ADVANCED CONSTRUCTION AND MANUFACTURING METHODOLOGIES FOR NEW NUCLEAR BUILD

OECD/NEA WORKSHOP – MARCH 16TH 17TH 2022

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A FEW WORD ABOUT SOME COST DRIVERS


Sources:
“The ETI Nuclear Cost Drivers Project: Summary Report” 20 April 2018
&
STATE-OF-THE-ART
A DESIGN AND
CONSTRUCTION
APPROACH THAT IS
STILL TOO
COMPARTMENTALIZED
DUE TO A LACK OF
APPROPRIATE TOOLS

Lack of digital means at the service of the extended enterprise

- NO shared modeling, calculation and site preparation tool: a multitude of non-interoperable tools between MOA, MOE, BE & builder
- No BIM interface / calculation model
- Manually developed calculation model, complex and time-consuming change management
- The constraints of the construction site integrated late after calculation of the reinforcement
- No reliable indicator of the level of constructability to guide design choices
STATE-OF-THE-ART CIVIL ENGINEERING DESIGN CALCULATIONS THAT HAVE BENEFITED LITTLE FROM THE MECHANICAL AND NUMERICAL ADVANCES OF THE PAST 30 YEARS

- Non-optimal reinforcement calculations in massive areas (significant part of nuclear structures)
- Subjective and often discussed manual methods of smoothing reinforcement resulting from finite element calculation in thin zones
- Recent numerical optimization techniques are not used

Reinforcement design with conservative tools and methods not suited to a systematic optimization approach
TWO PRIORITY AREAS FOR IMPROVING THE DESIGN

**Digitalizing Civil Engineering**
- Digital mockup
- Optimizing calculation model
- Drawings
- Construction

**Optimizing Civil Engineering calculation**
- More realistic models
- Optimized methods in massive areas
- Optimization of the reinforcement at the appropriate scale
OBJECTIVES

- Reduce the cost and duration of Civil Engineering design by providing tools for greater automation and fluid and dynamic management of changes

- A relevant and optimized calculation model automatically developed from the digital model (BIM)
- Integration into the digital model of all the information necessary for the Civil Engineering calculation and the establishment of plans (additions to the current BIM format)

- Reduce the cost and duration of Civil Engineering construction by optimizing reinforcement and better integrating constructability indicators into the design process

- Reliable constructability indicators available from the conceptual design stage to guide design choices
- A more realistic calculation model, especially in massive areas
- An adapted and optimized calculation of reinforcement, where the margin is better controlled in the different zones
COST, DURATION AND RISK SURROGATE MODEL

Design area
- Safety requirements
- Constructive solution
- Site
- Materials
- Loadings

Simulations
\[ y = f(x) \]
\[ y = \{ A_{SX}, A_{SY}, A_{IX}, A_{IX}, A_{SW}, h, l \} \]

Construction
- Feedback of recent projects
- Cost estimate by expert opinion
- Site risk analysis
- Assessment of deadlines

\[ z = f(y) \]
\[ z = \{ t_{construction}, e_{construction}, P_{const.(y)} \} \]

Quantities of interest
- Schedule duration
- Raw material cost
- Overnight cost
- Risks

Métamodèle TCD-R
\[ z \approx \tilde{f}(y) \]
AUTOMATIZATION FOR THE BETTERMENT OF MECHANICAL MODELING

BIM format associating structural properties:
- Loads
- Safety requirement
- Reinforced Concrete properties (concrete classes, Reinforcement, cover ...)

IA guided recognition of structural parts:
- Massive parts
- Slabs
- Walls
- Wall-slab junctions

Hybrid models
Optimizing the structural behavior
EXAMPLE OF A FICTIONAL BUILDING SUBJECT TO AN EARTHQUAKE

Seismic qualification is optimized
Anchorage design is optimized
Anchorage / reinforcement interaction is simplified

25% less steel
More homogeneous
AUTOMATION OF THE MASSIVE PARTS BY MEANS OF OPTIMIZED STRUT-AND-TIE MODELS

Automatic generation of every possible ties and struts

Optimization of the reinforcement accounting for the standards

Gustavo Mendoza-Chavez Ph. D. Thesis 2018, Université Paris-Est


CHANGING THE REINFORCEMENT CALCULATION SCLAE

Simplifying the rebar
Smoothing the peaks with a strong mechanical background
FEW CONCLUDING WORDS

- Building complex is simple BUT building simple is complex
- Building simple is building safe
- Spending time during design = saving time BUT Spending time on site = wasting time
- The evolution has to be carried out to help the engineers to focus on tasks where they have their added-value: architecture & process
- Intensive digitalization at the service of co-engineering:
  Interoperable digital solution involving new optimization technics and improvement in modeling methods
- Engineers should not waste their time in trying to solve unoptimized practices, or in adapting to changes that are too late considered
THANK YOU FOR YOUR ATTENTION!

