Ocean waves and shock waves

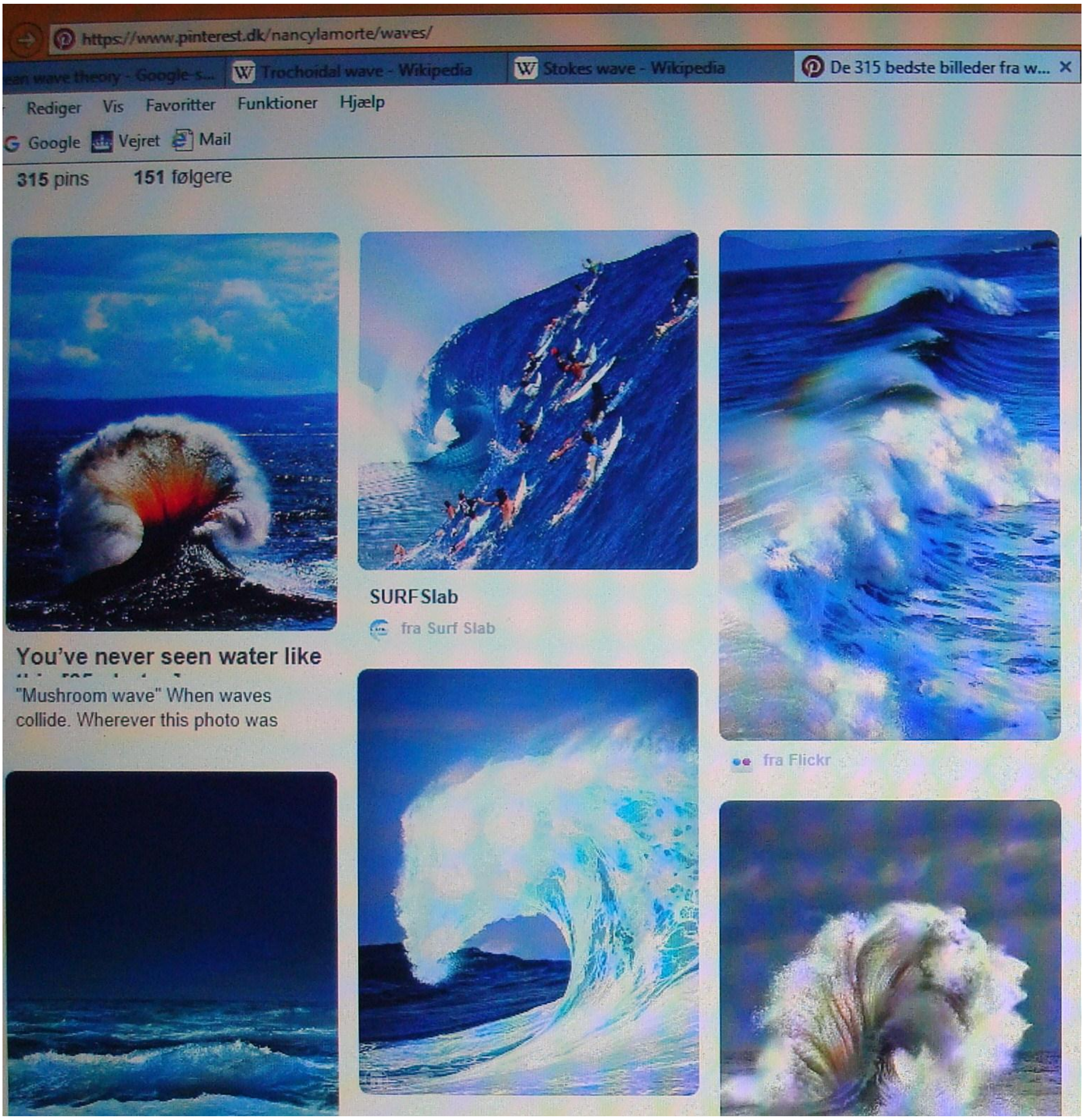
Photo1. 2009 June 6. Two persons are here enjoying the sun on a pier at the south coast of France when suddenly some special waves arrive, seemingly ordinary small waves, in between giving shock forces on the vertical wall with high water splashes. The two girls here did not want to pay to rent the chairs you see on the quay to the left, and with eventually about 20 high splashes coming, many chairs will soon be left wet, while the two girls out here did not get any water.

