ORE
since 1966
OCEAN AND RESOURCES ENGINEERING
IN THE SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY AT THE UNIVERSITY OF HAWAIʻI AT MĀNOA

# Guide to Graduate Studies and Research in Ocean and Resources Engineering at University of Hawaiʻi at Mānoa

Updated December 2023

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# BACKGROUND

Hawai‘i’s unique location, climate, year-round ocean accessibility, and marine-oriented activities make the University of Hawaii at Mānoa (UHM) an ideal place for education and research in ocean and resources engineering. The graduate program in ocean engineering at UHM was established in 1966 and is one of the first in the United States. Ocean Engineering became an academic department in the College of Engineering in July 1968. In July 1977, the department was accredited for its Master of Science program by the Engineer's Council for Professional Development (ECPD), now known as the Accreditation Board for Engineering and Technology (ABET). In October 1988, UHM officially integrated all marine-oriented programs into the School of Ocean and Earth Science and Technology (SOEST). The Department of Ocean Engineering and the Hawaii Natural Energy Institute of the College of Engineering became part of SOEST to form the technology component of this school. In July 1999, the department changed its name to Ocean and Resources Engineering (ORE) to better reflect the research focus of the faculty.

Educational and research emphasis in ORE is placed on coastal, offshore, ocean resources, and oceanographic engineering. Coastal engineering deals with coastal and harbor problems, sediment transport, nearshore environmental engineering, and coastal flood hazards. Offshore engineering deals with structures and systems used in the deeper parts of the ocean and includes hydrodynamics of fluid-body interaction, seakeeping and dynamic responses of ships and platforms, and hydroelasticity of floating structures. Ocean resources engineering focuses on the systems associated with the ocean’s energy, mineral, and living resources, the potential use of the ocean for waste disposal, and the environmental and economic aspects of such activities. Oceanographic engineering includes the design, operation, and maintenance of the mechanical, electrical, and computing systems that support oceanographic research and marine operations.

# ACADEMIC PROGRAM

## *Program Educational Objectives*

ORE offers a graduate program leading to the Master of Science (MS) and Doctor of Philosophy (PhD) degrees. The goal of the program is to prepare students for the engineering profession and to conduct research. These objectives, along with the curriculum described below, were developed in collaboration with ORE’s advisory panel.

The program educational objectives at the MS level is to produce graduates who:

1. Are able to handle multidisciplinary problems by assimilating relevant information and applying mathematics, science, and engineering principles;

2. Are proficient engineers translating client's requirements and technical needs into solvable tasks and synthesizing solutions into actionable recommendations or engineering designs;
3. Have broad understanding of the ocean and resources engineering disciplines as well as the changing needs and technologies in the industry;
4. Are highly proficient and ready to assume responsibility on tasks related to one or more of the ocean and resources engineering disciplines;
5. Are able to make proper judgment related to professional, ethical, managerial, economic, and other non-technical issues commonly encountered in engineering practice; and
6. Can communicate in written and verbal form and work effectively with peers, clients, and the public in conveying new ideas, products, or designs.

The program at the PhD level shares the objectives of the MS program, with the added emphasis on producing graduates who:

1. Can conduct original research and develop new technologies in ocean and resources engineering; and
2. Have the experience to publish in refereed journals.

This additional emphasis prepares our doctoral graduates to pursue research careers in industry and academia.

## *MS Degree*

An important goal of the MS program in Ocean and Resources Engineering is to direct students' previous education and work experience to ocean-related engineering careers. Students upon graduation from the program will achieve the following student outcomes:

1. Working knowledge of fundamental mathematics, science, and engineering principles that include statics, dynamics, fluid mechanics, solid mechanics, and probability and statistics
2. Proficiency in the core program of Ocean and Resources Engineering that comprises hydrostatics, oceanography, water waves, underwater acoustics, ocean instrumentation, and laboratory and field experience
3. Mastery of at least one of the four Ocean and Resources Engineering disciplines that include coastal, offshore, ocean resources, and oceanographic engineering
4. An ability to identify, formulate, and solve complex ocean and resources engineering problems by applying principles of engineering, science, and mathematics
5. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
6. An ability to communicate rationale, methodologies, and recommendations of projects effectively in written and verbal form with a range of audiences

7. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
8. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
9. An ability to develop and conduct research through appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions, and
10. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
11. Meeting of educational goals through a customized program of study, training, and research.

The ORE program at the MS level has the following requirements:

- Pre-program,
- MS General Exam,
- Core, option-area, and elective courses, and
- MS thesis (Plan A) or independent project (Plan B).

The pre-program includes a general education component, one year of college-level mathematics and science (30 credits), and one and one-half years of engineering topics (45 credits) that must include computer aided design, statics, dynamics, fluid mechanics, solid mechanics, and probability and statistics. The pre-program provides students with a broad educational background that covers the technical and non-technical issues commonly encountered by engineers in professional practice. Students with an undergraduate degree from an ABET accredited engineering program usually satisfy most of the pre-program requirements a priori. Not all students in the program have an undergraduate degree in engineering. The department requires all students to have completed the required pre-program courses listed in Appendix B before graduation.

The MS degree can be earned under the Plan A (thesis) or Plan B (independent project) option or enroute to Doctorate (see next section). This requires a minimum of 30 academic credits, at least 24 of which must be earned in advanced courses numbered 600 or above. Up to two credits of directed reading registered for letter grade and six transferred credits that have not been used in obtaining a prior degree can be counted toward the MS requirements. Students who satisfy the pre-program requirements must take the ORE general examination during the first semester of their full-time enrollment. This test is used to gauge incoming students' knowledge of mathematics, science, and basic engineering principles, as well as their preparation for graduate-level coursework. Students requiring pre-program work must take the general examination in the semester following the completion of their pre-program, and prior to their semester of graduation. The general examination may be repeated once. Students are encouraged to take the Fundamentals of Engineering (FE) examination instead and those who have passed the FE examination within the three years prior to their admission to ORE are exempt from taking the general examination.

