Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe

Project # 10 – SERENA

Seismic Response of Novel Integral Abutment-Bridges

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Keywords
Seismic Soil-Structure Interaction, Integral Bridges, Shaking Table, backfill/pile isolation, Eurocode 8.

Figure

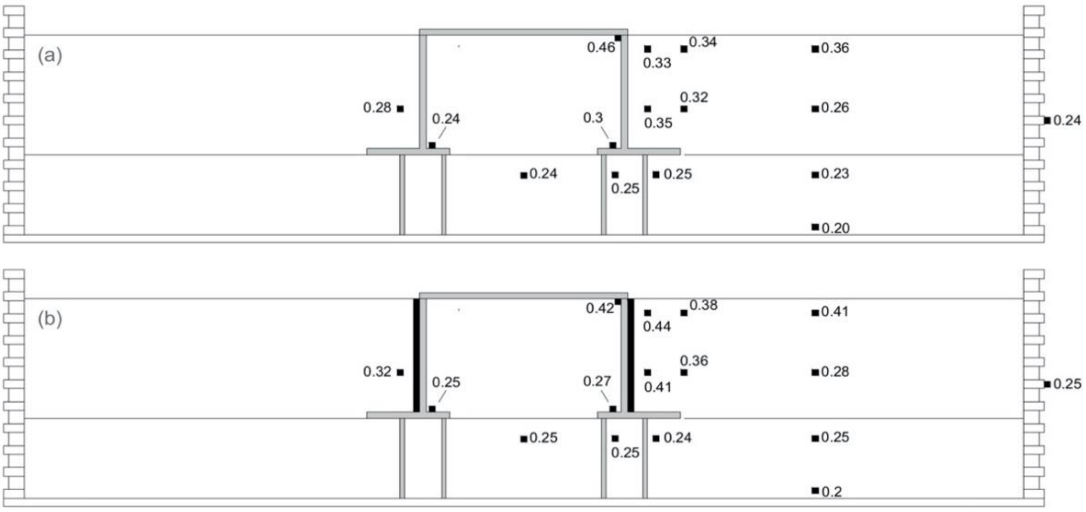

Fig.1 Maximum accelerations recorded by the sensors positioned in the backfill soil and on the bridge; comparison between two cases with piles connected to the foundation: without (a) and with (b) compressible inclusion layer behind the abutment wall (adapted from Fiorentino et al. 2019b)

Main Results

Integral Abutment Bridges (IABs) are characterised by the absence of bearing supports and expansion joints between the deck and the abutments/piers, thus reducing construction and maintenance costs. IABs are characterised by a complex Soil-Structure Interaction (SSI) with respect to conventional bridges; therefore, the static and dynamic effects of the SSI should be considered in the design. Despite

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the large number of IABs worldwide and related numerical studies, few experimental tests were performed, and codes lack related seismic prescriptions, including Eurocodes.

Project SERENA aimed at conducting experimental shaking table tests on a scaled bridge model inserted into the large “shear stack” soil container of the EQUALS – BLADE Laboratory of the University of Bristol. The novelties of the project are the following:

1. the first dynamic test on a shaking table of an Integral Abutment Bridge model including Soil-Structure Interaction
2. the mitigation of earth pressures on the abutment walls and the overall effects induced by the introduction of a compressible inclusion between the soil and the abutment walls
3. the investigation of the effects of pile disconnection with/without compressible inclusion layers
4. evaluation of scaling criteria for dynamic SSI.

The bridge model was scaled to match the dimensions of the soil container on the shaking table. In doing so, attention was paid to the development of appropriate scaling laws that will allow extending the results obtained with the scaled model to real scale IABs. The results in terms of accelerations allow recognising some patterns in the seismic response of the model and the soil. In the backfill, it was found that the inclusion of layers of PU foam increases the accelerations in the soil while, on the other, its presence reduces the accelerations of the bridge, which are smaller than in the surrounding soil. After the tests, settlements in the configurations with compressible inclusion layers behind the abutment wall were larger. This result indicates the necessity of a careful design of approaching slabs. The pile disconnection is promising as well. Scaling laws here developed will permit to analyse real backward bridges. The results can be used as a first step towards developing engineering provisions for IABs which are absent from existing regulations such as Eurocode 1998.2 (Bridges). Further experimental and numerical analyses can be proposed based on this research such as the validation of scaling methodologies, use of different backfill soil, different geometries of backfill soil or the development of behaviour factor for IABS.

