Università degli Studi dell'Aquila
Dipartimento di Ingegneria Civile, Edile-Architettura e Ambientale

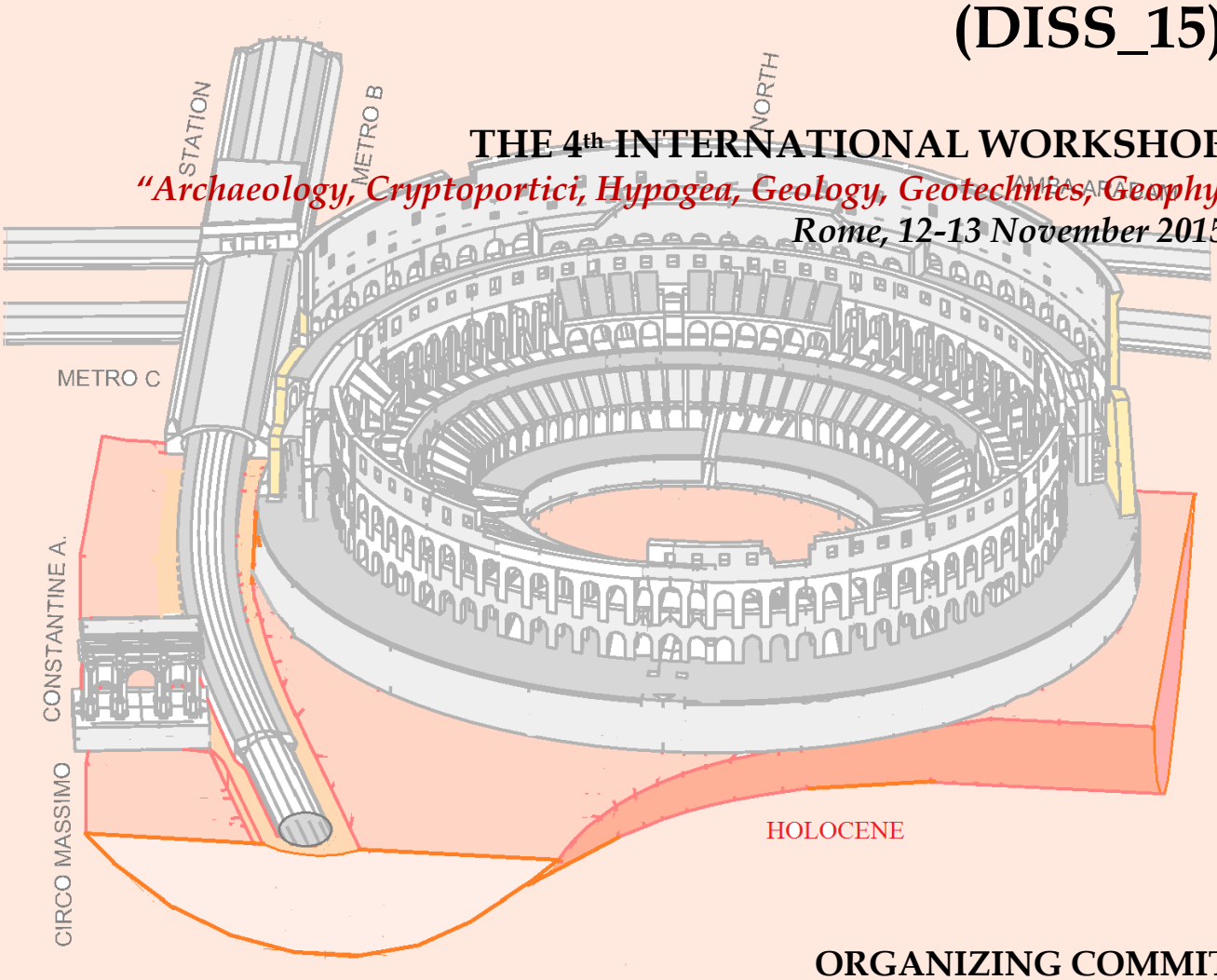
SAPIENZA
UNIVERSITÀ DI ROMA

DYNAMIC INTERACTION OF SOIL AND STRUCTURE (DISS_15)

THE 4th INTERNATIONAL WORKSHOP

"Archaeology, Cryptoportici, Hypogea, Geology, Geotechnics, Geophysics"

Rome, 12-13 November 2015



Proceedings of the 4th International Workshop on "Dynamic Interaction of Soil and Structure (DISS_15)"

Dynamic Interaction between Soil, Monuments and Built Environment

Rome, 12-13 November 2015

DYNAMIC INTERACTION OF SOIL AND STRUCTURE (DISS_15)

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3rd DISS_13, Rome 12-13 December 2013, Carlo Baggio, Paolo Clemente, Yutaka Nakamura, Luciana Orlando, Antonio Rovelli, Gianfranco Valente, DISS_*Edition*, ISBN 978-88-94011418.

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Anna Maria Giovenale - Preside Facoltà di Architettura
Francesco Prosperetti - Soprintendente speciale per il Colosseo
Angelo Luongo - Direttore Dpt DICEAA Università dell'Aquila
Carla Cappiello - Presidente Ordine Ingegneri Provincia di Roma

1) Wireless dynamic monitoring of the Colosseum in Rome: Part I: Instrumentation

M. Sgroi, M. Tommasi, A. Gullotta, G. Monti, F. Fumagalli, G.C. Marano, G. Quaranta

ABSTRACT

Le vibrazioni naturali che consentono di eseguire un monitoraggio hanno in genere intensità molto basse

Tuttavia, consentono di eseguire l'aggiornamento dei modelli rappresentativi lineari, ad es. agli EF, attraverso l'accordo con le misurazioni della risposta dinamica

Inoltre, sebbene vibrazioni di bassa intensità non producano un rischio impellente per le strutture, esse, col tempo, possono aumentare la vulnerabilità strutturale negli elementi danneggiati o deteriorati

Per esempio, le vibrazioni indotte da veicoli o treni nelle vicinanze possono divenire molto pericolose per gli edifici che abbiano subito terremoti

Per le murature antiche le vibrazioni ripetute per un numero di cicli elevato portano a una riduzione della resistenza della muratura a causa del deterioramento della malta, dando così luogo al distacco o al danneggiamento degli elementi soli

Modellazione di edifici storici sotto vibrazioni ambientali

Gli elementi strutturali sono tipicamente in condizioni di deterioramento variabile; inoltre, cedimenti e spostamenti della struttura possono aver ridistribuito carichi e tensioni su percorsi non noti

I modelli meccanici per murature deteriorate da carichi ciclici dinamici sono di incerta affidabilità

Valutazione sperimentale tramite monitoraggio dinamico

Il monitoraggio wireless offre vantaggi sostanziali negli edifici storici

Affidabilità dei limiti vibrazionali

- I criteri utilizzati sono fortemente empirici
- Per stabilire un criterio, vanno prese in considerazione le caratteristiche vibrazionali, l'importanza e la condizione di deterioramento del sito, l'impatto culturale, sociale ed economico
- Un'impostazione probabilistica del problema sarebbe un passo in avanti significativo.

2) Wireless dynamic monitoring of the Colosseum in Rome. Part II: Response analyses

G. Monti, F. Fumagalli, G.C. Marano, G. Quaranta, R. Rea, B. Nazzaro

ABSTRACT

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Tuttavia, consentono di eseguire l'aggiornamento dei modelli rappresentativi lineari, ad es. agli EF, attraverso l'accordo con le misurazioni della risposta dinamica

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3) Dynamic Characteristics of the Colosseum at the Pillar #40 Comparing the Results of Microtremor Measurement in 1998 and 2013

Yutaka Nakamura[1], Jun Saita[1], Tsutomu Sato[1] and
Gianfranco Valente[2]

Abstract

Our first near full-scaled microtremor measurement at Colosseum was in 1998, and we had an opportunity to measure again near the pillar #40 in 2013 at almost the same point of that of the past measurement. Here, the results of the measurement in 1998 and 2013 at the pillar #40 can be compared. As a result, both spectral shapes agree well in wide frequency range. However confirming the detail of the predominant frequency and the amplification factor, they slightly differ for each other. The result of measurement in 2013shows that the peaks shifts to a little higher in radial direction and lower in circumferential direction, and the amplification factor becomes larger for each direction. And the mode changing the phase for 180 degrees between 3F and 4F can be commonly observed in 1998 but not in 2013. There seems to be something structural difference between 3F and 4F, for example the affection of the 2009 L'Aquila earthquake or the work of the floors and the fences of 4F and 3F in 2010. If the degradation of the structure can be grasped quantitatively with periodic microtremor measurement, it is possible to maintain rationally and is not impossible to take a countermeasure as reinforcement of maintenance prophylactically and properly. It is necessary for establishing the method for applying to confirm the accuracy of the microtremor measurement, and to make clear the reason of changing the dynamic characteristics at pillar #40 quantitatively.

