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BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.

Foundation Vibration Analysis with Simple Physical Models

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Geotechnical design calculations

Geotechnical design calculations (EC7):

Ultimate limit state design (ULS) with mostly (trivial) analytic computations (static force and momentum balance)

Serviceability limit state design (SLS) with mostly analytic but increasingly also with numerical computations (deformation analysis)

Geotechnical design practice:

For individual design procedure steps different software tools are available

Engineers must master and follow the development of numerous software tools

A unified engineering platform comprising numerous design computations and analyses would be of great advantage

Geotechnical design practice:

Implementation of analytical design methods in GIBIANE and native Cast3M procedures for ULS design

Additional numerical analyses for verification and SLS design with the Finite Element Method in Cast3M

The unification of the design concepts in one system makes Cast3M a very powerful geotechnical engineering environment

The Cone Method (Swiss theory, J.P.Wolf)

Foundation design for dynamic loading:

Three dimensional problem with six degrees of freedom in time or frequency domain

High modelling effort for routine engineering problems

Additional questions concern material damping and absorbing boundaries

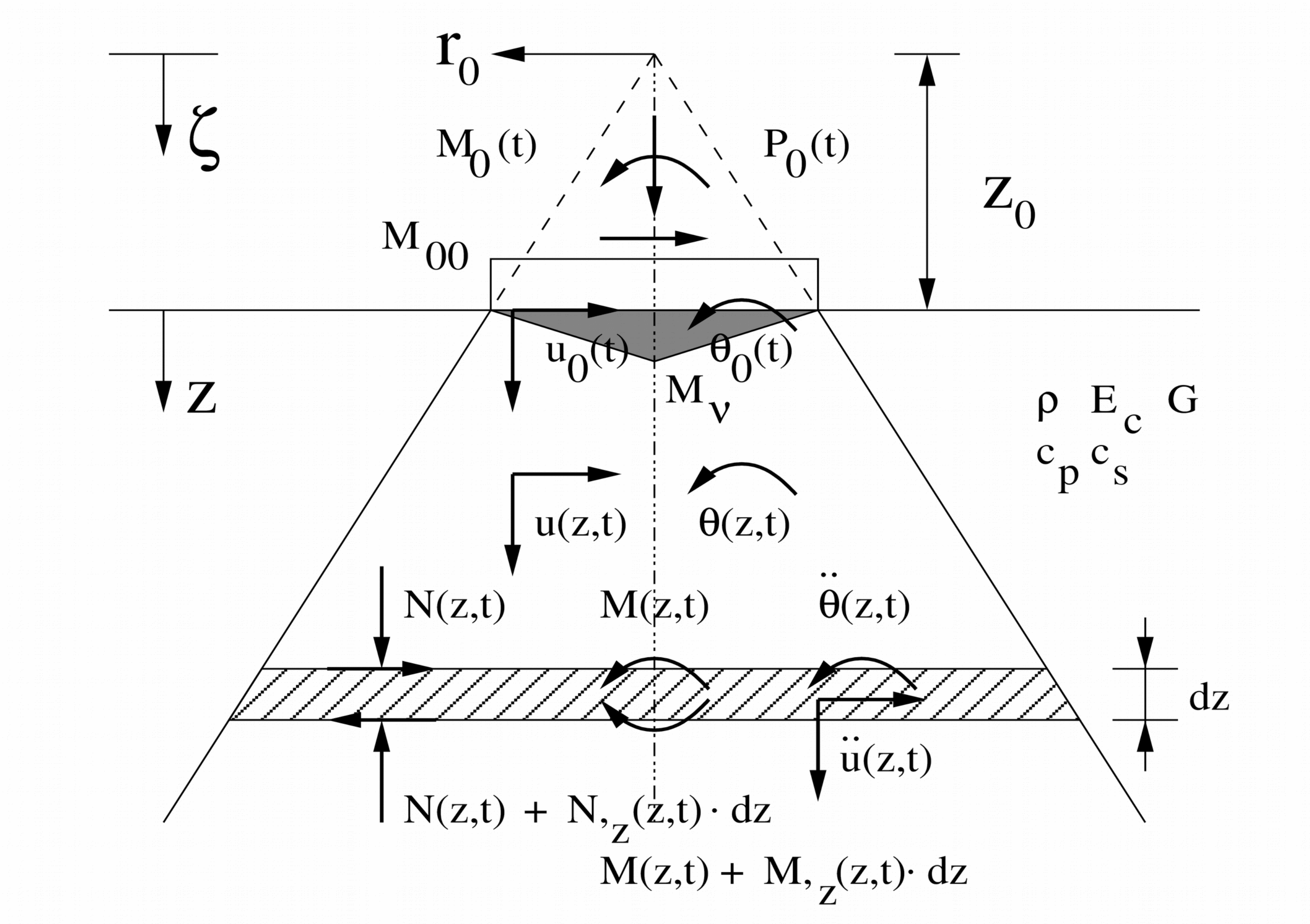
The Cone Method:

A cone with appropriate aperture represents the mechanical behaviour of the dynamically loaded half-space

Individual treatment of translational and rotational degrees of freedom

Construction induced coupling of degrees of freedom is possible

Mechanical concept of the Cone Method for homogeneous half-space



The Cone Method:

Wave equation for translation degrees of freedom in the cone frustum:

$$(\zeta u)_{,tt} = c_{c/s}^{2} (\zeta u)_{,\zeta\zeta}$$

Wave equation for rotation degrees of freedom in the cone frustum:

$$\vartheta_{,tt} = c_{c/s}^{2} \left(\vartheta_{,\zeta\zeta} + \frac{4}{\zeta} \vartheta_{,\zeta} \right)$$

The Cone Method:

Time domain analysis for translation:

$$\left(M_{0u}+\Delta M_u\right)\ddot{u}_0 + C_u\dot{u}_0 + K_u u_0 = P_0(t)$$

Time domain analysis for rotation:

$$\left(M_{0\vartheta}+\Delta M_\vartheta\right)\ddot{\vartheta}_0 + C_\vartheta\left(\dot{\vartheta}_0-\dot{\vartheta}_1\right) + K_\vartheta\vartheta_0 = M_0(t)$$

$$M_{\vartheta 1}\left(\dot{\vartheta}_0-\dot{\vartheta}_1\right) + C_{\vartheta 1}\vartheta_1 = 0$$

The Cone Method:

Frequency domain analysis for translation:

$$S_u(\omega) \cdot u(\omega) = P_0(\omega)$$

$$S_u(\omega) = K'_u - M_{u0}\omega^2 + iC'_u\omega$$

Frequency domain analysis for rotation:

$$S_\vartheta(\omega) \cdot \vartheta(\omega) = M_0(\omega)$$

$$S_\vartheta(\omega) = K'_\vartheta - M_{\vartheta 0}\omega^2 + iC'_\vartheta\omega$$

