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SYSTEMIC SEISMIC VULNERABILITY AND RISK ASSESSMENT OF PORT FACILITIES. AN APPLICATION TO THESSALONIKI'S PORT.

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In view of the importance of ports in today's society, it is clear that the extended loss of functionality of major ports could have major regional, national, and even world-wide economic impacts. Harbors comprise complex systems consisting of several lifelines and infrastructures, which interact with each other and with the urban fabric. The resilience and continuity of shipping operations at a port after an earthquake depends not only on the performance of its individual components, but on their location, redundancy, and physical and operational connectivity as well, that is, on the port system as a whole.

In the framework of the European FP7 project SYNER-G (http://www.vce.at/SYNER-G), a general methodology was developed for the assessment of the systemic vulnerability and performance of harbors, simulating port operations and considering also the interactions among port elements (Pitilakis et al. 2014). An object-oriented structure for the harbor system is defined, in order to specify the system down to its lowest-level component, and specific attributes of each class or sub-class are defined. Interactions between port components and sub-systems and/or 'external' systems (like electric power network) are investigated, based on their typologies. Using appropriate methods, relevant performance indicators at system-level, whose applicability depends on the level of analysis chosen, are defined. This type of analysis allows identifying the most critical elements for the functionality of the port system (i.e., the components that may potentially control the performance of the harbor), considering inter- and intra-dependencies of all the components (internal and external to the harbor).

The objective of the present study is twofold: to develop and test a general method specific for the systemic vulnerability and performance of harbors. Thessaloniki's port (the 2nd largest port in Greece) is used as a case-study. The seismic hazard is assessed through the shakefield method, making use of the seismic zones proposed in SHARE project (Giardini et al. 2013). The systemic vulnerability methodology and software implementation are first described, followed by the description of the system topology and characteristics and the input for the analysis. Within this methodological framework, waterfront structures, cargo handling equipment and power supply system are examined. Appropriate fragility curves are applied for the vulnerability assessment of each element at risk. The results are obtained through a Monte Carlo simulation (MCS) which samples spatially and cross-correlated fields for all the relevant seismic Intensity Measures (IMs) and, for each of these sampled scenarios, damages and functional consequences. Performance Indicators (PIs) are then calculated and statistically combined (Fig. 1, 2, 3). The importance of each component to the functionality of the port is evaluated through the statistical correlation between its functionality and the system PIs (Fig. 4). The same analysis is then repeated considering the effects of one specific seismic scenario (M=6.5 near Thessaloniki) in order to investigate the variability on harbour's performance induced by the spatial correlations of IMs (Fig. 5). Finally, the sensitivity analysis of the results to some of the selected models is performed, in order to start constraining the potential effect of epistemic uncertainty on the presented modelling procedures (Fig. 6, sensitivity on functionality model).

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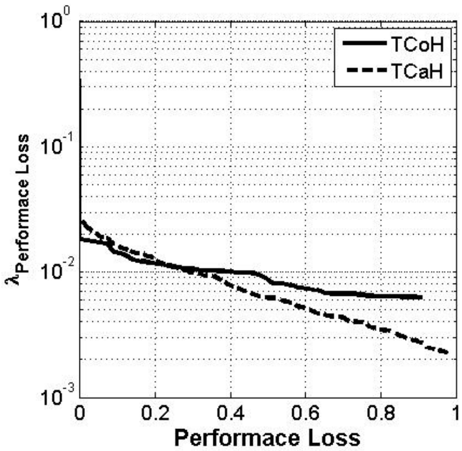

Fig. 1. MAF of exceedance curves (“performance curve”) for two PIs performance loss (TCoH= total number of containers handled (loaded and unloaded) per day, in Twenty-foot Equivalent Units (TEU), TCaH= total cargo handled (loaded and unloaded) per day, in tones). PIs are given in terms of normalized performance loss (1-PI/PImax), where PImax is the respective value referring to normal (non-seismic) conditions. For performance loss values below 20% TCaH yields higher values of exceedance frequency, while for performance loss over 20% TCoH yields higher values of exceedance frequency.