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4) Attempts to Estimate the Physical Property of Surrounding Ground and Foundation Concrete of Colosseum using Microtremor

Yutaka Nakamura[1], Jun Saita[1], Tsutomu Sato[1] and
Gianfranco Valente[2]

Abstract

Colosseum has been built on a flat elliptic ring foundation with a hole at arena. This foundation consists of two layers made by roman concrete. SDR conducted microtremor measurement at totally 71 points at ground floor, underground, Hypogeum and surrounding ground of Colosseum till December 15, 2013. This report describes the attempt to estimate the physical property of the foundation concrete and surrounding ground of Colosseum using past microtremor measurement data at the ground level and its surrounding ground. Mainly with the vibration of radial direction, some impressive result was obtained such as that the distribution of predominant frequency on the foundation is corresponds to the distribution of clack at the lower concrete estimated by numerical analysis. Estimation of S wave propagation velocity of upper and lower concrete of Colosseum foun- dation was attempted, because a possibility of capturing the multi reflection phenomena in Colosseum foundation with 12 m thickness from QTS devised to obtain SH wave multi reflection. There are almost no comparable data, it is so insufficient to verify the proposed method, but the reasonability of the method can be explained. This method is a simple method and is possible to measure repeatedly and precisely. The authors will progress the validation of the estimation result with comparing to the other research result considering the estimation error and statistical scatter.

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5) A METHODOLOGY FOR THE RELIABLE 3D DISS MODEL OF COLOSSEUM. PART ONE: SOIL AND FOUNDATIONS

Rocco Alaggio[1], Franco Di Fabio[1], Angelo Di Egidio[1],
Donatella Dominici[1], Gino D'Ovidio[1], Angelo Luongo[1],
Luca Macerola[1], Vincenzo Massimi[1], Yutaka Nakamura[2], Marco Tallini[1],
Gianfranco Totani[1], Gianfranco Valente[1]

Abstract

At 3.32 a.m. on 6th April 2009, the main shock of L'Aquila earthquake travelled through the soil, and INGV recorded a seismic sequence in Rome, in underlying soil and Colosseum. Since 2000 years, the soil transmits all the vibrations to the monument, by ambient vibrations too. The usual models of Structural Engineering have elevation fixed at the basis and the soil is missing, as in Figure 6; the vehicles' vibrations and seismic actions cannot arrive to the monument. We propose a new methodology collecting three models by Geophysics, Structural and Transportation Engineering. For trains, a multibody model reproduces Metro B and C, and a 600x600x80m soil clod is enclosed. From the year 2000, the PC allowed the analysis with 500,000 d.o.f., and a DISS Group grown up between Italian Universities, ENEA, INGV, SSBA of Rome, SDR of Tokyo, producing three International Workshops. For Colosseum, we were exceptionally lucky for three reasons: 1) the tests in 200 points (never used before) were at disposal, 2) many man hours were spent with pure scientific interest, without time deadline, 3) we successed in identifying the map of 350 elasticity modules by comparison between tests and analyses, approaching good tolerances. The reliability was demonstrated by linear dynamic analyses performed for the aforementioned actions. The final objective is to bring to perfection the proposed methodology up a small tolerance everywhere, in order to allow an engineer middle professionist to check deterministically and not intuitively on PC the effect of all: a) traffic and materials variations, on the surface and inside the tunnels, b) eventual seismic improvement. Further tests and analyses are needed for: c) Constantine Arch, cryptoportici and tunnels of Metro B and C; d) improvement of geometric and mechanical characteristics of foundations and soil; e) further cars and trains' models; f) the map of damping coefficients.

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2. SDR, Tokyo, Japan.

6) A METHODOLOGY FOR THE RELIABLE 3D DISS MODEL OF COLOSSEUM. PART TWO: ELEVATION AND TESTS

Rocco Alaggio[1], Franco Di Fabio[1], Angelo Di Egidio[1],
Donatella Dominici[1], Gino D'Ovidio[1], Angelo Luongo[1],
Luca Macerola[1], Vincenzo Massimi[1], Yutaka Nakamura[2], Marco Tallini[1],
Gianfranco Totani[1], Gianfranco Valente[1]

Abstract

At 3.32 a.m. on 6th April 2009, the main shock of L'Aquila earthquake travelled through the soil, and INGV recorded a seismic sequence in Rome, in underlying soil and Colosseum. Since 2000 years, the soil transmits all the vibrations to the monument, by ambient vibrations too. The usual models of Structural Engineering have elevation fixed at the basis and the soil is missing, as in Figure 6; the vehicles' vibrations and seismic actions cannot arrive to the monument. We propose a new methodology collecting three models by Geophysics, Structural and Transportation Engineering. For trains, a multibody model reproduces Metro B and C, and a 600x600x80m soil clod is enclosed. From the year 2000, the PC allowed the analysis with 500,000 d.o.f., and a DISS Group grown up between Italian Universities, ENEA, INGV, SSBA of Rome, SDR of Tokyo, producing three International Workshops. For Colosseum, we were exceptionally lucky for three reasons: 1) the tests in 200 points (never used before) were at disposal, 2) many man hours were spent with pure scientific interest, without time deadline, 3) we successed in identifying the map of 350 elasticity modules by comparison between tests and analyses, approaching good tolerances. The reliability was demonstrated by linear dynamic analyses performed for the aforementioned actions. The final objective is to bring to perfection the proposed methodology up a small tolerance everywhere, in order to allow an engineer middle professionist to check deterministically and not intuitively on PC the effect of all: a) traffic and materials variations, on the surface and inside the tunnels, b) eventual seismic improvement. Further tests and analyses are needed for: c) Constantine Arch, cryptoportici and tunnels of Metro B and C; d) improvement of geometric and mechanical characteristics of foundations and soil; e) further cars and trains' models; f) the map of damping coefficients.

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7) MARBLE, CERAMICS AND STEEL-CERAMICS ANTI SEISMIC BASEMENTS FOR HIGH VULNERABLE STATUES

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ABSTRACT
New anti seismic basements made by ceramics, steel-ceramics, granite and marble have been developed by the Italian National Agency for new technologies, Energy and Sustainable Economic Development (ENEA) for protection of high vulnerable statues of primary importance as regards the impact of events like earthquake, vibrations, shocks and, last but not least, inappropriate handling when moving inside the museum and during transportation. The design approach of the basements was to confer the seismic isolation function to their architectural geometry according the following design targets: maximum seismic isolation, achieved by means of large displacements, low stiffness, low dissipation, reversibility of the intervention; fully compatibility of the materials; easy maintenance. The new basements can be also made by granite, ceramic or steel/ceramics and used to protect delicate instruments for hospital and strategic infrastructures. Regarding the protection in the museum's exposition sites, four examples are shown related to the marble basements for the *Bronzi di Riace* at the Archaeologic Museum of Reggio Calabria, the steel-ceramics basement for the *S. Michele Arcangelo* by Ugolino da Bologna and the *Annunciazione group* by Francesco Mochi at the Museum of the Opera del Duomo di Orvieto (MODO), the proposed marble and steel ceramic basement for the *David di Michelangelo* at the Galleria dell'Accademia of Firenze. Two examples are shown related to the handling and transportation: the marble statue of the emperor Augustus, known as *Augusto da Prima Porta*, from Vatican Museum to the temporary expositions at the Scuderie del Quirinale in Roma , Italy and at the Grand Palais in Paris, France, and the transportation of the *Bronzi di Riace* from Palazzo Campanella to the Archaeologic Museum of Reggio Calabria.