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The Cone Method:

Frequency domain analysis for translation:

$$K'_u = \frac{\varrho\, c_{c/s}^2\, A_0}{z_0} = K_u$$

$$C'_u = \varrho\, c_{c/s}\, A_0 = C_u$$

$$\Delta M_u = 2.4\, \pi \left(\nu - \frac{1}{3} \right) \varrho\, r_0^3 \geq 0$$

The Cone Method:

Fundamental equation for cone height results from elementary solutions of elasticity theory for stiff disk foundations:

$$\frac{z_0}{r_0} = \frac{(1-\nu)\,\pi}{4}\left(\frac{c_c}{c_s}\right)^2$$

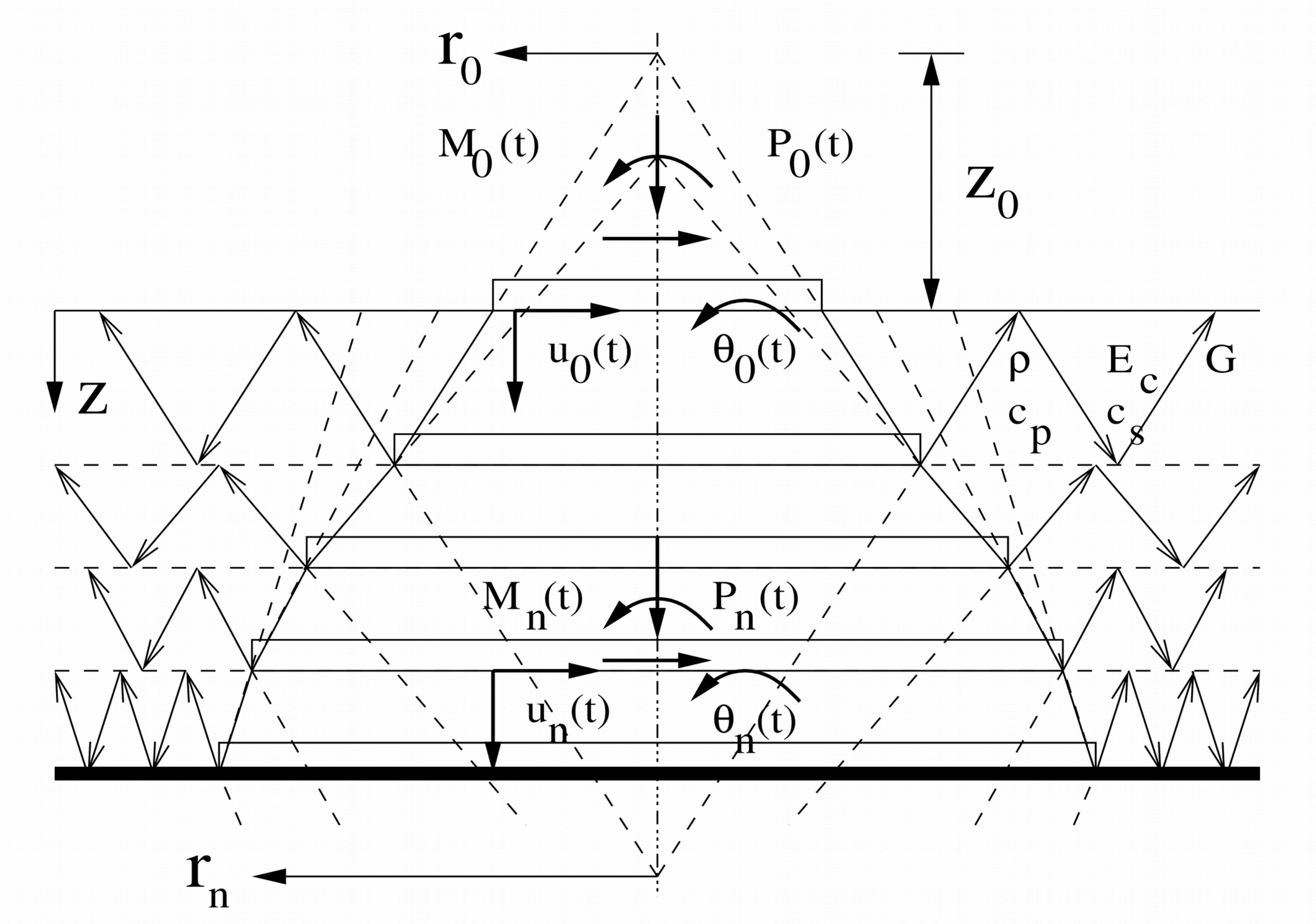
The Cone Method:

Double asymptotic theory converting into rigorous solutions at vanishing and at infinite frequencies

It has been successfully extended for horizontally layered half-space, embedded foundations and pile foundations

The Cone Method delivers results with reliable accuracy for engineering design

Mechanical concept of the Cone Method for half-space with horizontal layering



The GIBIANE
Complex Procedure Collection

The Complex Procedure Collection:

@COMPLEX.procedure
@COMPLEX.notice

Comprehensive GIBIANE library implementing the most important analysis operations for complex numbers

Inclusion into the ’main branch’ of Cast3M after final validation and verification

The Complex Procedure Collection:

Complex procedures have a distinguishable name: @Cxxx

'@' symbol marks external contribution

Procedures treat all internal variables as local (decorated with '!' symbol)

Procedures strictly avoid internal generation and passing of references

The Complex Procedure Collection:

Complex numbers are simply represented with TABLE objects

’RE’ table entry for real part (R.’RE’)

’IM’ table entry for imaginary part (R.’IM’)

The GIBIANE implementation could be significantly improved with native Cast3M procedures in ESOPE

The Complex Procedure Collection:

Usage example:

A=TABLE;	B=TABLE;	R=TABLE;
A.’RE’=1.0;	B.’RE’=3.0;	R.’RE’=0.0;
A.’IM’=2.0;	B.’IM’=4.0;	R.’IM’=0.0;

Z = @CADD R A B ;

R.’RE’=4.0; R.’IM’=6.0;

Z on the left side has the reference of R (!)