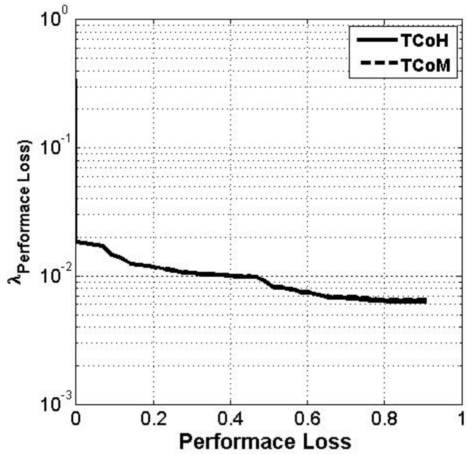

Fig. 2. MAF of exceedance curves (“performance curve”) for two PIs performance loss (TCoH= total number of containers handled (loaded and unloaded) per day, in Twenty-foot Equivalent Units (TEU), TCoM= total number of containers’ movements per day, in Twenty-foot Equivalent Units (TEU) for the whole harbor facility). The comparison of the estimated MAF curves (in terms of normalized performance loss) shows no difference, meaning that no road closures are observed. Thus, the interaction with building collapses and consequent road closures is not important to the port’s overall performance in this particular case study.

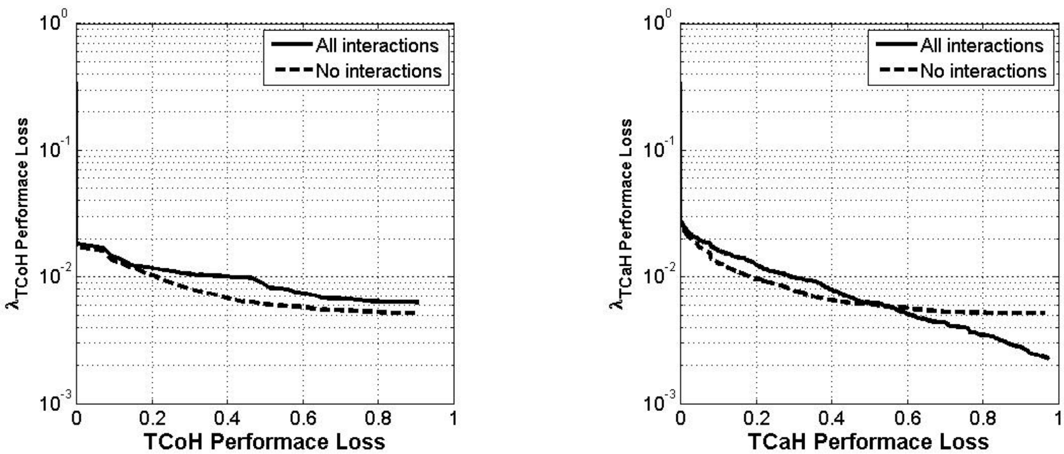

Fig. 3. MAF curves for TCoH (left) and TCaH (right) for Thessaloniki’s port, with and without interaction with EPN and building collapses. The effect of this interaction can be very important for performance loss levels over 10% for TCoH and 5% for TCaH.

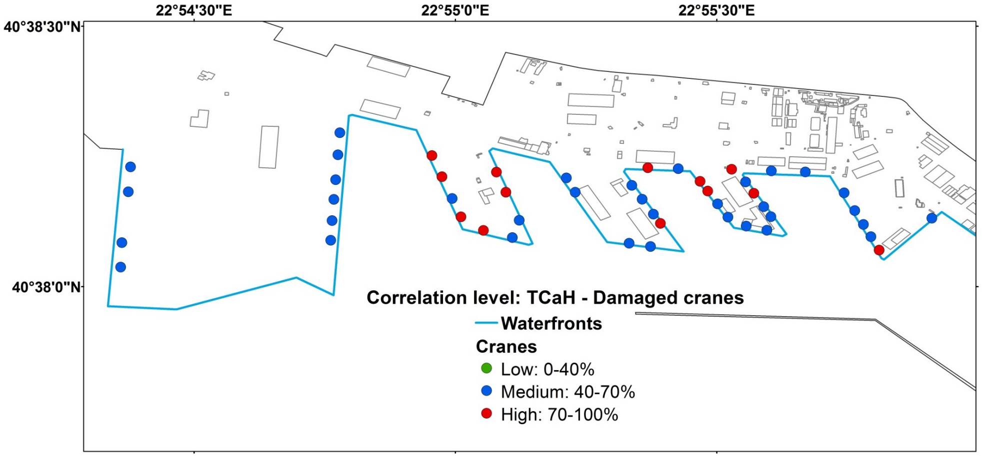

Figure 4. Correlation of damaged cranes to port performance (PI=TCaH). The most critical components can be identified in relation with their contribution to the performance loss of the system. All cranes have medium (40-70%) to high (over 70%) levels of correlation, indicating their great importance to the functionality of the overall port system.

