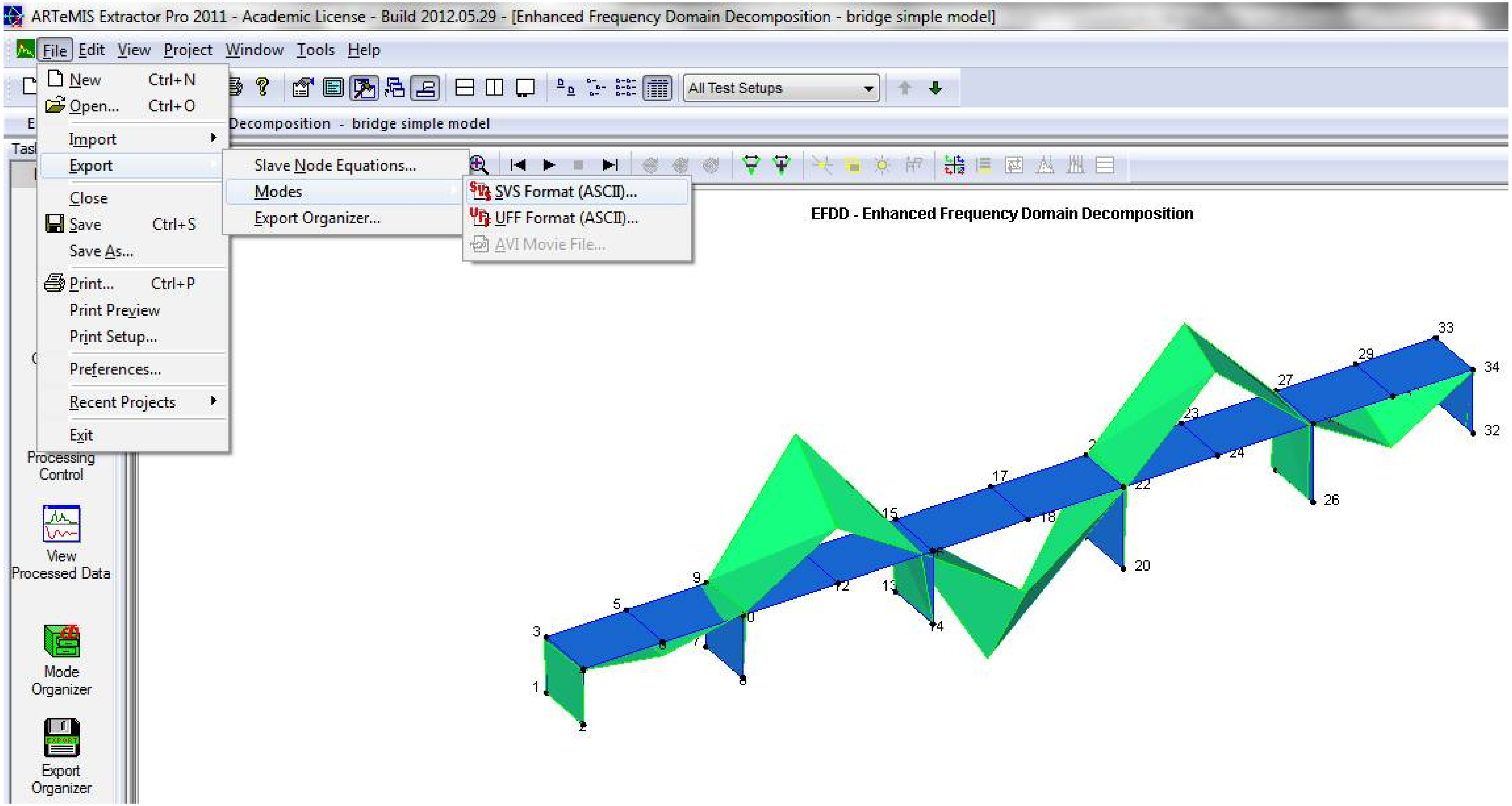

Modal Values
Frequency = 3.855 Hz
Damping = 2.258 %
Display Settings
Rotation Horz. = 30°
Rotation Vert. = 30°
Translation Horz. = 0
Translation Vert. = 0
Zoom Level = 138%
Amplitude = 16%
Phase Angle = 270°
Frames per Sec.= 0


Modal Values
Frequency = 4.971 Hz
Damping = 1.364 %
Display Settings
Rotation Horz. = 30°
Rotation Vert. = 30°
Translation Horz. = 0
Translation Vert. = 0
Zoom Level = 138%
Amplitude = 16%
Phase Angle = 306°
Frames per Sec.= 0


Modal Values
Frequency = 5.342 Hz
Damping = 1.656 %
Display Settings
Rotation Horz. = 30°
Rotation Vert. = 30°
Translation Horz. = 0
Translation Vert. = 0
Zoom Level = 138%
Amplitude = 16%
Phase Angle = 306°
Frames per Sec.= 0


Modal Values
Frequency = 6.698 Hz
Damping = 2.101 %
Display Settings
Rotation Horz. = 30°
Rotation Vert. = 30°
Translation Horz. = 0
Translation Vert. = 0
Zoom Level = 138%
Amplitude = 16%
Phase Angle = 270°
Frames per Sec.= 0

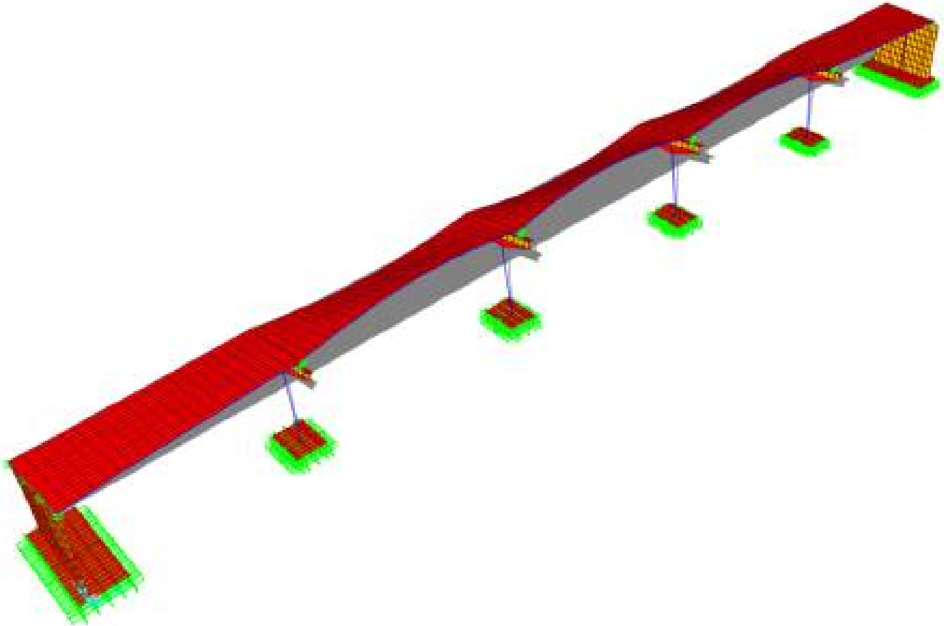
Transfer data to another program

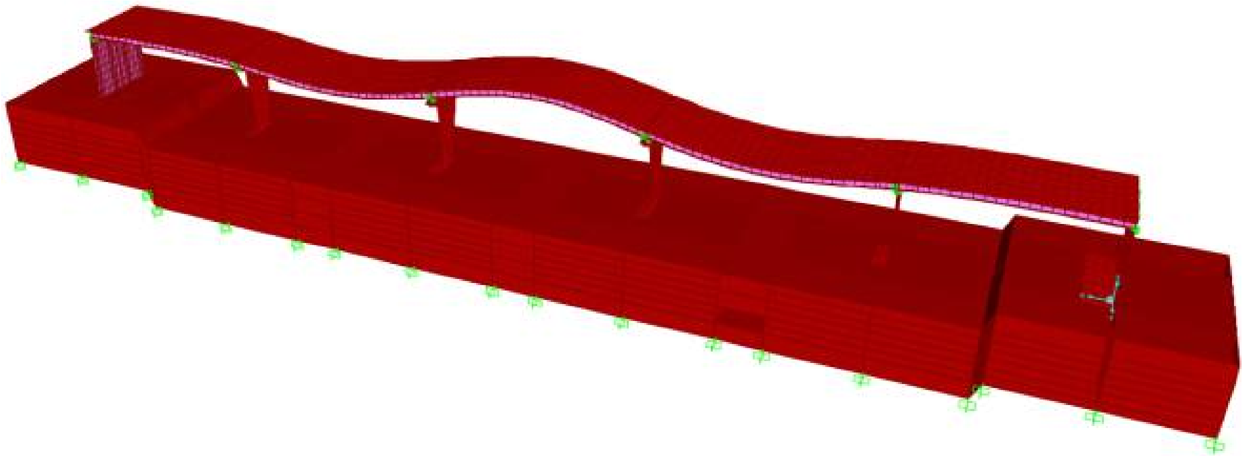


Transfer data to another program

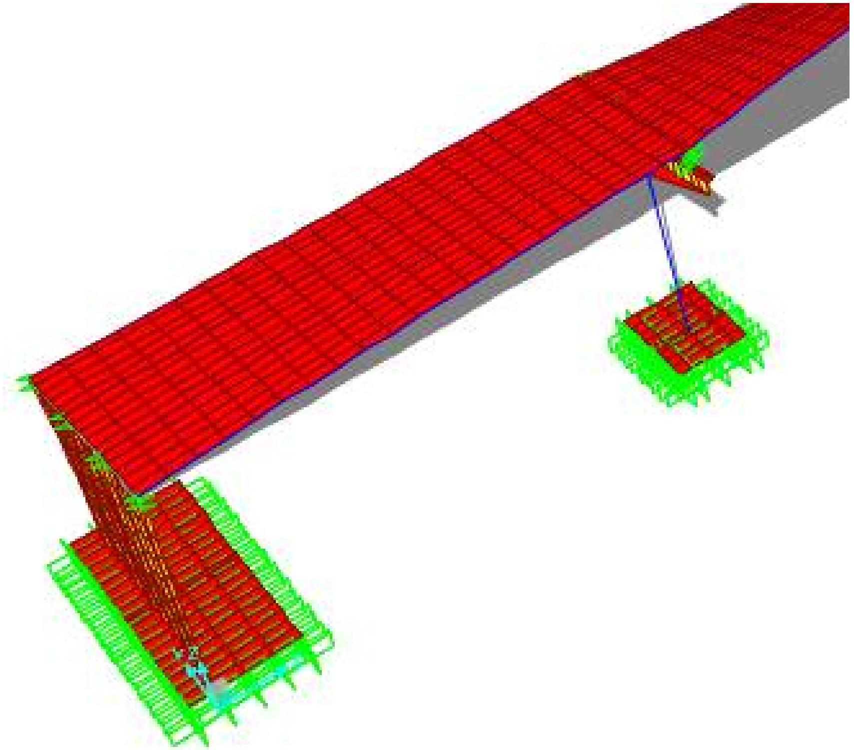
```
PROJECT
        bridge simple model

ESTIMATOR
        EFDD

CREATION: DATE / TIME
        05-02-2019  12:59:48

FREQUENCY [HZ]: MEAN / SDEV
        5.061297e+000   1.615336e-001

DAMPING [%]: MEAN / SDEV
        4.747341e-001   3.778914e-001

MODE SHAPE: NODE / X-ABS / X-ANG / Y-ABS / Y-ANG / Z-ABS / Z-ANG
     1  9.431071e-005  7.459833e-001    1.709870e-004 -2.433685e+000    1.960708e-004 -2.314426e+000
     2  9.431071e-005  7.459833e-001    1.709870e-004 -2.433685e+000    1.960708e-004 -2.314426e+000
     3  7.123571e-003 -5.848127e-002    6.099146e-003  2.878916e+000    1.573048e-002 -1.885182e-001
     4  1.277901e-002 -5.125383e-001    1.509170e-003  2.165547e+000    5.564497e-003 -2.335294e-001
     5  3.425575e-003 -1.569467e-001    6.408876e-003  2.820791e+000    6.603787e-002 -1.448654e-001
     6  8.125906e-003 -4.849984e-001    2.574844e-003  1.800826e+000    5.444222e-002 -8.100022e-002
     7  6.280960e-004 -3.018174e+000    2.477513e-003 -1.925434e+000    5.468138e-004 -5.964908e-001
     8  6.280960e-004 -3.018174e+000    2.477513e-003 -1.925434e+000    5.468138e-004 -5.964908e-001
     9  9.248136e-003  3.127642e+000    8.989895e-003  2.712072e+000    4.017190e-003 -2.864276e+000
    10  6.594064e-003 -2.678254e+000    5.855004e-003  2.045557e+000    2.505217e-002  2.890893e+000
    11  1.133036e-002  2.905615e-001    2.571387e-002  2.682781e+000    3.445395e-001 -2.933430e+000
    12  8.263057e-003 -3.884530e-001    4.545895e-003 -1.354741e+000    1.917288e-001 -3.096154e+000
    13  0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000
    14  0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000
    15  2.401533e-002  7.478308e-002    1.456134e-002  2.737559e+000    5.296701e-003 -7.953909e-001
    16  5.509119e-002 -1.662650e-001    7.442271e-003 -1.112156e+000    6.211388e-003 -7.789988e-001
    17  1.309099e-002 -1.039611e-001    1.062308e-002  2.644106e+000    5.702300e-001  8.182932e-002
    18  1.150952e-002  1.594058e-001    1.031973e-002  1.823201e+000    2.716287e-001 -3.137015e-002
    19  0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000
    20  0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000    0.000000e+000  0.000000e+000
    21  1.221992e-002 -3.069241e+000    8.424345e-003  1.146059e-001    1.959220e-002 -3.028303e+000
    22  9.303311e-003 -3.061638e+000    4.602038e-003  3.078395e-001    7.737632e-003  2.741012e+000
    23  1.025400e-002 -2.003499e-001    3.597291e-002 -5.032605e-002    4.486939e-001  3.046585e+000
    24  2.974520e-002 -2.116074e-001    1.156797e-002  2.908508e-001    4.305395e-001  2.967145e+000
    25  2.379017e-003  1.337041e+000    1.559053e-002 -2.400484e+000    9.100566e-004  3.111554e+000
    26  2.379017e-003  1.337041e+000    1.559053e-002 -2.400484e+000    9.100566e-004  3.111554e+000
    27  1.012475e-002 -1.235074e-001    1.153484e-002 -8.530902e-002    1.969482e-003  3.059765e+000
    28  2.194410e-002 -2.078846e-001    6.798723e-003 -5.110546e-001    1.690048e-003 -1.313633e+000
    29  2.811259e-003 -4.929229e-002    1.462436e-002 -3.729983e-001    1.050228e-001  4.092124e-003
    30  1.952254e-002 -3.611832e-001    8.996897e-003 -2.871362e-001    1.628685e-001  9.145228e-002
    31  2.252805e-003  2.965043e+000    2.909772e-002 -2.372199e+000    1.104219e-003  5.504559e-001
    32  2.252805e-003  2.965043e+000    2.909772e-002 -2.372199e+000    1.104219e-003  5.504559e-001
    33  2.761637e-003  3.048759e+000    2.445003e-003 -7.370661e-001    2.454410e-003 -5.408179e-002
    34  8.531215e-003 -1.307161e+000    7.520241e-003 -1.468414e+000    1.061927e-002 -7.434440e-002
```

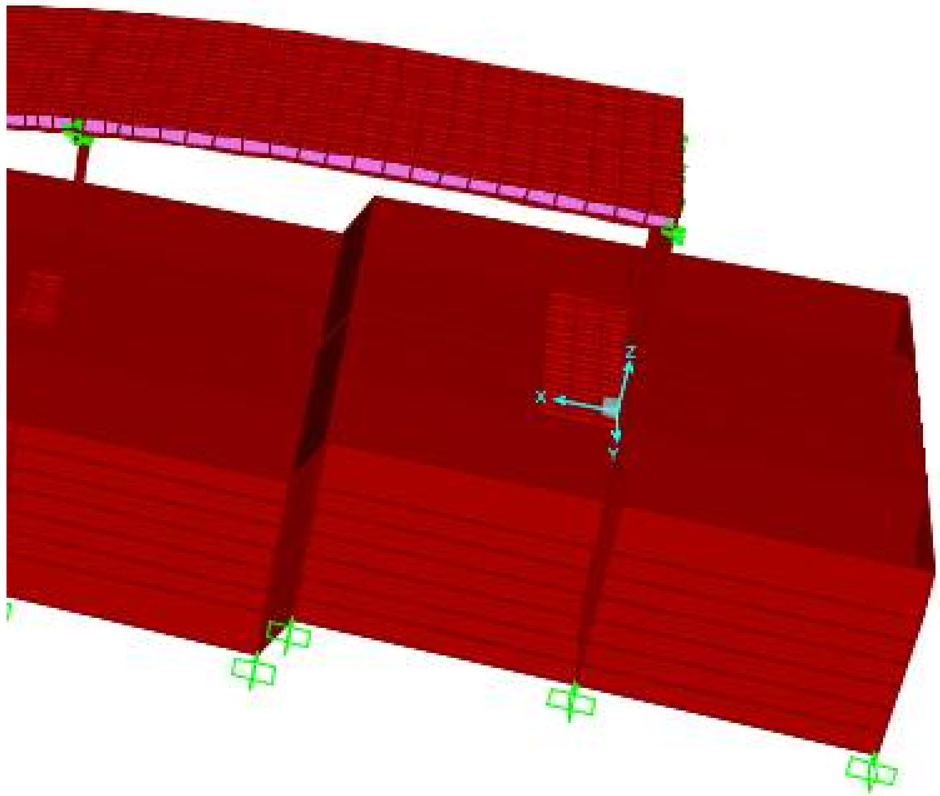
Finite Element Models (FEMs)





Finite Element Models (FEMs)





Review of the FEMs

S1-NB1-M1 S2-NB1-M1 S3-NB1-M1 S4-NB1-M1 S5-NB1-M1 S6-NB1-M1	S1-NB1-M2 S2-NB1-M2 S3-NB1-M2 S4-NB1-M2 S5-NB1-M2 S6-NB1-M2	S1-NB2-M2 S2-NB2-M2 S3-NB2-M2 S4-NB2-M2 S5-NB2-M2 S6-NB2-M2	S1-NB3-M2 S2-NB3-M2 S3-NB3-M2 S4-NB3-M2 S5-NB3-M2 S6-NB3-M2

SOIL	NEOPREN ELASTOMERIC BEARING	CONCRETE STRENGTH
S1- absolute stiff S2 – 10 x k (S4) S3 – 5 x k (S4) S4 – empirical stiffness of soil (k = 15000kN/m^2) has been selected based on the experience with similar soils S5 – layered soil (LS) with modulus E determined by (PGSM) S6 – LS with 10% of modulus E	NB1 – designed stiffness (DS) NB2 – 1.5 x DS NB3 - stiff	M1 – designed strength (fck = 30MPa, Ecm = 31GPa) M2 – theoretical strength after 45 years' service (Ec0 = 38,5GPa)

Modal frequencies

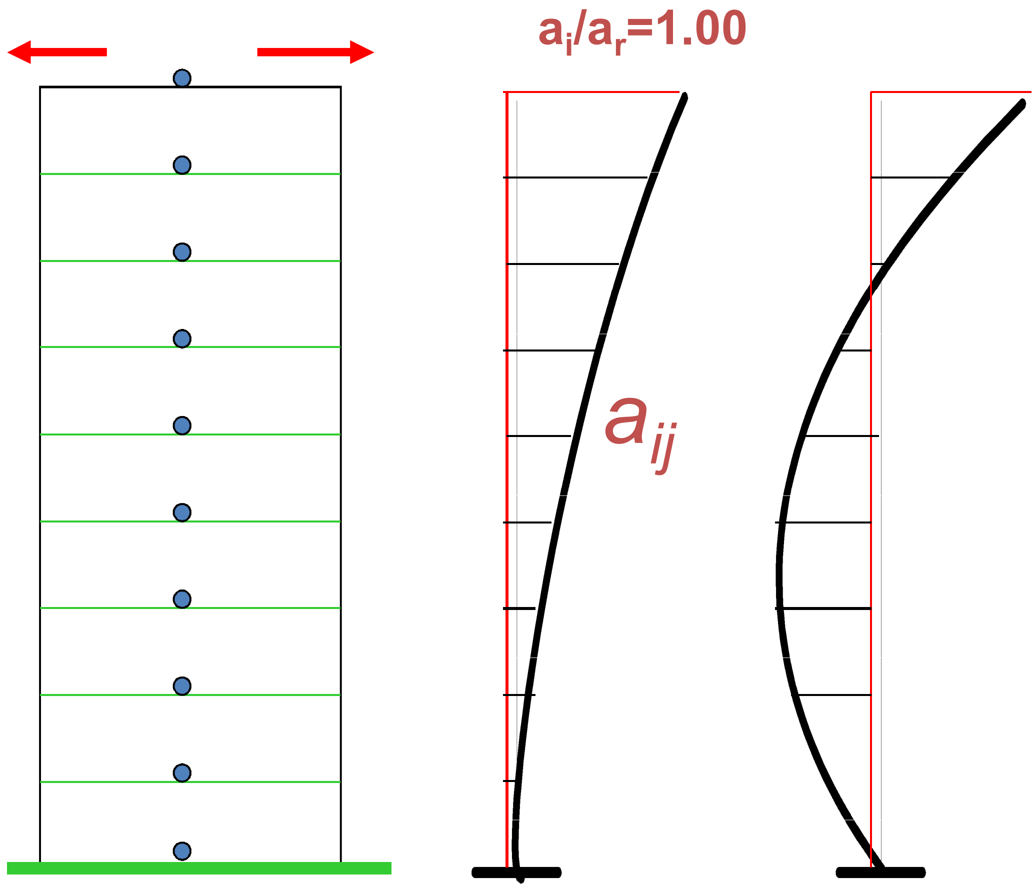
	LONGITUDINAL MODE	TRANSVERSE MODE	BENDING MODE	TORSIONAL MODE
Ambient Vibration Measurements	-	3.855	4.971	5.342
FEMs				
S1-NB1-M1	2.654 (2)	2.803 (3)	3.673 (4)	3.896 (6)
S2-NB1-M1	2.442 (1)	2.454 (2)	3.654 (3)	3.810 (6)
S3-NB1-M1	2.267 (2)	2.148 (1)	3.651 (4)	3.616 (3)
S4-NB1-M1	1.567 (2)	1.444 (1)	3.630 (4)	2.967 (3)
S5-NB1-M1	2.523 (2)	2.312 (1)	3.907 (6)	3.711 (5)
S6-NB1-M1	2.459 (2)	1.969 (1)	3.884 (6)	3.405 (4)
S1-NB1-M2	2.751 (1)	**3.641 (2)**	3.798 (5)	4.377 (6)
S2-NB1-M2	2.512 (1)	2.522 (2)	3.828 (3)	3.949 (6)
S3-NB1-M2	2.323 (2)	2.198 (1)	3.824 (4)	3.737 (3)
S4-NB1-M2	1.586 (2)	1.448 (1)	3.794 (6)	3.030 (3)
S5-NB1-M2	2.614 (2)	2.369 (1)	4.081 (6)	3.806 (5)
S6-NB1-M2	2.542 (2)	2.011 (1)	4.054 (6)	3.483 (3)
S1-NB2-M2	2.971 (1)	**3.731 (2)**	3.825 (3)	4.443 (6)
S2-NB2-M2	2.666 (2)	2.556 (1)	3.860 (3)	4.065 (6)