The Complex Procedure Collection:

Basic operators:

@CABS , @CARG , @CNIL , @CEQT , @CCJG , @CNGT , @CCRT , @CPLR , @CCMP

Elemental mathematics:

@CADD , @CSUB , @CMUL , @CDIV

The Complex Procedure Collection:

Advanced mathematics:

@CEXP , @CLOG , @CPOW , @CSQR , @CCBR , @CRTN

Trigonometric and hyperbolic operators:

@CSIN , @CCOS , @CTAN , @CASN , @CACS , @CATN , @CSNH , @CCSH , @CTNH , @CASH , @CACH , @CATH

The Complex Procedure Collection:

Implementation is based on open-source code examples from Perl, Javascript and Node.js

Verification and validation is based on systematic test routines in Python (cmath package)

Analysis of a foundation under vertical dynamic loading in frequency domain

The Cone Method:

Frequency domain analysis for translation:

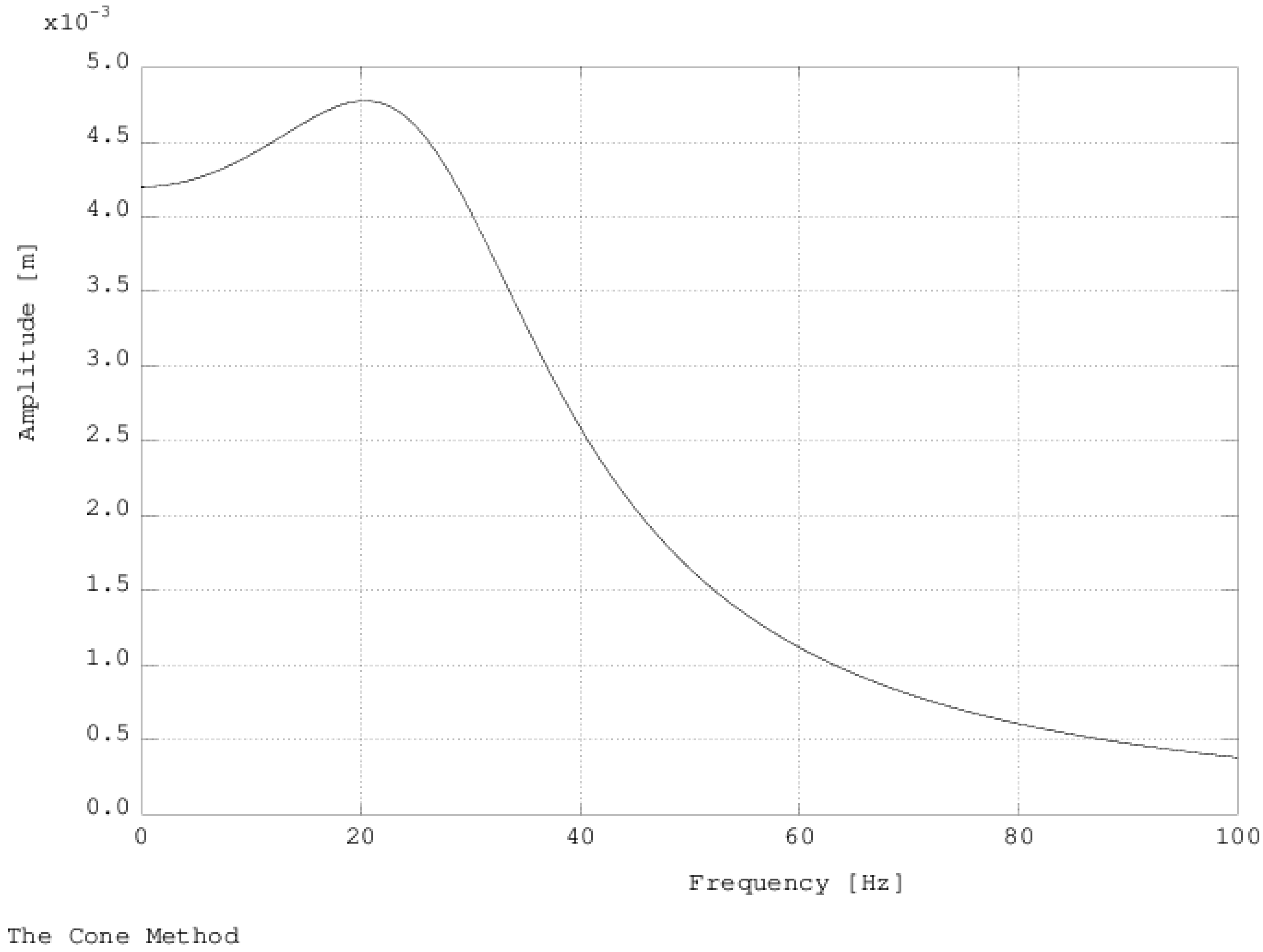
$$r_0 = 1.0\ [m],\ m = 6.0e3\ [kg],\ \Delta M_u = 923.6\ [kg]$$

