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CASH BENCHMARK ON THE BEYOND DESIGN SEISMIC CAPACITY OF REINFORCED CONCRETE SHEAR WALLS

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ABSTRACT

CASH is an international benchmarking program organised under an initiative of the OEDC-NEA (Nuclear Energy Agency). The main objective of CASH is to evaluate the reliability of predictive analysis tools and methods as well as engineering practice know how to assess the seismic capacity of reinforced concrete shear walls to withstand strong earthquakes considered for beyond design situation.

The CASH benchmark consists of two phases. During the first stage of the program, participants are invited to qualify and calibrate their numerical models and study methodology based on several experimental loading conditions (static pushover, static cyclic and dynamic). The experimental reference case is based on the “SAFE” reinforced concrete shear wall panels (EDF/COGEMA) tested at the European Laboratory for Structural Assessment (ELSA, Joint Research Centre). These tests were carried out on the main reaction wall using a pseudo-dynamic test program. This article presents the results expected from the participants.

During the second stage, the participants would have to assess the capacity of a scale 1 shear wall extracted from an NPP building, predicting its response to various seismic loading intensities (pushover, cyclic and dynamic analyses) and provide estimates on the capacity of the RC wall.

INTRODUCTION

CASH is an international benchmarking program organised under an initiative of the OEDC-NEA (Nuclear Energy Agency). The main objective of CASH is to evaluate the reliability of predictive analysis tools and methods as well as engineering practice know how to assess the seismic capacity of reinforced concrete shear walls to withstand strong earthquakes considered for beyond design situation. The participation to the CASH program is open to experts from consulting firms, research organizations, NPP owners, regulatory authorities, and in general to all those accepting to perform computational prediction of experimentally tested and real structures.

The experimental reference case is based on the “SAFE” reinforced concrete shear wall panels (EDF/COGEMA) tested at the European Laboratory for Structural Assessment (ELSA, Joint Research Centre). These tests were carried out on the main reaction wall using a pseudo-dynamic test program. Several runs are applied on each specimen until the ultimate capacity of the structure is reached.
During the first stage of the program, from November 2014 to September 2015, participants are invited to qualify and calibrate their numerical models based on several experimental loading conditions (static pushover, cyclic and dynamic). During the second stage, from November 2015 to November 2016, the participants would have to assess the capacity of scale 1 shear wall extracted from an NPP building, predicting its response to various seismic loading intensities (pushover, cyclic and dynamic analyses) and provide estimates on the capacity of the RC wall.

This paper presents the framework of the benchmark with the expected results from the participants and the comparison objectives. An introduction to the second phase of the benchmark is also proposed.

GENERAL PRESENTATION OF THE CASH BENCHMARK

The main objective of this benchmark is to evaluate the seismic non-linear response of a multi-storey shear wall representative of a real NPP building structure.

Considering the dimensions of such structure, there are no experimental test recordings that may be used as a reference for the benchmarking purpose. In the absence of reliable test data it would be difficult to evaluate modelling results obtained by partners with different methodologies and improve our knowledge on this critical subject.

As a substitute to real test data, here the idea is to allow all partners to adjust and improve their modelling methodology by performing a preliminary study of scaled RC shear wall tests well documented with reliable recorded measures (phase 1). After this, participants are invited to proceed with the modelling and predictive calculations of the real structure (phase 2).

The work in phase 1 is organised in different tasks with increasing complexity, in order to allow participants to improve and calibrate their modelling technique. These are illustrated in Figure 1.

Task 1

SAFE pseudo-dynamic test recordings may be used to perform static computations using measurements from the jacks and displacements sensors. By considering the envelope of the force – displacement curve, the experimental capacity diagram of the shear wall is determined.

This can then be used to perform the simplest non-linear computational modelling analysis of the shear wall (task 1-A) without the additional difficulties in considering reverse cyclic loading, seismic inertial forces and damping. Test recordings are provided to participants allowing them to make all necessary adjustments and modelling parameter identifications.

A mesh sensitivity exercise is required to evaluate its effect of results by performing analyses using three meshing with different discretisation refinement.

As participants are free to calibrate material properties of their modelling, Task 1-B analyses are proposed to evaluate the response of their constitutive laws for both concrete and rebar steel. By comparing these results to SAFE sample test measures, our goal is to evaluate the degree of productiveness of modelling techniques of participants.

Task 2

Quite similar to the previous task, here the complexity of the study is increased by applying the shear wall to the entire static cyclic loading as in SAFE test conditions.

By maintaining as much as possible the same modelling parameters from task 1-A, here the goal is to evaluate the capacity of modelling techniques to predict the static cyclic response of SAFE specimens.

