★張 哲維 特定助教

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研 究 課 題： 沿岸プロセスの解明と，自然災害の軽減及び気候変動への適応のための
グリーン・グレーインフラの適用に関する総合研究
(Study of coastal processes and the application of green/gray infrastructure to natural disaster reduction and climate change adaptation)

専 門 分 野： 沿岸水理学，環境流体力学，海岸工学，海岸災害・減災
(Nearshore Hydrodynamics, Environmental Fluid Mechanics, Coastal Engineering, Coastal Disaster and Reduction)

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異常気象や津波による沿岸災害により、過去数十年間で数千の人命と財産が奪われました。気候変動と海面上昇への対応に向けて、世界中の沿岸コミュニティは、自然災害を軽減し、沿岸の回復力を高めるためのより高効率的な戦略を必要としています。

そこで候補となるのが、グレーインフラ（水工構造物）とグリーンインフラです。グレーインフラは、設置が容易で専門知識が十分に得られているため、頻繁に使用されていますが、維持にコストがかかり気候変動への適応性に欠けると言えます。一方、グリーンインフラは、自然の障壁として機能しながら生態系を保護するものですが、実用化のためには研究量が未だ不足しています。沿岸を保護し、その他のコベネフィットを最大限利用可能とするために、グレーとグリーンの両インフラを活用する最善策が提案されていますが、さらなる調査が必要な状況です。

そこで、現在の私の研究では、沿岸の物理過程を研究し、沿岸環境のさまざまな要素が短期間の異常気象や長期的な気候変動の中でどのように絡み合っているかを解明します。そして、波浪と、土砂と、グレーまたはグリーンのインフラ間の動的な相互作用を異なる時間枠で評価する統合アプローチを確立し、波の災害と海岸侵食の削減、および将来の沿岸計画と管理のための気候変動への適応に対するより良いソリューションを提供することを目指しています。

Coastal disasters due to extreme weather and tsunami events cost thousands of lives and properties over the past decades. Climate change and rising sea level pose greater challenges to worldwide coastal communities, requiring more efficient strategies to mitigate natural hazards and enhance coastal resilience.

Engineering (gray) infrastructure, despite being heavily used due to the ease of installation and relatively sufficient expertise, is costly to maintain and lacks the adaptability to changing climate. Alternatively, green infrastructure serves as a natural barrier and conserves the ecosystem. However, more quantitative studies are still in demand for their practical application. To maximize coastal protection and other co-benefits, an optimized arrangement utilizing both gray and green infrastructures is proposed while warrants further investigation.

Accordingly, my current research is to study coastal processes and understand how different elements in a coastal environment intertwine with each other in short-term extreme weather events and the long-term changing climate. I aim to establish an integrated approach to evaluate the dynamic interactions among waves, sediments and gray/green infrastructures over different time frames, providing a better solution to the reduction of wave disasters and coastal erosion, and climate change adaptation for future coastal planning and management.

Challenges to coastal zones worldwide

Coastal regions are undergoing continuous changes due to the natural processes and anthropogenic effects. Shoreline erosion and coastal flooding is already a great concern in many coastal communities. Due to rapid economic development, coastal communities have become intensely populated, exposing them to greater risks by natural disasters such as extreme weather events and tsunami inundations. Climate change and sea level rise are likely to worsen the situation, increasing the difficulties in coastal planning of protective infrastructures and maintenance in the long term. Considering these challenges, it is imperative to find a better solution for both coastal disaster reduction and climate change adaptation.

Protective infrastructure against coastal disasters

Engineering infrastructure (e.g. sea walls, dikes, breakwaters, levees) has been widely used along the coasts in most developed countries due to the ease of installation and relatively sufficient expertise. However, its high maintenance cost, the detrimental impacts on coastal habitats and the lack of capacity for climate change adaptation urge coastal scientists to seek an alternative or the next generation of protective infrastructure.

Green infrastructure, known as nature-based solutions, includes coastal vegetation, sand dunes, sandy beaches and coral reefs. As a part of coastal ecosystems, green infrastructure was capable of reducing extreme waves and stabilizing coastal erosion. For instance, coastal forests (including coastal trees and mangroves) were found effective against extreme waves in recent field records, e.g. Indian Ocean Tsunami in 2004 and Super typhoon Haiyan in 2013. Compared with traditional engineering approaches, natural infrastructure is considered to be a subset of resilient infrastructure that is environment-friendly and adaptable to changing climate, as suggested in the Intergovernmental Panel on Climate Change (IPCC Working Group II, 2014).

Despite the promising features in coastal protection, green infrastructure is not widely applied in practice due to a lack of quantitative design guidance and systematic investigations. Moreover, few addressed the complex interactions among water waves/flow, sediments and green/gray infrastructures in an integrated context. To maximize coastal protection along with other co-benefits, a hybrid approach that adopts both green and gray infrastructures was suggested while quantitative evaluation of the multiple-layer protection is needed to facilitate future coastal planning and management.

Integrated study of complex coastal processes

To adopt effective protection and adaptation strategies, we need to understand how different elements in a coastal environment intertwine with each other not only in short-term extreme weather events, but under the long-term changing climate. Thus, the objective of my current study is to establish an integrated system that evaluates and monitors the complex interactions among waves, sediments and different types of infrastructures over different periods of time. The proposed research will be conducted through a combination of laboratory experiments, numerical modeling and field surveys.

By conducting field studies, first-hand field information will be obtained, e.g. physical characteristics of different infrastructures. These measured attributes will be used in both lab experiments and numerical simulations. In the laboratory experiments, 3D technology will be employed to produce scaled-down infrastructures to resemble the field conditions. For instance, 3D-printed trees will be produced based on the scanned images obtained from the fields. With the laboratory facilities, e.g. the Hybrid Tsunami Open Flume in Ujigawa Open Lab, a variety of wave conditions including tsunami waves and storm surges will be simulated. Factors associated with the interactions among water waves, green/gray infrastructures and sediments, including wave attenuation, coastal erosion and sedimentation, will be measured. To improve the quantification of sediment movements and turbulent mixing in different setups, advanced experimental techniques (e.g. Particle Image Velocimetry and high-speed cameras) will also be used to visualize detailed flow fields.

With the findings in the fields and experimental tests, a coastal wave model will be developed with proper incorporation of the effects of green/gray infrastructures. To seamlessly simulate wave propagation from the deep ocean to coastal regions and improve the computational efficiency, the developed wave model will be coupled with ocean-scale models. To investigate the dynamic interactions of waves, infrastructures and sediments, a coastal morphological model will also be developed to evaluate the topographic evolution in a longer time frame. With the coastal wave model, ocean-scale model and the morphological model, I aim to establish an integrated modeling system that evaluates and monitors the dynamic interactions among the primary elements in coastal environments. With inputs such as field conditions, wave projections and rising sea level, the modeling system can simulate coastal processes and provide risk assessment over different time horizons. The risk assessment will facilitate future coastal planning, such as optimizing the design of protective engineering infrastructures and improving cost-efficiency. This line of research will contribute to the design of a sustainable environment that can adapt to a changing climate and mitigate natural hazards.

Figure 1
Examples of gray and green infrastructure in coastal environments: top - breakwaters along the Ogata coast (Niigata, Japan); bottom - mangrove forests in Iriomote island (Okinawa, Japan)

Figure 2
A conceptual framework of the complex coastal processes

References

IPCC. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.