$$E = 1.0e8\ [N/m^2],\ \nu = 0.4\ [1],\ \varrho = 1750.0\ [kg]$$

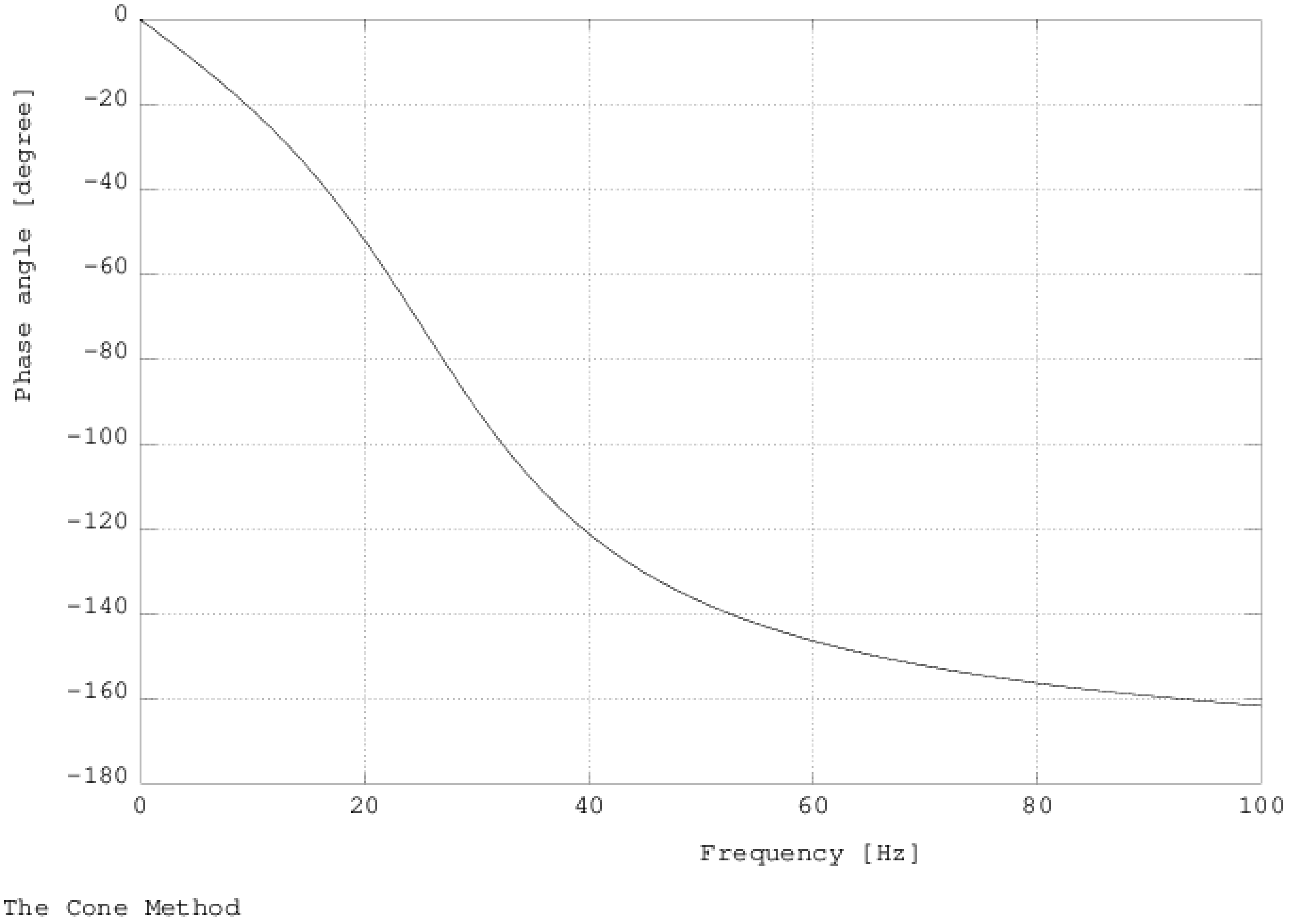
$$P(\omega) = 1.0e6 + 0\,i\ [N]$$

$$u(\omega) = S^{-1}(\omega) \cdot P(\omega)$$

The Cone Method - Amplitude:



The Cone Method – Phase angle:



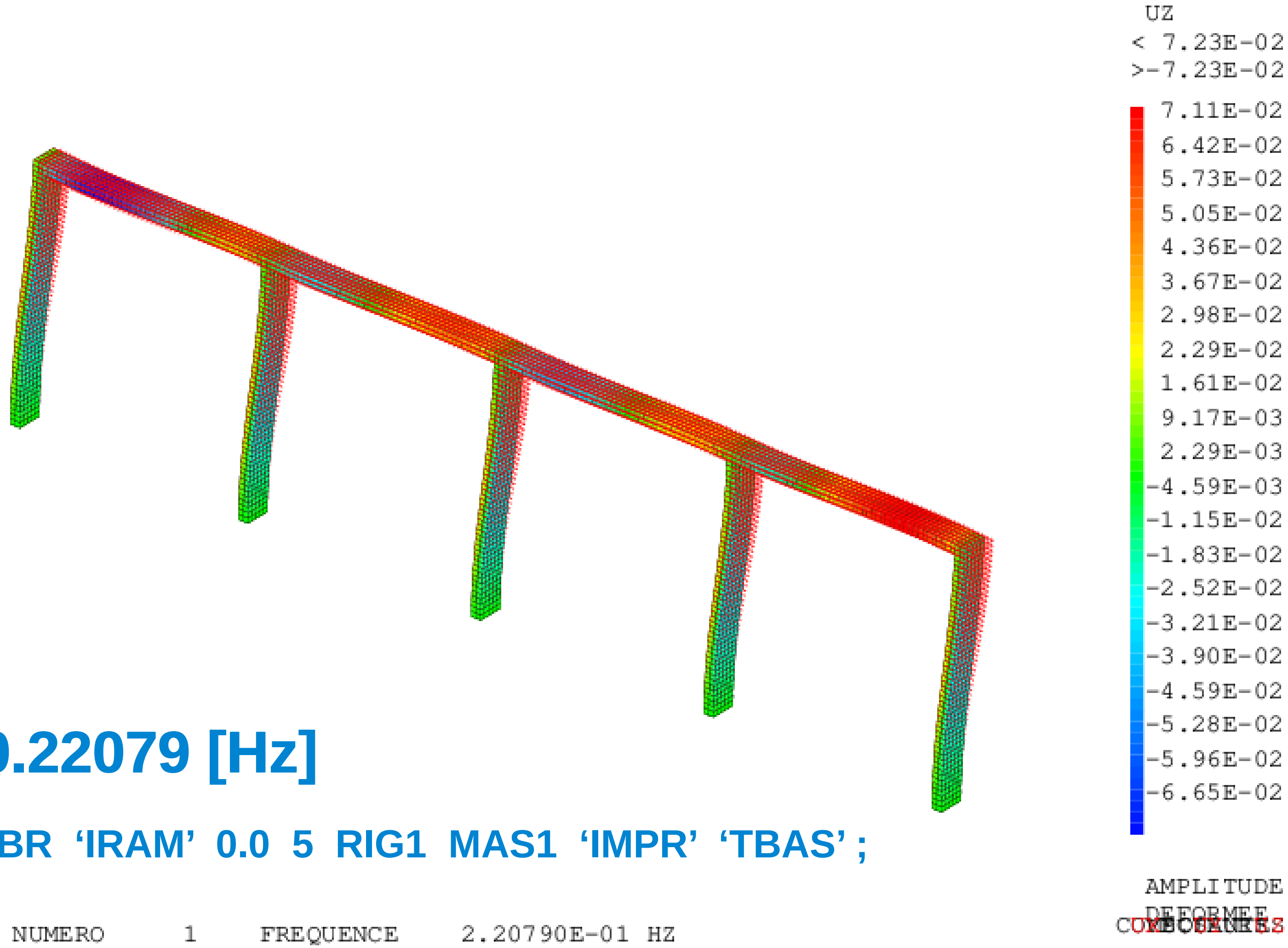
Conceptional Case Study (qualitative analysis)

Vibrations of a tall viaduct bridge on non-flexible foundations

Non-flexible foundations
Vertical displacements under self-weight

RES1 = RESO RIG1 LICHP1 ;

