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Division V

OECD/NEA/CSNI PROJECT ASCET ON NUMERICAL SIMULATIONS OF SQUAT SHEAR WALLS WITH ALKALI-SILICA REACTION

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ABSTRACT

The alkali–silica reaction (ASR), a type of alkali–aggregate reaction (AAR), is observed in some concrete structures of nuclear facilities in eastern North America, Europe and Japan. The working group on integrity and ageing of components and structures (WGIAGE) under the Committee on the Safety of Nuclear Installations (CSNI) of the Nuclear Energy Agency (NEA) has put in place a three-phase international research program titled *Assessment of Structures Subject to Concrete Pathologies* (ASCET). Phase I of the project was related to the general recommendations for aging of concrete structures with concrete degradations, while Phases II and III were related to the numerical simulations of squat shear walls with the same geometry and reinforcement: three with ASR concrete and two with regular concrete. All shear walls were manufactured and cured under accelerated aging at the University of Toronto, under a CNSC research program. This paper presents the numerical simulation benchmarks performed in ASCET Phases II and III. Nine teams from Canada, France, Japan, Sweden, and Untied States participated in the ASCET benchmark. Most of the participants used commercially available software and modelled the ASR concrete degradation using different approaches. The ASCET Phase II benchmark (2017) consisted of blind simulations of shear walls tests with ASR and regular concrete after 995 and 975 days of accelerated aging. To calibrate the numerical models, the organizing committee provided the participants with the tests results of the ASR and the regular concrete after 260 and 240 days of accelerated aging. In Phase III, the organizing committee provided the participants with all available information on these four walls and, in addition, the test results of one ASR concrete wall tested after 610 days of accelerated aging. All the walls were loaded using the same protocol. The amplitude of the horizontal in-plane cycling loading was incrementally increased up to the failure of the wall. The load in the vertical direction was the same for all walls producing the vertical stresses typical for dead load in nuclear facilities. Maximum shear (ultimate) capacity, failure modes, crack patterns, structural ductility and energy dissipation were considered for this benchmark. The findings of the testing program were: 1) ultimate wall capacity under in-plane horizontal loading was not affected by ASR and 2) structural ductility and energy absorption (hysteretic damping) were significantly reduced. All participants successfully simulated the ultimate wall capacity. However, the simulations of failure modes, crack patterns, structural ductility and energy dissipation were less successful. The paper provides conclusions of the numerical simulations and recommendations for conducting this type of structural analysis.

INTRODUCTION

The alkali–silica reaction (ASR), a type of alkali–aggregate reaction (AAR), is observed in some concrete structures of nuclear facilities in eastern North America, Europe and Japan. The working group on integrity and ageing of components and structures (WGIAGE) under the Committee on the Safety of Nuclear Installations (CSNI) of the Nuclear Energy Agency (NEA) has put in place a three-phase international research program titled *Assessment of Structures Subject to Concrete Pathologies* (ASCET). Phase I of the

project was related to the general recommendations for aging of concrete structures with concrete degradations (NEA/CSNI, 2016), while Phases II (NEA/CSNI, 2018) and Phase III (NEA/CSNI, 2019) were related to the numerical simulations of squat shear walls with the same geometry and reinforcement: three with ASR concrete and two with regular concrete. This paper addresses the numerical simulation benchmarks performed in ASCET Phases II and III.

TEST SETUP

A schematic of the shear wall test setup is shown in Figure 1. Five squat shear walls with same boundary elements (same dimensions, same reinforcement and cured at 50 degrees C and 95% of humidity) were tested (Orbovic et al, 2015). The lower beam is fixed on the strong floor with a steel beam and the strong anchor in its center and laterally, with the 2 in. steel plates. The upper beam is free to rotate during the lateral cyclic loading. A dead load of 800 kN was applied on the upper beam. Figure 2 a) shows loading cycles and their number as well as the position of linear variable differential transformer (LVDT) gauges for lateral displacement measurements. The measured displacements provided to the participants were the displacements of the A frame (the difference between the top displacements and two bottom displacements). The ASR expansions for controlling concrete specimens (prisms) aged for the same length of time as the walls were: 0.19% (ASR A1), ASR B1 (0.215% expansion at age of 610 days) and 0.223% (ASR B2). The wall dimensions and the reinforcement are presented in Figure 3.