Ocean wave shock force on a vertical wall (quay or vertical wall breakwater) gives a big force to be considered when designing the construction. How big can a maximum force be when a vertical wave front hits a vertical wall? Will it, as was predicted, be a so called “hammer shock” determined by the elasticity of the water. No, such a big force could not be obtained in numerous experiments in USA, 1968. (Kamel, U.S. Army Engineer Waterways Experiment Station). The “water hammer” does not hit the wall in vacuum, and the water is not solid. The thin air slit in between the water front and the wall has to be squeezed out, giving a reactionary force that will slow down the water and start to move the fluid upwards a split second before the water hits the wall, and in this way avoid most of the big elasticity force. My theory of 1969 with very approximate calculations showed that the shock force could only be about 1/5 of the elasticity force, and this seemed also to be the result from the USA experiments.

8 photos and 2 graphs on 8 pages by Niels Mejlhede Jensen 2017

Photo2, 3. The quay wall is seen to be vertical. People are swimming by the calm beach here. There is seen a very little top spilling breaker here, maybe a standing breaker caused by a wave reflected from the wall. One of the small incoming waves here will turn over and result in a shock force and during 10 minutes about 20 of such small waves gave impressive shock splashes.

Photo4. There is no wind so the splash water sprays mainly vertical, and the man by the flag post is not washed away. The shock wave phenomena here can be caused far out in the ocean by a wind gust for some minutes, or caused by a ship passing by and creating waves.



You've never seen water like

"Mushroom wave" When waves collide. Wherever this photo was

Photo5. This is a photo of my computer screen (2017.10.08) of spectacular waves shown on the internet. The brave surfers will a moment later have the top of the wave breaking down. When such a curling wave hits a vertical wall then an air pocket can be enclosed to give an air cushion that will soften the shock force of the oncoming water. The compression of the air cushion gives the oncoming water time to pump a lot of energy into the air cushion. The air cushion then explodes upwards throwing the above water high up.

The vertical water front shock I considered in my theory, will give a bigger force of shorter duration, and without air pockets to collect energy it will not splash as high.

If the top of the breaking curling wave here is without softening air bubbles when it hits the wall then the water will locally give a moderate shock force according to my theory, (and not the much bigger elastic hammer shock, described by e.g. professor Lundgren 1969 DTU and others).

Wave bigger than the lighthouse it's hitting

Photo6.