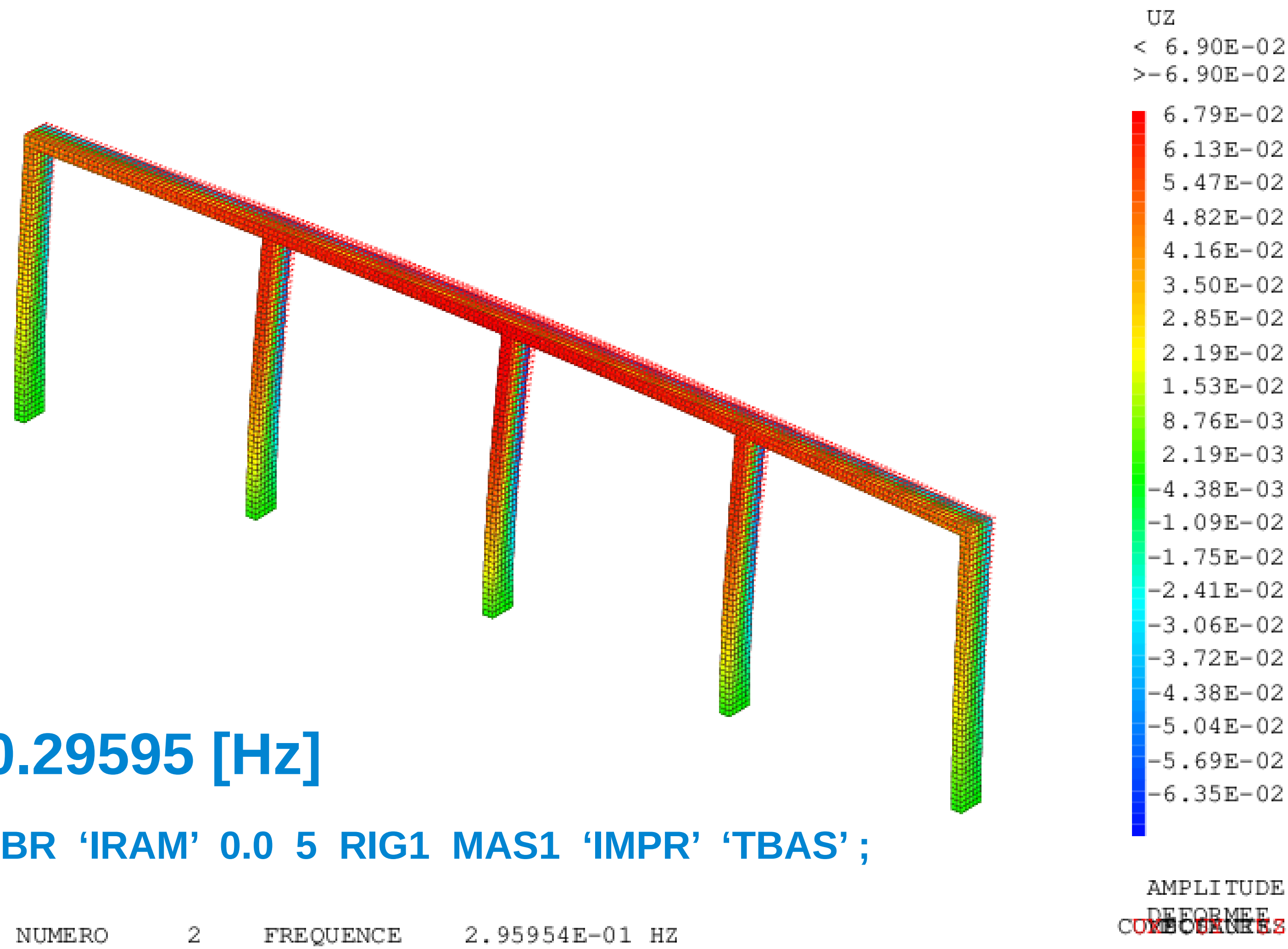
Non-flexible foundations
First eigenfrequency and eigenmode



Fn,1 = 0.22079 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

Non-flexible foundations
Second eigenfrequency and eigenmode



Fn,2 = 0.29595 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

Non-flexible foundations
Third eigenfrequency and eigenmode

Fn,3 = 0.35570 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

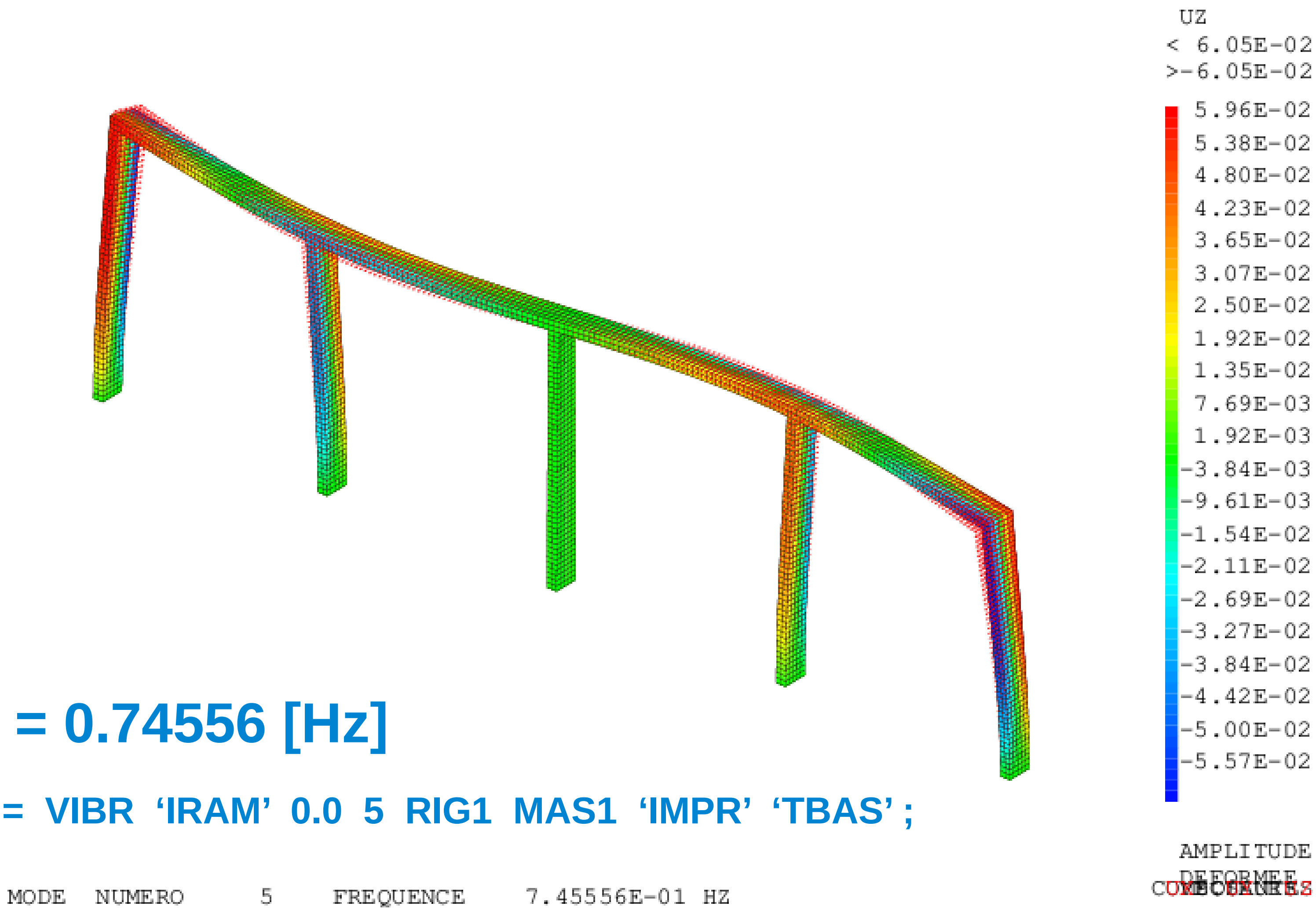
Non-flexible foundations
Fourth eigenfrequency and eigenmode

