Wind Effects around Wildlife Exclusion Fences: A study comparing Porous to Solid Fences and how the design choice may affect species with moisture sensitive skin

Author: Eojin Kim, BS Computational Fluid Dynamics, Engineering Science, UC Berkeley, Ph.D. candidate, Rotating Stratified Shear Flow, Harvard University, 2019

Abstract

Recent projects raised the question about whether solid exclusion fence barriers cause problems for amphibians. The objective of this study is to test the hypothesis that wind flowing around solid barriers creates turbulent, chaotic, desiccating air currents at ground level from which amphibians cannot easily extract themselves. Without barriers, terrestrial animals do not normally experience this intensity and type of air flow in the zone which they occupy. Natural no-slip conditions at ground level normally keep wind velocities near zero (ground level). Evidence from the Dexter/Funari 2018 study suggest that these types of air currents develop around solid fences. The objective of this research was to study, and confirm this phenomenon using a Computational Fluid Dynamics (CFD) model. The results show that air can flow-through porous barriers (barriers with 50% or greater open area), eliminating the possibility that turbulence or chaotic, circular flow eddies develop. The study also indicated that solid fences can indeed create chaotic wind flows, secondary flows, and eddy currents which can significantly degrade the environment near the fence for vulnerable, moisture sensitive animals.

Introduction

A recent project in Alameda County, CA using a solid barrier exclusion fence had over sixty (60) California tiger salamanders (*Ambystoma californiense*) found dead, desiccated along the fence (Table 1). *(Exclusionary Fencing for Central CA tiger salamanders – Lessons Learned, Funari (USFWS), Dexter (Condor Country Consulting), February 2018).* Sixteen other projects utilizing a Rigid Polymer Matrix porous exclusion barrier, two of which were nearby and concurrent, had zero reported CTS mortalities.

Month	Observed	Relocated	Mortality	% Mort
Apr-15	0	0	0	0%
May-15	6	3	3	50.0%
Jun-15	219	172	47	21.5%
Jul-15	349	341	8	2.3%
Aug-15	300	294	6	2.0%
Sep-15	57	55	2	3.5%
Oct-15	23	22	1	4.3%
Nov-15	60	60	0	0.0%
Dec-15	0	0	0	0.0%
Jan-16	0	0	0	0.0%

Table 1: Solid Exclusion Fence Mortality Count: Golden Hills Wind Energy Repowering Project, Alameda County, CA.

Table 1 reports the number of desiccated individuals found along the exclusion barrier during the project (Funari). After June 2015, indicated in yellow, aggressive measures were taken to reduce mortality: pitfall traps were installed. Many biologists were deployed to the site and traps were checked more than once a day. Cover boards and artificial burrows were placed along the fence-line.

Determinants of Evaporative Water Loss

The major challenge faced by amphibians in terrestrial environments is evaporative water loss through their skin. The greatest challenge to the survival of most amphibians is the maintenance of water balance. Some amphibians have evolved morphological, physiological or behavioral adaptations that reduce rates of water loss, but amphibians that spend most of their time on the ground generally lack adaptations for retarding evaporative water loss and do not differ greatly from species that spend most of their time in or near water. For example, salamanders such as *Triturus*, *Salamandra* and *Ambystoma* all have high rates of water loss and are not well adapted to responding to high rates of water loss. The variables that affect rates of water exchange between amphibians and the environment have been reviewed by several authors (Spotila 1972; Tracy 1975, 1976, Spotila and Berman 1976; Shoemaker et al. 1992; O'Conner & Bakken 1992). In simple terms, the rate of evaporative water loss by an amphibian is a function of the water vapor density gradient between the animal and the environment, the resistance of the animal to water loss, and the surface area of the skin exposed to the air. The vapor density gradient is largely a property of the physical environment and cannot be modified by the animal. It is the difference between the water vapor density at the animal's surface and the water vapor density of the surrounding air. Both temperature and relative humidity of the air affect the vapor density gradient. The gradient will increase as the body temperature of the animal increases or as the humidity of the surrounding air decreases. An animal's boundary layer resistance also comes into play. When an animal is immobile or if wind velocity is low, water evaporated from the skin's surface forms a thin layer around the animal and the surrounding environment, thereby reducing evaporative water loss. Movement by the animal or air moving across the animal's surface breaks up this boundary layer. Hence, as wind velocity increases or chaotic flows develop, the resistance afforded by the boundary layer decreases and evaporative water loss rate increases. The speed at which air flows over the surface of an amphibian's skin affects the rate at which the water evaporates. As wind blows, it breaks up existing water vapor barriers and sweeps away airborne water particles which are in the air. The vapor density of the air in the region of this evaporation is reduced, which allows more water molecules to dissipate into the air. Wind keeps relative humidity unsaturated near the skin surface. Higher or more chaotic winds increase evaporation rate from an animal's skin. The surface area of the skin exposed to the air has a major effect on rates of water loss. This makes newly metamorphized juveniles especially vulnerable to desiccation.

