Flow regime transformations in the 2011 tsunami, Northern Honshu, Japan

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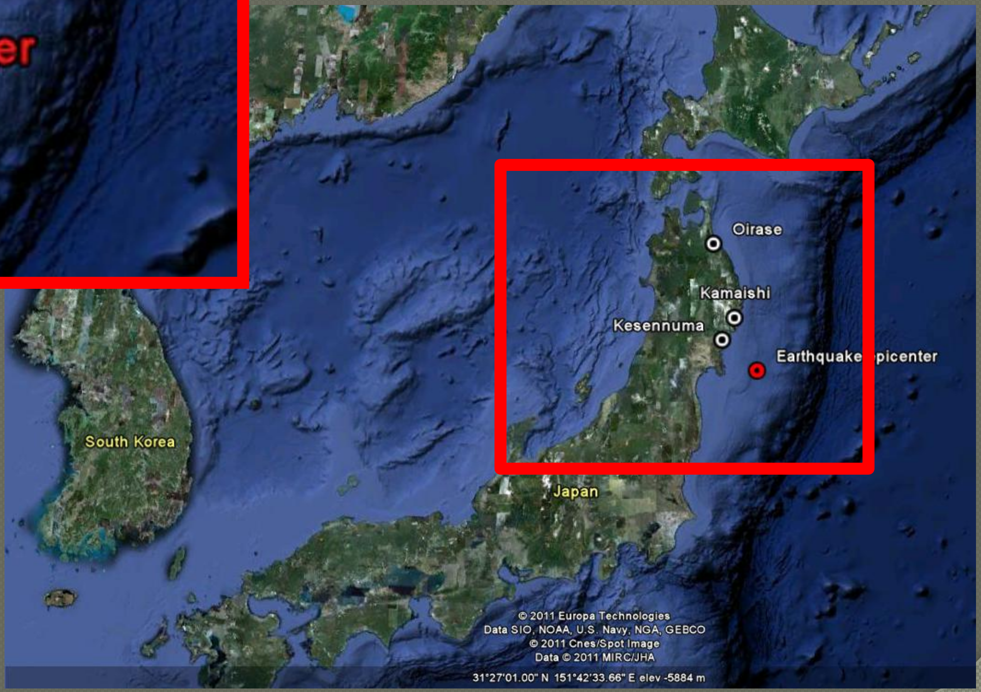
Locations


Oirase
Kamaishi
Kesennuma
Sendai
Epicenter


Oirase
Kamaishi
Kesennuma
Earthquake picenter
South Korea
Japan
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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Data © 2011 MIRC/JHA
31°27'01.00" N 151°42'33.66" E elev -5884 m

Questions

How do the dynamics of a tsunami change when it comes onshore?

- Is there a useful hydraulic analog for the behavior of the onshore tsunami?
- By what processes does it transform from a inviscid clear water wave to a viscous debris-laden flow?