List of Publications

Fiorentino G., Cengiz C., De Luca F., Briseghella B., Lavorato D., Mylonakis G., Sextos A., Nuti C., Shaking Table tests on Integral Bridge Model including Soil-Structure Interaction, Proceedings of XVIII ANIDIS Conference, 15-19 September 2019, Ascoli Piceno, Italy.

Fiorentino G., Cengiz C., De Luca F., De Benedetti G., Lolli F., Dietz M., Dihoru L., Lavorato D., Karamitros D., Briseghella B., Isakovic T., Vrettos C., Topa Gomes A., Sextos A., Mylonakis G., Nuti C. (2019), Shaking Table Tests on an Integral Abutment Bridge Model: Preliminary Results, COMPDYN 2019, 7th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, M. Papadrakakis, M. Fragiadakis (eds.), Crete Island, Greece, 24–26 June 2019.

Deliverable D10.1 – Technical report on SERA Transnational Access activities. Project # 10 - SERENA - Seismic Response of Novel Integral Abutment-Bridges.

Access to Data and Services

Data used in the publications are available in full within each publication. Data access can be granted through the SERA project data portal. Data upload onto Celestina software is ongoing.

WP 13-TA 6: Project #11 – 3DROCK

Statistical verification and validation of 3D seismic rocking motion models (3DRock)

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Keywords

Rocking structures, seismic excitation, model verification, response modification, earthquake engineering

Figures

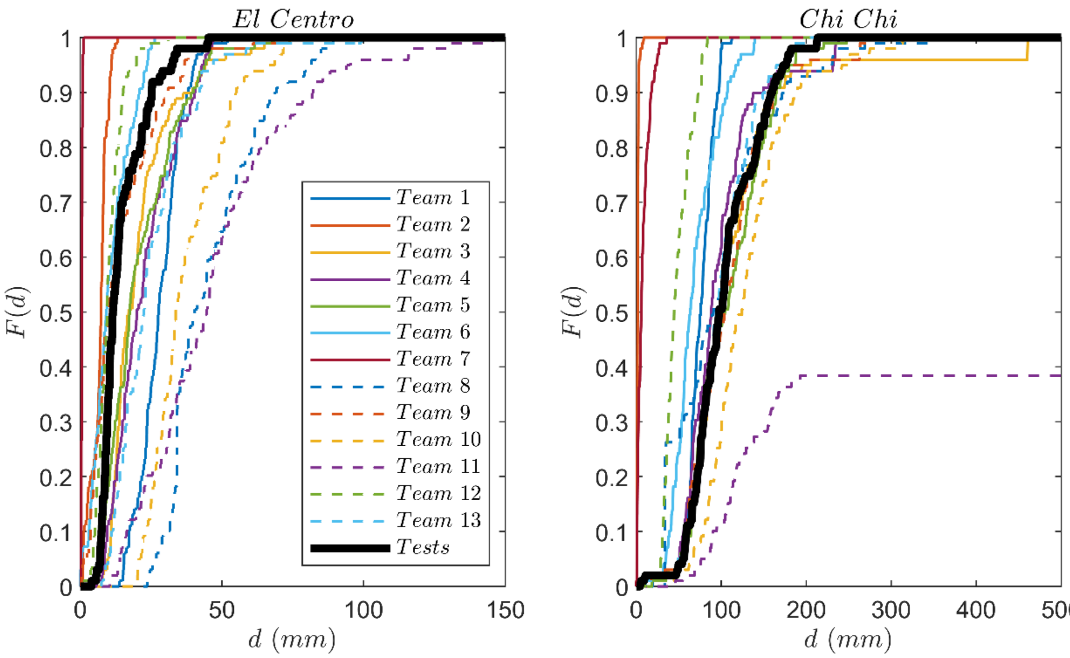

Fig.1 The cumulative distribution function of the specimen displacement (d) for the two utilized ground motion test sequences “El Centro” and “Chi Chi”: tests and predictions of the teams

Main Results

The 3D rocking oscillator model is useful because it describes the seismic behavior of unanchored equipment and because unrestrained rocking has been suggested as a seismic response modification technique. A major critique against rocking systems has been that their responses are not only hard to predict by existing numerical models, but that the response is inherently unpredictable. Therefore, in the context of earthquake engineering, the objective of this study is to answer two important questions:

Is wobbling motion inherently unpredictable? If not, are existing models good enough to predict the response?