The core, option-area, and elective courses offered by ORE are listed in Appendix B. The four core courses provide students with a broad understanding of the topics of interest to ocean and resources engineering. This includes hydrostatics, oceanography, water wave mechanics, and underwater acoustics. The laboratory course connects material covered in the classroom with observations made and data collected in the ocean. The option-area courses prepare students for specialization in coastal, offshore, ocean resources, and oceanographic engineering. The capstone design project is typically team-taught by faculty members and practicing professional engineers. Its objective is to familiarize students with the planning and execution of an engineering project in a consulting firm setting. All students are required to participate in a public speaking workshop organized by the department, take an on-line research ethics training class, and attend 15 seminars which cover the latest in developments and research – as well as contemporary issues – related to ocean and resources engineering. The core, option-area, and seminar requirements amount to 25 academic credits; the remaining credits are to be chosen to form a coherent plan of study.

Students typically complete their study with a thesis (Plan A) or independent project (Plan B). The thesis is research oriented and carries six academic credits. The independent project focuses on engineering application and design and carries three academic credits. Both require a proposal outlining the subject area, objectives, proposed methodology, sources of data, and anticipated results, and must be approved by a committee of at least three graduate faculty members. The majority of this committee should be comprised of ORE departmental, cooperating, and affiliate graduate faculty members and the committee should include at least one ORE departmental faculty member. The committee must be approved by the ORE Graduate Chair who, in consultation with the Committee Chair, may appoint additional member(s) to the committee. The thesis/project provides students with an opportunity to explore and contribute to the development of the latest technologies, methods, and datasets in an ocean and resources engineering discipline. This work results in a thesis (Plan A) or a report (Plan B) that should demonstrate both mastery of the subject matter and an aptitude for clear and effective communication. The student must present and defend their work at a final examination, which provides the committee with an opportunity to assess the student's understanding and ability to integrate his or her work at the MS level. The MS final examination may be repeated once.

### *PhD Degree*

Students pursuing a PhD are required to achieve a broad understanding of the principal areas of ocean and resources engineering, as well as a thorough understanding of their research area. Students are expected to have knowledge related to fundamental engineering courses (see Appendix B for the MS basic engineering pre-program requirements) as well as the core courses of the ORE MS degree. Doctoral students are also encouraged to take courses relevant to their research interests.

The ORE program at the PhD level has the following requirements:

- PhD qualifying exam,
- An advanced mathematics course at the graduate level and ORE 792 Seminar
- PhD comprehensive exam, and
- PhD dissertation and defense.

All intended PhD candidates are expected to take a qualifying examination, preferably before or during the third semester of full-time enrollment. In addition to covering basic undergraduate mathematics and engineering fundamentals, the examination tests the students' understanding of the core courses of the ORE MS degree. The examination is conducted by ORE's PhD qualifying exam committee and the outcome is determined by a vote of the departmental faculty. The qualifying examination may be repeated only once.

After passing the qualifying examination, the student forms a dissertation committee and begins preparing his/her dissertation proposal. The dissertation committee should consist of a minimum of five graduate faculty members with at least one ORE departmental faculty member and at least one faculty member from outside ORE not involved in the proposed research to serve as the university representative. The majority of this committee should be comprised of ORE departmental, cooperating, and affiliate graduate faculty members. The committee must be approved by the ORE Graduate Chair who, in consultation with the Committee Chair, may appoint additional member(s) to the committee. Upon completion of their dissertation proposal, the student must take a comprehensive examination which is conducted by the dissertation committee. This is meant to measure the student's preparation and ability to conduct original research in the area of the proposed dissertation topic. The examination consists of a presentation of the student's proposed research followed by an oral component in which the student must defend the novelty of the proposed research, address any issues raised by the committee, and demonstrate his/her ability to successfully conduct the proposed independent and original research. The comprehensive examination may be repeated only once.

With recommendation by the graduate chair, a doctoral candidate may earn an MS degree upon completion of the degree requirements with a Plan A thesis, Plan B project or a PhD proposal successfully defended. The degree may not be awarded retroactively. The candidate must file a Graduate Application for Degree by the appropriate deadline in the semester when the requirements are met. Students who already have an MS degree in an equivalent field are not eligible for this enroute option.

PhD students are expected to publish their research in refereed journals. This provides feedback from the research community while developing a publication track record prior to graduation. The student must present and defend the dissertation at a final

examination, which is conducted by the dissertation committee. This examination may not be repeated except with approval from the graduate program and the Graduate Division, which has additional rules pertaining to the defense.
http://manoa.hawaii.edu/graduate/content/final-defense

### *Responsible Conduct of Research Training*

The University of Hawaiʻi (UH) values research integrity. To help ensure compliance with UH policies, all ORE students are required to complete the online portion of the Responsible Conduct of Research (RCR) training before submitting a research proposal. Details are available on the UH RCR website in the Collaborative Institutional Training Initiative Certification (CITI) section.
https://www.hawaii.edu/researchcompliance/responsible-conduct-research

### *Individual Development Plan*

All ORE students are required to formulate and regularly update their Individual Development Plans. Academic advisors work with individual students to refine their aspirations for graduate studies into seven Student Educational Goals:

1. ORE Specialization
2. Research and training
3. Teaching and mentoring
4. Place, culture, and ethics
5. Oral and written communication
6. Leadership, teamwork, and networking
7. Career development

The Individual Development Plan (IDP) helps students identify their strengths and weaknesses and to set milestones and plans. Development of an IDP is an iterative process. Students fill out a self-assessment questionnaire in ORE IDP Form 1 and then work with their academic and research advisors to define milestones, strategies, and outcomes in ORE IDP Form 2. The IDP focuses on goal setting and skill development rather than outcome assessment. The IDP forms are reviewed and updated at the beginning of each semester, at which time the milestones and goals are revised based on levels of accomplishment in the prior semester. ORE IDP forms are available on the ORE website.
https://www.soest.hawaii.edu/ore/program/forms-and-procedures/

### *Admission*

Students are admitted for graduate studies based on their scholastic records. Candidates for the MS program typically have a bachelor's degree in an engineering discipline, which provides an adequate background in mathematics, science, and mechanics. Students with undergraduate degrees other than engineering will be required to make up deficiencies in basic engineering courses. Students seeking admission to the PhD program should have an MS in engineering, or equivalent qualifications. Exceptionally qualified students with a BS in engineering who do not hold an MS degree may petition for direct admission to the PhD program. Admission letters include a preliminary list of deficiencies, if any, determined by the ORE Graduate Chair.