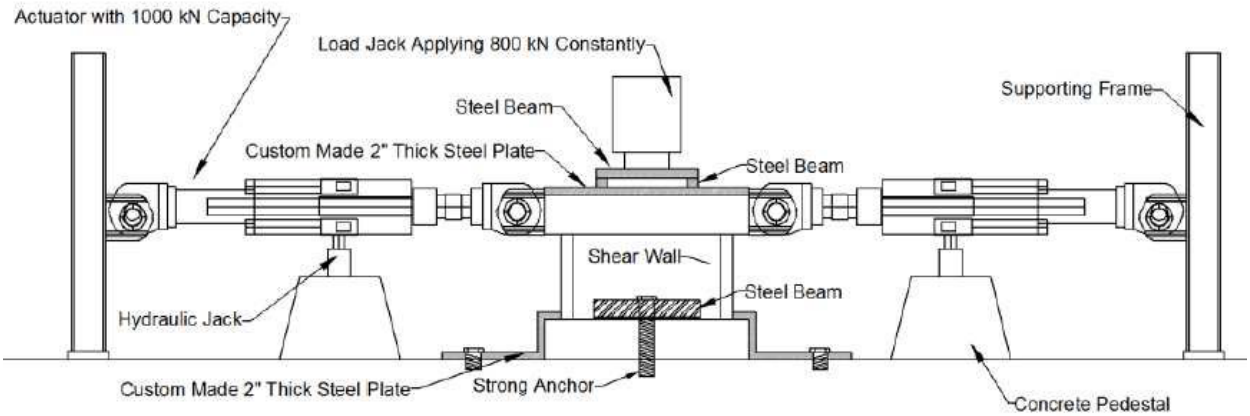
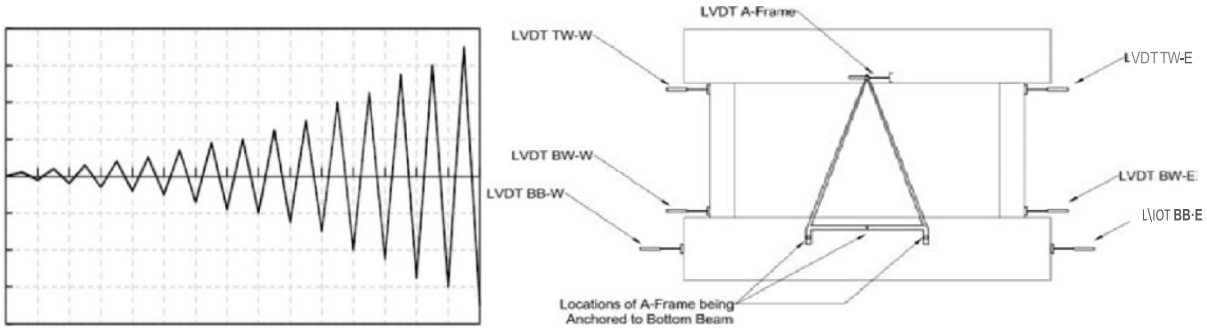


Figure 1. Schematic of the test setup



a) Cycle Number b) LVDT gauges

Figure 2. Number of cycles and placement of gauges

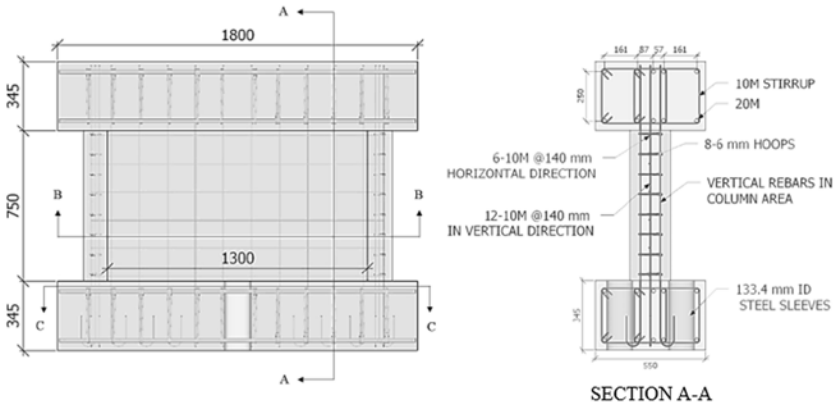


Figure 3. Dimensions and the reinforcement of the wall

TEST RESULTS

The test results in terms of Force-Displacements curves for two regular and three ASR walls, provided by the University of Toronto, are presented in Figures 4 and 5 (NEA/CSNI/R(2019)11). Draft Report on the Phase 3 of the Assessment of Structures Subjected to Concrete Pathologies (ASCET). The differenced in regular walls tested with different ages is not significant. The hysteretic loops for ASR walls ASR B1 and ASR B2 have a different shape comparing to the hysteric loops of regular walls (REG A and REG B) (single-slope in ASR walls versus two-slope in regular walls) and different narrowness (the ASR walls hysteric loops are much narrower than regular concrete walls hysteretic loops). Therefore, the energy dissipation under cyclic loading in ASR walls is significantly lower than in regular walls. Maximum displacements and ductility are significantly reduced as well in aged ASR B1 and ASR B2 walls. There is also a significant difference between ASR A1 and aged ASR B1 and ASR B2 walls. The authors do not have an explanation for this difference. The results of ASR A1 wall should be taken with caution.

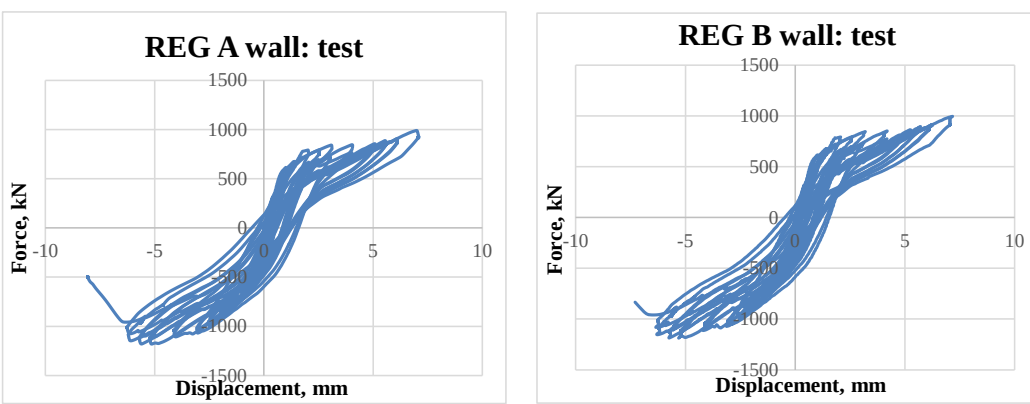


Figure 4. Force-displacement curves for regular concrete walls REG A (240 days) and REG B (970 days)

