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Driftwood trapping function of a driftwood trap installed upstream of concrete closed dam

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[Abstract]

Two methods were proposed for adding a driftwood trapping function to a concrete closed dam, one is to install a driftwood trap directly on the upstream face of the concrete closed dam installed in the bedload section (linear layout), and the other is to install a driftwood trap on the sedimentation face of the concrete closed dam installed in the bedload section (convex layout). In order to understand the effectiveness of the two types of facilities installed upstream of the concrete closed dam, we investigated the status of the driftwood trap in the upstream area of the weir and changes in the water depth upstream of the weir through hydraulic model experiments. As a result, it was confirmed that when driftwood was trapped, the amount of driftwood flowing out of the trap surface decreased at once due to the narrower spacing between the components. To ensure the driftwood trapping function, “the length of the facility > the width of the channel” is required, regardless of the ponding or bedload conditions. If the length of the facility (width of the capture surface) exceeds the width of the channel, the progress of the weir’s depth rise is inhibited. In order to control the progression of weir raising depth, “apparent channel width > 3 times the channel width” should be adopted, regardless of ponding or bedload conditions.

Key words：concrete closed dam, woody debris, driftwood trap, bedload section

1 Introduction

About half of driftwood in flood reaching sabo weir/dam flows through and passes hydraulically non-consecutive "impermeable" facilities even if the amount is not excessive [1]. Therefore, an augmentation of driftwood entrapment (reaping) function has been proposed by our Center as two types of driftwood trapping/reaping works joined to upper parts of dam spillway. One is to join rigidly and directly onto the upper face of facilities (hereafter "straight layout") while the other is to put the trapping structure on

Straight layout　　Convex layout

Fig. 1 Driftwood trap installed on the upper streamside of a Hydraulically Non-Consecutrive Sabo Dam (concrete closed)

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stabilized footing embedded excavating sedimentation surface (hereafter "convex layout") (See Figure-1).

Many studies have been carried out on the dynamics of driftwood and on the function of driftwood entrapment (reaping) works in research, experiment, and analysis. Field surveys by Ishikawa et al [2] showed an estimation method of driftwood production in basins and of their mean length. Ozaki et al [3] showed that driftwood has a strong influence on how debris flows are blocked and deposit through field surveys of entrapment forms at steel-framed hydraulically consecutive sabo dams. Yamada et al [4] derived volumetric rate of driftwood for hydraulically non-consecutive dams in their field surveys. Mizuhara [5), 6] deepened understanding of one-log motion to conclude that the ultimate relative velocity of a log is proportional to its weight and channel gradient in concern through their channel experiments. Mizuhara [7), 8] conducted another set of hydraulic experiments to indicate that backwater impoundment caused by driftwood depends upon their velocity, specific weight, and their forms modeled after hydraulically non-consecutive da reservoirs. In addition, Mizuhara [9)-11] carried out basic experiments on how driftwood can be blocked in their channel experiments in view of the relationship between mechanics of entrapment and entrapment rates. The driftwood entrapment rates increase with driftwood densities, with a threshold density over which the rates get to a plateau. The driftwood entrapment rates are large when surface flood velocity and its depth are reduced. Shibuya et al [12] conducted a set of experiments with different driftwood lengths for quantifying entrapment mechanisms. Their results show that entrapment rates are subject to maximum lengths of driftwood, their diameters, interval spacing of entrapment/reaping works, height of entrapment works, among which means driftwood length is also numbered. As for analytical study, Shibuya et al [13), 14] made numerical simulation to reproduce their channel experiments of driftwood entrapment and deposition. Therefore, there are already many studies on dynamism and mechanism how entrapment per se acts on driftwood flowing down. Effective structural improvement of driftwood entrapment function in regard to existing sabo facilities, largely with hydraulic drop, is unattainable without attaching and rigidly joining structural installation on upper parts of the facilities. There is no noticeable study on this type of functional augmentation.

This study examines driftwood entrapment and water depth changes upstream of a modeled sabo facility in order to grasp entrapment effects of two types of structural augmentation, which leads to our goal - shedding light on their effective layout and drawing a proposed entrapment volumetric estimation method. Here, layout is seen as effective and appropriate to the degree it can stand without water impoundment even if reaping much driftwood, also to the degree the size and numbers of driftwood reapers required to achieve specified function.

2. Driftwood Reaper directly joined to the upper part of hydraulically non-consecutive sabo weir/dam

2.1 Characteristics of straight layout

When the spillway of sabo facilities is cut out to install driftwood reapers in a bedload-dominant stream section, sediment and driftwood are separated ending up with only driftwood trapped. In case spillway gets clogged by driftwood, upstream impoundment leads to sedimentation (Figure-2). Planned estimation of driftwood entrapment for hydraulically non-consecutive sabo check dam is widely set with 2% as its maximum, a due engineering judgement based on experience. When more driftwood needs to be reaped, driftwood reapers become disproportionately large in comparison to existing facilities as a whole. In that case, major structural modification to transform them into completely hydraulically-consecutive facilities is the way-out. As such, structural augmentation to be considered for joining structural frame to existing non-consecutive sabo facilities has the maximum reduction target of driftwood entrapment as 2% of planned sedimentation volume of facilities under study [15].

