Failure of the Tacoma Narrows Bridge: Flutter not Resonance

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What Didn't Happen

NOT Resonance

Resonance

- excite at a given frequency f_o.
- resonance frequency of the bridge

$f_b \approx f_o$.

There was NO driving at fixed frequency f_o .

NOT Alternatively shed vortices

- Strouhal frequency ≈ 1 Hz.
- Bridge frequency ≈ 1/5 Hz.

Wind tunnel tests show that:
the bridge controlled the vortices,
NOT that the vortices drove the bridge.

Events

June 1, 1940 — **Center ties installed.**
Diagonal cables from the span to the main suspending cables.

June 28, 1940 — **Hydraulic damping.**
Shock absorbers - destroyed by sandblasting the steel.

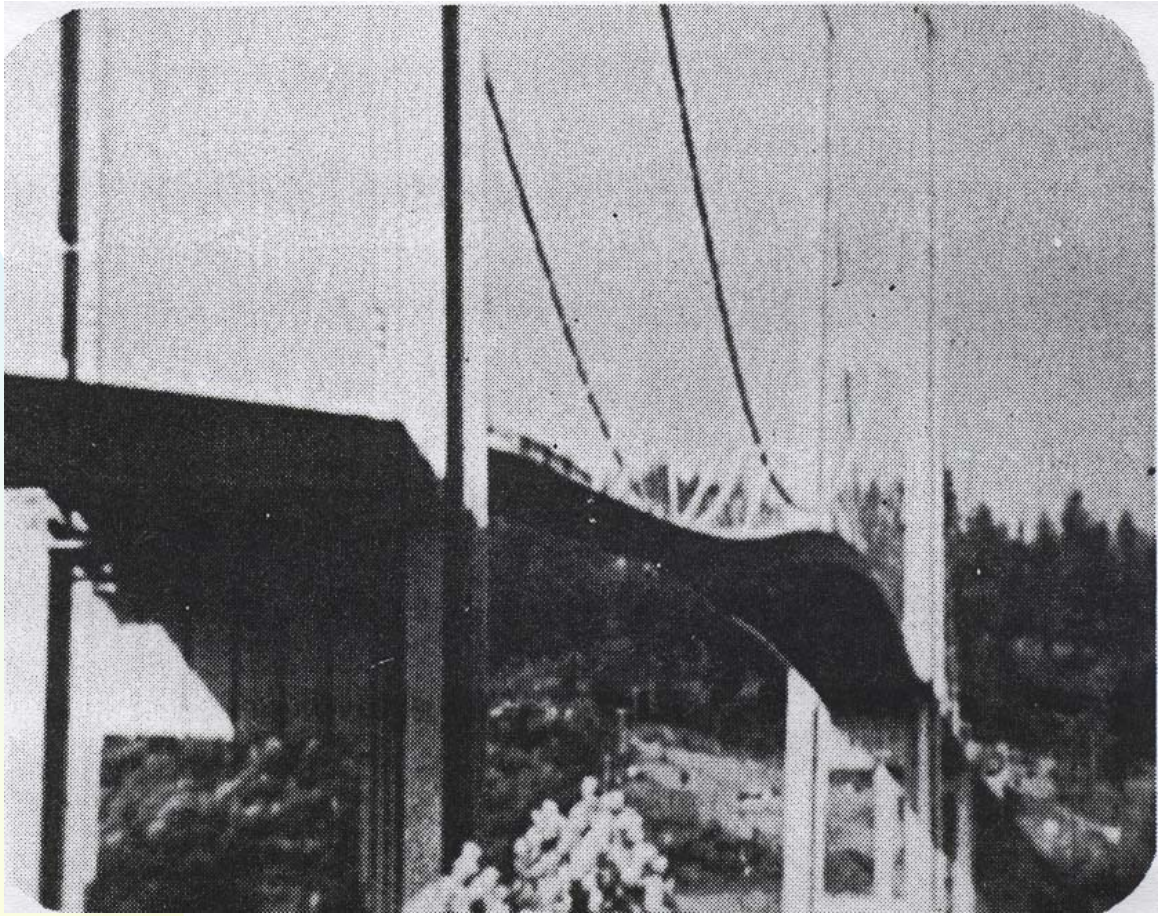
July 1, 1940 — **Bridge opened.**

October 4, 1940 — **Side span hold-down cables.**

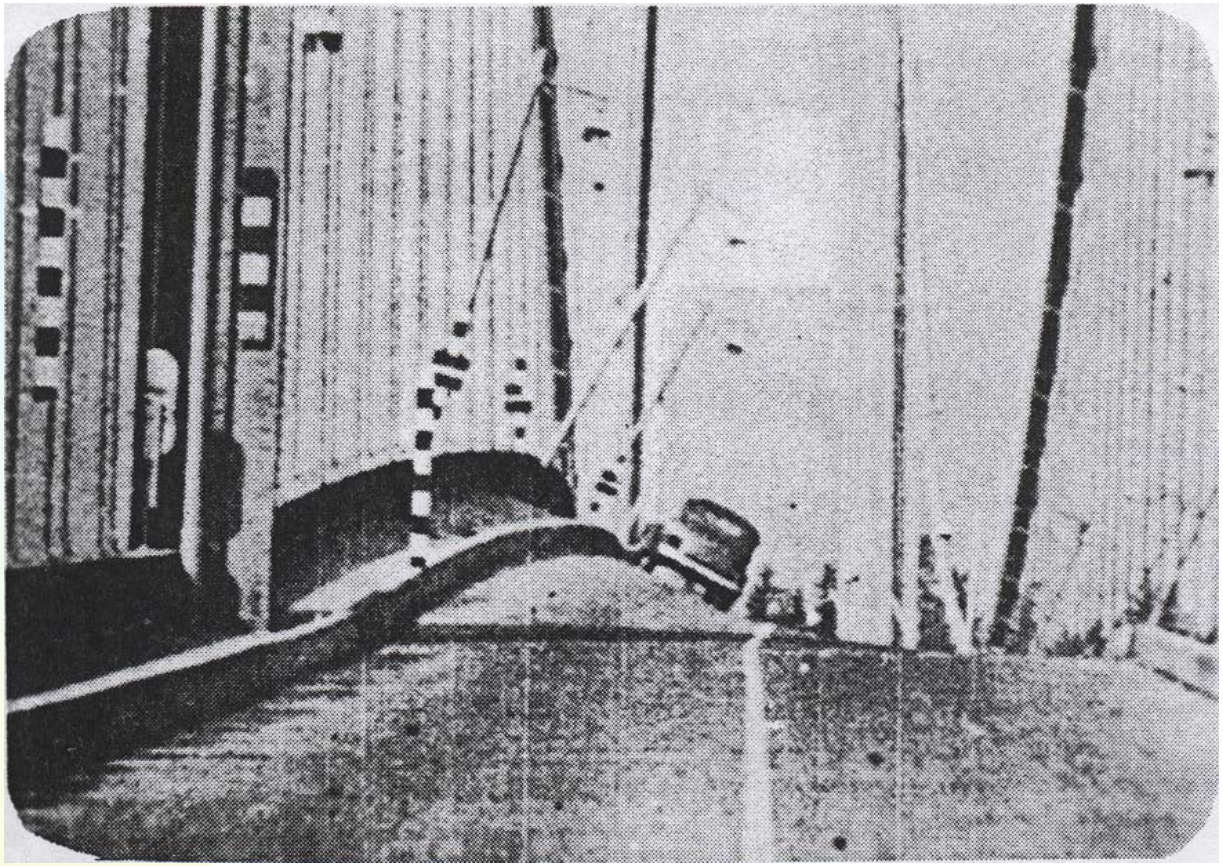
November 7, 1940 — **Maximum wind = 42 mph (68 Km/hr).**
Several hours of typical vertical motion.