Tsumani comes onshore

offshore ▲

onshore ▶

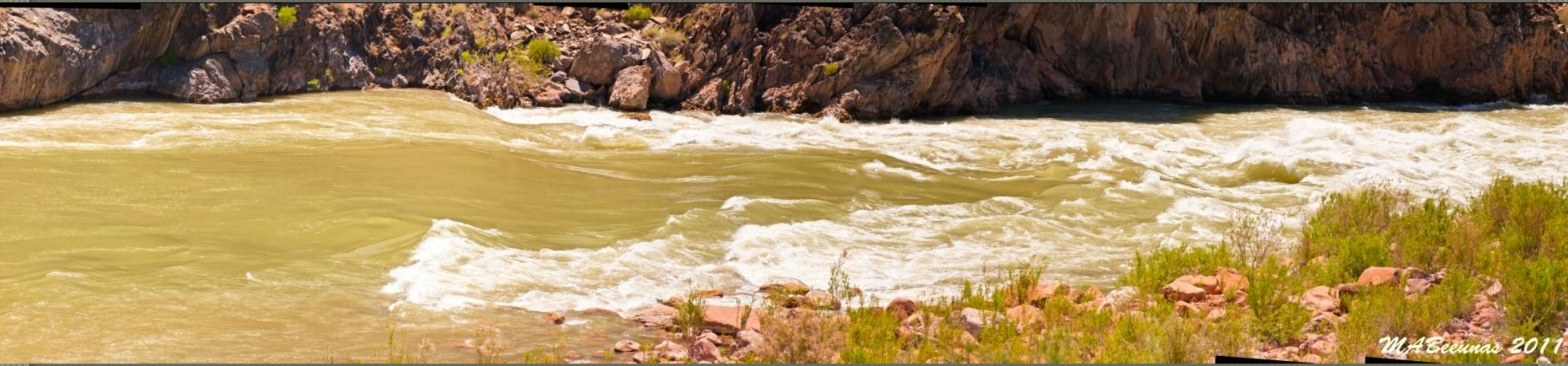
◀ Debris-laden flow

Background: Colorado River hydraulics

- Crystal Rapids, Colorado River, Grand Canyon, USA
- Standing waves result from constriction
- Similar features in onshore tsunami

Photo credit: Mark Beeunas 2011

Background : Froude number, sub- and supercritical flow



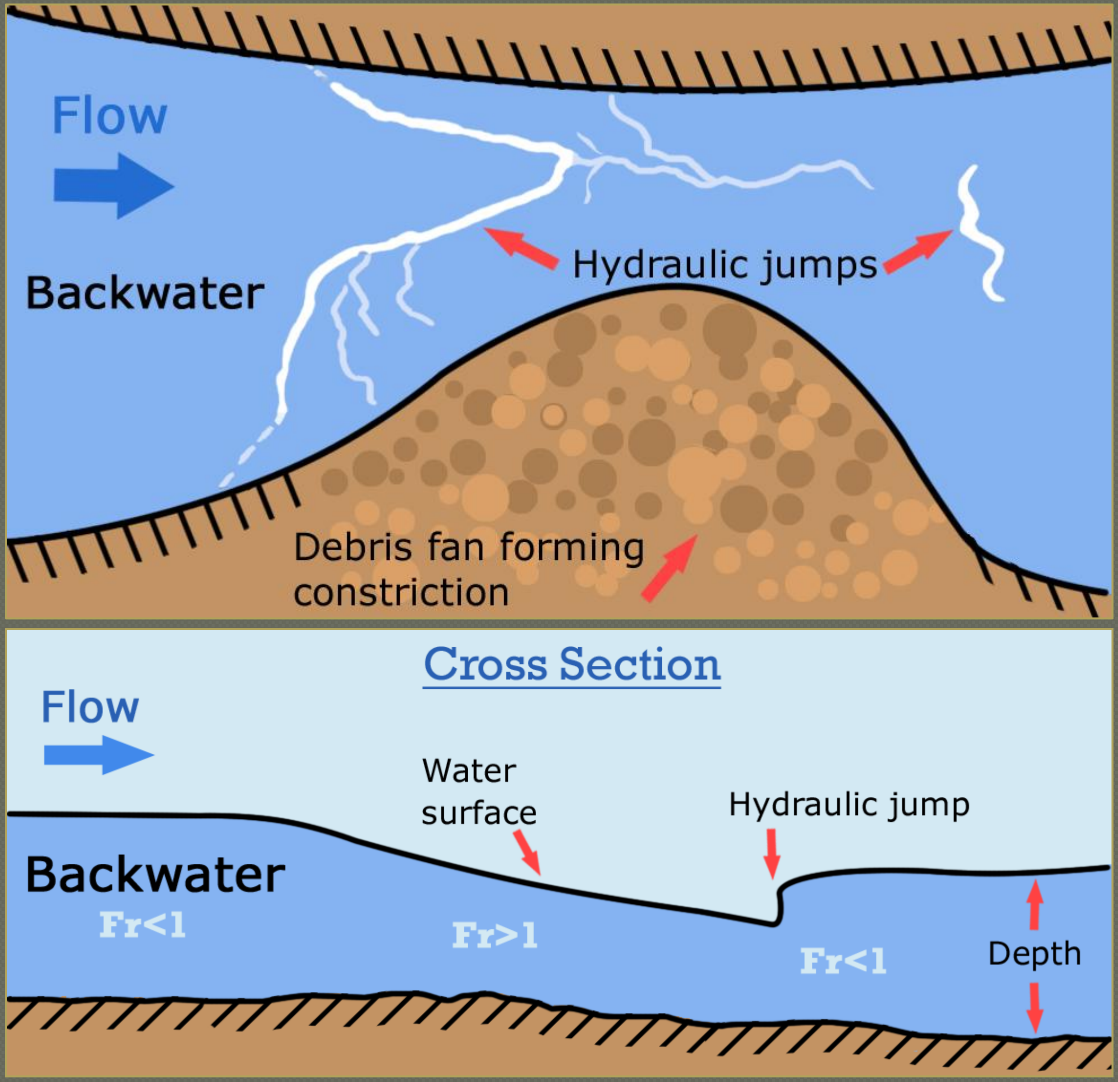
$$Froude\ number = \frac{characteristic\ flow\ velocity}{gravity\ wave\ velocity}$$

