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DYNAMIC CONTROL OF RIGID-FAILURES MODES IN MASONRY STRUCTURES SUBJECT TO GROUND MOTION

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Abstract. *In the paper one presents some research developed at the University of Naples in the field of structural dynamic control. The research is mainly focused on the possibility of applying control systems to the protection of existing and masonry constructions through the setup of ad-hoc strategies and devices, which are suitably conceived and designed in order to fit the main characteristics, behavior and collapse modes of the structural components. Rigid-failure modes are referred to, with the articulated model consisting of macro-elements whose motion is activated during the dynamic event.*

The final task consists of achieving an adequate mitigation of the dynamic effects due to the possible occurrence of earthquakes. The researches involve both theoretical, numerical and experimental features on the topic, including some design issues.

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1 INTRODUCTION

Approaches to the problem of attenuation of the structural response vary from the setup of control devices for reducing the structural vibrations [1]-[10] to the development of reinforcement techniques, also involving new composite materials [11]-[14], for increasing the dynamic strength of the structure, even in masonry constructions [15]-[19].

In the paper one presents some research developed in the field of protection of new and existing structures subject to dynamic events. The described researches involve both theoretical, numerical and experimental features on the topic.

One essentially refers to the mitigations of the effects relevant to the activation of rigid modes under dynamic ground shaking, which do often occur in a variety of existing structures and structural components subject to earthquake and may be responsible of the achievement of the collapse condition.

In more details, when referring to monumental constructions such as masonry vaulted structures subject to dynamic ground motion, the structural model is usually assumed to activate some rigid-failure schemed behaviour due to the formation of the cracks, which allow the formation of kind of macro-elements with the development of relative rotations constrained in their sign.

The whole dynamic analysis would require to remove the small displacement hypothesis , and to account for the response of rigid-plastic structures subjected to impulsive or pseudo-impulsive dynamic loads through the search of approximate solutions. Some studies are reported aimed at controlling the articulated motion by the proper design of a chain cable.

In the second part of the paper, one refers to studies concerning models that may be assimilated to rigid blocks, and where pure rocking motion is analyzed; in this case, the response attenuation is accomplished by means of dampers that introduce additional dissipative liquid masses.

2 TIE-ROD DEVICE FOR VAULTED STRUCTURES UNDER DYNAMIC SHAKING

2.1 The model and the control approach

In order to control the dynamic articulated motion of masonry vaulted structures occurring during earthquakes, some possible modification of classical retrofit provisions may be considered in order to realize more effective control strategies.

In particular a control strategy may consist of designing a device based on the regulation of a chain cable and of setting up an ad-hoc control algorithm for the proper tuning of the chain in order to get an overall stress reduction in the masonry.

By referring to articulated modes of masonry portal arches, based on the coupling of the single modes which may be referred to for the two cases of the unchained and chained model, one may perform dynamic analyses through modal approximation methods. The arch model, interpreted by a rigid-failure scheme in masonry material, is assumed to be equipped with a tie-rod, whose length may be ruled through the selected control algorithm.

This condition is considered to constitute an intermediate situation between the two single-mode cases of the arch without tie or with non-stretch (inextensible), as shown in Figure 1. a) and b), respectively. The coupled behaviour is inferred from a suitable combination of the modal contributions representing the two considered cases.