Modal frequencies

	LONGITUDINAL MODE	TRANSVERSE MODE	BENDING MODE	TORSIONAL MODE
Ambient Vibration Measurements	-	3.855	4.971	5.342
FEMs				
S3-NB2-M2	2.442 (2)	2.224 (1)	3.857 (3)	3.857 (4)
S4-NB2-M2	1.627 (2)	1.467 (1)	3.827 (6)	3.124 (3)
S5-NB2-M2	2.804 (2)	2.411 (1)	4.184 (6)	4.126 (5)
S6-NB2-M2	2.715 (2)	2.046 (1)	4.156 (6)	3.755 (4)
S1-NB3-M2	3.574 (1)	**4.246 (3) (fig.14a)**	4.136 (2)	**5.026 (5) (fig.14b)**
S2-NB3-M2	3.207 (2)	2.689 (1)	4.261 (3)	4.383 (4)
S3-NB3-M2	2.915 (2)	2.317 (1)	4.253 (4)	4.143 (3)
S4-NB3-M2	1.965 (2)	1.528 (1)	4.198 (4)	3.320 (3)
S5-NB3-M2	3.407 (2)	2.513 (1)	**4.639 (3)(fig.14c)**	4.847 (3)
S6-NB3-M2	3.239 (2)	2.146 (1)	4.609 (4)	4.318 (3)

(n) marks in parenthesis denote modes of certain models

Comparison of the modes parameters (mode shapes) identified by AVM and FEMs

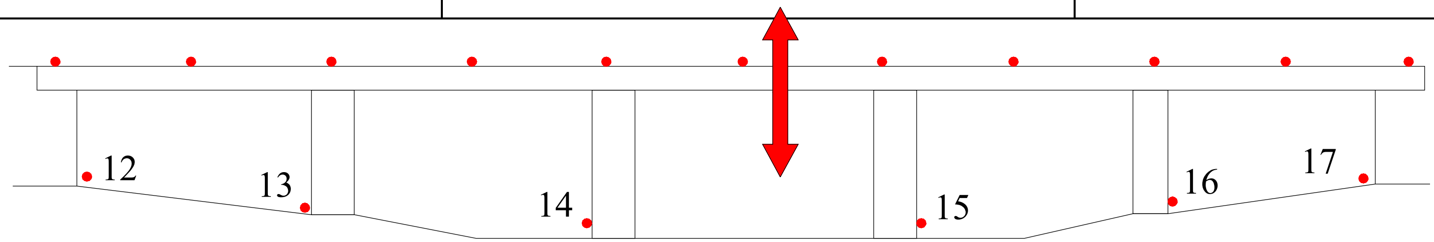


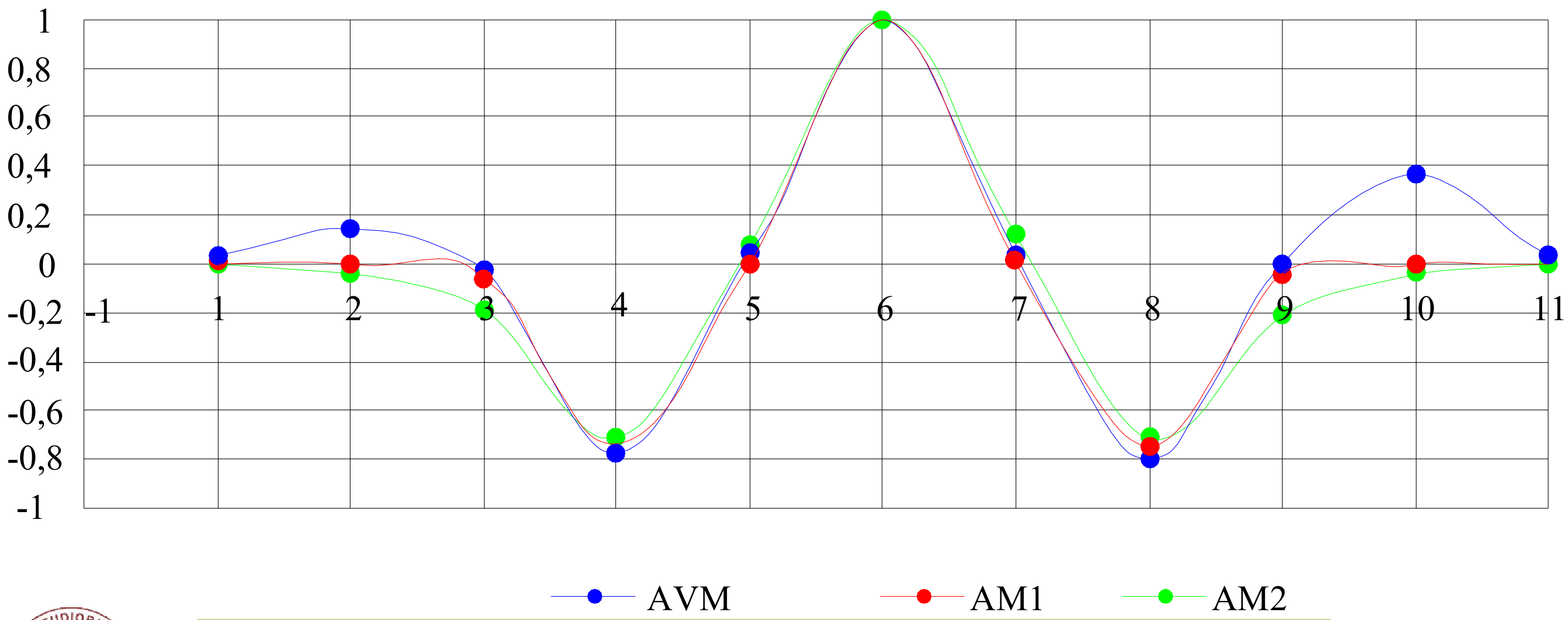
Normalized amplitudes at selected points (levels) for each particular mode shape

$$a_{i,j} = \frac{\left|X_i(f_j)\right|}{\left|X_r(f_j)\right|}$$

Experimentally and mathematically identified first vertical mode shapes

	FIRST TRANSVERSE MODE	FIRST VERTICAL MODE
AMBIENT VIBRATION TEST	3.855	4.971
ANALYTICAL MODEL AM1	3.641	3.798
ANALYTICAL MODEL AM2	2.513	4.639



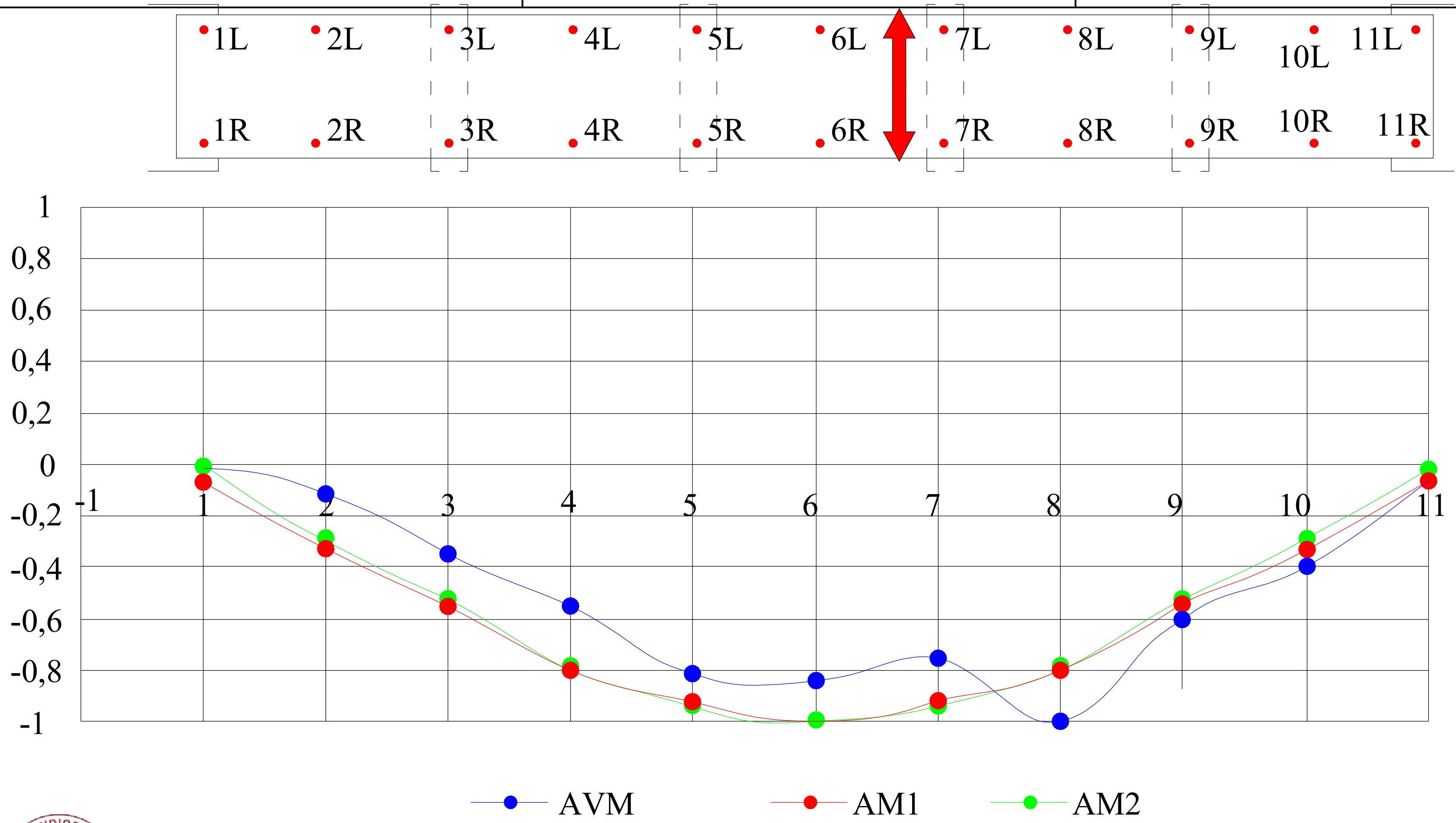


The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the
Erasmus+ Programme
of the European Union

Experimentally and mathematically identified first transverse mode shapes

	FIRST TRANSVERSE MODE	FIRST VERTICAL MODE
AMBIENT VIBRATION TEST	3.855	4.971
ANALYTICAL MODEL AM1	3.641	3.798
ANALYTICAL MODEL AM2	2.513	4.639



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

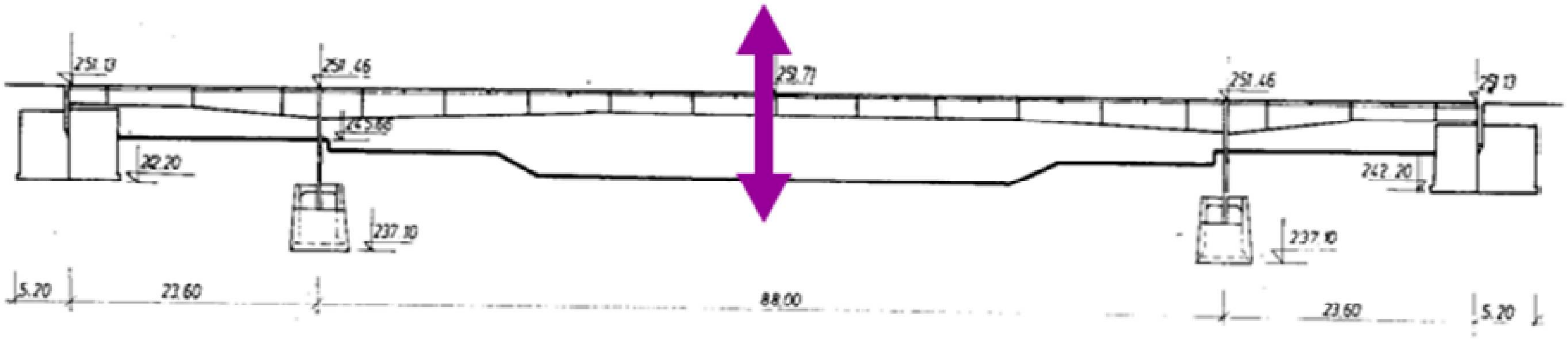
Co-funded by the Erasmus+ Programme of the European Union

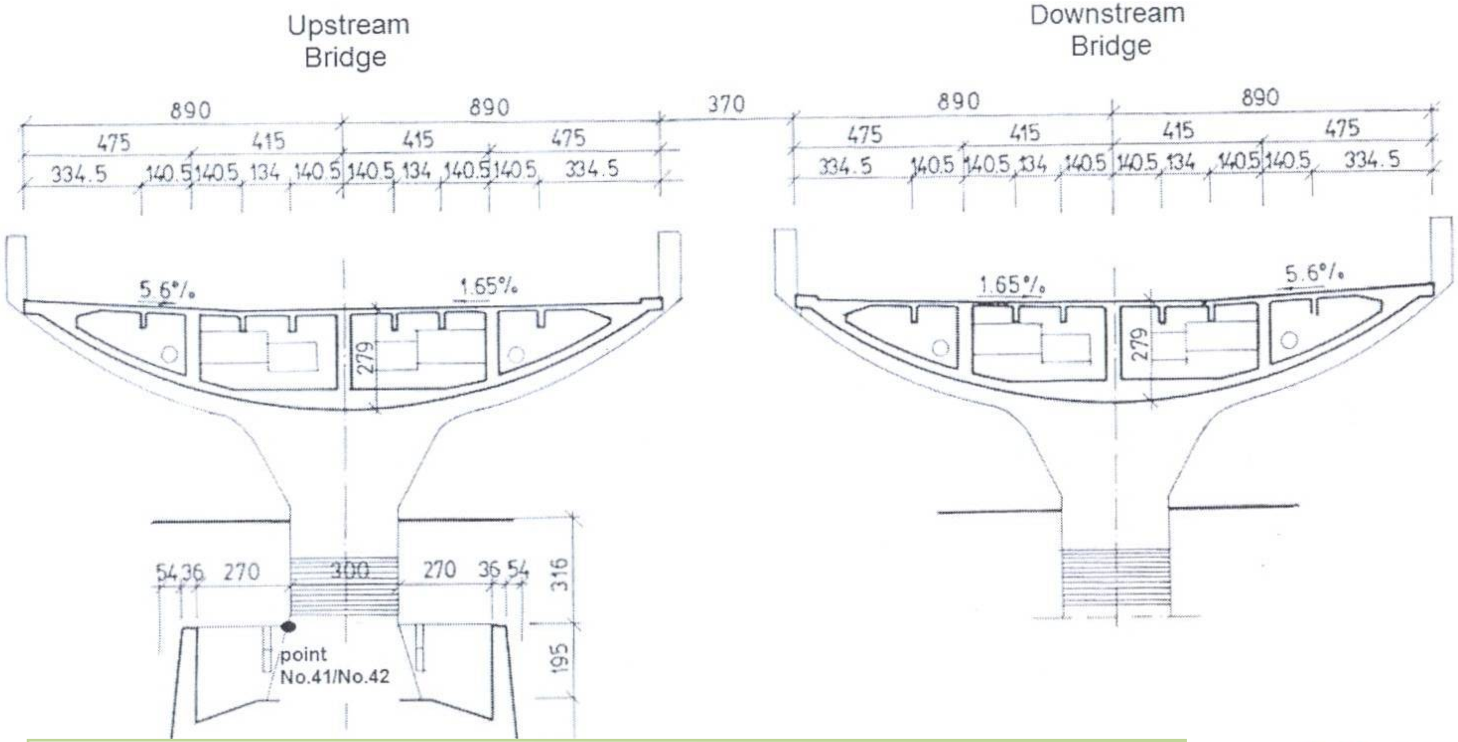
CASE STUDY 2 – THE TWIN BRIDGE "GOCE DELCEV" IN SKOPJE

The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

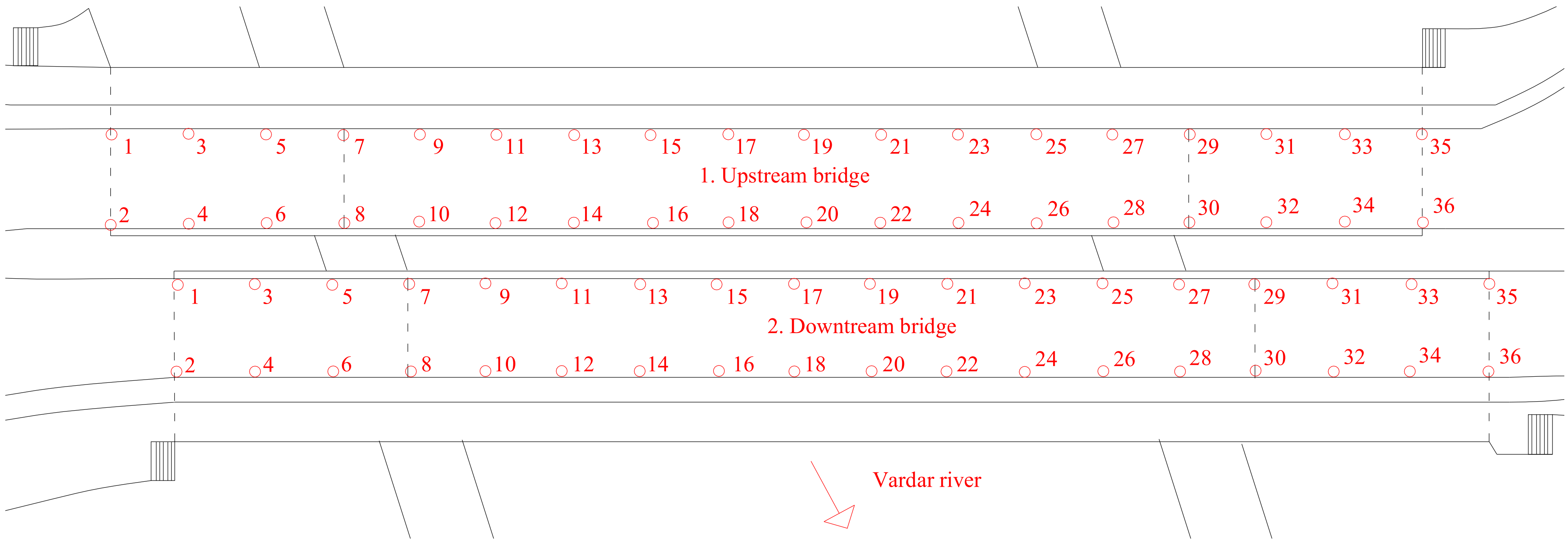
Co-funded by the Erasmus+ Programme of the European Union

Elevation and cross-sections of the bridge



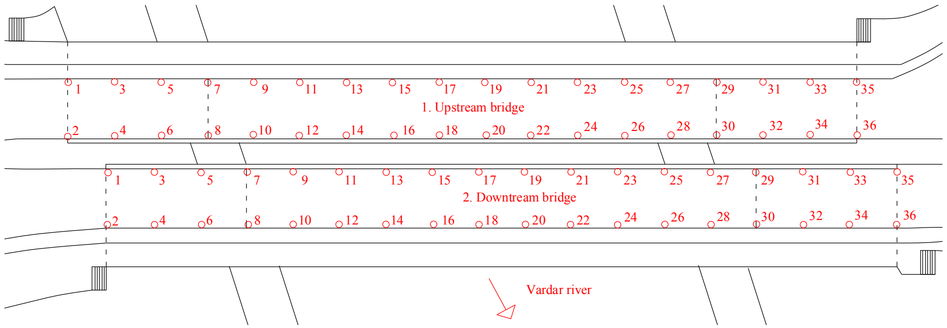


Measurements setup



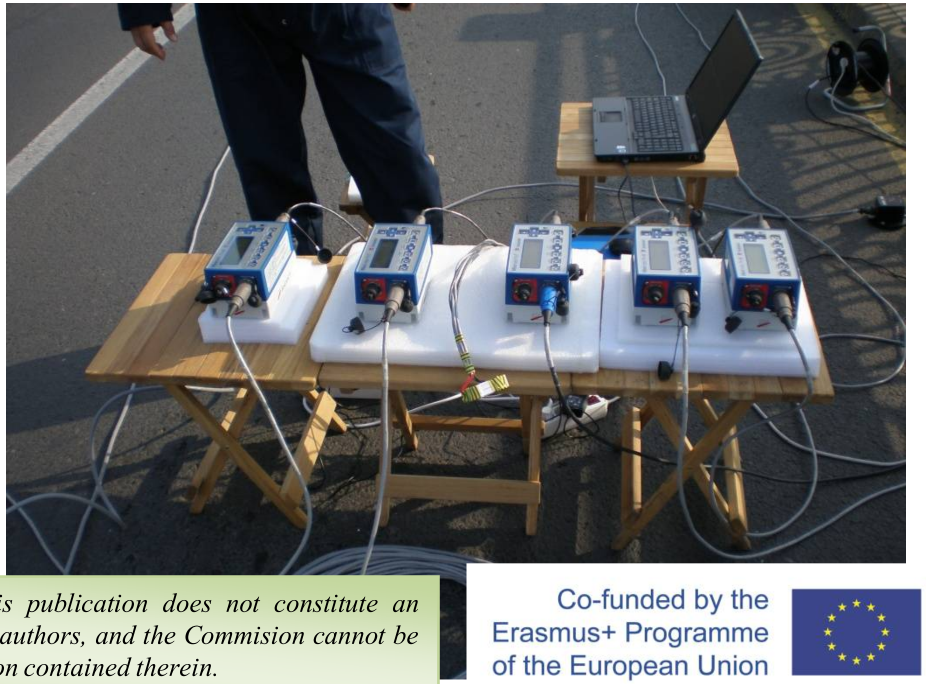
The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union



