# SEISMIC ANALYSIS OF SHEAR WALL MODEL

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**Abstract-** The shear wall which resisted the earthquake, although its design code limits were exceeded, is analyzed. Measured data obtained during full-scale cyclic testing of reinforced concrete low-rise shear-wall serve as the starting basis for numerical research in the paper. Two nonlinear numerical models of the wall are derived: Single degree of freedom model consisting parallel springs and sliding elements and single degree of freedom model with material law obtained as envelope curve of the measured hysteresis. Various aspects of behavior under seismic loading are studied using the models. The linear and nonlinear behavior shear wall under seismic excitation is analyzed in time domain. Results of both models are compared. It is shown that the mass of the surrounding structure strongly influences the linear respectively nonlinear behavior of the wall.

**Index Terms-** Experimentally based numerical seismic analysis, low-rise reinforced concrete shear walls, SDOF model.

## I. INTRODUCTION

Earthquakes caused the deadliest disasters in the past decades. We are not able to avoid the occurrence of earthquakes, but we can prevent the impact of earthquakes using knowledge of earthquakes and structures in their coherence. There are examples of structures resisted the earthquake, although the design code limits used for these structures were exceeded. This is the source of inspiration for this paper. The aim of the paper is to analyze all available facts of "surprising" resisted structure and to derive the consequences. The response spectra of the 2007 Chūetsu earthquake surpassed the design spectra for the investigated structures of the nuclear power plant. No significant damage of Kashiwazaki-Kariwa nuclear power plant bearing structures was reported by IAEA (International Atomic Energy Agency) expert group, 2007 [1]. It has been subsequently determined that the low-rise reinforced concrete shear walls used in nuclear power plant are generally not sufficiently theoretically and experimentally investigated.

## II. CURRENT RESEARCH

Reinforced concrete shear walls are frequently used in civil engineering as structural elements resisting horizontal forces in the plane of the wall. The stiffness of the shear wall has to keep drifts within reasonable limits. Generally shear walls are divided into two groups based on their geometry: high-rise and low-rise shear walls. High-rise shear walls are governed by flexural behavior similar to a cantilever beam. The flexural behavior of reinforced concrete walls has been examined and it is theoretically described (see Orakcal et al., 2006 [2]). The behavior of low-rise shear walls is governed mainly by shear behavior. Although there has been considerable activity directed towards low-rise shear walls this area of research is still in progress (Lopes, 2001 [3] Greifenhagen et al., 2005 [4], Thomson et al, 2009 [5], Brun et al., 2011 [6]) One of the reasons is that low-rise shear walls are frequently used in nuclear power plants.

## III. TESTING

The laboratory testing of low-rise reinforced concrete shear wall was carried out by the European Laboratory for Structural Assessment of Joint Research Centre at their facilities in Ispra, Italy within the scope of the IRIS project [7]. The database of lab test results is used in the proposed project.

The reinforced concrete shear wall specimens comprised the low-rise shear wall part connected at the top and bottom to massive beams. Beams served to shear force transfer from the testing apparatus to the concrete wall.

The load was equally distributed to the lower and upper beams. The objective of the testing was to follow the behavior of wall in cyclic shear loading up to its failure.

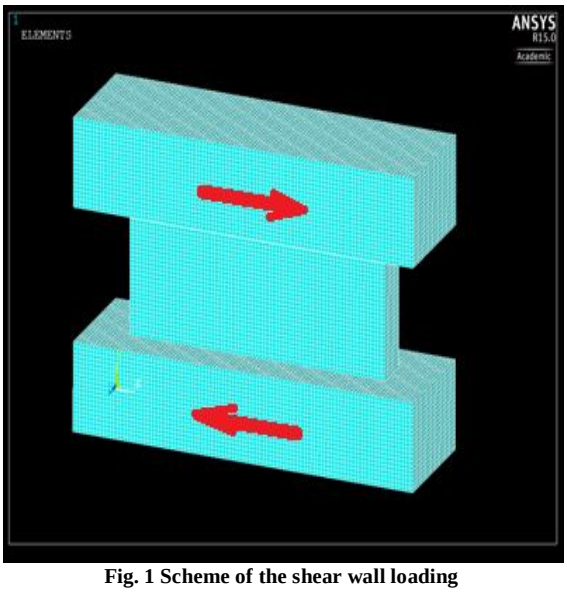



**Fig. 1 Scheme of the shear wall loading**

.A load cycle was defined as reaching the target load in one direction then retracting the actuators and subsequently pushing the wall in the opposite direction until target load has been reached then released. The detailed load history of the test is summed up in outcome database.