Figure-3 shows cross-section and planner view of straight layout of driftwood reapers. They are attached to upper parts of hydraulically non-consecutive sabo facilities. This straight layout assumes impoundment of upstream sediment reservoir, presumably caused by weir wings, for the purpose of engineering safety judgment [16]. Driftwood is entrapped chiefly on upper front face (#1) of reaping components (hydraulically permeable). The reapers have


Fig.2 Sediment and driftwood capture at partially hydraulically consecutive sabo dam

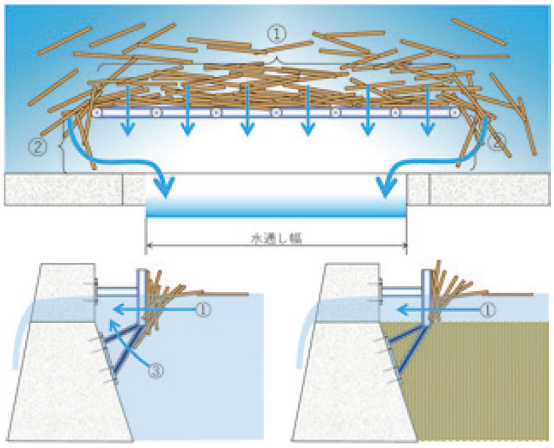


Fig.3 Straight layout spillway (water way)

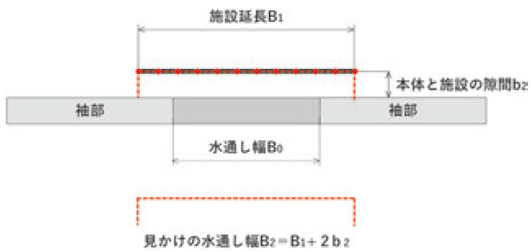


Fig.4 Effective/Apparent channel width in a straight layout

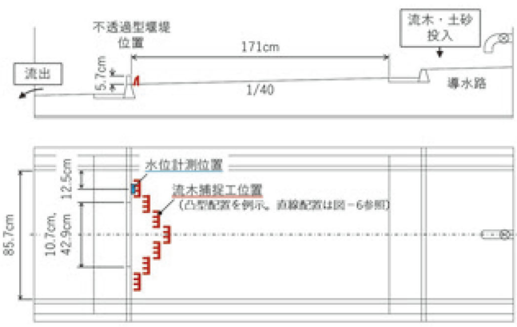


Fig.5 Waterway hydraulic model

such room between main weir, which effectively widens apparent spillway circumference (See Figure-4) for promotion of water spill down, resulting in less risk of impoundment. On the other hand, in a straight layout with a margin to full sedimentation level, spill-out channels are found through the lower parts (#3). In other words, their is an open channel with identical width of entrapment upstream face, which is expected to act until it is clogged. This channel from below is blocked when sedimentation reaches its full level. In case entrapment upper front (#1) is completely clogged by driftwood, the only remaining way-out is the room of #2, which poses significant impounding risk. Experience taught us that entrapment upper front in many cases leaves some conduit, but with clogging advances the risk of backwater looms large.

2.2 Experiment 1 (Straight layout)

2.2.1 Methodology of experiment

Figure-5 shows the form and dimension of model channel for experiment. The channel is straight in shape with its geometric scale equal to 1/70. The gradient supposes bedload transportation mode with 1/40. Bed roughness is provided with sand glued to the bed. For the case of spillway width 1/8th (10.7 cm for the experiment) of 60-m stream width (85.7 cm for the experiment), the bed is fixed due to impoundment by weir wings, supplying only flood water. For the case of spillway width 1/2nd (42.9 cm) of stream width, movable bed is prepared to reproduce impacts of running flood through spillway, with sand supplied in concomitance with water discharges. Water discharges are set to be 3.0 m (4.3cm for scaled experiment) in a steady state for the spillway cross-section for each case.

The water discharge for spillway/stream = 1/8 case is 1.5 m^3/sec, while for 1/2 case it is 3.5 m^3/sec. The length of driftwood is uniformly set to 5.0m (7cm, with its diameter 0.2cm in the scaled apparatus). The driftwood is put into from upstream of the channel with a constant interval (100 logs per min). The aggregated total of the logs is 500 for cases from #1 through #3, and 1000 for cases #4. The components have a modeled interval of 1/2nd of driftwood length. The space (room) between main weir and augmented structures is set to be equal to the length of the log. Driftwood flowing through the entrapment apparatus per unit time are numbered with backwatering water stage elevation measured. Driftwood entrapment is observed by way of recorded video.

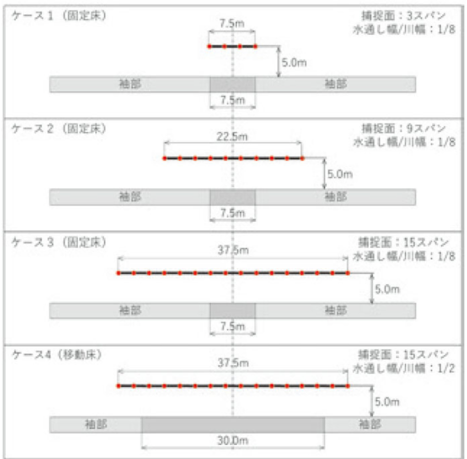


Fig.6 Outline of the case（experiment 1）

Figure-6 is an overview of driftwood reapers installed in parallel to spillway, which shows their relative positions. Upstream of the weir apparatus experienced impoundment due to stage elevation caused by weir wings in cases #1 through #3 (fixed bed). Total stretch of facility (width of driftwood reaper) varies to equal, 3 times, and 5 times of spillway width. For case #4 (movable bed), upstream flow regime is that of bedload mode (subcritical) flow in the face of the reaper while in the face of wings, water velocity is nearly zero due to backwatering. The total stretch of facility remains the same for that of case #3 for ease of comparison.

2.2.2 Results and analysis of experiments

(1) Uncaptured driftwood flowing-down rate (number of incoming logs - entrapped logs)

Figure-7 shows uncaptured driftwood flowing-down rates for case #1 through #4 (straight layout) with input logs per unit time as a denominator and those flowing-down through driftwood reapers as a numerator (Hereafter "Uncaptured Driftwood" and "Flowing-down" are used interchangeably.). For cases #1 to #3, the stream bed fixed, flowing-down through the reapers came to near zero as the input amount reaches 200. Non-entrapped driftwood is those which floated through intervals between weir wings and reapers. None penetrated through driftwood reapers' entrapment face. No statistical correlation was found between numbers of flowing-down through the reapers and stretch of facilities up until input amount of driftwood equal to 100. This is likely because orientation of floating logs, rather than the expanse, strongly impacted entrapment. Therefore, numbers of flowing-down were fluctuating until input amount reached 100, beyond which self-inducing entrapment of driftwood blocked the fleeing logs, with sharp precipitation of flowing-down through the reapers.