Similar to task 1-A, task 2-B is proposed to participants to evaluate the response of material constitutive modelling.

Task 3

Finally, in this task 3-A, dynamic seismic loading considerations are taken into account, by asking participants to perform analyses, in the same PSD conditions as during SAFE tests.

In case of any modifications from participants in material modelling, task 3-B similar to previous tasks 1-B and 2-B is proposed.

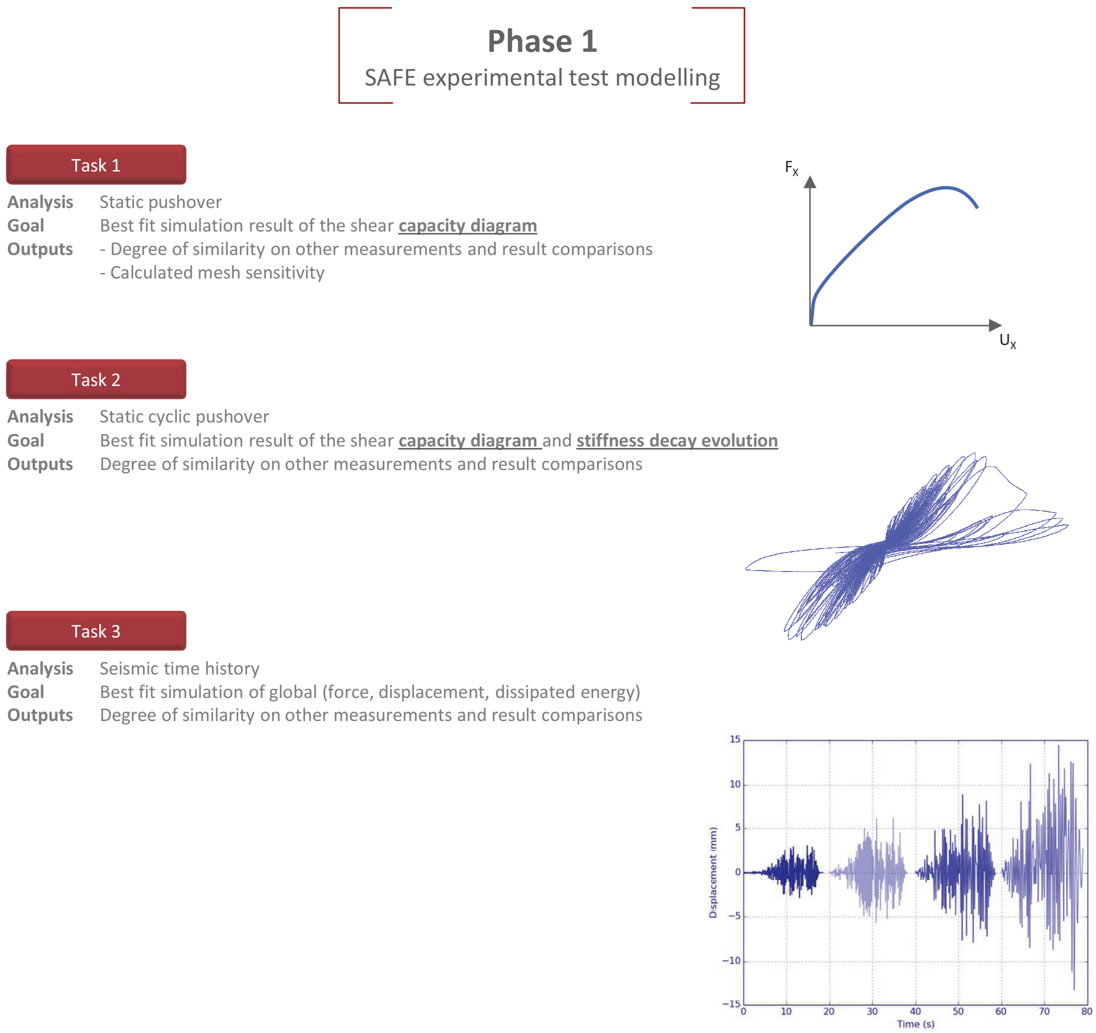

Figure 1 CASH Phase 1 Overview

SAFE EXPERIMENT DESCRIPTION

The SAFE experimental campaign (EDF/COGEMA/JRC) consists of a series of pseudo-dynamic tests carried out at the JRC Ispra laboratory in Italy, using 13 shear walls. This consists in applying loading evaluated by the computational pseudo-dynamic algorithm using hydraulic actuators. The tests were designed such that each specimen has a different natural frequency (4, 8 or 12 Hz). A unique input signal is used for the entire campaign. For each specimen, the input signal is calibrated to reach the design level of the structure. Additional runs are then applied with higher intensities until the ultimate capacity is reached.

