Closure of Millennium Bridge

June 12, 2000 at the Millennium Bridge, London, UK

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The Millennium Bridge, built to commemorate the arrival of 2000, opened as a new crossing over the Thames. People flocked to cross this bridge, however, the pedestrians caused the bridge to sway and when the amplitude reached several centimeters it was closed due to the danger just two days after opening. The cause was insufficient stiffness, especially in the lateral direction.

1. Event

The Millennium Bridge, the £18.2 million (approximately 3.3 billion yen) project built to commemorate the arrival of 2000, opened on June 10, 2000 as London's new Thames footbridge crossing. People flocked to cross this bridge, however, the pedestrians caused the bridge to sway and when the amplitude reached several centimeters it was closed due to the danger just two days after opening. The cause was insufficient stiffness, especially in the lateral direction.

2. Course

On June 10, 2000, the Millennium Bridge opened to the public as a new Thames crossing linking the City of London at St. Paul's Cathedral with the Tate Modern Gallery at Bankside. An estimated 80,000 to 100,000 people crossed the bridge on the opening day to visit the new bridge and the Tate Modern Gallery.
As large crowds walked across the bridge, it started swaying and wobbling side to side (70 mm at most) in the wind so violently that some clung on to the side of the bridge and others reported feeling sick. No limit was imposed on the number of pedestrians allowed to cross the bridge at that time.
Because of safety concerns, the Millennium Bridge was closed on June 12, just two days after opening.
After cause analysis and countermeasure in place, the bridge re-opened on February 22, 2002.

3. Cause

Mechanism that caused the lateral swaying follows:
A pedestrian walk generates a sideways load (25 N per person) with every step (Figure 1).
When a large number of the people happen to take the same step at the same time, the bridge sways a little.
The pedestrians then walk in sink with the swaying and the effect multiplied to produce the large swaying.

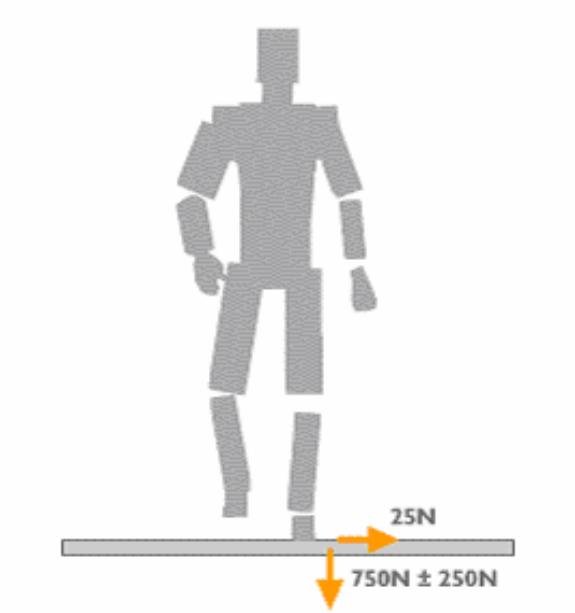

Figure 1. Vertical and Sideways Loads [1]

While the Millennium Bridge was a beautiful design, however, it lacked the proper stiffness in the lateral direction.

The designing company, Arup Group, Ltd. later discovered that other bridges with less than 1.3 Hz of natural frequency could sway sideways with walkers in excess of certain limits. They found videotape showing the 1975 swaying of Auckland Harbour Road Bridge that had a completely different structure from the Millennium Bridges. The synchronized footfall effect on lateral forces had not been widely published and thus bridge experts had not been aware of it. This may mean that vertical forces and motion induced by footfalls have been well known and documented but the lateral swaying is taken as a trivial phenomenon and has not made it to the building codes. Details are unknown. I have addressed this to Professor Yozo Fujino of Tokyo University who was appointed as a member of the investigation commission. A non-disclosure agreement, however, held him from giving me any information

4. Immediate Action

Officials first tried to limit the number of pedestrians on the bridge, but it did not help reducing the lateral swaying. In order to ensure public safety, the officials closed the bridge on June 12 and started the investigation to identify the cause. The designer Arup formed the project for the investigation.

