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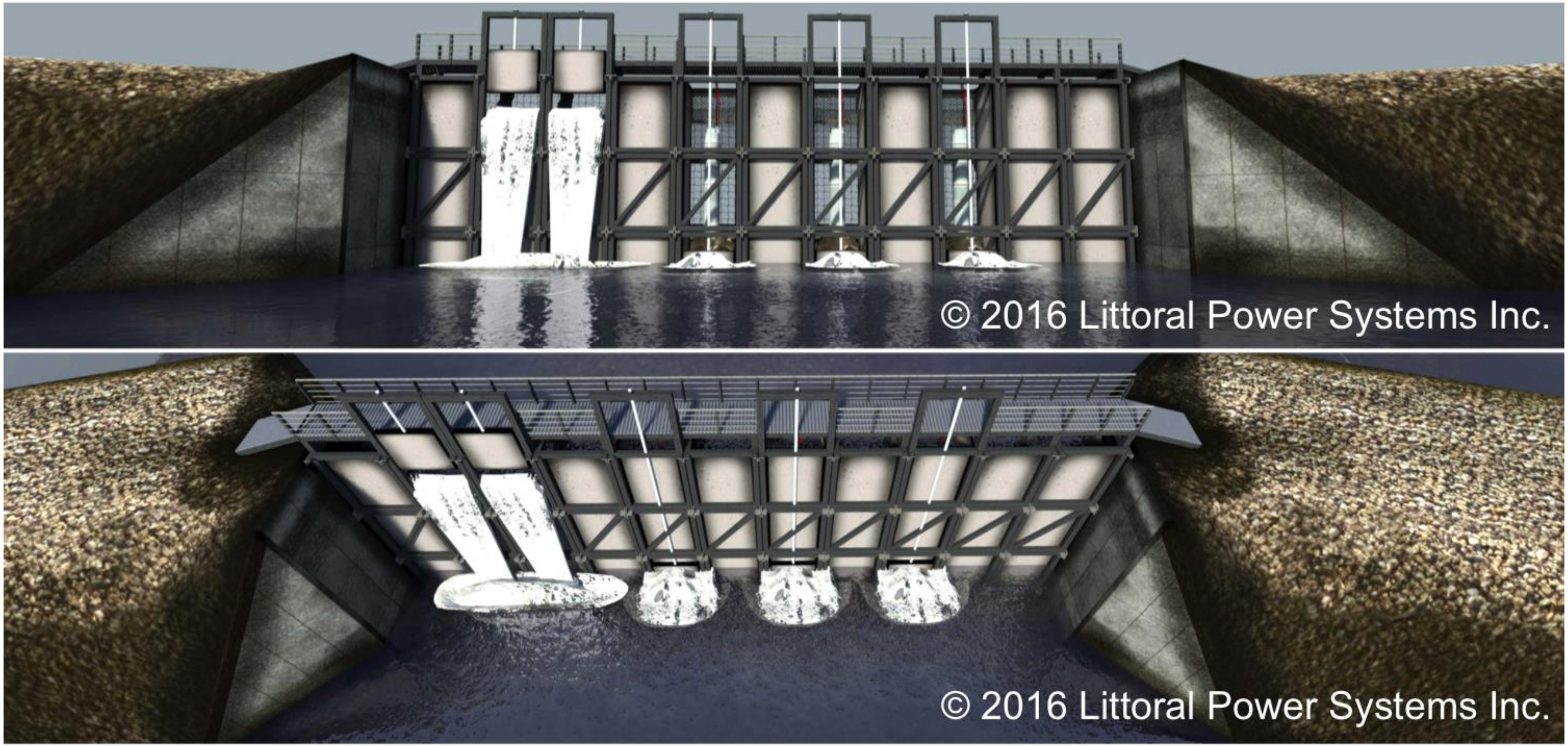

Modular Low-Head Hydropower System

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Feb. 2017

Project Overview

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“A cost-disruptive, low impact, modular form factor low-head hydropower system”

The challenge: New stream-reach development requires low environmental impact and low cost civil works.