Methods

The objective of this research was to study and understand wind flow around two different types of exclusion fences; solid and porous, using a Computational Fluid Dynamics (CFD) model. The simulation software utilized was Ansys 19.2 Fluent (https://www.simutechgroup.com/ansys-software/fluid-dynamics)

Major Modeling Assumptions:

- Incompressible fluid: when density remains constant with respect to pressure a fluid is considered incompressible. Air flow in this analysis can be treated as incompressible flow since Mach number is less than 0.3.
- 2D flow: The simulation length and time scales are miniscule compared to the rate at which the fence is curved in the field. Therefore, a 2D simulation (not 3D) is appropriate.
- The study focused on time dependent flows. Natural wind flows are characterized by natural oscillations, wind gusts and constantly changing wind velocity.
- Boundary Conditions: No slip (zero velocity) at grade and fence surfaces (all surfaces). Flow is equal to natural (characteristic) wind speed on top. Characteristic wind speed at the inlet are specified system parameters.
- Fence Height: Simulations were run with increased domain height to assure that boundary effects did not falsely affect the result. Similar flow characteristics and results were obtained for fences of two different heights (24" and 36"). Simulations compared at 3 m/s and 10 m/s
- The distance between the model inlet and the fence was set to allow incoming wind to develop a full boundary layer before reaching fence
- Turbulence behavior calculated via kappa omega, SST, and kappa epsilon equations.
- Fence porosity (% open area) in all porous fence simulations was set at 50%
- Flow development is different at different surface roughness levels, but flow behavior and measurements between solid and porous fences are comparable with varied levels of surface roughness.
- **Coefficient of drag** was calculated for both porous and solid fence in steady state and in time dependent flows. In fluid dynamics, the drag coefficient (commonly denoted as: Cd) is a number that aerodynamicists use to model all of the complex dependencies of shape, inclination, and flow conditions on an object. The drag coefficient then expresses the ratio of the drag force to the force produced by the dynamic pressure times the area.
- **Vorticity Analysis:** In CFD the numerical solution of the governing equations can yield all the fluid properties in space and time. This overwhelming amount of information must be displayed in a meaningful form. Vorticity is the curl of velocity field and a measure of local rotation of fluid (tendency of a fluid particle to circulate at each point). It is a vector quantity and it gives circulation per unit area. A plot of vorticity across a given domain allows visualization of the strength (circulation density) and direction of fluid (rotation). Vorticity was the main tool for flow visualization in this simulation. Note that a vorticity value can be high near a boundary due to shear, but it doesn't imply swirling motion at the boundary. (Appendix)
- **Velocity Vector Analysis:** A velocity vector represents the rate of change of the position of an object. The magnitude of a velocity vector gives the speed of an object while the vector direction gives its direction. If the vector field represents the flow direction and velocity of a moving fluid, then the curl is the circulation density of the fluid.

Results & Observations

Coefficient of Drag (Cd):

The coefficient of drag (Cd) was evaluated for both porous and solid fences with various windspeeds with steady-state and oscillating wind velocities. A very large difference in Cd was evident. Since the difference in surface area between the solid and porous fences is much smaller than their difference in Cd, it can be understood that drag forces on a porous fence with a 50% open area (POA) is dramatically reduced (Figure 1). This relationship held at different oscillation periods. Shorter periods tended to amplify this effect. For this reason, we see that solid fences must withstand much greater wind-driven forces and pressure than porous fences. The greater pressure and forces can have deleterious effects on the fence infrastructure and can generate large lift forces driving solid fences up and out of their trench.