Keywords: *Marble basements, steel-ceramics basements, earthquake protection, movable cultural heritage, vibrations, Handling of statues, transportation of statues.*

8) Dynamic Soil Structure interaction of the Leaning Tower of Pisa

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Abstract

The soil underlying the bell Tower of Pisa plays a fundamental role on the behavior of the famous monument. The soil-structure interaction of the Tower was studied first by Grandori and Faccioli in 1993. In their work the tower was modeled by means of a 2D model without considering the inclination. So doing, they obtained a fundamental period equal to 1.36 s. It is worth noting that this period is much longer than the period experimentally measured in more recent researches. A second study was made by ISMES (1994). They identified experimentally bending and torsional modes only, thus it was not possible to calibrate the vertical foundation impedance. From the beginning of 1999 until the first half of 2001, an extensive intervention of under-excavation was also made – which stopped the increment of Tower's tilt – and the "Catino" was connected to the foundation. In April/May 2002, a drainage system was set up to lower the underground water level, whose fluctuations were considered the main cause of variations in the inclination of the Tower. The history of the interventions is described in a paper by Burland and Viggiani (2009). In the light of this recent changes in the foundation boundaries, the present study aims at updating and improving the structural characterization of the leaning Tower of Pisa using its earthquake-induced experimental response. In doing so, special attention has been paid on the identification of the parameters that regulate the dynamic response of the foundation. A simplified model of the soil on the basis of its dynamic properties has been elaborated using the formulations proposed by Wolf (1994) and Mylonakis and Gazetas (2006). Hence, a finite element (FE) model that takes into account the inclination of the structure has been elaborated, by assuming the position of the centroids reported in the work by Macchi and Ghelfi (2002). The numerical values of the impedances have been calibrated in such a way to reduce the distance between the natural frequencies identified experimentally and those obtained from the FE analysis. This latter shows that vertical response determines a very large base bending moment even larger than that due to the horizontal seismic input. The study allowed to identify the modal frequencies of the first three modes of the Tower. The first two are bending modes in N-S and E-W direction, respectively, both with a frequency around 1 Hz. The third is a vertical mode with a frequency around 3 Hz. This is a quite new result since the only evidence in literature in presented in Nakamura (1999). Based on modal frequencies, six dynamic impedances at the base of the dam were calibrated. These could give us also informations about the static behavior of the foundation. These are preliminary results, because due to the lack of an adequate network of instruments on the elevation of the Tower it was not possible to draw with sufficient accuracy the modal shapes of the structure. Finally, a synthetic evaluation of the seismic input by means of a hybrid method that combines the Probabilistic and the Deterministic Seismic Hazard Assessments is presented. Ongoing works regard the improvement of the monitoring network and the execution of new geophysical tests in the Square of Miracles.

9) AD HOC ANALYTICAL EQUATIONS AND PROBABILISTIC TREATMENT OF UNCERTAINTIES FOR THE SEISMIC ASSESSMENT AND AMELIORATION OF A XVI CENTURY RETAINING WALL IN CENTRAL ROME

Enrica Di Miceli [1], Giorgio Monti [2], Vincenzo Bianco [3], and Maria Grazia Filetici [4]

ABSTRACT

This paper presents a study aiming at assessing the seismic safety and developing the rehabilitation design of a masonry retaining wall, known as *Bastione Farnesiano*, and placed around the *Palatinum* hill, in the central archeological area of Rome, in Italy. It is a singular artifact of its kind and hardly identifiable with known stereotypes or constructive models. The phase of survey, together with both the material and degradation analyses, showed the impossibility to define with certainty some features, even geometrical, of the monument, necessary to reach a judgment about its safety. Therefore, it was necessary to formulate the risk assessment problem by taking into due consideration all uncertainties and evaluating them in probabilistic terms. A simple mechanical model, considering different and alternative collapse modes, was developed and, after characterizing the uncertain parameters in probabilistic terms, Monte Carlo simulations were carried out. Based on the obtained results: a) the value of the current risk index has been determined, and b) a sensitivity analysis has been performed in order to identify the parameters that mostly affect the monument safety. This sensitivity analysis has provided useful information that has allowed to orient the seismic amelioration design strategy by acting on one of the parameters that have greater impact on the risk reduction.

Keywords: Seismic Assessment, historical heritage, retaining wall, uncertainties, Monte Carlo simulations.

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10) THE ROLE OF GEOMATICS FOR THE CULTURAL HERITAGE

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Abstract

With a recent report of UNESCO, a systematic and periodic documentation of all cultural heritage becomes necessary for their complete, both qualitative and quantitative documentation. The obtained data include necessary information in order to make strategic choices for the building and to plan future conservations or recovery of the heritage.

The field of geomatics, in this contest, can offer a wide range of instrumentation and surveying techniques capable to providing accurate data that allow to define the situation of the object at the time of the survey and consequently to monitor its variation over time.

It is important to mention for instance, the possibility to create a digital high-resolution 3D models, obtained through the photogrammetry and laser scanner techniques, geometrically corrected by Total station or GNSS survey and finally georeferenced, useful to create a complete database of the cultural heritage, and for the production of BIM systems.

In this paper, some examples of survey for complete documentation of monumental buildings of L'Aquila are presented.

11) Extending a Disaster Risks Policy Ontology by using DEM concepts.

Aleksander González[1], Giusseppe Brando[1], Enrico Spacone[1]

Abstract

In the formulation of public policies for cities resilience, a common language concerning the actions to be taken by public administrations should be established.

The academic community has introduced several ontologies about disasters. An ontology defines a vocabulary for stakeholders who desire to share information in a common domain. It includes formal definitions of basic concepts, as well as the relations that link them each other.

In order to make the currently used ontologies less general, we propose to extend them by including concepts extracted from specific tools defined for urban risk assessment.

Currently, Digital Elevation Models (DEMs) are used diffusely in many geographically oriented software. Their implementation is becoming quicker and easier due to more performant engineering software and tools. A digital elevation model (DEM) is suitable for representing the uninterrupted varying topographic surface of the Earth. Utility of these tools is evidenced by having a look to the lot of digital topographic data available in the software industry.

In this research we aim at proposing an ontology to describe uses and applications of Digital Terrain Model, and its utility as a urban assessment risk tool. This way, we can extend current available disaster ontologies by means of specific tools that are used for assessing urban risk management.

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12) Metodologia integrata per la valutazione della vulnerabilità di siti archeologici: il Teatro Romano di Verona

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Abstract

Le metodologie basate sulla conoscenza per la valutazione della sicurezza strutturale e della vulnerabilità del costruito storico si basano sull'applicazione di un approccio operativo che si articola in diverse fasi includendo la ricerca storica, l'esecuzione di indagini non distruttive o mediamente distruttive, il monitoraggio e l'analisi strutturale. Il monitoraggio rappresenta uno strumento utile da impiegarsi lungo l'intero processo di conoscenza non solo nella diagnosi preliminare, ma anche per il controllo della qualità e dell'efficacia degli interventi, nell'ambito di opportuni programmi di conservazione e protezione del bene oggetto di studio. In quest'ottica il monitoraggio diviene essenziale per: (i) la valutazione del reale comportamento strutturale e l'identificazione delle vulnerabilità, preliminarmente all'esecuzione di qualsiasi intervento; (ii) la minimizzazione e ottimizzazione degli interventi, in primo luogo fornendo indicazioni riguardo a quelli non necessari e/o invasivi.

Tale metodologia è stata recentemente applicata e validata dagli autori ad un sito archeologico di particolare rilevanza: il Teatro Romano di Verona.

L'approfondimento della fase della conoscenza (analisi storica, rilievo, studio del sottosuolo, proprietà dei materiali), combinato con l'installazione di un sistema di monitoraggio permanente e la modellazione strutturale, ha permesso di conseguire un'affidabile valutazione delle vulnerabilità del sito con l'obiettivo di garantirne un'efficace e attenta protezione e valorizzazione.

