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ANALYSIS OF A REINFORCED CONCRETE CONTAINMENT VESSEL BY MEANS OF MULTI-LAYERED SHELL ELEMENT MODELLING

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INTRODUCTION

The problem of **energy resources exploitation** is of strong importance, in particular because of the global warming effects and pollution. Beside carbon fossil power plants, **nuclear power plants (NPP),** Figure 1, are still used in 30 countries: in this case there is also the vital issue of **population safeguard**. Moreover, a considerable amount of energy is produced by reactors that need a renewal process in a short time [1]. **Reinforced concrete (RC) components** in NPP are of strong importance for the safety and for the operation of the plants themselves. Such RC components must be modelled and analyzed under severe load conditions. The **calibration** of the models via **experimental tests** comparison is a key point for obtaining reliable solutions for the seismic assessment of existing NPPs and for the definition of a rational design for the new ones.

Figure 1. Maanshan nuclear power plant, Taiwan (credits: Wikimedia Commons)

SIMULATION OF A NUCLEAR CONTAINMENT VESSEL UNDER SEVERE CYCLIC LOADING

In the poster it is reported the response prediction of a **1/13 scaled model of a reinforced concrete containment vessel**. The specimen was tested at the National Research Center for Earthquake Engineering**,** Taipei (Taiwan), in March 2015. The specimen was tested under the effect of cyclic loading protocol, reported in figure. Non linear finite analyses have been carried out with Abaqus code by adopting multi-layered shell elements. The non linear behaviour of RC structure is evaluated with **PARC_CL** (secant) and **PARC_CL2.0** (with plastic strain) crack models, Figure 4, implemented in the user subroutine UMAT.for for loading-unloading and reloading conditions.

Figure 2 Test setup @ NCREE lab(Credits: Stocchi)

The scaled RCCV was tested with 5 actuators under which applied the cyclic load. Additional vertical loading was equal to 70 t.

Vessel: 2 layered 4 nodes shell elements (type=S4) with 3 integration points for each layer
Top and bottom slabs: 9 nodes brick elements (type=C3D8R)
Complete model:
- Globally 12000 elements
- 2800 non-linear shell elements