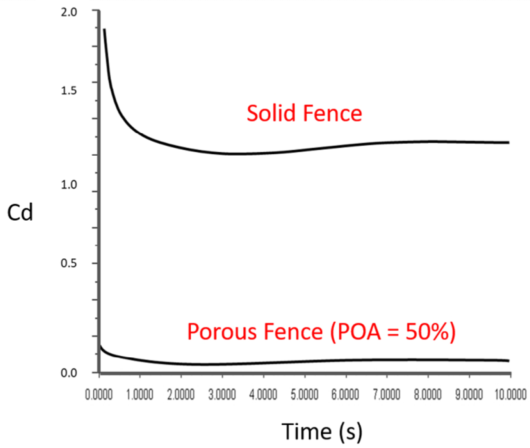

Figure 1: Coefficient of Drag in steady state at 5 meters/second. Porous vs. Solid Exclusion Fence

Pressure Development

Pressure distribution around the fences was evaluated. As expected from the Cd analysis, pressure is very high for solid fence, with much less pressure developing in front of a porous fence (Figures 2 & 3). This indicates why a solid fence is significantly more susceptible to structural deterioration or upward lift and loss of trench due to wind. This analysis also indicates much higher energy release and potential for chaotic wind flows.

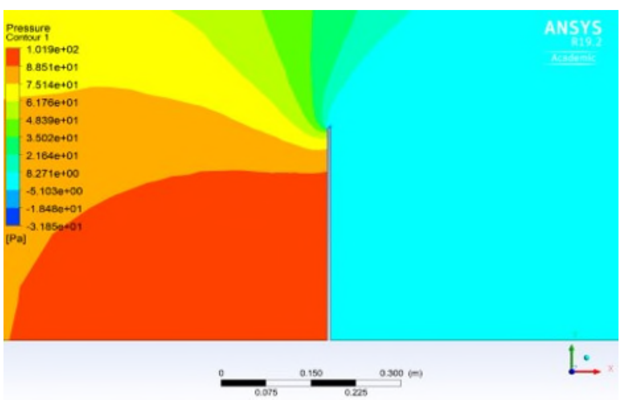

Figure 2: Solid Fence pressure profile

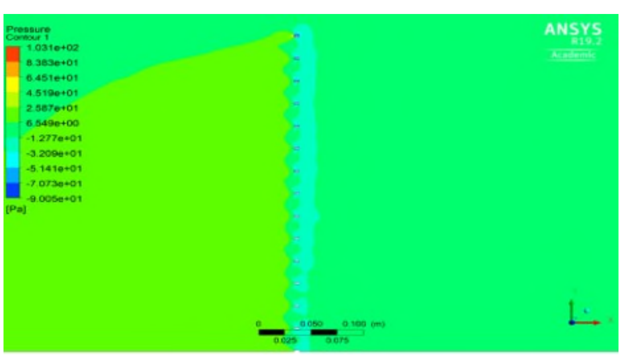

Figure 3: Porous Fence pressure profile

With respect to forces which develop upon a fence, flow conditions on both sides of a porous fence are similar to flow conditions without a fence.

Vorticity Analysis – a measure of fluid rotation

Vorticity is the curl of velocity field and a measure of local rotation of fluid (tendency of a fluid particle to rotate or circulate at a point). It is a vector quantity and it gives circulation per unit area. By plotting vorticity, it allows us to better visualize the dynamics across a complex flow field. In these resulting vorticity plots for solid and porous fences (figure 4 & 5), note that the scale indicates intensity of curl in both directions. **blue** is high intensity in clockwise direction and **red** is high intensity in counterclockwise direction. Snap shots were taken 1.5 seconds into simulation. Wind oscillation was set at 3 seconds per cycle.

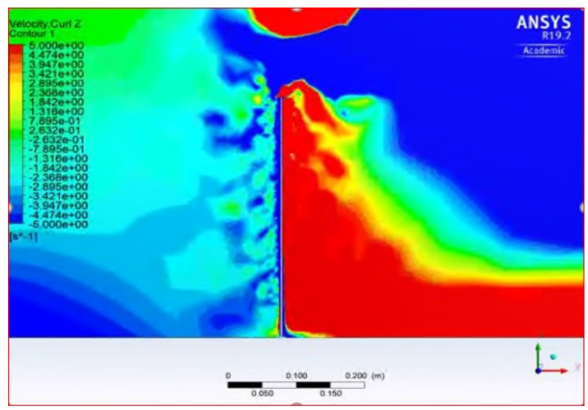

Figure 4: Solid Fence vorticity: indicates chaotic/turbulent swirling flows in both directions on both sides of the fence.