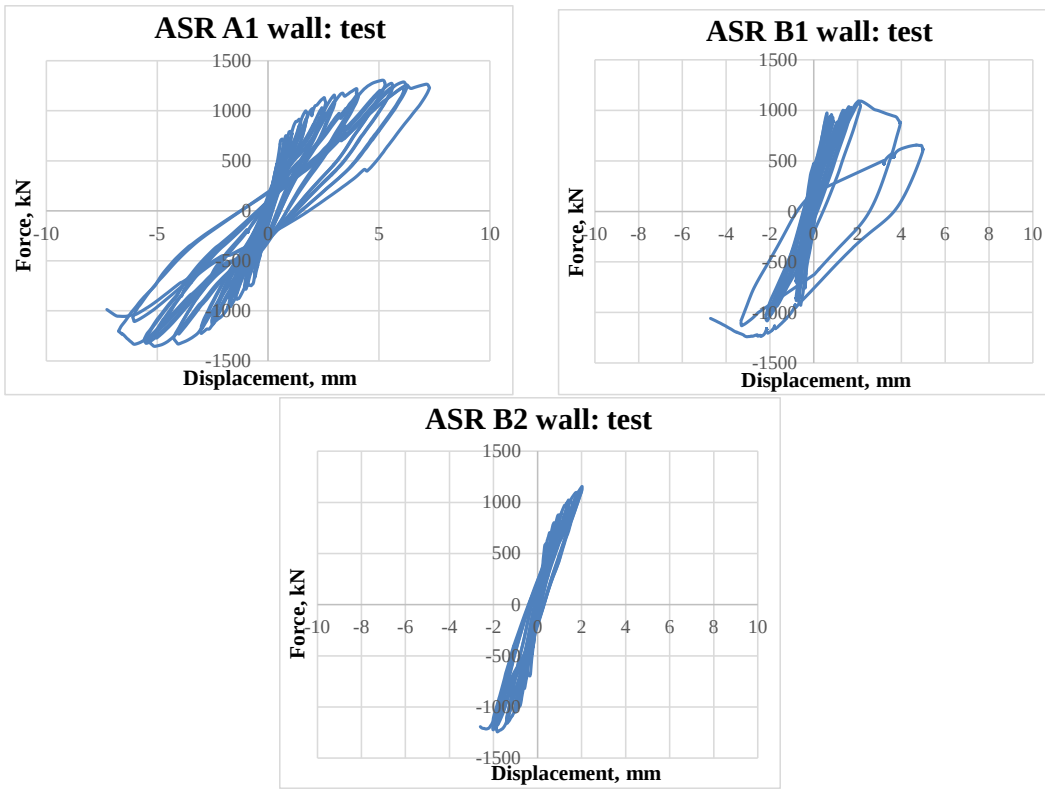


Figure 5. Force-displacement curves for walls with alkali aggregate reaction ASR A1 (260 days), ASR B1 (610 days), ASR B2 (995 days)

ASCET BENCHMARK PARTICIPANTS

The participants of the numerical benchmark were: CNSC (Canada) EDF (France), NRA, (Japan), Nagoya University (Japan), Kansai University, (Japan, Phase II only), SCANSCOT Technologies (Sweden), US NRC, UC Davis (Phase III only), University of Toronto, University of Colorado at Boulder (Phase II only). In this paper, benchmarks of Phase II and Phase III are discussed but only the results of Phase III are presented in the NEA/CSNI/R(2019)11, Draft Report on the Phase 3 of the Assessment of Structures Subjected to Concrete Pathologies (ASCET).

FINITE ELEMENT (FE) SIMULATION RESULTS

CNSC Software, Model and Test Results

Based on test runs during the phase II, the explicit FE code LS-DYNA, 2-D shell model and nonlinear material (concrete) model MAT_172/ *MAT_CONCRETE_EC2 were selected (Sagals et al, 2019).
Material data and equations governing the behavior of this model were taken from Eurocode 2 Part 1.2 (General rules – Structural fire design). The material model could represent plain concrete only, reinforcing steel only, or a smeared combination of concrete and reinforcement. The model includes concrete cracking in tension and crushing in compression, and reinforcement yield, hardening and failure. Properties are thermally sensitive. The concrete expansion due to alkali aggregate reaction was introduced as thermal expansion.The Finite Element Analysis (FEA) accurately predicted the ultimate displacement and slightly over predicted the strength of regular walls. However, the shape of the hysteric loops was not well predicted, resulting in higher and wider loops and higher energy absorption in FEA. The behavior of walls B1 and B2

with alkali aggregate reaction was well captured especially the reduced ductility and narrow hysteretic loops resulting in low energy absorption (Figure 6).