Figure 2 presents a schematic diagram of the loading device.

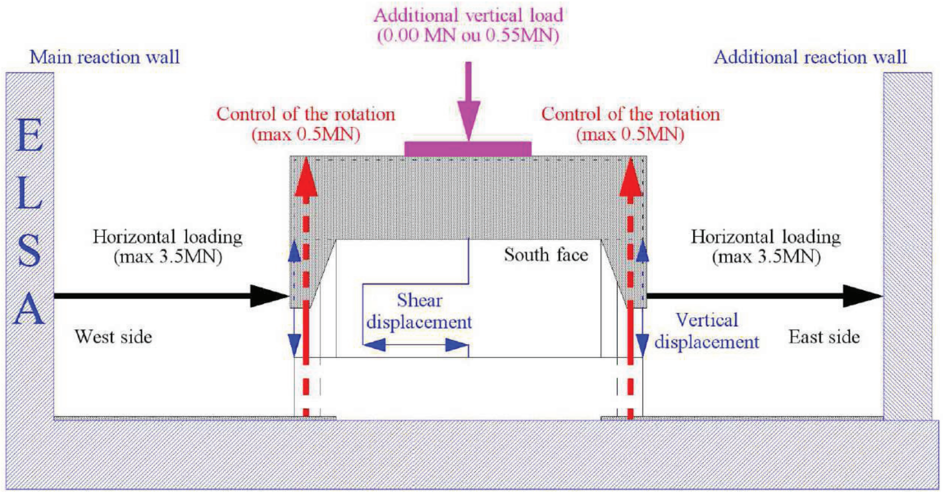

Figure 2. Schematic diagram of the loading device

For the purpose of the CASH benchmarking phase 1, four specimens are selected: T6, T7, T8 and T9. Geometrically, specimens are identical. Their differences are in horizontal reinforcement, vertical compressive stress and the first vibration frequency. The main features of these specimens are listed in Table 1.

Table 1. Main characteristics of the SAFE specimens (measured values)

		SAFE test specimens			
		T6	T7	T8	T9
Web thickness	t (cm)	20	20	20	20
Horizontal reinforcement ratio	ρ_h (%)	0.628	0.628	0.402	0.402
Vertical reinforcement ratio	ρ_v (%)	0.402	0.402	0.402	0.402
Physical mass of the top beam (including steel cover) Isotropic in all directions	M_{ph} (t)	25	25	25	25
Vertical stress in shear walls	σ_v (MPa)	1.01	1.01	0.32	0.32
Numerical PSD masse Effective only in the direction // to shear wall	M_{PSD} (t)	1 227	11 247	1 227	11 247
Elastic horizontal stiffness	K_d (MN/m)	5 346	5 767	4 555	3 742
1st horizontal deflection vibration frequency	f_1 (Hz)	10.4	3.6	9.6	2.9
Seismic input loading amplification factors: RUN 1 RUN 2 RUN 3 RUN 4	α (-)	 1.0 1.3 1.5 1.8	 1.0 2.0 5.0 10.0	 1.0 1.4 1.8 -	 1.0 3.0 6.0 10.0

SAFE tests reports are processed and essential data are prepared and provided to the participants on the benchmark website http://benchmark-cash.org. Available information is:

- Drawings (concrete and steel rebars)
- Experimental setup including boundary conditions and loading jacks
- Material properties
- Measuring devices and their locations
- Measured recordings (displacements, accelerations, strains, forces)
- Pictures of the shear wall at different run stages

The force-displacement records for specimens T6 to T9, represented in Figure 3, illustrate the different responses of the four specimens studied. Specimen T6 and T7 have a similar capacity around 5MN, while the ultimate capacity of the specimen T8 and T9 (with less horizontal reinforcement that T6 and T7) is around 4MN. The differences between the various specimens are more obvious if we compare the result for a given run (Run1) with the same intensity. The specimen T6 and T8, with a higher frequency than T7 and T8, exhibit a non-linear response, while the specimen T7 and T9 seem to remain almost linear elastic.