Keywords: Monitoraggio strutturale, indagini diagnostiche, analisi strutturali, vulnerabilità sismica, valorizzazione

13) Structural identification of historical bell-towers through ambient vibrations measurements and numerical modelling

F.T. Gizzi, D. Liberatore, N. Masini, M. Bruno, M.R. Potenza, M. Scavone, M.Sileo, L. Sorrentino, C. Zotta, T. Pagnoni

ABSTRACT

Experimental evaluation of the fundamental frequency of bell-towers.
Identification of possible resonance effects between soil and structure.
Correlation between the dynamic properties determined through in situ measurements and FE modelling.
Objectives of ambient vibrations measurements: - identification of eigenfrequencies and eigenmodes, - validation and updating of FE models, - identification of possible local modes, - identification of damage, - integration of in situ and laboratory tests on materials.
In recent years, applications have been carried out that require the use of a small number of sensors, or even just one portable sensor located at different points of the structure (Liberatore et al., 2009; Masini et al., 2012), yielding the eigenfrequencies and the corresponding dominant direction of motion.
These applications are complemented by a FE modal analysis of the structure.
Measurements and FE analysis are closely interrelated: the former provides the eigenfrequencies which are used to calibrate the FE model, the latter provides the modal shapes, which in turn are compared with the dominant direction of motion provided by the measurements.
The dynamic-based identification of damage is usually referred to as global method, able to detect the presence of damage. However, it could be not enough accurate to determine type and extent of damage. On the other hand, visual inspection or non-destructive tests such as acoustic emission, GPR, IR thermography, sonic and ultrasonic tests, also referred to as local methods, are more accurate in the localization and definition of damage.
The eigenfrequencies can be calculated according to several methods, among which the Standard Spectral Ratio (SSR) and the Horizontal-to-Vertical Spectral Ratio (HVSR) are commonly used.
The SSR method calculates the eigenfrequencies from the peaks of the ratio between the amplitudes of the Fourier transforms of the horizontal component at a point of the structure and at the base (Parolai et al., 2005; Gallipoli et al., 2009). The integration of ambient vibration measurements and FE analysis yields a reliable estimation of masonry initial modulus of elasticity. In the case of isolated bell-tower, the first two modes along each principal direction are correctly identified. The SSR and HVSR methods yield similar results. A number of frequencies are identified that are not reproduced by the FE model. These frequencies are presumably due to the effect of structure (church) - soil - structure (bell-tower) interaction. In the case of bell-tower connected to the church, the FE model of the bell-tower restrained by the church is only able to yield the first mode – and corresponding frequency – along each principal direction, whereas large discrepancies arise in the higher modes. Therefore, in order to match the experimental results, a “global” model including the church is needed. Further measurements, complemented with FE modelling, will validate/integrate existing formulae for the estimation of eigenfrequencies as function of dimensional/material/ constructive data.

14) Structural Monitoring of Heritage Constructions: some contributions of LESE-FEUP

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ABSTRACT

The need for intervention on heritage constructions often calls for deciding whether the bearing structure can be kept in the existing conditions or should it be retrofitted by introducing more or less significant modifications. In most cases this question is not straightforward to handle and it is not easily manageable by most of technicians engaged in the design of rehabilitation solutions for built heritage. For this reason, very often existing old structures may not have been considered to be adapted for new demands and functions, without prior and proper assessment of their capability of ensuring adequate performance under desired conditions. Moreover, the result of such assessment (or lack-of-assessment) is likely to have great impact on the social and economic aspects of a given rehabilitation solution.

In this framework, the experimental assessment of the structural behaviour of existing heritage construction is paramount, as a decision tool to the support the intervention or non-intervention option in a given rehabilitation process. Typically, that assessment can be made at a given short-time period (or instants), such as in the case of load tests, or during larger time windows normally associated with structural monitoring, either continuously or discrete on time.

Over the last 12 years, the Laboratory for Earthquake and Structural Engineering (LESE) of the Faculty of Engineering of University of Porto has been involved in several monitoring activities on heritage structures, aiming at the evaluation of their structural response over time, either to find-out or to check any damage progression/stabilization.

This contribution reports on a few case-studies for which LESE has designed, developed and implemented continuous monitoring systems allowing for continuous survey of their structural response and, in some of them, to support the decision about the real need for possible interventions. Both bridge, church and public building structures are reported, most of them with high heritage value. A brief overview is included concerning the most relevant issues about monitoring devices, systems and options, as well as the most important outcomes from the monitoring results and their impact on the stakeholders' decisions.

15) Seismic behaviour of a caisson supporting a bridge pier

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Abstract

This paper shows the results of 3D FE coupled dynamic analyses carried out in the time domain to study the seismic performance of a rigid and massive caisson foundation supporting a slender bridge pier. The system is subjected to a real acceleration time history. To evaluate the permanent displacements induced by seismic loading soil behaviour was described using an elasto plastic hysteretic model capable to provide a fair estimate of non linear soil behaviour and hysteretic damping under cyclic loading conditions. The analyses were carried out in terms of effective stresses in undrained conditions, thus evaluating excess pore water pressure induced by earthquake loading. Displacement and rotation time histories obtained with and without the bridge pier are presented. These results are compared with those computed from linear equivalent *free–field* analyses.

vords: *Bridges, caisson foundations, non linear behaviour, coupled dynamic analyses, performance*

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16) ON THE FILTERING EFFECT INDUCED BY EMBEDDED FOUNDATIONS

by Riccardo Conti, Marco Morigi, & Giulia M.B. Viggiani

Seismic performance of structures is usually evaluated under a fixed-base assumption, applying a base slab input motion equal to the free-field motion, *i.e.* neglecting the dynamic interaction between the structure, the foundation and the foundation soil. Soil-structure interaction results from both kinematic effects, whereby a foundation with no mass modifies the input motion solely by its stiffness, and inertial effects, as the motion of the foundation is further modified as a result of the inertia actions in the structure-foundation system. Numerical, experimental, and theoretical studies have shown that kinematic interaction can have significant effects on the dynamic behaviour of deep foundations and that the motion of the foundation may differ from that in free-field conditions, depending on the frequency content of the earthquake, the geometry of the problem and the relative stiffness between foundation and ground. This paper deals with the filtering effect induced by embedded foundations on the input motion transmitted by the soil to the superstructure. The relevant parameters, described through three kinematic interaction factors, are obtained by dimensional analysis of the problem. Based on the results of 2D finite difference analyses and of a simplified 1D theoretical model, it can be shown that these interaction factors depend both on the ratio between the depth of embedment of the foundation and the input signal wavelength ($\square H/V_S$), and on the aspect ratio of the foundation (B/H). Simplified expressions to compute the interaction factors in practice are proposed.

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17) STRUCTURAL RESPONSE INCLUDING SEISMIC SOIL-PILE-STRUCTURE INTERACTION

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Keywords: Shaking table tests, period elongation, damping ratio

Abstract:
The seismic soil-pile-structure interaction (SPSI) can considered as the combination of two different mechanisms under dynamic loadings. The first one is related to the stiffness contrast between pile and soil (kinematic interaction), whereas the second one is due to the variation of the soil response around the foundation due to the inertial forces generated by the structure (inertial interaction). The evaluation of the contribution of each mechanical and geometrical characteristic of the system in the complex SPSI phenomenon is not trivial. Thus, an effective way to investigate such phenomenon is analyzing the response of physical scaled model on 1-g an n-g devices. To do so, a set of shaking table tests is discussed in this paper. The scaled physical model is formed by a group of piles in a by-layer deposit with and without a single degree of freedom connected to the foundation with several configurations. This paper assesses the role of the foundation system on the structural response evaluated in terms of period elongation and damping ratio. The input considered is the Tolmezzo earthquake ground motion record from the Friuli 1976 earthquake scaled at the model size. The experimental results are also compared in the paper with classical solutions.