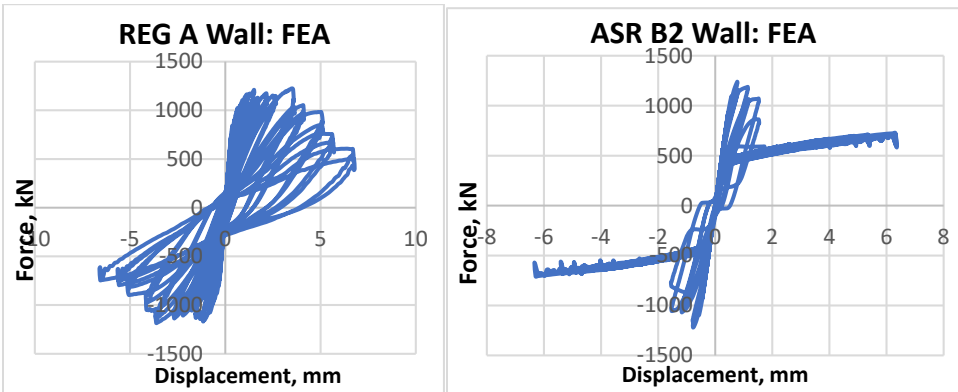


Figure 6. Force-displacement curves for regular wall REG A (240 days), ASR B2 (995 days)

US NRC Software, Model and Test Results

The software used in the US NRC study for 2D and 3D nonlinear finite element analysis (NEA/CSNI, 2019) was VecTor3 and VecTor2 software developed by the University of Toronto (Wong, Vecchio and Trommels, 2002). VecTor2 (2D non-linear analysis) uses a plane stress formulation with features to account for, in approximation, out-of-plane concrete expansion and resulting confinement provided by out of plane reinforcement. Those features enable consideration of confinement provided by the stirrups in the end elements (columns) of the shear walls. Two 3D models were developed, in which the reinforcement was modeled in two different ways, i.e., smeared reinforcement and discrete reinforcement; brick solid elements are used to model the concrete. The boundary conditions are as follows: the vertical displacements at the bottom of the concrete beam and the horizontal displacement at the center of gravity (CG) of the bottom concrete beam are fixed.

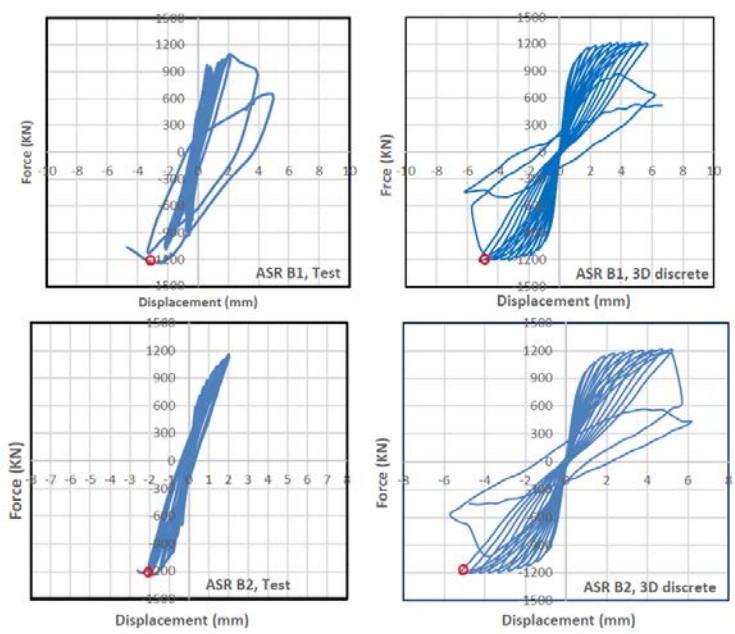


Figure 7. Force-displacement curves: test results (left hand side) and FE simulations (right hand side) for walls with alkali aggregate reaction ASR B1 (610 days), ASR B2 (995 days)

Based on comparison of the results of 2D, 3D smeared and 3D discrete reinforcement, the 3D discrete reinforcement model was selected for this benchmark and sensitivity studies.

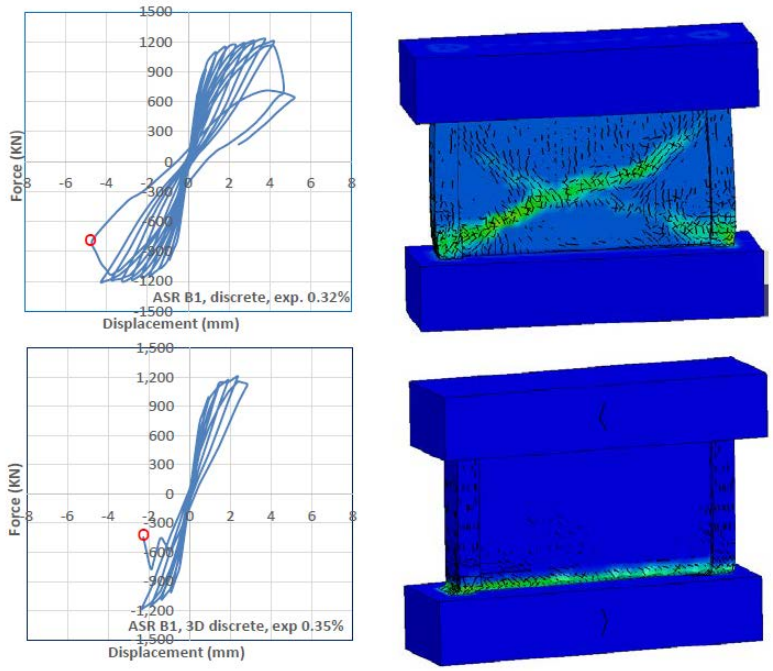


Figure 8. Force-displacement curves, crack pattern and failure modes of ASR B1 wall for 0.32% and 0.35% expansion