To this end, an experimental campaign has been designed to obtain observations of wobbling motion to be compared with those gained from numerical simulations. Two sets of models were studied: "Free Rocking" representing unanchored equipment; and "Wobbling Frame" representing a design approach that can be used for the rocking isolation of bridges or buildings. To constrain the uncertainty in the excitation, a stochastic model was used to generate synthetic ground motion ensembles that match the physical characteristics of recorded ground motions. Each ensemble contained 100 excitations. One ensemble was used to study the Free Rocking specimens and two ensembles were used to study the Wobbling Frame.

Numerical simulation of the tests on the Free Rocking specimens is currently being performed. The response of the Wobbling Frame was the subject of an international blind prediction contest. The contestants had to predict the Cumulative Distribution Functions (CDF) of the maxima of the responses. Thirteen teams using FEM, DEM and Rigid Dynamics models responded. Notably, the same model predicted the CDF of the response for one ground motion family well, while it performed poorly on the other (Fig. 1). This finding shows that there is space for improvement in modelling of wobbling structures. Interestingly, both FEM and DEM can overestimate or underestimate the response depending on the input parameters used.

Moreover, the best models used zero Rayleigh damping and only relied on friction between the contact surfaces to dissipate energy, showing that damping models should be physics-based. An analytical dynamics model that prevents sliding and twisting was found to consistently overestimate the response of this structure because it did not model sliding. A more involved investigation on the modelling parameters that optimize the prediction of the Wobbling Frame is the subject of current research.

List of Publications

Publications and openly accessible deliverables are in preparation.

Access to Data and Services

Data upload onto Celestina software is ongoing.

Blind prediction contest data is available at: https://peer.berkeley.edu/news-and-events/2019-blind-prediction-contest

WP 13-TA 6: Project #12 – REBOND

Response of as-Built and strengthened three-leaf masonry walls by Dynamic tests

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Keywords

earthquake engineering, three-leaf masonry walls, effects of vertical ground motion component, masonry wall reinforcement

Figure

Fig.1 Typical masonry wall specimen tested.

Main Results

The main scope of the RE-Bond (REsponse of as-Built and strengthened three-leaf masONry walls by Dynamic tests) project was to investigate the effects of the vertical ground motion component on the response of three-leaf walls, representative of buildings found in historical canters in Central Italy. Squat rectangular and T-walls were tested on the shake table as-built and after reinforcement with composite cross ties. The selection of the recorded ground motion signal focused on near fault records with an important vertical component. The walls were designed to represent walls at the top level of a masonry building with low axial load. Also, the walls were designed to fail in shear. The tested specimens showed indeed shear failure with clearly visible diagonal cracks. The wall strength decreased due to the presence of the vertical ground motion component with respect to the test with the horizontal component only. The cross ties improved the behaviour of the walls by increasing their strength. Reinforcement of the masonry walls was applied by the Italian Kerakoll group): GeoSteel connectors with mortar injections were added on the entire thickness of the longitudinal wall and diagonal steel connectors with mortar injections were added between the two orthogonal walls in T-walls. Reinforcement increased the seismic capacity by 20 % thanks to the presence of the connectors. Extensive numerical modelling of the tested walls accompanied the test. The test results are currently being interpreted.

List of Publications

Publications and openly accessible deliverables are in preparation.

Access to Data and Services

Data upload onto Celestina software is ongoing.

