Title: The Tacoma Narrows bridge collapse, 1940

Speakers: Bill Unruh

Series: Cosmology & Gravitation

Date: May 09, 2024 - 11:00 AM

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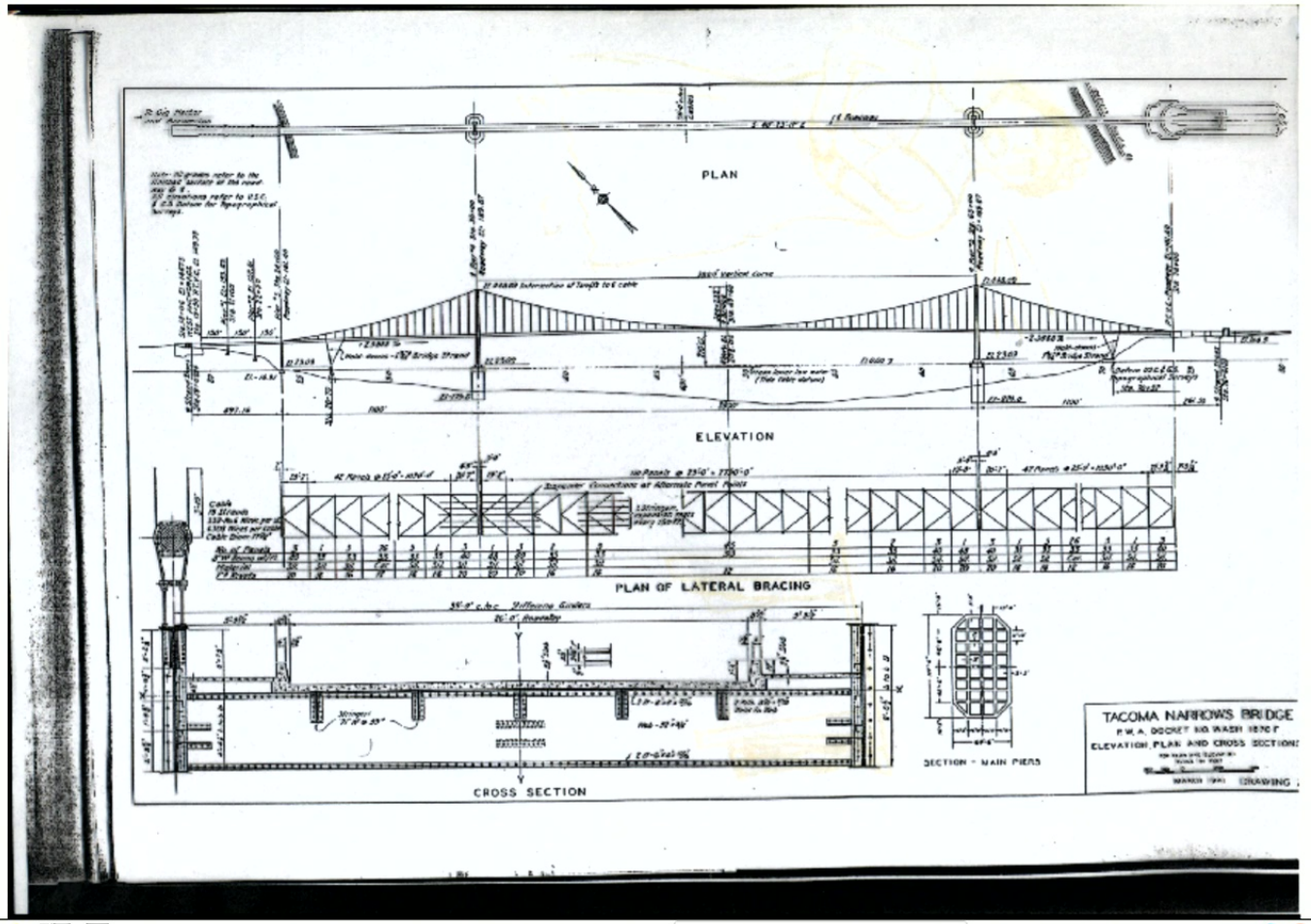
Abstract: 4 months after it opened, the Tacoma Narrows bridge, one of the world's longest suspension bridges at the time, collapsed spectacularly in the first storm that hit it. Though it was built to exceed all of the standrds at the time, something clearly went wrong. The failure was filmed from almost the beginning to the end (about 1 hour), and that film has been shown to almost all first year physics or engineering classes as an example of resonance, that explanation is clearly nonsense. What happened? Why did it collapse. The explanation is closely linked to, for example, the reason that clarinets or flutes, or even violins, make their music. With Daniel Green (whom you may remember from his time at Toronto) we were able to show in detail what happened.

Tacoma Narrows Bridge Disaster
1940

1938 Bridge OKed July 1940 opened



One reporter trapped by motion with the family dog
He crawled out of car (motion about 1 g) and crawled along sidewalk about 1/6 mile. Dog refused to leave car

Farquharson (U. Washington) civil eng. involved in design walked along centerline (node) to try to rescue/move car. Dog bit him and 1g accel caused car to skitter around. He inspected bridge (esp. vertical cables), and casually walked back to shore. (film)

Dog was only fatality.