For the regular walls, the maximum capacity is well predicated, however, the displacements are underestimated and the model does not reproduce the two-slope hysteretic curves. For the walls with alkali aggregate reaction (ASR B1 and ASR B2) the peak strength is captured well but in these cases the models overestimate the displacements and ductility of walls with ASR (Figure 7). As previously mentioned, the test results of ASR A1 wall should be taken with caution. The sensitivity studies performed involve the following parameters: 1) effect of concrete expansion on wall capacity, 2) effect of maximum aggregates size, and 3) the effect of concrete models. The conclusion of sensitivity studies was an existence of a cliff-edge effect in wall behavior, or sudden significant change in wall behavior due to small variation in input parameters. For example, the change of unconfined expansion due to the ASR from 0.32% to 0.35% (Figure 8), or the change of aggregate size from 20 mm to 15 mm produce a change in the failure mode from shear to sliding. The change was manifested in a different failure mode. The failure modes changed from though web failure to shear-friction failure at the contact between the lower beam and the web.

EDF Software, Model and Test Results

The software used in this study was Code Aster with the concrete models FLUA_PORO_BETON and ENDO_PORO_BETON (Ghenassia et al. 2019). The main difference with the model developed in Phase II is in boundary conditions. In Phase II the lower beam was fixed to the floor at the point of the central bolt. In Phase III a sensitivity study was performed with: a) modeled test set-up and b) fixed lower beam to the slab. Additional sensitivity study was performed using variation Re-closure Characteristic Stress (REF). The REF is the stress which is necessary to close the crack. Diminution of ductility was obtained

for lower REF (change from 10 MPa used in Phase II to 5 MPa). Despite the modification, the difference between regular and ASR walls the reduction in ductility and fracture energy were not successfully simulated. The hysteretic curves of regular and walls with alkali aggregate reaction are similar in shape and maximum displacements.

NRA Report

The NRA performed the numerical simulations using FINAS/STAR software (NEA/CSNI, 2019). Two-dimensional shell and three-dimensional solid elements were used in the analysis. The non-orthogonal 3 directional smeared crack model of Maekara and Fukuura was used to introduce a nonlinear material model of reinforced concrete to FINAS/STAR. An analytical model of an alkali aggregate expansion from the study of V. Gocevski's paper based on the theory of Pietruszak, which simply express the Alkali aggregate reaction degradation phenomenon was incorporated into the non-orthogonal 3-directional smeared crack model of the FINAS-STAR.

Two models were used in this analysis: 2D model 3D elements. In the 3D model the wall reinforcement was modelled in the middle of the wall with a continued line of elements. Based on preliminary analysis it was concluded that the 3D model gave the results closer to the tests results and it was decided to use 3D model in the prediction of the behavior with alkali aggregate reaction.

The analysis results of the wall with regular concrete and the wall with reactive concrete showed similar behavior. The hysteretic loops have almost identical shape. Ultimate strength and the maximum displacements were similar. There is no difference in energy consumption between two hysteretic loops. The failure was initiated in both cases by tension at the connection between the wall and the lower beam. The difference between the regular wall and the wall with alkali aggregate reaction is in the width of the compression strut. The compression struts in the wall with alkali aggregate reaction are wider which can be caused by the lower compression strength of the concrete.

A series of additional sensitivity studies was performed varying concrete compression strength, tensile strength, bond characteristic parameter and the possibility of rotation of the upper beam. Seven cases in total were studied. With lower compressive strength, due to alkali aggregate reaction, the peak shear force was reached between 3-4 mm which is still above the displacement of 2 mm reached in the experiment. The conclusion made is that the lower compression strength leads to smaller displacements and earlier failure. The other conclusion is that the experiments were affected by the boundary conditions and the material properties of the flange pillar, the loading upper beam and the lower beam.

University of Toronto Report

The software used in the University of Toronto study for 2D and 3D nonlinear finite element analysis was VecTor2 software developed by the University of Toronto (Wong, Vecchio and Trommels, 2002). VecTor2 (2D non-linear analysis) uses a plane stress formulation with features to account for, in approximation, out-of-plane concrete expansion and resulting confinement provided by out of plane reinforcement (NEA/CSNI, 2019). This feature enables consideration of confinement provided by the stirrups in the end elements (columns) of the shear walls. A series of sensitivity studies was performed included: Boundary conditions, Smeared versus discrete reinforcement, 3D effect, Confinement of concrete, Bond strength, Reinforcement buckling and, Cover spalling and element erosion.

The overall conclusion is that three factors were identified as having a notable effect on the computed response: the boundary conditions, strength enhancement due to confinement and concrete compression response (included the post-peak stiffness). The factors without significant effect are: smeared or discrete representation of the reinforcement, three-dimensional effects, bond strength, reinforcement buckling,

cover spalling and element erosion. However, the sensitivity studies have not shown the main factor for ductility reduction and energy absorption in walls with alkali aggregate reaction.

Nagoya University Report

A discrete type numerical model, Rigid-Body-Spring Model (RBSM) developed by Kawai (1978) was used in this analysis. In the RBSM, concrete is modeled as an assemblage of rigid particles interconnected by springs arranged along their interface (NEA/CSNI, 2019).