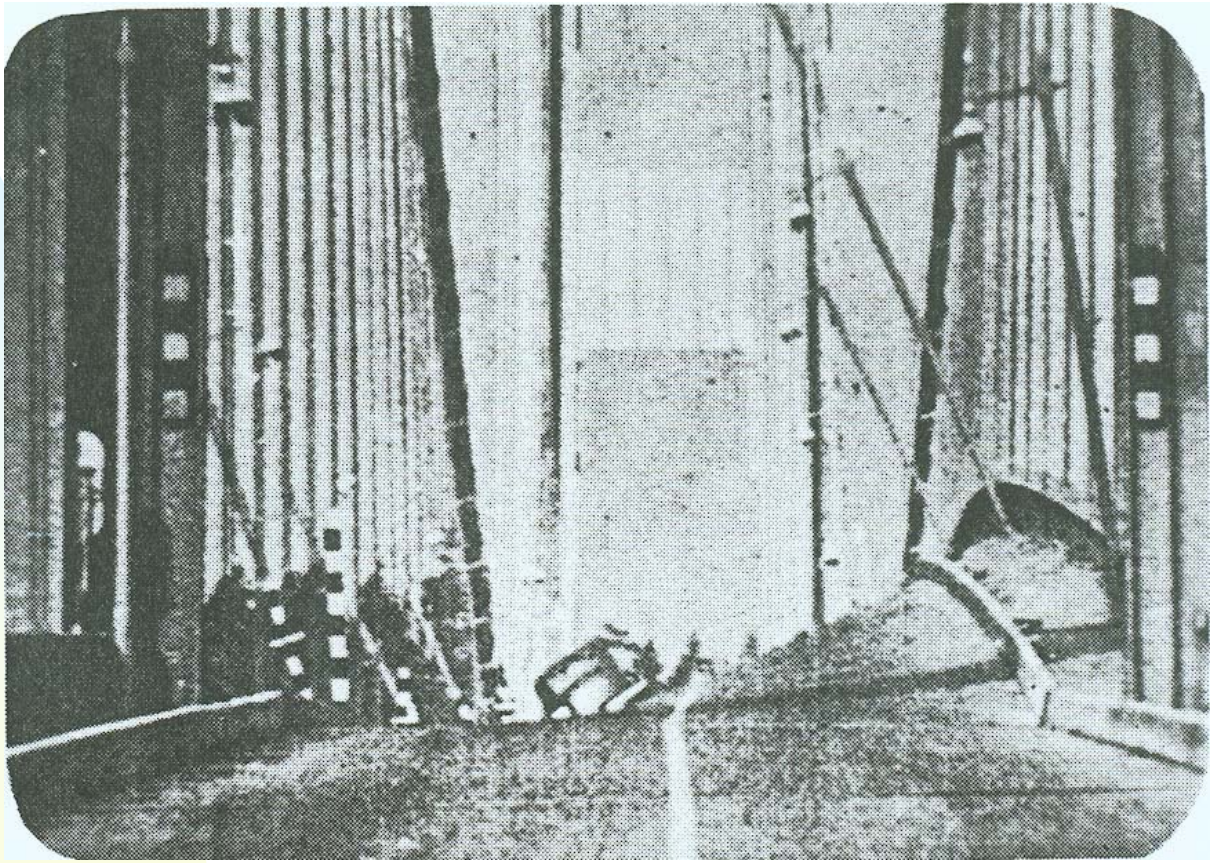
Suddenly, violent TORSION.