Deadlines to submit applications for admission to the ORE graduate program are January 15 for fall semester admission and August 15 for spring semester admission. The ORE application checklist (available on the ORE admissions webpage) includes all the forms and supporting documents that need to be submitted; application materials should be submitted to the UHM Graduate Division, with supplemental materials submitted via the Graduate Application Supplemental Documents Upload Website.

Detailed admission requirements and forms are available at the University of Hawaiʻi Graduate Division web page. GRE test results are not required but will be considered if submitted. Official English Proficiency Exam scores are required from non-native English speaking students. TOEFL – Test of English as a Foreign Language – minimum scores are 600/100 (paper/Internet), with subtest scores of 25 for listening and 25 for speaking. IELTS – International English Language Testing System – minimum score is 7.00.
http://manoa.hawaii.edu/graduate/content/prospective-students

Forms required by ORE can be downloaded from the ORE admissions web page.
http://www.soest.hawaii.edu/ore/program/admission/

- Supplemental information form
- Statement of objectives
- Letter of recommendation form
- Graduate assistantship application

After the required documents are received, the Graduate Division screens the application to ensure that university admission requirements are satisfied. The ORE Admissions Committee and ORE Graduate Chair then evaluate the application and determine the applicant's admissibility to the ORE program.

### *Advising and Progress*

Upon admission, the ORE Department Chair meets with each incoming student at a preliminary conference to discuss the program requirements and establish the educational goals. The ORE Graduate Chair will reconfirm any pre-program deficiencies for students from non-ABET accredited undergraduate programs through evaluation of transcripts and course descriptions. The UHM Graduate Division requires that all transfer credits must be approved during the first semester of enrollment, and must not have been used in obtaining a prior degree. The ORE program allows up to six transfer credits from courses taken elsewhere. These courses must be equivalent to the core and option-area courses of the program and approved by the course instructors upon evaluation of the course notes, assignments, and exam questions. If these requirements are met, the ORE

Graduate Chair then recommends to the Associate Dean of Graduate Division to approve the transfer credits.

The ORE Graduate Chair serves as the advisor to students who do not meet the pre-program requirements. Once pre-program requirements are met, the ORE Department Chair appoints an academic advisor from the pool of ORE departmental faculty. The academic advisor helps students develop a program of study meeting their specific educational goals, navigate the program requirements, and ensures that all university and department guidelines are met. At the onset of their research, students must select a research advisor to guide their research and serve as their Committee Chair.

The Graduate Division requires that several forms are submitted by the student during their program to track progress. These forms can be found on the Graduate Division website.
http://manoa.hawaii.edu/graduate/content/forms

In addition to the Graduate Division forms, PhD students are required to submit internal Form I-A (Dissertation Committee and Proposal, available at https://www.soest.hawaii.edu/ore/program/forms-and-procedures/) prior to scheduling their comprehensive examinations. Their research proposal must be attached to the form and submitted to the Graduate Chair for approval. ORE further monitors progress of MS students through an internal student progress form which is updated each semester and upon graduation. The purpose of this progress form is to help keep students on track and to provide data for subsequent assessments of the ORE program.

Policies regarding conduct and harassment are available on the SOEST website.
https://www.soest.hawaii.edu/soestwp/sexual-harassment-and-bullying/

## *Timeline*

The minimum residency requirement for an MS degree at UHM is two semesters full-time. The following chart outlines the typical timeline to satisfy the requirements in the MS program. Since the core and option-area courses are offered with the fall-spring sequence, most students begin their enrollment in the fall semester. Students who do not require pre-program coursework proceed directly to the program coursework and take the general examination during their first semester. Most complete the degree requirements between 20 months and two years. Students with pre-program deficiencies typically spend three years full-time to complete the program.

Table 1. Typical ORE MS Timeline

| MS Requirements | Semester | | | Semester | | | Semester | | |
|---|---|---|---|---|---|---|---|---|---|
| | Fall | Sp | Sum | Fall | Sp | Sum | Fall | Sp | Sum |
| Pre-program | | | | | | | | | |
| General Examination | | | | | | | | | |
| Coursework | | | | | | | | | |
| Approval of research | | | | | | | | | |
| Research | | | | | | | | | |
| Final Examination | | | | | | | | | |

The minimum residency requirement for a PhD degree is three semesters full-time. Based on Graduate Division statistics, the average time to complete a PhD degree in ORE is 5.5 years. The following chart shows the typical timeline to satisfy the PhD program requirements. Most students admitted into the PhD program satisfy the pre-program requirements and proceed directly to the program coursework. PhD students typically take the qualifying examination after a full year of coursework. The comprehensive examination should be taken within three years of enrollment.

Table 2. Typical ORE PhD Timeline

| PhD Requirements | Semester | | | Semester | | | Semester | | | Semester | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fall | Sp | Sum | Fall | Sp | Sum | Fall | Sp | Sum | Fall | Sp | Sum | Fall |
| Pre-program | | | | | | | | | | | | | |
| Program Coursework | | | | | | | | | | | | | |
| Qualifying Exam | | | | | | | | | | | | | |
| Approval of research | | | | | | | | | | | | | |
| Research | | | | | | | | | | | | | |
| Comprehensive Exam | | | | | | | | | | | | | |
| Dissertation Defense | | | | | | | | | | | | | |

Students failing any one of the general, qualifying, comprehensive, or final* examinations twice will be dropped from the program (*if a retake is granted in the case of a PhD exam). Students who do not complete all requirements within seven years after admission will be placed on academic probation. Extension for up to three years beyond the seven-year time limit  is possible only upon submission of a petition to the Graduate Division via the ORE Graduate Chair providing a detailed degree plan and timeline for completion of all degree requirements.