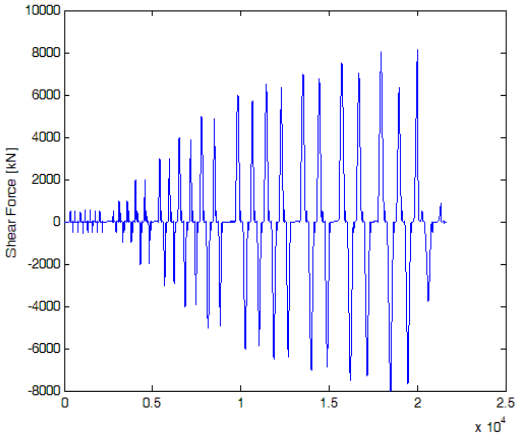



**Fig. 2 Horizontal loading: shear forces**

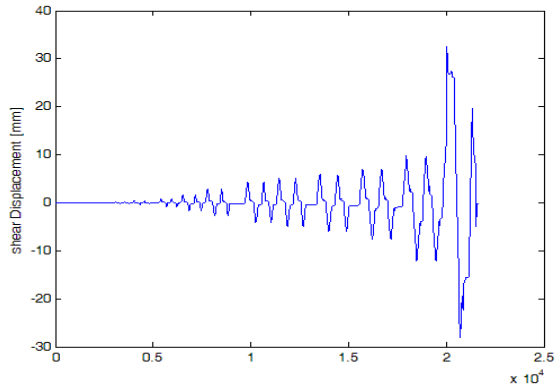



**Fig. 3 Measured horizontal displacements**

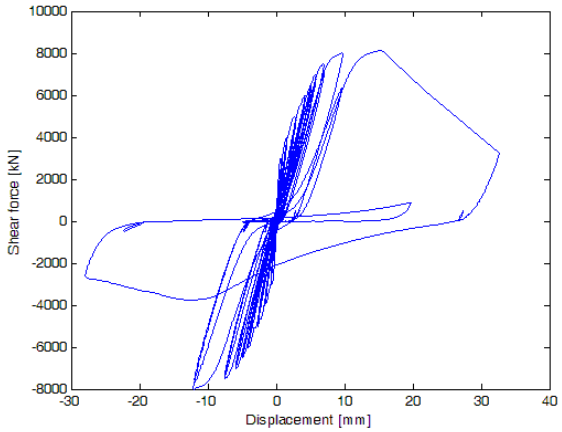



**Fig. 4 Forces vs. displacements in horizontal direction**

The forces and displacements in horizontal direction were recorded. The yield of the reinforcement and the failure of the whole wall were observed at the end of test.

## IV. NUMERICAL MODELS

The idea of the models is based on measured horizontal forces and evocated displacements at the top of the wall. The information from testing leaded into one degree of freedom model. Two nonlinear numerical models of the wall are derived: Single degree of freedom model consisting parallel springs and sliding elements and single degree of freedom – first model, model with material law obtained as envelope curve of the measured hysteresis – second model. The decreasing stiffness in each cycle of the hysteresis was taken in account. Stiffness of parallel springs with slide elements in the first model were derived from individual cycles of the hysteresis and whole model was calibrated on the base of lab testing. In the model the stiffness reduction in the sequence of load cycles is taken into account with help of limit slide forces. After reaching the slide forces, the parallel springs are gradually rejected. Comparison of experimentally and numerically obtained hystereses verified the model.

The ANSYS finite element package was used for numerical modeling and analyses. The advantage of "simple" single degree of freedom models is in effective application in expensive analyses e.g. time history seismic analyses of structural systems containing shear walls.