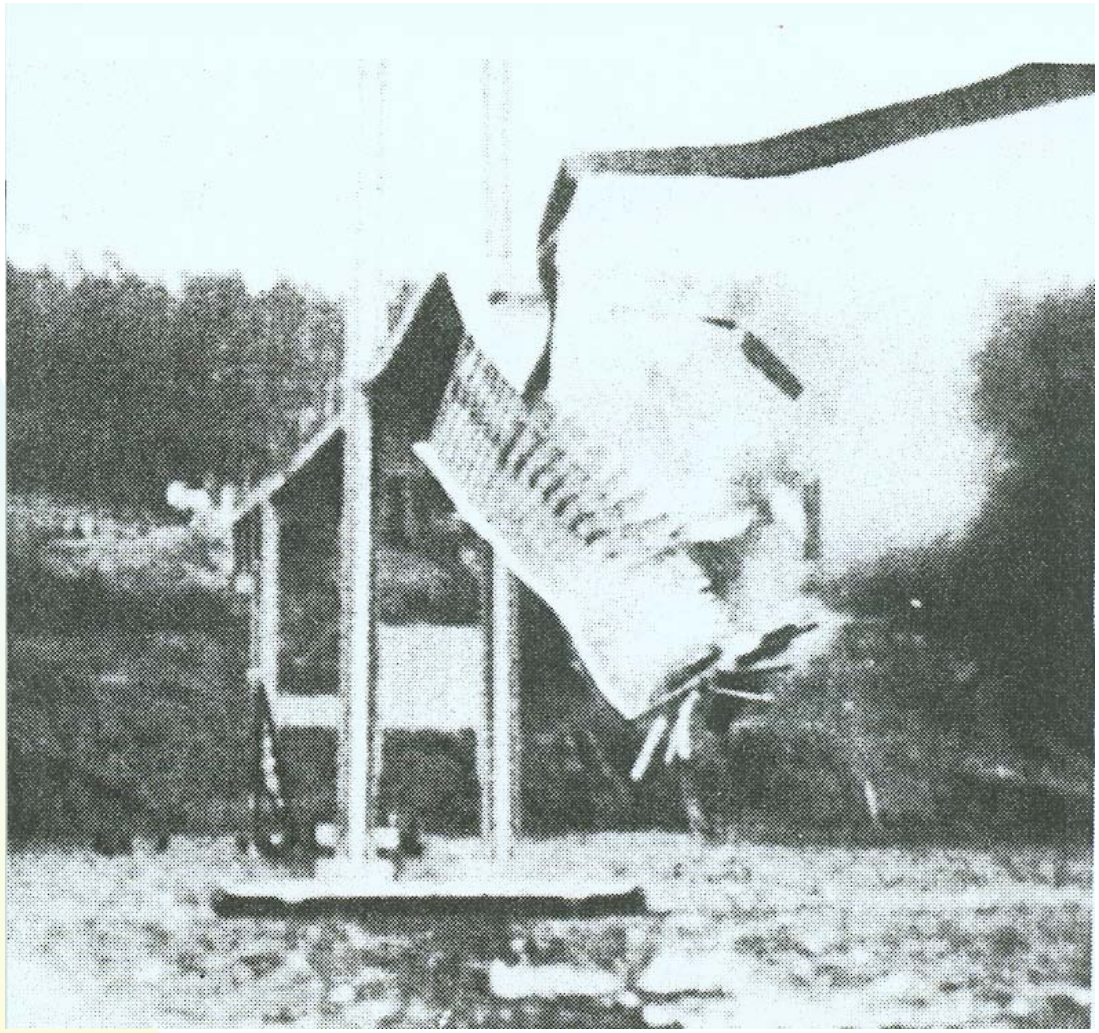
- 10 minutes - damage
- 50 minutes - collapse.