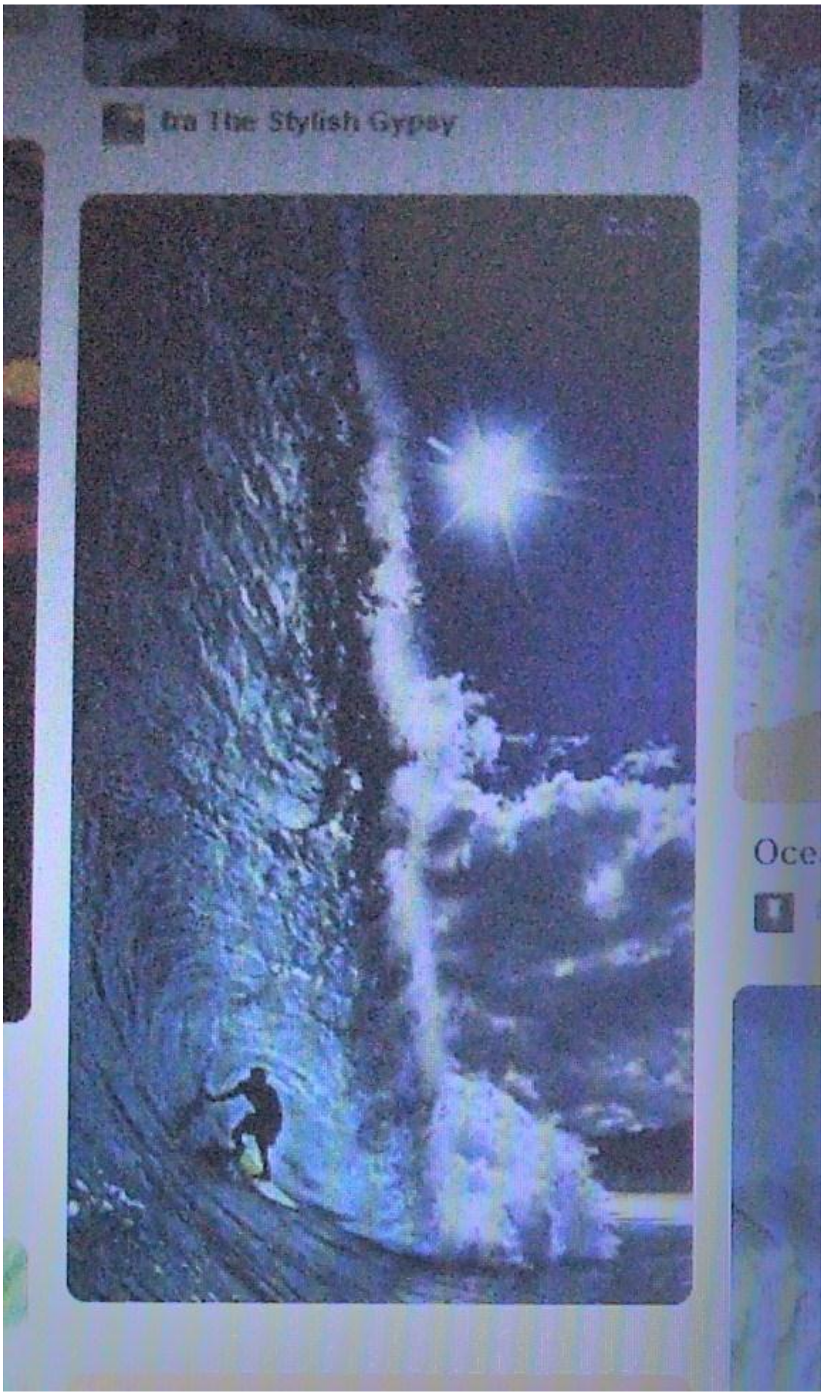
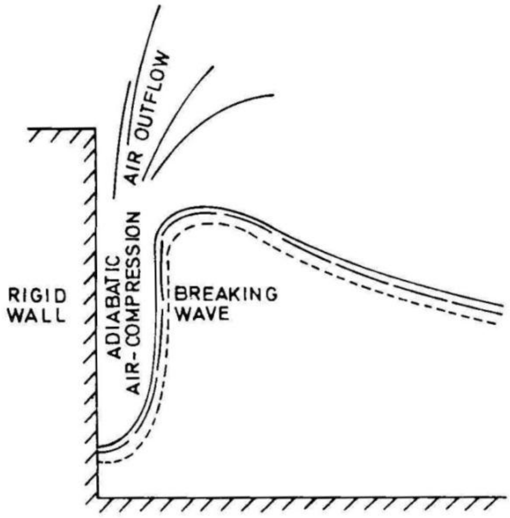


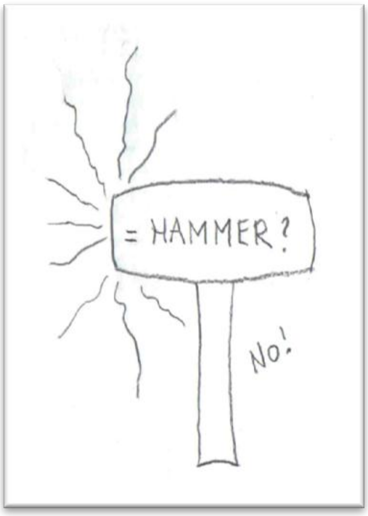
Photo7. How steep a wave is possible?
Can a vertical wall be hit by a vertical water front wave?