18) SOME ASPECTS OF THE SEISMIC BEHAVIOUR OF LARGE HOMOGENEOUS EARTH DAMS

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Abstract

Instability phenomena of large existing earth dams are one of the major source of seismic vulnerability of Italy, as most of them were constructed in the absence of specific seismic regulations. Therefore, it is necessary to investigate the response of such earth structures when subjected to severe earthquake loading, estimating the safety conditions with respect to deformation phenomena which can compromise the water retention capability. However, earth dams are complex structures and their study is difficult even in static conditions. Further difficulties arise in seismic conditions because of the transient nature of the earthquake action inducing inertial forces that change with time.

This paper shows some preliminary results of a study on the seismic behaviour of large earth dams. Specifically, the study relies on the availability of the monitoring data from an existing homogeneous earth dam during the construction and the impoundment phases. A two-dimensional numerical model has been conceived introducing some simplifying assumptions on the actual geometry of the embankment, to obtain a schematic layout that is sufficiently representative of the case at hand still reproducing the main aspects of the dam behaviour under seismic conditions. The numerical model includes the explicit simulation of the construction and impoundment phases. Iterative pseudo-static analyses were conducted by uniformly accelerating the finite-difference model of the dam to investigate the plastic mechanisms forming under critical conditions. The seismic performance of the hydraulic retention scheme was then evaluated through a series of dynamic analyses in which acceleration time-histories were imposed to the bottom boundary of the same numerical models used for the pseudo-static analyses. The analyses were repeated accounting for the bedrock deformability.

The results of the dynamic analyses evidenced that a significant reduction of the seismic energy is obtained if the deformability of the bedrock is accounted for in the analyses, this resulting in lower permanent displacements of the dam body. Conversely, the vertical component of the seismic action induces a sensible increase of seismic displacements, so that analyses conducted neglecting the vertical component of the ground motion can lead to an unsafe evaluation of the water retention capability.

Keywords: homogeneous earth dam, pseudo-static numerical analysis, dynamic numerical analysis.

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19) DYNAMIC BEHAVIOUR OF RETAING WALLS: EXPERIMENTAL RESULTS AND FIRST NUMERICAL ANALISYS

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ABSTRACT

La presente nota dà conto dei risultati di alcune prime analisi numeriche, eseguite sulla base dei dati sperimentali ottenuti durante una vasta campagna di prova, realizzata su modelli di muro a mensola presso l'Università di Bristol. Si inserisce in una più ampia attività di ricerca, ormai in corso da alcuni anni presso il Dipartimento di Ingegneria dell'Università del Sannio, in stretta collaborazione con atenei italiani ed internazionali, volta all'analisi del comportamento dinamico delle opere geotecniche sotto azioni sismiche, allo scopo di giungere a criteri di progettazione delle opere di sostegno, che tengano in conto del reale comportamento dell'opera e siano rispettosi dei principi del "Capacity design". Nel corso della sperimentazione a Bristol, sono stati testati diversi modelli in scala di muro a mensola e terrapieno, sottoponendo il sistema geotecnico ad azioni cicliche e dinamiche mediante una tavola vibrante 1-g.

Nella fase iniziale di tali prove, è stata, sempre, eseguita un'identificazione dinamica del sistema, impiegato un segnale di input di piccola ampiezza (accelerazione massima 0,005g) "spalmato" sulla banda 1-100 Hz (c.d. White-noise test). Durante queste fasi, sono stati acquisiti i dati di una serie di accelerometri sistemati sul muro, nel terreno di base e nel terrapieno a tergo del muro, esaminando i segnali attraverso un analizzatore di spettro.

Valutando i dati a disposizione, si è, innanzitutto, pervenuti all'identificazione dinamica del sistema, attraverso l'individuazione delle frequenze proprie di tutti sistemi meccanici che compongono il modello (muro, terreno di fondazione e terreno di riempimento) e, in seguito, si è costruito un modello numerico mediante il codice FLAC che potesse ben interpretare il comportamento analizzato.

Il confronto eseguito tra i risultati sperimentali ottenuti su tavola vibrante, i risultati delle simulazioni numeriche e le soluzioni semplificate fornite da Gazetas (1996) ha consentito di valutare la generale efficacia di queste ultime nella stima della risposta dinamica del sistema a piccole deformazioni. Esse, tuttavia, non consentono di tener conto di alcuni aspetti di dettaglio che modificano, a volte in maniera sensibile, la risposta del sistema, la quale è risultata, invece, catturata efficacemente da un modello numerico, semplice, ma ben dettagliato negli aspetti fondamentali.

20) Dynamic soil-structure interaction for a long-span suspension bridge with dissipative foundations

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Abstract

The towers of the Izmit Bay suspension bridge were provided with a dissipative foundation system, consisting of a gravel layer interposed at the contact between the foundation slab and the pile group, intended to limit the seismic loads transmitted to the superstructure. The bridge is in close proximity to the North Anatolian fault, responsible of a high seismic hazard characterised by with important near-source effects such as relevant amplitudes of the vertical motion. This paper describes an innovative approach for predicting the behaviour of the bridge accounting for the soil-structure interaction effects and for the behaviour of the above dissipative system. The approach entailed the use of three-dimensional numerical analyses, carried out in the time domain using non linear constitutive assumptions for the soil. The numerical model included the entire sequence of the soil deposits extending down to the bedrock, and a simplified structural model of the towers, that was calibrated to reproduce the main aspects of the dynamic behaviour of the superstructure. The results of the analyses show that the seismic performance of the dissipative foundations is strongly affected by the amplitude of the vertical motion. The dissipative contact at the slab-pile interface is fairly efficient in limiting the seismic forces transmitted into the superstructure; however, it appears that the horizontal permanent displacements of the tower foundations derive mostly from permanent strains occurring within the subsoil, rather than from relative displacements at the foundation-pile contact, as originally intended in the design of the bridge.

Keywords: Dynamic soil-structure interaction, anti-seismic technology, numerical modelling.

21) ADVANCED NUMERICAL APPROACHES TO THE SEISMIC SOIL AND STRUCTURAL RESPONSE ANALYSES

Angelo AMOROSI[1] Daniela BOLDINI[2] and Annamaria DI LERNIA[3]

ABSTRACT

A 3D non-linear finite element approach is developed to study the free-field seismic ground response and the soil-structure interaction (SSI) phenomena at the Lotung site (Taiwan) during the earthquake event occurred on May 20 1986.

The site was extensively instrumented with down-hole and surface accelerometers, these latter located also on a 1/4–scale nuclear power plant containment structure. An advanced constitutive model is adopted for simulating the soil behaviour, while a linear visco-elastic behaviour is assumed for the structural model.

Both the free-field and SSI analyses are carried out applying both the NS and EW horizontal components of the acceleration time history as recorded at the depth of 47 m b.g.l. The predicted ground response results are in fair agreement with the recorded motion at depth and at the surface. Also, the dynamic response of structure is well captured for this specific seismic event, thus confirming the validity of the numerical approach.

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22) Seismic site response in selected areas of Western L'Aquila Plain by using 1D and 2D numerical modeling

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Abstract

We report the preliminary results of the 1D and 2D numerical modeling, preparatory for the third level microzoning in selected areas of Western L'Aquila Plain. The analysis was carried out on a geological section representative of the subsoil model of those areas by using the software EERA and LSR 2D for 1D and 2D modelling respectively. The methodologies reported in Gruppo di lavoro MS (2008) and Gruppo di Lavoro MS–AQ (2010) were also taken into account. The preliminary results of the seismic site response have identified the likely valley effects on the edges of the section (double values in pseudo-acceleration between 1D and 2D modeling) and the lack of 2D effects in the middle of the section.