Fn,4 = 0.47951 [Hz]

SOL1 = VIBR 'IRAM' 0.0 5 RIG1 MAS1 'IMPR' 'TBAS' ;

MODE NUMERO 4 FREQUENCE 4.79506E-01 HZ

Non-flexible foundations
Fifth eigenfrequency and eigenmode



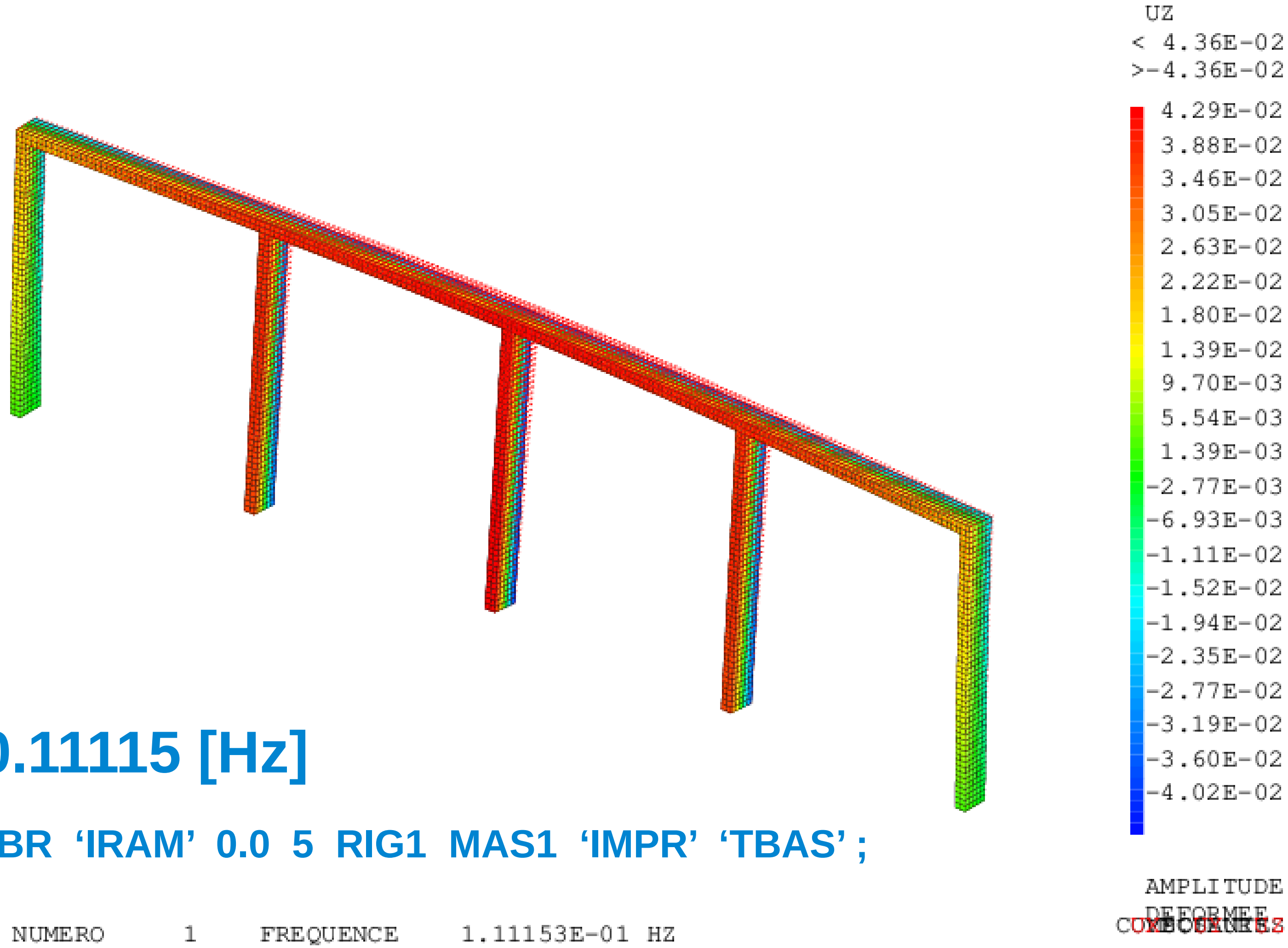
Fn,5 = 0.74556 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

Conceptional Case Study (qualitative analysis)

Vibrations of a tall viaduct bridge on flexible foundations (low stiffness in the middle)

Non-flexible foundations
First eigenfrequency and eigenmode



Fn,1 = 0.11115 [Hz]