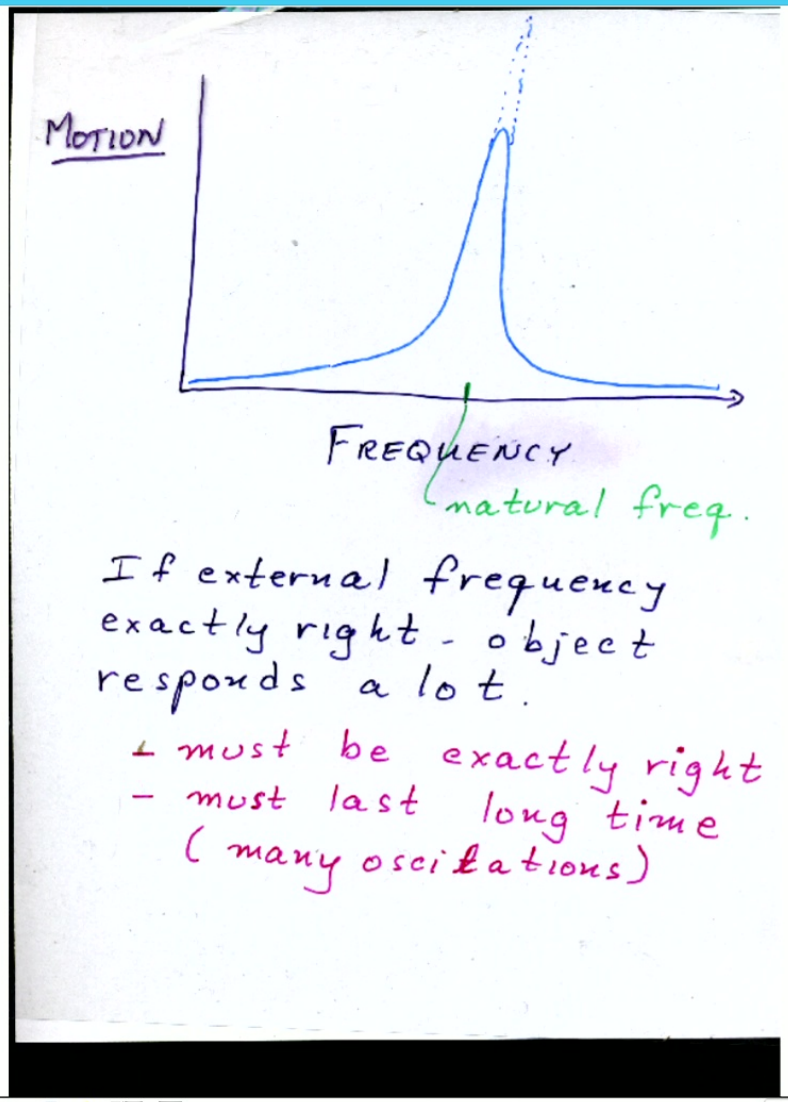
What Happened? Why did bridge do that?

Popular theory amongst physicists-- Resonance
(Film shown in many engineering and physics classes to illustrate resonance.)

Clearly thoughtless explanation

RESONANCE ?

IF SINGER SINGS EXACTLY
RIGHT NOTE LOUDLY ENOUGH
GLASS SHATTERS.



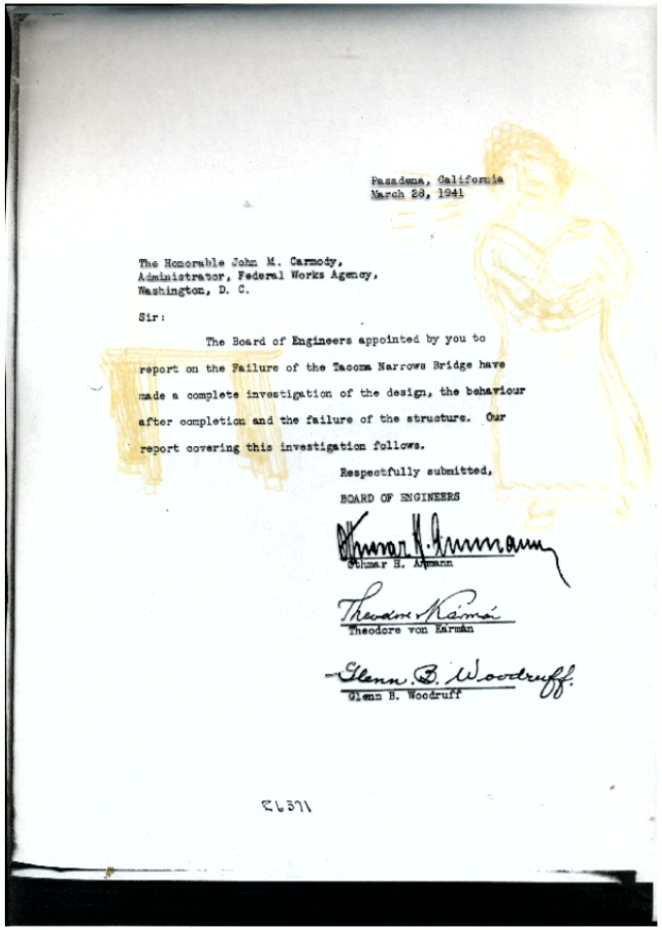
Large response only if driving freq. very close to osc freq. Wind does not behave that way.

von Karmen vortex street freq abot 10 times too large. and variable.