23) Dynamic Characteristics of Hagia Sophia in Istanbul before and after the 1999 Kocaeli Earthquake by Microtremor Measurements

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Abstract

Hagia Sophia is a huge structure rebuilt in 537AD with a big dome. It has been suffered accidents as collapsing the dome repeatedly by earthquakes but the original shape has been remained miraculously. A Mw7.4 earthquake about 100km away attacked and affected Hagia Sophia in August 17, 1999. We had measured microtremor of some structures in Istanbul including Hagia Sophia two months before the earthquake by chance. Two weeks after the earthquake, we had measured at almost same place again. Hagia Sophia was affected severely estimated from the predominant frequency sift. This fact has been already reported and this time the situation of the changing dynamic characteristics before and after the earthquake is reanalysed with 48 points from the response spectra, vibration locus and mode and so on. As a result, the response spectra of the main structure shows many peaks, mainly one clear peak for EW direction and two peaks for NS direction. Amplification factors of EW component are larger than that of NS component and both of them at south side are larger than that at
north side. Amplification factors decreased obviously after the earth- quake for entire the EW component. But for NS direction, it was almost same at the dome cornice, increased at southern side of 2nd cornice or gallery level (hereafter 3F or 2F respectively) and decreased drastically at northern side of 3F or 2F. The torsional vibration in the horizontal plane can be detected by the simultaneous measurement at east and west main pears on 2F and 3F. It shows complexities as some is confirmed in a south-north couple and the other is confirmed only at the one part. It shows that each part moves with a certain level of degree of freedom and suggests the progress of degradation.

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24) A comprehensive model for the prediction of vibrations due to underground railway traffic: formulation and validation

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ABSTRACT

In this communication, a numerical approach for the prediction of vibrations induced in buildings due to railway traffic in tunnels is presented. The numerical model is based on the concept of dynamic substructuring, being composed by three autonomous models to simulate the following main parts of the problem: i) generation of vibrations (train-track interaction); ii) propagation of vibrations (track-tunnel-ground system); iii) reception of vibrations (building coupled to the ground). The methodology proposed allows dealing with the three-dimensional characteristics of the problem with a reasonable computational effort [1, 2].

After a brief description of the model, its experimental validation is performed. For that, a case study about vibrations inside of a building close to a shallow railway tunnel in Madrid is simulated and the experimental data [3] are compared with the predicted results [4].

Finally, the communication finishes with some insights about the potentialities and challenges of this numerical modelling approach on the prediction of the behavior of ancient structures subjected to vibrations induced by human sources (railway and road traffic, pile driving, etc.)

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25) Data analysis and numerical simulations of the 2009 L'Aquila seismic sequence recorded in the Colosseum

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Abstract

We show a preliminary study concerning the interaction between the incoming seismic wave-field and the structure of Colosseum during the aftershocks sequence of the 6 April 2009 **M** 6.3 L'Aquila mainshock. Experimental results are used for tuning numerical simulations of the dynamical behaviour of the *Anfiteatro Flavio* in order to estimate the dumping matrix either of the soil and of the Colosseum, being such knowledge the basis for planning actions aiming at consolidating the monument.

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26) Ambient vibration recordings at Anfiteatro Flavio. The ENEA-INGV acquisition campaign of June 2014

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Keywords: Ambient vibration, Spectral analysis, Polarization analysis

Abstract

The paper describes the acquisition campaign and the preliminary data analysis of ambient vibration recorded on June 24th -25th 2014 at the 'Anfiteatro Flavio' by the INGV-ENEA working group.
Aim of the activity was to investigate the vibration level induced by natural and anthropic sources to the monument and to detect its spatial and temporal variability to be correlated with some possible heterogeneity in the subsurface geological structure or in the foundation characteristics.
Data were collected using high sensitivity three-component seismic sensors connected to high dynamic range data loggers synchronized by GPS absolute timing.
Sensors were deployed in two different configurations at the foundation level that recorded continuous data for time windows of few hours during the day. A third deployment was made inside the so-called 'Commodo Passage', an underground structure carved into the foundation of the monument. In this case instruments operated both at day and night allowing verifying the daily variations of vibration level.
Three extra sensors were installed on a vertical alignment using all the reachable levels of the monument in correspondence of its northwestern side ('Sperone Valadier'). Aim of this deployment was to investigate the variation of vibration level as a function of instrument elevation on the structure and of direction of vibration.
Data were analyzed mainly using conventional spectral techniques and spectral ratio between the horizontal and the vertical components of motion (H/V spectral ratio).
The preliminary data analysis highlighted the presence of some clear resonance peak at low frequency (0.3-0.4 Hz) to be put in relation with the geological structure of the site.
Another clear observed feature is the low pass filtering action carried out by the monument's foundation, which is very effecting in reducing the level of the traffic induced vibrations. This characteristic can be used as a tool for mapping the lateral extension of the foundations.
The significant variation of spectral amplitudes at recording site due both to the station position and to the recording times does not correspond to any variation in the H/V spectral ratio that show a good stability.
The analysis of data recorded by vertically aligned instruments finally allows to separate the effects subsurface geology and structure in the observed motion.

27) Experimental and numerical dynamic identification of Carmine bell tower in Naples (Italy)

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Keywords: dynamic identification, soil-foundation-structure interaction, numerical simulation

The present study deals with the dynamic identification of Santa Maria del Carmine bell tower, a 68 m tall masonry structure, representing the highest historical monument as well as an important cultural symbol in the city of Naples. Right after the construction, the tower was destroyed by a far-field strong earthquake occurred in Sannio in 1456, maybe due to double resonance phenomena, soon after it was reconstructed and nowadays it is undergoing restoration. The tower rises on a soft deposit of man-made ground and alternating layers of marine sands and volcanic ash, overlaying a bedrock of yellow tuff. Historical researches and geophysical investigations consisting of Electrical Resistivity and Ground Penetrating Radar, together with vertical and inclined boreholes, were recently performed to reconstruct the geometry and the depth of the masonry foundations (de Silva et al., 2014). A CPT, a 60m deep Down-Hole, and several laboratory static TX and cyclic/dynamic RC-TS tests were carried out in order to define the strength and the strain-dependent stiffness and damping of the different soils.

The deformability of the soil-foundation system was expected to be relevant for the dynamic behavior of the tower, so that numerical analyses on a complete model of soil, foundation and structure were performed through the FLAC3D code. To preliminarily calibrate the model, it was excited by a noise signal, lasting 5 s, monitoring the response for 10 s in order to simulate the behavior in free vibration in the last 5 s.

The displacements at each level of the structure were analyzed in the time and frequency domains, to identify the principal vibration modes of the complete system. The second natural frequency of the full model resulted close to the first frequency of the soil, calculated through the transfer function between the ground motions at the foundation level and at the bedrock depth. The same analysis was repeated on the fixed base model, usually adopted in the seismic design, in order to highlight the effect of the soil deformability on the structural response.

The results of the fixed base model and of the compliant base model were compared to the vibration frequencies and to the corresponding deformed shapes detected *in situ* through measurements of the displacements of the tower under ambient noise (Ceroni et al., 2009). The complete model shows the best fitting with respect to the frequencies and the deformed shapes, evaluated through the Modal Assurance Criterion, especially at the second mode, which may be also affected by resonance phenomena (de Silva et al., 2015).

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28) ACOUSTIC AND VIBRATIONAL TESTS OF THE EFFECTS INDUCED ON BUILDINGS BY THE DEMOLITION OF THE "PONTE DEL BARCO" PARCO DELLE CASCINE - FIRENZE - TOSCANA

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Key words Acoustic test, Vibration test, Demolition noise, UNI9916, UNI9614, Florence

ABSTRACT

For demolition of Ponte del Barco, the Torrente Mugnone overpass at the Parco delle Cascine of Firenze, were checked up entities in the field of energy and vibrational noise produced during activities on sensitive lens, considering the building located near the structure being demolished. The vibrations to the building have been checked with reference to noise thresholds of disturbance to the person (UNI 9614) and resentment/damage to the building (UNI 9416). Evaluation of transient vibration actions on the building were examined during the demolition of the structure, carried out using excavator CAT 320 D LN equipped with concrete crusher, and handling stages of demolition material using excavator ZAX 240 Hitachi equipped with a shovel. The tests were conducted with Symphonie type level meter (class 1 REF. EN60651/94 and EN60804/94) and oriented velocimeters n.4 recording stations using GEOBOX of Sara Electr. Instr. The noise level was compared with the acoustic limits of the area and the intensity of vibration induced on sensitive building was related to thresholds of disturbance to the person and damage to structures, ensuring that in the course of the demolition operations were the conditions of security of operators in the area and the absence of damage to the buildings. Based on the findings from the analysis, the acoustic activity of demolition of the Bridge in Florence took place within the acoustic limits of exemption of localization activities (class IV – area of intense human activity). The exceeded the thresholds of vibrational disturbance to the person was checked, in reference UNI 9614; the exceeded the thresholds for structural damage was not checked, in reference to UNI 9916. The attendance of the necessary staff for testing acoustic and vibrational did not affect any sensitive subject even in the presence of the excess of noise and vibration thresholds of disturbance to the person.