WP 13-TA 6: Project #21 – NSFUSE

Ductile steel fuses for the protection of critical non-structural components

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Keywords
nonstructural component, steel fuses, peak floor acceleration, peak component acceleration, component ductility

Figures

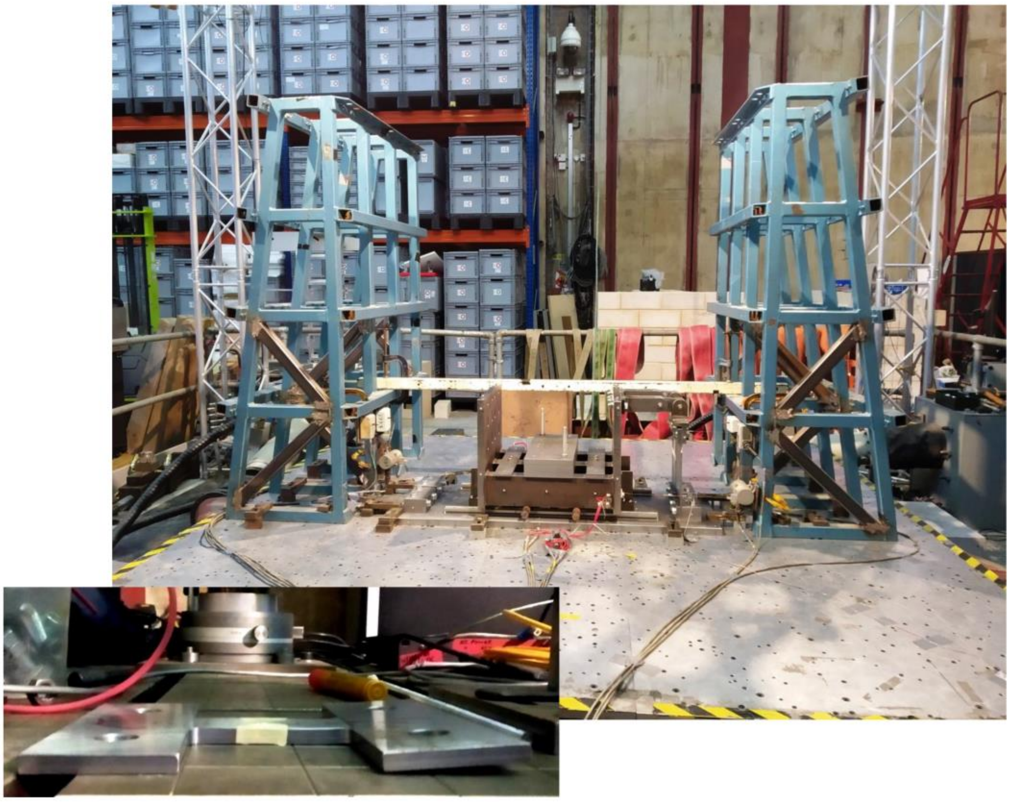

Fig.1 Ductile steel fuse tested on the shaking table

Main Results

Community-critical buildings often face lengthy functionality disruptions due to non-structural damage triggered by even low- or moderate-intensity earthquakes. The problem lies in the dynamics of narrowband excitations appearing at the floors (and ceilings) of buildings and the corresponding resonant response of many rigidly-connected components, introducing component accelerations that can exceed by several orders of magnitude the (already amplified) peak floor response. In contrast, as was recently proven through analytical studies undertaken by members of this research team, a controlled yielding anchor could offer a reliable detuning effect that only requires a minor ductility of 1.5-2.0 to achieve substantial reductions in acceleration demands.

NSFUSE experimental project offered an actual verification of the concept at hand, by means of a series of one-dimensional earthquake simulation tests realized at the Bristol University shake table facility. The test specimen tested on the shake table was a Single-Degree-of-Freedom (SDOF) carriage-like configuration, that was able to move on two rollers supports. The test specimen was attached to its one end to two “fuse” plates, essentially acting as cantilevers to provide resistance to the sliding of the carriage. For targeting different vibration periods, the carriage was loaded with different masses, whereas by modifying the geometry of the steel fuses different stiffness and component ductility levels were attained. The shake table tests were conducted using narrow-band floor acceleration input signals that were recorded in instrumented buildings in California (USA) during three different earthquake events.

