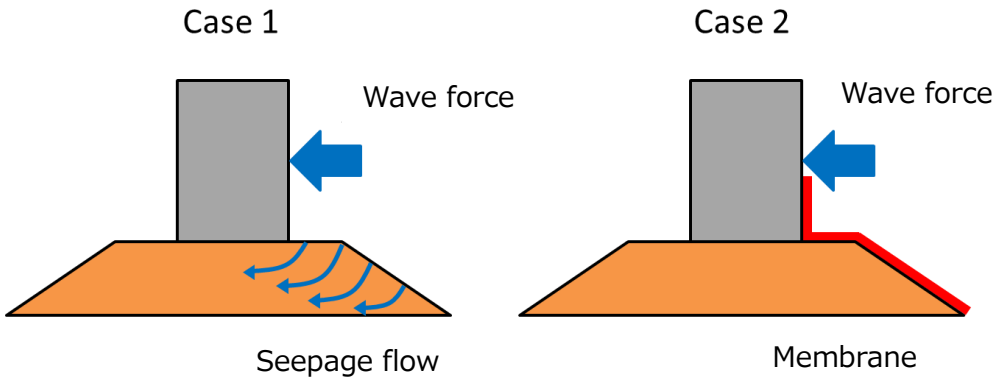
# Analysis of combined failure of breakwater due to tsunami

Tsunami at 2011 off Tohoku Pacific Ocean earthquake brought serious damage to breakwater at the by mouth of Kamaishi Harbor.

Investigation into the mechanism of failure lead to combined failure mechanism, which consists of difference in sea water levels in and out the harbor due to tsunami, seepage flow through rubble mound below the breakwater leading to decrease in effective stress and shear strength, combined with wave force due to tsunami.

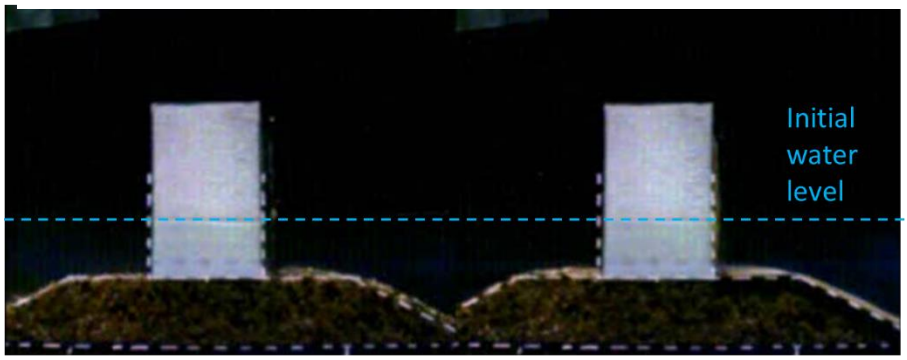
In order to study this mechanism, Disaster Prevention Research Institute, Kyoto University, performed centrifuge tests of breakwater with the same condition at the site allowing seepage flow through rubble mound (Case1) and artificially preventing seepage flow by setting up membrane (Case2).




Evaluate the effect of seepage flow by comparing Cases 1 and 2.

The following shows the centrifuge model test setup. No damage is recognized in Case 2 (see video).

**Case 1** (Wave force & seepage flow)　**Case 2** (Wave force only)




**Case 1** shows initially erosion at the front of rubble mound with sand uplifting at the back, then the rubble mound is sheared and caisson slides and overturns.

By large deformation (finite strain) analysis program FLIP TULIP, analysis is performed by applying wave force due to tsunami and, in Case 1, also by applying excess pore water pressure due to tsunami at the surface of rubble mound on the side of in-coming tsunami for simulating seepage flow in the rubble mound. As shown in motion picture (video) of computation results, excess pore water pressure in the rubble mound is increasing with the in-coming tsunami and when the effect of seepage flow reaches the limit of stability, the breakwater is overturned together with the failure of rubble mound.