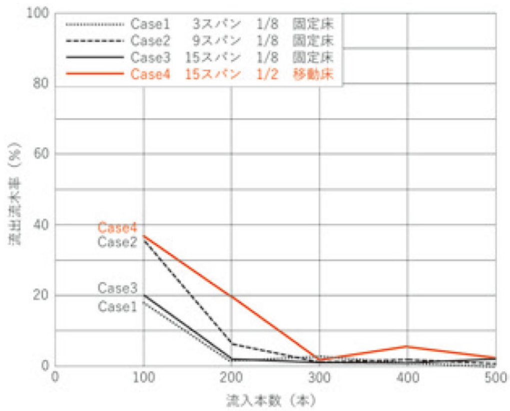


Fig.7 Uncaptured driftwood floating logs rate − amount of input/inflowed driftwood

Case #4, a movable bed, had some discrepancy with other cases, where more driftwood flowed down through reapers below input level of 200. Beyond 200, driftwood themselves interacted mutually, reducing numbers of fleeing floating logs. Notwithstanding, since residual water velocity acted on trapped logs to destabilize and release out, the uncaptured driftwood flowing down rate did not calm down. This may explain an increment of flowing-down logs in comparison to impounded conditions, supposedly.

(2) Elevated water depth due to driftwood entrapment

Figure-8 shows elevated water depth at weir wing in relation to input floating logs per unit time. For all cases, water depth at spillway after entrapment remained as at the beginning. In each case, water depth at weir wing rose as time elapsed, indicating entrapping faces being blocked by driftwood.

Case #1 to #3 were with impoundment, where entrapment faces remained some marginal channel for water. Elevated water depth in case #1 to #3 suggests that the longer the stretch of facility (width of driftwood reaper) to the width of the spillway, the less likely backwatering impoundment occurred. Since the spacing room between the entrapment structure and the main weir is identical for all cases, circumferences of entrapment faces impacted on the degree of water depth elevation. The incompleteness of blockage at entrapment faces meant more water channel as the total circumference became larger.

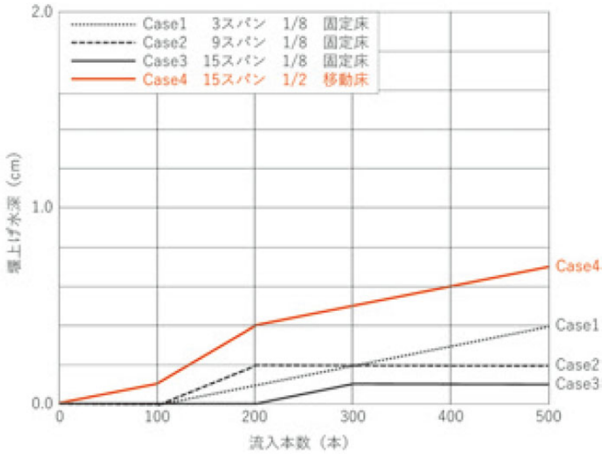


Fig.8 Dammed up depth − amount of inflowed driftwood

In case #1, water depth became elevated with the increasing input of floating logs, where impoundment was caused by weir wings from the beginning. As entrapment face was narrowly set equal to that of spillway, with floating logs penetrated into entrapment faces causing blockage, backwatering increased water depth.

For case #2 and #3, to the contrary, backwatering impoundment level reached a plateau as input level of floating logs became more than 200 through 300, where stretches of entrapment faces were wide enough in relation to that of spillway. Since upstream of weir wings is sufficiently impounded, entrapment faces of structures reaped floating logs only near the water surface. Those floating logs came after blocking became unstably astray on water surface, which did not contribute to driftwood blocking. The water depth of impoundment became stable thereafter. Case #3 shows a larger water depth than Case #2 due to the impact of entrapment faces stretched up to the upstream of weir wings. Namly, as the length of facilities covers broader expanse than spillway, driftwood-inducing backwatering stops progressing further. Moreover, the longer the expanses of facilities, the less likely water depth becomes larger.

In Case #4, sediment was transported by flowing water. Once driftwood entrapment occurred on trapping faces, with blocking backwatering, upstream sediment reached less to facilities. Namely, even with sediment supply, with the progress of driftwood entrapment and blocking of entrapment faces, upstream water level was raised to an impounding state. When blocking reached to some extent, with impoundment, further backwatering seemed suppressed, with the rising rate close to that of case #1. As the water velocity was decelerated, sediment reached less up to driftwood entrapment structures, ending up with less blockage. In other words, for movable bed experiments, transported sediment clogged trapping faces, resulting in backwatering which led to an impounding state. In turn, this suppressed further blockage by sediment, which led to less sediment transportation, resulting in a state close to that of fixed bed.

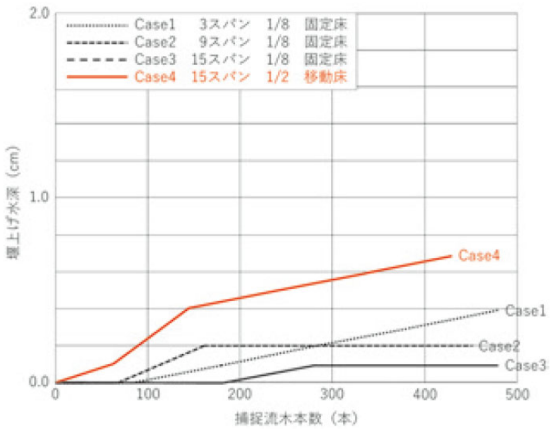
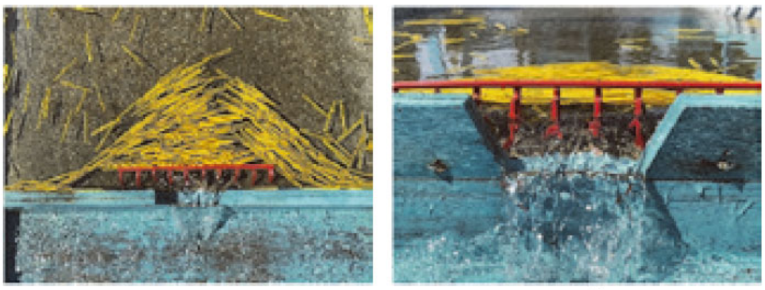


