Revealing transport mechanism of coastal boulders onto the cliff based on field survey, laboratory experiment, and numerical simulation

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Coastal boulders transported onto the cliff (elevation is ranging from several meters to several ten meters) by storm waves or tsunamis have been reported around the world (e.g. Hall et al., 2006). In Pacific Northwest, there is the 2.9 t boulder deposited on the 50 m high cliff (Williams et al., 2004). In Shimoji Island, Japan, approx. 5000 t boulder is deposited on the 12.5 m high cliff (Kato et al., 1989). However, a transport mechanism of boulders onto a cliff by extreme waves has been unclear. In this study, we examined the transport process of coastal boulders onto a cliff based on field survey, laboratory test, and numerical simulation.
We firstly conducted the field survey at the northwest coast of Hachijo Island, Japan. In this site, up to 58 t boulders is has been distributed on the 5 m high cliff. The boulders are distributed up to 90 m inland from the cliff-edge. There is two type of boulders; its shape is rectangular and rounded. From the field evidences, rectangular shape boulders and rounded boulders might have been originated from the cliff edge and bottom of the cliff (i.e., from the sea floor), respectively.
In order to reveal the mechanism of boulder transport onto the cliff, we conducted the laboratory experiment. Based on Fluid similarity law, we introduced the 1:25 scaled topography in wave tank. From the left side of wave tank, the dam break flow was input. Before the experiment, the block was set at the bottom and cliff edge. When dam break flow was input, the bore hit the cliff, then the bore moved toward vertical direction in front of the cliff. Then, the blocks were transported toward vertical direction from the bottom or edge of the cliff because vertical hydraulic force acted on the block.
We also conducted the cross sectional two-dimensional simulation of boulder transport by tsunami and storm waves in real scale at this site. We conducted calculation of the following three types of boulder transport: (1) from the bottom onto the cliff using the revised model of Imamura et al. (2008), (2) from the cliff edge onto the cliff using the revised model of Weiss et al. (2015), and (3) boulder transport on the cliff toward inland using the model of Imamura et al. (2008).
As the result of the boulder transport from the bottom onto the cliff top, the transport can be induced by storm waves if water level rise (=storm surge) was not generated. The tsunami with extremely shorter period can also induce that transport. However, tsunami with normal period such as several ten minutes can’t induce that transport, because water level is slowly increased in front of the cliff. Thus, vertical velocity become small in that condition, so that boulders were not transported onto the cliff.
As the result of boulder transport from the cliff edge onto the cliff top, the transport can be induced by storm waves that water level rise was 0 m~ +2 m. The tsunami with extremely short period can also induce that transport. However, if tsunami wave period is normal (several ten minutes), the boulders were not transported onto the cliff.

As the result of boulder transport on the cliff toward inland, storm waves that water level rise was +2˜+4 m can explain the actual distribution of boulders. In case of tsunami, the calculated distribution of boulders was up to several hundred meters inland, so that the distribution induced by tsunami greatly exceeded the actual distribution. Therefore, it is likely that the distribution of coastal boulders at this site has been formed by storm waves instead of tsunami.
The boulders can be transported from bottom onto the cliff in the condition that water level rise was not generated, therefore it is likely that swell or waves due to seasonal winds in winter might have launched those boulders. In contrast, the boulder transport from cliff edge onto the cliff and distribution of boulders on the cliff can be explained by storm waves during typhoon in the condition that water level rise was occurred. The distribution of boulders at this site has been complexly constituted by waves under the setting both water level rise was or was not generated.

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