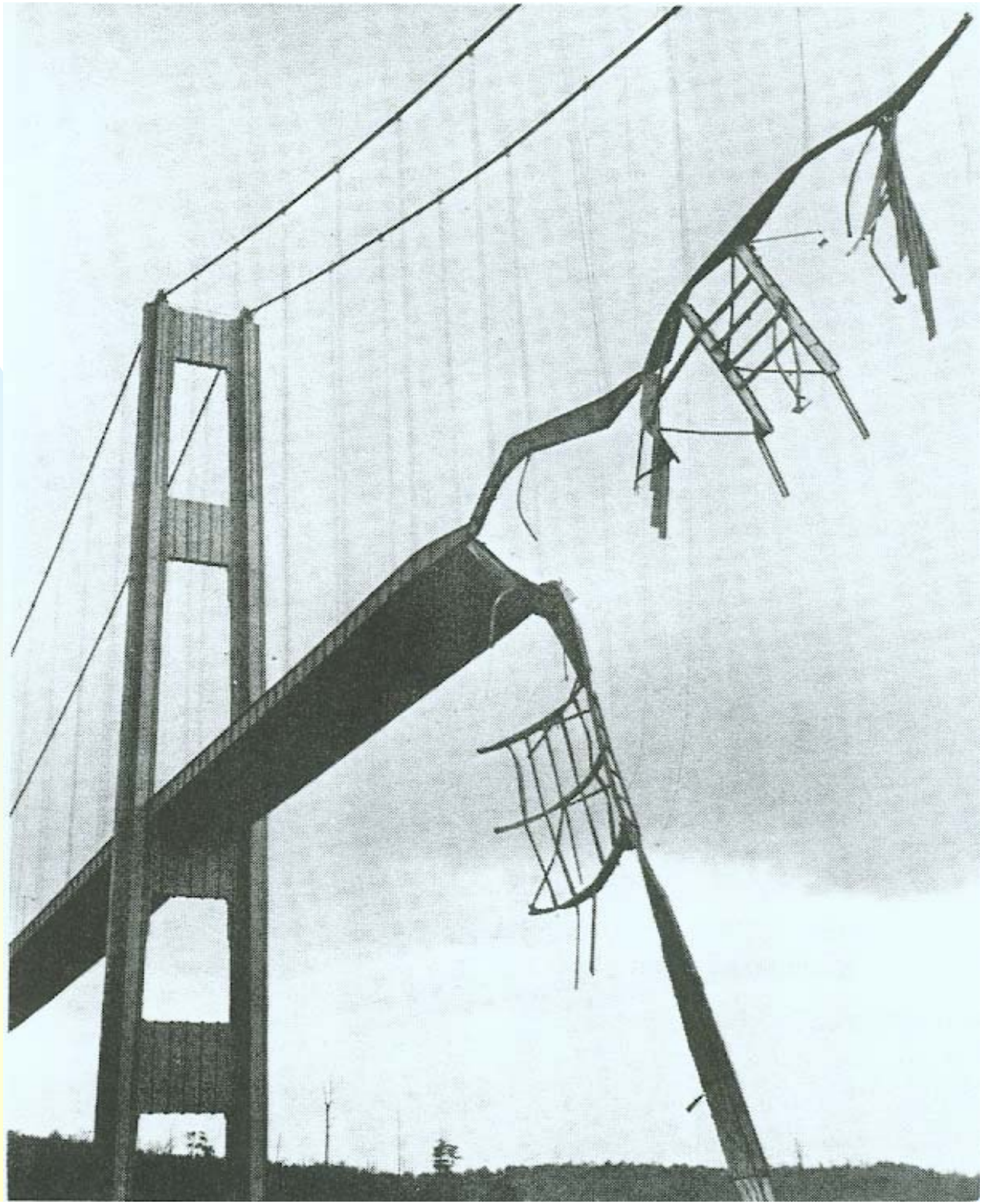


“Somewhat irregular torsion in main span after about 30 minutes of catastrophic motion.”