Fig.9 Dammed up depth − amount of captured driftwood

Figure-9 is a plot derived from Figure 7 and Figure-8, where the horizontal axis is numbers of entrapped floating logs and the vertical axis is backwatering water depth. Water discharge through entrapment faces is regulated by residual area of entrapment faces after driftwood blocking and water velocity at and through the faces. However, residual areas cannot easily be specified as formation of blocking floating logs varied case-by-case. The same is true for water velocity at the faces, which allows us to compare only with backwatering water depth. Case #1 and case #2 has a crossing point where increment rate of backwatering depth is 0.2 cm, with the aggregated total number of logs about 280. On the other hand, the corresponding increment of backwatering depth in case #3 was 0.1 cm at the same entrapped floating logs.

For case #1, backwatering water depth saw gradual increase until 500 floating logs were put to finish, which suggested that blockage by floating logs at entrapment faces induced additional impounding rise. Contrary, for case #2 and case #3, backwatering water depth remains stably still even with the increase of input floating logs. Figure-10 shows driftwood entrapment in experiment for case #2. Floating logs were captured near the surface of water at the facility, while others were drifting on the impounding surface upstream of the facility. Namely, as the water depth came to a standstill, floating logs were not trapped by entrapment faces but were stored floating on impounding surface. For this storing effect fully in play, the facility expanse needs to be broadened over that of spillway. This effect observed herein is regulated by water fleeing space between main weir and driftwood entrapment structures.



From above　　From front

Fig. 10 Driftwood capturing condition of case 2

3. Driftwood reaper set on the surface of sedimented reservoir upstream of hydraulically non-consecutive sabo facilities

3.1 Characteristics of convex layout

Entrapment by driftwood reapers in a stream section predominantly of bedload mode is described. Non-consecutive sabo facilities in bedload stream section are without margin to full sedimentation, as they are not excavated in sediment management. Water surface is on the sedimentation of the reservoir, on which driftwood float down. Driftwood reapers need to be such entrapment structures as to capture floating logs. As such, it is imperative for the reapers to protrude their components over the water surface. On the other hand, the bedload section has broader basin area than debris flow dominant section in general, which in turn means larger amount of driftwood production. Entrapment volume of driftwood, according to current technical code, is estimated by multiplying impounding area by the log diameter, assuming that floating logs distribute uniformly on the water surface. Assumption of impoundment implies level water surface, which reduces the impounding area and entrapment volume of floating logs in comparison to incoming driftwood, for planners.

Sediment reservoir is not accompanied by impoundment (i.e., standing water) where spillway is wide enough or weir wigs are short, leading to non-negligible water velocity. When driftwood entrapment is planned on this state of sediment reservoir, it is in a condition of standing independently in an open channel

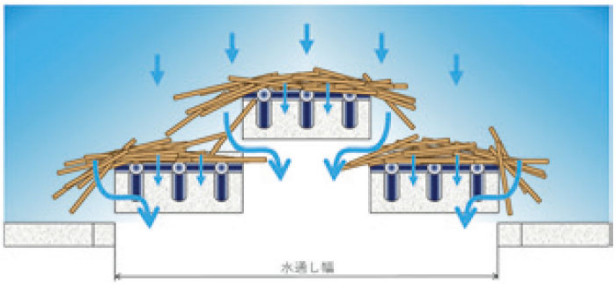


Fig. 11 Convex layout waterway

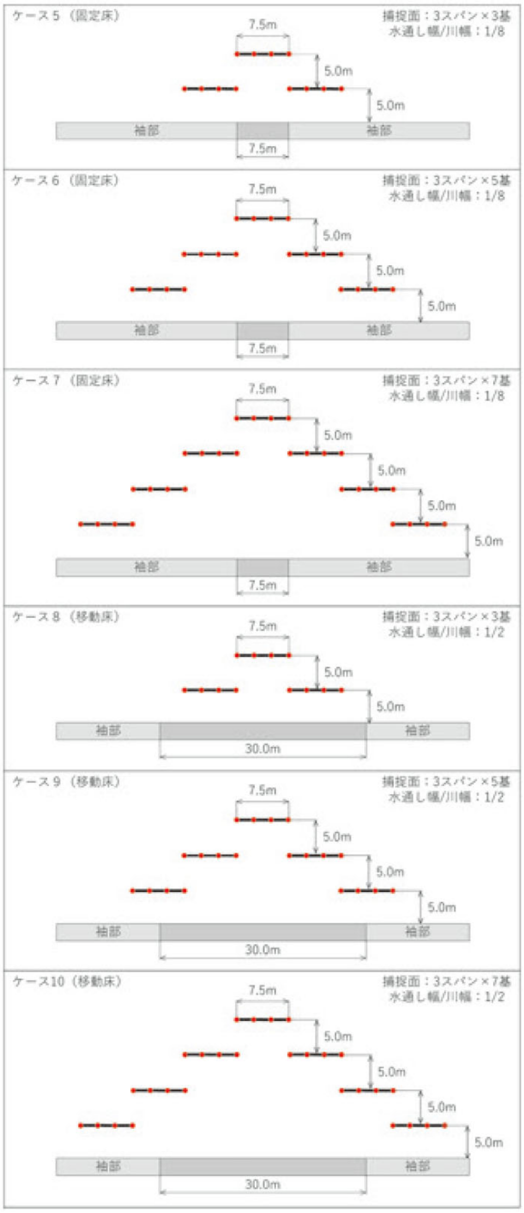


Fig. 12 Outline of the case (experiment 2)

(ending up with simple damming). A straight layout of driftwood reapers can lead to blocking backwatering seen in experiment case #1. Practically, it is feared that such backwatering leads to detrimental water elevation beyond the planned height of facilities, allowing incoming floating logs to get over the facilities.