The NSFUSE experimental campaign provided concrete evidence for the benefits of designing the non-structural components (or their anchors) to respond in-elastically during earthquakes that are sufficiently strong to induce damages in such elements. In fact, it was showcased that:

(a) the a_p factor, which provides a measure of how much the peak component acceleration (PCA) is amplified relative to the peak floor acceleration (PFA). Hence, the ratio PCA/PFA could reach a peak that, for the case at hand of the component period being tuned with the fundamental period of the supporting structure, could be very high if the non-structural components were designed to respond elastically
(b) even small mobilized fuse ductility levels are enough to substantially reduce the acceleration demands for non-structural components attached to buildings and
(c) steel fuses were proven capable of developing a controlled yielding anchor mechanism.

All in all, the NSFUSE project offered ample evidence for the fuse concept and therefore to soon find its way in prospective design codes.

List of Publications

Kazantzi A.K., Vamvatsikos, D., Miranda, E. Evaluation of seismic acceleration demands on building non-structural elements, *Journal of Structural Engineering*, 2020a.

Kazantzi A.K., Vamvatsikos, D., Miranda, E. The effect of damping on floor spectral accelerations as inferred from instrumented buildings, *Bulletin of Earthquake Engineering*, 18:2149–2164, 2020b.

Miranda E., Kazantzi, A.K., Vamvatsikos, D. New approach to design acceleration-sensitive non-structural elements in buildings, 16th European Conference on Earthquake Engineering, Thessaloniki, Greece; 2018.

Access to Data and Services

Data upload onto Celestina software is ongoing.

WP 13-TA 6: Project #22 – SEBESMOVA3D

Seismic Behaviour of Scaled Models of Groin Vaults Made by 3D Printers

D. Foti [1], S. Silvestri [2], S. Ivorra [3], D. Theodossopoulos [4], S. Baraccani [2], V. Vacca [1], R. White [5], M. Dietz [5], G. Mylonakis [5, 6, 7]

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Keywords
Groin vault, shaking table test, 3D printed blocks, frequencies, SEBESMOVA3D

Figure

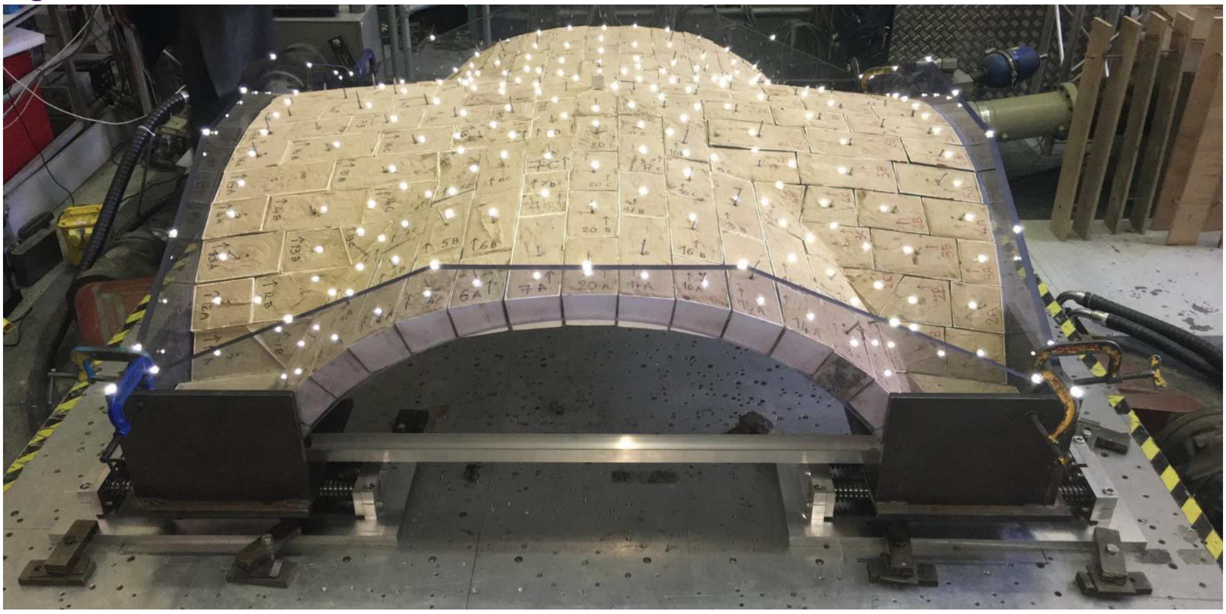

Fig.1 The vault specimen tested on the shaking table

Main Results

A huge number of shaking table tests was performed on a scaled groin vault model made of 3D printed plastic blocks filled with mortar.

