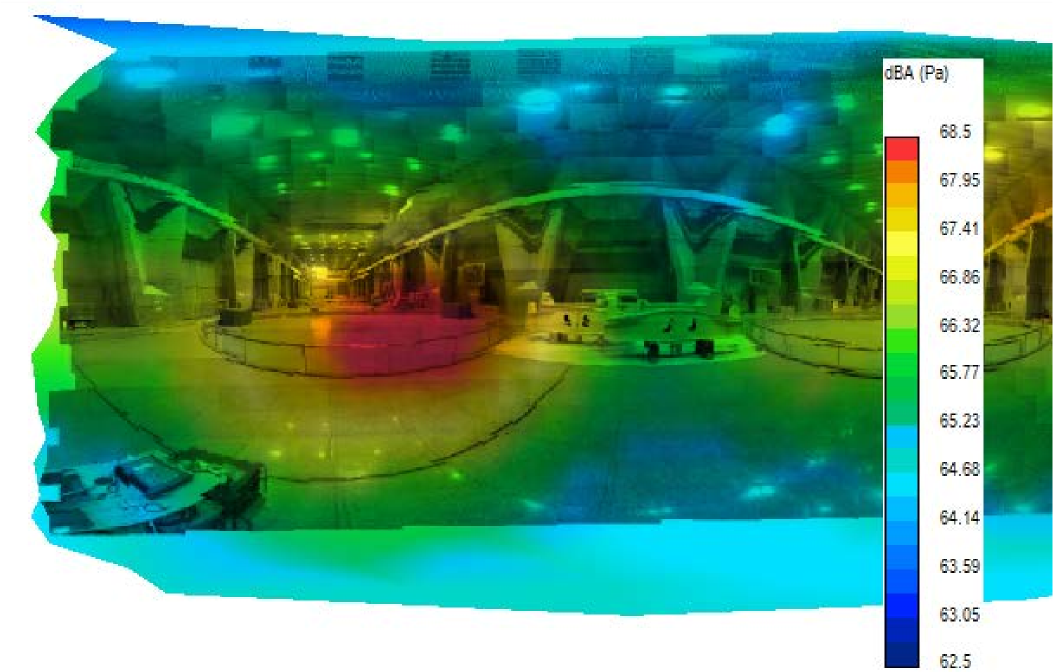
RECLAMATION
Managing Water in the West

Engineering Controls for Hydroelectric Powerplant Noise Reduction

Research and Development Office
Science and Technology Program
Final Report ST-2014-6433-01



U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

February 2015

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover photo: Acoustic array in powerplant.

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14. ABSTRACT *(Maximum 200 words)*
The US Department of Interior Bureau of Reclamation (Reclamation) and the US Army Corps of Engineers (USACE) oversee a number of hydroelectric powerplants across the U.S. and noise induced hearing loss (NIHL) has become the number one workers compensation safety issue in Reclamation. Most of reclamation's powerplants are over 40 years old and were constructed before many modern noise control technologies were developed. The Occupational Safety and Health Administration (OSHA) requires the reduction or elimination of a hazard, such as exposure to prolonged high noise levels, to be addressed through the implementation of engineering controls prior to implementing administrative and personal protective equipment strategies. The goal of this program is to identify areas with noise levels in excess of 85 dBA and identify engineering control strategies that can be implemented to reduce these noise levels.

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Abbreviations and Acronyms

dBA	A-weighted decibels
DOD	Department of Defense
NCE	Noise Control Engineering, Inc.
NIHL	noise induced hearing loss
ONR	Office of Naval Research
OSHA	Occupational Safety and Health Administration
Reclamation	Bureau of Reclamation
RSHS	Reclamation Safety and Health Standards
USACE	U.S. Army Corps of Engineers
WHO	World Health Organization

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Executive Summary

Occupational Safety and Health Administration (OSHA) requires reducing or eliminating a hazard, such as exposure to prolonged high noise level. OSHA noise limits are 90 A-weighted decibels (dBA) for eight-hours of exposure with a 5 dB exchange rate. A hearing conservation program is to be implemented for levels 85 dBA and above. Other regulatory agencies, such as the Department of Defense (DoD) and the World Health Organization (WHO), use 85 dBA as the limit with a 3 dB exchange rate. The Bureau of Reclamation's (Reclamation) Safety and Health Standards (RSHS) (October 2009) specifically states in Section 2.1.1 that "The operating organization must provide a safe and healthful work environment." Section 7.3.1 of the RSHS further requires the use of "engineering controls as the primary means to minimize workplace health hazards. Engineering controls may include, but are not limited to, the use of enclosures, isolation, substitution of materials, or ventilation."