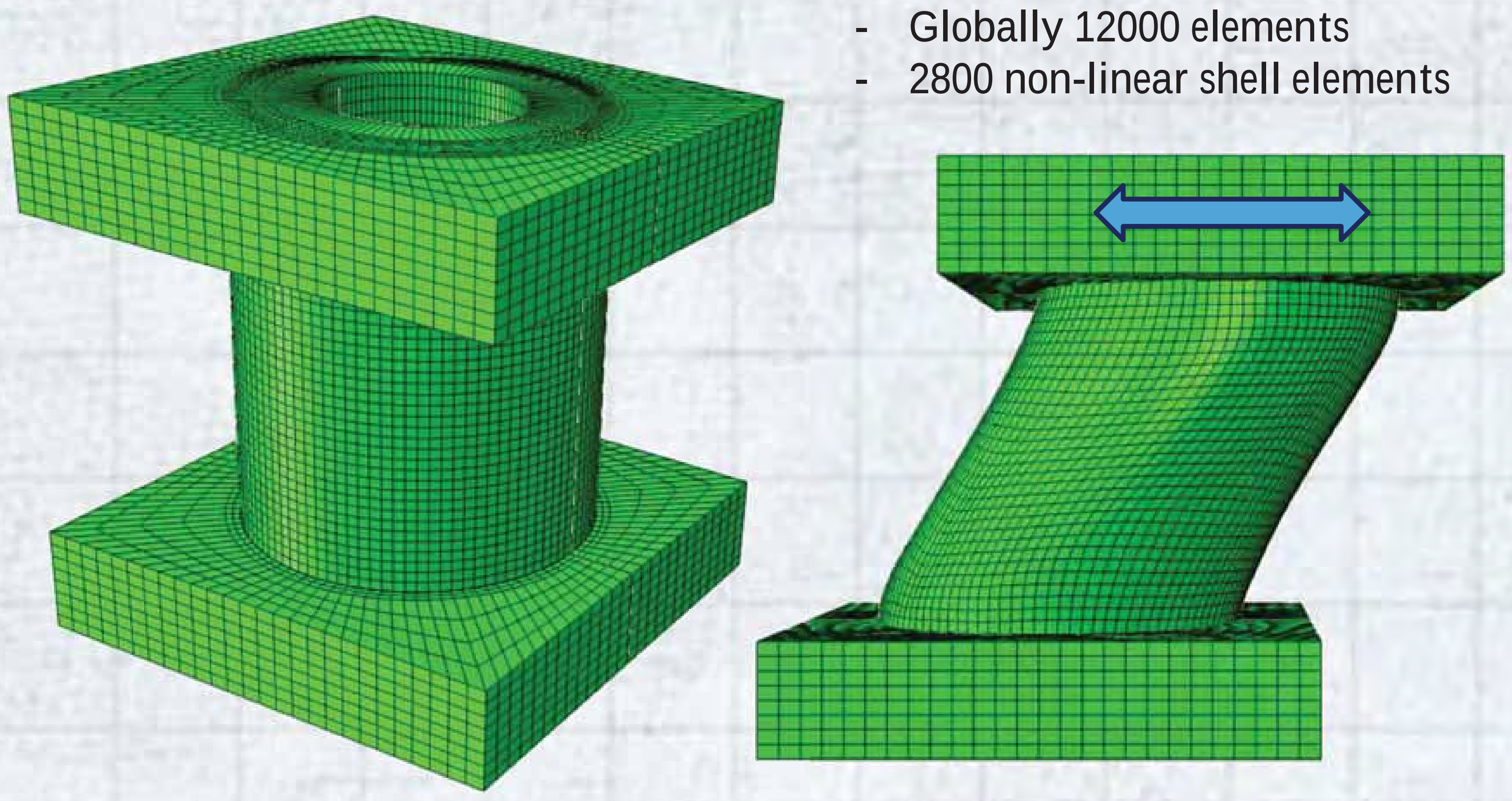


Figure 3. Numerical model for undefromed and deformed shape.

PARC_Cl Smeared crack model [2]