Setup	Moveable stations	Base stations
M1	37,38	16R
M2	1,2,3,4	16R
M3	1,2,3,4	16R
M4	5,6,7,8	16R
M5	9,10,11,12	16R
M6	13,14,15	16R
M7	17,18,19,20	16R
M8	21,22,23,24	16R
M9	25,26,27,28	16R
M10	29,30,31,32	16R
M11	33,34,35,36	16R
M12	33,34,35,36	16R
M13	39,40	16R
M14	41,42	16R

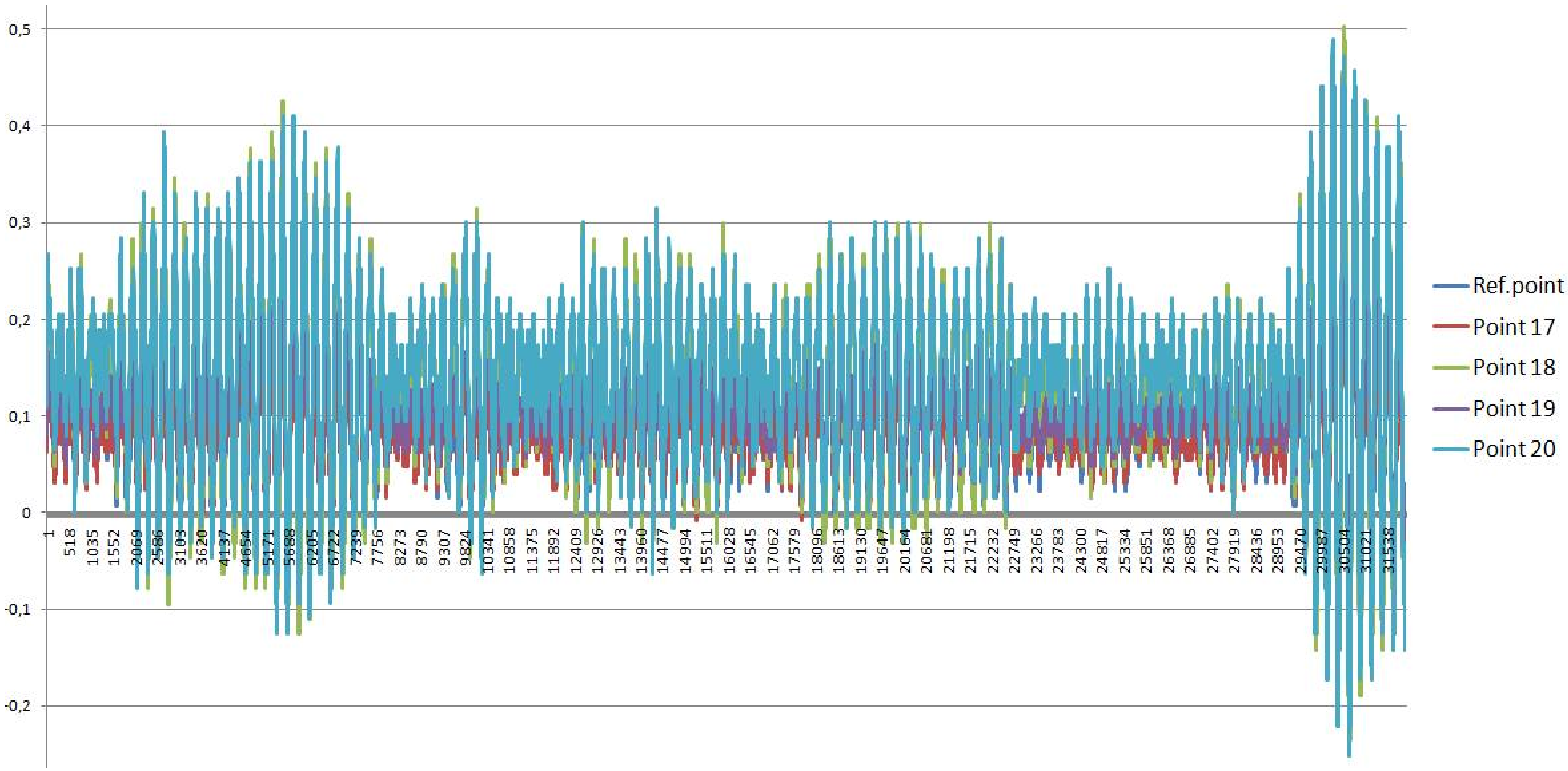


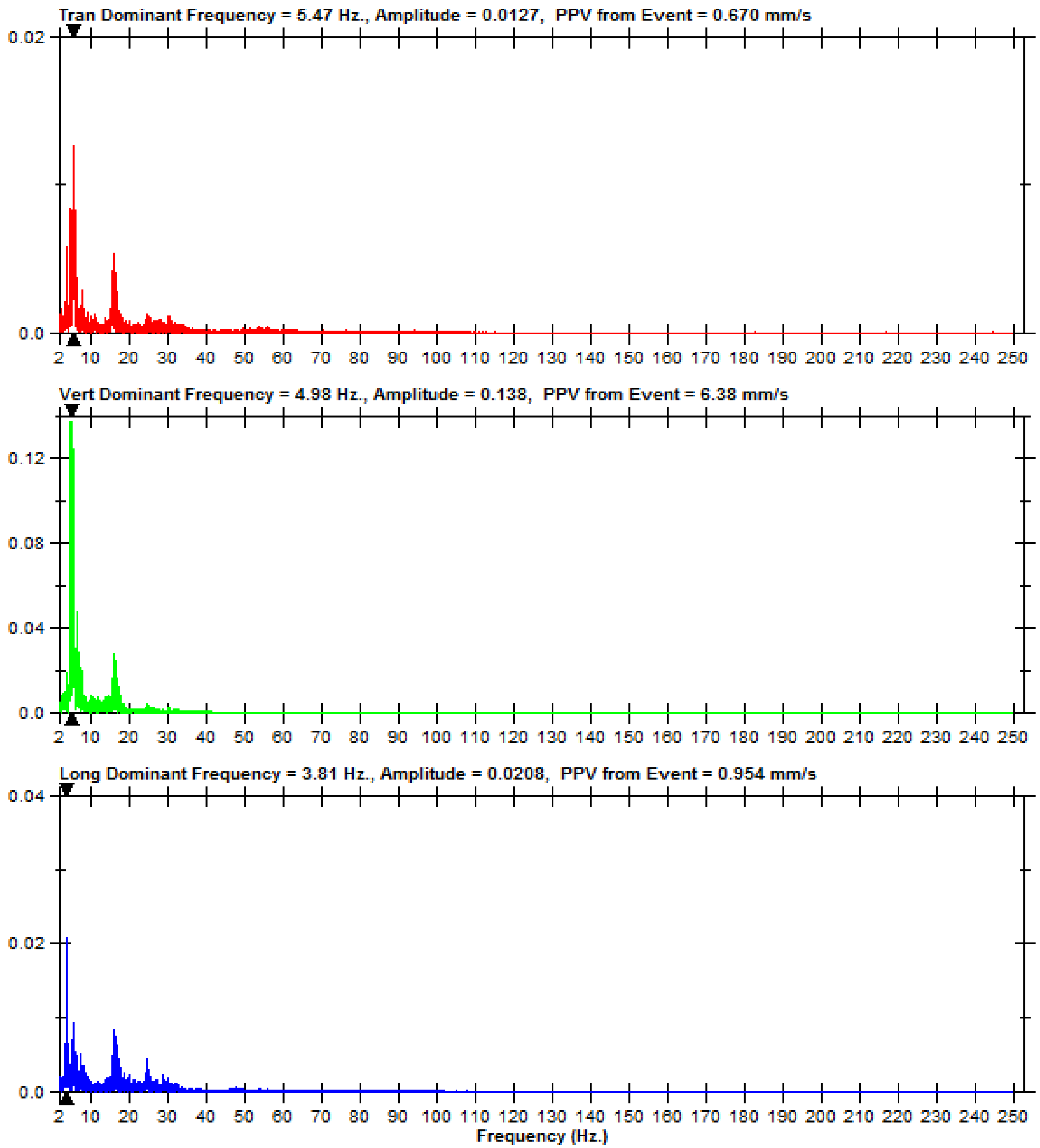
The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

Transversal chanels



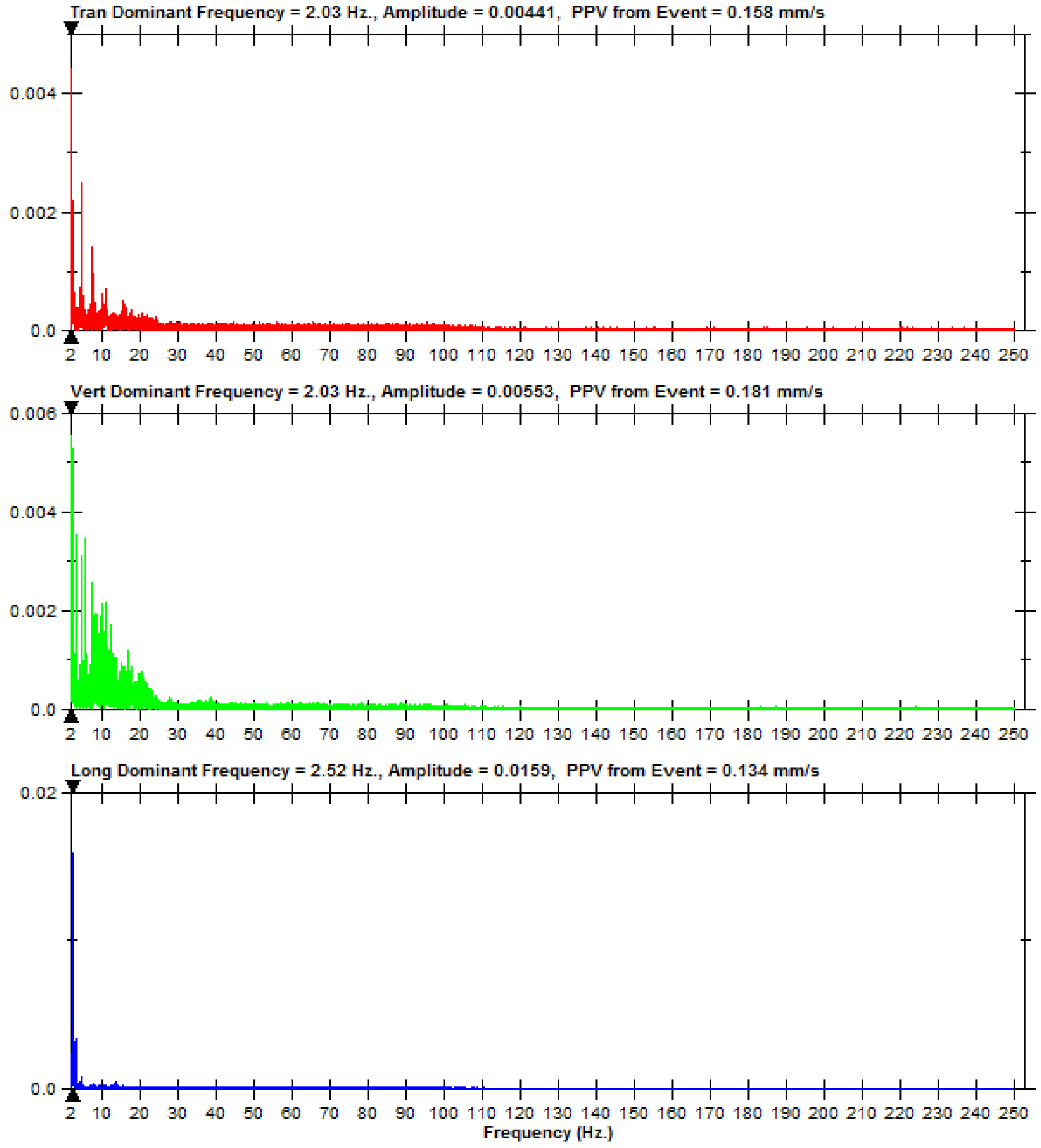
Measurement on base station 16R



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

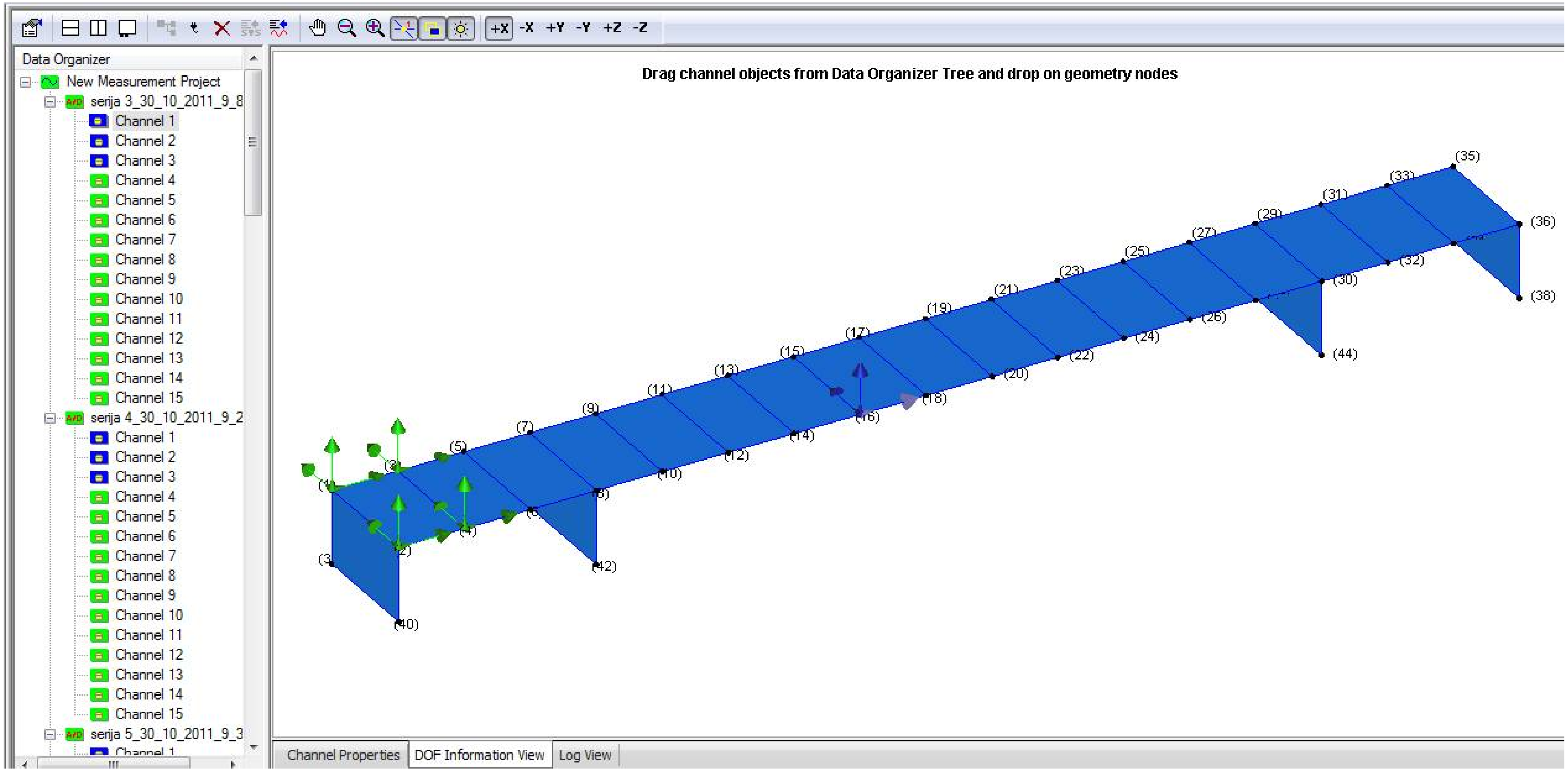
Measurement on moveable station



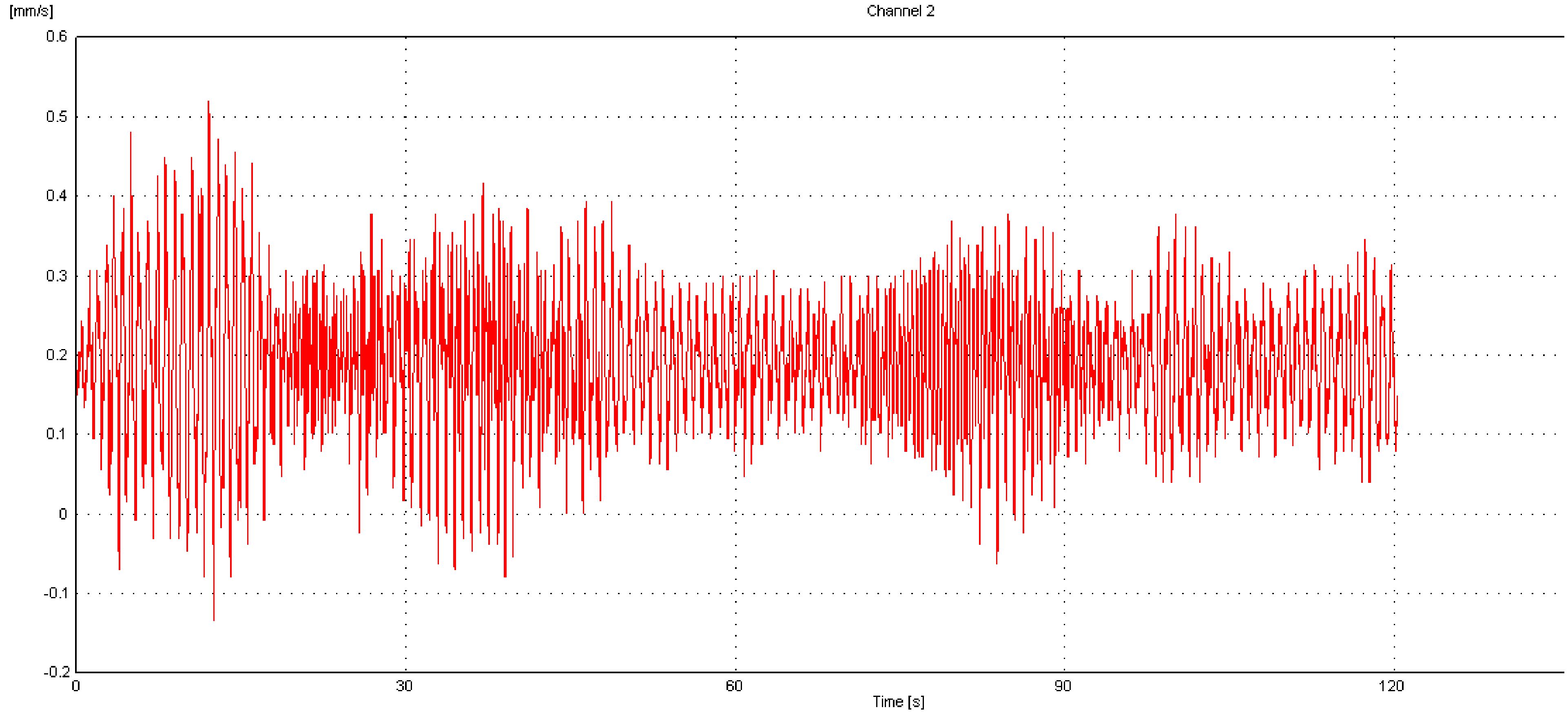
Measured dominant frequency

Measuring points	1st freq. (Hz)	2nd freq. (Hz)	3rd freq. (Hz)
16R, 1, 2, 3, 4	1.30V, 2.00VTL, 1.98L, 1.30V, 1.98	1.98VT, 2.88L, -, 1.99VTL, -	-, 3.31L, -, 2.86L, -
16R, 5, 6, 7, 8	1.28V, 2.03VT, 2.03VT, 2.03VT,	2.03VT, 2.92V, 2.92L, 2.92L, 2.92L	4,27V, -, -, -, -
16R, 9, 10, 11, 12	1.29V, 1.29V, 1.29V, 1.30V, 1.30V	2.05VT, 2.06VT, 2.06VT, 2.05VT,	-, -, -, 2.95L, -
16R, 13, 14, 15	1.28V, 1.28V, 1.28V, 1.28V	2.02VT, 2.02VT, 2.02VT, 2.02VT	-, 2.91L, -, 2.91L
16R, 17, 18, 19, 20	1.29V, 1.29V, 1.29V, 1.29V, 1.28V	2.03VT, 2.03T, 2.03VT, 2.03T, 2.03T	4,23V, 3.34L, -, 3.35L, 3.35L
16R, 21, 22, 23, 24	1.28V, 1.28V, 1.28V, 1.28V, 1.28V	2.02VT, 2.02VT, 2.02VT, 2.02VT,	-, 2.90L, -, 2.91L, 2.91L
16R, 25, 26, 27, 28	1.28V, 1.28V, 1.28V, 1.28V, 1.28V	2.00VT, 2.00VTL, 2.00VT, 2.00VT,	-, 2.88L, 2.88L, 2.88L, 2.88L
16R, 29, 30, 31, 32	1.27V, 1.80VTL, 1.80VT, 1.80V, -	2.10VT, 2.10VTL, 2.10VT, 2.10VT,	-, 2.88L, 2.88L, 2.91L, 2.91L
16R, 33, 34, 35, 36	1.28V, 1.28V, 1.28V, 1.28L, 2.00L	2.02VT, 2.02VTL, 2.02VTL, 2.02TL,	-, 2.84L, -, 2.84L, -
16R, 37, 38	1.27V, 4.20VTL, 2.00T	2.01VT, -, 2.14V	4.23V, -, 8.88L
16R, 39, 40	1.29V, 2.90L, 2.07V	1.97VT, 7.83T, 4.63T	-, 13.7V, 11.8L
			5.