Not Resonance

Scanlan and Billah shredded Physicists (1991 in AmJPhys)

At end of Nov Commitee set up to investigate Collapse



Pasadena, California
March 28, 1941

The Honorable John M. Carmody,
Administrator, Federal Works Agency,
Washington, D. C.

Sir:

The Board of Engineers appointed by you to report on the Failure of the Tacoma Narrows Bridge have made a complete investigation of the design, the behaviour after completion and the failure of the structure. Our report covering this investigation follows.

Respectfully submitted,

BOARD OF ENGINEERS

Othmar H. Ammann

Theodore von Kármán

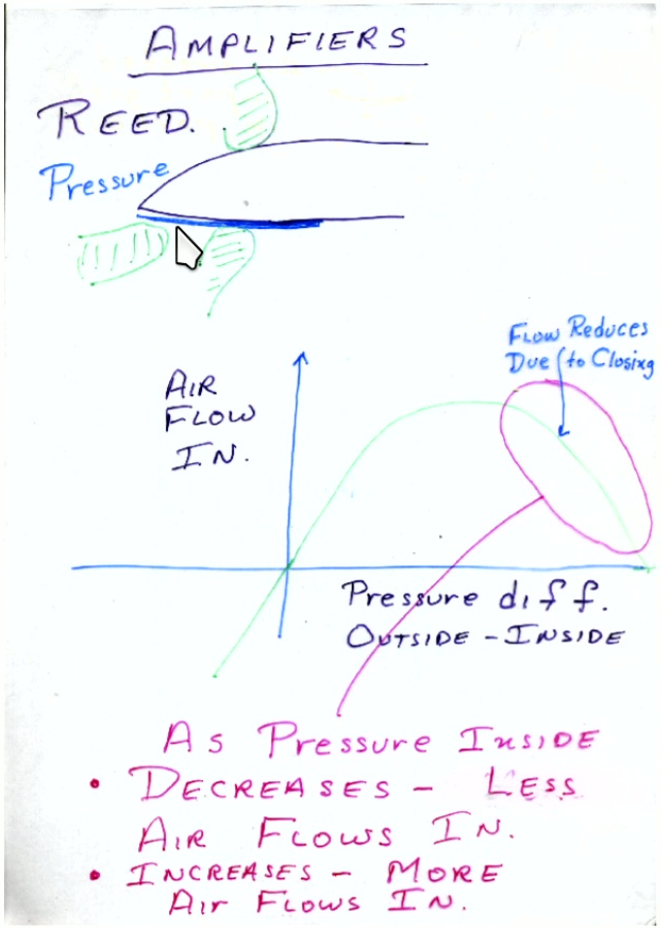
Glenn B. Woodruff

The bridge met all standards for design and construction. But they only covered static forces

Wind tunnel tests v Karmen
The bridge became an amplifier (negative damping)

No How or Why

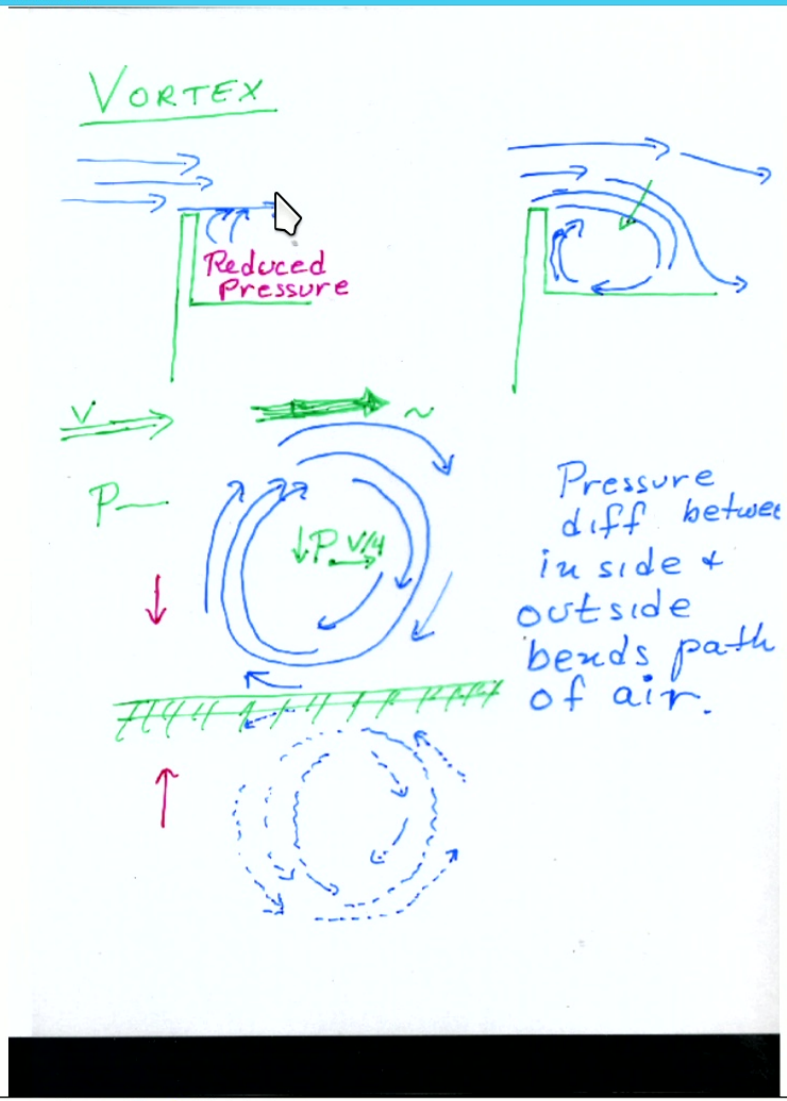
Clarinet- Amplifier plus time delayed feedback