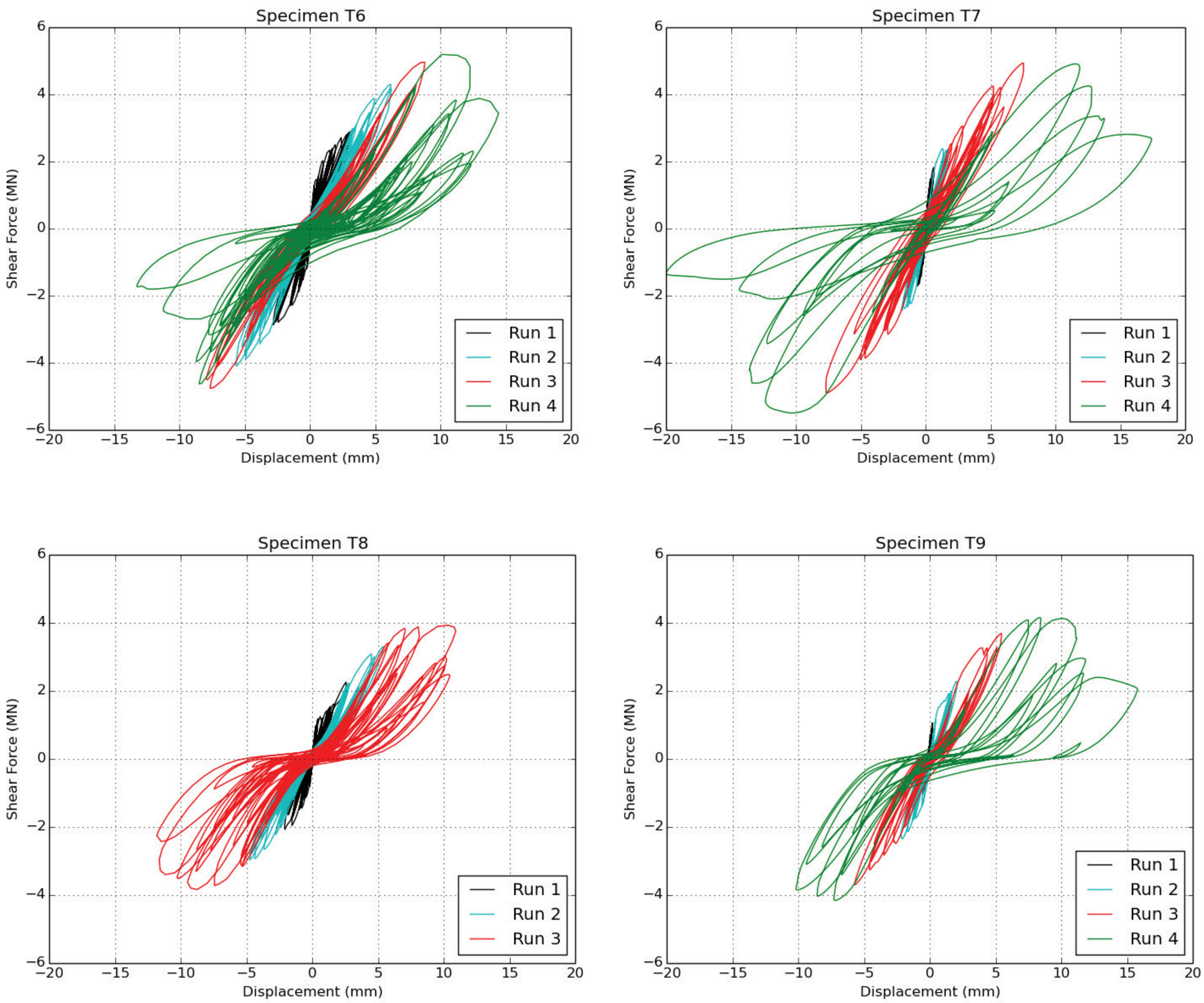

Figure 3. Specimens T6- to T9 responses

PHASE 1 SPECIFICATIONS

The detailed specifications of the benchmark phase 1 are provided in the report NECS (2014) and communicated to participating teams, as well as all available experimental data. These include experimental setup description, material properties, type and location of sensors and loading conditions.

To ease the work of the participants, four meshing (from coarse to refined discretisation) of the specimen are provided, using both shell and solid elements. However, participants are free to use them or create any other modelling. A mesh sensitivity analysis is required in task 1 (phase1), and each team may consider the one with best results to proceed with the rest of the studies.