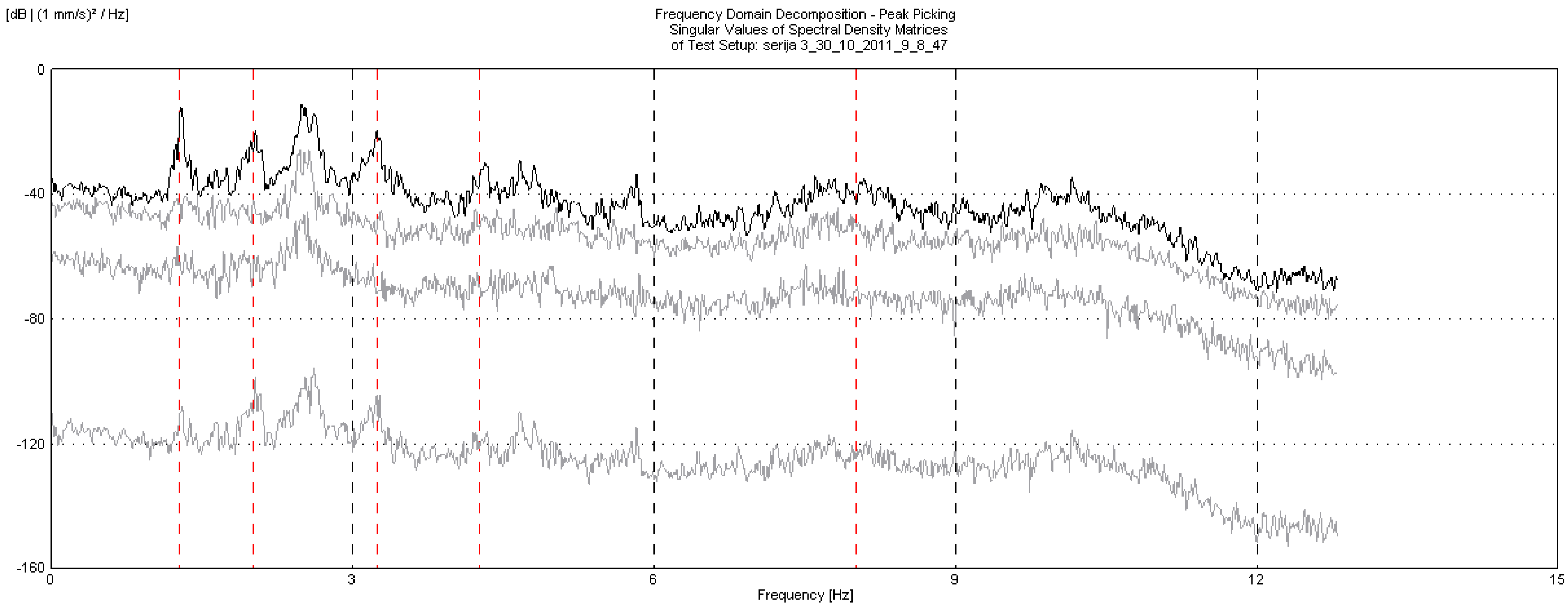
ARTeMIS


+X -X +Y -Y +Z -Z
Data Organizer
New Measurement Project
serija 3_30_10_2011_9_8
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 6
Channel 7
Channel 8
Channel 9
Channel 10
Channel 11
Channel 12
Channel 13
Channel 14
Channel 15
serija 4_30_10_2011_9_2
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 6
Channel 7
Channel 8
Channel 9
Channel 10
Channel 11
Channel 12
Channel 13
Channel 14
Channel 15
serija 5_30_10_2011_9_3
Drag channel objects from Data Organizer Tree and drop on geometry nodes
(35)
(36)
(38)
(44)
Channel Properties
DOF Information View
Log View

ARTeMIS



ARTeMIS

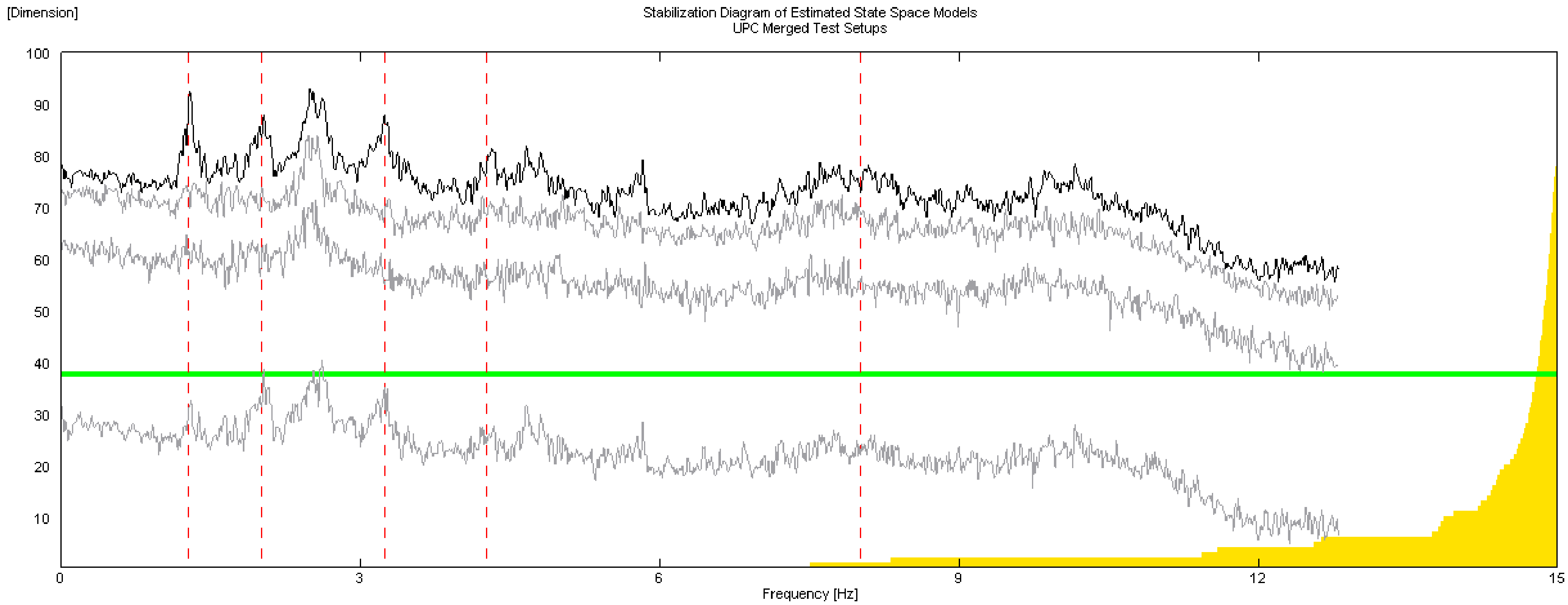


[dB | (1 mm/s)² / Hz]
Frequency Domain Decomposition - Peak Picking
Singular Values of Spectral Density Matrices
of Test Setup: serija 3_30_10_2011_9_8_47
0
-40
-80
-120
-160
0
3
6
9
12
15
Frequency [Hz]

ARTeMIS

[dB | (1 mm/s)² / Hz]
Average of All Spectral Densities for all Test Setups
0
-30
-60
-90
-120
0
6
12
18
24
30
Frequency [Hz]

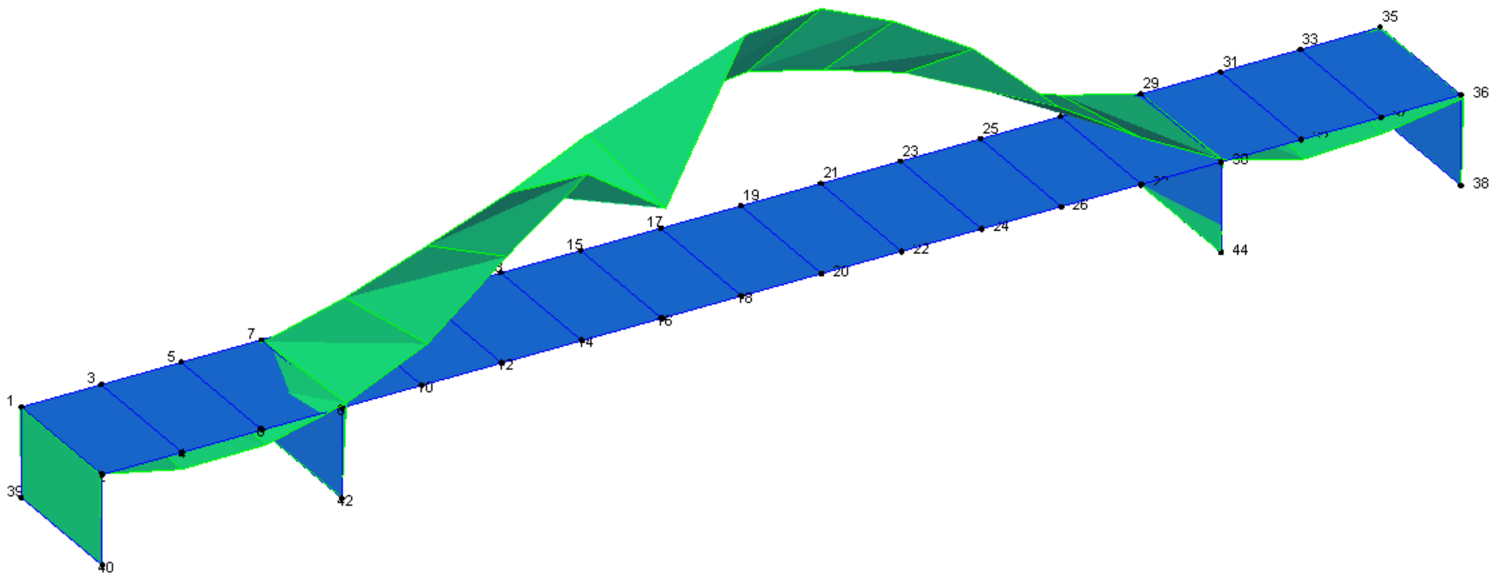
ARTeMIS



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

1st vertical mode



Modal Values

Frequency = 1.273 Hz

Damping = 0.9538 %

Display Settings

Rotation Horz. = 30°

Rotation Vert. = 29°

Translation Horz. = 0

Translation Vert. = 0

Zoom Level = 140%

Amplitude = 100%

Phase Angle = 125°

Frames per Sec.= 0

Undeformed Geometry

Lines

Surfaces

Deformed Geometry

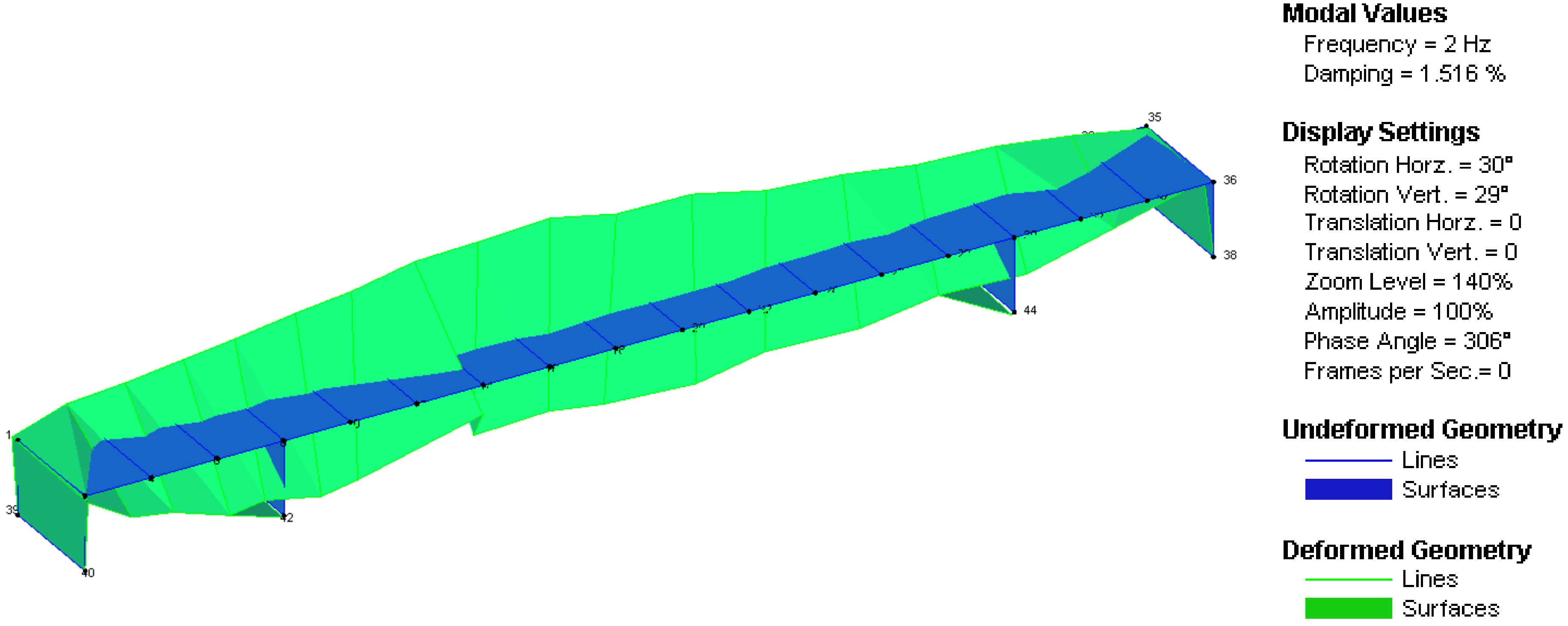
Lines

Surfaces

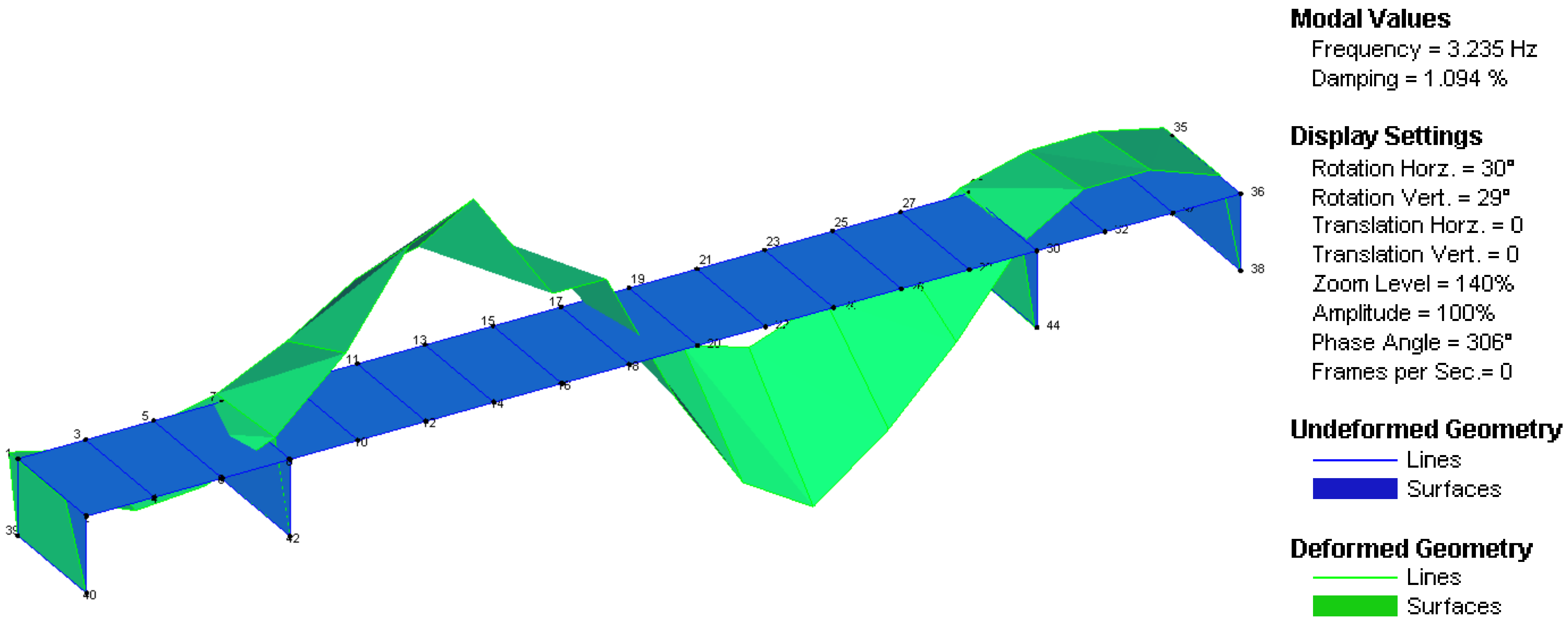
The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

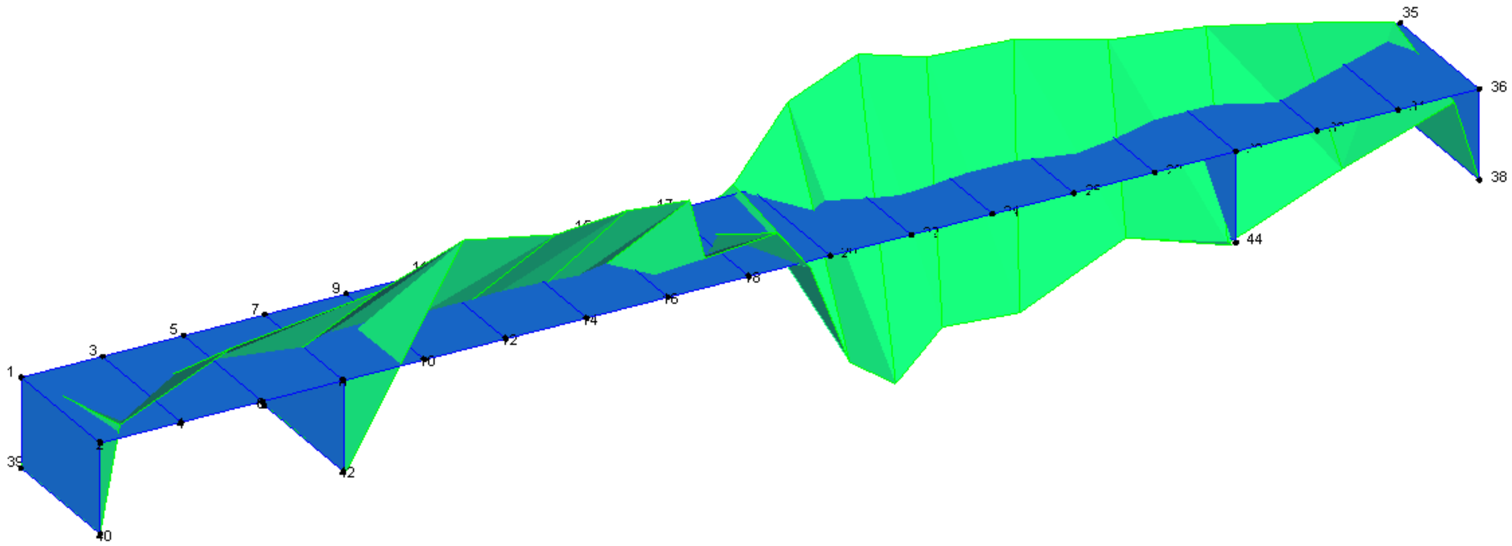
1st transverse mode



2nd vertical mode



2nd transverse mode



Modal Values

Frequency = 4.65 Hz

Damping = [None]