The crack pattern is strongly affected by the mesh design since the cracks initiate and propagate through the interface of particles. Therefore, a random geometry of rigid particles is generated by a Voronoi diagram, which reduces mesh bias on the initiation and propagation phase of potential cracks. Each rigid particle has three translational and three rotational degrees of freedom defined at the centroid of the particles (Figure 18). The interface of two particles is divided into several triangles with a center of gravity and vertices of the surface as seen in the figure. One normal and two shear springs are set at the center of each triangle. By distributing the springs in this manner, the model accounts for the effects of bending and torsional moment without any rotational springs (Yamamoto et al., 2008).

Reinforcing bar is modeled as a series of regular beam elements that can be freely located within the structure, regardless of the concrete mesh design (Bolander and Saito, 1998). Three translational and three rotational degrees of freedom are defined at each beam node. The reinforcing bar is attached to the concrete particles by means of zero-size link elements that provide a load-transfer mechanism between the beam node and the concrete particles. For the reinforcing bar, the bilinear kinematic hardening model is applied. The hardening coefficient is 1/100. Crack development is strongly affected by the bond interaction between concrete and reinforcing bar. The bond stress–slip relation is provided in the spring parallel to the reinforcement of linked element. The proposed ASR model is composed by chemical model and expansion model. In the chemical model, the amount of ASR gel (*Vgel*) is estimated. The input parameters of the model are aggregate size, reactive aggregate rate and alkali amount. In addition, the model considers the reaction rate of aggregate as described later. In the expansion model, expansion strain is estimated. The expansion strain is described by *Vgel* and expansion reduction effect due to absorption area surrounding each aggregate and expansion crack itself. The simulations of both the monotonic and the cyclic loading simulations results are performed. The simulation results show that in the case of cyclic loading the load capacity and the ductility is slightly lower than the case of monotonic loading. The simulation results of ASR walls show that the load capacity decreases due to alkali aggregate reaction. While, in the test result, alkali aggregate reaction slightly increases the capacity and significantly decreases ductility.

SCANSCOT Presentation

The software used in the analysis is ABAQUS/Explicit (NEA/CSNI, 2019). The model was built using 3D solid elements and reinforcement was modelled using discrete bars with no bond slip. The lower and upper beam was modelled as elastic. The concrete constitutive model was Concrete Damage Plasticity model form ABAQUS. The alkali aggregate reaction was modeled using simplified engineering approach as isotropic (thermal) expansion. In Phase II the model underestimated the capacity of both regular and reactive wall. The failure mode was ductile failure mode. The new feature used in Phase III was bond interaction between the reinforcement and the concrete. The analysis was done for monotonic loading only.

Sensitivity studies were perfored varying the parameters in the bond slip model and it was found that the results in terms of ulitmate capacity, ductily and crack distribution are very sensitive to smalll varaitions in model parameters.

UC Davis Report

The software used was MS ESSI Simulator (Modeling and Simulation of Earth quakes, and Soils, and Structures and their Interaction), that is also known as the Real ESSI Simulator. MS ESSI Simulator is a

software, hardware and documentation system for high fidelity, high performance, time domain, nonlinear/inelastic, deterministic or probabilistic, 3D, finite element modeling and simulation of (a) statics and dynamics of soil, (b) statics and dynamics of rock, (c) statics and dynamics of structures, (d) statics of soil-structure systems, and (e) dynamics of earthquake-soil-structure system interaction (NEA/CSNI, 2019).

Beam slabs and steel plates are modeled using 27 Node-Brick element, while steel bolt is represented as a single truss element. The shear wall is modeled using nonlinear layered plane stress elements. For the web part of the wall, the elements have a horizontal rebar layer, a vertical rebar layer, and an unconfined concrete layer. For the boundary elements (columns) of the shear wall, the elements have an additional layer of confined concrete. It is emphasized that the main wall is really made from unconfined concrete, and the only actually confined concrete is within concrete boundary elements. The bottom of the model is restrained in all directions, while the lateral sides of the bottom beam slab are restrained in direction of imposed motion. Since the shear wall consists of 2D plane stress elements, the out-of-plane displacement is also precluded. The sides of the top beam slab are also restrained to have the same displacement, which is important to represent the boundary conditions of the physical experiment. Initial model included inelastic contact elements (stick-slip and gap open and close) at the bottom boundary. However it was concluded that there will be no slip and there is no gap opening so these elements were removed in order to speed up computations. The concrete material model used in this study was developed by Faria et al. (1998). Model features: 1) distinct stress-strain envelopes obtained under compression or under tension, 2) stiffness recovery after loading reversal, 3) higher concrete strength under 2D or 3D compression test, compared to 1D loading, and 4) plastic deformations discernible after some compressive stress limit is reached

The ESSI simulation curves show good agreement with experimental results (Figure 9). The differences in the envelopes of the cyclic loading curves, between the numerical and experimental results, are within 10%. The shear strengths and failure loads/displacements given by ESSI simulations match well with the values determined by physical experiments for regular walls. UC Davis team is the only participant, which predicted well bi-slope hysteretic curves of regular walls. However, the UC Davis report does not contain the simulations of ASR B1 and ASR B2 walls. Therefore, the possibility to model the ductility reduction in aged ASR walls is unknown.

