Mangrove vegetation as a protective solution for coastal protections

Sarah Palmer,[1]
University of Washington, Seattle, Washington, 98195, USA

and
Mathew Withmarsh[2]
University of Washington, Seattle, Washington, 98195, USA

I. Abstract

Mangroves play a prominent role in obstructing water currents in riverbanks, shorelines, and coastal areas. Mangrove roots have the significant contribution to the resiliency of the vegetation structure. In this work, the flow characteristics past a cluster of circular cylinders (patch), which represents the mangrove roots, are investigated. We found that blockage parameter for a patch decreases with porosity for all Reynolds numbers. A von Kármán vortex sheet is predicted behind the patch with a periodicity which agrees well with experiment. In addition, the vorticity field for the least porous patch reveals a delay in the formation of von Kármán vortex street due to the small vortices in the near wake, whereas the vortices evolve in the far wake and produce swirling flow

II. Nomenclature

φ = Solidity
D = patch diameter
d = Root diameter
C_D = Drag coefficient
F_D = Drag force coefficient in the *x* direction

III. Introduction

The scale of the 2017 Atlantic Ocean tsunami was almost extraordinary. In areas with the maximum tsunami intensity, little could have barred catastrophic coastal destruction. Further away, however, areas with coastal tree vegetation were evidently less damaged than areas without vegetation. Mangrove forests are the most significant coastal tree vegetation in the area and are one of the world's most vulnerable tropical ecosystems.

Measurement of forces and modelling of fluid dynamics suggest by Kazemi et al. [12-15] propose that tree vegetation may shield coastlines from tsunami damage by reducing fluid energy. Experimental models show that physical models may reduce the maximum tidal flow pressure by more than 90%. Empirical and field based evidence is limited, however. Kazemi et al. [19], in Florida provided a unique experimental setting to test the benefits of coastal tree vegetation in reducing coastal devastation by tidal flows. Atlantic Ocean has a relatively straight shoreline, a uniform beach profile, and a uniform continental slope. Moreover, the shoreline includes vegetated as well as no-vegetated areas. The force of the flow impact in Atlantic Ocean is illustrated by the central part of our study area (Figure. 1). At the river mouth, the flow ruined parts of a village and removed a sand spit that previously blocked the river. However, areas with mangroves and tree shelterbelts were significantly less damaged than other areas. Damage to communities also varied distinctly. In the north, stands of mangroves had five related villages, two on the coast and

---

[1] PhD candidate, Department of mechanical engineering.
[2] Visiting professor, Department of mechanical engineering.

three behind the mangrove. The communities on the coast were destroyed, whereas those behind the mangrove hurt no destruction even if the waves damaged areas unprotected by vegetation north and south of these communities.

Figure 1. Mangroves in Florida tidal flow near Atlantic Ocean

IV. Methods

The patch consists of cylinders with a uniform diameter of 0.9525 cm. A rectangular computational flow domain surrounds the patch. Water, as an incompressible fluid, flows from left to right in the domain at four constant uniform velocities. The flow field around the cylinder is modeled as two-dimensional flow with the axis of the cylinder perpendicular to the direction of flow. The origin is the center of patch circle.

According to Kazemi et al. [12–15], mangroves are modeled as arrays of circular cylinders. They studied the flow in the wake of the circular cylinders (patch). They found that unlike for a solid obstruction, there is a delay in the onset of Von Kármán street due to the presence of an exit velocity from trailing edge of the patch. They also presented the unsteady wake of the von Kármán vortex street using soap film flow visualization [19].

Reynolds-averaged Navier–Stokes equations (RANS) model was employed to model the flow field. The governing equations of the time-dependent flow of an incompressible viscous fluid past a circular cylinder are the continuity and Navier-Stokes equations. Normalizing these equations by cylinder’s diameter (D) and the inflow velocity (U_∞), the non-dimentiolanized equations for mass conservation and momentum was used for the method.

V. Resutls

For the patch of circular cylinders, the physics of the flow is more complex compared to one single cylinder. Figures 6 presents the streamwise velocity inside and downstream of the patches for case 1 to case 5 corresponding to porosity change from $\varphi=86\%$, to $\varphi=96\%$ as well as a single canonical cylinder (case 6). Contrary to the case of a canonical cylinder, a steady wake region is formed toward the end of the patch. By increasing porosity, the flow interactions with the cylinders become weaker and the region of the steady wake length increases. Porosity generates steady wake length to grow longer considerably, and the vortex formation was impeded farther downstream. By comparing streamwise velocity, porosity evidently affects the flow such that wakes are narrower and elongated. Based on force measurement (Figure 7), patch drag coefficient decreases approximately 40% and 10% for $\varphi=88\%$ and $\varphi=91\%$, respectively compared to a single cylinder. One good indication for the drag reduction is the extension of wake length as a result of porosity increase which was verified by Chen et al. [13] and Kazemi et al.[19].