Reclamation and the U.S. Army Corps of Engineers (USACE) collaborated to address existing noise issues at nine of their powerplants, ranging from small to very large. To diagnose and determine optimal treatments to reduce noise levels via feasible engineering controls, this Science and Technology Program research project measured noise and vibration measurements, including using acoustical array technology in these powerplants.

General recommendations for implementing engineering controls that can be applied in all powerplants include:

- Purchasing quiet machinery and tools when repairing or replacing plant equipment

- Providing adequate acoustical isolation with properly engineered enclosures for noise sources such as compressors or pumps, which are difficult to reduce noise levels at the source

- Providing better acoustical isolation from turbine pits by using flexible acoustical absorption materials such as panels or curtains

This project evaluated nine powerplants and provided recommended treatments, including applying spray-on damping material on vibration surfaces, treating hard surfaces such as powerplant and turbine pit walls with micro-perforated panel absorbers, and using acoustical barriers. Engineering design that combines these different technologies can result in a significant reduction of facility noise levels that optimizes performance and cost and considers the impact on maintenance.

Background

Introduction

Reclamation has the responsibility to deliver water and generate power and oversees a number of hydroelectric power powerplants across the U.S. Hearing loss has become the number one workers compensation safety issue in Reclamation. Over the last 10 years, Reclamation paid approximately 5.24 million dollars in hearing loss claims. Noise Control Engineering, Inc., (NCE) has been working with the Office of Naval Research (ONR) to reduce noise induced hearing loss (NIHL) issues in military applications. ONR has been asked by Reclamation for assistance in identifying noise sources and helping to implement controls to reduce employee exposure to noise.

Reducing continuous noise in the powerplants will help prevent hearing loss and will minimize future hearing loss claims. Most of the existing powerplants are over 40 years old and were constructed before many modern noise control technologies were developed. It is paramount to determine the source and type (frequency and level) of noise generated in the powerplants prior to evaluating potential mitigation measures. OSHA requires eliminating or reducing a hazard through engineering controls prior to implementing administrative and personal protective equipment strategies.

Noise is often overlooked as a hazard because there are no obvious indicators of acute or chronic exposure. However, NIHL is one of the highest workers compensation expenses agencies have for non-traumatic injuries. NIHL is preventable. Research is ongoing to address the risk of Navy personnel to NIHL through a systems engineering approach with the Navy’s human systems integration expertise. This research includes developing experimentally verified models to predict potential high level environments aboard U.S. Naval vessels and develop effective treatments. This technology is also being expanded to include marine vehicles. These models are then being used to design treatments for compartments by treating the noise at the source (if possible), but more frequently by treating the transmission path to the receiver.

To optimize the transmission path treatment for effectiveness and cost, it is necessary to understand how the noise is entering a compartment. This path is often complicated by the presence of multiple noise sources and multiple potential paths. Because of the nature of typical sound fields within a compartment, it is often difficult if not impossible to clearly identify the noise paths into a compartment and the ranking of these paths in order to develop and optimize an effective treatment strategy. One of the cutting edge technologies, developed as part of the ONR effort, an acoustic array to help identify ‘acoustic hot spots’ at the sound source and along the path.

This effort assisted Reclamation and USACE in significantly reducing NIHL exposure of powerplant employees by measuring noise levels to determine noise levels and sources and designing feasible engineering controls to reduce these levels and applying noise-reduction technologies.

The reference section cites four analyses and reports on various powerplants. A discussion and definitions of some of the acoustic terminology used in this report is included in the glossary.