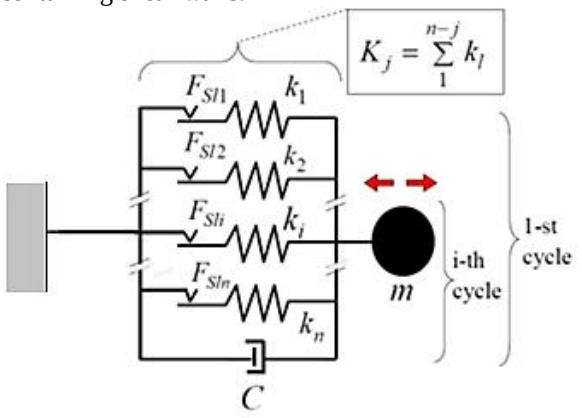



**Fig. 5 Parallel spring model**

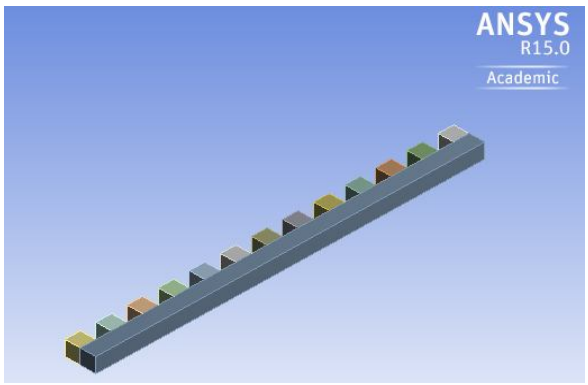



**Fig. 6 Parallel spring model in ANSYS**

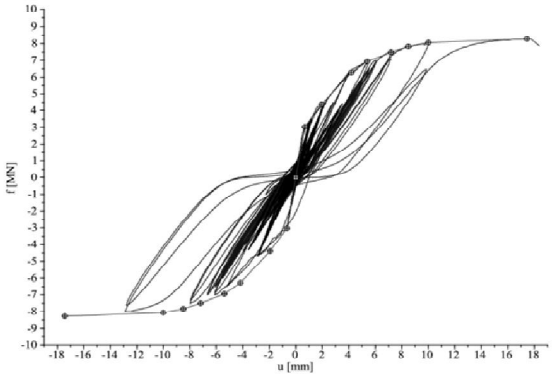



**Fig. 7 The envelope curve of hysteresis in ANSYS**

Both models were verified using the same testing loading. The response – displacement of the models is presented in Fig. 8 and compared with Fig.3.

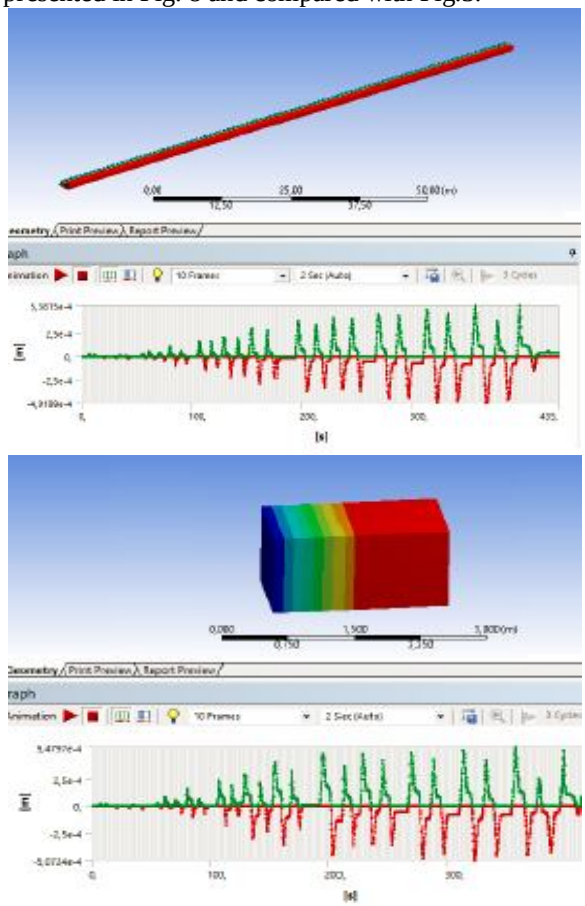


**Fig. 8 Comparison of displacements – first and second model**

## V. TIME HISTORY ANALYSIS SEISMIC ANALYSIS

The numerical investigations use the proposed numerical models. Various aspects of behavior under seismic loading are studied using the models. Models are used to analyze the linear and nonlinear behavior of a single RC shear wall under seismic excitation.

The El Centro accelerogram was used to test the linear and nonlinear behavior of the tested shear wall. The mass of the single degree of freedom model was derived from the dead load of the wall and was increased in the following analyses (the mass of the surrounding structures was added). In the first case, the behavior of the wall remained in linear domain. The linear behavior explanes the "survival" of the shear walls of Kashiwazaki-Kariwa nuclear power plant during Chūetsu earthquake.