Delayed feedback
Sound waves traveling to end of tube and reflected back
T=4L/c --Cyl pipe
T=2L/c -- Conical pipe

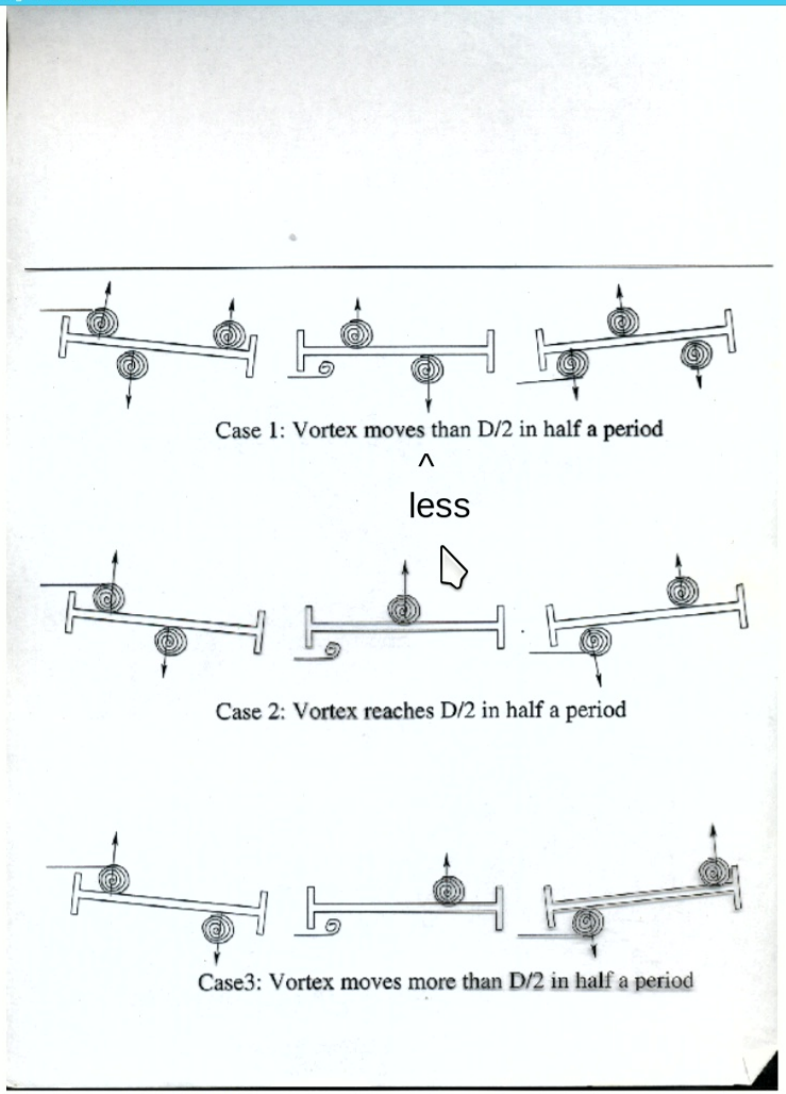
I wanted to know what the detailed mechanism was.
Extremely bright undergrad student (I had worked with him in High School on Hartle-Hawking vs Linde-Vilenkin models of quantum Universe).-- Hired him as summer student.

I came across Guido Morgenthal's thesis on discrete vortex technique for solving "incompressible" flow problems
(ie , vel sound >> all velocities in problem)
and he kindly allowed us to use his program VXFlow.