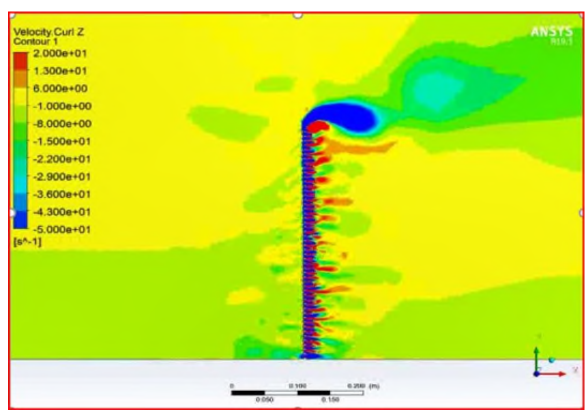

Figure 5: Porous Fence vorticity: except within the pores, this graph indicates flows are much like having no fence at all.

Velocity Vector Analysis

A velocity vector plot indicates magnitude of velocity and direction of flows at points throughout the studied flow field. Velocity Vector analysis shows that wind flows through the porous fence (Figure 6).

Flow concentrates at increased velocity thru the pores in order to maintain mass balance, but velocity dissipates rapidly on other side of barrier. All flows are in one direction (left to right). There is no indication of eddy flow on a scale which disturbs the main flow (there is eddy flow on small scale within the pores), which is the swirling air and the reverse flows created when the fluid is in a turbulent flow regime.

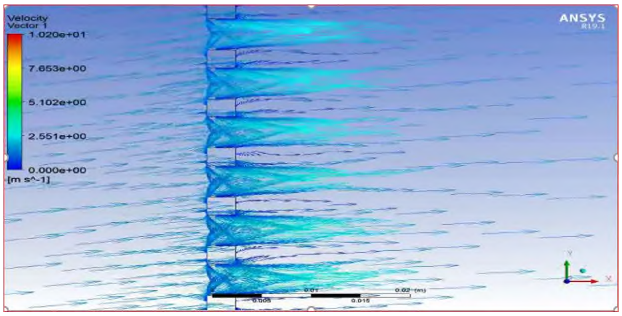

Figure 6: Velocity vector analysis: Porous Fence – a zoomed-in view of flow thru the open pores showing rapid dissipation on downstream side (50% open area)

Results from Solid Fence velocity vector analysis shows swirling reverse flows on both sides of the fence (Figure 7).

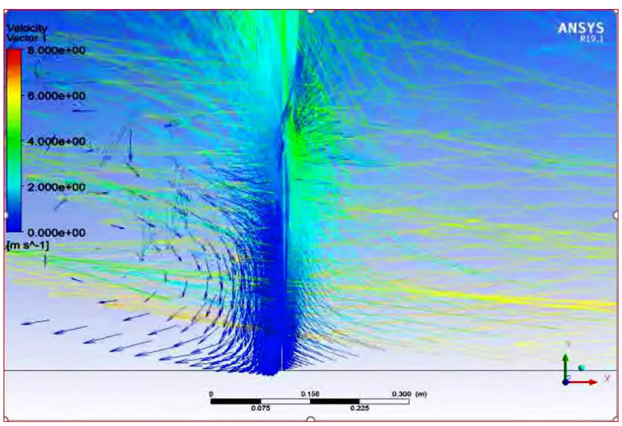

Figure 7: Velocity vector analysis: Solid Fence

Discussion

In this study, air flow around solid and porous fences was evaluated. The analysis indicates swirling and reverse air currents are generated on both sides of a solid fence. A porous fence with 50% open area maintains flow similar as having no barrier or fence in the studied domain. With a solid fence, a high-pressure region is developed as turbulent flow and large eddies are created near the fence on both sides. It is likely that these chaotic flows play a role in removing moisture from moisture sensitive species that do not normally encounter these kinds of flows in the terrestrial habitat they occupy. Flow conditions on both sides of a porous fence is similar to flow conditions without a fence. Flow concentrates at higher velocity through the pores in order to maintain mass balance, but velocity dissipates rapidly on other side of barrier

Based on the results it is reasonable to conclude that under certain conditions (high winds, arid conditions) solid fences can create a dangerous environment near the fence for vulnerable species (Figure 8). Exclusion fences are intended to prevent mortalities in construction sites and on road surfaces. It is also reasonable to conclude that the use of highly porous fences can reduce mortalities along the fence but also reduce the amount of monitoring and human resources required to prevent mortalities along the fence.