Partners:

- **GZA GeoEnvironmental**: geotechnical/ dam module/ ancillaries (Chad Cox, P.E., co-PI)
- **UMass-Dartmouth**: spillway module (Daniel MacDonald, Ph.D.)
- **National Renewable Energy Laboratory (NREL**: Levelized cost of energy (LCOE)/ risk register/ reference siting (Elise DeGeorge, Scott Jenne, David Snowberg)
- **Alden Research Laboratory**: turbine module/ structural analysis (Dave Schowalter, Ph.D, Mark Graeser, P.E.)

Program Strategic Priorities

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Next Generation Hydropower (HydroNEXT)

Optimization

- Optimize technical, environmental, and water-use efficiency of existing fleet
- Collect and disseminate data on new and existing assets
- Facilitate interagency collaboration to increase regulatory process efficiency
- Identify revenue streams for ancillary services

Growth

- **Lower costs of hydropower components and civil works**
- Increase power train efficiency for low-head, variable flow applications
- Facilitate mechanisms for testing and advancing new hydropower systems and components
- Reduce costs and deployment timelines of new PSH plants
- Prepare the incoming hydropower workforce

Sustainability

- **Design new hydropower systems that minimize or avoid environmental impacts**
- Support development of new fish passage technologies and approaches
- Develop technologies, tools, and strategies to evaluate and address environmental impacts
- Increase resilience to climate change

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The Impact

- 50% reduction in civil works costs versus traditional concrete installation
- Enables ecological small, low head and run-of-river installations that take advantage of new streamlined FERC regulations.
- Modular, prefabricated dam, spillway, and powerhouse modules with dimensions and connectors of shipping containers make up a kit of standardized parts to flexibly fit a wide variety of sites, that can be quickly installed, and can be removed at the end of their useful life leaving little if any environmental footprint.

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Technical Approach

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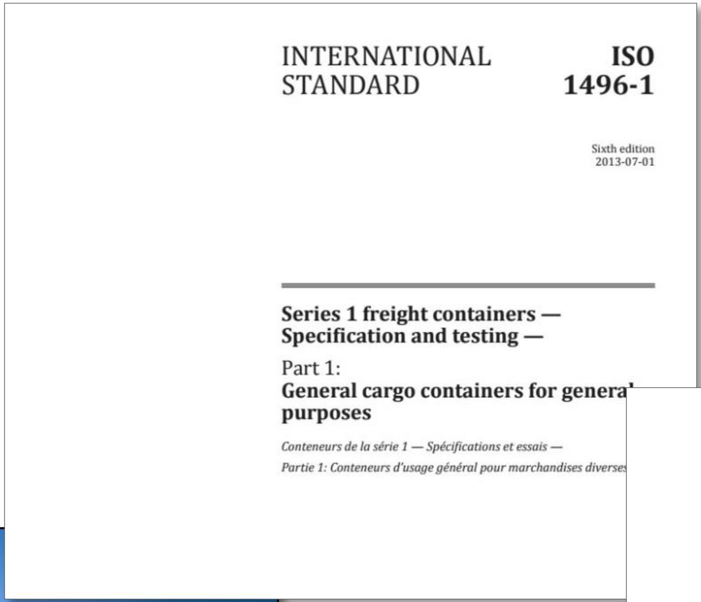