Supercritical	Fr > 1
Critical	Fr = 1
Subcritical	Fr < 1

- **Supercritical** flow transitions to **subcritical** through **hydraulic jump**
- Standing waves indicate **hydraulic jumps**

Photo credit: Mark Beeunas 2011

Colorado River: Map view and surface profile of constriction

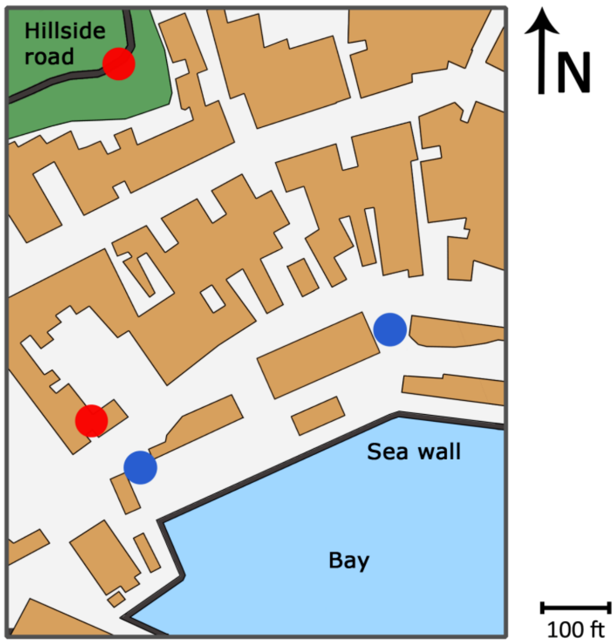


- **Supercritical** tongue bounded by oblique **hydraulic jumps**
- Compare to onshore tsunami flow through urban corridors