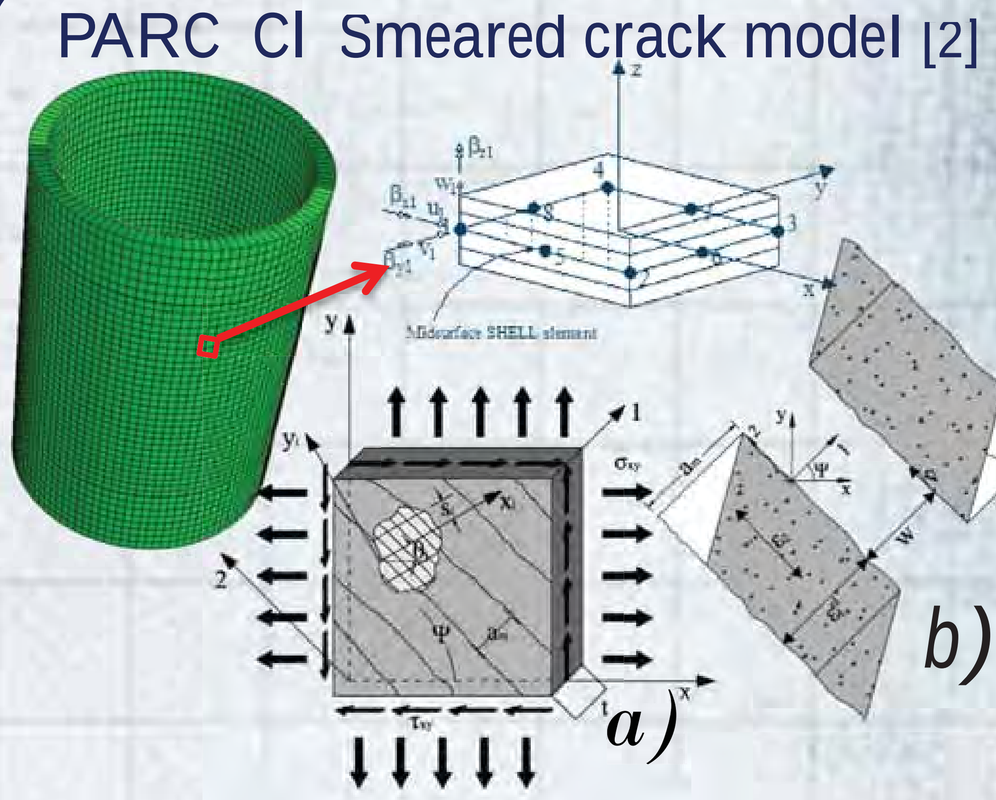
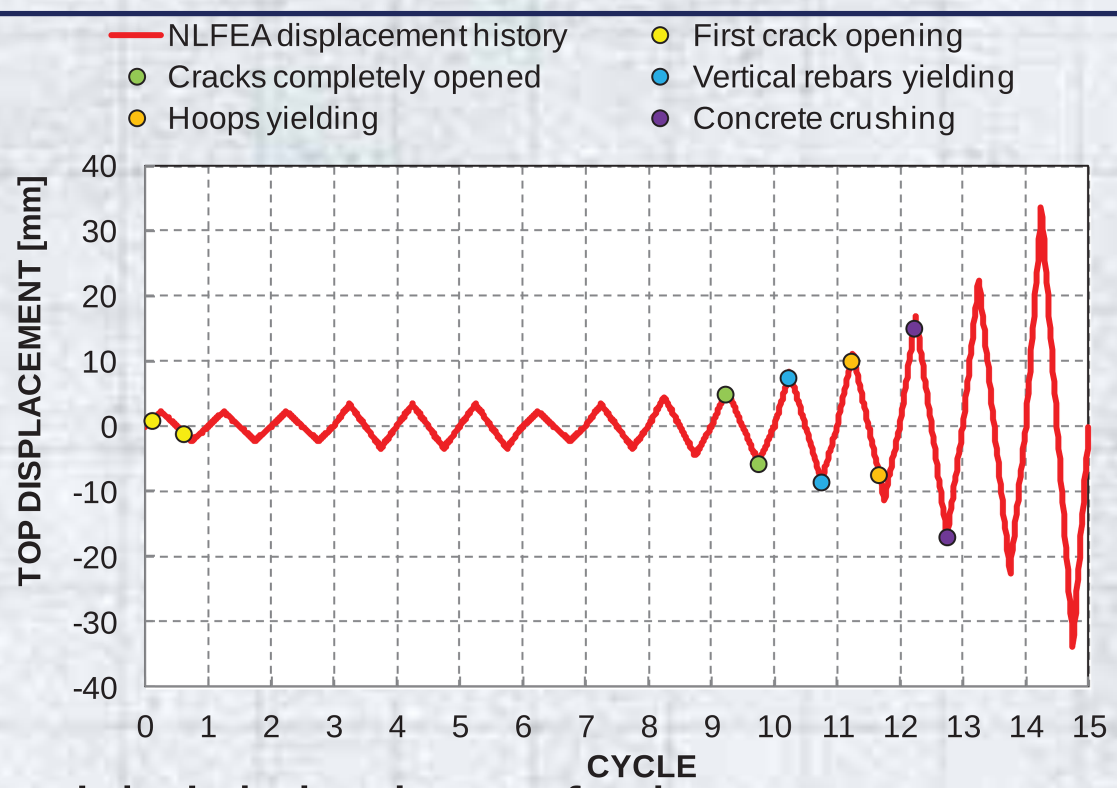
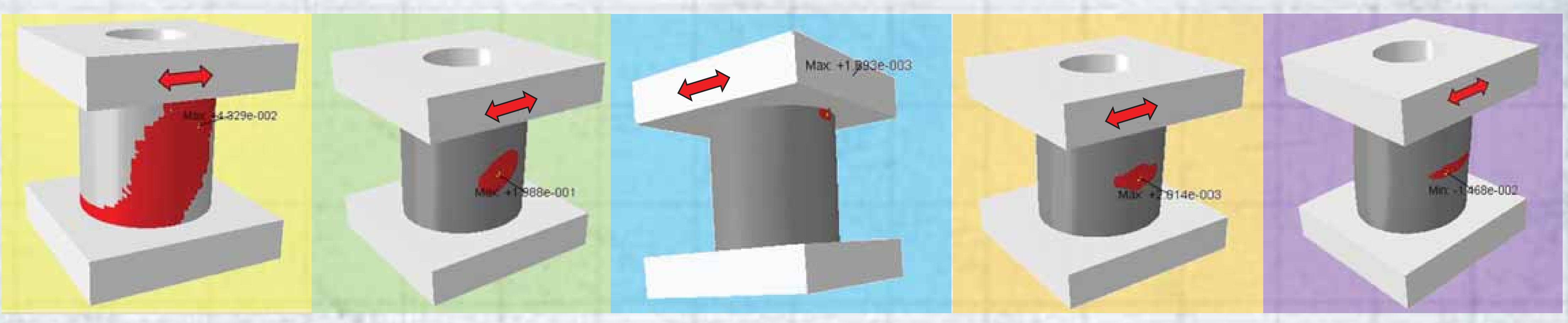


Figure 4. FEM model and a) reinforced concrete element subjected to plane stress state, b) kinematic quantities

A cyclic analysis up to collapse was performed. The main events detected during the analysis are reported in figure 5.