INTERNATIONAL STANDARD

ISO 1496-1

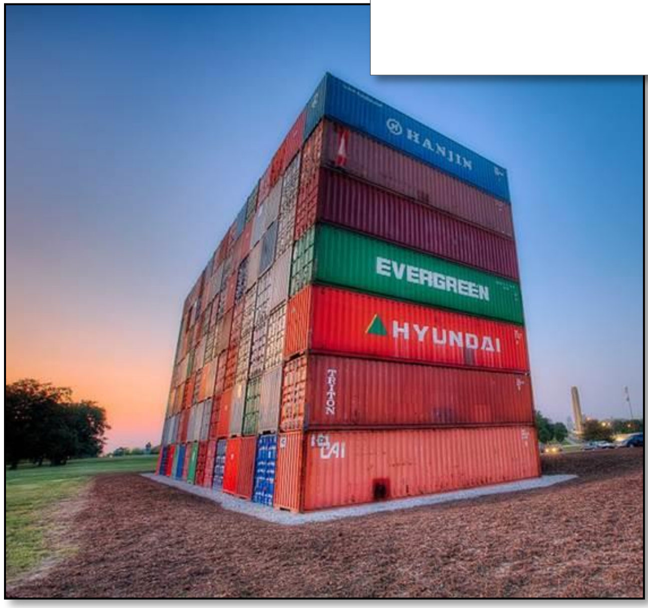
Sixth edition
2013-07-01

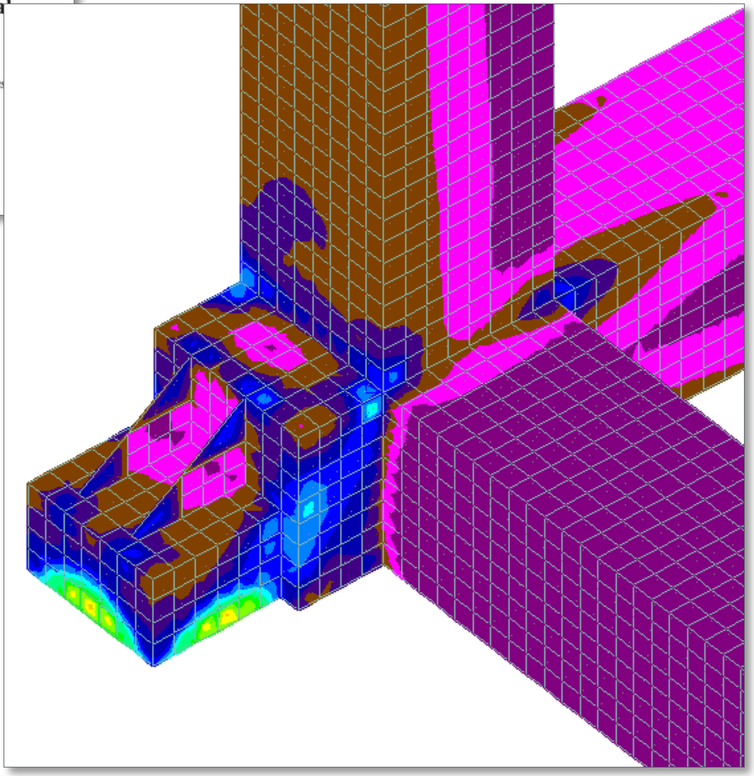
Series 1 freight containers — Specification and testing —

Part 1:
General cargo containers for general purposes

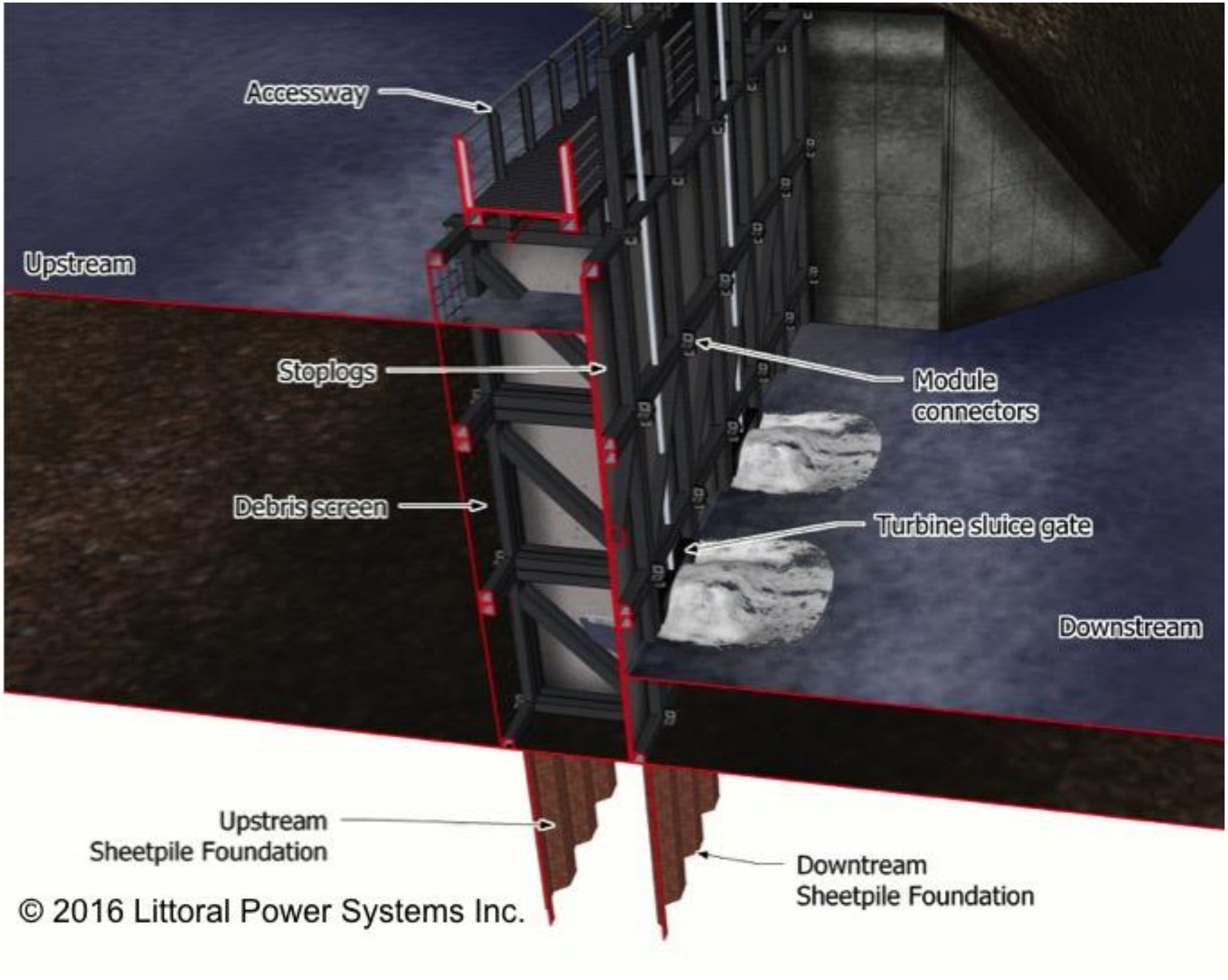
Conteneurs de la série 1 — Spécifications et essais —