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Steel plate-concrete structures
Structural form, applications and construction experience

B A Burgan
16 March 2022
Outline

- Structural form
- Not a new concept - Examples
- SCHEDULE
Steel plate-concrete structures
Steel plate-concrete structures
Steel plate-concrete module manufacture
Steel plate-concrete module manufacture
Steel plate-concrete –
Joining of modules

- Butt welded
- Fillet welded
- Bolted
Advantages

- Steel plates act as reinforcement
- Temporary formwork is eliminated
- Steel plates act as water-tight membranes
- Steel plate and studs replace the embedded plates
Embedded Plates
Modular Construction of NPP (Japan)

- First structure: Kashiwazaki-Kariwa 6 and 7 NPP (2002)
Awa Shirasagi Ohashi Bridge, 2012
Westinghouse AP1000
Rainier Square Tower, Seattle, USA (2020)
Rainier Square Tower
Frame Construction Options & Programme

Traditional Concrete Core Construction Schedule

Steel Plate - Concrete Composite Core
Constructed in Sequence

Achieved with SC cores

Original programme

Traditional concrete core

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

Months
SCHEDULE
Project Partners and Organisation

WP1 : ENGINEERING & CALCULATIONS (EGIS)

WP2 : TECHNICAL SPECIFICATION & MONITORING (GEN IV) (CEA)

WP3 : DURABILITY SPECIFICATIONS GUIDE (AM)

WP4 : WELDING SPECIFICATIONS GUIDE (AM)

WP5 : CONSTRUCTION METHOD STATEMENT (BOUYGUES)

WP6: STEELWORK EXECUTION DRAWINGS (PEIKKO)

WP7: MANUFACTURE STEEL COMPONENTS

WP8: INSTRUMENTATION (EDF)

WP9: SITE PREPARATION, CONSTRUCTION OF PILOT BUILDING & PARTIAL DISMANTLING (BOUYGUES)

WP10 : DESIGN AND CONSTRUCTION FEEDBACK AND LESSONS LEARNT (SCI)

WP11: ENGINEERING COORDINATION AND RISK MANAGEMENT (EDF)

WP12: PROJECT COORDINATION (SCI)

Project sponsors

22 March 2022
The EDF Diesel Generator Building (DUS)
SCHEDULE Demonstration Buildings (DUS in SC)
EDF – Les Renardières
NEA Advanced Construction & Manufacturing
Advanced Manufacturing and Welding Techniques Workshop – Session 2

Dr Steve Jones CEng, FWeldI - Chief Technology Officer – Nuclear AMRC
Professor of Joining Technologies – University of Sheffield

Date: 16th and 17th March 2022
1. Introduction to the Nuclear AMRC, its remit and mission delivery strategy

Our mission
To help UK companies win work in nuclear & other high-value manufacturing sectors.

Delivered through two core work programmes:

• Manufacturing innovation.
• Supply chain development.
2. Main productivity and conventional commodity usage

Previous conventional RPV forging practices and connection weld lines

Conventional ingot processing
Source: Sheffield Forgemasters RD26

Image courtesy of NuScale Power Inc
2. Main productivity and Innovative commodity usage

The use of powder + hot-isostatic pressing to create a homogeneous isotropic material to enhance performance and design.

**SMR Lower Head**
- **66% Scale**
- Achieved geometry
- 3250kg

**SMR Upper Head**
- **40% Scale**
- 27 penetrations
- 1650kg

All images courtesy of EPRI
2. Main productivity and innovative commodity usage

- Advanced Forging practices
- Advanced Forming processes
  - PM-HIP
- Advanced Joining processes
  - EBW and DLO

Hollow ingot technology
Source: Sheffield Forgemasters RD26

Advanced Metrology to support HF method
Source: Sheffield Forgemasters RD26

Image courtesy of EPRI and NuScale Power Inc
3. Is the TRL the only capability indicator? What about MRL and SCRL?