The surfer’s big steep wave here breaks near a beach.
If such a steep wave breaks near a vertical wall shortly after a preceding wave with its backwash has produced an outgoing current at the bottom, then it might be possible that a vertical waterfront can hit over an area, giving the biggest possible shock force.
How often can that happen in e.g. a 100 year period, and what serious damage will the very short lasting shock force then create locally or on the stability of a breakwater caisson?

For getting a better useful understanding of water waves and their interaction with structures scientists and engineers observe and measure in nature and in laboratory model tanks. For my master thesis I conducted model experiments with a vertical wall breakwater in a wave flume at the Danish Technical University (DTU in Copenhagen). This made me consider alterations to the traditional standing wave theory.
But how to create a vertical waterfront hitting a wall?

USA experiment, 1968:
To evaluate the formula for the elastic hammer shock from a vertical wave front hitting a vertical wall the model experiments in USA was “turned around” to: a horizontal wall hitting down on a calm horizontal water surface and measuring the pressure with small pressure cells. I do not know much about those tests. The maximum pressures measured were about 1/5 of the elastic hammer value. And the average value was much less. The water surface was described to get uneven and rough just before the horizontal “wall” hit it. This does not surprise me because the rapid out streaming air will start to create random small water waves (like when the wind blows over the ocean and creates waves). So a lot of softening small air cushions is created.
So the maximum shock force on a vertical wall is rather much less than the hammer shock value.





Graph1.

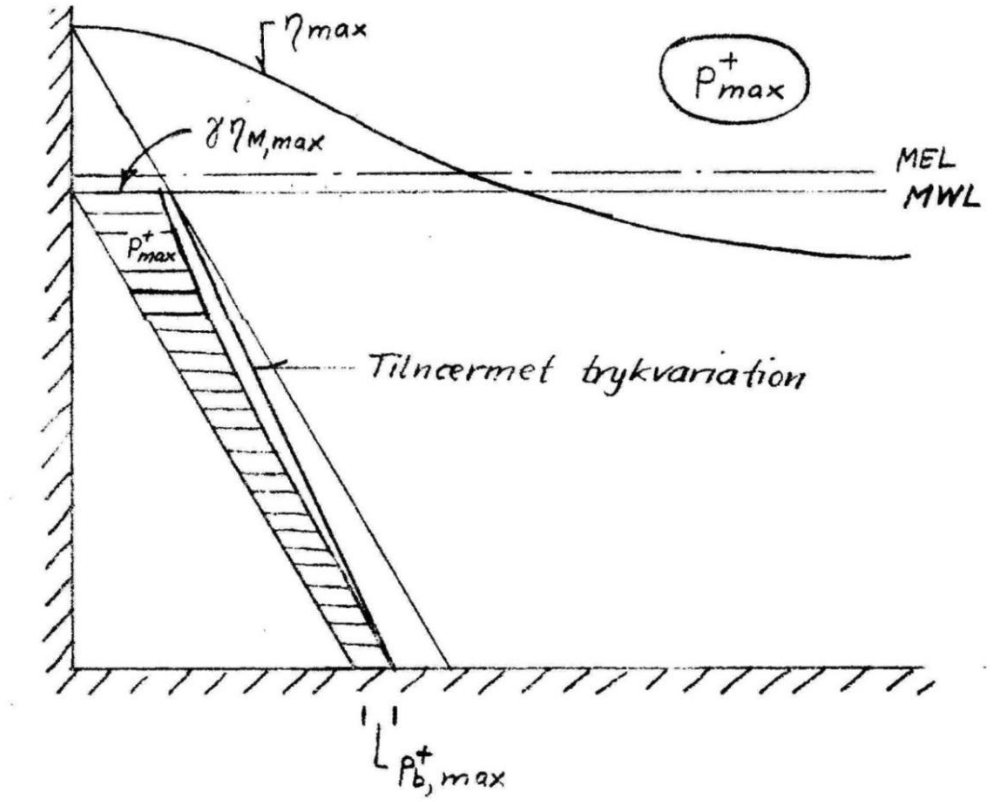
When a metal hammer hits a hard wall an elastic compression wave will travel with the sound velocity from the front to the back of the hammer, so the whole hammer participates in an elastic shock. Water is not in one piece but fluent, so only the front part gives the shock force, and the water behind will move upwards somewhat like in a standing wave. In practical calculations we say that it is only the so called hydrodynamic mass that gives the shock force.