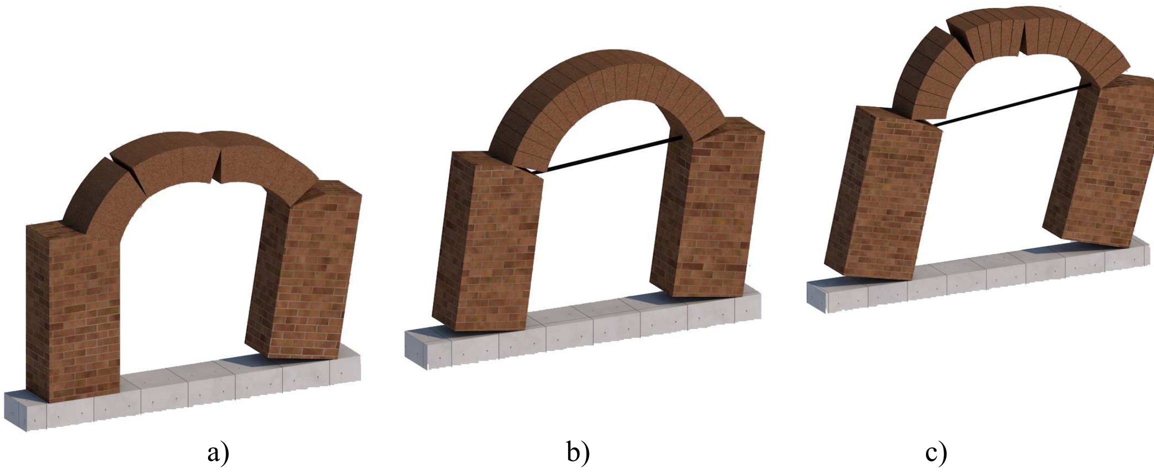


Figure 1: The not retrofitted model a); the model with the inextensible chain cable b), and with the extensible chain cable c).

The dynamic equilibrium of the combined modal behaviour is then handled by introducing a first order approximation and linearization in order to subsequently formulate the algorithm, which is aimed at controlling the length of the tie and at mitigating the dynamic effects on the structural response. The final behaviour referred to the arch equipped with an extensible tie, is shown in Figure 1.c).

2.2 Design of the control algorithm

The control strategy is aimed at suitably calibrating the length variation of the rod cable in order to mitigate the dynamic effects induced in the vaulted structure by the ground motion.

With reference to the second order differential dynamic equilibrium system, the problem is essentially set up in such a way to push the coupled behaviour of the masonry portal towards an uncoupled rigid one; a linear feedback governing the dependence of the tie elongation on the response variables is introduced through the control parameter ψ in the controlled motion equation .

The search of the optimal control coefficient can be turned into the problem of the search of the constrained minimum of a properly defined operator of the impulsive response function, mainly inferred in energetic terms.

In synthesis, in order to realize an effective and energetically economic control, the problem may be formulated in such a way that the maximum value of the tie length $\Delta\ell_{max}$ attained during the motion duration T_o is kept contained within a certain predefined threshold. After some further developments, the problem is then set up in energetic terms, by introducing some operators accounting for the maximum attained response $\Re(T_o|\Psi)$ during the motion and the maximum rod elongation $\Im(T_o|\Psi)$ and performing the constrained minimization, such that $\Im(T_o|\Psi)$ is kept bounded by the threshold value $\Im^*$

$$\begin{cases} \text{Find} \;\; \underset{\Psi}{\text{Min}}\, \Re(T_o|\Psi) \\ \text{Sub} \;\;\; \Im(T_o|\Psi) \le \Im^* \end{cases} \tag{1}$$

2.3 Control performance

As concerns the performance of the proposed control system one may refer to the diagram reported in Figure 2, where the operator representing the maximum attained response (to be quantified according to the scale on the left side of the diagram) and the operator representing the maximum chain elongation (to be referred to the right side scale) are plotted versus the control coefficient ψ. One may notice that the response operator attains its minimum values under negative values of the parameter.

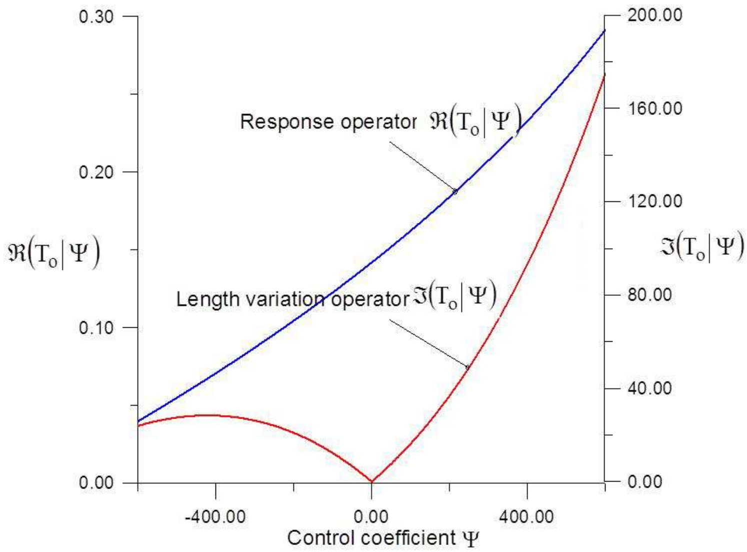


Figure 2: Diagram of the response and tie length operators versus the control coefficient ψ.

The comparison with the uncontrolled case of the tie (achieved under a null value of ψ) allows to observe that a further improvement in the response mitigation may be attained by controlling the elongation of the chain cable. Good results may be still obtained when choosing a more binding value of the control operator, namely by giving more weight to the energetic economy. Actually, by selecting large negative values of the control coefficient one may then achieve, at the same time, the double effect of minimizing costs while maximizing control effectiveness; in this case particular attention has to be paid to prevent compression in the tie.