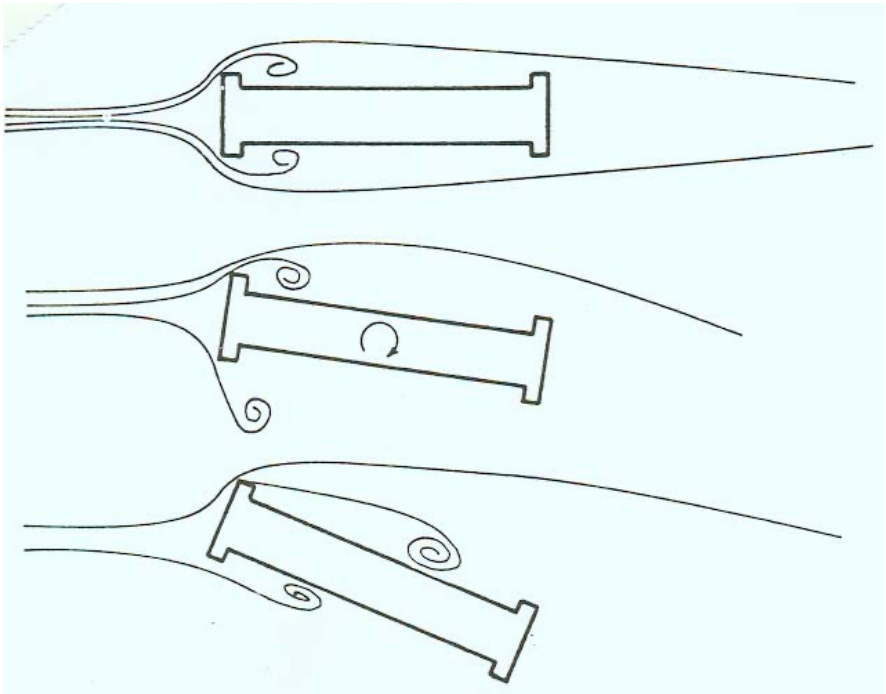




Cause of Failure

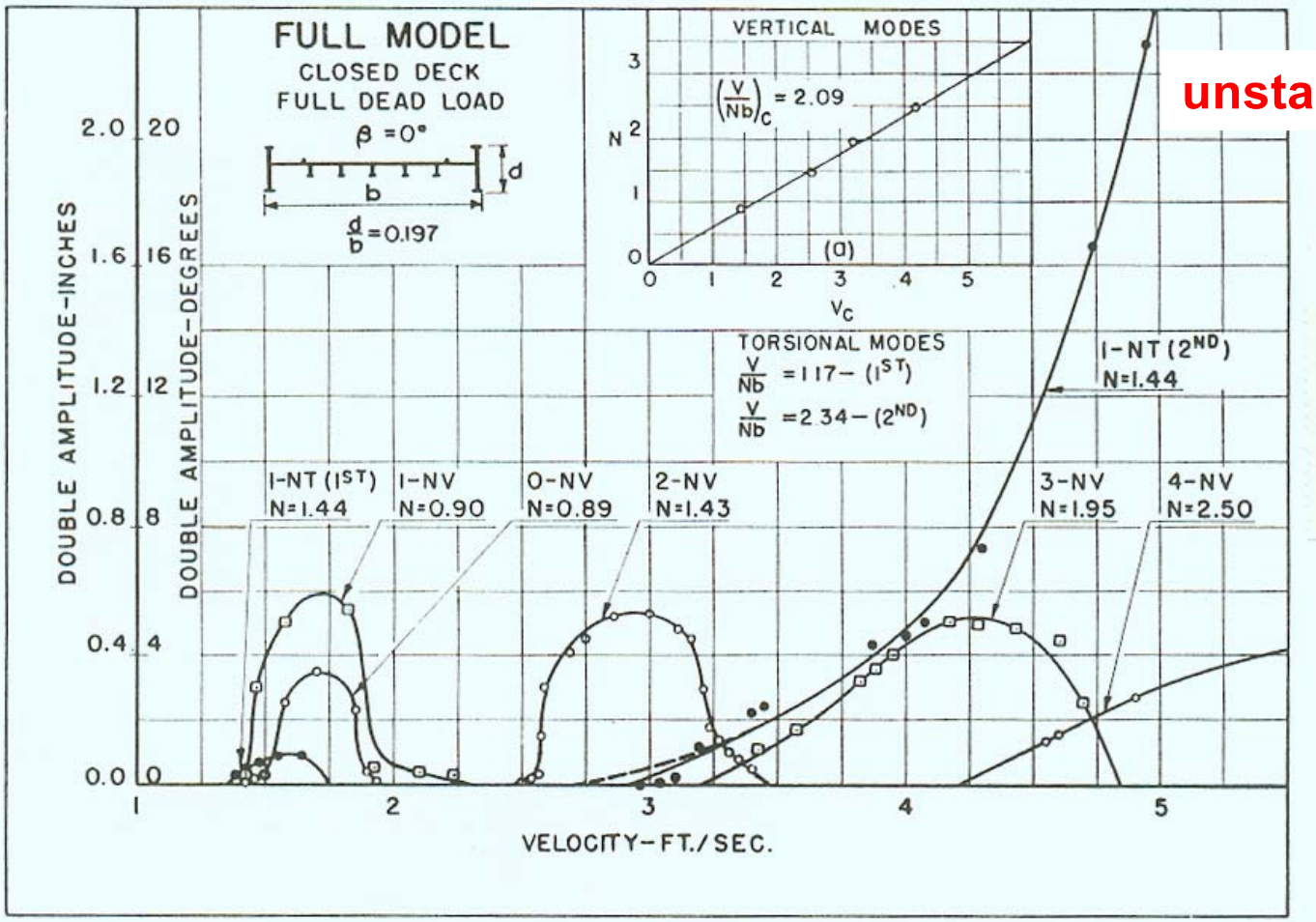
Positive Feedback

- The wind twisted the deck.
- The change in the angle of the deck caused the wind to change.
- The change in the wind made the deck twist more.



Full Model Wind Tunnel

Structural Research Laboratory, University of Washington, Seattle.