Is the air slit of negligible influence?
No. The air will either form bubbles in the water, or form small pocket air cushions, or flow out leaving a reactionary force to slow down the water, slow down the water hydrodynamic mass which then will start to splash upwards a split second before the water hits the wall. The air slit reduces the elastic hammer compression in the water to almost nothing.
Even if it is only a narrow "tongue" of the wave or a small part of the water that hits the wall the escaping air will reduce the shock force. We do not get a hammer shock. Whether it is the whole wave or just a minor part of the wave like e.g. a "wave tongue" from the top of the wave that hits the wall, then it will not be an elastic hammer shock because the air in between the water and the wall has to escape.
(Wiegel USA 1964 shows a graph with measurements of a plunging breaker on a sloping bottom with a vertical wave front rather like the one shown in the graph1 above).

Harbor structures with a vertical wall facing the ocean waves must be designed to withstand the wave force. For a breakwater made of big concrete caissons the wall structures can locally get a very big pressure of very short duration relevant for the design of the concrete, a shock wave force. Or the whole caisson structure gets a wave pressure lasting up to 2 – 3 seconds, like from big standing waves, a force that maybe is relevant for the stability and foundation of the caisson.

Example: a big wave hits a wall on 10 m water depth with 3 m/sec water velocity. My approximate theory calculates the maximum shock force to 30 m water height pressure (300 kN/m^2). The elastic hammer shock theory gives up to10 times so big a pressure. So the vertical wall breakwater here should be designed to withstand a local pressure of 300 kN/m^2, a very local and very short pressure. But for the stability and foundation of the breakwater this very short local force may not be relevant, compared to the force on the whole breakwater of much longer duration from a more regular wave, like from the standing wave (next page:).

Overturning moment calculation … turned over?



Graph2.
This graph from the Technical University of Denmark in Copenhagen shows their formula for the wave pressure from a second order regular standing wave when the wave is topping with maximum height, based on the second order Stokes wave theory. So the crest is higher than the trough is deep. At maximum crest the downwards vertical acceleration is at its maximum, reducing the gravity force from the water. We see that the wave pressure above mean water level here is proposed equal to the hydrostatic pressure from the top and down, without considering the effect of the acceleration. For the big relevant design waves this gives a pressure here that is up to 100% too big. The wave pressure above mean water level is important for the overturning moment in calculating the stability and foundation of the breakwater, for which the standing wave pressure lasting 2 – 3 seconds may be more critical than a shock wave pressure lasting only a fraction of a second.

A so called first order wave theory (the famous Airy wave theory) is a mathematical calculation of waves where it is necessary to neglect terms that are “small of second and higher order regarding the wave height. So in the graph above the vertical acceleration of the wave top and Newton’s 2 law is neglected in a second order wave. By making a more appropriate neglecting of higher order terms a more relevant pressure distribution is obtained that fulfill Newton’s 2 law at the wave surface, as was shown in my theses. In e.g. a first order theory appropriate alterations of second and higher order can be made in any expression for pressure, velocity, acceleration, crest height, trough depth etc. without affecting the validity of the basic equations in the wave theory. Make a higher order alteration of e.g. the acceleration distribution to fit the surface, and see that it is OK by going through all equations in the wave theory, as written by me (can be seen on my internet web).
The splendid wave theories of Airy and Stokes do not need to be used in a dogmatic way.

(Experts: For my wave pressure and mathematical theories, see: WWW.Mejlhede.dk).

This is the last of this series of waves from the storm at Porthcawl

Photo8.. and the last of my pages.