# FACULTY

## *Departmental Faculty*

ORE has 8 departmental faculty members. All faculty members are graduate faculty with the UHM Graduate Division and are responsible for instruction, research, and administration within the department. To administer the department, faculty serve rotational terms as ORE Department Chair and Graduate Chair.

- K.F. Cheung, PhD, PE, Professor – Coastal and offshore engineering, marine hydrodynamics, water wave mechanics, tsunamis, coastal flood hazards
- D. Gedikli, PhD, Assistant Professor – Marine structures (ships and offshore structures), experimental hydrodynamics and fluid-structure interactions, structural dynamics, dynamical systems
- B.M. Howe, PhD, Researcher (research professor) – Ocean acoustics including tomography and ambient sound, ocean observing sensor webs including fixed (e.g., cabled) and mobile platforms (e.g., gliders and profilers), navigation, and communications
- Z. Huang, PhD, Professor – Marine energy, hydrodynamics of ocean waves, coastal and ocean engineering, coastal sediment transport, coral reef hydrodynamics, tsunami hazard mitigation
- M. Krieg, PhD, Assistant Professor - Marine Robots, biomimicry analysis, unconventional propulsion, hydrodynamic modeling, autonomous systems and control, distributed fluid sensing, coupled autonomous systems
- E.M. Nosal, PhD, Associate Professor – Passive acoustic monitoring methods, ocean ambient noise, sediment acoustics, bioacoustics, signal processing, inverse methods
- J.E. Stopa, PhD, Associate Professor – Marine forecasting / hindcasting, data analysis applications in geophysical datasets, oceanic remote sensing, spectral wave models, wind and wave climate
- Y. Yamazaki, PhD, Assistant Researcher – Tsunami numerical model development, tsunami generation and earthquake rupture mechanism, coastal flood hazard mitigation

## *Cooperating Graduate Faculty*

ORE has a number of cooperating faculty members from other research or academic units at UHM. Cooperating faculty members give seminars on their research, serve on student research committees, and advise students on their theses or independent research projects.

- M. Chyba, PhD, Professor of Mathematics – Robotic control theory and systems
- P. Cross, PhD, Specialist at Hawaii Natural Energy Institute – Meteorology, oceanography, wave energy, renewable energy generation
- O. Francis, PhD, PE, Professor of Civil Engineering – Coastal infrastructure, sustainable water and wastewater systems, ocean waves
- R. Ghorbani, PhD, Professor of Mechanical Engineering – Renewable energy
- B.T. Glazer, PhD, Professor of Oceanography – Instrumentation
- J.R. Smith, PhD, Specialist (Marine Geophysical) and Science Program Director, Hawaii Undersea Research Laboratory – Marine mapping technology and instrumentation
- J. Yu, PhD, Researcher, Hawaii Natural Energy Institute – Marine bioproducts
- F. Zhu, PhD, Assistant Researcher, Hawaii Institute of Geophysics and Planetology – Dynamics and control, machine learning, autonomous systems, robotics

## *Affiliate Graduate Faculty*

ORE has several affiliate faculty members from the engineering and scientific communities. Affiliate faculty members volunteer their time and bring individual expertise, external perspectives and real-world engineering experience to the academic program. Some of them serve on student research committees and team-teach the capstone design project with the ORE faculty.

- E.M. Briggs, PhD, Senior Scientist at Aquatic Labs
- C. Ertekin, PhD, Professor (retired), Ocean and Resources Engineering
- D. Greeson, PhD, US Navy Captain (ret), Nuclear Engineer, Pearl Harbor Naval Shipyard
- P. Gruden, PhD, Cetacean Acoustics Researcher, Research Corporation of the University of Hawaii
- E. G. Pawlak, PhD, Professor of Mechanical and Aerospace Engineering, University of California San Diego
- D. Rezachek, PhD, PE, Alternate Energy Specialist (retired), Energy, Resources, and Technology Division, Department of Business, Economic Development and Tourism, State of Hawaii, Honolulu, Hawaii
- D.A. Smith, PhD, PE, Senior Coastal Engineer, Sea Engineering

- L. VanUffelen, PhD, Assistant Professor, Department of Ocean Engineering, University of Rhode Island
- D. Vithanage, PhD, PE, Technical Director and Vice President, Oceanit Laboratories, Inc., Honolulu, Hawaii

### *Adjunct Faculty*

- B. Jones, PhD, Director of Data and Modeling and Associate Director, Applied Research Laboratory, University of Hawaiʻi
- S.W. Yoon, PhD, Adjunct Professor of Ocean & Resources Engineering

## RESEARCH FACILITIES

### *HIG 109*

ORE's collaborative teaching and research space in HIG 109 (750 sqft) is a hub for scientific exploration and learning. HIG 109 is used to construct and test marine renewable energy systems, and is integral to courses like ORE 609 Hydrodynamics of Fluid Body Interactions, ORE 612 Dynamics of Ocean Structures, and ORE 677 Marine Renewable Energy. It houses the recirculating flow channel (part of the Fluid-Structure Interaction and Nonlinear Dynamics Lab, see below), and has a clear test section with dimensions of 0.2 meters in width, 0.66 meters in length, and 0.2 meters in height, and operates within a flow speed range of 5 to 165 cm/s. Multiple workbenches house an array of essential equipment, including computers, a tensile test machine, high-speed cameras, a PIV laser, and various measurement sensors such as accelerometers and strain gauges. HIG 109 offers a vibrant space for interdisciplinary research and hands-on learning experiences.

### *HIG 151*

The department's largest facility, located in HIG 151, is a multi-use laboratory space accommodating both teaching and state-of-the-art research needs. A large wave flume is the centerpiece of this versatile laboratory space (see "Wave Flume Facilities" below).

Laboratory modules that use this facility to promote engaging hands on learning have been developed for ORE 411 Buoyancy and Stability, ORE 601 Ocean Engineering Laboratory, ORE 609 Fluid Body Interactions, ORE 612 Dynamics of Ocean Structures, ORE 657 Autonomous Marine systems, ORE 653 Ocean Instrumentation and Technology and ORE 677 Marine Renewable Energy. In addition to ORE internal classes, HIG 151 promotes university wide cooperation and partnership by making the facility available to classes from other departments/units, such as the Oceanography department, which uses the lab for three of their courses (OCN 201, 620, and 660).