Offshore to onshore: Urban corridors

Kamaishi, Iwate Prefecture

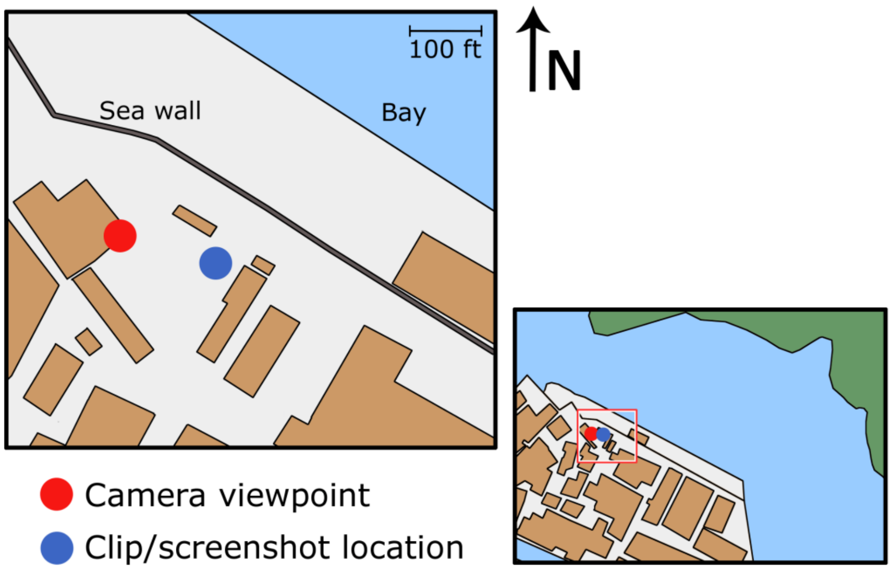
street layout before March 2011 Tsunami



- Camera viewpoint
- Clip/screenshot location

Kesennuma, Miyagi Prefecture

street layout before March 2011 Tsunami
(from satellite photos post-tsunami)



- Camera viewpoint
- Clip/screenshot location

Features of tsunami flow: Standing waves

Tsunami at sea

- Flow between buildings is analogous to flow in natural river channels
- Clips show undular waves and oblique hydraulic jumps

For more videos: www.GeologyInMotion.com

Features of tsunami flow: Standing waves

Kamaishi – undular wave

- Flow between buildings is analogous to flow in natural river channels
- Clips show undular waves and oblique hydraulic jumps

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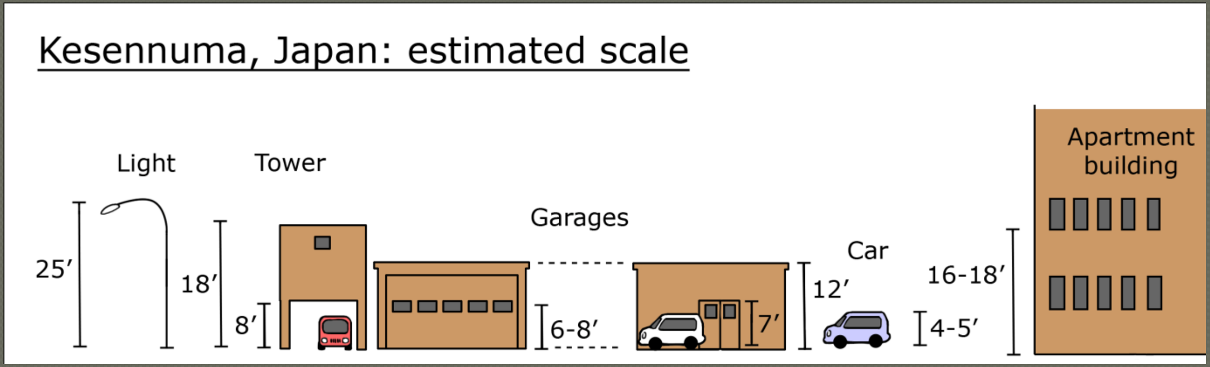
Features of tsunami flow: Standing waves

Kesennuma – oblique hydraulic jumps

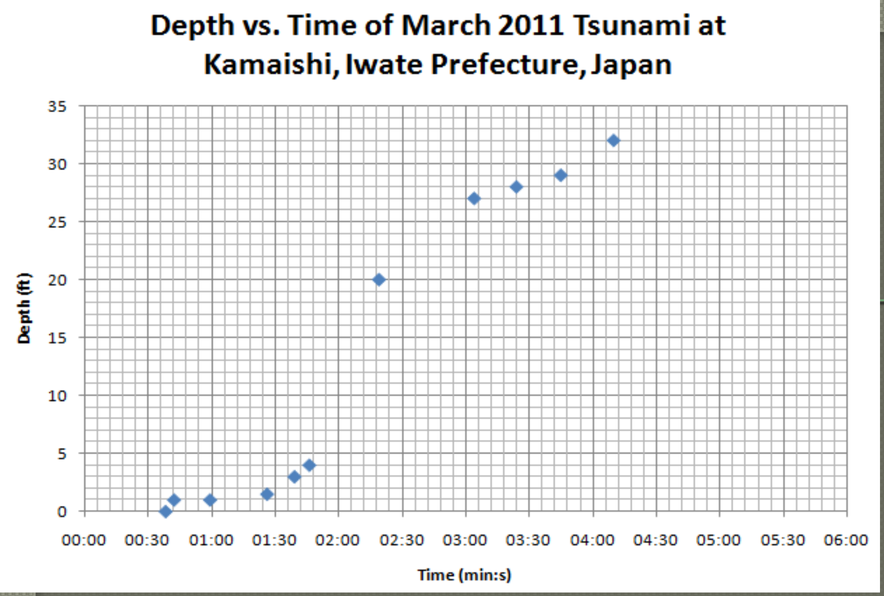
- Flow between buildings is analogous to flow in natural river channels
- Clips show undular waves and oblique hydraulic jumps