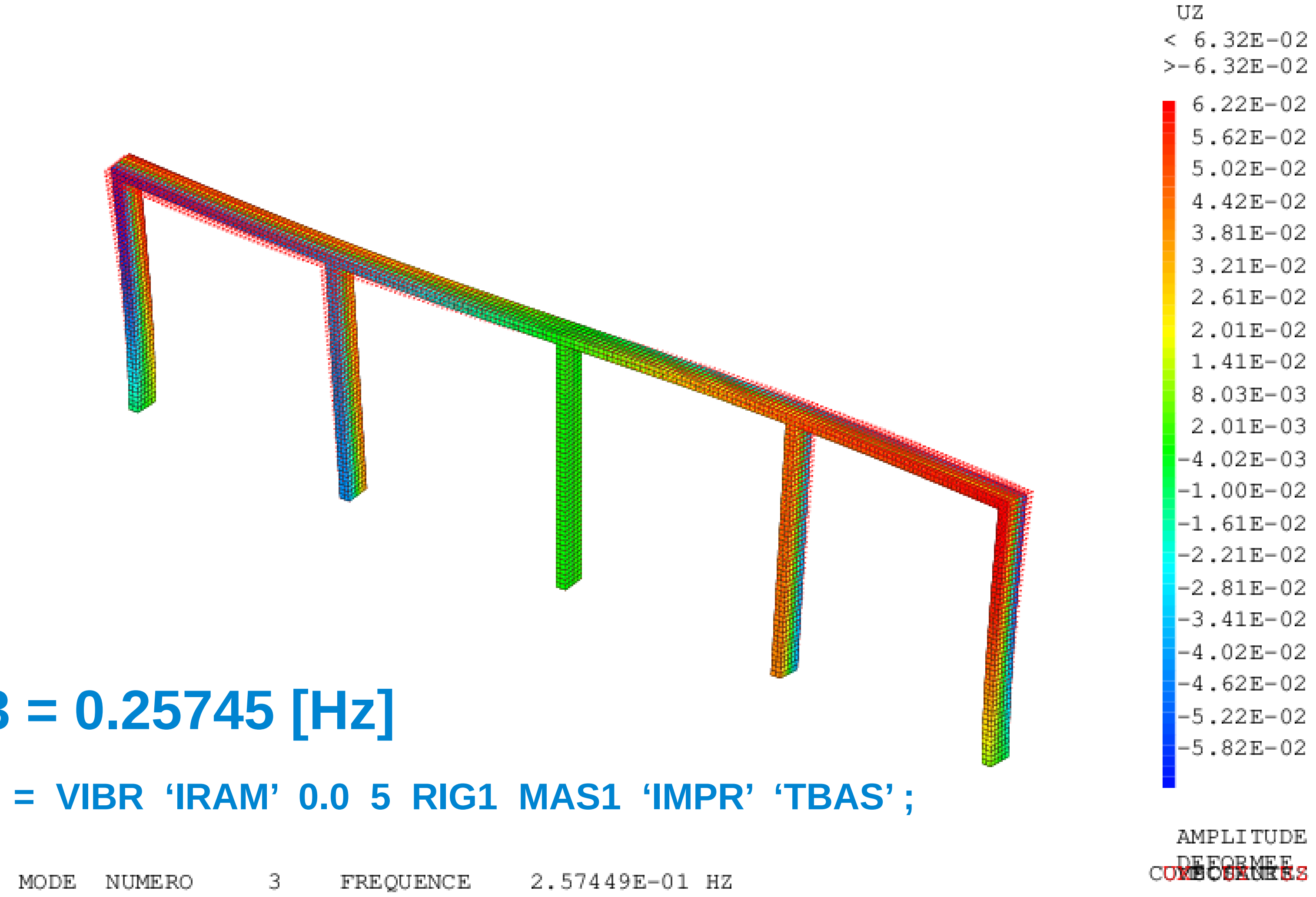
SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

Non-flexible foundations
Second eigenfrequency and eigenmode

Fn,2 = 0.14203 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

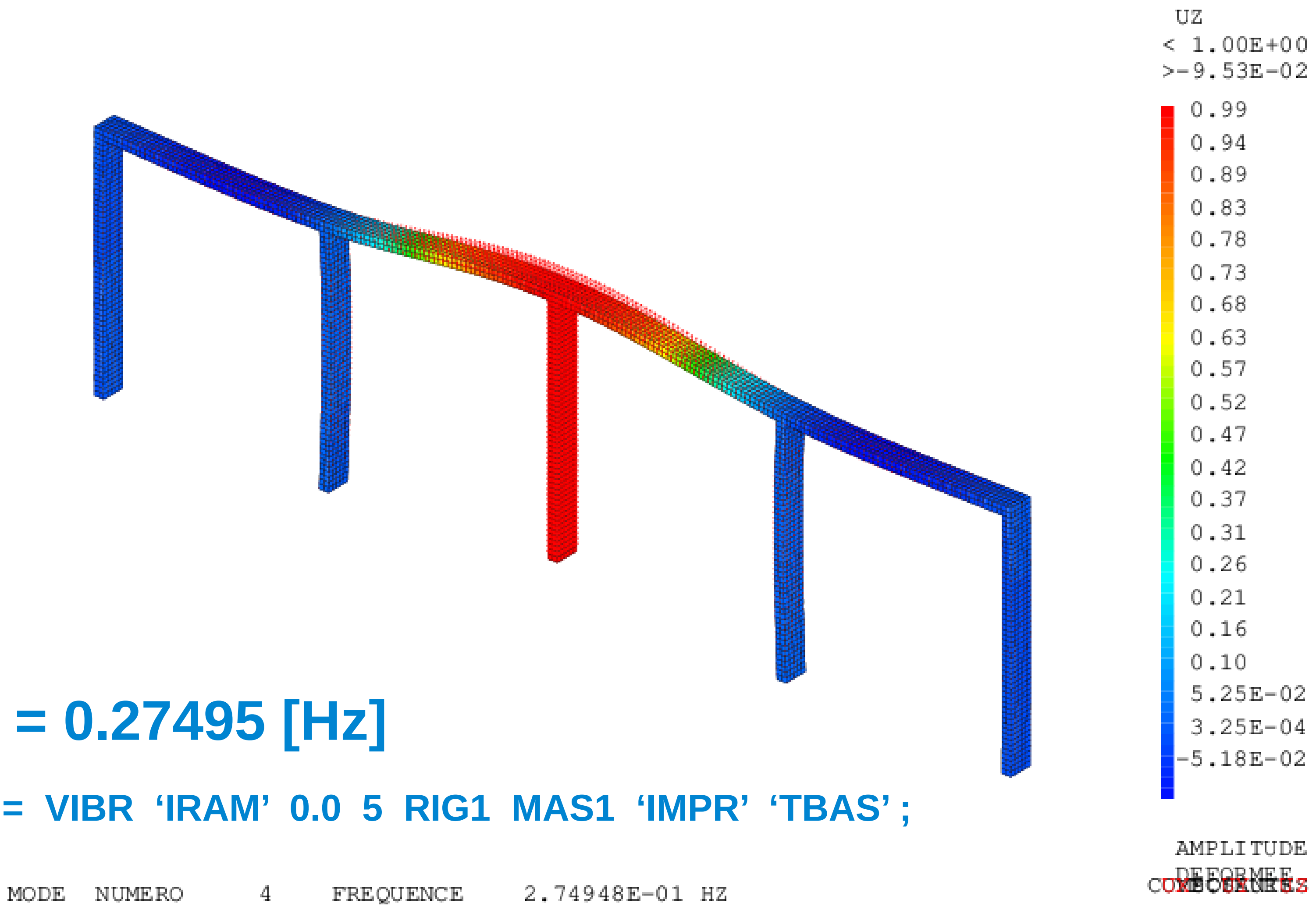
Non-flexible foundations
Third eigenfrequency and eigenmode



