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Canada

CNSC PERSPECTIVE ON GAPS IN KNOWLEDGE FOR CONCRETE CONTAINMENT STRUCTURES FOR LTO

NRC Hybrid Workshop on Structural Materials: What Research for Beyond 80 Years?

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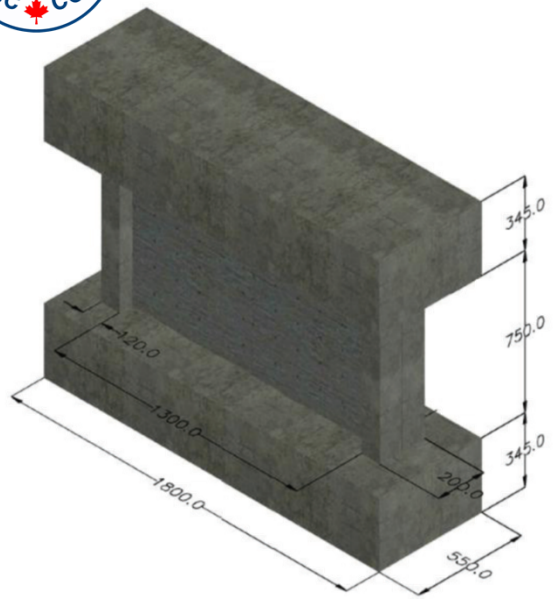
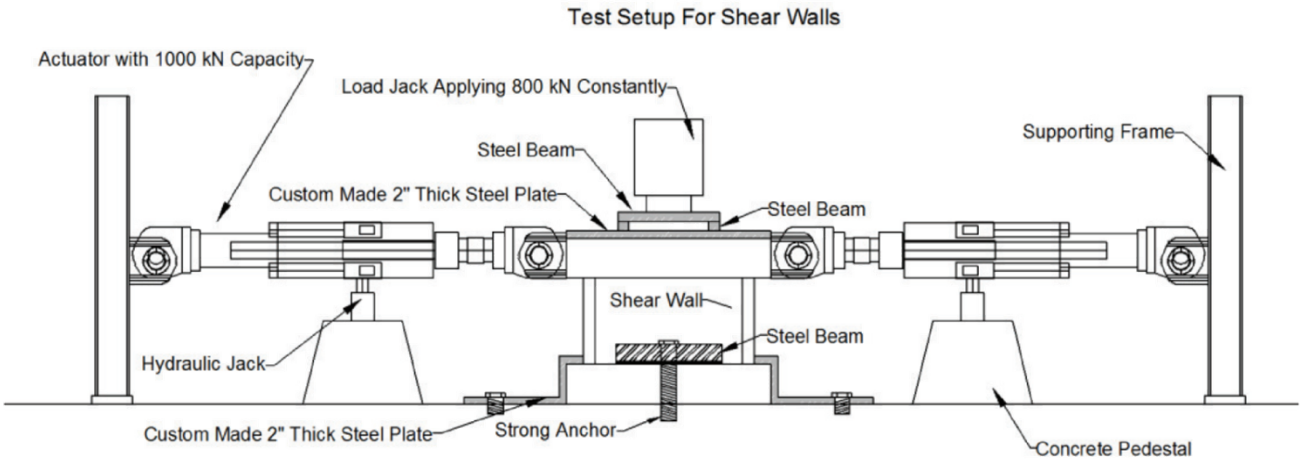
CNSC Research on ASR (1/3)

- Significant amount of reactive aggregates in Eastern NA
- AAR identified at Gentilly-2 NPP
- Need to assess consequences of AAR on the containment structures
- Research project initiated at the time of G2 licence renewal

CNSC Research on ASR (2/3)

- Structural tests (shear walls, reactive and non-reactive aggregates)