Technical Concepts – Summary of Noise Control Techniques

This section provides a general discussion of the treatments investigated for use in the powerplants. Maintenance considerations were taken into account in suggesting noise control techniques for hydroelectric powerplants. Materials and methods needed to be as maintenance free as possible and still achieve the desired noise reduction necessary to reduce potential hearing loss among powerplant workers. Materials also need to meet safety regulations for fire, smoke, and toxicity.

Damping

Damping is a term used to describe applying a viscoelastic material to a structure to reduce the vibration of that structure. Since noise (acoustical energy) can be generated by a structure that vibrates and is an efficient radiator, reducing the surface velocity due to damping will also reduce noise. Damping material comes in many shapes and sizes. Proposed damping uses a spray-on material that goes on in layers. The layers are then built up to the desired thickness (typically one-half the thickness of the structure being damped to be effective).

Tuned Resonance Sound Absorption

A tuned absorber is a device that is designed to absorb energy at particular frequencies. A muffler is the most well-known example for absorbing energy to reduce noise. The muffler is essentially a cavity that is designed to absorb acoustical energy. The tuned absorber in this case is a perforated panel offset from the plant’s wall. By adjusting the hole sizes and spacing, acoustical energy at certain frequencies will be “trapped” between the panel and the wall and will dissipate. Absorption can be increased significantly by also adding an absorptive material, such as encapsulated fiberglass, to the space between the surface and the perforated panel.

The basic concept behind using absorption in areas with hard surfaces, such as the main floor of powerplants and also turbine pits, is to reduce the reverberation time. A high reverberation time means that acoustical energy echoes off the hard surfaces and does not dissipate. This reflected energy continues to add to the acoustical energy continually coming from the source and as a result, noise levels remain high. By absorbing this energy and reducing the reverberation time, the overall noise levels in the space will be reduced. This same effect can also be achieved by adding traditional acoustical absorption material to the surfaces; however, this material would require higher maintenance than the perforated metal panels that will be proposed.

Acoustic Barriers and Cladding

The concept of an acoustic barrier is a simple one. By placing a solid wall (barrier) between the sound source and the receiver, the acoustical energy gets reflected back to the source and will not reach the receiver, thus reducing overall noise. There are many examples of barriers, but the most common include acoustical enclosures, panels, curtains, and cladding. Acoustical “curtains” can also take the form of overlapping hanging panels which could form a flexible barrier. This type of control is ideal for spaces where frequent access is required, yet a significant reduction in the transmission of acoustical energy is desired, such as turbine pit accesses. Acoustic cladding refers to a treatment consisting of a layer of low impedance material, such as fiberglass, covered by a high impedance protective layer, such as lead-vinyl. This material is usually attached directly to the structure, such as pipes, to reduce radiated noise.

Measurement Techniques

Data were acquired using a multi-channel measurement system (Figure 1). Acoustic measurements were obtained using laboratory quality microphones. Vibration data were acquired using accelerometers which were attached to the structures using non-permanent methods such as magnets, beeswax and or a contact adhesive. Both single axis and triaxial accelerometer configurations were used. All instrumentation was under calibration from a certified laboratory and in addition, at each facility, end-to-end calibrations were performed to verify sensitivity values through the complete measurement chain. The field measurements included storage of raw time data as well as narrowband and one-third octave band analysis at multiple locations in each powerplant.

In addition to acquiring noise and vibration levels, an acoustic array using focalization technology was employed to verify the acoustic “hot spots” and provide insights into treatment methodologies. The acoustic array technology features a 3D solid sphere acoustic camera to capture sound pressure levels and specialized software algorithms to localize the sources of noise entering the space. Geometry information was obtained by performing a scan with the built-in camera in the sphere. Measurements were then taken simultaneously with the 36 built-in array microphones. The processed measurements produced the sound field which was then overlaid onto the physical picture to localize the sources of acoustic energy. Typical configurations for the array, microphone and vibration measurements are shown in Figures 2 through 4.

Figure 1. LMS multi-channel data acquisition system.

Figure 2. Typical acoustic array and microphone measurement configurations.