Fn,3 = 0.25745 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

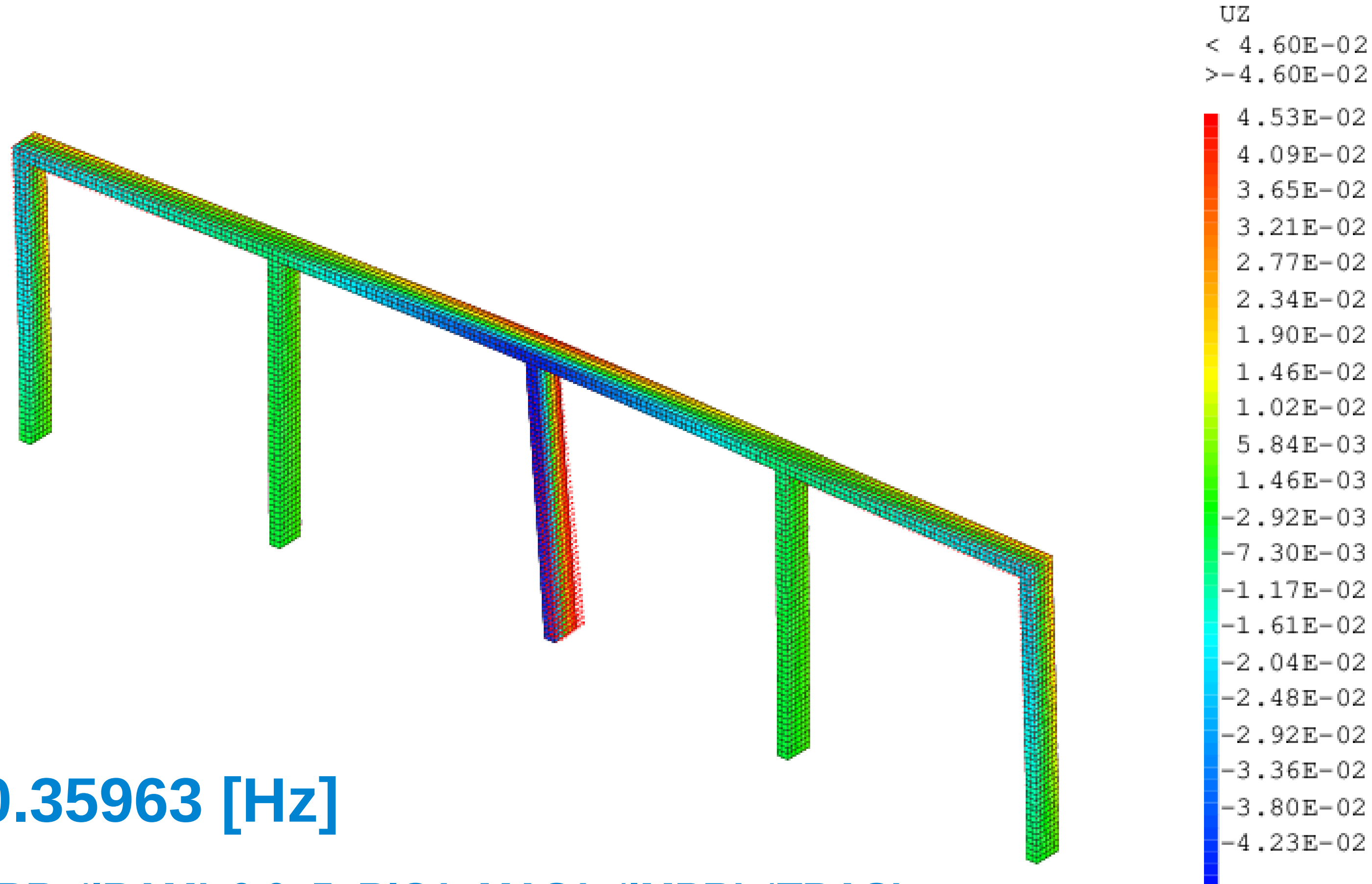
Non-flexible foundations
Fourth eigenfrequency and eigenmode



Fn,4 = 0.27495 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

Non-flexible foundations
Fifth eigenfrequency and eigenmode



Fn,5 = 0.35963 [Hz]

SOL1 = VIBR ‘IRAM’ 0.0 5 RIG1 MAS1 ‘IMPR’ ‘TBAS’ ;

AMPLITUDE
DEFORMEE

MODE NUMERO 5 FREQUENCE 3.59628E-01 HZ

Foundation design for dynamic loading:

In the case of long bridges, the numerical simulation of the subsoil behaviour can represent a very high effort (huge geometry)

The Cone Method can deliver reliable and validated foundation stiffness and damping properties for time and frequency domain analysis

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Summary and conclusions

Summary and conclusions:

Cast3M offers the unique opportunity for geotechnical design in ultimate (ULS) and serviceability (SLS) limit state in one engineering environment

An extensive complex analysis procedure library has been implemented primarily for frequency domain analysis

Summary and conclusions:

The Cone Method is a very useful practical engineering method for the design of foundations under dynamic loading

Based on the presented complex analysis procedure library, the Cone Method can be implemented into the Cast3M engineering environment

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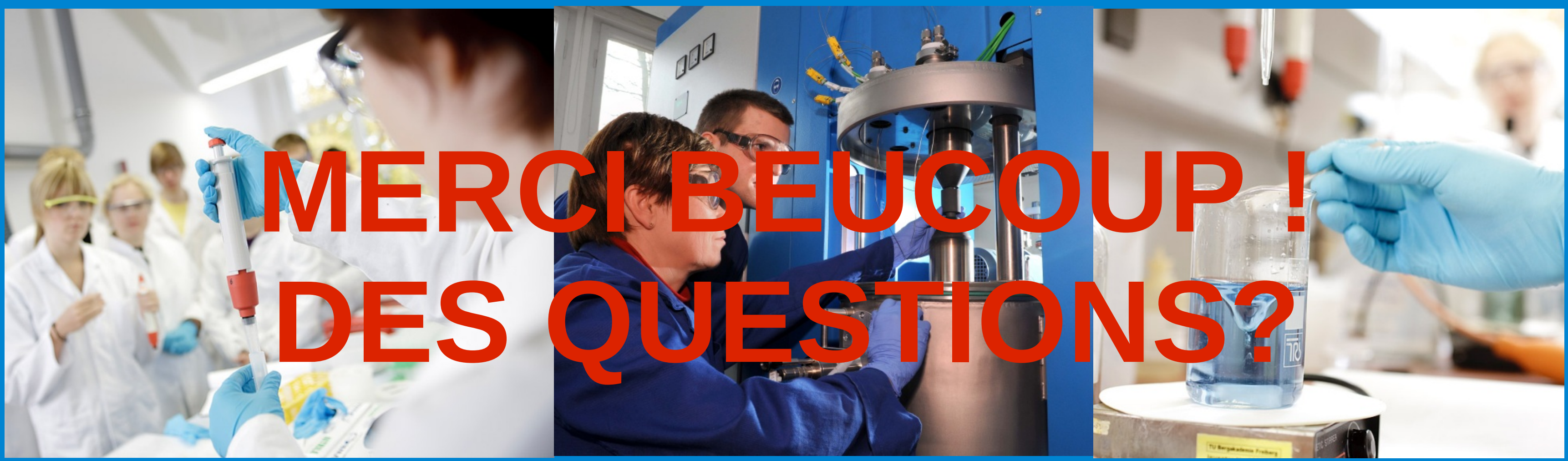

MERCI BEUCOUP !
DES QUESTIONS?

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