Therefore, following arrangement may make sense to suppress unwanted backwatering water elevation. Instead of laying out the reaping structures lineally across the stream, dissected unit components are laid out in a convex shape towards the upstream. This formation has an advantage for flood water to run through each unit component, beside the expanses between entrapment facilities and main weir. Figure-11 shows water paths when units are arranged in the convex shape towards the upstream. As shown in the figure, with the increase of the separated units, more paths are made for water, resulting in larger effective width of spillway circumferentially.

This experience assumes cases of setting a layout of driftwood entrapment on fully sedimented reservoir upstream of hydraulically non-consecutive sabo facilities (man-made waterfall), where water velocity is observed and where sediment is predominantly transported as bedload. We examined how experimented driftwood is entrapped as well as how backwatering depth is suppressed in a scaled-down modeled apparatus.

3.2 Experiment 2 (Convex layout)

3.2.1 Experiment method

The same fluid channel is used as in straight layout. Water discharge and sediment supply conditions are the same as Experiment 1. The interval of driftwood entrapment components is set to a half (1/2) of input floating log (representing 2.5 m in real scale). One unit is composed of three units.

Figure-12 shows an overview of the driftwood entrapment where the units are set in a convex formation on the upstream of the supposed spillway, where relative position of the spillway and units are depicted. 3 units were laid out for cases #5 and #8; 5 units for cases # 6 and #9; and 7 units for cases # 7 and #10, all in a convex formation seeing towards upstream. The chief purpose of experiments is to examine the influence of blocking backwatering to driftwood entrapment. Therefore, the width of the spillway was set to the $1/8^{th}$ of that of stream width in cases #5 through #7, with a fixed bed and only with water discharge (no sediment supply). The width of spillway was set to be a half (1/2) of the stream width in cases #8 through #10, with a movable bed and with sediment supply in concomitance with water discharge (fully in equilibrium following sediment formula). The total number of input floating logs for cases #5 through #10 was set to 1000.

3.2.2 Results and analysis of experiments

(1) Uncaptured driftwood flowing-down rate (number of incoming logs - entrapped logs)

Figure-13 shows uncaptured driftwood flowing-down rates for case #5 through #9 (convex layout) with input logs per unit time as a denominator and those flowing-down through driftwood reapers as a numerator (As in the previous section, "Uncaptured driftwood" and "Flowing-down driftwood or floating logs" are used interchangeably.). For cases #5 to #9. Results of 3 cases in Experiment 1 (straight layout) are plotted together for reference. Floating logs underwent more blocking around the input level of 400 for cases #5 through #7 (convex layout), while for the cases #1 through #3, the ceiling lies around 200. Even under the same impounding condition, cases #5 through #7 allowed more floating driftwood to fee and flow down from the slit room between units. In other words, under impounding conditions, the straight layout performs better than the convex layout for driftwood entrapment.

In case #8, driftwood kept floating down from the beginning of 100 up through the climax of 1000 logs, with some fluctuation. This is explained chiefly by the limited expanse of entrapment structure within the width of the spillway, which enabled those floating logs reaching to the space between weir wings and entrapment structures to flow downstream.

On the other hand, uncaptured driftwood flowing-down logs decreased with the increase in inflowing floating logs in case #9 and #10. Since the expanse of the entrapment facility was broader than that of spillway, with entrapment faces blocked, fleeing and flowing-down logs were reduced. Namely, in a convex layout, expanded effective circumference broader than spillway width allows it to make driftwood entrapment effective.

(2) Backwatering water depth caused by floating logs entrapment

Figure-14 shows backwatering water depth at the spillway in relation to numbers of input floating logs per unit time. 3 cases from Experiment 1 (straight layout) are illustrated as a

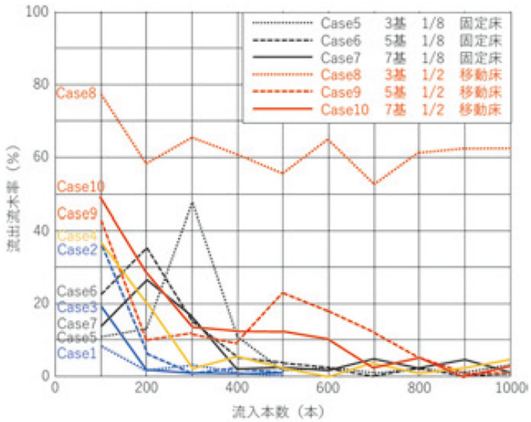


Fig.13 Uncaptured driftwood floating log rate -amount of input/inflowed driftwood

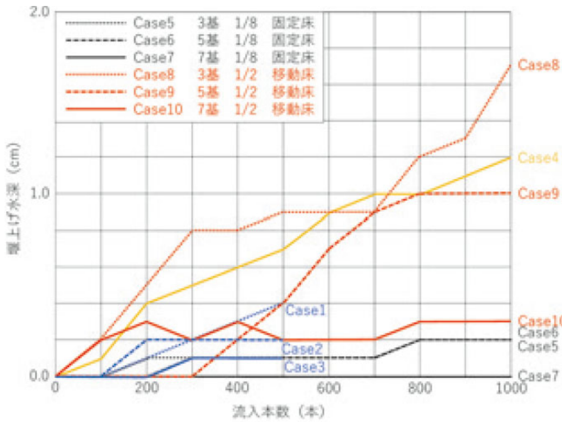


Fig.14 Dammed up depth − amount of inflowed driftwood

reference too.

Cases #5 through #7 (convex layout) saw water level risen by weir wings as in Experiment 1, leading to floating driftwood logs on impounding water surface. For case #5 and #6, minor backwatering was observed at input floating logs 200 through 300 of the initial stages. The water depth remained mostly stable as time passed, within almost the same range as that of case #3 (straight layout). There was no backwatering regardless of input floating logs for case #7. The convex shaped layout under an impounding state allowed those logs near the spillway to be drained downstream while at the entrapment faces up from weir wings floating logs remained drifting on the surface. Layout fully across the stream as in case #7 prevented backwatering notably. This may indicate that increased drainable water through circumference of facilities is larger than negative blocking impact at entrapment faces on balance. For cases # 8 through #10 (convex layout), water got backed up over upstream of wings. Water ran down smoothly with sufficient velocity in an open channel form since the spillway was wide enough. Namely, as in movable-bed of case #4 (straight layout), sediment was transported by water. For case #8, water was backed up even at the input level of 1000 floating logs. This is due to the increasing blockage at entrapment faces, since the faces were narrower than that of spillway.

