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PSEUDO-DYNAMIC TESTING WITH NON-LINEAR SUBSTRUCTURING: IMPLEMENTATION AND APPLICATION TO SEISMIC ASSESSMENT OF BRIDGES

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Abstract. *The response to seismic events of bridge structures is of great importance since it is usually required that they remain fully operational after an earthquake. Therefore, the ELSA laboratory has implemented the concept of pseudo-dynamic with substructuring to perform the vulnerability assessment of bridges on near real-scale models. The methodology has been applied to assess the vulnerability of the Talbergang Warth bridge in Austria. The presentation will describe and discuss the main features of the method, its laboratory implementation and the conclusions drawn from the laboratory testing.*

1 SUMMARY OF PRESENTATION

The response to seismic events of bridge structures, significant components of lifelines, is of great importance since it is usually required that they remain fully operational after an earthquake. Throughout Europe the bulk of existing bridges is not designed for seismic resistance and consequently has limited deformation capacity and poor hysteretic behaviour. In addition, the lack of capacity design results in undesired failure modes that further complicate their retrofitting. In the absence of codified requirements for existing bridges and as new earthquakes cause the revision of seismic maps, there is the need to assess the existing bridges. Extensive analytical studies have been performed but few experimental results on the nonlinear response of irregular bridges subjected to asynchronous motion are available. Hence, it is required by modern design codes to consider the space variability of the input motion or alternatively to provide movement joints.

Large-scale tests are a valuable tool in clarifying these aspects. In spite of the large testing facilities existing in a very few laboratories in the world, such as the ELSA reaction-wall facility the JRC, it is clear that a complete realistic physical model of a bridge cannot be physically tested since even these laboratories cannot accommodate such a large model. Furthermore, the costs of such a model and test set-up would be prohibitive. The development of the pseudodynamic test method with substructuring at the ELSA laboratory [8, 11, 9, 7] provides simplified, yet accurate, tools allowing the testing of the complete bridge system using the existing laboratory capacity. Furthermore, non-linear substructuring techniques open the possibility to address cases which combine non-linear hysteretic numerical modelling with physical testing, such as bridges with a large number of piers, reducing considerably the costs of models and test set-up [3, 2].

The object of the last test campaign on bridges at ELSA [1] was to assess the vulnerability an Austrian highway bridge, the Talbergang Warth bridge (794 m long, six piers with different heights and reinforcement detailing, see Fig. 1). Cyclic tests on models of a short pier and a tall pier were initially performed in order to calibrate the numerical models for the substructured piers. The pseudodynamic tests with asynchronous motion and nonlinear substructuring were then performed for three earthquake intensities.

The implemented non-linear substructuring technique for the pseudodynamic tests is schematically presented in Figure 1. Two computers were used to run the numerical models of the substructured piers, each one running two numerical pier models. The communication between the workstations was done via the local network using standard Internet connections. The master modelling process performed the time integration of the motion of the whole bridge where each pier was condensed on two DOFs (the base and the top lateral displacements), and the deck was considered as being linear elastic. The displacement to be imposed on the piers was transmitted at each time step to 3 processes: two of them performed the nonlinear loading of the four numerical piers and the third was the master experimental process which in turns piloted the two controllers of the physical