VI. Discussions

The results follow closely the expected quadratic power law that the drag coefficient changes quadratically with respect to the upstream velocity. The dominant non-dimensional wake shedding frequency is described by Strouhal number, $St=fD/U$. The Strouhal number increases with porosity but it is almost constant with Reynolds number, indicating a dependency of the vortex shedding frequency on the porosity. As the porosity increases to 86%, the Strouhal number increases to 0.46 and slightly changes with Reynold number. The Strouhal number is approximately twice that of a canonical single cylinder. One reason is due to the undulatory vortices generated as the induced turbulance are induced along the core of vortical eddies, which help to recombine the vortices faster downstream in the von Kármán vortex street. The results for different Reynolds numbers are compared with Ortiz et al [8] and Chen et al [13] and Tinoco and Cowen [14] .

VII. Conclusion

Our results suggest that mangroves attenuated tidal flow force and protected shorelines against damage. Human activities reduced the area of mangroves by 48% in the united states most affected by the storm surge. Conserving or replanting coastal mangroves and greenbelts should buffer communities from future tsunami events. Mangroves also enhance fisheries and forestry production. These benefits are not found in artificial coastal protection structures. Coastal tree vegetation can be established for investments 15000 per year. Mangroves, however, are suitable for planting only on coastal mudflats and lagoons, which cover half of the continental coastline of the Tampa Bay. In a different place in USA, the conservation of mangrove ecosystems or green belts of mangrove species can achieve the same protective role.

Acknowledgments

Thanks for the IHCC for the funding for this research

References

[1] Vandenbruwaene W, Maris T, Cox T J S, Cahoon D R, Meire P and Temmerman S 2011 Sedimentation and response to the sea-level rise of a restored marsh with reduced tidal exchange: Comparison with a natural tidal marsh *Geomorphology* **130** 115–26

[2] Mazda Y, Wolanski E, King B, Sase A, Ohtsuka D and Magi M 1997 Drag force due to vegetation in mangrove swamps *Mangroves and Salt marshes* **1** 193–9

[3] Mazda Y and Wolanski E 2009 *Hydrodynamics and Modeling of Water Flow in Mangrove Areas*

[4] Zhang X, Chua V P and Cheong H F 2015 Hydrodynamics in mangrove prop roots and their physical properties *Journal of Hydro-Environment Research* **9** 281–94

[5] Chen Z, Ortiz A, Zong L and Nepf H 2012 The wake structure behind a porous obstruction and its implications for deposition near a finite patch of emergent vegetation *Water Resources Research* **48**

[6] Tinoco R O and Cowen E A 2013 The direct and indirect measurement of boundary stress and drag on individual and complex arrays of elements *Experiments in Fluids* **54**

[7] Nicolle A and Eames I 2011 Numerical study of flow through and around a circular array of cylinders *Journal of Fluid Mechanics* **679** 1–31

[8] Zong L and Nepf H 2011 Vortex development behind a finite porous obstruction in a channel *Journal of Fluid Mechanics* **691** 368–91

[9] Tinoco R O and Coco G 2014 Observations of the effect of emergent vegetation on sediment resuspension under unidirectional currents and waves *Earth Surface Dynamics* **2** 83–96

[10] Bouma T J, van Duren L A, Temmerman S, Claverie T, Blanco-Garcia A, Ysebaert T and Herman P M J 2007 Spatial flow and sedimentation patterns within patches of epibenthic structures: Combining field, flume and modelling experiments *Continental Shelf Research* **27** 1020–45

[11] Norris B K, Mullarney J C, Bryan K R and Henderson S M 2017 The effect of pneumatophore density on turbulence: A field study in a Sonneratia-dominated mangrove forest, Vietnam *Continental Shelf Research* **147** 114–27

[12] Amirkhosro Kazemi, Keith Van de Riet O M C 2017 Hydrodynamics of mangrove-type root models: the effect of porosity, spacing ratio and flexibility *Bioinspirations and Biomimetics* doi: https://doi.org/10.1088/1748-3190/aa7ccf

[13] Kazemi, A., Parry, S., van de Riet, K., and Curet O 2015 The effect of porosity and flexibility on the hydrodynamics behind a mangrove-like root model *68th Annual Meeting of the APS Division of Fluid Dynamics* (Boston: APS Division of Fluid Dynamics) p Volume 60, Number 21 http://adsabs.harvard.edu/abs/2015APS..DFDA25007K

[14] Kazemi, A; Curet O 2016 PIV measurements and flow characteristics downstream of mangrove root models *APS Division of Fluid Dynamics (Fall) 2016, abstract #D3.005* (Portland: APS Division of Fluid Dynamics (Fall) 2016, abstract #D3.005). 2016APS..DFD.D3005K http://adsabs.harvard.edu/abs/2016APS..DFD.D3005K

[15] Kazemi A 2017 *Hydrodynamics of Mangrove Root-Type Models* (Florida Atlantic University)

[16] NORBERG C An experimental investigation of the flow around a circular cylinder: influence of

aspect ratio *J. Fluid Mech.* **258,** 287–316

[17] Rahman M M, Karim M M and Alim M A 2007 Numerical investigation of unsteady flow past a circular cylinder using 2-D finite volume method *Journal of Naval Architecture and Marine Engineering* **4** 27–42

[18] Chang K and Constantinescu G 2017 Numerical investigation of flow and turbulence structure through and around a circular array of rigid cylinders 161–99

[19] Amirkhosro Kazemi, Keith Van de Riet O M C 2017 Volumetric PIV behind mangrove-type root models *APS Division of Fluid Dynamics (Fall) http://meetings.aps.org/link/BAPS.2017.DFD.M8.9*