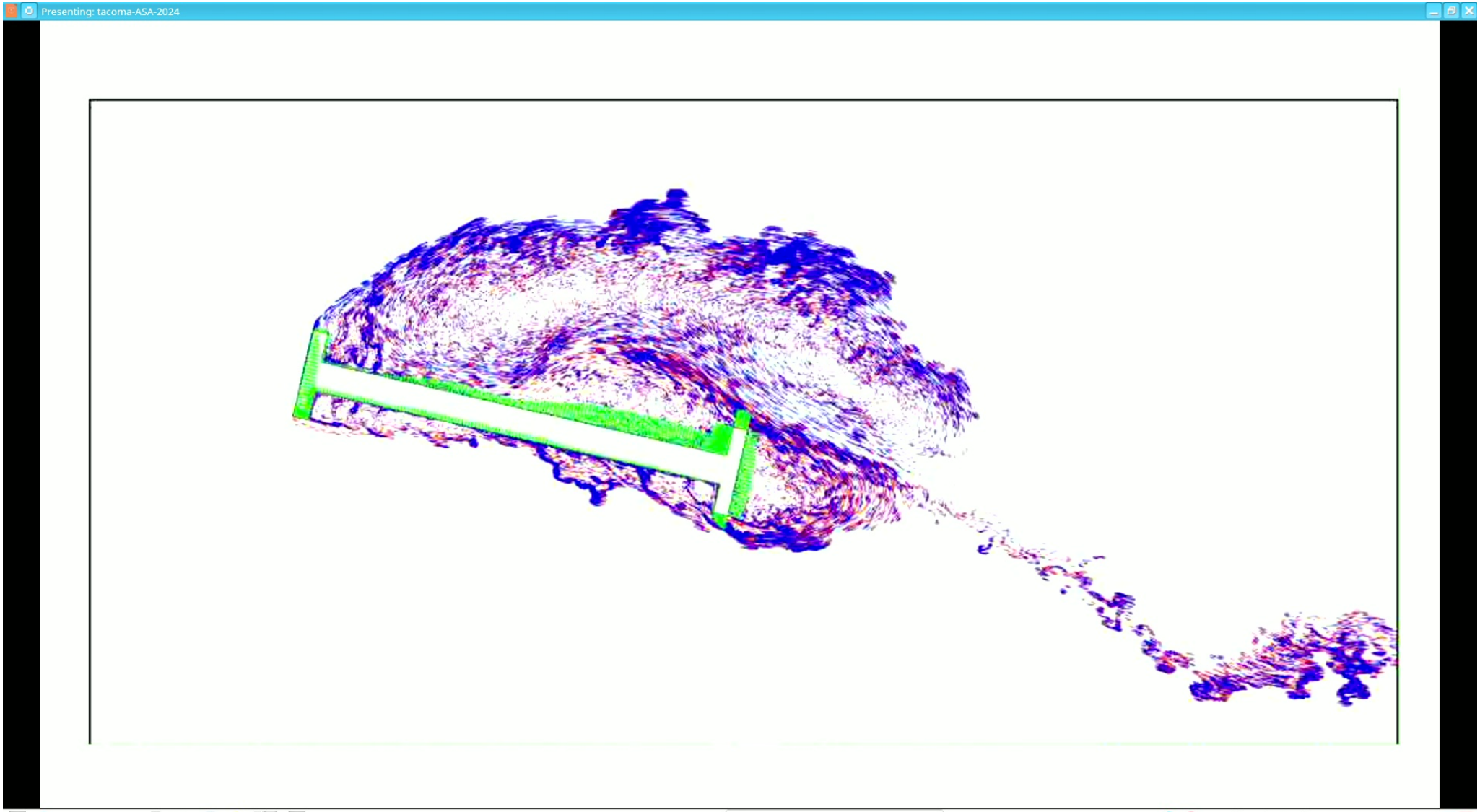
Vortex is low pressure area (Needs to so air revolves around center)

Low pressure sucks up on bridge deck



Larson's Model (2001)