HIG 151 has 4 general use workbenches, each of which can seat 4-6 students, that are designed to be versatile and modular to accommodate a variety of possible testing scenarios. Each workstation contains common elements used in different experiments, including a computer, a benchtop power supply, a benchtop multimeter, and an NI external USB data acquisition card to sample from whatever sensors are being tested. These workstations support student research, capstone projects, and outreach efforts.

This facility also has two 3D printers (one with continuous fiber composite printing capabilities) and a small shop area for prototype fabrication.

### *Wave Flume Facilities*

The HIG 151 wave flume has an inner cross section of 800 x 800 mm and a length of 12 m. The width is adequate for research purposes, so that it can fit workable scale models of energy converters, marine vehicles, and offshore structures. The flume has a paddle type wave generator, which can be used to generate either monochromatic waves with a single specified wavelength and wave height, or random waves with a specified spectral density function, such as a Bretschneider spectrum.

The department has a second 10 m long wave flume with a flap-type generator for monochromatic waves and a blower for wind waves. The flume is 0.2 m wide and 0.3 m high for demonstration of a range of free-surface flow phenomena including wind wave generation, wave shoaling, wave breaking, wave reflection, and down-slope currents.

Students also have access to a wave flume in the Hydraulics Laboratory of the Department of Civil and Environmental Engineering for ORE 601 and research work. The flume is 9.14 m long, 0.15 m wide, and 0.39 m high with a programmable wave maker and wave gauges connected to a data acquisition system controlled by the WinLabEM software. Also available is a high-speed camera that can capture wave processes through the clear acrylic walls at 400 fps. ORE students have used the flume for MS and PhD research on wave loads and overtopping with publications in refereed journals.

### *Fluid-Structure Interactions and Nonlinear Dynamics Laboratory*

The Fluid-Structure Interactions and Nonlinear Dynamics Laboratory uses experimental, theoretical, and numerical tools to understand fluid-structure interaction phenomena from a fundamental point of view and with applications in several fields including wave energy, open-ocean aquaculture, and offshore engineering. The laboratory houses a number of experiment tanks, which are used for both research and teaching demonstrations. These include a controlled flow tank of 4 m (L) by 1.5 m (W) by 1 m (H), and a rotating circular flow tank of 1 m (D) by 0.6 m (H). The circular flow tank is designed to work similar to a re-circulating channel that is capable of producing uniform and sheared flow conditions.

Laboratory instrumentation includes several sets of GoPro cameras and two high-speed cameras with a Digital Particle Image Velocimetry (DPIV) System that can obtain two-dimensional fluid velocity fields behind bluff bodies and capture motion characteristics of flexible structures. Additional equipment includes data acquisition boards and one operating computer to control the experiments with supporting software packages including MATLAB, LabView, ProAnalyst, and many other miscellaneous instruments.

## *Surface and Underwater Propulsion and Robotics (SUPR) Lab*

The SUPR Lab is devoted to fundamental research on the stability, control dynamics, fluid-body interaction, and propulsion of autonomous marine vehicles both on the surface and underwater, and on leveraging novel sensing techniques to generate a better understanding of the surrounding fluid dynamic environment in real-time. The lab is located at the UH Marine Center in Honolulu Harbor, providing direct access to research vessels of all sizes for future field testing and deployment.

One of the main features of this facility is a large multi-use fluid testing tank (Figure 1). The tank measures 4.1 m long, 1.3 m wide and 1.1 m high. The tank has a model positioning system that can hold station in a desired static configuration during testing or be used as a carriage for small scale towing tank testing. The dynamic positioning system has two degrees of freedom with 3.5 m of travel along the tank and 1.25 m travel across the width, with a maximum velocity of 0.7 m/s in either direction. The tank is constructed out of acrylic panels attached to a steel frame providing visual access from all sides, facilitating particle image velocimetry measurement of flow fields surrounding vehicles and propulsors. The lab has a full range of data acquisition hardware and multiple workbenches are present for construction, maintenance, and storage of prototype vehicles and subsystems.

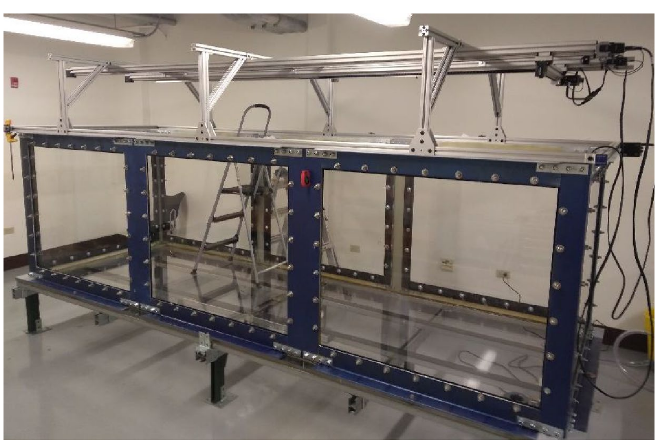

Figure 1. Multi-use testing tank installed at SUPR Lab. The tank has dynamic model positioning capabilities and allows for visual access from all sides for flow measurement/filming.

Both the Fluid-Structure Interaction and Nonlinear Dynamics Laboratory and the SUPR Lab are collocated at the UH Marine Center with shared physical space and facilities.

## *Instrument and Sensor Development*

ORE maintains laboratory facilities with bench and workshop space for instrument development and benchtop testing including access to 3D printers, electronics workspace, tools for minor machining, dedicated wet and chemical bench space, and a variety of support software.

## *Aloha Cabled Observatory (ACO)*

The ALOHA Cabled Observatory (ACO) is a general purpose "node" providing power, communications, and timing connectivity for scientific use at Station ALOHA 100 km north of Oahu. Included are a suite of basic sensors making core measurements as well as local sensing of the water column. At 4728 m deep, it is the deepest scientific outpost on the planet with power and internet connections (Figure 2).