The vault was built according to two support conditions (on four fixed supports and two fixed supports and two one-way moveable carriages equipped with lateral springs) as well as different boundary conditions along the four lateral arches (wooden panels, Plexiglas panels, cut Plexiglas panels and no panels) to account for different confinement levels.

Random signals were systematically carried out to get the dynamic properties of the vault model. Harmonic inputs with different frequencies ranging between 1 Hz and 50 Hz were imposed in one horizontal direction with increasing amplitude, up to collapse.

The presence of a gum layer in-between two following blocks has a strong influence on the global behaviour. Furthermore, it seems to govern the dynamic response of the vaulted structure, especially for high-acceleration and low-frequency harmonic inputs. The results of the experimental campaign revealed a strongly non-linear behaviour.

The most important results can be summarised as follows:

1. The fundamental frequency of the vault model decreases with increasing acceleration.
2. Keeping all the conditions the same, configuration 2 (differential horizontal shear displacements at the supports through two moveable springs) reaches the collapse condition for a lower acceleration than configuration 1. The pseudo-static response of the vault induced by imposed shear displacements at its springings often represents the predominant cause of damage/failure, overshadowing the dynamic response of the vault itself, justifying the need for this series of tests.
3. The analysis of the cumulative displacements and the collapse acceleration values show that the vault made of plastic mortar bricks with gum-layer interfaces is not particularly susceptible to cumulative damage.
4. The vault with these specific geometries and support conditions seems to be more vulnerable to low-frequency (resonance) harmonic inputs if compared to seismic inputs.
5. The construction phases, as well as the fact that the seismic response of the vault with no panels along the lateral arches is similar to that of the vault weakly confined through the Plexiglas panels, indicate that the corner areas close to the springings are the critical ones, upon which attention should be paid to get static stability and higher seismic performances. This response is well known since ancient times when past repairs showed that these portions were constantly strengthened to be better embedded in the surrounding vertical masonry structures.

List of Publications

D. Foti, S. Silvestri, S. Baraccani, S. Ivorra, D. Theodossopoulos, V. Vacca, V. Campanella, J.V. Ochoa Roman, L. Cavallini, R. White, M. Dietz, G. Mylonakis. Experimental tests of a groin vault in dry-bonded voussoirs under dynamic excitation. 17th World Conference on Earthquake Engineering, 17WCEE Sendai, Japan- September13th to 18th 2020.

Access to Data and Services

Data upload onto Celestina software is ongoing.

WP 13-TA 6: Project #35 – SHATTENFEE

SHAking Table TEsting for Near Fault Effect Evaluation

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Keywords
Earthquake engineering, Seismic hazard, Site effects, Near-fault effects, Modal identification.

Figures

Fig.1 Test rig, comprising a 3.2 m high, 0.9 m diameter PERSPEX® cylinder and a 1:10 scaled pile model.

Main Results

The investigation of vertical ground motions, near-fault effects, and the ensuing soil-structure interaction is still scarce; therefore, the SHATTENFEE project aimed at investigating near-fault response of soil. To do so, the vertical dynamic behaviour of a typical soil deposit, with and without the presence of a foundation pile, has been explored experimentally by using the 6-degree-of-freedom shaking table of the University of Bristol. A newly designed test rig, which comprises a 3.2 m high and 0.9 m diameter PERSPEX® cylinder, was utilised to experimentally analyse the vertical wave propagation of homogeneous soil in a 1:10 scaled model. For scaling the time by using frequency similitude between the prototype and the model, two values (3 and 7) were considered. A total of 209 tests were carried out during the experiments. Different types of dynamic functions and seismic records were used as input motion at the base of the cylindrical model. To perform the dynamic identification of the system, vertical noise functions and sweep functions (sinusoidal waveforms) were utilised. To assess the seismic response of the scaled model, natural records were also applied. Three near-fault vertical accelerograms were selected from the Italian Strong Motion Network (RAN database): L'Aquila 2009 (AQK station), Mirandola 2012 (MRN station) and Centro Italia 2016 (AMT station, near Amatrice).