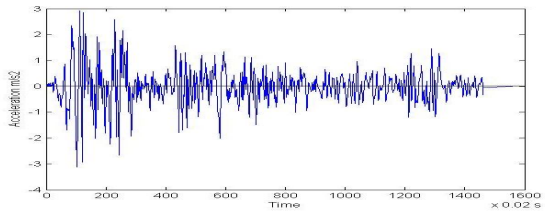


**Fig. 9 El Centro earthquake excitation**

The response of the first model – parallel springs

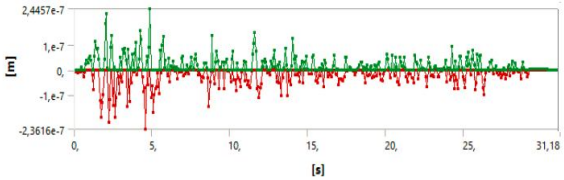


**Fig. 10 Response of the wall in elastic domain**

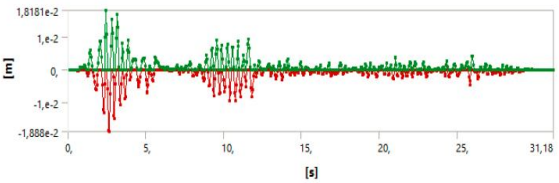


**Fig. 11 Inelastic response of the wall**

In the Table 1 is compared the mass, the displacement and the mass/displacement ratio

**Table 1**

| Mass | 1 | 10 | 100 | 1000 | 10000 |
|---|---|---|---|---|---|
| Displ. | 2.45e-7 | 2.45e-6 | 2.66e-5 | 2.98e-4 | 1.82e-2 |
| Displ./Mass | 100.0% | 100.2% | 108.8% | 121.7% | 743.4% |

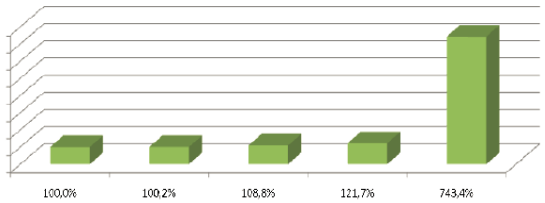


**Fig. 12 Displacement vs. mass ratio**

The response of the second model –hysteresis envelope model

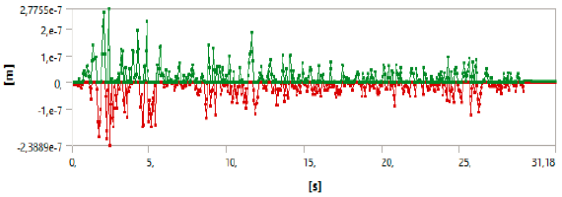


**Fig. 13 Response of the wall in elastic domain**

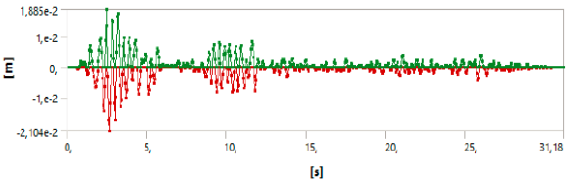


**Fig. 14 Inelastic response of the wall**

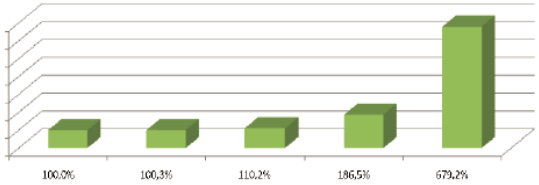


**Fig. 15 Displacement vs. mass ratio**

In the Table 2 is compared the mass, the displacement and the mass/displacement ratio

**Table 2**

| Mass | 1 | 10 | 100 | 1000 | 10000 |
|---|---|---|---|---|---|
| Displ. | 2.78e-7 | 2.78e-6 | 3.06e-5 | 5.18e-4 | 1.89e-2 |
| Displ./Mass | 100.0% | 100.3% | 110.2% | 186.5% | 679.2% |

## VI. SUMMARY

The single degree of freedom models of low rise reinforced concrete shear wall is designed on the base of experimental testing. The models are applied in time history analysis by earthquake excitation. The first model – parallel spring model is more accurate in comparison to the second model - envelope hysteresis model. It is shown that the mass of the surrounding structure strongly influences the linear respectively nonlinear behavior of the wall.

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