Supplement of Earth Surf. Dynam., 13, 341–348, 2025
https://doi.org/10.5194/esurf-13-341-2025-supplement

Supplement of

Surficial sediment remobilization by shear between sediment and water above tsunamigenic megathrust ruptures: experimental study

Chloé Seibert et al.

Correspondence to: Chloé Seibert (cseibert@umn.edu)

Section 1: Calculation of long-period of horizontal oscillation's fundamental mode.

The horizontal oscillation's fundamental mode is modeled as a horizontally polarized ¼ wavelength S-wave with a node at the top of the subducting oceanic basement and a maximum amplitude at the top of the forearc wedge. The periods are calculated from the weighted average of S-wave velocities, Vs, obtained from the pre-stack depth migration interval P-wave velocities (Vp) in profile D11 (Kodaira et al., 2017) and the standard Vs=Vp/1.74. Given high fluid content and overpressure in the upper plate from the subducted sediment this value of Vs is likely an overestimate, leading to an underestimate of the periods.

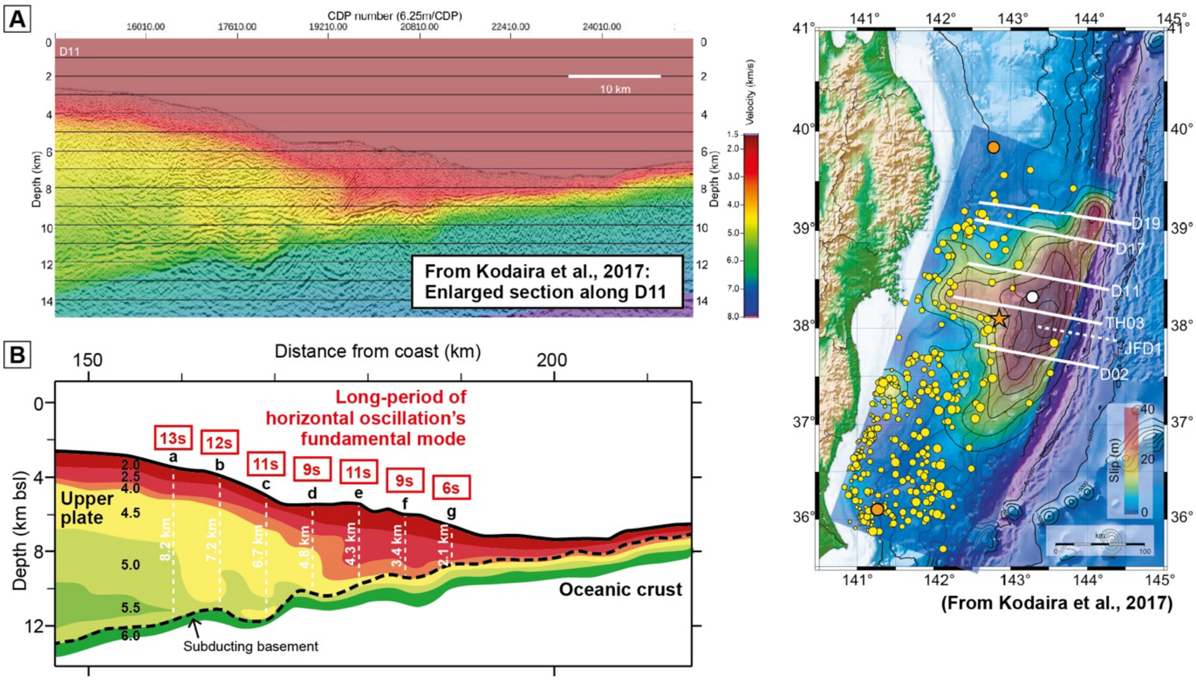

Figure S1: A: Profile D11, pre-stack depth migration interval P-wave velocities, and its location on the map highlighting the co-seismic slip distribution and the epicenters of the 2011 earthquake (star) and aftershocks (circles) from Kodaira et al. (2017). B: Simplification of the velocity model and location of the cross-sections (a to g) where we have calculated the long-period of horizontal oscillation's fundamental mode.

Table S1: Calculation of the period for horizontally polarized ¼ wavelength S-wave through seven cross-sections (a to g, located on Figure S2).