The SHATTENFEE has investigated the vertical dynamic behaviour, in free-field conditions, of Leighton Buzzard Sand-B to estimate:

1. the fundamental vertical period of vibration (T_v)
2. compression wave velocity (V_p)
3. and vertical amplification.

The dynamic response of the homogeneous soil is studied by analysing and comparing the acceleration time-histories recorded at different levels of the soil column; thus, the amplification function is computed which, in turn, provides the natural frequency of the soil model. When a vertical noise function with an amplitude of 0.05 g was considered, a value of 46.5 Hz was determined for the soil column.

Accurate measurements of V_p were also performed during the experiments, allowing the evaluation of the soil stiffness and frequency variation with the level of excitation (soil nonlinearity in compression). The measurement of the V_p allowed the validation of the theoretical formula for the vertical period Tv ($Tv=4H/V_p$).

Finally, the accelerometric data recorded at the base (along the soil columns) and the soil surface (analysed both in the time and in the frequency domain) revealed that the vertical amplification is significant confirming the results obtained from the predictions of the numerical simulations.

List of Publications

List all publications or openly accessible deliverables relevant to your main results.

Access to Data and Services

Data upload onto Celestina software is ongoing.

WP 13-TA 6: Project #36 – SSI-STEEL

Soil-Structures Interaction effects for STEEL structures

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Keywords

Soil-Structure Interaction, Steel Structures, Ductility Demand, Shaking table Tests, Earthquake Engineering

Figure

Figure 1. Dual steel frame (*DSF*) with a new brace-type damper made of a shape memory alloy material.

Main Results

The SSI-STEEL project (Soil-Structures Interaction effects for STEEL structures) deals with an experimental campaign to be carried out, through shaking table tests, on different steel structural systems to achieve a better knowledge about the SSI effects on their dynamic linear and nonlinear responses. In particular, three structural types are investigated, those are: i) a Concentrically Braced Frame (*CBF*), ii) a Moment Resisting Frame (*MRF*) – also considering the presence of a beam reduced end sections – and iii) dual steel frame (*DSF*) with a new brace-type damper made of a shape memory alloy material.

Few similar experimental studies concerning SSI effects on steel frames are currently present in literature. They are often focused on Single-Degree-of-Freedom (SDOF) systems made of a column with a mass atop or, when more complex structures are considered, only investigate specific aspects influencing the structural response of steel structures, such as the deformation in the elastic field.

On the other hand, there are non-experimental studies that compare the SSI influence on the responses of different steel structural types designed according to the same criteria, as well as that also consider nonlinear phenomena such as buckling and yielding. These are the aspects that the project aims to investigate with the goal to lead the current knowledge to a larger extent and to propose modification factors, to be expressed as a function of the soil-to-structure relative stiffness, to be included in the current design formulations that are of interest for technicians. Therefore, the proposed research represents a significant breakthrough in the field of structural/geotechnics engineering, with evident returns in terms of Code/Provisions updates and meaningful design tools that will be used by engineers in the future.

Currently, the prototypes to be tested have been designed, manufactured and shipped to the University of Bristol (UBRI). Also, the most suitable accelerograms have been selected based on numerical analyses carried out in ABAQUS, FLAC and MIDAS software. Although ten (10) laboratory days have already been provided by the host, the shaking table tests have not been carried out yet, as UBRI and the earthquake lab closed following the escalation of the COVID-19 pandemic in the UK. The pandemic also restricted the visiting researchers who could not travel to Bristol. The tests will be carried out later, after the restrictions are lifted.

List of Publications

The following publications have been scheduled:

- SSI effects on Concentrically Braced Frames by Shaking table tests
- SSI effects on Moment Resisting Frames by Shaking table tests
- Dual Steel Frames with Strain Rate Dependent Dampers under SSI effects
- On the suitability of different Numerical Modelling Approaches of SSI effects in the light of shaking-table tests

Access to Data and Services

Data upload onto Celestina software is ongoing.