5. Countermeasure

In order to reduce the lateral movement, the project concluded that the bridge needed to either absorb pedestrians' footsteps with dash pots or have its structure stiffened so the bridge would not resonate with

the pedestrian's footsteps. Arup decided to dampen the shock from the pedestrian's footsteps, because laterally stiffening the bridge would change the bridge's appearance.

Two forms of passive dampening were employed on the Millennium Bridge. (Figure 2): one for absorbing the most of the lateral forces created by pedestrians, and the another one for absorbing vertical forces.

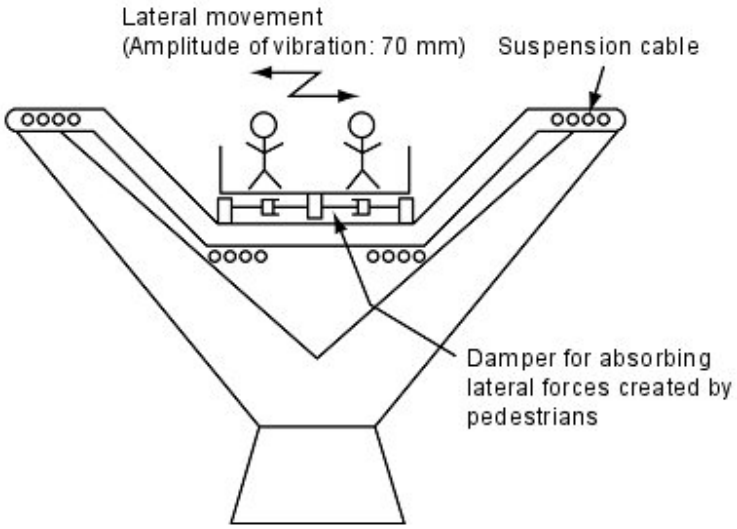

Figure 2. Cross-section of Millennium Bridge [3]

Fall of suspension bridges were reported at the Irwin River in 1831 in the suburbs of Manchester, U.K. and at the Maine River in 1850 in Un-juor, France. Both incidents were caused by marching soldiers on the bridge. (A. Sutcliffe, et al., 1972, *Episode Science IV*, Gendai Kyoyo Bunko, Shakai Shisousha.)

The corrections cost £5 million (approximately 0.9 billion yen).

With corrections in place, more than 2000 people walked across the bridge to test its movement. The bridge reopened on February 22, 2002.

6. Summary

The Millennium Bridge was designed by Arup Group, Ltd. of the U.K., one of the leading structural design consultants in the world. Even such a professional engineering team made a design error. Arup reported this incident and their findings in detail on their web site. The pages have descriptions that appear to avoid the responsibility by pointing to similar events other than the Millennium Bridge, however, the incident teaches about a past failure with a public construction and lots of lessons that we can see through it.

7. Knowledge

(1) Resonance can easily destroy the structures and machines.

(2) Accidents easily happen when conditions exceed what we have planned.

(3) Development of novel products requires thorough research of related information and analysis.

8. Background

The U.K. had three projects to commemorate the arrival of 2000, including the London Eye (sometimes called the Millennium Wheel), the Millennium Dome and the Millennium Bridge. The Millennium Dome attracted small number of people with poor planning and the London Eye project kept having troubles one after another. The public had great expectations for the last Millennium Bridge.

The design of the bridge was a competition winner by the famous architect Foster and Sir Anthony Caro of sculptures. The design had horizontal cables that held the girders. It was a light weighted, transparent and noble design with lots of urban taste. It was the first new bridge across the Thames in London in 108 years since the Tower Bridge in 1894.

References

[1] Arup Group Ltd., http://www.arup.com/millenniumbridge/

[2] Yamada Structural Design Office, http://homepage2.nifty.com/y-structure/index.html

[3] Mas ayuki Nakao (2005) *1000 Scenarios of Failure*, Morikita Shuppan Co., Ltd.