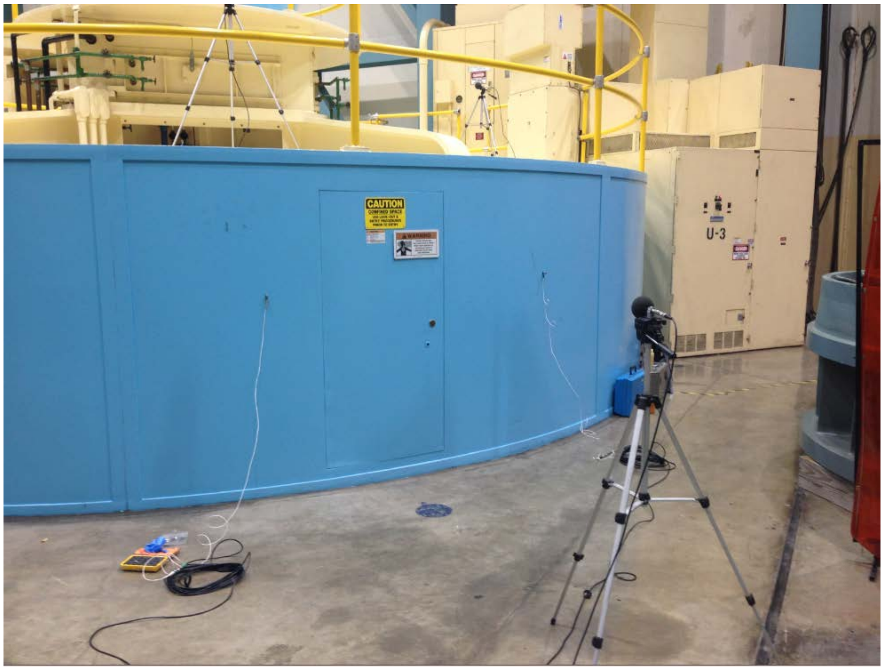

Figure 3.Typical accelerometer and microphone measurement configurations on a generator.

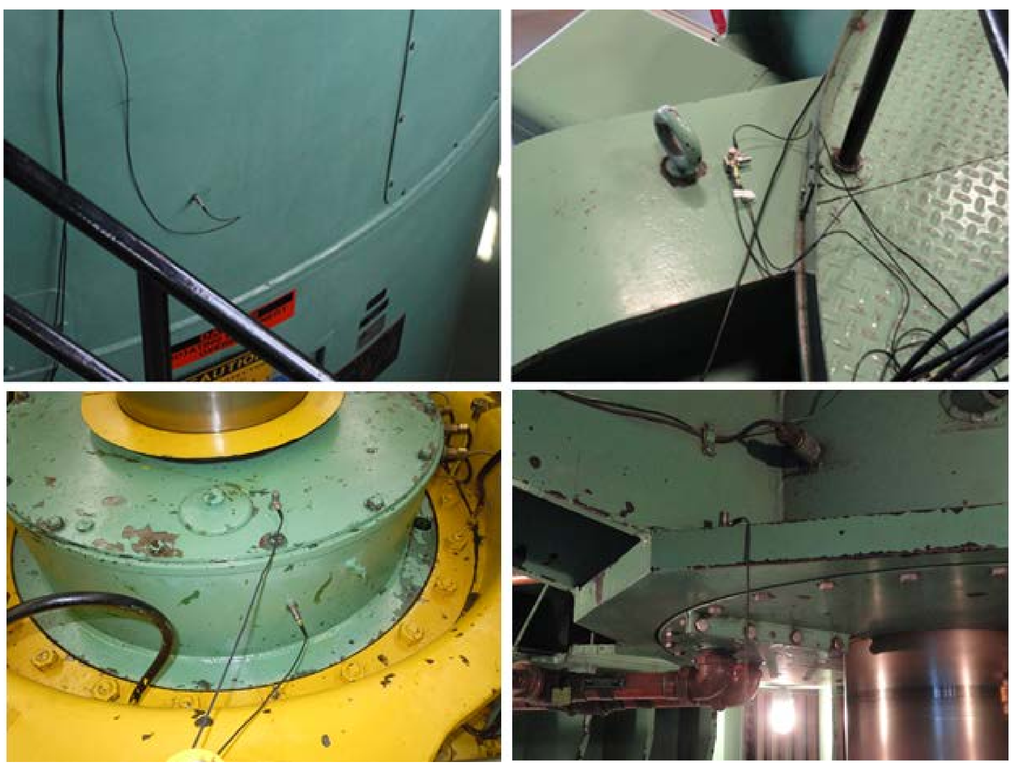

Figure 4. Typical single axis and triaxial accelerometer measurement configurations.