Partie 1: Conteneurs d'usage général pour marchandises diverses





Technical Approach



Accomplishments and Progress

Global stability analysis

- sliding – overturning – flotation

Seepage analysis w/varying riverbed compositions

- meets USACE (Cedergren) guides

Leakage worst case per AWWA C563

- 0.07% of flow rate through turbine

Structural integrity

- per AISC and USACE
- a per USACE ETL 1110-2-584
- ISO 1496-1:1990 containers

LCOE analysis

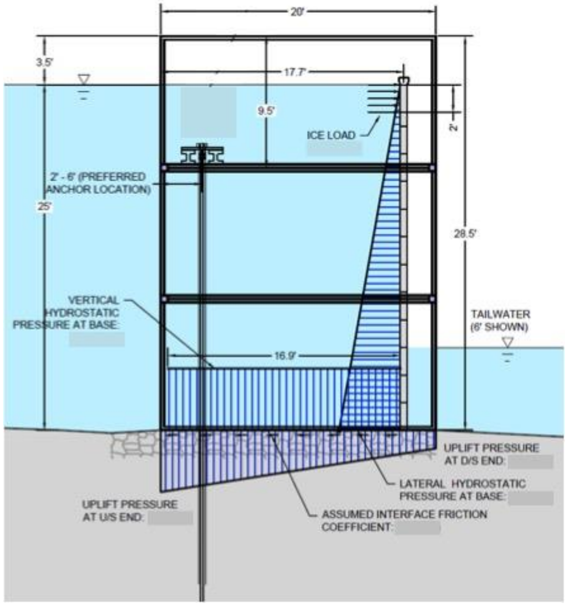
- >50% reduction in civil works cost
- 13.4¢/kWh