Contains essentials but not details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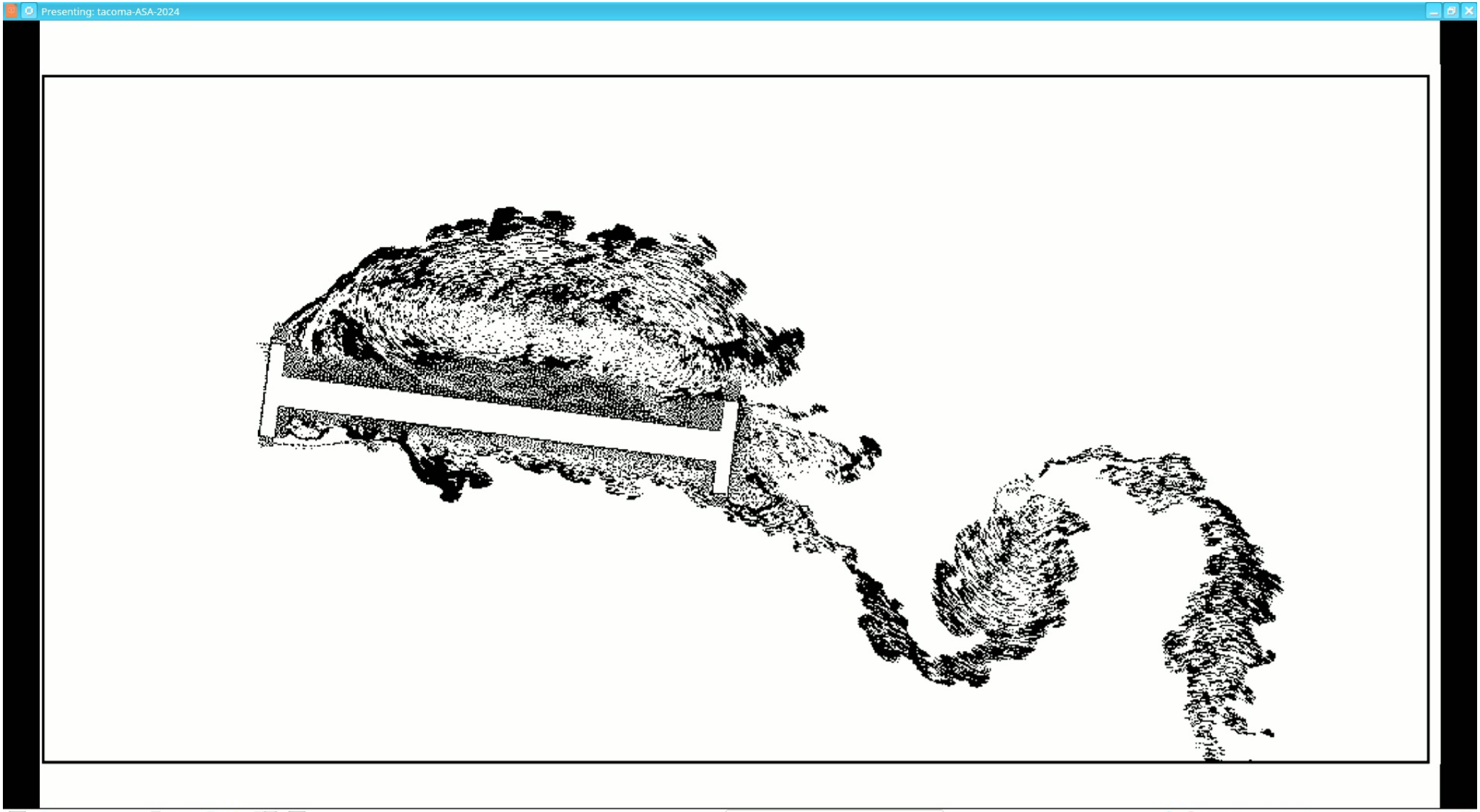
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