The ACO was deployed in June 2011 to support scientific research. Station ALOHA is the field site of the NSF-funded Hawaiʻi Ocean Time-series (HOT) program that has investigated temporal dynamics in biology, physics, and chemistry since 1988, at conditions representative of roughly 70% of the world ocean. Research cruises (~monthly since 1988) sample the ocean from top to bottom to monitor and study changes on scales of months to decades. The co-located Woods Hole mooring (WHOTS) provides meteorological and upper ocean physical data. Together, HOT, ACO, and WHOTS provide a unique set of complementary in-situ observations of the ocean across all disciplines and regimes.

The ACO system uses a retired AT&T telecommunications cable. In 2007 the cable was cut and one end moved slightly and a 'proof module' hydrophone attached. A general purpose 'node' was connected in June 2011 and the ACO has been providing power (1200 W), network communications (100 Mb/s), and timing (1 µs) to the seafloor node and instruments at 4728 m water depth since then. During a service cruise in November 2014, a camera system (CAM2 and LIGHT1) and a basic sensor package (BSP1) were added. Station ALOHA is unique for the combination of long-term world-class ocean sampling coupled with multitudes of short to long-term process studies and other research.

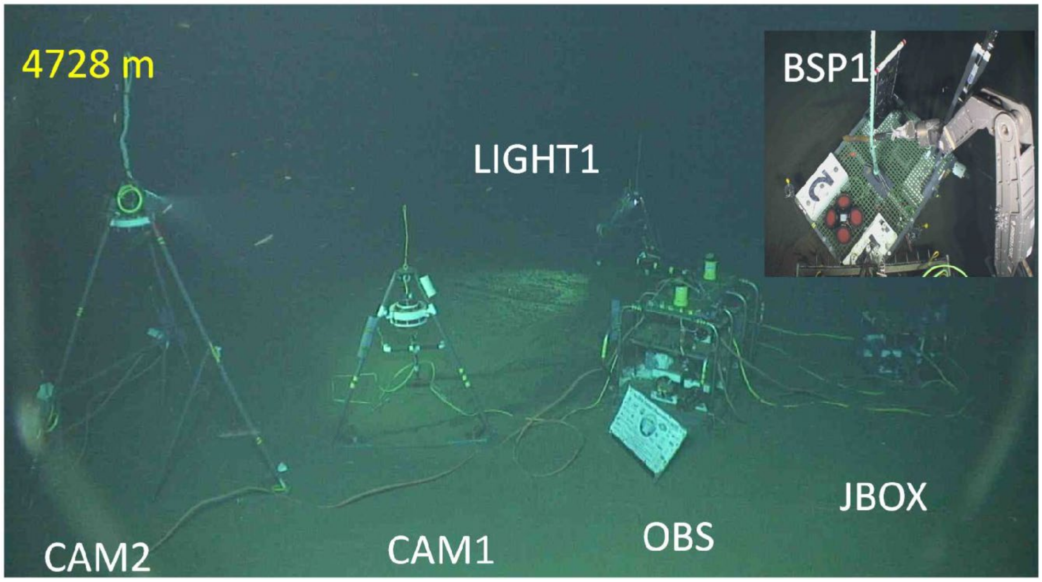

Figure 2. The ACO configuration (November 2014). The BSP1 sits off to the right about 18 m. A banner with contributors is by the OBS (photos by *Jason*).

While supporting scientific research, the ACO provides many opportunities for teaching and research within classes, degree projects, and independent studies. These include learning spectral analysis of ambient sound, analyzing the real-time data, software for displaying raw and video/audio data, developing and preparing instrumentation and infrastructure for deployment, and participating in cruises with leading edge equipment. The SOEST 6000-m rated remotely operated vehicle (ROV) supports the latter. ACO is a topic in various classes: ORE 202 Ocean Technology, OCN 363 Earth System Science and Data, ORE 654 Ocean Acoustics, ORE 601 Ocean Engineering Laboratory, ORE 603 Oceanography for Engineers, and ORE 766 Numerical Methods.

## *Kilo Nalu Observatory*

The Kilo Nalu Observatory (KNO) on the south shore of Oahu provides a window into the nearshore coral reef physical, biological, and chemical environment. The permitted 7-acre in-ocean test range off Kewalo Basin, which extends from 5 to 20 meters depth with test platforms equipped with shore-cabled power and data connections, provides a direct bridge between lab-based and in-situ experiments (See Figure 3). The observatory is managed and maintained by ORE for research on marine alternative energy (a “nursery” site), autonomous undersea vehicle development (mobility and fine control, positioning, docking), artificial reefs, surface waves and currents, new sensors (e.g., pH and alkalinity) and more. A shore-side radar system provides wide area surface wave coverage. ORE also uses KNO as its “natural” laboratory to train its students, both (future) undergraduate and graduate, for ocean instrumentation, field work, data analysis, and teamwork.

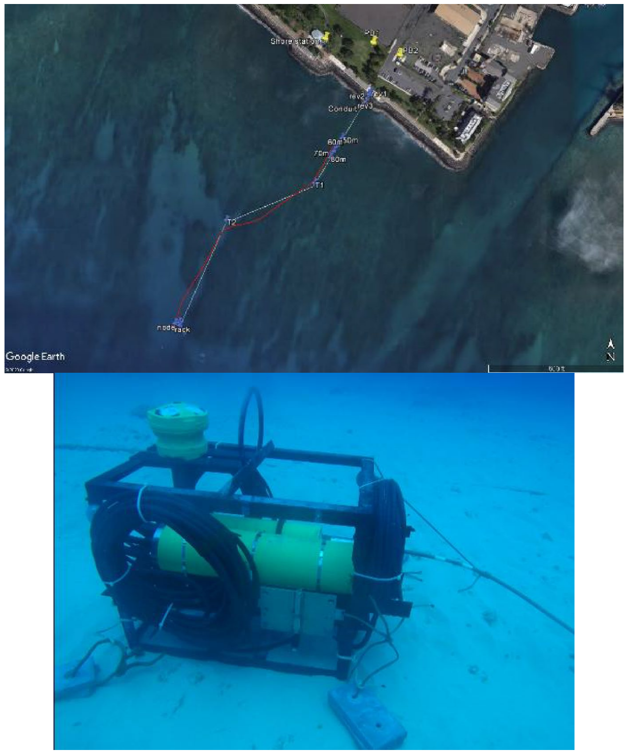


Figure 3. Kilo Nalu Observatory cable route (left) and acoustic Doppler current profiler (right).