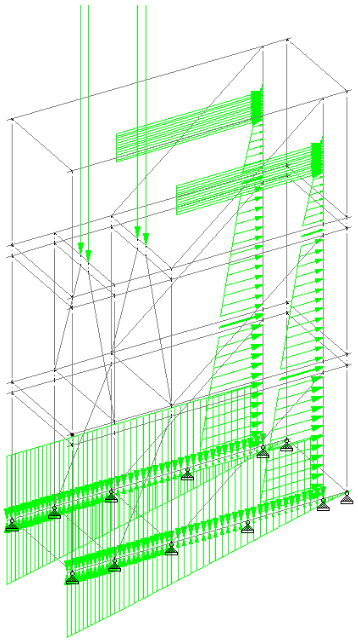
Statistical tool – LCOE vs. site

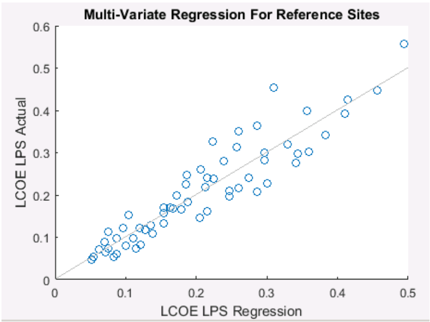
Turbine selection – 20+ considered

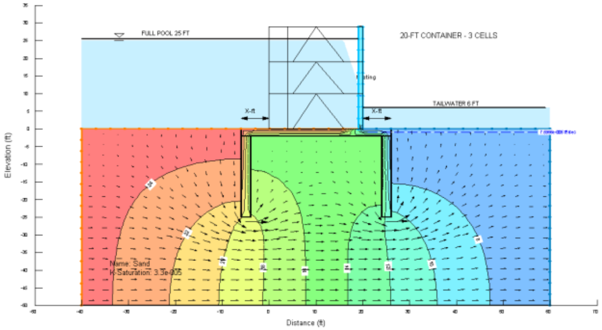
Spillway – pneumatic modular

- large debris passage









Project Plan & Schedule

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Budget Period 1: Preliminary designs

Four main modules: Dam, Power (turbine/draft tube), Spillway, Penstock

Feb 1 – Apr 30 Define requirements	May 1 – Jul 31 Preliminary design concepts	Aug 1 – Oct 31 Analyze	Nov 1 – Jan 31 Modify

Aug 1 – Mar 31
Ancillary items, deployment/maintenance scenarios, failure rates

- M#1:LCOE model set-up for req't input
- M#2: Preliminary design concepts complete
- M#3:LCOE model exercised to perform sensitivity analysis and results indicate design or scenario options to achieve LCOE metric
- Go/No-go #1: Dam modules stable/capable in global stability and seepage conditions.

Budget Period 2: Detailed designs for test articles, full size testing for structure and leakage

Apr 1, 2017 – Mar 31, 2018

Project managed with waterfall and agile elements. Risks tracked via NREL Risk Register.

Project Budget

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Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
				$ 285.347k	$ 74.768k

- Values shown are for invoiced and reimbursed life-to-date amounts as of 9/30/2016.
- Budgeted amounts for budget period 1, Feb 1, 2016 thru March 31, 2017, are: $766.559k federal, and $192.115k cost share.
- Total project thru March 2018 amounts are: $1,421.67k federal, and $371.111k cost share.

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- GZA GeoEnvironmental: **Chad Cox P.E. co-PI**, Bin Wang P.E.
- Alden Research Laboratory: David Schowalter Ph.D., Mark Grasser P.E., Greg Allen P.E., Brian McMahon P.E., Rhonda Young
- University of Massachusetts – Dartmouth: Daniel MacDonald, Ph.D., May May Khin, Michele Winchel
- NREL: Scott Jenne, David Snowberg, Elise DeGeorge

Communications and Technology Transfer:

- Four blog posts on LPS web site, www.littoralpower.com
- Article on Alden website, https://www.aldenlab.com/News/Alden-News/ArticleID/41/Modular-Dams-for-Hydropower
- Provided graphics for Oak Ridge National Laboratory, Adam Witt, presentations
- Environmental Business Council of New England 3 Nov 2016
- Potential investors – individual/ family/ private/ public – three key leads
- Potential pilot site owners – following eight leads

Next Steps and Future Research

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FY17/Current research:

Budget Period 2 will refine the designs and LCOE model.

1) for the spillway module, use CFD simulations to prove no substantial erosion danger during flooding,
2) for the dam module, build two modules, and test them in a flood wall to prove stability, leakage, and structural adequacy, and
3) analyze LCOE for concrete baseline, an LPS module pilot site and an envisioned full scale scenario at a reference site.

Proposed future research:

1) Explore site flexibility via simulations of installations – topography, hyrodology, and geotechnical.
2) Explore applicability to infrastructure repair – install/monitor dam modules in a field/pilot test site.
3) Explore abutment design concepts for various site conditions.
4) Explore applicability to add power to non-powered dams.