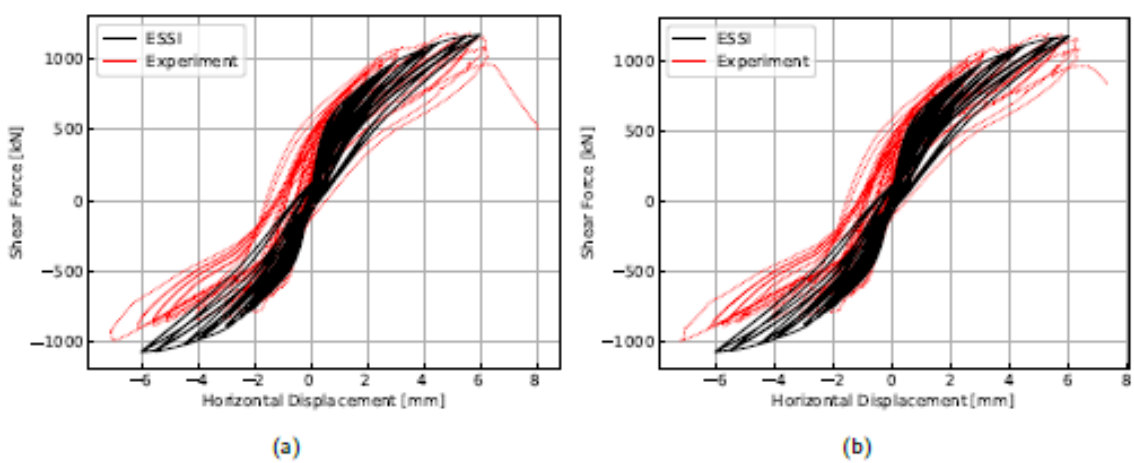


Figure 9. UC Davis hysteretic loops for REG A (a) and REG B (b) walls

DISCUSSION

The analyses CNSC and UC Davis are two simulations that captured well some aspects of the test results and the wall behavior. The hysteretic loop shapes for the regular walls and the wall with ASR tested for the shorter aging period were captured well by the UC Davis analyses. Unfortunately, the UC Davis analyses did not include the two tests with advanced alkali aggregate reaction. The CNSC study predicted well the loss of ductility and energy absorption. However, it is not clear why those two sets of simulations were better in the entire set of predictions. The CNSC used a simple approach for modeling concrete expansion due to alkali aggregate reaction using thermal expansion. The concrete model and its post-peak behavior under compression could be a governing parameter for modeling loss of ductility as shown in studies performed by US NRC and the University of Toronto.

The ASCE standard 43-05 provides the criteria for the design of nuclear facilities. Allowable drift Limits are provided as a function of limit state and structural systems. The criteria provided below are for structural shear walls. There are four Limit State (LS) criteria for four levels of seismic criteria in terms of structural drift LS-A (conventional structures) to LS-D (nuclear power plants).

Figure 10 provides force-displacement curves for the regular wall REG A and the wall with alkali-aggregate reaction ASR B2 with the design criteria in terms of allowable drifts. The limits are calculated as a function of the drift and plotted on Figure 9. For shear-controlled walls ASCE 43-05 (Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities) provides for:

- LS-A and LS-B (conventional structures) 0.75% and 0.6%, respectively, and
- LS-C and LS-D (nuclear structures) 0.4%.

In general it is a practice for the assessment of existing structures to adopt less stringent acceptance criteria than for the design of new builds. For shear controlled walls of existing conventional structures ASCE 41-06 (Seismic Rehabilitation of Existing Buildings) provides for conventional longitudinal reinforcement with nonconforming transverse reinforcement: LS (Life Safety) 0.8% and CP (Collapse Prevention) 1%. The test campaign performed at the University of Toronto does not confirm this practice. It means that the acceptance criteria for the assessment of nuclear facilities with alkali aggregate reaction, or any other concrete degradation mechanism resulting in concrete swelling, should be more stringent than for the design of new facilities.

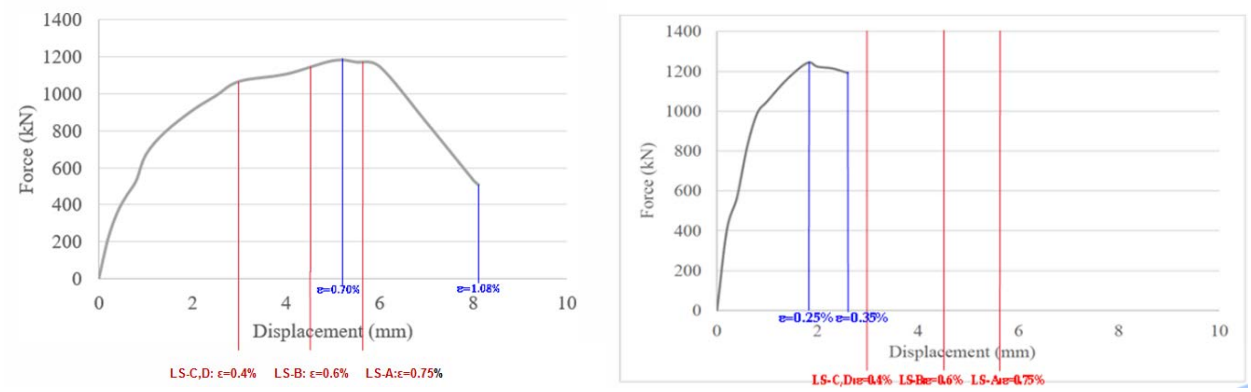


Figure 10. Force-displacement backbone curves for REGA A and ASRB2 walls

CONCLUSIONS

The objective of the series of CSNI WGIAGE ASCET (Assessment of Structures Subjected to Concrete Pathologies) activities (Phases I, II and III) was to make general recommendations for aging management of concrete nuclear facilities taking into account the effect of concrete pathologies on structural degradation.