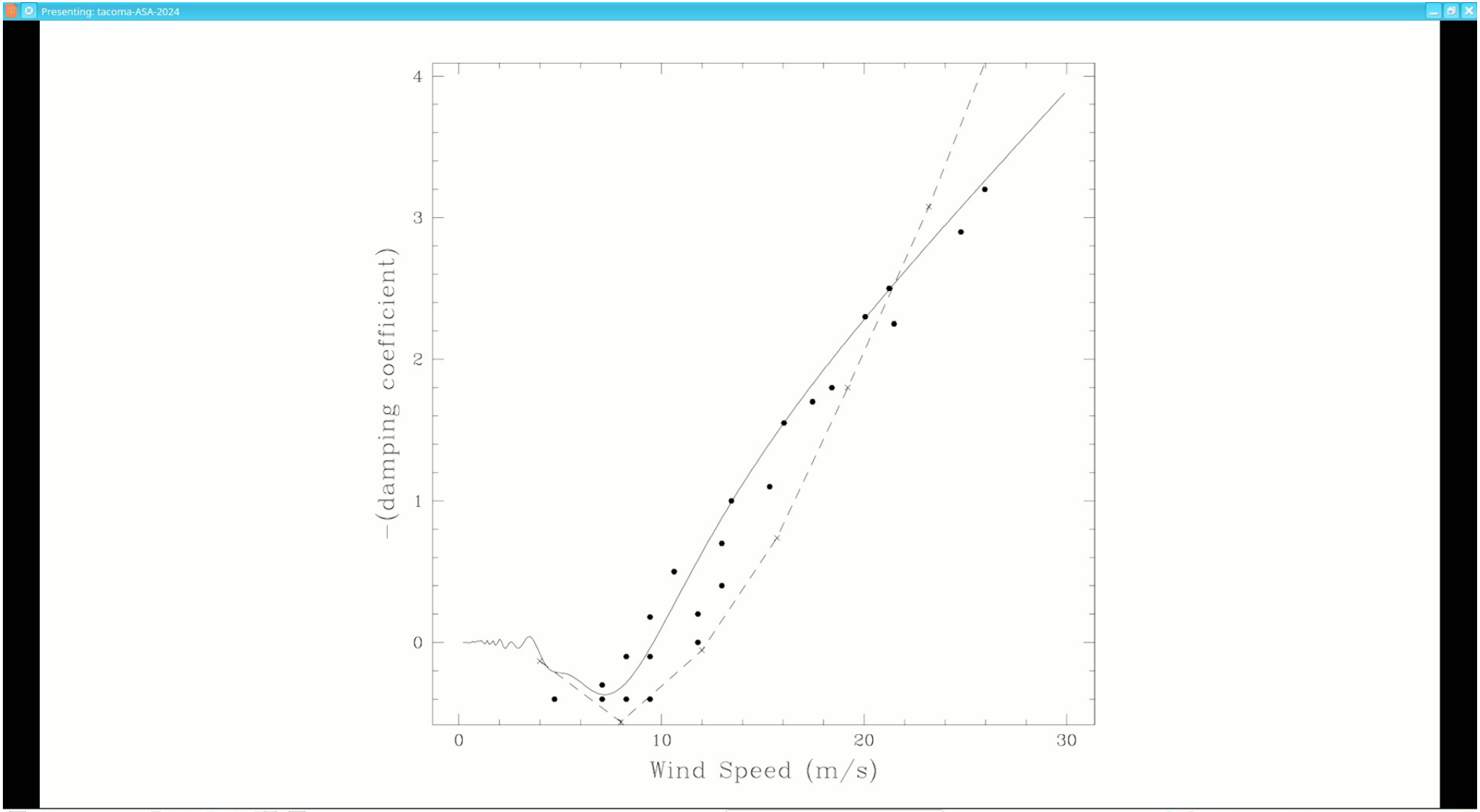
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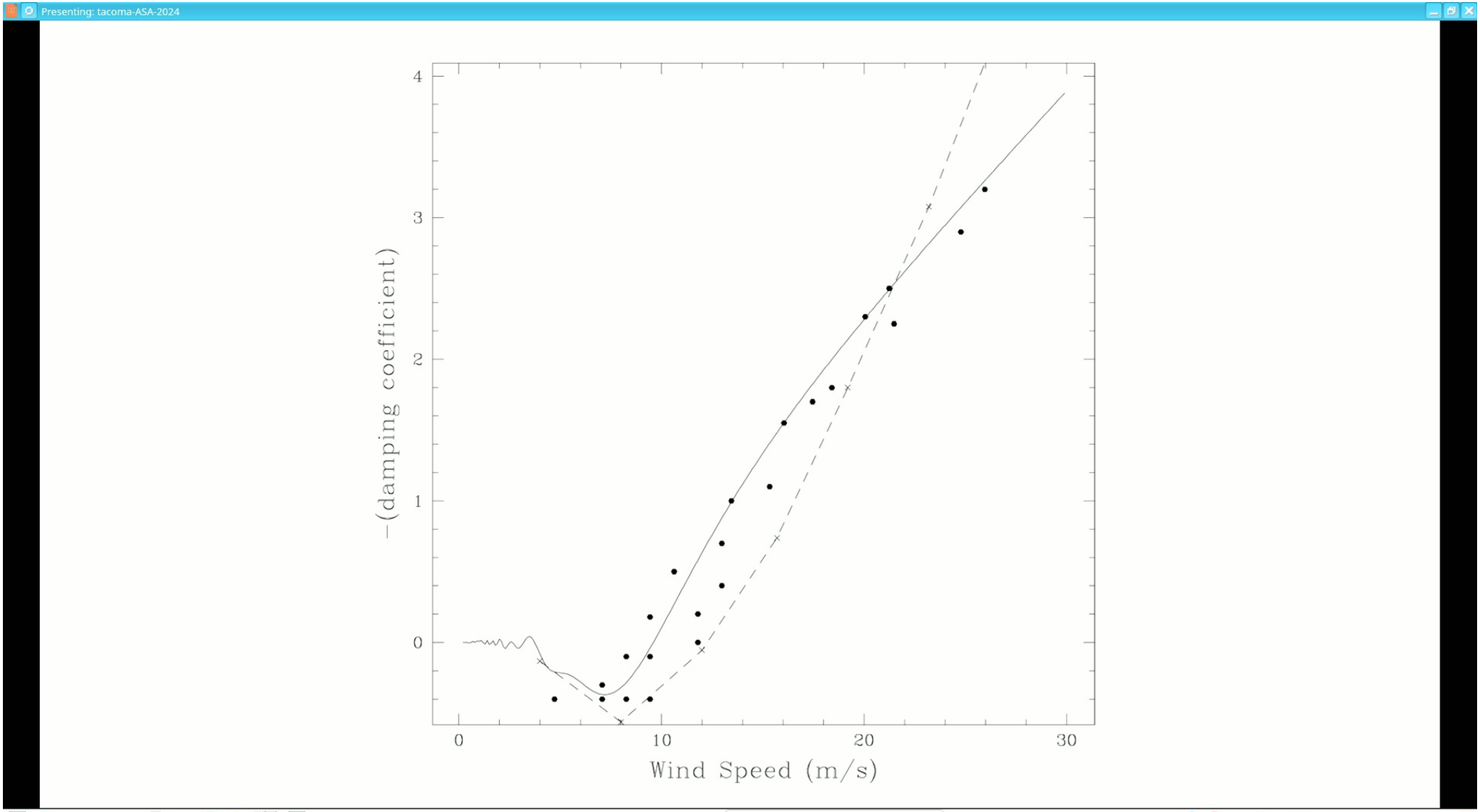
Experimental Evidence