29) Intermediate disconnection of structures to improve the seismic response

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Abstract

The use of the Base Isolation (BI) and the Tuned Mass Damper (TMD) to reduce vibrations in structures is well known from several years. It is interesting to note that, in a conceptual point of view, both these techniques are principally based on an appropriate ”disconnection” of vibrating masses. In the last years various studies have started to investigate the opportunity to move from the classical conceptual frame related to these subjects. For example, in [1] it is investigated the use of the TMD in a base isolated structure, in [2] new stories are placed on an existing building to act as a TMD while the performance of a mid-story disconnection has been lately analysed in [3].

Regarding the possibility to disconnect the structure at different levels, to improve its overall dynamic response, it would be of interest to wonder what are the limits that exist between the BI and TMD and when the disconnection can be considered as a base isolation or a tuned mass damper system. This paper tries to give an answer to this question by introducing a simple two-degree of freedom model that may be taken as representative of structures where a BI- or a TMD-scheme is used. This ”archetype” 2-DOF system has a constant total mass while stiffness and mass ratios, related to the two degrees of freedom are taken as variable parameters. Several seismic base accelerograms are used in the analysis.

An extensive parametric analysis is performed to characterize the system. Two different types of behavior maps, one referring to the BI and the other to the TMD, are obtained for each seismic source. In these maps the regions where a base isolation or a tuned mass damper system works properly, are well recognizable and, beside them, it is also possible to point out some other regions of the parameters space where both systems work well. A superposition of this latest maps, each one obtained for a single earthquake, is performed in order to define a sort of ”performance maps’ spectrum”. Several numerical simulations, conducted on shear-type systems, are performed to confirm the results provided by the simple two-degree of freedom model.

Keywords

Tuned mass damper, base isolation, archetype system, gain parameter and map.

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30) A SIMPLIFIED APPROACH TO EVALUATE SEISMIC REPONSE OF EXISTING MASONRY STRUCTURES BASED ON PROBABILISTIC ANALYSIS

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ABSTRACT

Still nowadays masonry structures comprise a majority of the global built environment in seismic region areas. Despite their prevalence and their long existence, their behavior of under earthquake loading is still not well understood, and extremely hard to predict. This is why the majority of these structures did not benefit from modern engineering design, but instead resulted from empirical expertise, furthermore masonry structures yields several unknowns, including the ones defining their interaction with soil. Finally the basic nature of masonry remains difficult to model. The problem is challenging and lessons from recent eartrhquake events highlight the extreme urgency for structural engineers to have a reliable and simple procedure to estimante seismic behaviour of existing masonry structures subject to different seismic action level.

The present paper intends to give a contribution in dealing with this issue by applying a global probabilistic analysis on different masonry structural units. Such approach is based on the Italian seismic code and relies on a simplified non-linear assessment method. Purposely developed codes have been used for deriving the equivalent bilinear constitutive laws of floors and of the entire structural unit. Afterwards, a fully probabilistic Monte Carlo-based analysis has been performed by including and consistently modeling all uncertainties affecting the structural response. Capacity-demand ratios and failure probabilities have been evaluated for every considered structural unit. The subsequent sensitivity analyses have allowed for identification and quantification of the effect of all considered variables on the global response. Some interesting remarks on results obtained have been developed in order to progress towards a reliable and simple assessment procedure.

KEYWORDS*: existing masonry structures, probabilistic analysis, simplified methods for seismic assessment.*

31) Effects of Piles Inclination and Layout on the Dynamic Response of Foundations and Superstructures

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Keywords: dynamic stiffness, inclined pile groups, kinematic response, soil-structure interaction, bridge piers.

In seismic areas, the use of inclined piles, to withstand horizontal forces, is not recommended by modern seismic codes because of their poor performance in past earthquakes. However, the awareness of the actual causes of failures, in conjunction with recent numerical studies demonstrating that inclined piles may sometimes have a beneficial effect on the behaviour of pile groups and superstructures subject to earthquake loadings, have contributed in recent years to increase again the use of inclined piles. As a consequence of this contrasted experiences, the design of foundations with inclined piles in seismic areas deserves attention and in-depth investigations aimed at evaluating effect of pile inclinations and group layout on the dynamic behaviour of the soil-foundation system and the superstructure.
In this paper, the dynamic stiffness and kinematic response of inclined pile groups characterised by different layouts and different pile inclinations are firstly investigated. Analyses of the soil-foundation systems are performed with a 3D numerical finite element model developed by the authors, accounting for the pile-soil-pile interaction and the radiation phenomena that characterize the pile vibrations induced by the earthquake motion. The model can handle pile groups with generic number of piles, layout and inclinations. In order to evaluate the effects of inclined pile groups on the dynamic response of superstructures, some applications concerning bridge piers are considered. The influence of key parameters, such as the piles inclination and the group configuration, on the structural behaviour (displacements and stress resultants) and on the foundation response is discussed, comparing results with those obtained by considering pile groups with vertical piles.

32) Undergroud FWD measurements for the assessment of soil transfer function

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ABSTRACT

Underground trains create vibrations that are transmitted through the ground to the surface buildings [1]. The amplitude of vibrations depends on factors as the vehicle characteristics, the train speed, the rail and wheel roughness, the properties of the tunnel, the propagation of waves through the soil and the properties of the structures. Our aim is to develop a numerical model able to predict vibration noise in surface buildings from excitation due to underground trains. This possibility is crucial especially in determining the type of countermeasures to avoid that an eccessive level of vibrations could reach the surface causing disturbance to the people living in the area [2].

To develop a reliable numerical model of the soil-structure interaction, wave propagation experiments between the tunnel and the surface buildings are generally carried out by means of a vibrodyne. The installation of such an equipment could be, however, very industrious and time-consuming. On the contrary, the use of a FWD is, in general, more rapid and it doesn't require complicated instruments to be set up. Therefore, we have investigated the possibility to use a Falling Weigth Deflectometer (FWD) was used to determine the tunnel and soil characteristics and the transfer function between tunnel and surface buildings. The identified model has allowed the prediction of vibration levels produced by the transit of test trains at variable speeds.

The experimental campaign was performed in 2011 at the new branch of Metropolitana di Roma Linea B1, near the existing station of Piazza Bologna.

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33) Ambient vibration measurements of fundamental period of vibration in masonry buildings: comparison with numerical analysis and code formulas

L. Sorrentino, D. Pofi, D. Liberatore

ABSTRACT

Unreinforced masonry buildings are rather earthquake vulnerable. Their simplified assessment requires an estimation of their period of vibration

Based on test on sixteen buildings, ambient vibrations can be used to estimate fundamental period

Duration of the record can influence the results, especially if vibration modes are close one to the other

The Standard Spectral Ratio and the Horizontal-Vertical Spectral Ratio yield similar results

The current Italian and European formula overestimates the fundamental period from abient vibrations

For the same buildings numerical models are available. The fundamental period of the elastic branch of the bilinear oscillator yields much longer periods

There is a conflicting push toward a reduction or a increase of the code formula.

Additional modelling is necessary, updating the models to match (in the elastic range) the measured periods and then evaluate period elongation.