3 TLD DEVICES FOR RIGID-FAILURES UNDER DYNAMIC SHAKING

3.1 Overall framework

The attachment of additional masses to the main structure with the objective of dissipating the energy supplied by the dynamic event and counteracting the incoming dynamic forces is a well-known control approach. Even in its passive mode it may give appreciable results in terms of attenuation of the structural vibration with a null control energy supply, once properly tuned the properties of the mass with reference to the characteristics of the structure.

When adopting sloshing masses, based on the energy dissipation through the liquid mass motion in suitably shaped tanks, high damping capacity may be conferred to the structure. This strategy may be applied in order to reduce vibrations occurring also in special structures, monolithically rocking under ground motion. This kind of failures often occurs in existing building elements and structures, which may behave according to rigid failure modes in many cases.

At the University of Naples "Federico II" some experimental tests have been executed on structural models assimilated to rigid blocks equipped or not with some liquid sloshing devices, demonstrating that the adoption of the Tuned Liquid Dampers (TLD), and their proper tuning, may lead to satisfactory results, in terms of mitigation of dynamics effects as regards to such type of failure.

Actually the need of predicting and preventing failures associated to rocking and overturning of rigid structures undergoing strong ground shaking have motivated a consistent number of studies on rocking response. Therefore the possibility of coupling some sloshing devices to rigid blocks for attenuating their response to dynamic excitations appears of main interest.

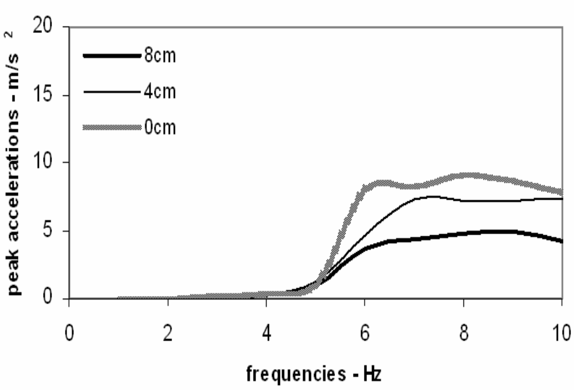
3.2 Experimental activity and results

In the following, one refers to some tests executed on some models acting as rigid blocks by means of a unidirectional shaking table moving in the horizontal direction for simulating the dynamic motion. The shaking table is an MTS system and is automatically connected to a system which both gives the input signal to the table and records the output signal.

The dynamic experiments have been executed on block models moving under pure rocking. The rocking motion is affected by very complex dynamics, that push towards the adoption of worst scenario approaches for vulnerability assessment that increase the robustness of forecasts.

The experiments were executed by keeping a fixed span and varying the frequency of the harmonic base-excitation inferred by the shaking table, and using different span values.

a)



b)

Figure 3: Sample of dynamic tests on rocking blocks with TLD: a) experimental test; b) comparison of data for the empty tank and the tank with 4 or 8 cm of liquid.

The first experimental campaign was developed on blocks, both having various sizes and geometric dimensions' ratios (thickness/height), made of thin aluminum plates of the type shown in Figure 3.a), and subject to pure rocking motion around its base edges.

At the second stage, an experimental investigation on the blocks coupled with a number of tuned liquid dampers (TLDs) with different geometries, shapes and liquid ratios was developed. Collected data from tests allow to show the potential of the strategy even in this case and to relate the response reduction to the liquid amount in the tanks and tank shape, as clear from the sample test whose results are reported in Figure 3.b).

The overall benefit by the liquid damper does not appear to be homogeneous on the frequency range, it is much higher in some frequency range which also depends of the geometrical/inertial properties of the structure under observation. As regards to the dynamic test execution, one should emphasize that shaking tables are usually adopted in order to reproduce/simulate the incoming dynamic excitation and to record the response data for the structural model under examination.

Actually, due to shaking table complexity, that includes a variety of mechanical, hydraulic and electronic components, there are many potential highly interdependent sources of distortion that alter the total effect of the system, so that a given command does not produce the expected response. It must be required for any case a specific setting of the systems which considers all the components of the problem. Anyway, although forecasts about the seismic motion are not easy to be obtained, such facilities allow to understand the behavior of different typologies of structures and materials, as well as to evaluate the effects of protection strategies.