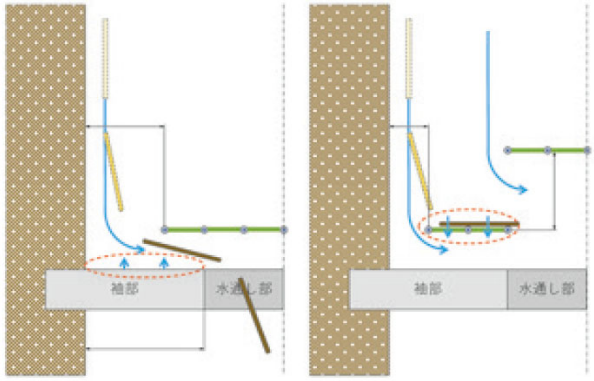


Fig. 15 Driftwood slipping through from the edge spaces

Case #9 has the same expanse of total facilities as in case #4, where backwatering water depth was in the same range but the rising rate of backwatering was slower in case #9. Backwatered water depth did not reach a stability for case #4 while for case #9 it reached a plateau level once input floating logs came to about 800. In the initial stages, entrapment faces were blocked as driftwood were trapped, which was followed by a relative stability of blocking saturation at the faces with floating logs entangling mutually away from facilities. In Case #10, floating logs evade through units with fluctuating flowing-down rates. Backwatering water depth stopped increasing from around input floating logs 200. Observation taught us similar entrapment mechanism in case #10 as in case #9. With increased unit components,

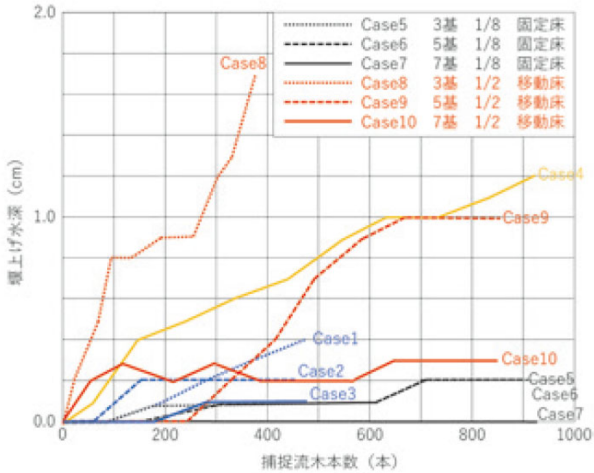


Fig. 16 Dammed up depth − amount of entrapped driftwood

evasive penetration may start earlier resulting in keeping water flowing capacity at entrainment faces and through unit components. Namely, even lower gradient in bedload section, it is safe to assume that expanded water flowability (drain-ability) of circumferential length of facilities reduce the risk of blocking backwatering.

Entrapping function near both stream banks in case #10 with 7 units is noteworthy. Edges of streams were wet, impounded by weir wings regardless of stream width or of spillway width, making driftwood logs float and drift, resulting in snipping away from spacing between main weir and driftwood entrapment (Figure-15). This fleeing evasion was seen even with 3 units and with 5 units. With 7 units laid out, where weir wings were not directly receiving floating logs, the presence of units allowed water to run down somehow, leading to floating log attracted to entrapment faces. This insight hinted that arranging entrapment unit right upstream of wings may prevent unintended floating logs drained downstream when planners put entrapment facilities for hydraulically non-consecutive sabo weir/dam. Figure-16 plots the relationship seen in Figure-13 and in Figure-14 with entrapped floating logs at the horizontal axis and backwatering water depth at the vertical axis.

Incremental backwatering for cases #5 and #6 (convex layout) reached a constancy of 0.1cm at around entrapment logs 300 as seen in case #3 (straight layout). Namely, Backwatering reduction of entrapment facilities is the same both for straight and for convex layout. The increment up to 0.2 cm around 700 input logs suggested the way entrapped logs change their entanglement as the process went on. Beyond that, the water depth remained mostly stable as impoundment where logs were floating and stored. No backwatering was found in case #7 even with increasing entrapment. This suggests that inter-unit spacing enabled water to run down even if entrapment faces were blocked by logs. With results of case #1 through #3 (straight layout), we may safely expect that self-induced backwatering of entrapment leads to deceleration of blockage and to driven drifting on impounding water surface off the facilities with a guarding set of entrapping units over weir wings, notwithstanding intensive blockage at entrapment faces right upstream of the spillway. This benefit is greater as more entrapping units are placed in the upstream of wings, near stream banks.

3 units 7 units

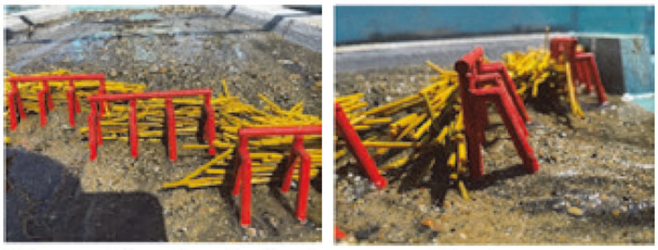
Fig.17 Driftwood entrapment condition by the difference in number of unit components

Backwatering water depth showed an unending upward trend with little saturation in case #8 (convex layout). In comparison to case #4 (straight layout), where the trend showed a similar tendency, the rate is about 2.7 times larger at around entrapped number of logs equal to 400. Case #4 regulated floating logs by the combination of direct entrapment by facilities and of indirect floating on impounding water surface, due, in part, to penetration, an evasion through component intervals. In case #8, entrapment faces acted more fully resulting in more areas blocked by floating logs. The degree differed for other cases; but with entrapment facilities covered over the space upstream of weir wings, spacing for water to be drained downstream such as between main weir and entrapment facilities or inter-units reduced unwanted backwatering. For that reason, expansion of entrapment front beyond spillway width allows us to reduce backwatering with the presence of spacing between structures, both in the straight layout and in the convex layout.