Probably more than one formula is necessary, one for Elastic Limit States and one for Ultimate Limit States

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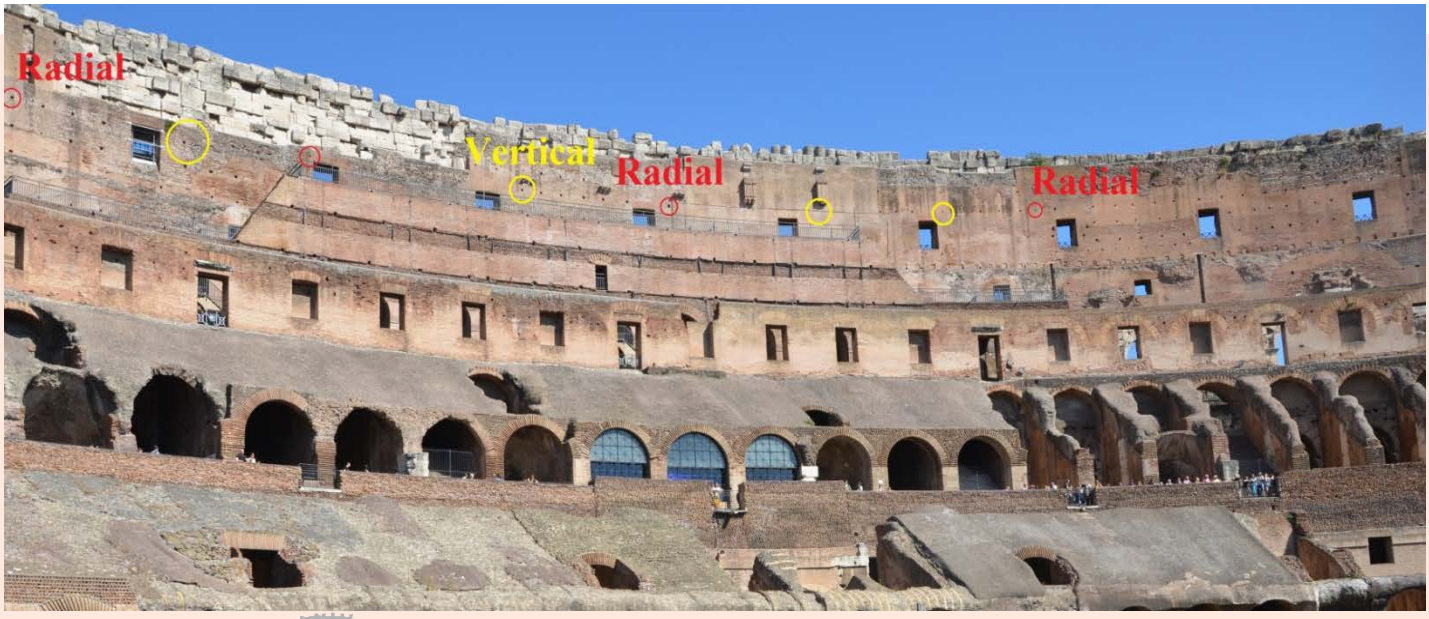

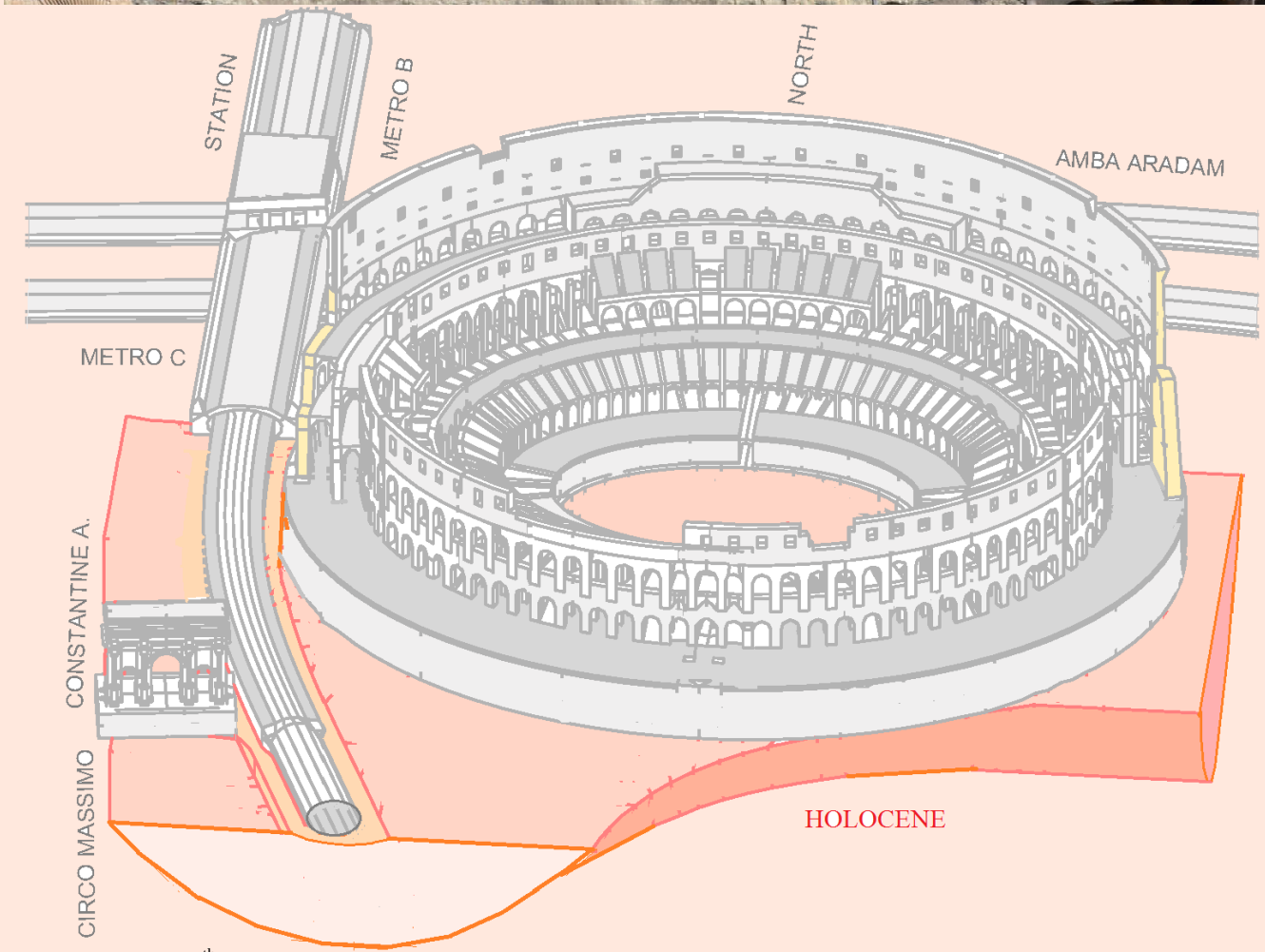

At 3.32 a.m. on 6th April 2009, the main shock of L'Aquila earthquake travelled through the soil, and INGV recorded a seismic sequence in Rome, in underlying soil and Colosseum. Since 2000 years, the soil transmits all the vibrations to the monument, by ambient vibrations too. The usual models of Structural Engineering have elevation fixed at the basis and the soil is missing; the vehicles' vibrations and microtremors cannot arrive to the monument. We propose a new methodology collecting three models by Geophysics, Structural and Transportation Engineering. For trains, a multibody model reproduces Metro B and C, and a 600x600x80m soil clod is enclosed. From the year 2000, the PC allowed the analysis with 500,000 d.o.f., and a DISS Group grown up between Italian Universities, ENEA, INGV, SSBA of Rome, SDR of Tokyo, producing three International Workshops. For Colosseum, we were exceptionally lucky for three reasons: 1) the tests in 200 points (never used before) were at disposal, 2) many man hours were spent with pure scientific interest, without time deadline, 3) we successed in identifying the map of 350 elasticity modules by comparison between tests and analyses, approaching good tolerances. The reliability was demonstrated by linear dynamic analyses performed for the aforementioned actions. The final objective is to bring to perfection the proposed methodology up a small tolerance everywhere, in order to allow an engineer middle professionist to check deterministically and not intuitively on PC the effect of all: a) traffic and materials variations, on the surface and inside the tunnels, b) eventual seismic improvement. Further tests and analyses are needed for: c) Constantine Arch, cryptoportici and tunnels of Metro B and C; d) improvement of geometric and mechanical characteristics of foundations and soil; e) further cars and trains' models; f) the map of damping coefficients.