Conventional RPV forging profiles and weld lines

Advanced RPV forging and weld profiles

Advanced materials and processing technologies with integral features

Hrs  Days

1577  99  GTAW

Hrs  Days

597  38  3° NG-GTAW 3-Head system

Hrs  Days

1820kg of CO₂

1932kgs

1535kgs

686kg of CO₂

Conversion from Carbon Trust 2008: Average grid electricity 1MJ = 0.2778kWh
1 unit of kWh = 0.537kgCO₂

SQBW 18

IC-EBW 1.2

9kg of CO₂

0kgs

Mass of filler wire (kg)
4. Changes in manufacturing philosophy – interdisciplinary innovation

The power of interconnectivity – avoiding manufacturing silos

The Golden Thread

- PM-HIP RPV-H 0.4 scale
- Advanced coolants
- In-chamber EBW
- Novel weld joints
- Local reduced pressure welding

- Artificial intelligence
- In-process inspection
- Simulation
- Advanced overlaying

Industry & RTOs

HVMC & Regulators

Integral vacuum chambers
1. Contractual and energy costs for nuclear need to be favourable to investors and consumers respectively.

2. A myopic silo approach to manufacturing RD&I cannot be tolerated in achieving these goals.

3. The concept of ‘design for manufacture’ vs ‘designing for performance’ must reach an equilibrium at the onset of the project – but continuously challenge the status quo for advancement to occur.

Future manufacturing engineering must consider that:

1. Contractual and energy costs for nuclear need to be favourable to investors and consumers respectively.

2. A myopic silo approach to manufacturing RD&I cannot be tolerated in achieving these goals.

3. The concept of ‘design for manufacture’ vs ‘designing for performance’ must reach an equilibrium at the onset of the project – but continuously challenge the status quo for advancement to occur.
Summary of 7 key drivers

1. Materials & processing developments must balance ‘design for manufacturing with design for performance’.
2. Improve design freedom to enhance engineering assurance and performance in a cost effective way.
3. Bridging the gap between industry and standards developers limited to resource and funds
4. Increased transparency to regulator database to mitigate failures in service.
5. Advancement of technology and workforce skills via an integrated readiness level (IRL) approach
6. Regulator to plan for methods to approve AI systems for manufacturing, EQ and processing assurance
7. Adoption of wider industrial practice - Increased automation, process standardisation and fabrication modularisation practices needed to remove variability.
National Reactor Innovation Center
Advanced Construction Technology

March 16, 2022
Ashley E. Finan, Ph.D., NRIC director
ashley.finan@inl.gov
nric.inl.gov
NRIC is a DOE-NE program, launched in FY2020

NRIC Accelerates Nuclear Reactor Demonstrations

- Authorized by the Nuclear Energy Innovation Capabilities Act (NEICA)
- Partner with industry to bridge the gap between research and commercial deployment
- Leverage national lab expertise and infrastructure
- Manage demonstrations to success
NRIC is partnering regionally and nationally to support demonstrations.
Priority: Empowering Innovators

• Demonstration Test Beds
• Experimental Facilities
• Virtual Test Bed
• Regulatory Risk Reduction

• Planning Tools
  • NRIC Resource Team
  • NEPA guidance
  • Demonstration Resource Network (https://nricmapping.inl.gov/)
  • Siting Tool for Advanced Nuclear Development
NRIC-DOME Test Bed
(Demonstration of Microreactor Experiments)

Strategy:
• Repurpose EBR II which operated from 1964 – 1994
• Establish a minimum viable test bed that is just flexible enough to test 4-5 known small modular reactors such as high temperature gas reactors

Capabilities:
• Small Modular Reactors (SMR) up to 20MW thermal power
• High-Assay Low-Enriched Uranium (HALEU) fuels < 20% enrichment
• Safety-Significant confinement for reactors to go critical for first time

Total estimated cost of Construction for DOME minimum viable test bed:
• $33M Range: $27M - $49M

Interested Companies: 5
Advanced Construction Technology initiative (ACT)

- ACT will significantly reduce the construction costs and schedule associated with new nuclear builds

- General Electric Hitachi Nuclear Energy (GEH) Team Lead
  - EPRI – Digital Twin, and NDE techniques
  - University of North Carolina @ Charlotte – Digital Twin
  - Nuclear Advanced Manufacturing Research Centre (NAMRC) – Advanced Sensor