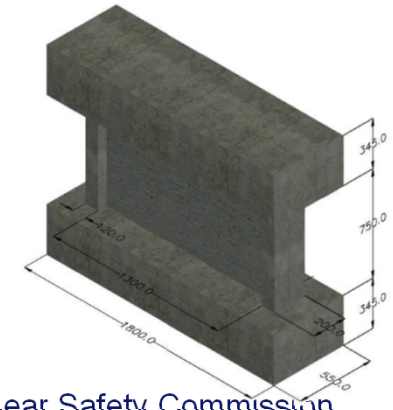


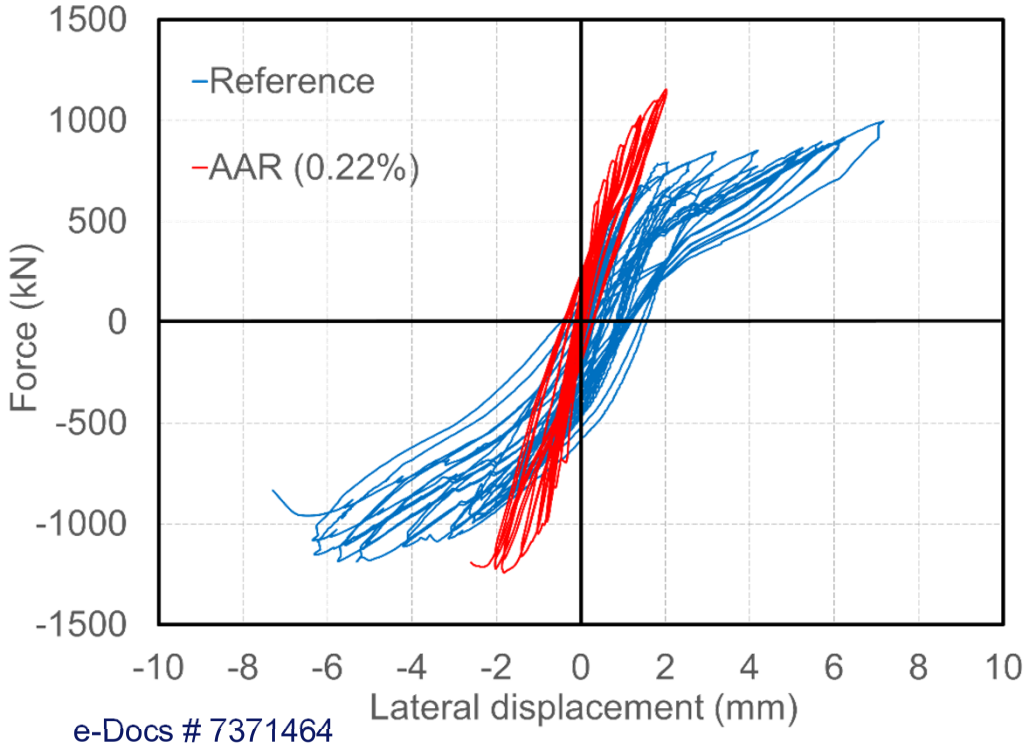


CNSC Research on ASR (3/3)

- Structural tests (shear walls, reactive and non-reactive aggregates)

Wall	Age (days)	Compressive strength (MPa)
ASR B2	995	63.0
REG B	975	80.1





ASCET project (1/6)

- Assessment of Structures Subjected to Concrete Pathologies
- Three-phase project
- Phase 1: establish state of knowledge and recommendations (research, modelling, regulation)
- Phases 2 (blind) and 3 (all data available), benchmark modelling of the CNSC structural tests performed at UofT

ASCET project (2/6)

- Some Phase 1 conclusions
  - Material testing on small scale samples is not sufficient
  - Concrete restraint (expansion), significantly modifies the structural behaviour (in particular for displacements/ductility).
  - Reduced-scale specimens with uniform curing conditions not necessarily relevant for the assessment of real structures.
  - Simultaneous actions of several degradation mechanisms.
  - NDT needed (difficulties for coring and other destructive methods).

ASCET project (3/6)

- Phases 2 (blind) and 3 (all data available), benchmark modelling of the CNSC structural tests performed at UofT
- Eleven teams participated in the benchmarks simulations of the ASCET project:

  CNSC, EDF, UofT, USNRC, Japan Nuclear Regulation Authority (NRA), Kansai University, French Institute for Radiological Protection and Nuclear Safety (IRSN), Swedish Radiation Safety Authority (SSM), University of Colorado (UoC), Nagoya University, and University of California Davis (UC Davis).

ASCET project (4/6)

Participant	Phase	Material models	ASR expansion models	Software
CNSC	II & III	*MAT_172/ *MAT_CONCRETE _EC2	Equivalent isotropic thermal expansion	LS-DYNA
EDF	II & III	FLUA_PORO_BETON and ENDO_PORO_BETON		Code ASTER
UoT	II & III	Smeared rotating crack model based on the Modified Compression Field Theory (MCFT) and the Disturbed Stress Field Model (DSFM)	6 models (uniform and anisotropic expansions)	VecTor 2
US NRC	II & III	Smeared rotating crack model based on the MCFT and the DSFM	Charlwood model	VecTor 2 / Vector 3
NRA	II & III	Maekawa and Fukuura	Pietruszczak, Ushaksaraei and Gocevski	FINAS / STAR
Kansai	II	Undisclosed	Undisclosed	Undisclosed
IRSN	II	Mazars' model	Poyet's model	Cast3M
SSM	II & III	Concrete Damage Plasticity (CDP)	Equivalent isotropic thermal expansion	Abaqus Explicit
UoC	II	Červenka and Papanikolaou	Saouma	Merlin
Nagoya	II & III	Bolander and Saito	Sugimoto et al.	In-house
UC Davis	III	Faria, Oliver and Cervera with the damage functions defined in Yang et al.		Real-ESSI Simulator