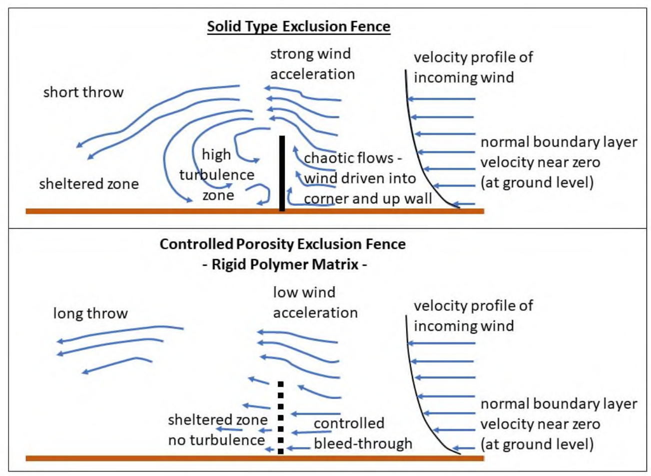

Figure 8: Flow profile comparison: Solid vs. Porous (50% Open Area) Exclusion Fences

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Appendix:

Explanation of the use of vorticity for flow visualization:

$$\frac{\partial \mathrm{V}}{\partial t} + \left(\underline{V} \cdot \nabla\right)\underline{V} = \nabla\Phi + \nu\nabla^2\underline{V}$$

$\nabla\Phi$ is used to refer to gradient of all potential terms, including gravity potential and pressure. ν refers to kinematic viscosity.

Advective component of equation can be rewritten as

$$\left(\underline{V} \cdot \nabla\right)\underline{V} = -\left(\underline{V} \times \underline{W}\right) + \frac{1}{2}\nabla V^2$$

And $V^2 = \underline{V} \cdot \underline{V}$

Replacing advective term via above equality, and taking curl of above equation, we get

$$\frac{\partial \underline{\omega}}{\partial t} + \left(\underline{V} \cdot \nabla\right)\underline{\omega} = \left(\underline{\omega} \cdot \nabla\right)\underline{V} + \nu\nabla^2\underline{\omega}$$

When curl of $\underline{V} \times \underline{\omega}$ was taken, following tensor calculus equality was used:

$$\nabla \times \left(\underline{A} \times \underline{B}\right) = \left(\nabla \cdot \underline{B}\right)\underline{A} + \left(\underline{B} \cdot \nabla\right)\underline{A} - \left(\nabla \cdot \underline{A}\right)\underline{B} - \left(\underline{A} \cdot \nabla\right)\underline{B}$$

Velocity and vorticity vector can be plugged into above equality. When we use the fact that we have incompressible flow, or $\nabla \cdot \underline{V} = 0$, and divergence of curl is always zero or $\nabla \cdot \underline{\omega} = 0$, we will end up with above vorticity equation. In addition, we are having 2-dimensional flow. Therefore, vortex stretching term vanishes or $\left(\underline{\omega} \cdot \nabla\right)\underline{V} = 0$

Therefore, vorticity equation reduces to

$$\frac{\partial \underline{\omega}}{\partial t} + \left(\underline{V} \cdot \nabla\right)\underline{\omega} = \nu\nabla^2\underline{\omega}$$

Above equation can be rewritten as

$\frac{\mathrm{D}\underline{\omega}}{\mathrm{Dt}} = \nu\nabla^2\underline{\omega}$ Where $\frac{D}{Dt}$ implies taking material time derivative. Material time derivative is rate of change of the variable on continuum fluid parcel, which can also be moving. When the above equation is non-dimensionalized, following equation can be obtained:

$$\frac{\mathrm{D}\underline{\omega}}{\mathrm{Dt}} = \frac{1}{\mathrm{Re}}\nabla^2\underline{\omega}$$

This study was on a very high Reynolds Number flow, where rate of diffusive process is very slow compared to advective processes. So, for brief time, we can expect continuum fluid parcel to preserve its vorticity.