- Modular Walling Systems Holdings Limited (MWS) – Steel Brick™

- Purdue University – Steel-Concrete Composite prototype testing

- Black & Veatch – Boring Technology, Construction of Demonstration, Decommissioning Plan, Scaling Prototype, & Site Selection

- Tennessee Valley Authority (TVA) – Industry Partner

Steel Bricks is a trademark of Modular Walling Systems Holdings Limited
Project Overview

- The project is a 1 year, $8.35M cost shared Public Private Partnership
  - FY-22 & FY-23 Phase 1 DOE-NE $5.8M $2.53 GEH $0.2 TVA
  - FY-23 – FY-25 Phase 2 Cost Estimate generated during early part of Phase 1
- Kickoff Meeting: January 27, 2022
- Milestones
  - 30% Design May 2022
  - Final Design January 2023
- Developing a Risk Register and Project Work Plan.
Technologies for Demonstration

- **Steel Bricks™**: modular steel-concrete technology panels made in a factory and assembled in the field,
  - reduce labor and rebar welding in traditional concrete strengthening techniques.
  - Steel Bricks is a trademark of Modular Walling Systems Holdings Limited

- **Vertical shaft construction**: leverage best practices from the construction industry

- **Digital Twin and Advanced Monitoring Technology**: a digital replica of the scaled demonstration nuclear structure with a cradle-to-grave approach
Construction and Integration Process

1) Preparation of Site
2) Excavation of the shaft
3) Placement of the mud mat/foundation
4) Assembly of the fabricated Steel Brick™ technology panel from offsite fabrication
5) Lower panels into shaft
6) Install Sensors for Digital Twin
7) Embedded Reactor Structure & Digital Twin
Steel Bricks™ Technology Panel

• State-of-the-art system that is trademarked by Modular Walling Systems Holdings Limited (MWS).

• Prototype testing of representative MWS panels to expand current fabrication knowledge for rectangular structures to cylindrical structures.

• Prototype testing, at Purdue, will establish DB and beyond DB structural performance. To support use in Seismic Category 1 structures and containments.

• Steel-Concrete Composite Systems fabricated offsite and filled with concrete on site:
  • Are faster to install than traditional concrete forms and the reinforcing steel rebar due to offsite fabrication
  • Have higher resistance to flexural stress damage
  • Prevents spalling of concrete
  • Prevents buckling of the steel, and improves its resistance to compression.
Vertical Shaft Construction

- Leverages best practices from the construction industry to reduce costs associated with excavation, inspections, and testing of safety-related backfill.

- Conceptual design for scaled structure for demonstration
  - Outer diameter 16 meters
  - Shaft depth 5 meters
  - Height above grade 2 meters
  - Commercial roof will keep structure weather tight.

- Potential to reduce the amount of excavation and engineered backfill needed, for reactor builds, by 1 million cubic feet.

- B&V is the lead on selection of boring technology, scaled structure and site selection.
Digital Twin and Advanced Monitoring Technology

• Demonstrating advanced condition and performance monitoring techniques for implementing construction and in-service surveillance programs to address NRC’s Regulatory Inspection and Monitoring requirements in 10 CFR 50.65.

• Demonstrating state-of-the-art Digital Twin replica of the structure to integrate sensor data, artificial intelligence, machine learning, and data analytics.

• A Mini Digital Twin will be deployed by EPRI and UNCC with the prototype at Purdue to collect data and validate sensor types determined by NARMC.

• Allows for continuous monitoring of the strains developed in the Steel Bricks™ and the subgrade in real time. This level of monitoring can be maintained during the life of the building.

• A goal is to engage the US NRC and other national regulators to review the techniques, evaluate inspection and acceptance criteria, and update the NRC Inspection Manuals and Inspection Procedures.
ACT Summary

• ACT will utilize expertise from industry, academia, and science centers to demonstrate construction technologies, not yet being used in the nuclear industry.

• Demonstrating these advanced construction technologies will build confidence with the advanced reactor developers, regulators, and nuclear construction entities.

• Utilization of these techniques in nuclear builds will significantly reduce cost and schedules for building new nuclear energy projects.
Goals for FY22

Maintain progress to support demonstrations by the end of 2025 and sustained innovation

- Prepare vital infrastructure
- Demonstrate cost-cutting technology
- Build and develop the NRIC team
- Provide planning tools and resources
- Anticipate and address regulatory needs
- Strengthen and expand partnerships and engagement
Thank you!
Questions?