The system currently has one primary node with three ports in addition to an ADCP. New instrumentation related to the above research topics is in the process of being added. The input to the primary node from shore is 400V and 1 GigE ethernet. Each port has circuit breakers, with programmable pulse width modulation to handle turn-on current surges, and its own independent ground fault monitoring circuitry (48 V and 400 V). All raw data is logged and plotted in real time. The system hardware, software, data management, and web services are all based on and shared with the ALOHA Cabled Observatory (ACO) and are consistent with de facto international "observatory standards." ACO uses KNO as a test bed.

## COMPUTING RESOURCES

The ORE program requires extensive use of engineering tools and computers in the coursework. Some students are exposed to state-of-the-art computing infrastructure and high-fidelity simulation models through MS and PhD research work. The following subsections outline the available facilities and discuss their availability for instructional use and student research.

## *Department Computing Facilities and Software*

The department operates a network of PCs installed with the current version of Windows and MS Office in POST 418. All students have laptop computers and research and teaching assistants have assigned PCs. Software available for all students includes
• Compiler: Fortran 95 Linux PRO v6.2, 95 Standard v5.7, C/C++
• Data processing and display: AutoCAD, Adobe Pro, Fusion 360, Matlab, Tecplot
• Engineering tools: Aces 7b, Delft Ship Pro v7.14
• Research tools: Mathematica, Matlab
The department employs two teaching assistants, who look after the computers, software, and network connections. The computer network in Holmes Hall is supported by the College of Engineering free of charge. The computers, software, and networks at faculty and student offices in other buildings are supported by the SOEST Research Computing Facility for a maintenance fee.

Faculty members, who specialize in numerical modeling, operate their own computer clusters that are available to students for research work. These include

- 448 NVIDIA Tesla GPU cores and 12 Intel Xeon CPU cores (Nosal)
- Two sets of 56 Intel Xeon(R) Platinum 8173 CPU cores and five sets of 18 Intel Xeon(R) E5-2760 CPU cores (Huang)
- 704 Intel Xeon X5550 2.67Hz, E5-2690 2.9GHz, and E5-2683 2.1GHz CPU cores (Cheung)
- TitanA375 - Dual AMD EPYC Rome 7002 Series- Scientific Research Workstation PC with 128 cores(Huang)

These clusters are maintained by the individual research group with support from the SOEST Research Computing Facility for a maintenance fee. Commercial and community software used for research includes

- Data processing and display: Adobe Pro, ArcGIS, Google Earth Professional, Labview, Matlab, Solidworks
- Ocean and coastal models: Delft3D, MITgcm, NEOWAVE
- CFD tools: OpenFOAM
- Ocean wave models: SWAN, WAVEWATCH
- Marine hydrodynamics: WAMIT, OrcaFlex, ProAnalyst

These resources support classroom instruction as well as student research on bioacoustics, floating structure dynamics, wave energy converters, ocean waves, nearshore processes, sediment transport, coastal flood hazards, and ocean climatology.

## *University-Wide and Off-campus Computing Resources*

The Hawaiʻi Data Science Institute (HI-DSI) is a UH-system wide initiative on interdisciplinary research and for catalyzing training capacity in data science, computation, and visualization. It operates a high performance computing cluster with accounts free of charge for faculty, staff, and students across all ten campuses. The cluster currently has 297 nodes, 6309 CPU cores, 56 GPUs, 50TB memory, and 1 PB storage with full-time support staff. The main processors are 2×Intel Xeon 6240R 2.4GHz with 192GB RAM and 8×Quadro RTX 5000 with 16 GB GDDR6 RAM. Researchers can also purchase or lease CPU and GPU nodes from HI-DSI or have their own clusters hosted for a maintenance fee.

Dr. Justin Stopa and his students have access to a high-performance computer called Datarmor through collaborative projects related to missions of NASA and the European Space Agency. The system, which is maintained by the French Research Institute for Exploitation of the Sea (IFREMER), has 7 PB storage and a capacity of 426 teraflops. There are 396 machines with 28 cores each for a total of 11,088 cores. Each machine has 128 GB of RAM. In addition, there is a Symmetric Multiprocessing (SMP) with 240 cores and 5 TB of RAM. There is another cluster called CERHOUSE that supports the satellite data archive of CERSAT for Europe. CERHOUSE is specifically designed for batch processing of satellite datasets. The system has 3 PB of storage and 70 16-core and 50 24-core machines for a total of 2320 cores optimized for batch processing. Each machine has 48 GB of RAM.

## FINANCIAL SUPPORT AND TRAINING OPPORTUNITIES

Financial support is available through graduate assistantships (research and teaching) and internships. Assistantships and internships include tuition waivers and subsidized fringe benefits. Research projects provide financial support to graduate assistants while providing them with the opportunity to participate in engineering studies and familiarize themselves with theoretical, numerical, and experimental methods. A number of local engineering firms sponsor ORE internships and provide practical training at their sites. Further details (and the assistantship/internship application) are available on the ORE admissions page. http://www.soest.hawaii.edu/ore/program/financial-support/

## PLACEMENT DATA

Statistics from the 2007-2019 graduates provide a clear picture of where ORE students are coming from and where they are heading after graduation. Approximately 30% of our students have Hawaiʻi ties (those who studied or worked in Hawaiʻi prior to enrollment), 45% were recruited from other parts of the U.S. and 25% from foreign countries. After graduation, 45% found work in Hawaiʻi, 45% found work outside of Hawaiʻi, 5% continued studies in Hawaiʻi, and 5% continued studies outside of Hawaiʻi. Nearly all graduates obtained employment or continued their studies in ocean and resources engineering (or related fields).