Five walls were tested at the University of Toronto as described in Test Setup Section. The main conclusions of the test campaign are: 1) the walls with alkali aggregate reaction have the same or even slightly higher ultimate shear capacity comparing the walls made of regular concrete, despite reduced compressive and tensile concrete strengths (NEA/CSNI, 2018). Therefore, the code equations for the design of concrete elements based on concrete compressive strength are not applicable, 2) the behavior of the regular walls did not change significantly with time, and 3) the behavior of the walls with alkali aggregate reaction experience with time significant loss of ductility and energy absorption, the hysteretic loops became very narrow.

Two phases of numerical simulations were performed. Phase II was a blind simulation and Phase III with available test results. Recommendations of Phase II workshop were followed in phase III and full set of test data provided by the University of Toronto were used. Almost all participants, independently of the software used, calculated to peak strength of the walls capacity 10 % difference of the measured values. However, the displacements and the shape of hysteric loops were more difficult to simulate. Eight comprehensive studies were performed with different teams using different approaches and different software. A number of sensitivity studies were performed in Phase III in order to determine governing parameters. Despite the recommendations of Phase II that boundary conditions should have an important effect, the sensitivity studies performed by the majority of participants concluded that it was not the case. The majority of participants adopted fixed base model to reduce computing time without significant impact on the results. Displacements, deformations, failure modes and crack patterns were addressed in detail in the Phase III benchmark. Each participant provided global wall response in terms of force-displacement curves as well as crack patterns and failure modes. Loss of ductility and energy absorption (hysteretic damping) of walls with ASR concrete, comparing to the walls regular concrete, are important findings of the test campaign performed at the University of Toronto. Finding of CSNI WGIAGE ASCET program is that those losses of ductility and energy absorption are difficult to model. Special attention should be paid in the assessment of concrete structures with ASR (or any other degradation mechanism resulting in concrete swelling) regarding the simulation of those phenomena and corresponding acceptance criteria. There is a need to provide acceptance criteria for the design and assessment of concrete structures with alkali aggregate reaction (or any other degradation mechanism resulting in concrete swelling).

The code equations related to the design capacity of concrete elements, that are based on concrete compressive strength are not applicable for ASR cases. Based on the results the capacity of structure with ASR is not directly correlated to the allowable displacements and drifts, as suggested in design standards. Therefore there is a need to provide separate, uncorrelated sets of acceptance criteria in terms of capacity and deformations, The deformation limits are governing and that should be taken into account into the assessment phase, New damping values for reinforce concrete elements with alkali aggregates reaction (or any other concrete degradation resulting in concrete swelling) should be provided. The values in current design and assessment standards are high comparing to the tests and results in underestimation of structural demand. Dynamic tests are needed in order to quantify the structural damping, and A special attention should be paid to repeated, cyclic loading such as seismic loading as the reduced ductility and structural damping will reduce the structural capacity and increase the structural demand. All participants captured well the peak strength capacity of walls with alkali aggregate reaction. Only a few simulations captured the reduction of the ductility and either energy absorption of the tested walls with the advanced ASR or the shape of hysteretic loops. However, the reasons for these successful simulations are unclear. Concrete constitutive model and its post peak behavior could be the reason. It is necessary to vary the concrete model in these simulations and to perform sensitivity studies in order to determine the governing parameters leading to the significant loss of ductility. The results are sensitive to a small variation of input parameters

resulting in different failure modes and/or modification in structural ductility (cliff-edge effect). The materials and their characteristics should be carefully defined based on material specifications and tests results.

Finding of ASCET program is that those losses of ductility and energy absorption are difficult to model. Special attention should be paid in the assessment of concrete structures with ASR (or any other degradation mechanism resulting in concrete swelling) regarding the simulation of those phenomena and corresponding acceptance criteria.

REFERENCES

ASCE/SEI 43-05 "Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities"

ASCE/SEI 41-06 "Seismic Rehabilitation of Existing Buildings"

Ghenassia D., Grimal E., Gallitre E., (2019). "Alkali Aggregate Reaction in Nuclear Concrete Structures: Modeling and Laboratory Tests on Reinforced Shear Wall", Transactions, SMiRT-25, Charlotte, NC, USA

NEA/CSNI/R(2019)11 Report on the Phase 3 of the Assessment of Structures Subjected to Concrete Pathologies (ASCET)

NEA/CSNI/R(2018)4 Report on the Phase 2 of the Assessment of Structures Subjected to Concrete Pathologies (ASCET)

NEA/CSNI/R(2016)13 Final Report on the Phase 1 of the Assessment of Structures Subjected to Concrete Pathologies (ASCET)

Orbovic N., Panesar D., Sheikh S., Vecchio F., Lamarche C-P., Blahoianu A., (2015). Alkali Aggregate Reaction in Nuclear Concrete Structures Part 1: A Holistic Approach, Transactions, SMiRT-23., Manchester, UK

Sagals G., Orbovic, Nitheanandan T., (2019). "Finite Element Analysis of Walls with Alkali-Silica Reaction Subjected to Constant Axial and Cyclic Lateral Loadings", Transaction, SMiRT-25, Charlotte, NC, USA