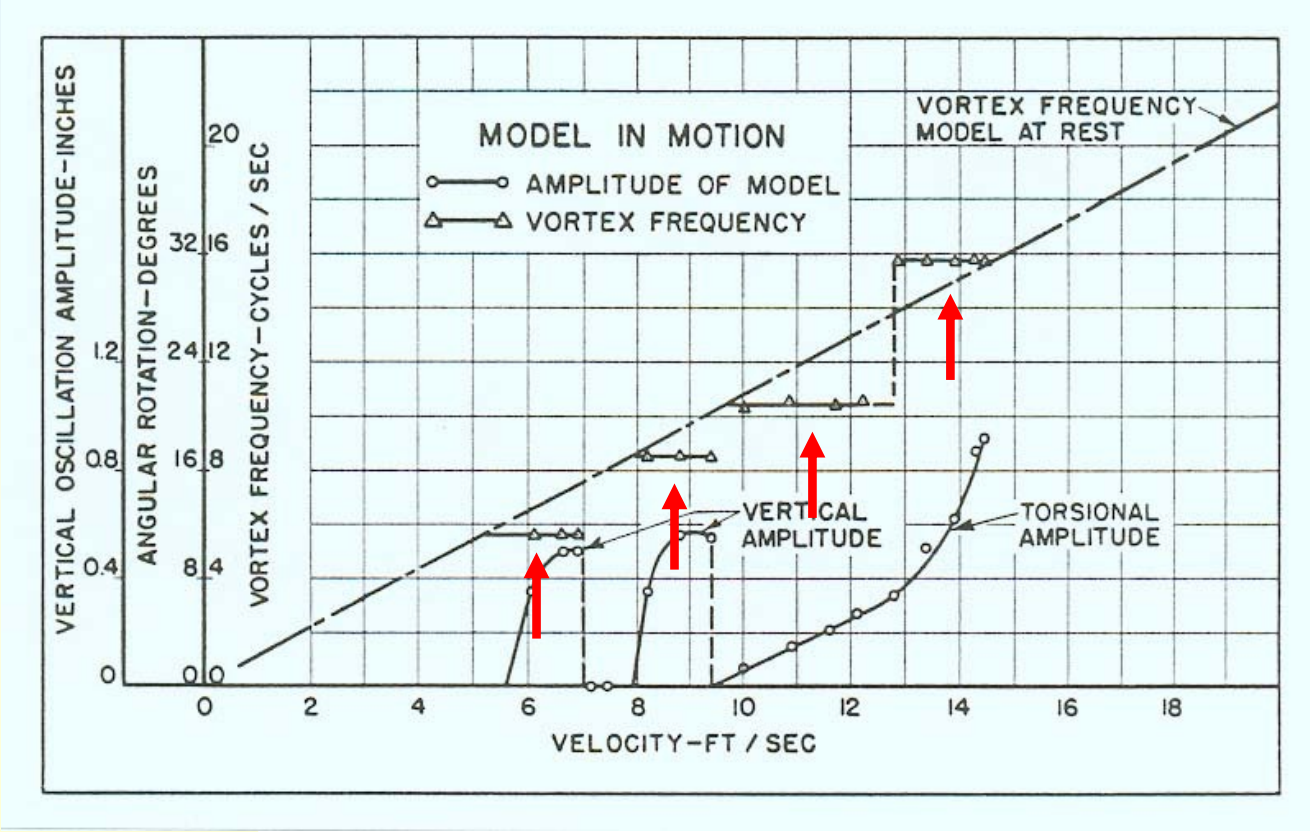
unstable

Model in Motion

California Institute of Technology.

T. Von Karman and L. G. Dunn 1950 Aerodynamic Stability of Suspension Bridges with special reference to The Tacoma Narrows Bridge, University of Washington Engineering Experimental Station, Bulletin No. 116, Part III.

The Bridge controlled the vortices!



The New Tacoma Narrows Bridge

Look at that Truss!

Failure or Success?

"...the Tacoma Narrows bridge failure has given us invaluable information...It has shown [that] every new structure which projects into new fields of magnitude involves new problems for the solution of which neither theory nor practical experience furnish an adequate guide. It is then that we must rely largely on judgment and if, as a result, errors or failures occur, we must accept them as a price of human progress"

- Othmar Ammann

"No one *wants* to learn by mistakes, but we cannot learn enough from successes to go beyond the state of the art. Contrary to their popular characterization as intellectual conservatives, engineers are really among the avant-garde. They are constantly seeking to employ new concepts to reduce the weight and thus the cost of their structures...The engineer always believes that he is trying something without error, but the truth of the matter is that each new structure can be a new trial...Such is the nature not only of science and engineering, but of all human endeavors."

- Henry Petroski

H. Petroski, To Engineer Is Human, Vintage Books, 1992