Results

During Phase I of this noise project, measurements were taken in nine different powerplants in the Pacific Northwest Region—seven plants run by Reclamation and two plants by the US Army Corp of Engineers. Based on the results of the measurement surveys, three Reclamation powerplants (Green Springs, Roza, and Chandler) were chosen to implement engineering controls where noise levels exceeded 85 dBA. Komrower 2014 documents the engineering controls that were installed in these powerplants and the measured effectiveness. These controls significantly reduced noise levels. Table 1 shows the measured noise levels before and after the installation of the engineering controls.

Table 1. Noise Level Reductions Achieved after Installing Engineering Controls at the Three Reclamation Powerplants

Powerplant	Location	Noise Levels prior to Engineering Controls Installation (dBA)	Noise Levels After Engineering Controls Installation (dBA)	Noise Level Reduction (dB)
Green Springs	Turbine Pit	101	98	3
	Penstock Area	90	74	16
	Control Room	81	71	10
	Cooling Water Area	87	78	9
Chandler	Between Gens 1 & 2	86	83	3
	In Front of Gen 2	86	82	4
	Between Gen 2 and Pump 1	86	83	3
	Between Pumps 1 & 2	86	81	5
	Main Floor Level			
	Main Floor Railing – Left of Generator	86	82	4
	Main Floor –Mid	86	78	8
	Main Floor Back Wall	85	79	6

Powerplant	Location	Noise Levels prior to Engineering Controls Installation (dBA)	Noise Levels After Engineering Controls Installation (dBA)	Noise Level Reduction (dB)
Roza	**Turbine Pit Level**			
	Main Floor Railing – Left of Generator	86	82	4
	Main Floor –Mid	86	78	8
	Main Floor Back Wall	85	79	6

Green Springs Powerplant

Green Springs Powerplant is located in Ashland, Oregon and consists of a single generator rated at 17 MW. This powerplant installed:

- Acoustic absorption material in the turbine pit
- Acoustic barrier in the turbine pit (Figure 5)
- Acoustic absorption panels in the penstock area wall
- Acoustic absorption material in the control room

Figure 5. Acoustical barrier between turbine pit and penstock area at Green Springs Powerplant.

Chandler Powerplant

Chandler Powerplant in Benton City, Washington (southeast of Prosser), consists of two generators, each rated at 6 MW and two 2,600 HP pumps. This powerplant installed:

- Acoustic absorption panels on the main plant walls
- Spray-on damping material on the cooling ducts
- Acoustic barrier around generators (Figure 7)

Figure 6. High transmission loss acoustic barrier in front of the generator cooling slots.

Roza Powerplant

The Roza Powerplant in the Yakima Valley in eastern Washington, and also consists of a single generator, rated at 13 MW and is located in Yakima, Washington. This powerplant installed:

- Acoustic fan silencers
- Acoustic absorption panels on the main plant walls
- Spray-on damping material over the cooling ducts (Figure 6)

Figure 7. Spray-on damping material on cooling ducts at Roza Powerplant.

Outreach and Presentations

Sharing the results of this research is critical to encourage other powerplants to measure noise levels and adopt innovative measures to reduce noise. As of publication, outreach efforts included:

- A paper, “Reducing Noise in Hydroelectric Powerplants,” will be presented at the AIHce Annual Conference in Salt Lake City, Utah in June 2015.

- A paper, “Noise Control in Hydroelectric Powerplants,” will be presented at the NHCA Conference being held in New Orleans in February 2015.

- A presentation, ONR Future Force Science & Technology Expo, DC Convention Center, Washington DC February 4-6, 2015

- A presentation, “Shipboard Noise Modeling and Engineering Controls to Reduce Noise Levels” at the ONR NIHL Annual Program Review showcased the work that we have done at the three Reclamation powerplants (Green Springs, Roza, and Chandler). This work was also be displayed at that conference in a poster session (see attached). This review was held in Annapolis, Maryland in August 2014.