Unfortunately Farquharson did not take a big bag of chaff with him to do a P(article)I(mage)V(elocimetry) experiment when he wandered onto the bridge. Fortunately vortexes are just as good. But only in a computer model.

The bridge obliged us by grinding huge slabs of concrete against each other and throwing concrete dust into the air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−(damping coefficient)
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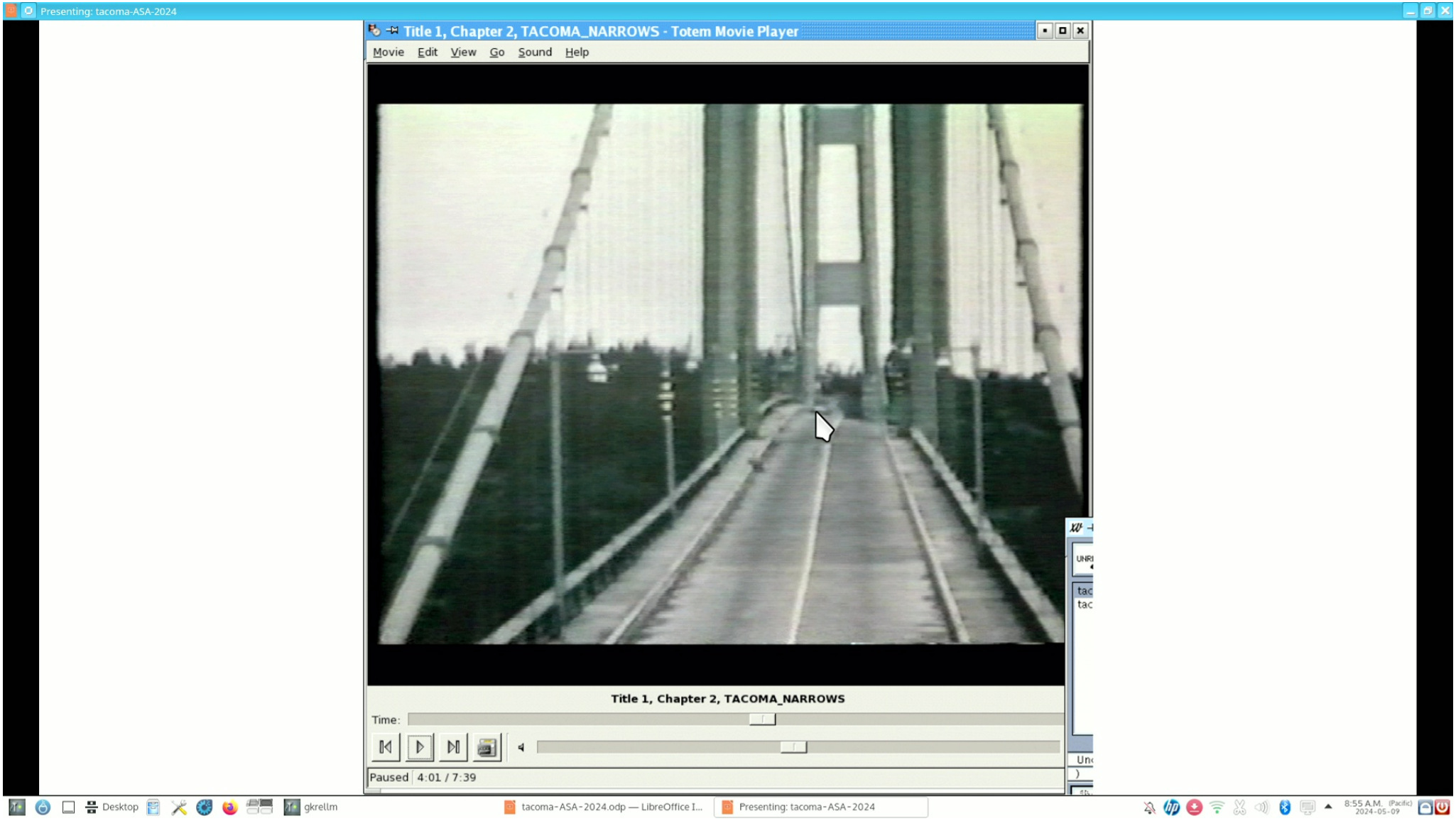
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PS: One of the banks in Tacoma had a large sign on their roof

As Safe as the Tacoma Bridge

It disappeared by the evening of Nov 7 1940.