Display Settings

Rotation Horz. = 29°

Rotation Vert. = 28°

Translation Horz. = 0

Translation Vert. = 0

Zoom Level = 140%

Amplitude = 100%

Phase Angle = 125°

Frames per Sec.= 0

Undeformed Geometry

Lines

Surfaces

Deformed Geometry

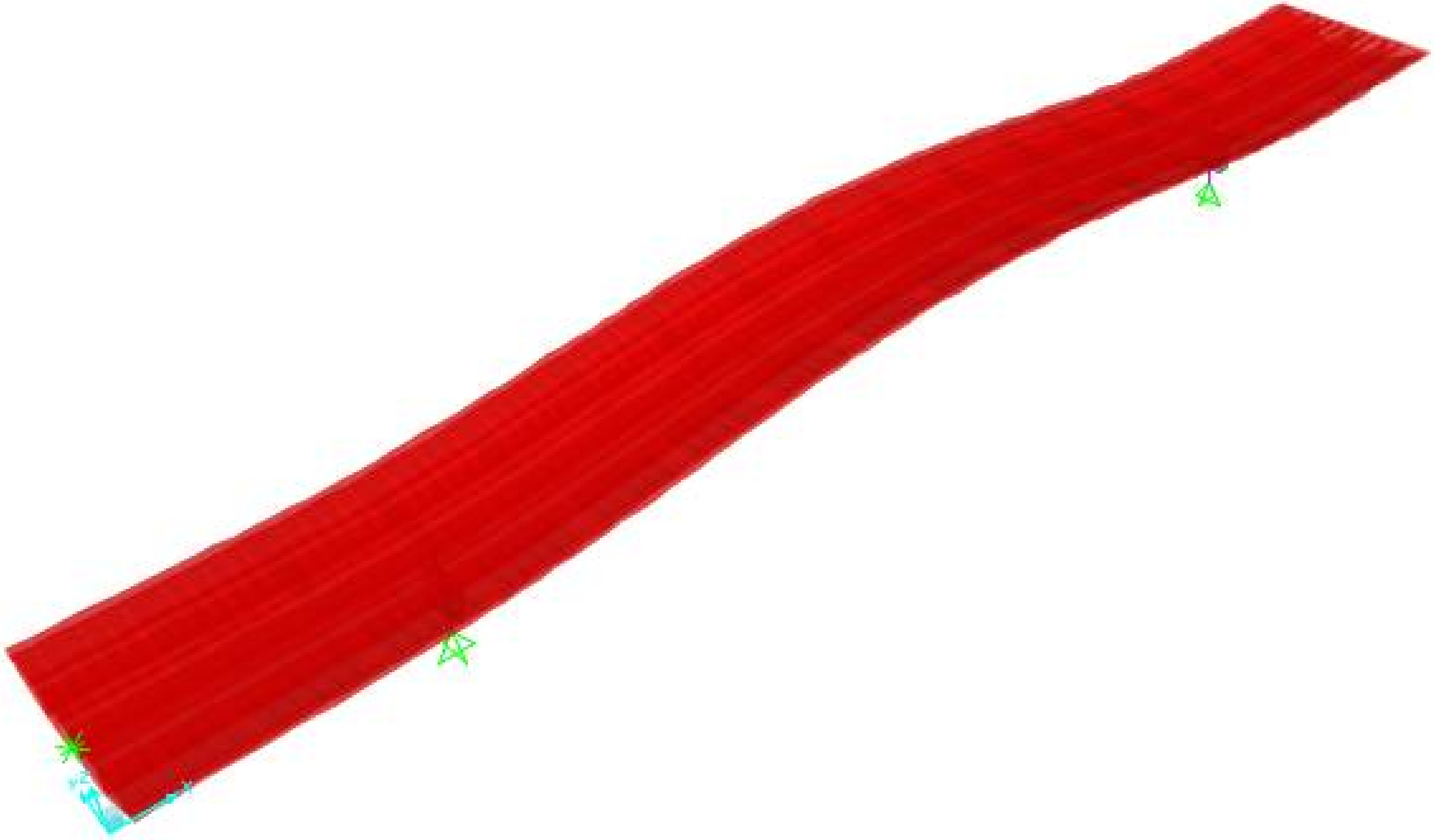
Lines

Surfaces

The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

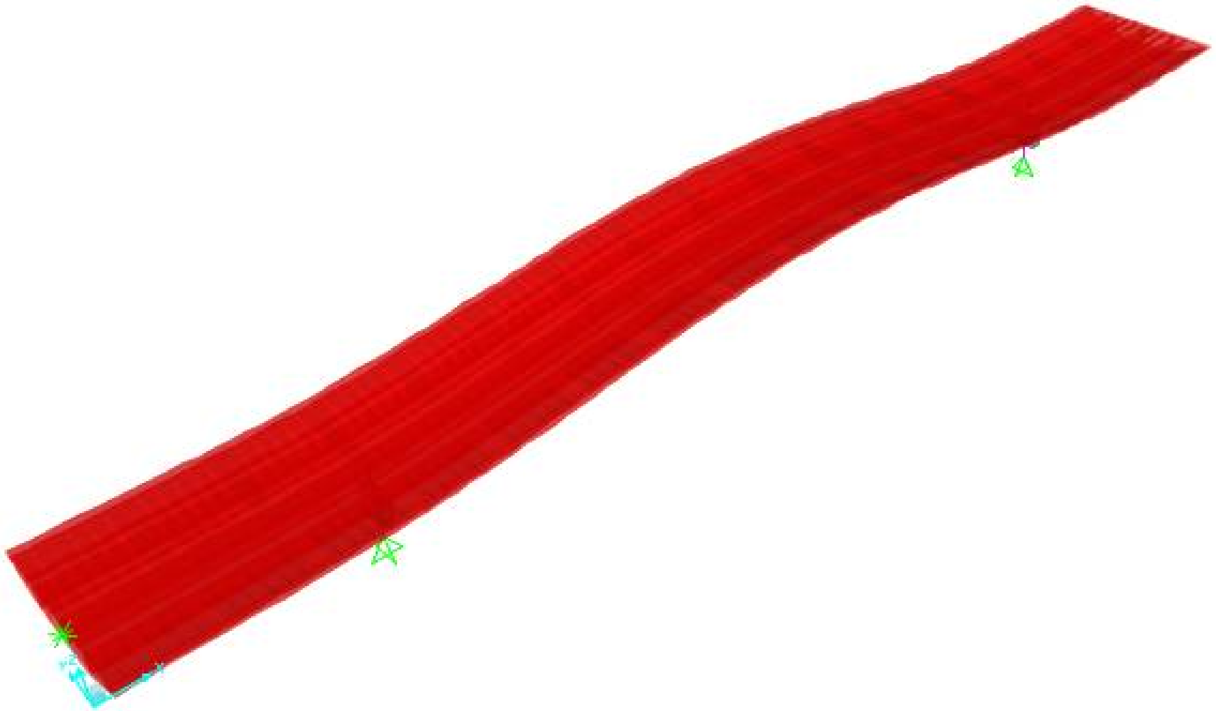
Finite Element Models (FEMs)



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

Mathematically identified 1st vertical mode



Modes	AVM	AM3
First vertical	1.273	1.273
First transverse	2.000	1.921
Second vertical	3.235	3.542
Second transverse	4.65	5.852

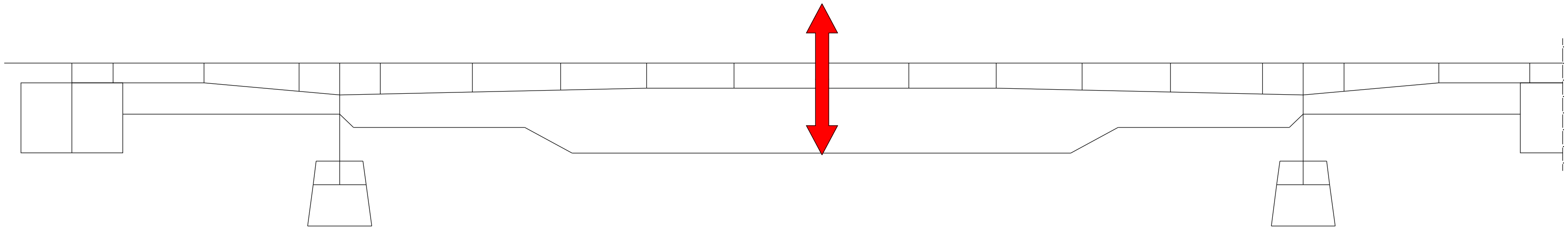
Mathematically identified 2nd transverse mode

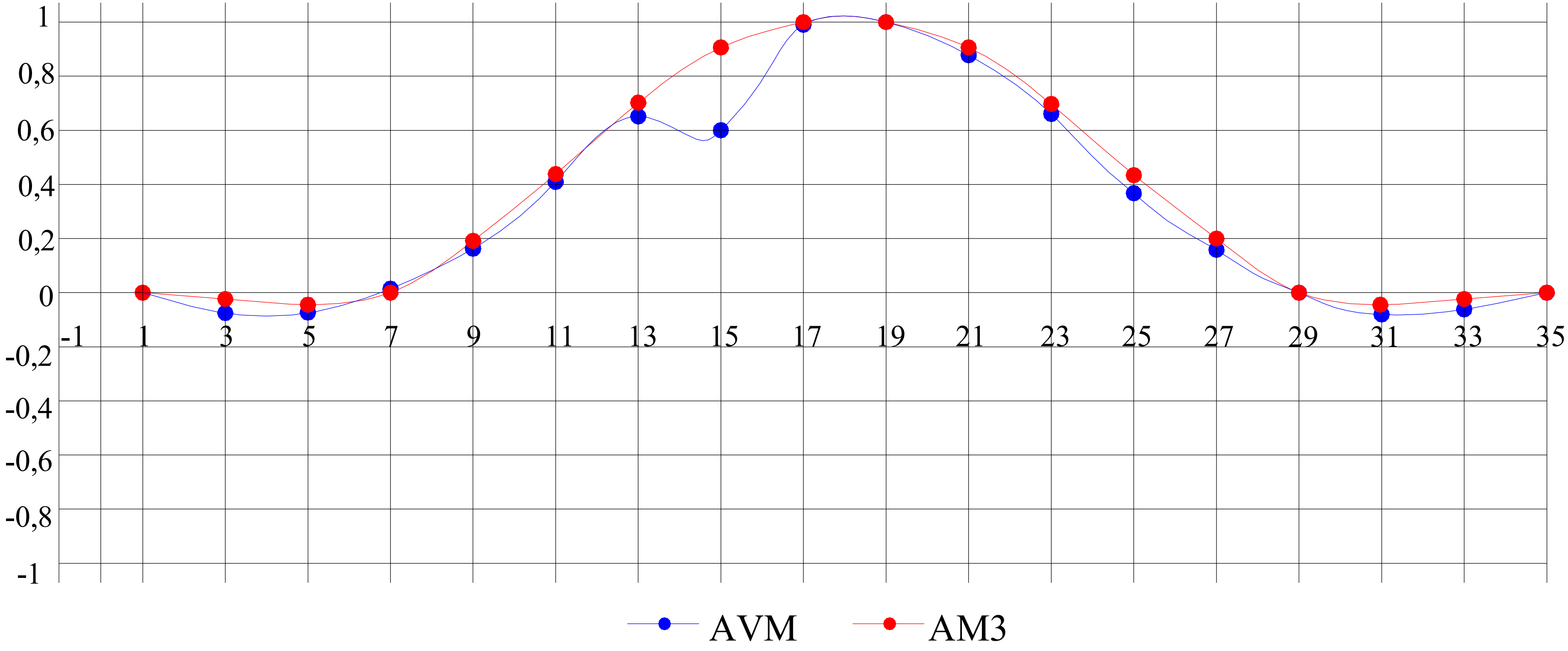
Modes	AVM	AM3
First vertical	1.273	1.273
First transverse	2.000	1.921
Second vertical	3.235	3.542
Second transverse	4.65	5.852

The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

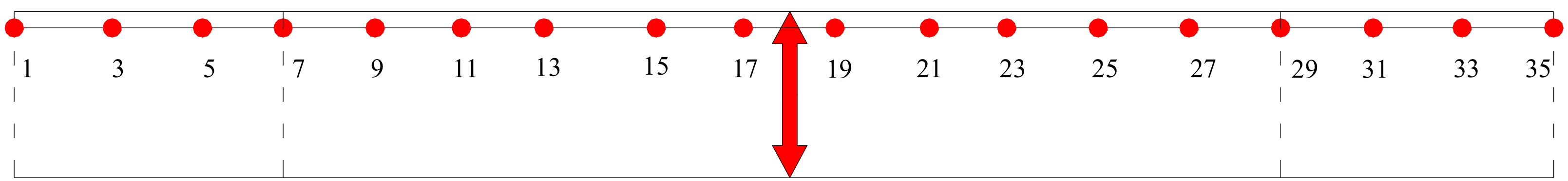
Co-funded by the Erasmus+ Programme of the European Union

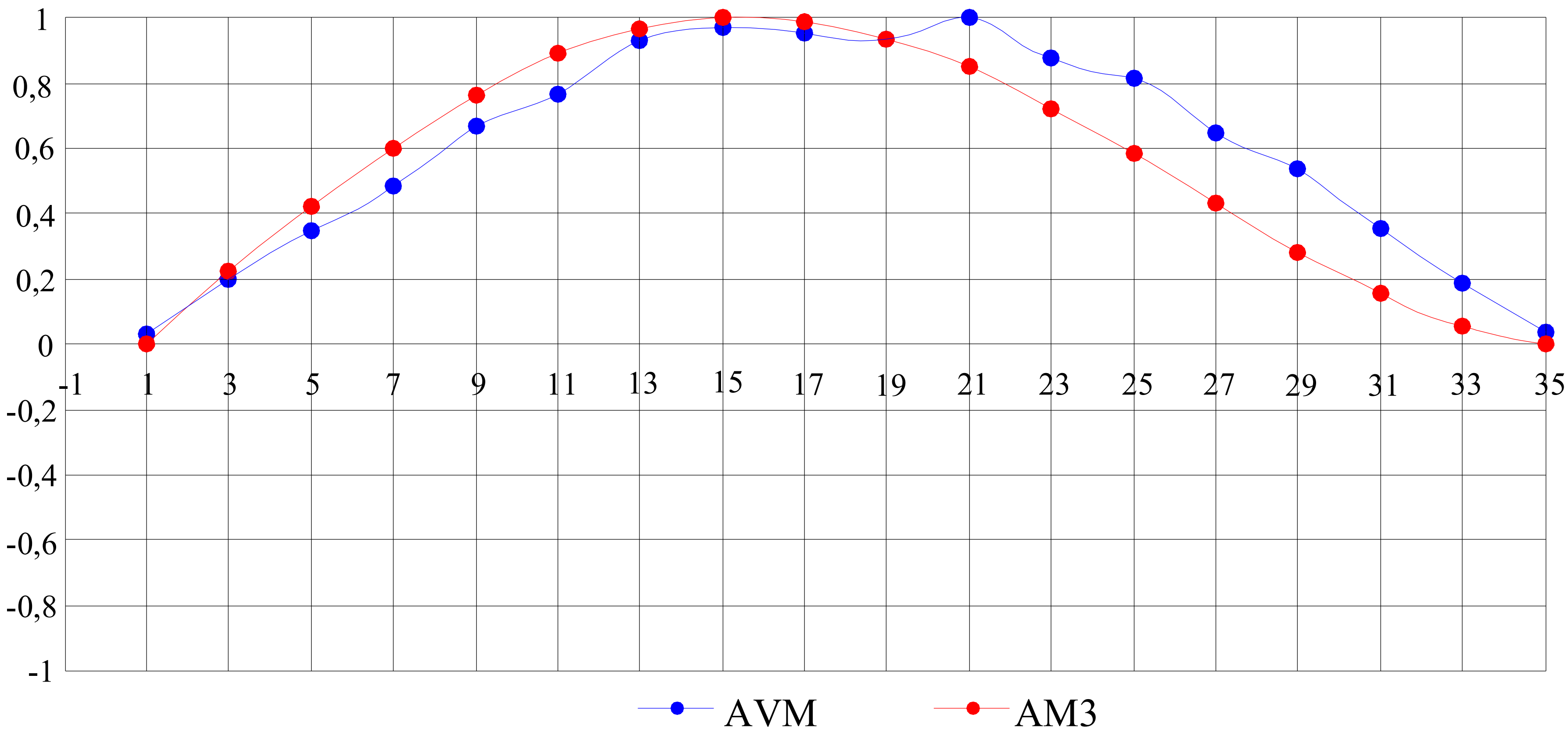
Experimentally and mathematically identified first vertical mode shapes



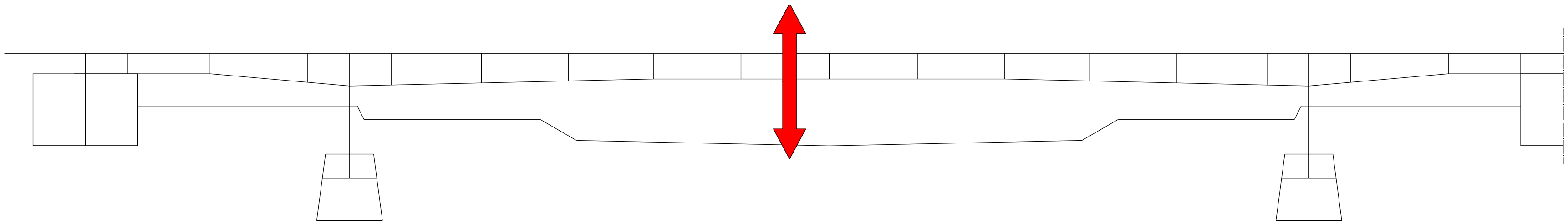


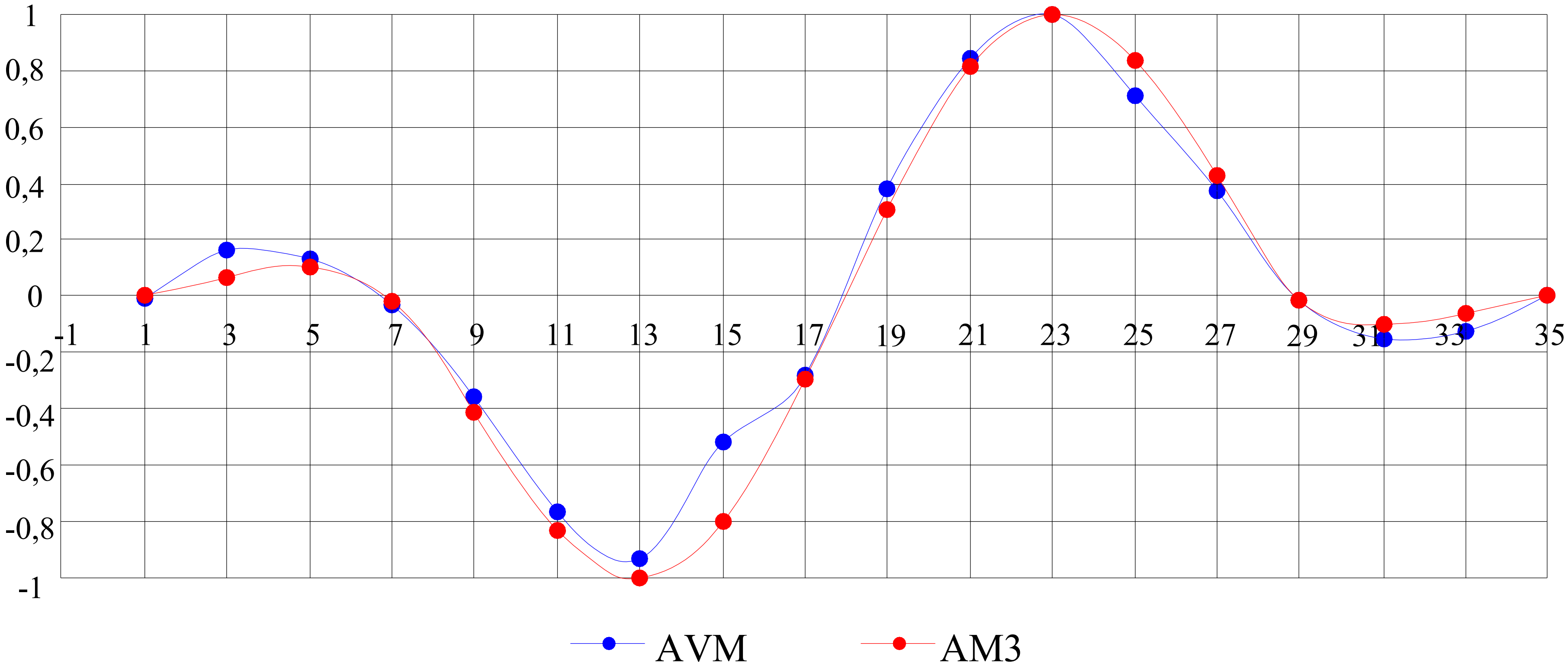
Experimentally and mathematically identified first transverse mode shapes



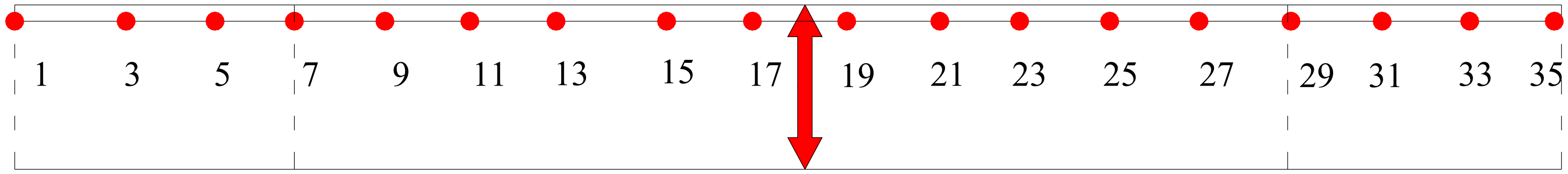


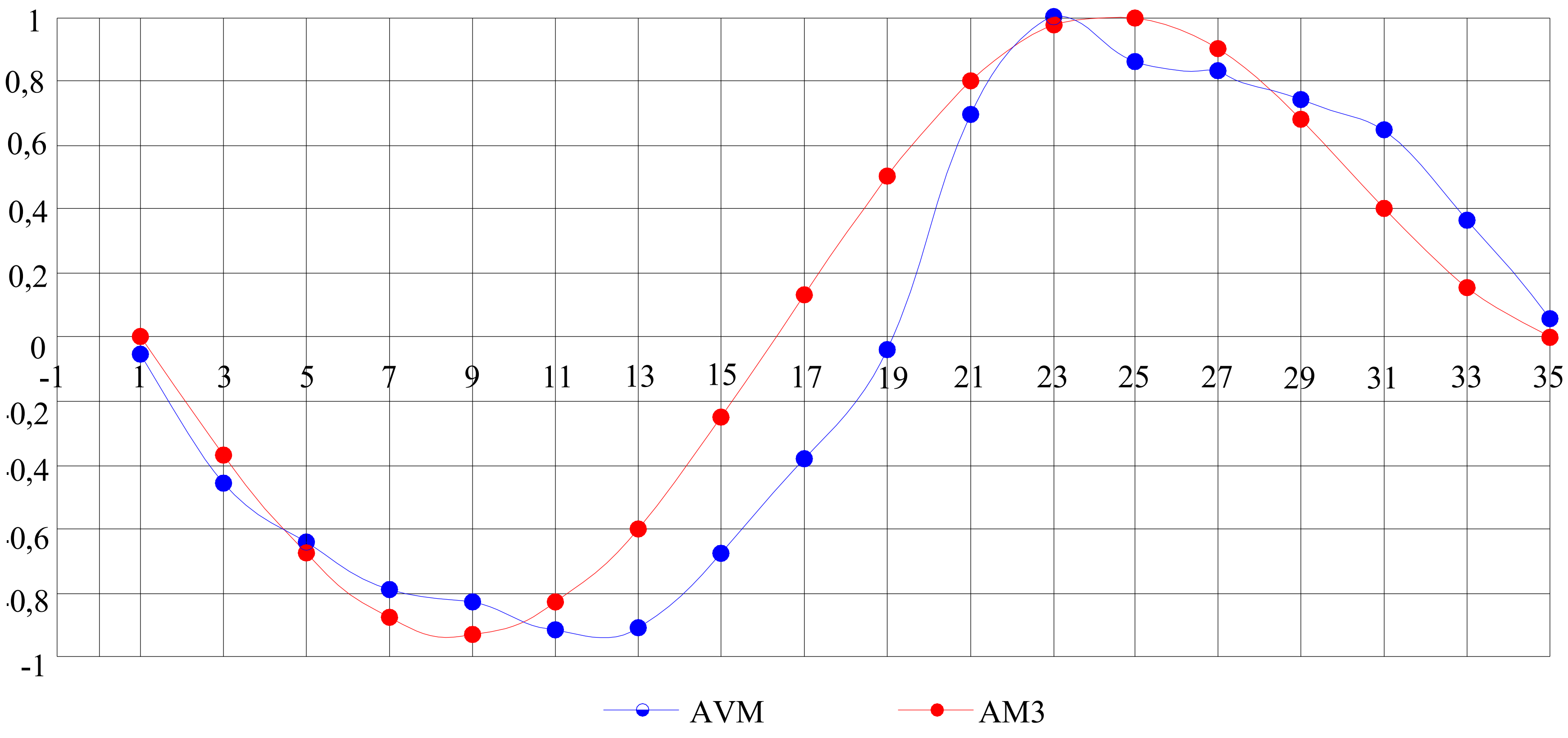
Experimentally and mathematically identified second vertical mode shapes