Section	Total thickness (km)	Thickness (km) for each interval of Vp (km/s)						Mean Vp (km/s)	Mean Vs (km/s)	Wavelenght (km)	Wave period (s)
		Vp=2	Vp=2,5	Vp=4	Vp=4,5	Vp=5	Vp=5,5				
a	8,2	0,7	0,7	0,3	2,7	3,8	0,0	4,3	2,5	32,7	13
b	7,2	0,6	0,7	0,4	4,9	0,5	0,0	4,1	2,3	28,7	12
c	6,7	0,5	0,5	0,7	4,1	0,8	0,0	4,1	2,4	26,6	11
d	4,8	0,9	0,7	0,8	2,4	0,0	0,0	3,7	2,1	19,0	9
e	4,3	1,3	2,0	0,7	0,4	0,0	0,0	2,8	1,6	17,2	11
f	3,4	1,0	1,6	0,7	0,0	0,0	0,0	2,7	1,5	13,5	9
g	2,1	0,9	0,9	0,2	0,0	0,0	0,0	2,5	1,4	8,3	6

Section 2: Physical experiments set up

The physical experiments were carried out at St Anthony Falls Laboratory (University of Minnesota, Minneapolis). These experiments are focused on earthquake-induced entrainment at the sediment water interface. They are simplified in some respects, but the key processes – boundary layer flow, sediment entrainment, and vertical shaking – are present at their natural scale in the experiments, so they are not in any sense 'scale models' of the natural case. Rather, the experiments are intended to help us understand which parameters influence the sediment entrainment. The element that mimics the seafloor subjected to earthquake motions consists of a rigid transparent rectangular duct (1 m-long, 0.2 m-high and 0.1 m-wide) closed at the top (Fig. 2a). This duct is mounted on a rigid frame connected to an offset shaft and motor that can shake it with periodic vertical motion at frequencies of 1-10 Hz and peak accelerations up to 1.5 g. The amplitude (d) of the shaking can be set to 20.65 or 31.75 mm and is fixed in each run. Thus, the acceleration (a) is set by adjusting the shaking frequency (f), calculated from: $a = d * (2\pi f)^2$

The duct is filled with water above a 0.07 m-thick sediment layer at the bottom. Above the top of the sediment, the ends of the duct are open and connected by flexible pipes to a water reservoir (Fig. 2b) that delivers a flow above the sediment while both sediment and water in the duct are subjected to vertical shaking. This flow of water above the sediment produces a shear at the sediment-water interface which represents that produced by the coseismic displacement and subsequent long-period motion of the outer upper plate. The induced shear stress is the same whether the ground is moving, and the water stays still, or the more usual case of a stationary bed and moving water. We have also simplified the quasi-steady oscillatory behavior of the motion to a steady unidirectional flow. In the section 2, Conceptual model, we have estimated a shear velocity of about 1m/s from publish results about the 2011 M9.0 rupture. In our experiment, we used this value as an upper limit for the flow velocity. The flow is set electronically and measured by a flowmeter sensor. Based on more than fifty calibration tests the flow error is typically < 5 %. The main observational data are high-resolution video images obtained from two cameras fixed on the side and top of the shaking frame downstream from inlet distortions of the flow (Fig. 2c). Bed topography is scanned with a laser tool before and after each run.

We started with well-sorted sands, to study the impact of vertical shaking on sediment whose entrainment is well understood. Then, we used more complex mixtures of sand, silt and clay-size bentonite sediment (Table S1). We used: 1) sand with the following distribution, 13% >250μm - 250> 77% >125μm - 125μm> 10%; 2) industrial silt from Zeeospheres LLC (called Grey Silt N800), which mainly consists of 90% coarse/medium silt and 10%> 63 μm; and 3) clay-size commercial bentonite. The bentonite belongs to the smectite clay group and is characterized by high water absorption. The sediment was placed in the duct where it was flattened but not compacted with the flat surface reaching up to the lower level of the pipes delivering the water. These mixtures, that are representative of marine muds, are a first step in exploring the results of the physical experiments. We intend to work with more complex and variable sedimentary mixtures in future experiments.

Table S2: Composition of the dry sediment fraction for the sand_poor and sand_rich mixtures.

	Fine Sand (%)	Silt (%)	Clay (%)
Sand_poor mix	10	40	40
Sand_rich mix	40	35	35

Section 3:

Table S3: Information for the Figure 3.

Mixture	Run #	Water content (%)	Flow velocity (m/s)	Shaking acceleration (g)	Run timing (min)	Erosion rate (cm/min)			Entrainement
						Topography profiles	From video records		
							Grain-by-grain	Stripping	
Sand_poor, freshwater mixture	2	50	1	0	10	-	0.036		Suspension, Bedload
	5	50	1	1	10	0.02	0.045		Suspension, Bedload, clumps' entrainments
	10	60	1	0	10	0.01	0.036		Suspension, Bedload
	24	70	1	1	10	0.02	0.03		Suspension, Bedload
Sand_rich, freshwater mixture	46	50	1	0	10	0.01	0.008		Suspension, Bedload
	50	50	1	1	10	0.015	0.029		Suspension, Bedload
	52	60	1	0	10	0.02	0.023		Suspension, Bedload, clumps' entrainments
	54	60	1	1	10	0.015	0.013		Suspension, Bedload, clumps' entrainments
	59	70	0.8	0	3.12	0.66	0.08	0.54	Suspension, Bedload, clumps' entrainments
	58	70	0.8	1	1.4	1.34	0.18	1.30	Suspension, Bedload, clumps' entrainments
	60	70	1	1	1.5	-		4.60	Suspension, Bedload, clumps' entrainments
	64	80	0.5	0	2	0.95	0.84		Suspension, Bedload, clumps' entrainments, sediment waves (?)
	65	80	0.5	1	2	1.15	0.95		Suspension, Bedload, clumps' entrainments, waves (?)
Sand_rich, sea-water mixture	67	70	0.5	0	3	0.88		0.77	Suspension, Bedload, clumps' entrainments
	69	70	0.5	1	1.5	-		3	Suspension, Bedload, clumps' entrainments