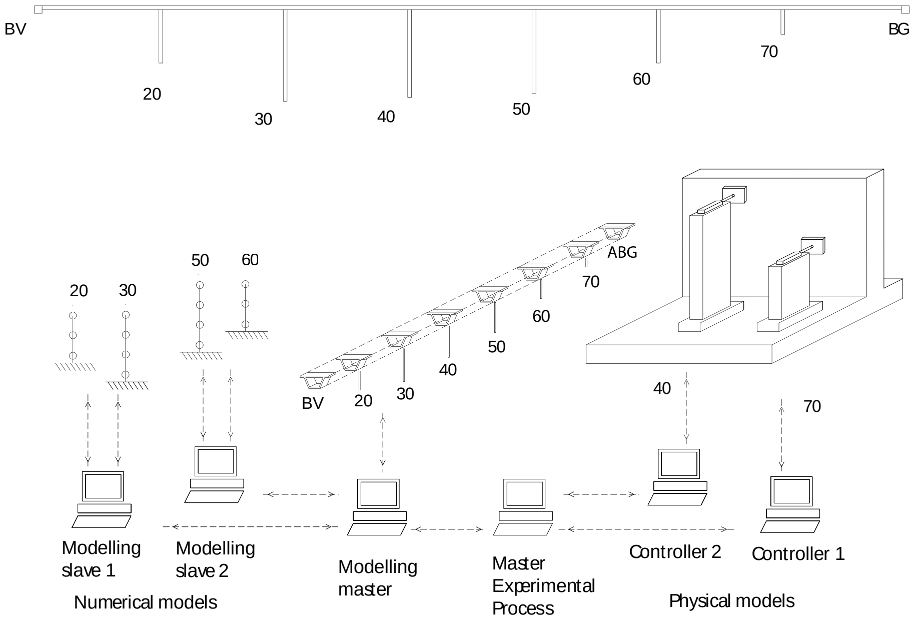

Figure 1: Schematic representation of the pseudodynamic test with substructuring on the Warth bridge.

piers in the laboratory.

In order to guarantee representative and accurate test results a series of pre-test numerical studies were performed addressing the following specific issues: numerical integration methods for the semi-discrete system of equilibrium equations (implicit vs α-Operator Splitting), simplification of the numerical models for the substructured piers, definition of asynchronous motions.

The semi-discrete system of equilibrium equations of motion was numerically integrated using both an iterative implicit and the non-iterative α-Operator Splitting [5] schemes. The results of the numerical simulation were similar. In addition, the results of the numerical simulation were in agreement with the results of the numerical dynamic analysis.

For the piers, the 2D fibre model [10] corresponding to the original rectangular-hollow cross-section was simplified as follows in order to increase the robustness and reduce the computation time, without compromising its accuracy. Since the cross-section is symmetric and the bending is applied along an axis of symmetry, an equivalent I cross-section was first considered. To further simplify the model, a new element was implemented for the reinforcement steel: the geometrical support was a point, enabling the use of better-distributed elements to model the vertical rebars. In addition, a new element was implemented for the modelling of the concrete with only two integration points instead of four. Finally, considering the symmetry of the geometry and the loading, only 3 DOFs per node were significant in that case. A 2D beam model was then used considering the simplified cross-section. All these alternative models gave consistent results; it was therefore decided to use the simplest one for the substructured piers. Finally, The constitutive law for steel was bilinear; numerical simulations giving results similar to those obtained by more realistic models. The foundation blocks of the piers were considered to remain elastic and to be fixed along all 3 DOFs.

The deck was modelled as a fibre/Timoshenko beam and was considered to remain elastic, in accordance with the requirements of modern codes for new bridges and assumptions commonly used in the design and retrofit of bridges. For the deck all 6 DOFs by node have been kept in order to better describe the coupling between translation, bending and torsion of the deck. An adequate connection between the corresponding DOFs of the deck and the top of the piers was established. The abutments constrained the displacement in all three axes and the rotation by the bridge axis.

The damping matrix was calculated by considering only the damping of the deck and assuming a truncated modal damping in order to avoid problems related to rigid body motion in case of asynchronous loading. The calculated eigenfrequencies were found in agreement to the experimentally measured values by dynamic in-situ tests. The asynchronous input motion was defined by artificial accelerograms generated by site compatible seismological models and scaled to the laboratory model.

Three earthquake pseudo-dynamic tests with increasing input intensities were successfully carried out on the bridge model. The results have shown that these structures have very little deformation capacity (see Figure 2). Furthermore, they are likely to collapse for earthquake intensities slightly higher the nominal ones. It is therefore confirmed that most existing bridges in earthquake prone areas in Europe have an unacceptable performance. Retrofitting of these infrastructures is therefore required.

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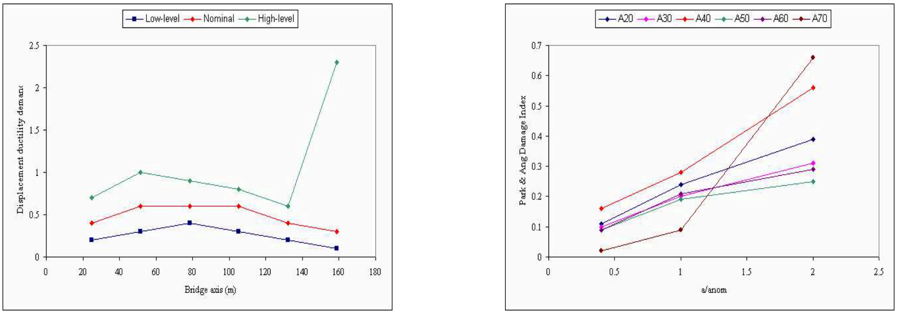

Figure 2: Ductility demand and vulnerability curves for the bridge piers for three input motion intensities

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