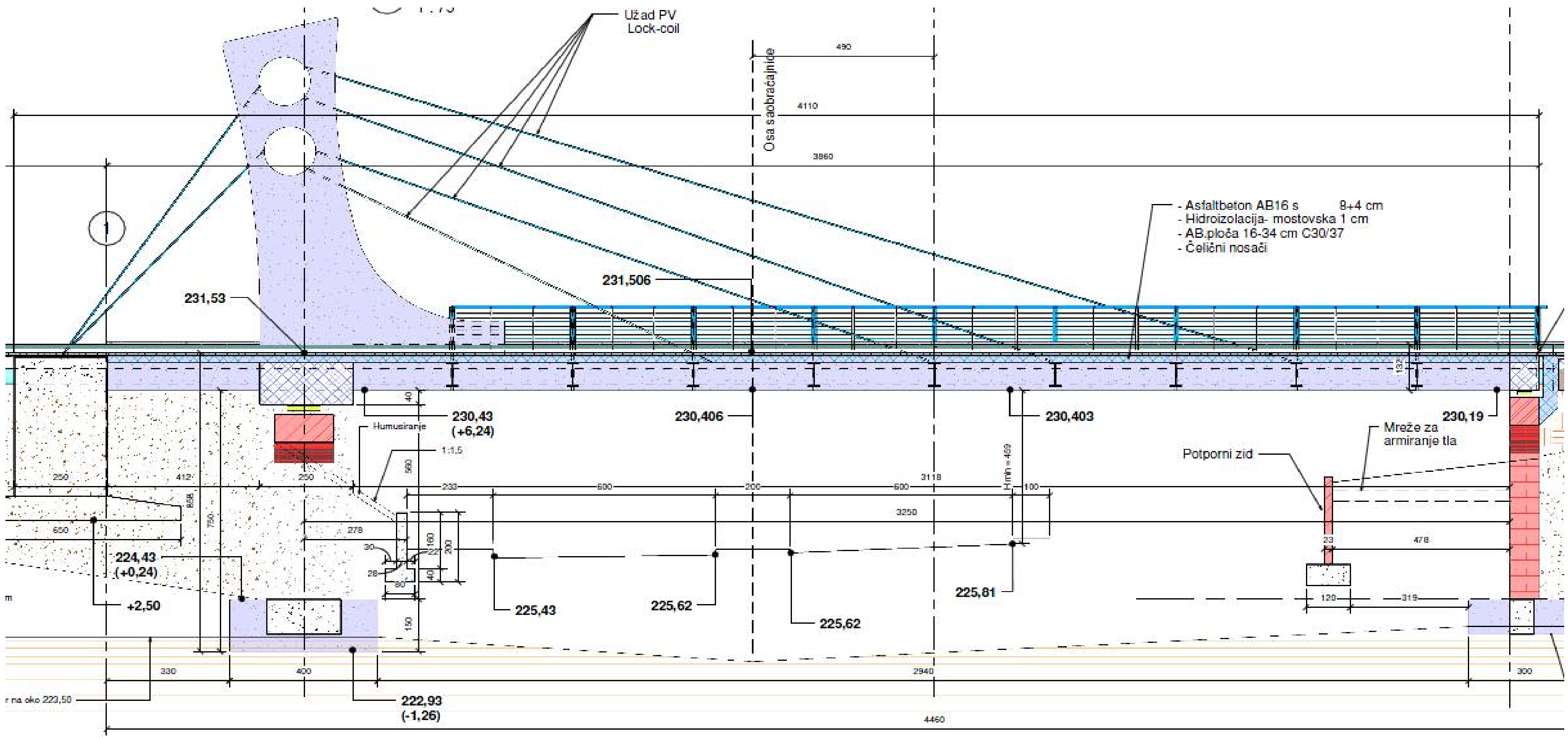
Experimentally and mathematically identified second transverse mode shapes

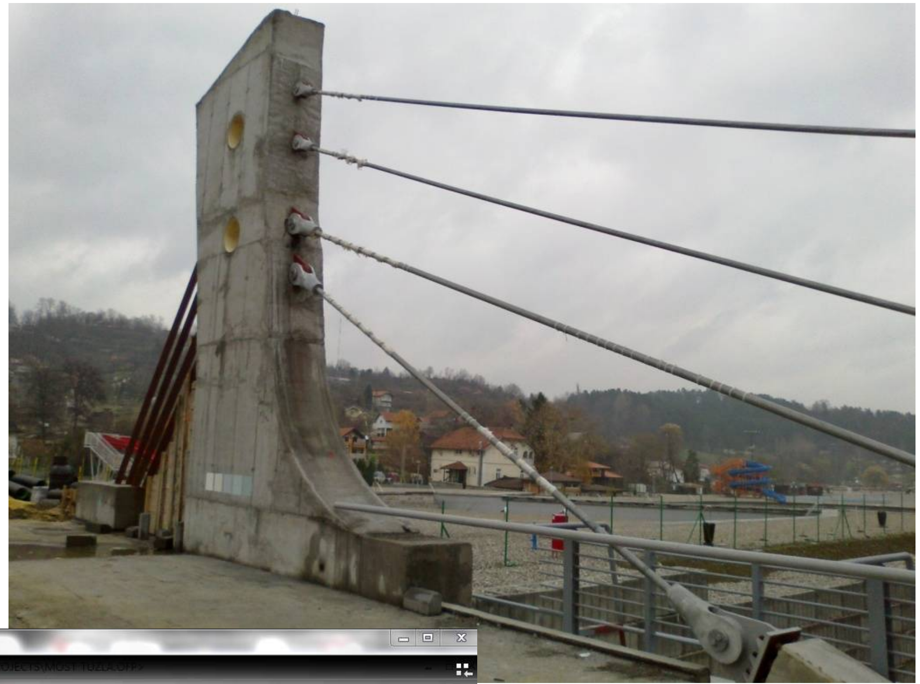


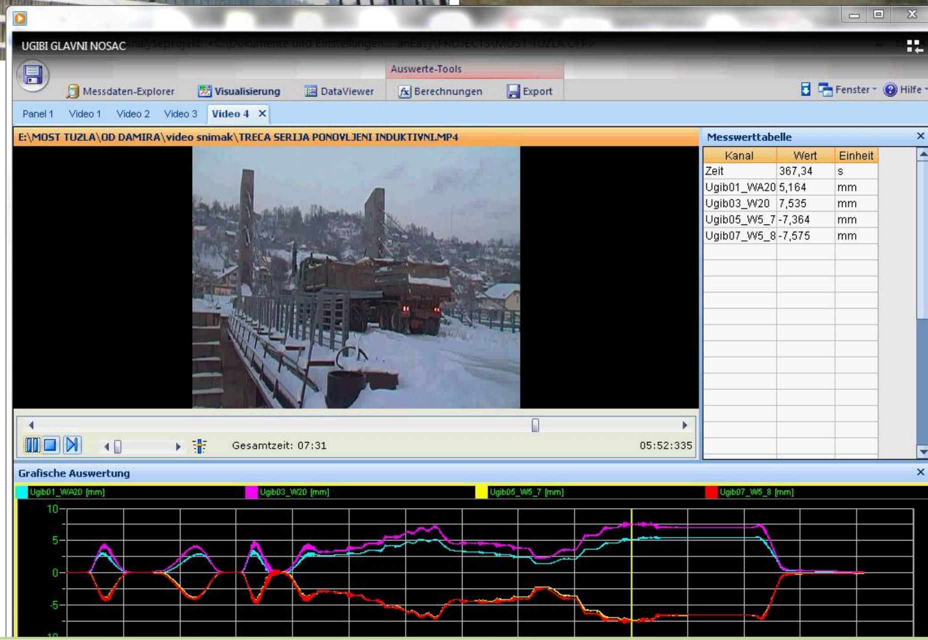


CASE STUDY 3 – THE CABLE - STAYED BRIDGE IN TUZLA

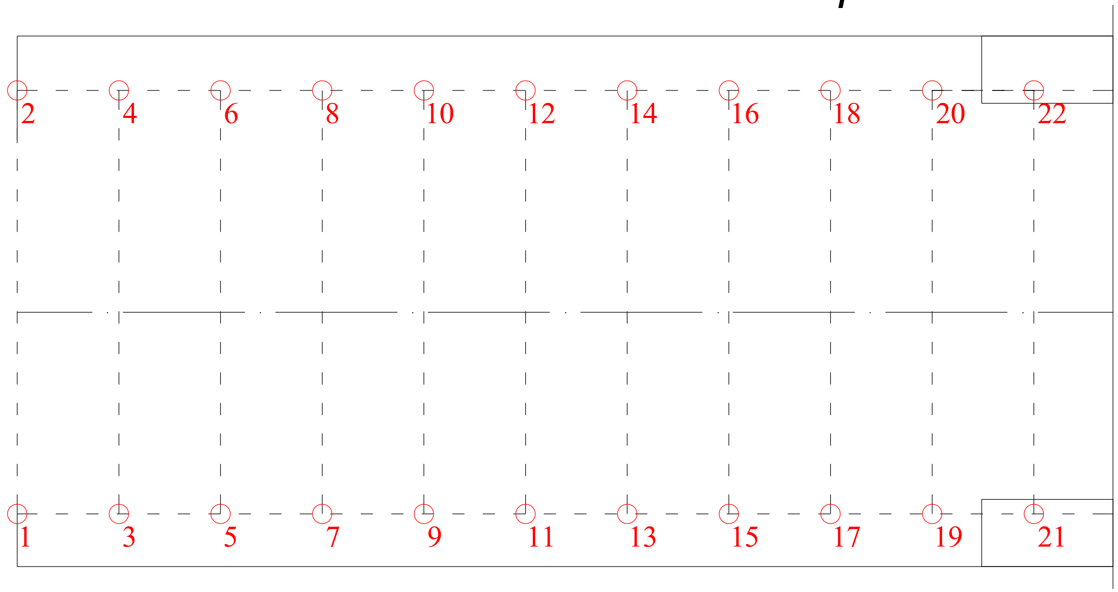
Elevation and cross-sections of the bridge

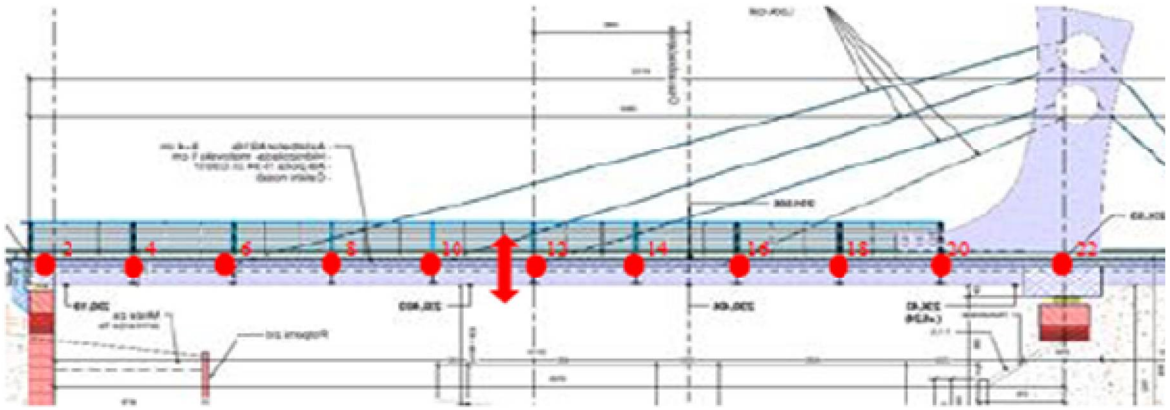


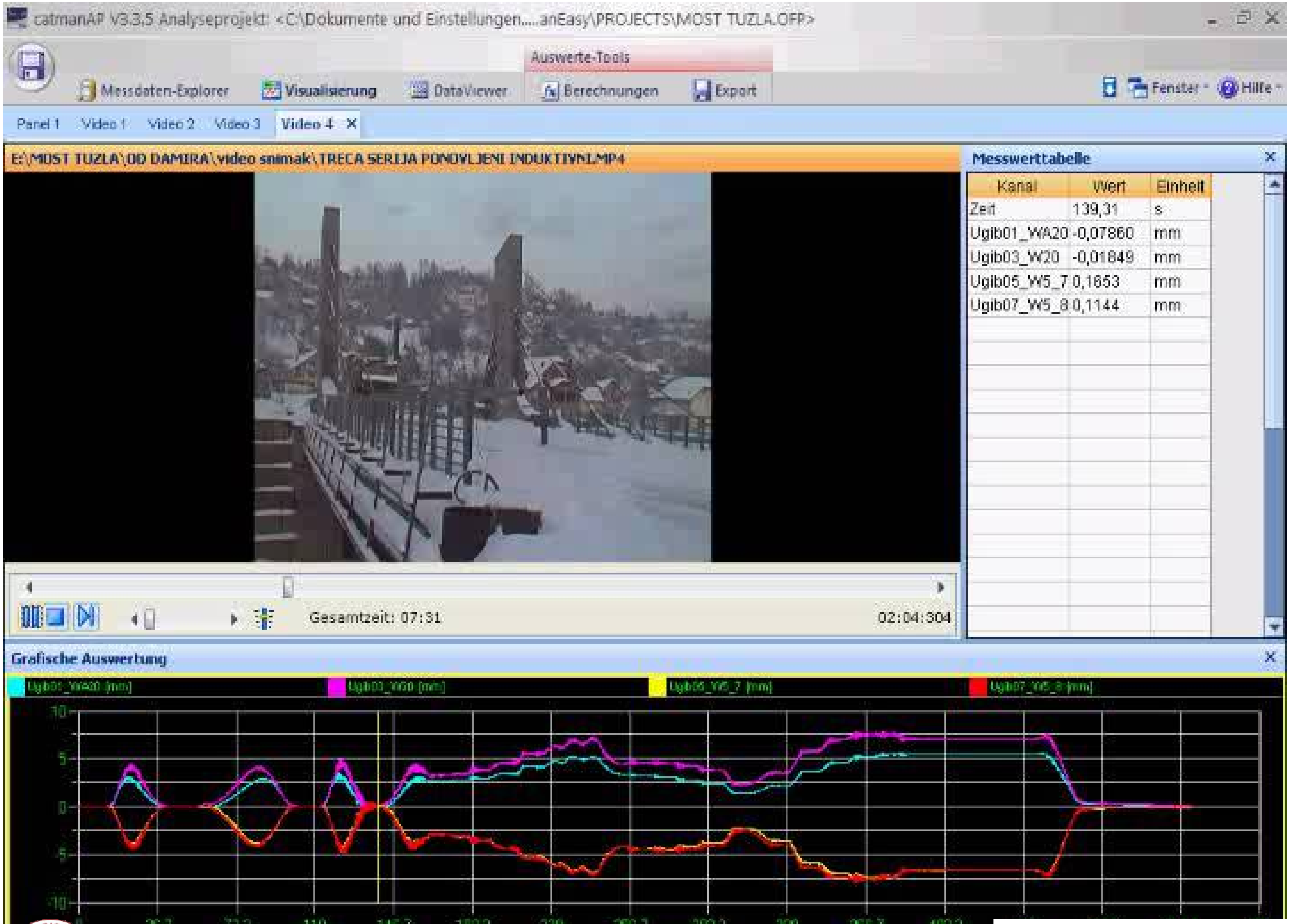



UGIBI GLAVNI NOSAC
Auswerte-Tools
Messdaten-Explorer
Visualisierung
DataViewer
Berechnungen
Export
Fenster
Hilfe
Panel 1
Video 1
Video 2
Video 3
Video 4
E:\MOST TUZLA\OD DAMIRA\video snimak\TRECA SERIJA PONOVLJENI INDUKTIVNI.MP4
Messwerttabelle
Kanal
Wert
Einheit
Zeit 367,34 s
Ugib01_WA20 5,164 mm
Ugib03_W20 7,535 mm
Ugib05_W5_7 -7,364 mm
Ugib07_W5_8 -7,575 mm
Gesamtzeit: 07:31
05:52:335
Grafische Auswertung
Ugib01_WA20 [mm]
Ugib03_W20 [mm]
Ugib05_W5_7 [mm]
Ugib07_W5_8 [mm]
10
5
0
-5