Career opportunities for graduates in ocean and resources engineering exist in several areas. Approximately 55% of the 2007-2019 graduates found work in private industry including consulting, environmental service, and construction firms in the U.S. About 15% of them joined, or continued their employment with, federal agencies such as the Army

Corps of Engineers and the Navy; 5% found work with U.S. community colleges and universities. Another 10% entered Ph.D. programs or received post-doctoral positions at U.S. universities. The 15% of graduates who went abroad continue to study, or work for government agencies and in academia.

## FURTHER INFORMATION

FOR FURTHER INFORMATION, WRITE:
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URL: www.soest.hawaii.edu/ore

# APPENDIX A. ADVISORY PANELS

The ORE faculty regularly assess and update the educational objectives, program outcomes, assessment processes, and academic program in general with input from alumni and their employers, as well as local and international panels of professionals representing the ocean and resources engineering communities.

# APPENDIX B. MS COURSEWORK REQUIREMENTS

## *Pre-program requirements*

ORE offers a graduate program and typically relies on the students' undergraduate education to fulfill the pre-program requirements which include:

1. A general education component including economics, management, and humanities;
2. One year (30 credits) of college level mathematics and basic science; and
3. One and one-half years (45 credits) of basic engineering science and design.

These requirements cannot be satisfied with graduate-level courses. Students with undergraduate engineering degrees normally satisfy these requirements and can directly proceed to the graduate-level ORE program. Students with undergraduate degrees other than engineering will be required to make up deficiencies in basic engineering courses, including

- Computer aided design (CAD),
- Statics (CEE 270),
- Dynamics (CEE 271 or ME 271),
- Fluid mechanics (CEE 320 or ME 322),
- Mechanics of materials (CEE 370 or ME 371), and
- Probability and statistics (CEE 305),

and elective courses in the following subjects depending on the student's intended option area in the department:

- Surveying,
- Hydraulics,
- Civil engineering materials,
- Structural mechanics,
- Geotechnical engineering,
- Environmental engineering,
- Corrosion engineering,
- Thermodynamics,
- Heat transfer, and
- Material science and engineering.

### *Course requirements*

The ORE MS graduate program includes a 12-credit core that covers:
- ORE 411 Buoyancy and Stability (3 credits)
- ORE 601 Ocean Engineering Laboratory (3)
- ORE 603 Oceanography for Ocean Engineers (3)
- ORE 607 Water Wave Mechanics (3)

The minimum required grade for the 4 core courses and their prerequisites is B-.

Students must take the 1-credit ORE 792 Seminar course, which requires attending at least 15 seminars related to ocean and resources engineering, completing Responsible Conduct of Research training, and completing a science communication workshop.

The MS program also requires a set of option-area courses to be completed. In consultation with their academic advisor, students select a 12-credit course of study in coastal, offshore, ocean resources, or oceanographic engineering. The course requirements for these option areas are listed below. Enrollment of ORE students in classes in departments other than ORE depends on the availability of the class and is subject to the approval of the Chair of the relevant department if a major override is needed.

Coastal engineering (12 credits)

ORE 783B Capstone Design Project – Coastal (3); and
Three of the following:
- ORE 609 Hydrodynamics of Fluid-Body Interaction (3)
- ORE 661 Coastal and Harbor Engineering (3)
- ORE 664 Near-shore Processes and Sediment Transport (3)
- CEE 656 Marine Geotechnics (3)
- GG 420 Beaches, Reefs, and Climate Change (3)

Offshore engineering (12 credits)

ORE 783C Capstone Design Project – Offshore (3); and
Three of the following:
- ORE 609 Hydrodynamics of Fluid-Body Interaction (3)
- ORE 612 Dynamics of Ocean Structures (3) or CEE 675 Structural Dynamics I (3)
- ORE 630 Structural Analysis in Ocean Engineering (3) or CEE 686 Finite Elements in Structures (3)
- CEE 656 Marine Geotechnics (3)
- ME 404 Computational Fluid Dynamics (3) or ME 626 Viscous Flows (3)

Ocean resources engineering (12 credits)

ORE 783D Capstone Design Project – Ocean Resources (3); and
Three of the following:

- ORE 609 Hydrodynamics of Fluid-Body Interaction (3)
- ORE 677 Marine Renewable Energy (3)
- ORE 678 Marine Mineral Resources Engineering (3)
- ME 453 Energy Conversion Systems (3)
- ME 610 Renewable Energy Engineering and Sustainability (3)

Oceanographic engineering (12 credits)

ORE 783C or 783D Capstone Design Project (3); and

Three of the following:

- ORE 608 Probability and Statistics for Ocean Engineers (3)
- ORE 654 Applications of Ocean Acoustics (3)
- OCN 620 Physical Oceanography (3)
- OCN 640 Observational Physical Oceanography (3)
- ME 451 Feedback-Control Systems (3) or ME 452 Robotics (3)

MS students round-out their studies with 6 credits following one of the following plans:

- Plan A: ORE 700 Thesis Research (6)
- Plan B: ORE 695 Master's Project (3) and a free elective course (3)

### *Other course requirements/options*

Although the UH Graduate Division requires a minimum of 30 credits for graduation, most students take more than the required minimum (averaging around 33 credits).

Students are encouraged to take courses in the other option areas as electives. In addition, ORE offers the following electives:

- CEE/ORE 621 Coastal Flood Mitigation (3)
- CEE/ORE 624 Coastal Modeling (3)
- ORE 641 Environmental Fluid Dynamics (3)
- ORE 657 Autonomous Marine Systems (3)
- ORE 680 Ocean Engineering and Resilience in a Changing Climate (3)
- ORE 699 Directed Reading or Research
- ORE 707 Nonlinear Water Wave Theories (3)
- ORE 766 Numerical Methods in Ocean Engineering (3)
- ORE 791 Special Topics

Other departments offer courses relevant to ORE. These courses are approved on an individual basis as electives by the academic advisor.