Backwatering water depth in case #9 (convex layout) is about the same as in case #4 (straight layout). They had minor discrepancies in that while in case #4 the water depth increased monotonously; the water depth came to a ceiling level at around entrapped logs equal to 650 in case #9. Observation showed no impoundment over the upstream of the spillway. Namely, backwatering water depth came to a plateau because blockage at entrapment faces being halted at the elevation with additional incoming floating logs added upstream of flocking entangled logs, which allowed water paths remain open. In both cases, the total length of facility circumference is the same. The difference was solely caused by that of layout, straight or convex. Thus, inter-unit spacing is thought to have an effect of reducing blockage.

Backwatering water depth of case #10 (convex layout) was slightly larger than that in straight layouts. With a low gradient in bedload section, entrapment faces tended to be readily blocked with all faces drawing floating logs. The backwatering water depth was the same as in case #2 and remained flat as in straight layout. Figure-17 shows flowing snapshots of case #8 and of case #10 in parallel; where the former had shorter expanses of entrapment facilities in comparison to the spillway width and the latter, the larger. In both cases, the spillway width is the same. Even after the entrapment, there was no water impoundment around the spillway with water flowing. Namely, even for a low gradient bedload section, with sufficient circumference of facilities over the upstream of the space of weir wings, backwatering is expected to be reduced as seen in facilities impounded.

As a matter of fact, in case #1 where the expanse of the facility is the same as that of the spillway, with floating logs drawn and driven into entrapment faces, there was blocking. However, in cases #2 and



Entrapment faces from the front　　　Side view

Fig. 18 Difference in the amount of entrapped driftwood by the capturing surface and the inter-unit

#3 where coverage of entrapment facilities was extended up to the upstream of wings, blockage was decelerated since the impoundment drove driftwood away from entrapment towards wing sides. Observation tells us that blocking formations differed between the upstream space of the spillway and of weir wings. Onto the spillway, entrapment faces grew clogged incrementally, while onto the wings, due to impoundment driftwood entrapment occurred only near the water surface and did not fully advance. Looking into how floating logs were entrapped, they accumulated in parallel to the water surface at the entrapment faces. Entangled accumulation of blocked floating logs is projected firstly onto stream-wise (to downstream, e.g.). Secondly, it is projected onto bank-wise (either to right or left bank). The geometry shows more room for the latter, i.e., seen from either of the banks (See Figure-18 for reference). Namely, the convex layout opened up a space for water flow in between units. The more unit components, the more likely water flows downstream. A layout with 5 units showed stable backwatering at around entrapped logs equal to 650 on one hand, while with 7 units, the backwatering water depth stayed the same as at the beginning.

4. Layout procedure of entrapment facility

4.1 Uncaptured driftwood flowing-down rate of floating rate

The most important function of driftwood reaper, an entrapment works, is prevention of floating logs passing through. Thus, the uncaptured flowing-down rate of driftwood is taken as an index, through which planned facilities can demonstrate its entrapment function as the index closing on to zero. Therefore, evaluation of entrapping function was attempted based upon uncaptured flowing-down rates introduced in Figure-13. Here, unit widths and inter-unit spacings were expressed as in Figure-19, where the spillway width is B0, expanse of facilities is B1, and effective (apparent) spillway width is B2.

Figure-20 plots the relationship, with facility expanse B1 / spillway width B0 as a

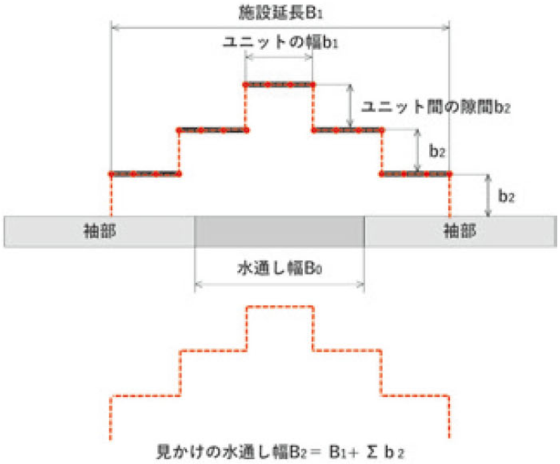


Fig. 19 Facility length B_1 and effective spillway width B_2

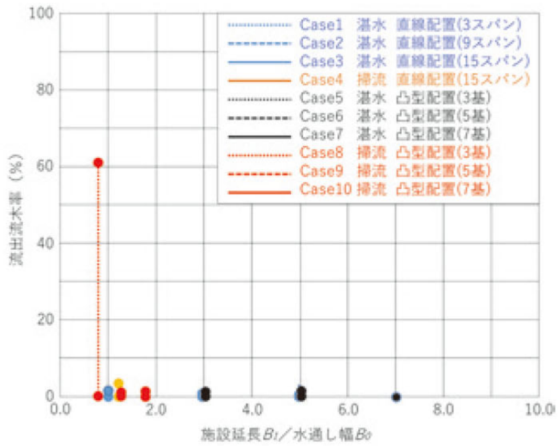


Fig. 20 Uncaptured floating log ratio − facility expanse B_1 / spillway(waterway) width B_0

horizontal axis and with uncaptured flowing-down rate from the beginning of floating log input through the end. For case #1 with impounding, the rate was less than 5%. The driftwood entrapment function worked fully even with B1= B0. For reference, existing driftwood entrapment works were planned as “facility expanse = spillway width,” where actually driftwood has been captured successfully [17]. The uncaptured flowing-down rate was intolerably high as 60% for case #8 with B1 < B0. Namely, in case planned facility expanse is smaller than that of spillway width, even with blocking at entrapment faces, successive floating logs supplied from upstream evade through the spacing between spillway and entrapment facility for a duration. Thus, the expanse of facilities (circumference) needs to cover the spillway width (expanse) fully, to ensure driftwood entrapment. In other cases, uncaptured flowing-down rates were below 5% regardless of impounding standing water or of running flowing water in tested bedload stream with B1 > B0. The result indicates that the simple rule-of-thumb is “facility expanse > spillway width” for effective driftwood entrapment.