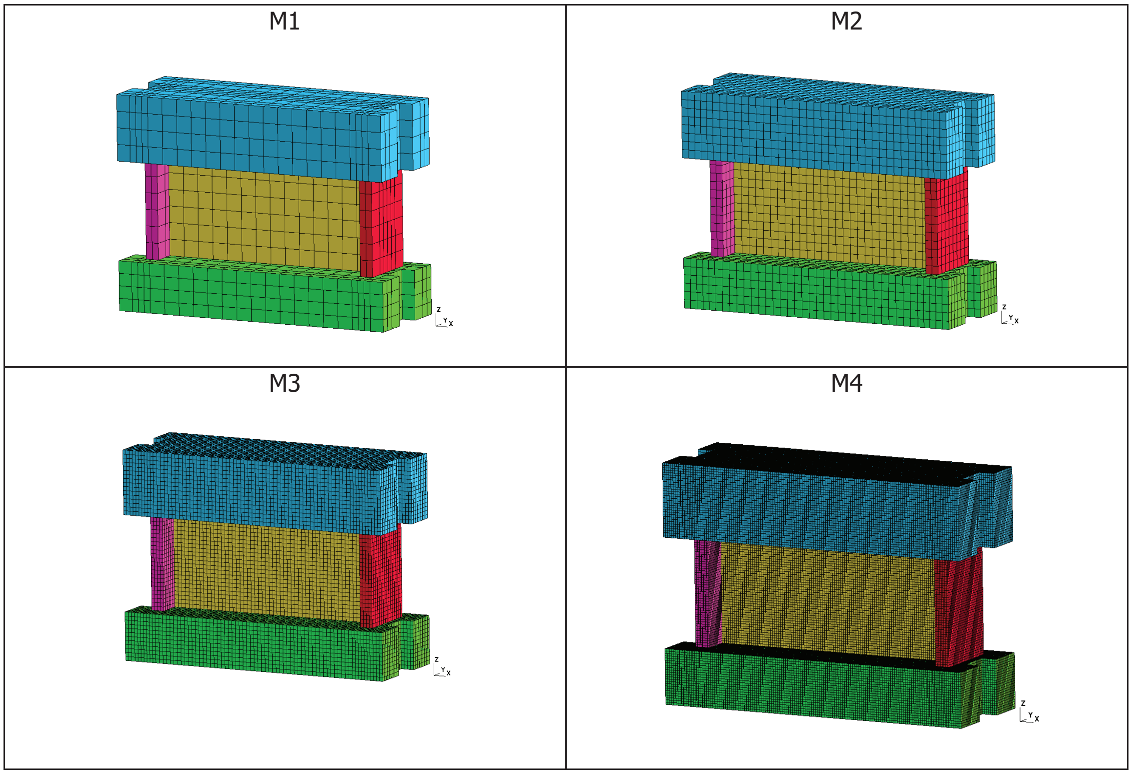

Figure 4. Provided meshing with different level of discretisation

The details of the experimental setup steel frame and vertical hydraulic jacks used to prevent the rotation of the upper beam of the specimen are not provided in the specification report, neither included in the provided FE meshing. In the modelling, this can be represented by other means, for which some guidelines are provided: upper and lower beams can be considered as linear elastic with strong stiffness, constrained rotations, etc.

A detailed list of required information is provided to each team by means of a spreadsheet file. These concern all modelling aspects from the meshing (element type and discretisation), material constitutive laws, resolution technique, extracted results, software, etc. This information may vary from one task to another. These will help the organization committee to interpret and compare the results of the various teams. The numerical data outputs consist of displacements and force records, deformed shapes and crack patterns views.

In addition to the results for the SAFE computations, teams are invited to perform elementary material tests of their constitutive laws (concrete and steel). These consist of uniaxial and shear cyclic loads on an elementary point or a single finite element. These are essential information in performing cross team comparisons at both local material and global structural scales, in order to explain differences and similarities, and their capacity to predict large scale studies from material properties.

PHASE 2 FUTURE WORKS

The phase 2 of the benchmark will deal with the study of a full-scale shear wall. The geometry and properties of the shear wall will be extracted from a nuclear power plant building. The shear wall will include an irregularity in elevation. The modelling techniques validated in phase 1 are used to carry on the predictive calculations (pushover, cyclic loads and dynamic). The objective of the phase 2 is to evaluate the ultimate capacity of the wall and the state of cracking. The results of the computation will be compared to the predicted ductility coefficients defined in standards (i.e. ASCE). This real case study will provide precious information for engineers to evaluate the ultimate capacity of structures for practical applications.

CONCLUSION

The benchmark CASH, organized by OCED-NEA, will gather international engineers and researchers on common exercises consisting of studying reinforced concrete shear wall capacity. The present article presents the first exercise proposed to the participants, base on the SAFE experimental tests. Four shear walls of entire programme have been selected for the purpose of this benchmark. Each participating team is invited to produce their best estimate calculation to evaluate the response of the specimens under static (monotonic and cyclic) and dynamic loading. The comparison of the modelling methods and the results of the participants will be released in November 2015 at the occasion of a workshop that will be held in Paris. The conclusions will be used for the second phase of the benchmark, where a full-scale shear wall of an NPP building will be studied.

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