ASCET project (5/6)

- Ultimate capacity of REG and ASR walls: OK ✓
- Prediction of displacements, hysteretic loops and loss of ductility of ASR walls: NOT OK ×
- Prediction of failure modes: NOT OK ×

ASCET project (6/6)

- Need for further work in modelling structural behavior of ASR affected structures
- Deformation limits are governing the overall behavior (not ultimate capacity)
- Special attention to repeated/cyclic loading such as seismic in light of the reduced ductility

Ongoing projects (1/5)

- ODOBA: consequences of swelling reactions for nuclear massive structures

  4 research axes:

  – scale effects
  – effects of reinforcement on the swelling development and cracking initiation and development
  – ageing effects and kinetics of the phenomena
  – monitoring through the use of NDE/NDT

Ongoing projects (2/5)

- Member of the EUG of the ACES project
  - WP 1. State-of-the-art of quantitative assessment of ageing of concrete SSC in NPPs
  - WP 2. Corrosion assessment of embedded liners in concrete
  - WP 3. Characterization, prediction and monitoring of internal swelling reactions in concrete
  - WP 4. Delayed strains of containment buildings in operational and accidental conditions
  - WP 5. Assessing the performance of irradiated concrete
  - WP 6. Dissemination, communication and training
  - WP 7. Project Management

Ongoing projects (3/5)

- Impact of climate change on NPP concrete structures
  - Increase in global average temperatures and atmospheric water vapor content over the past 60 years
  - Impact of climate change on concrete structures
  - Structural integrity and leak tightness
  - Durability (F-T cycles, carbonation / corrosion, etc.)

Ongoing projects (4/5)

- Impact of climate change on NPP concrete structures
  - Climate change assessments and projections (next 50 years) in Canadian regions with NPPs
  - Climate change related degradation factors for NPP concrete containment structures
  - Synthesis of projected climate data and potential adverse effects of DMs – Identify gaps in knowledge
  - Develop STAR on the impact of climate change on concrete containment structures

Ongoing projects (5/5)

Table 9-1: Ranking of Factors Affecting Containment Integrity

No.	Climate Variables	Effects on Nuclear Safety (i.e., Leaktightness & Structural Integrity)	Deterioration Mechanism/Impacts
1	Atmospheric CO2 concentration	Most Influential	Carbonation
2	Freeze-Thaw		Freeze-Thaw Concrete Cracking
3	Convective available potential energy (CAPE) – an indicator of tornado occurrence		Tornado Missiles/ Plant Operational Impacts
4	Extreme CAPE		Tornado Missiles/ Plant Operational Impacts
5	Tropical cyclones influence		Plant Operational Impacts
6	Wave frequency of height thresholds		Chloride Diffusion/ Operational Impacts
7	Extreme Precipitation (3 hours and 24 hours)		Flood damage/ Plant Operational Impacts
8	Annual/Monthly Mean Temperature		Carbonation, AAR, Sulfate Attack, Shrinkage, Creep

Gaps in knowledge (1/3)

- Reservoir temperature
  - impact on FFS of concrete structures when subjected to higher temperatures (e.g. reduced E, thus increasing deflections and ω, etc.).
- Safety and resilience against extreme precipitation and flooding

Gaps in knowledge (2/3)

- Atmospheric CO2 concentration (carbonation)
  - need for long-term experimental studies to evaluate performance of concrete containment structures under increased CO2 levels

- Creep
  - higher temperatures
  - post-tensioned tendons
  - leak tightness

Gaps in knowledge (3/3)

- Corrosion
  - Increased Cl^- due to increase in sea levels
  - impact on PT tendons, rebars, liners
- Tornado hazard
  - need for large-scale physical testing of concrete containment structures against tornado missile impacts
- ASR
  - effects of changes in ambient temperature and humidity due to climate change on concrete degradation caused by AAR (e.g. Gentilly containment structures)

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Acknowledgement

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