Section 4:

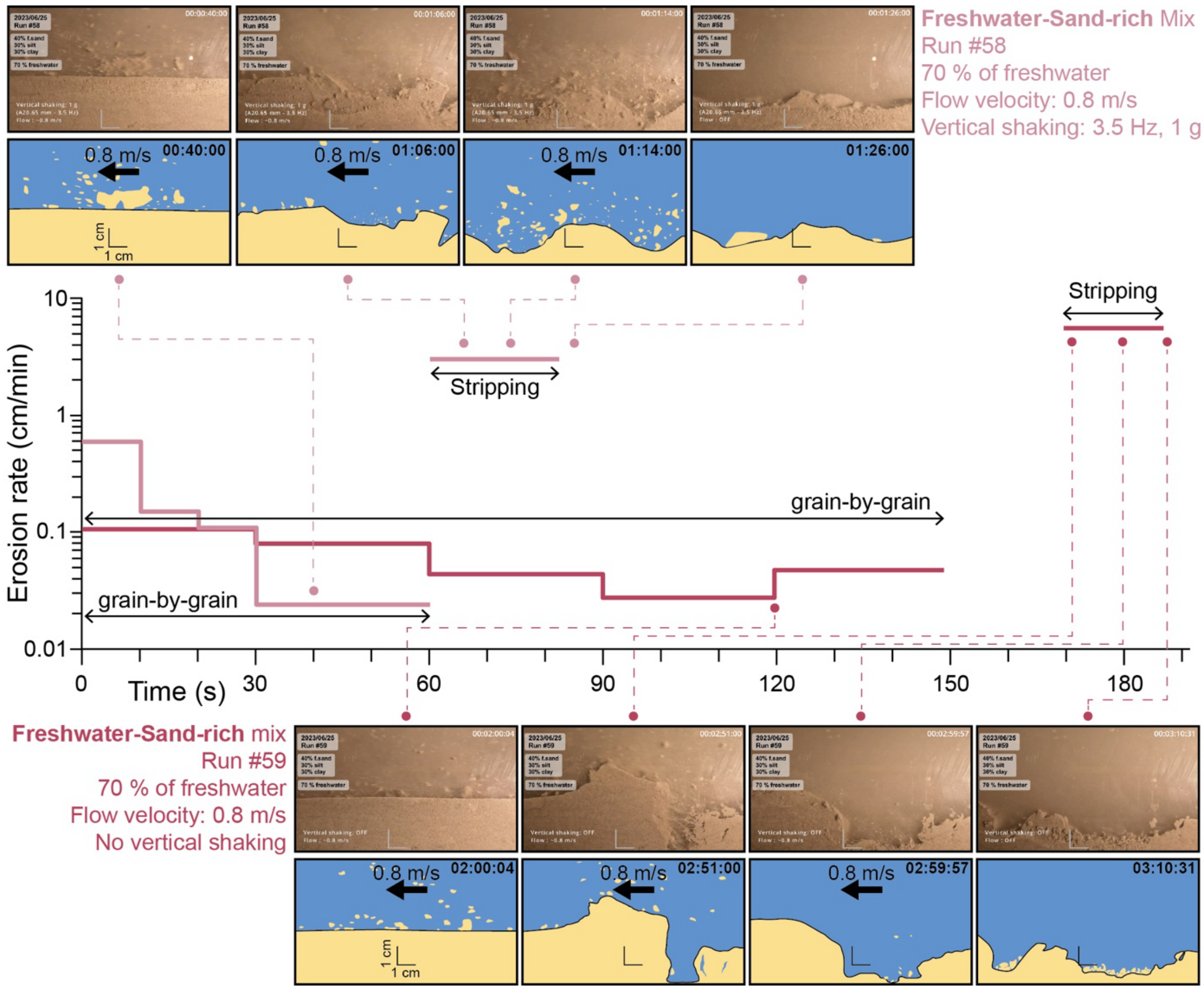

Figure S4: Evolution of the erosion rate of sand-rich mix sediment with 70 % of freshwater under a flow velocity of 0.8 m/s without vertical shaking (Run #59, dark pink) and with a vertical shaking at 1 g (Run #58, light pink). The photos and their interpretative cartoons highlight different steps of runs; the black arrow gives flow direction.

Kodaira, S., Nakamura, Y., Yamamoto, Y., Obana, K., Fujie, G., No, T., ... & Miura, S. (2017). Depth-varying structural characters in the rupture zone of the 2011 Tohoku-oki earthquake. *Geosphere*, *13*(5), 1408-1424.