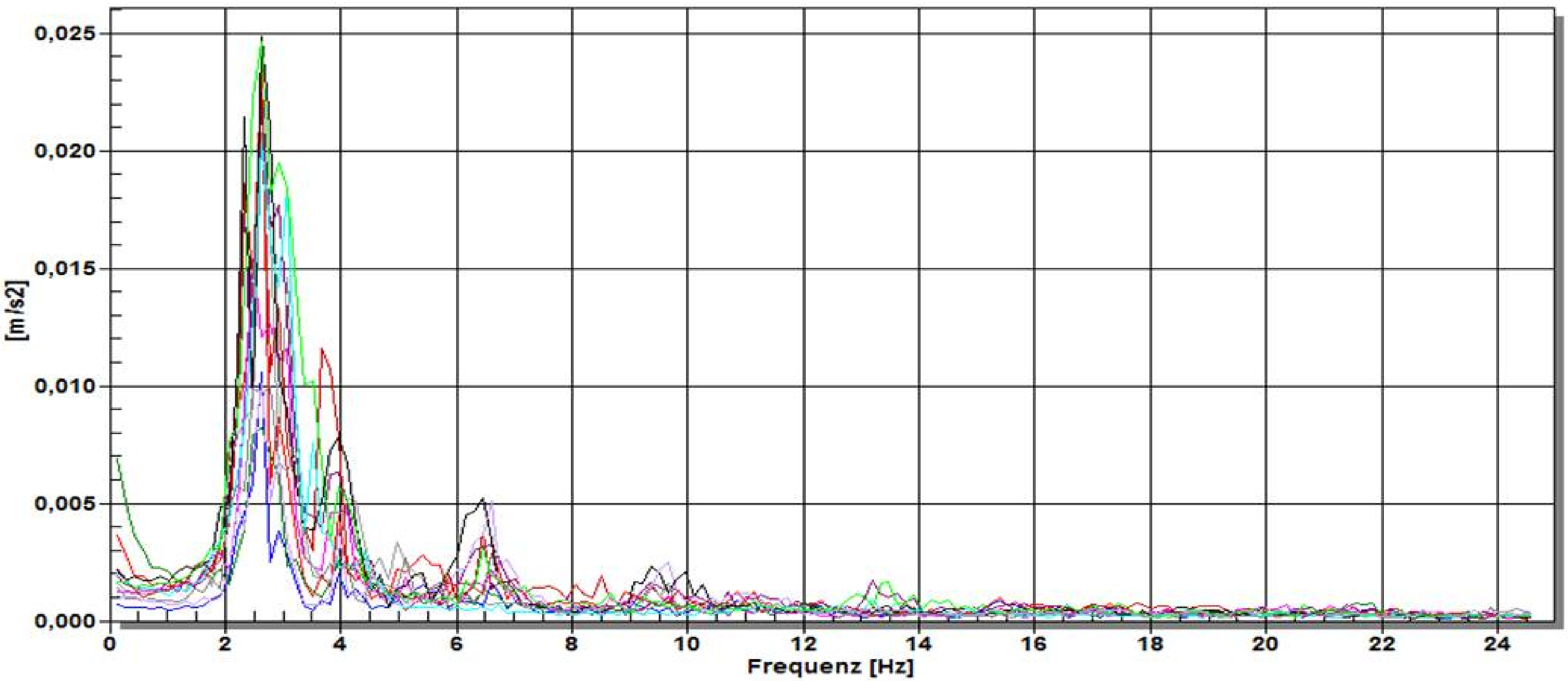
Measurements setup



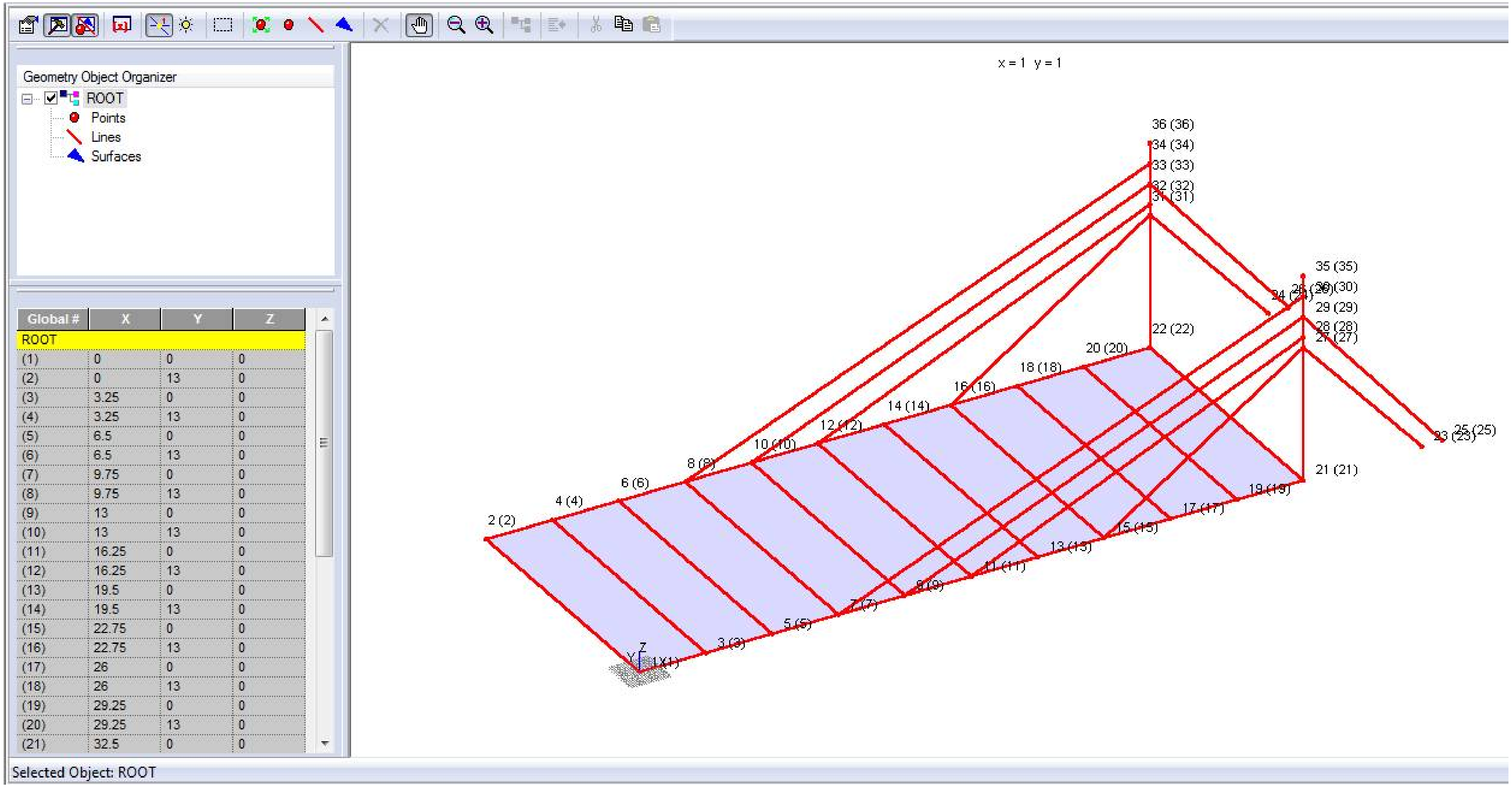



catmanAP V3.3.5 Analyseprojekt: <C:\Dokumente und Einstellungen.....anEasy\PROJECTS\MOST TUZLA.OFP>
Auswerte-Tools
Messdaten-Explorer
Visualisierung
DataViewer
Berechnungen
Export
Fenster
Hilfe
Panel 1
Video 1
Video 2
Video 3
Video 4
E:\MOST TUZLA\OD DAMIRA\video snimak\TRECA SERIJA PONOVLJENI INDUKTIVNI.MP4
Gesamtzeit: 07:31
02:04:304
Messwerttabelle
Kanal | Wert | Einheit
Zeit | 139,31 | s
Ugib01_WA20 | -0,07860 | mm
Ugib03_W20 | -0,01849 | mm
Ugib05_W5_7 | 0,1653 | mm
Ugib07_W5_8 | 0,1144 | mm
Grafische Auswertung

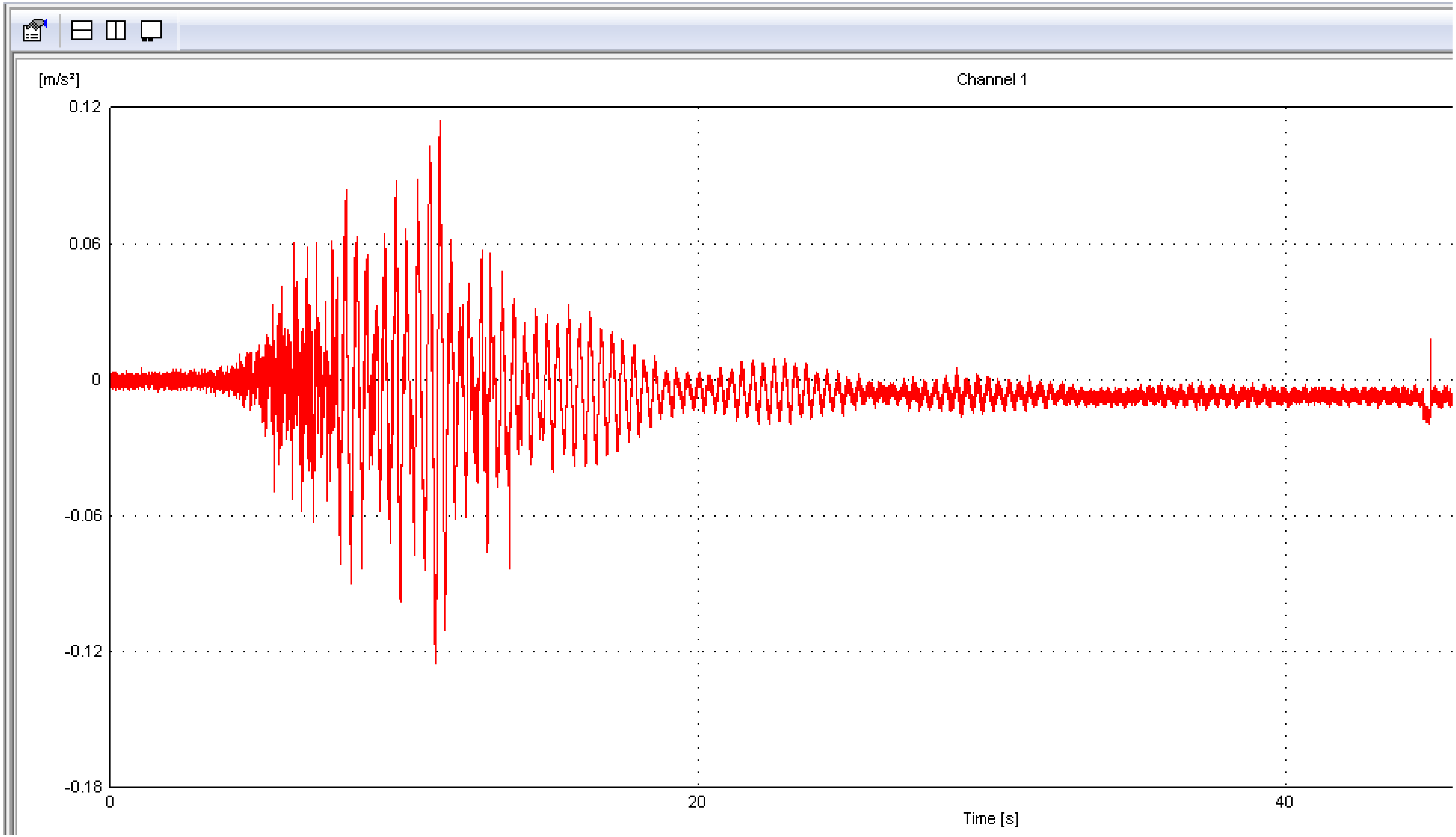
Frequency spectrum



ARTeMIS


Geometry Object Organizer
ROOT
Points
Lines
Surfaces
Global # X Y Z
ROOT
(1) 0 0 0
(2) 0 13 0
(3) 3.25 0 0
(4) 3.25 13 0
(5) 6.5 0 0
(6) 6.5 13 0
(7) 9.75 0 0
(8) 9.75 13 0
(9) 13 0 0
(10) 13 13 0
(11) 16.25 0 0
(12) 16.25 13 0
(13) 19.5 0 0
(14) 19.5 13 0
(15) 22.75 0 0
(16) 22.75 13 0
(17) 26 0 0
(18) 26 13 0
(19) 29.25 0 0
(20) 29.25 13 0
(21) 32.5 0 0
x = 1 y = 1
36 (36)
34 (34)
33 (33)
32 (32)
35 (35)
29 (29)
28 (28)
22 (22)
20 (20)
18 (18)
14 (14)
21 (21)
2 (2)
4 (4)
6 (6)
3 (3)
5 (5)
Selected Object: ROOT

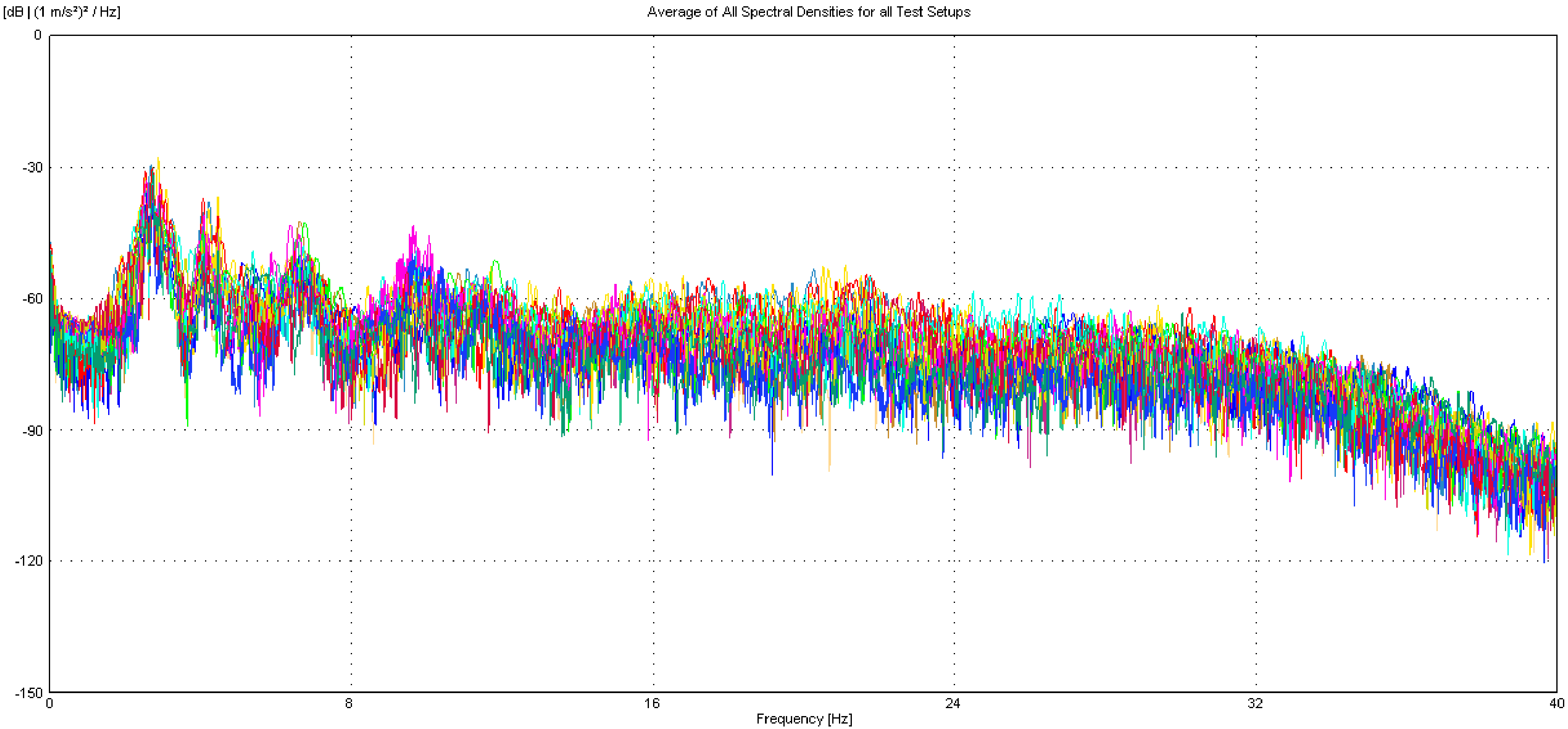
ARTeMIS



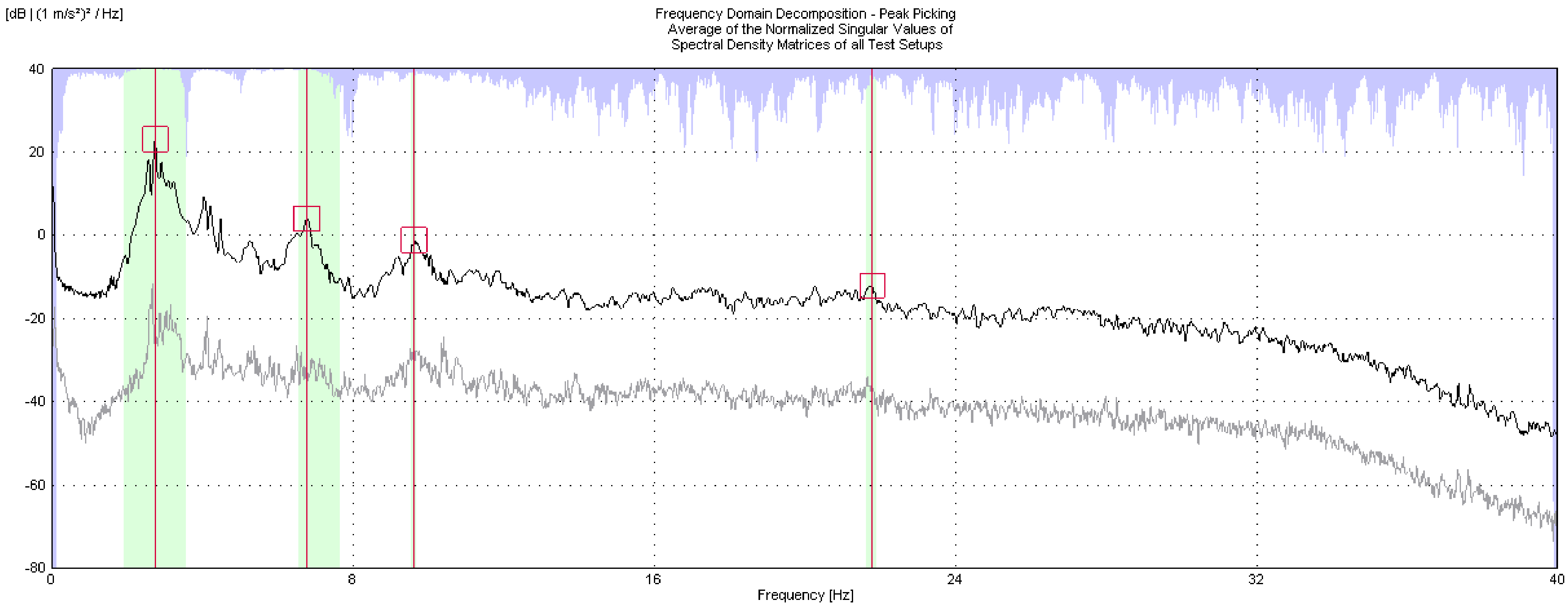
The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

ARTeMIS


[dB | (1 m/s²)² / Hz]
Average of All Spectral Densities for all Test Setups
0
-30
-60
-90
-120
-150
0
8
16
24
32
40
Frequency [Hz]