Hydrographs: Methods

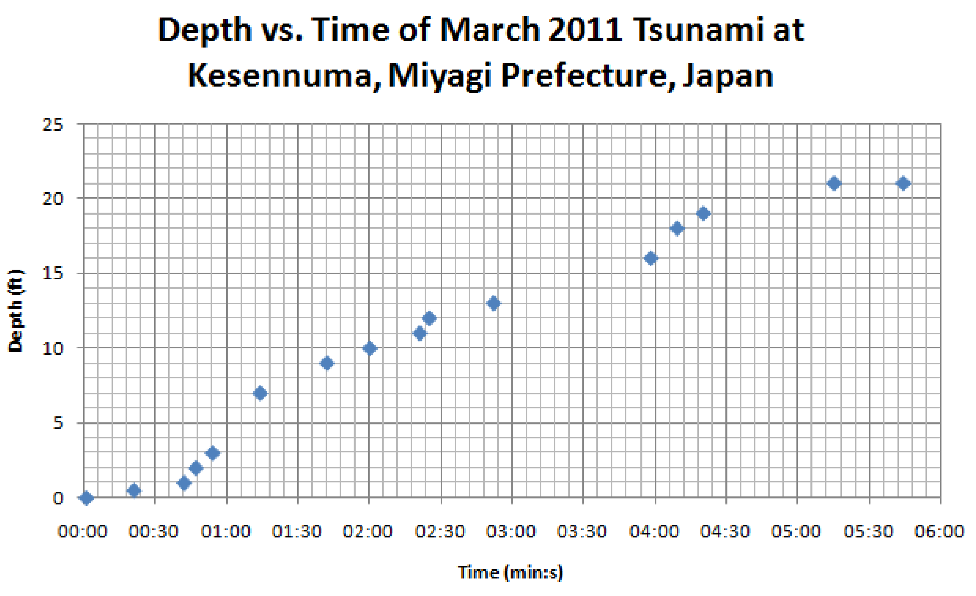
- Hydrographs were constructed from video footage of the incoming Tsunami available in multiple locations on the web.
- Continuous video allowed use of video timer as hydrograph time.
- An estimated reference scale was constructed for each video using common objects such as cars, building stories, or ladder rungs.