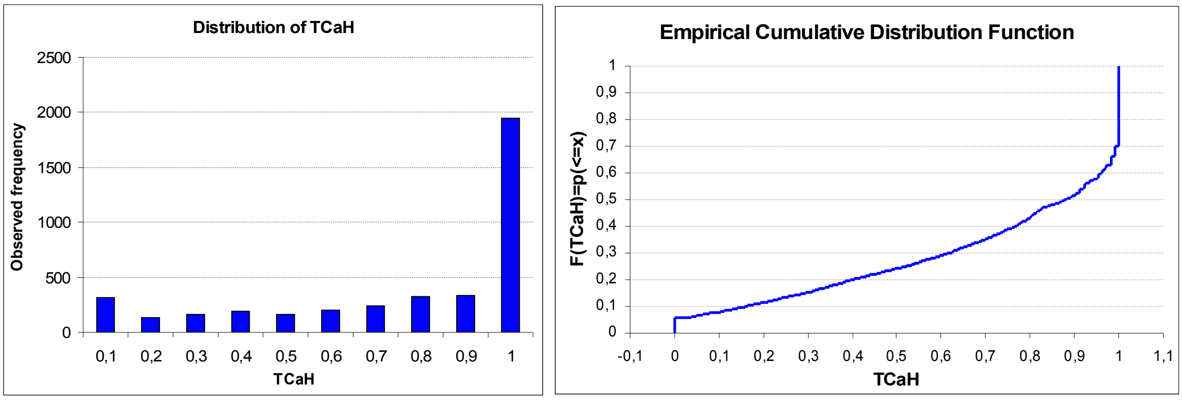

Figure 5. Histogram (left) and empirical cumulative distribution (right) of TCaH for a specific seismic scenario (M=6.5 earthquake near Thessaloniki). There is a bimodal distribution, where the modes (most frequent events) are (1) no changes in the PI (TCaH = 1) and (2) a complete loss in functionality (TCoH = 0), but there are also cases of partial loss. The empirical cumulative distribution shows that in approximately 30% of cases there is not loss, while in the 65% of cases there is a partial loss in functionality.

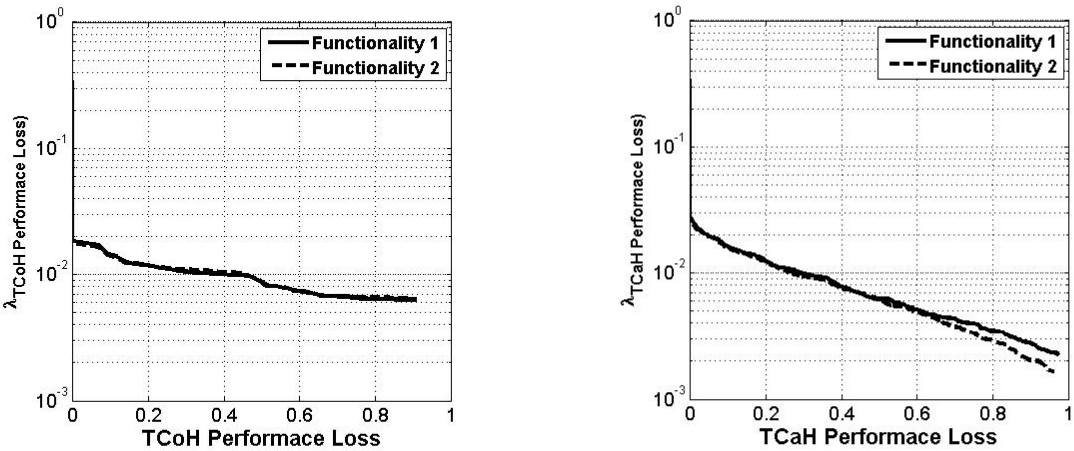

Figure 6. MAF curves for TCoH (left) and TCaH (right) for Thessaloniki's port using different functionality definitions for waterfront structures. There is some difference for TCaH with lower values of exceedance frequency for performance loss levels over 65%. High levels of performance loss correspond to lower probabilities of exceedance (or higher return periods). This is related to the fact that partial functionality of waterfronts is assumed for higher levels of damage, resulting in reduction of the port performance loss.