First crack opening	Crack opening	w	>0 mm
Cracks completely opened	Crack opening	w	>0.18 mm
Vertical bars yielding	Steel tensile strain	ε_s	>0.0018
Hoops yielding	Steel tensile strain	ε_s	>0.0019
Concrete crushing	Concrete strain in compression	ε_c	<-0.0083

Figure 5. Loading protocol and main events detected during the simulation.

The global behaviour of the RCCV is described with good approximation. The peak force at maximum displacement is correctly estimated, however the detected failure mode is not consistent with the experimental test. The estimation of steel strain (here omitted) is good up to failure.

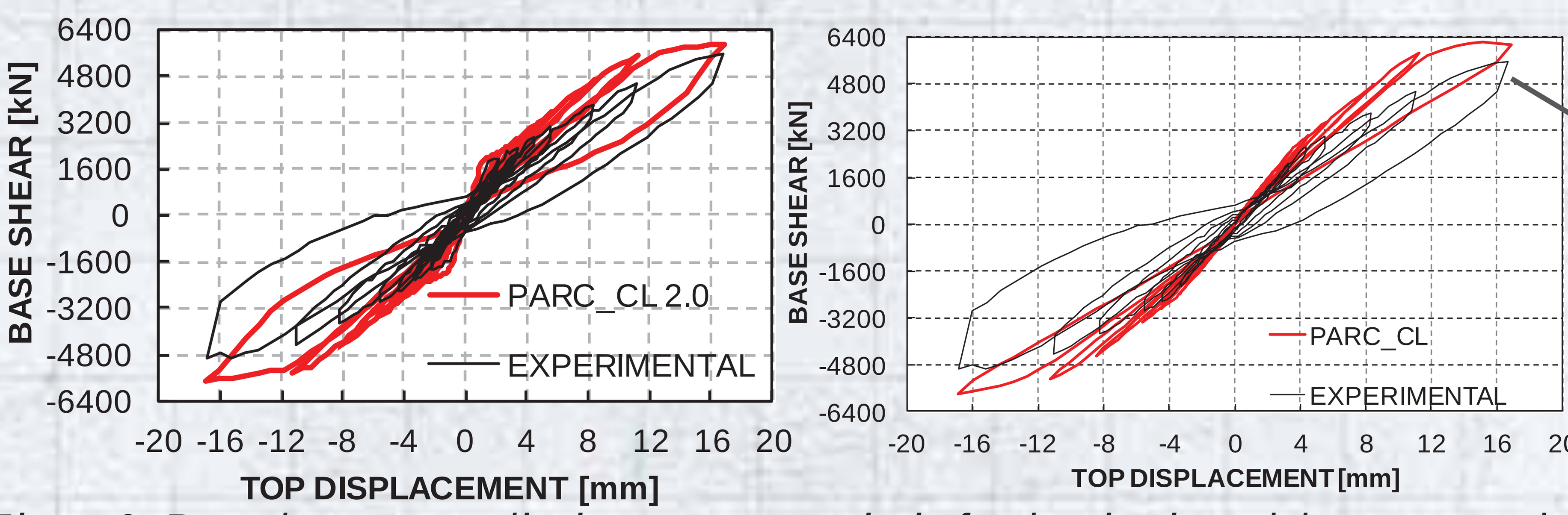


Figure 6. Base shear vs. top displacement respectively for the plastic and the secant model.

Figure 7. Sliding shear failure at interface (Credits: Stocchi).

CONCLUSIONS AND ACKNOWLEDGEMENTS

One application of the PARC_CL and PARC_CL 2.0 models a nuclear vessel cyclic analysis is shown. The models can in general provide good results for the response prediction of structures under cyclic. In fact, it is able to predict with **good estimation both of global** (displacements, peak shear force) **and local** (concrete and steel strains) **EDPs**. Despite good results, the research enlightened the importance of the implementation of the **contact problem** of structural walls to foundation and further investigations are needed. Professor T.Hsu (University of Houston), prof. Hwang (National Taiwan University) and the NCREE staff are gratefully acknowledged for their fundamental help.

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[2] Belletti B, Esposito R, Walraven J (2013). “Shear Capacity of Normal, Lightweight, and High-Strength Concrete Beams according to ModelCode 2010. II: Experimental Results versus Nonlinear Finite Element Program Results”. ASCE *Journal of Structural Engineering*, 139(9), 1600-1607.