- A poster, “Noise Control in Hydroelectric Powerplants,” was on display at the 2014 NHCA annual meeting in Las Vegas, Nevada in March 2014.

- The Knowledge Stream Hydropower and Renewable Energy Issue (Summer 2014, Newsletter 2014-04, page 19) “Making Reclamation Powerplants a Quieter Place”

- An article, “This Voodoo Noise Control Stuff Really Works!” appeared in Reclamation’s The Safety Factor (July 2014) http://intra.usbr.gov/ssle/safety/Factor/SafetyFactor_July2014.pdf

- An article, "Federal Agencies Team Up to Reduce Noise in Dams, Hydroelectric Plants,” was published in AIHA Weekly E-ssential Connection April 4, 2012.

- ONR provided a press release, March 26, 2012. http://www.onr.navy.mil/en/Media-Center/Press-Releases/2012/Noise-Dam-Hydroelectric-Power-ONR.aspx.

Conclusions and Next Steps

The implementation of engineering noise controls in the Green Springs, Roza, and Chandler powerplants significantly reduced overall noise levels in all three powerplants. In the Green Springs plant, noise reductions of 10-16 dBA were observed in the penstock area and control room. Roza saw reductions in noise levels of 4-8 dBA on the main floor and Chandler recognized a 3-5 dBA reduction. Except for directly inside the turbine pits and one area outside the turbine pit at the Roza plant, all levels in all the powerplants area were below the 85 dBA target; thus, hearing protection should no longer be needed. For the turbine pit, appropriate single hearing protection should be worn; double hearing protection is no longer required.

On the turbine pit level at Roza, noise levels were still close to the 85 dBA target because the direct path from the turbine pit opening was not treated. Due to cooling restraints, high airflow must be maintained into the turbine pit and the doors to the pit are generally left open. If a further reduction in noise levels is desired in this area, a potential solution which would require further research and development, but which is very feasible, would be to design and build an acoustically treated entrance to the pit area.

Because of the success of this pilot program, a number of other powerplants are being targeted for installation of these noise reduction engineering controls. This new research helps Reclamation take the steps necessary to assure that noise does not harm its workers.

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Glossary

A-weighted sound is a measure of the sound pressure level designed to reflect the acuity of the human ear, which does not respond equally to all frequencies. The ear is less efficient at low and high frequencies than at medium frequencies. To describe sound, as a single value, it is necessary to reduce the effects of both low and high frequencies with respect to the medium frequencies. The result is said to be A-weighted, and the units are dBA (Noise Pollution Clearing House, Noise Control Terms Made Somewhat Easier, David Kelos & Al Perez).

All definitions below are per ASTM Standard C634-11.

airborne sound—sound that arrives at the point of interest, such as one side of a partition, by propagation through air.

damp—(verb) to cause a loss or dissipation of the oscillatory or vibrational energy of an electrical or mechanical system.

decibel, dB—the term used to identify ten times the common logarithm of the ratio of two like quantities proportional to power or energy. See sound level.

noise reduction—the difference between the average sound pressure levels either at two well defined locations based on existing conditions, or at a single location before and after some mitigation measure is implemented.

octave band—a band of sound frequencies for which the highest frequency in the range is (within 2%) twice the lowest frequency. The position of the band is identified by the rounded geometric mean of the highest frequency and the lowest frequency of the band. The nominal mid-band frequencies of “preferred” octave bands as defined in ANSI S1.6 fall in the series 16, 31.5, 63, 125, 250, 500, 1000 Hz etc.

reverberation—the persistence of sound in an enclosed or partially enclosed space after the source of sound has stopped; by extension, in some contexts, the sound that so persists.

sound level, as used in this report - dBA—where the A designates the frequency weighting with a slow exponential time weighting. See dB.

sound pressure level—of airborne sound, ten times the common logarithm of the ratio of the square of the sound pressure under consideration to the square of the standard reference pressure of 20 μPa. The quantity so obtained is expressed in decibels.

unit—measurement, a precisely specified quantity in terms of which the magnitudes of other quantities of the same kind can be stated.