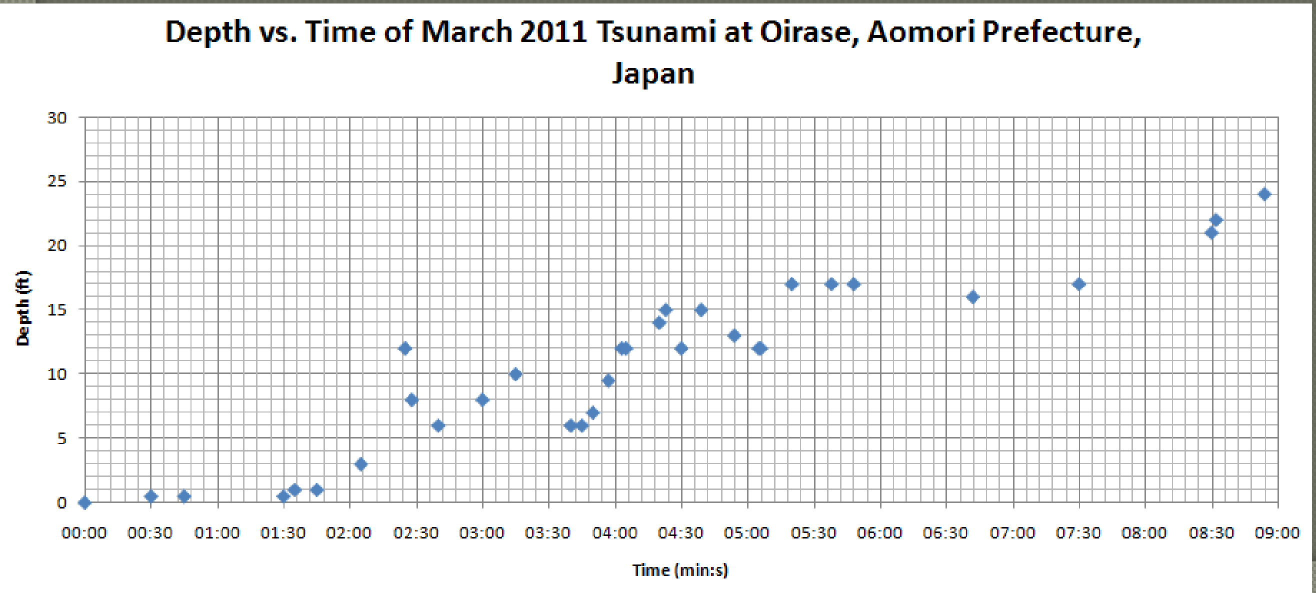
Hydrographs



▲ Kamaishi



▲ Kesennuma



◀ Oirase

Features of tsunami flow: Developing tsunami

Kesennuma – tsunami arrives

- Characteristics change rapidly as tsunami removes obstacles and entrains debris.

For more videos: www.GeologyInMotion.com

Features of tsunami flow: Developing tsunami

Kesennuma – tsunami removes building

- Characteristics change rapidly as tsunami removes obstacles and entrains debris.

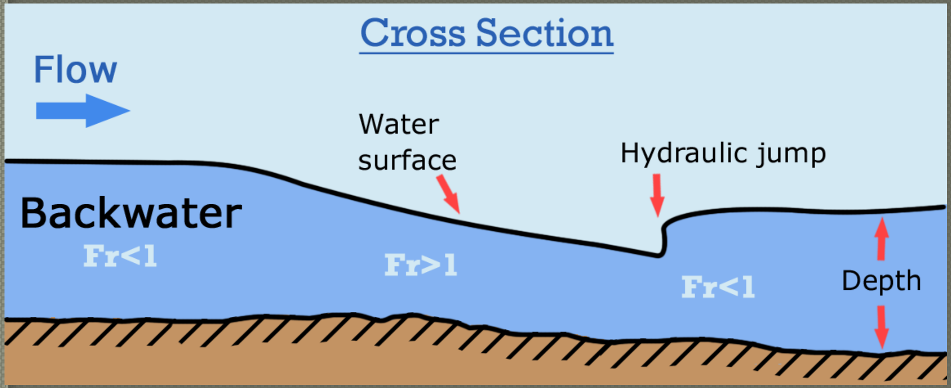
For more videos: www.GeologyInMotion.com

Features of tsunami flow: Developing tsunami

Kesennuma – tsunami at greatest depth

- Characteristics change rapidly as tsunami removes obstacles and entrains debris.

Onshore tsunami: Backwater effects?



- Water builds up behind the constriction because it can't fit through the narrower channel.
- Can backwater effects be distinguished from the developing tsunami?

Answers and conclusions

Dynamic analog for onshore tsunami?

- As tsunami propagates through urban corridors, flow displays hydraulic features typical of high-gradient rivers, such as the Colorado River in the USA.

Transformation from a clear water wave to debris-laden flow?

- Erosion and entrainment from adjacent infrastructure feeds debris into the water streams, bulking the flow, increasing its density, and thus, its erosive power.

Relevance to engineering:

- For engineering design purposes, flow of tsunamis through urban corridors could be modeled as water flowing in river channels with erodible boundaries.