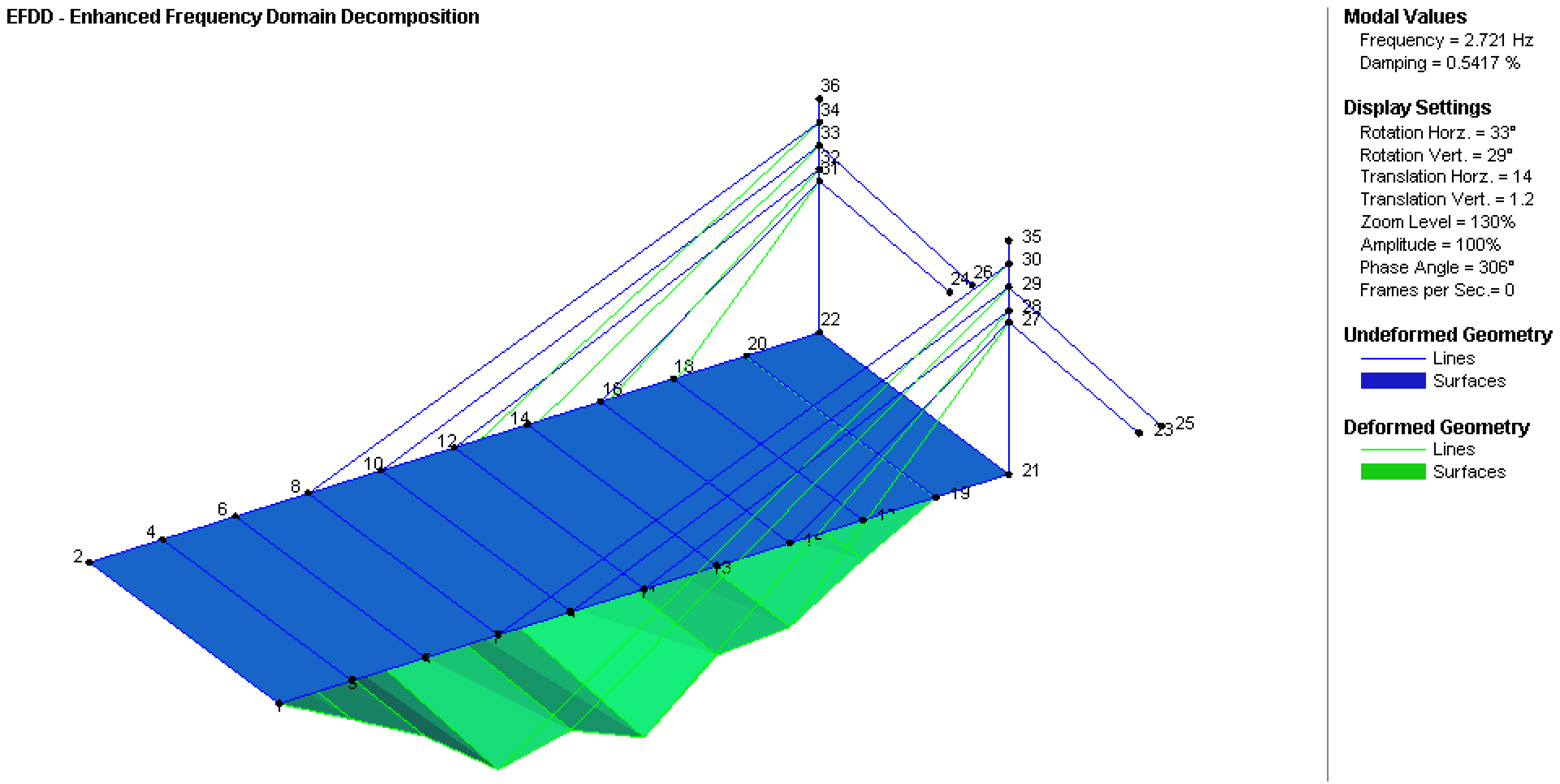
ARTeMIS



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

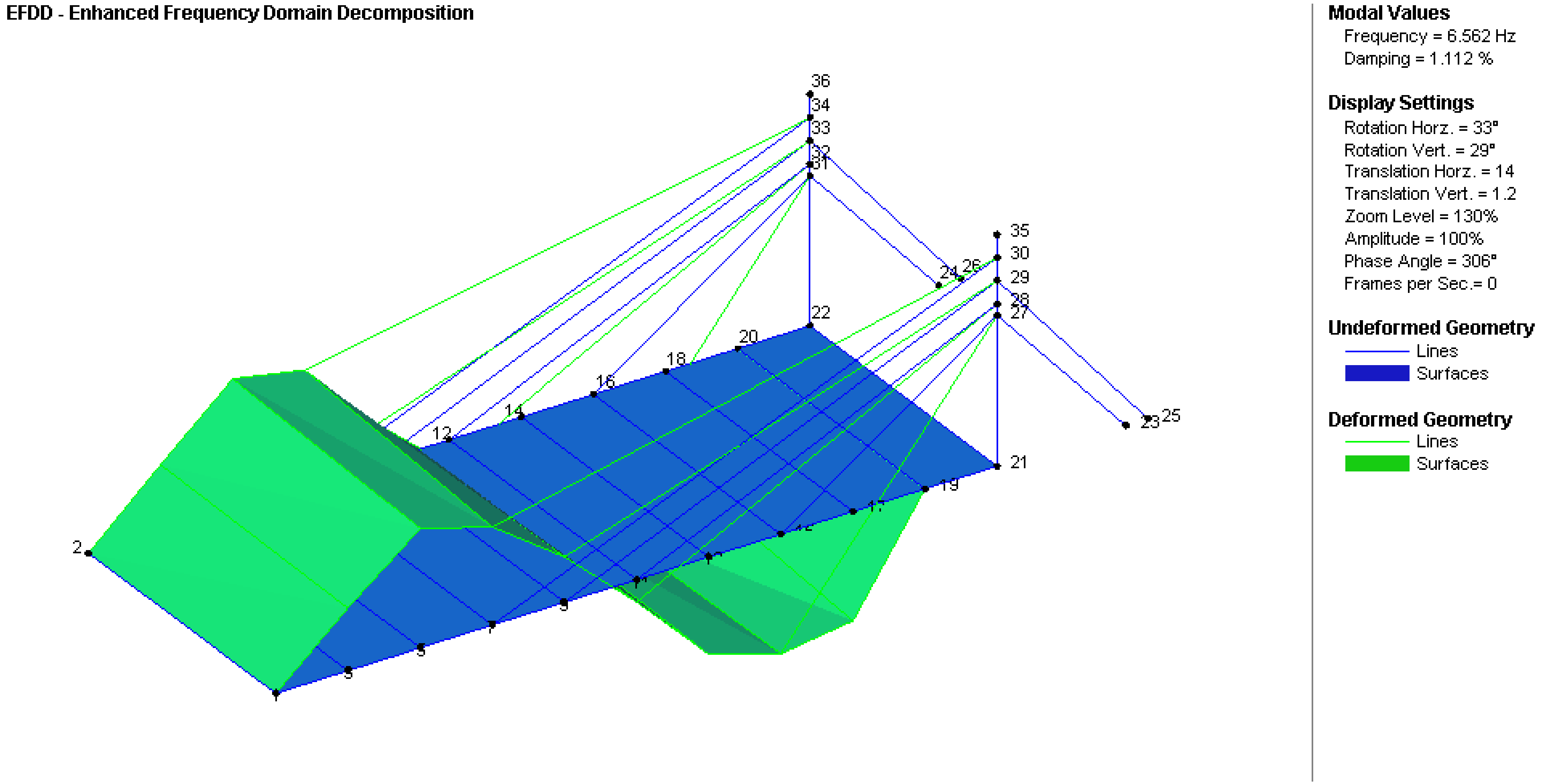
1st mode



The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

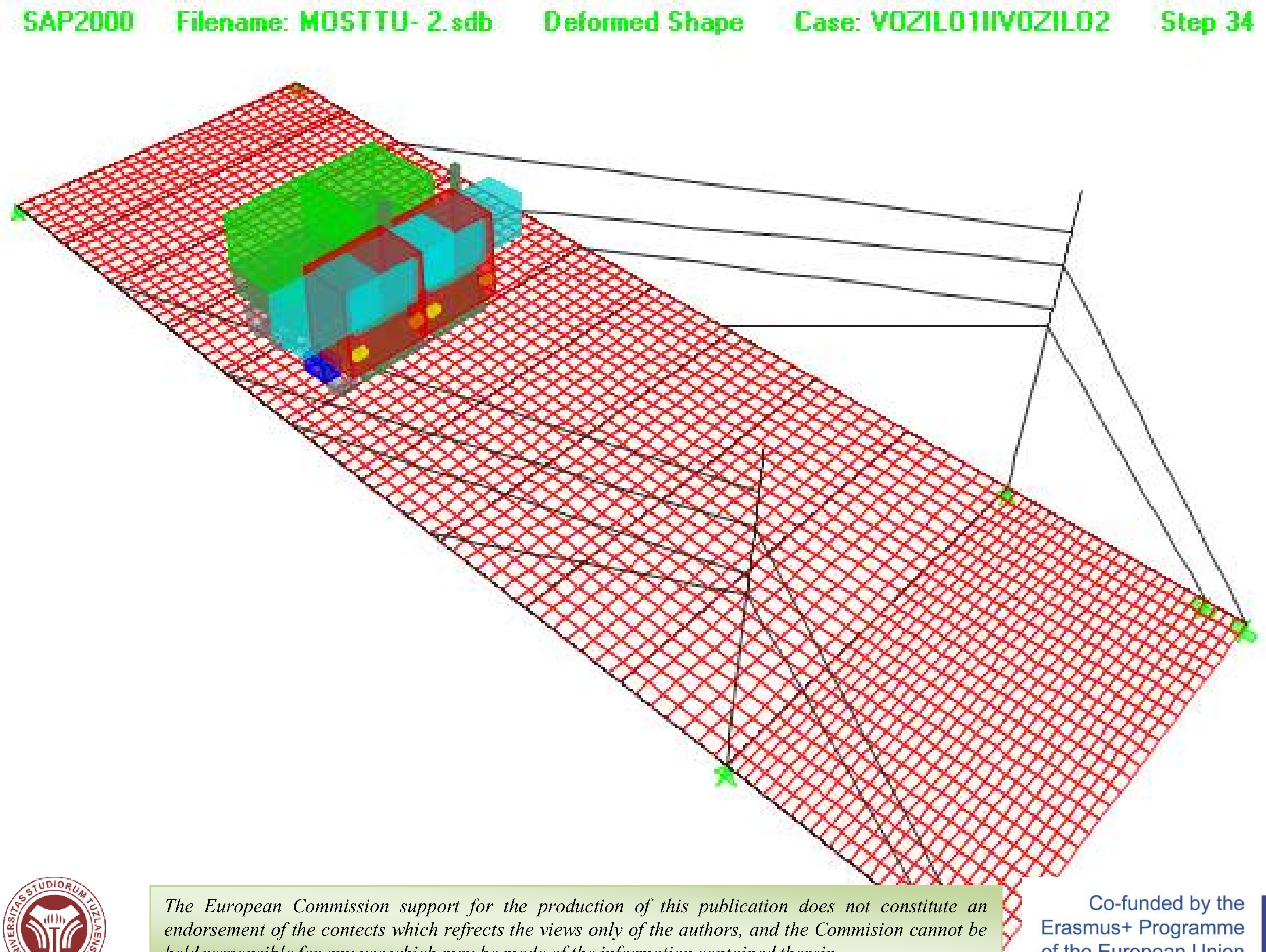
Co-funded by the Erasmus+ Programme of the European Union

2nd mode

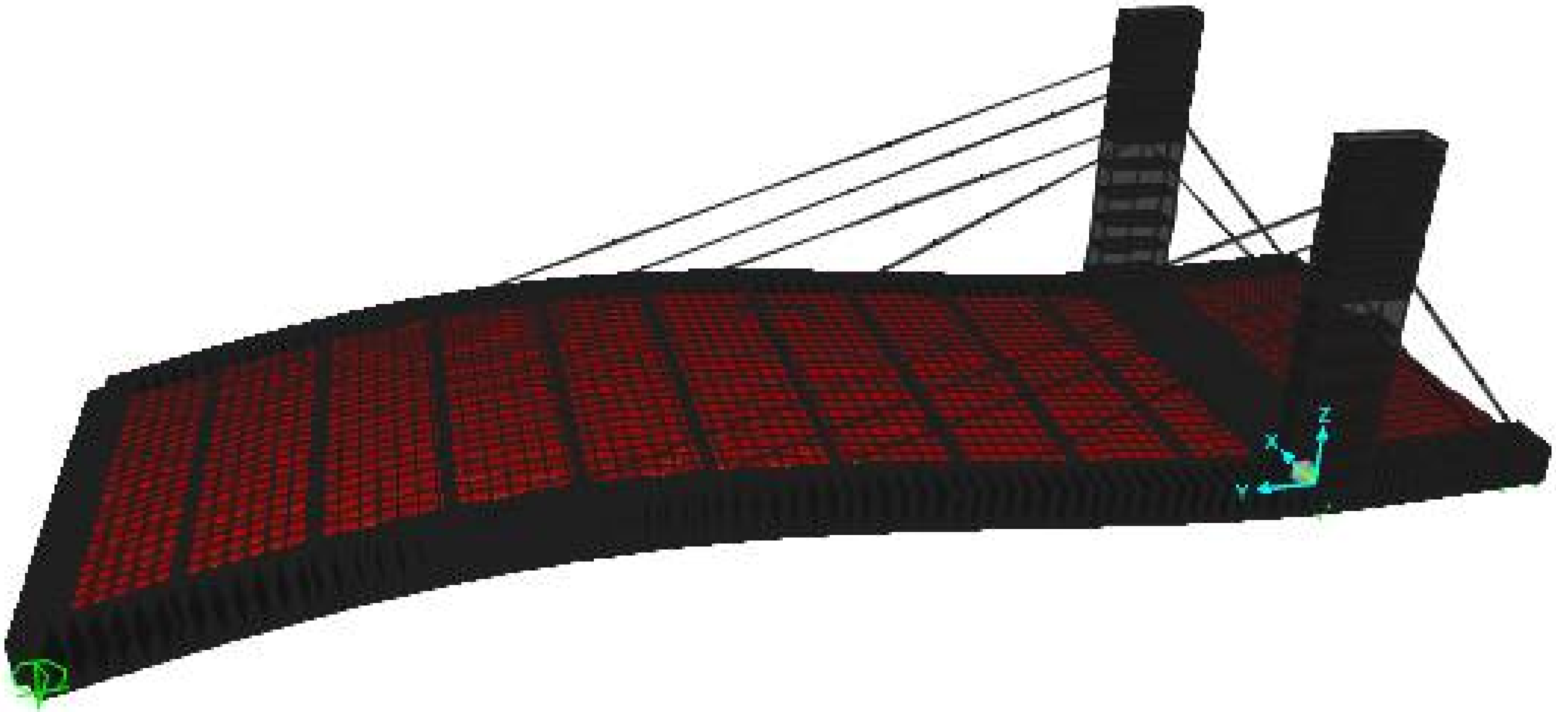


EFDD - Enhanced Frequency Domain Decomposition
36
34
33
32
31
35
30
29
28
27
24
26
22
20
18
16
14
12
2
1
3
5
7
9
21
19
23
25
Modal Values
Frequency = 6.562 Hz
Damping = 1.112 %
Display Settings
Rotation Horz. = 33°
Rotation Vert. = 29°
Translation Horz. = 14
Translation Vert. = 1.2
Zoom Level = 130%
Amplitude = 100%
Phase Angle = 306°
Frames per Sec.= 0
Undeformed Geometry
Lines
Surfaces
Deformed Geometry
Lines
Surfaces

Finite Element Models (FEMs)



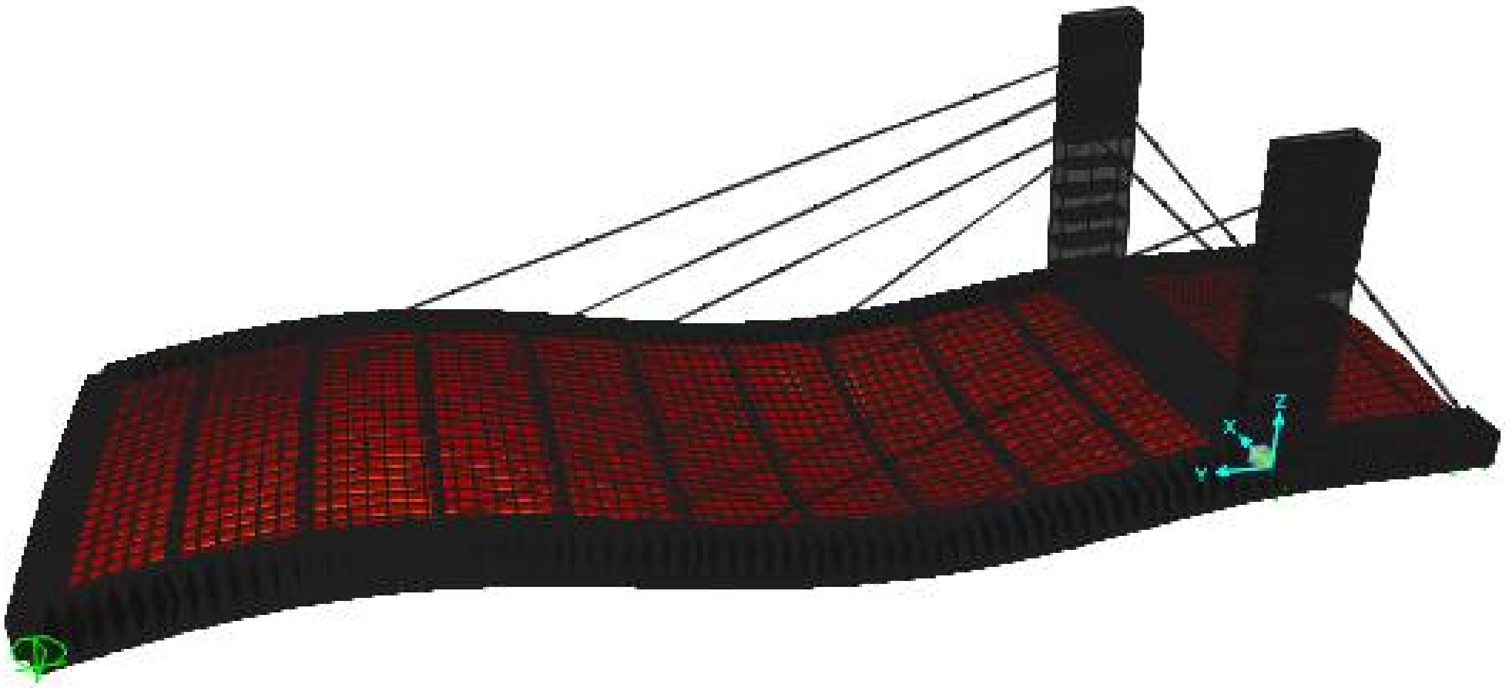
Mathematically identified 1st mode



Experimentally and mathematically identified modal frequencies (Hz)

MODES	AVM	AM4
FIRST MODE	2.719	2.727
SECOND MODE	6.790	6.512

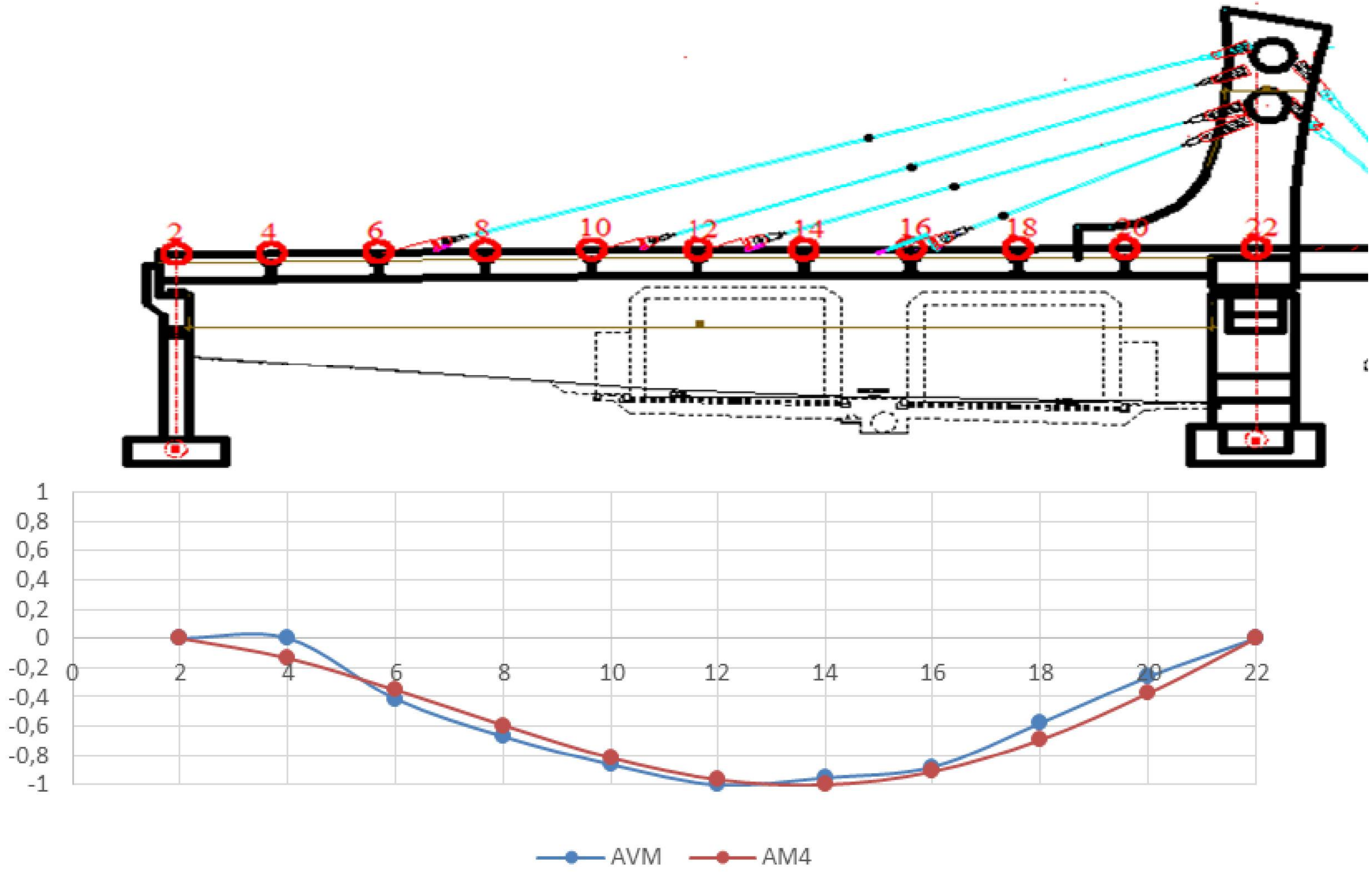
Mathematically identified 2nd mode



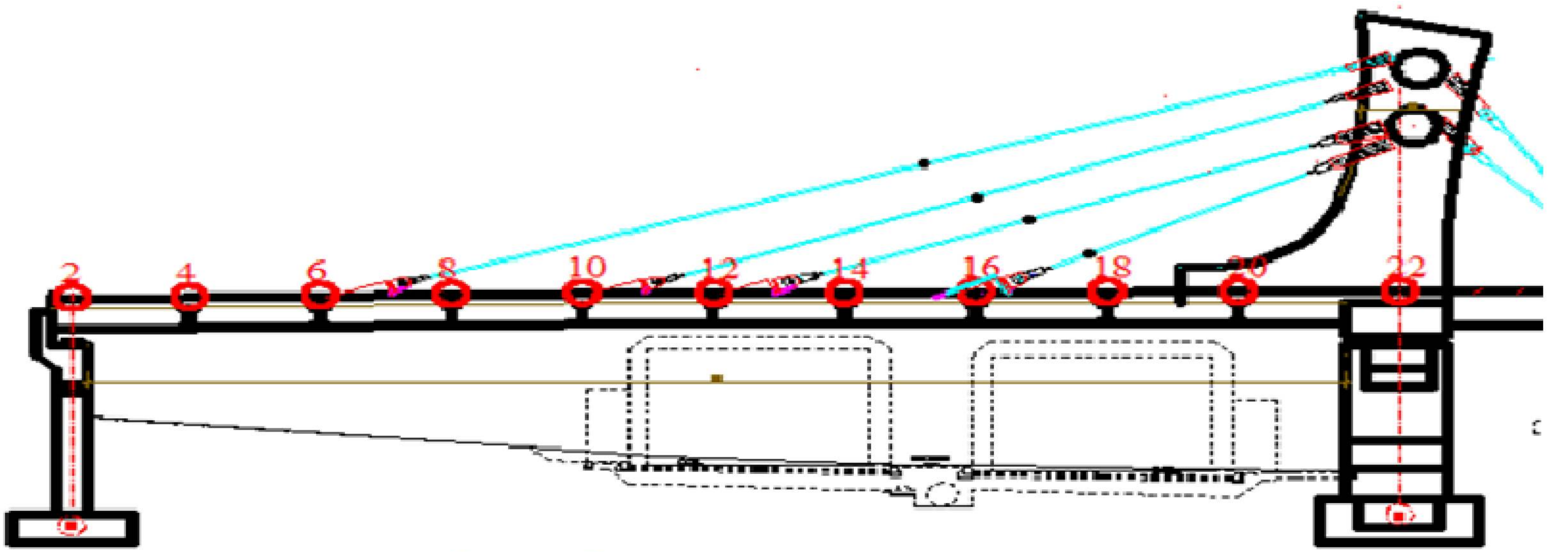
Experimentally and mathematically identified modal frequencies (Hz)

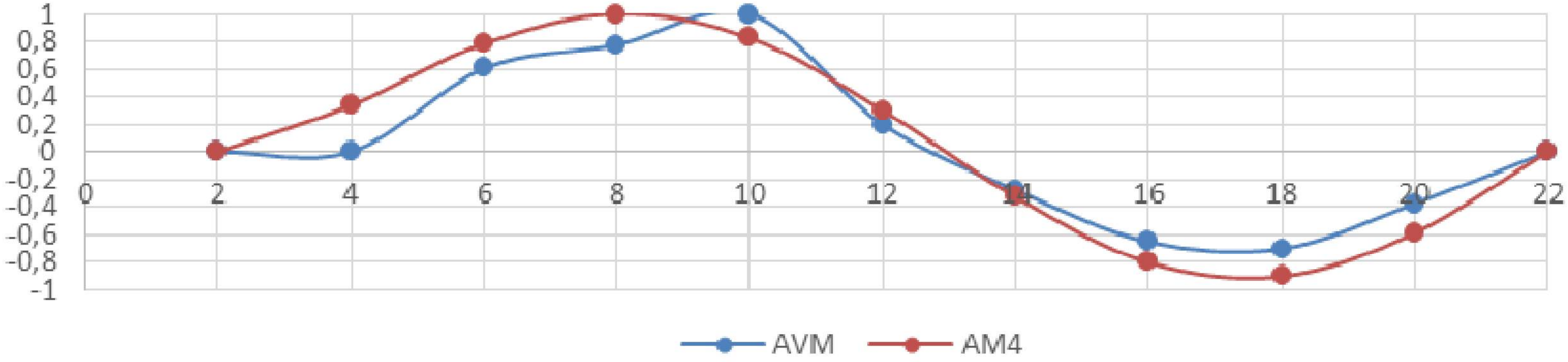
MODES	AVM	AM4
FIRST MODE	2.719	2.727
SECOND MODE	6.790	6.512

Experimentally and mathematically identified first mode shape



Experimentally and mathematically identified second mode shape





The European Commission support for the production of this publication does not constitute an endorsement of the contects which refrects the views only of the authors, and the Commision cannot be held responsible for any use which may be made of the information contained therein.

Co-funded by the Erasmus+ Programme of the European Union

The presented studies show that the signal analysis of ambient vibration records allows the determination of the dynamic characteristics of the bridge. In addition, the frequency and associated modes of vibration can be assessed with adequate mathematical model. The presented results clearly indicate the great potential that ambient vibration measurements hold for monitoring bridge structures. The data collected during the ambient vibration test, which only took some hours and very few resources, processed with adequate algorithms provided very useful information. The comparisons presented in case studies constitute a validation of the developed mathematical models and at the same time permit some fine tuning, especially concerning the boundary conditions and unexpected channel errors. In particular, this slides clearly shows that it was possible to extract a lot of useful information from data collected during the ambient vibration test.

Co-funded by the
Erasmus+ Programme
of the European Union

Thank you
for your attention

e-mail: damir.zenunovic@untz.ba

Knowledge FOr Resilient soCiEty