4 CONCLUSIONS

In the paper, some possible approaches to the control of structures activating under ground shaking rigid failure modes are presented. In this class, typical examples are represented by masonry constructions which usually obey articulated rigid mode behaviours. As regards to vaulted structures a possible variation to classical retrofit methods is presented in order to improve their performance, resulting in a good balance between performance and energy costs; on the other side, when referring to constructions or single structural components such as walls behaving according to the rigid block model, the mitigation of the dynamic response is successfully achieved through the adoption of special oscillating masses.

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REFERENCES

[1] Baratta, A., Corbi, I., Corbi, O., Algorithm design of an hybrid system embedding influence of soil for dynamic vibration control, *J. Soil Dynamics and Earthquake Engineering*, 74, 79-88 (2015).

[2] Baratta, A., Corbi, I., Corbi, O., Mastorakis, N., Strategies for the protection from structural failures under seismic events, *International Journal of Mechanics*, 9, 69-75 (2015).

[3] Corbi, I., Corbi, O., Macro-mechanical modelling of pseudo-elasticity in shape memory alloys for structural applications, *J. Acta Mechanica*, 1-9, DOI: 10.1007/s00707-016-1624-3 (2016).

[4] Baratta, A., Corbi, O., Dynamic Response and Control of Hysteretic Structures, Intern. *Journal of Simulation Modeling Practice and Theory*, 11, 371-385 (2003).

[5] Constantinou, M.C., Whittaker, A.S., Kalpakidis, Y., Fenz, D.M., Warn, G.P., Performance of Seismic Isolation Hardware under Service and Seismic Loading; Technical

Report MCEER-07-0012; *Multidisciplinary Center for Earthquake Engineering Research*, State University of New York at Buffalo: Buffalo, NY, USA (2008).

[6] Corbi, I., Rakicevic, Z.T., Shaking table testing for structural analysis, *International Journal of Mechanics*, 7(4), 459-466 (2013).

[7] Corbi, O., de Barros, R.C., Seismic protection of civil buildings by visco-elastic magneto-rheological fluids, *International Journal of Mechanics*, 7(4), 518-525 (2013).

[8] Corbi, O., Zaghw, A.H., Properties and design of dissipative visco-recentring SMA members for civil structures, *International Journal of Mechanics*, 7(3), 285-292 (2013).

[9] Corbi, O., Zaghw, A.H., Elattar, A., Saleh, A., Preservation provisions for the environmental protection of egyptian monuments subject to structural vibrations, *International Journal of Mechanics*, 7(3), 172-179 (2013).

[10] Sang-Hoon O., Sang-Hoon S., Sang-Ho L., Hyung- Joon K., Seismic Response of Base Isolating Systems with U-Shaped Hysteretic Dampers, *Int J Steel and Structures*, 12(2), 285-298 (2012).

[11] Baratta, A., Corbi, I., Topology optimization for reinforcement of no-tension structures, *J. Acta Mechanica*, 225 (3), 663-678 (2014).

[12] Baratta, A., Corbi, O., An approach to the positioning of FRP provisions in vaulted masonry structures, *J. Composites Part B: Engineering*, 53, 334-341 (2013).

[13] Corbi, I., FRP reinforcement of masonry panels by means of c-fiber strips, *Journal Composites Part B*, DOI: 10.1016/j.compositesb.2012.11.005 (2012).

[14] Corbi, I., FRP Composites Retrofitting for Protection of Monumental and Ancient Constructions, *Open Construction and Building Technology Journal*, 6, 361-367 (2012).

[15] Corbi, I., Corbi, O., Analysis of bi-dimensional solids with internal unilateral constraint coupled to structural elements with different degree of connection, *J. Acta Mechanica*, 228(2), 607-616 (2017).

[16] Corbi, I., Corbi, O., Theorems for masonry solids with brittle time-decaying tensile limit strength, *J. Acta Mechanica*, 228(3), 837-849 (2017).

[17] Corbi, I., Corbi, O., F. Tropeano, Stability assessment of an historical masonry bridge through the LA kinematic theorem for NT structures, *Int. J. Mechanics*, 10, 305-311 (2016).

[18] Baratta, A., Corbi I., Corbi, O. , Stability of evolutionary brittle-tension 2D solids with heterogeneous resistance, *J. Computers and Structures*, 174, 133-138 (2016).

[19] Baratta, A., Corbi, I., Corbi, O., Analytical Formulation of Generalized Incremental Theorems for 2D No-Tension Solids, *J. Acta Mechanica*, 226 (9), 2849-2859 (2105).