4.2 Backwatering water depth

Existing driftwood entrapment works had an unwanted side effect of backwatering upstream as entrapment faces blocked by floating logs, requiring to ensure a larger spillway opening higher than the entrapment works. In cases where entanglement of accumulated entrapped driftwood, flood water has not been reported to flow over the top of sabo facilities. In the bedload section, with driftwood entrapment layers parallel to water surface, accompanied by backwatering water elevation, there is a risk of sabo facility overflowed. Therefore, backwatering in bedload stream section is to be avoided structurally. In order to examine if proposed layouts can reduce the risk of backwatering, backwatering water depth was analyzed with the index of effective (apparent) spillway width B2 / (actual) spillway width B0.

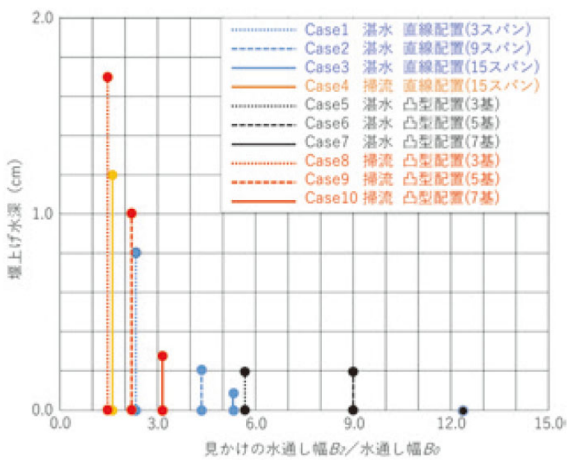


Fig.21 Dammed up depth − effective spillway width B_2/ spillway width B_0

Figure-21 is a plot with the ratio of effective (apparent) spillway width B2 / (actual) spillway width B0 as a horizontal axis and with backwatering water depth from the beginning of input timing through the end as a vertical axis. Only case #1 among those with impoundment saw constant leveling up of water. For other cases of impoundment, the level gets flattened with minor backwatering. Only case #10 among those with running water in the bedload stream section came to levelling. For other cases of running water, backwatering saw progress. They are classified as rising cases for B2/B0 less than 3.0 and levelling cases for the value over 3.0. In actual streams where water is regulated by geomorphology (in line with and in crossing), changing pattern of discharge, and shape of existing sabo facilities, which makes it difficult for planners to assume standing or running states of water upstream of facilities. The result, however, strongly suggests that setting “effective spillway water passing width > 3 times that of actual existing spillway” is imperative from practical point of view to avoid backwatering regardless of impoundment or smooth bedload running water.

5. Entrapped driftwood volume

5.1 Impounding case

For the case of driftwood entrapment under impounding state, at the upstream space of the spillway, driftwood is driven into entrapment faces without complete blocking of the entire faces. The blockage concentrates only near the water surface. Thereafter driftwood hovers on the impounding water surface. Figure-22 is drawn from entrapment observed in straight layout, not from among present experiment, for reference. Entrapped floating log volume is a sum of dissected portion of floating logs V1 and those captured logs V2 at the entrapment faces, noted as the following equations.

$V_1 + V_2 = A \text{ x } d + 0.5 \text{ x } h^2 \text{ x } B_0 \text{ x } \gamma$ (1)

Where, $V_1 + V_2$: entrapped driftwood volume (m^3)

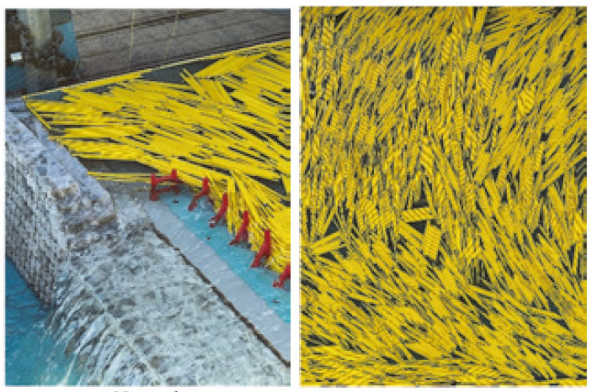
A: Impoundment area (m^2)

d: diameter of floating log (m)

h: water depth (m)

B_0: spillway width (m)

γ : spatial density (0.3)



Near the weir water surface

Fig.22 Driftwood capturing condition in a ponding state

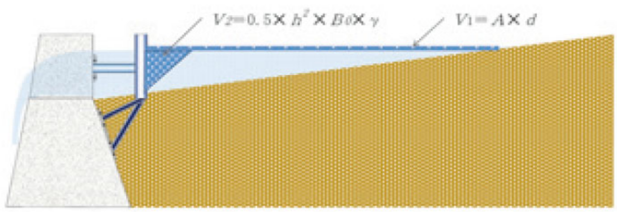


Fig.23 Amount of captured driftwood in a impounding state

Driftwood volume V_2 occurs on the circumferential expanse of facilities, upstream of the spillway without complete blockage, as seen in our experiments. The entrapment concentrates densely over the faces with the width equal to the spillway (water depth times spillway width). Away from the center axis of the spillway, in space over the upstream of weir wings, floating logs were counted as drifting volume V_1 only. Namely, Driftwood entrapped volume of V_2 is smaller than an approximated triangular-shaped area of "spillway width x square of water depth x 1/2 x spatial density." Entrapment faces over the space upstream of weir wings are with one or two accidentally trapped logs only, where effective entrapment is expected only to those floating on the impounding water surface V_1. Namely, driftwood entrapment volume, under impoundment, standing water condition, is that derived according to the current technical code of entrapment volume V_1 equal to impounding water surface x floating log diameter, which coincides with realistic volume for planners. The assumed spatial density (filling rate) is set to be 0.3, which was obtained by field surveys in the past [18]. The current enforced technical code assumes uniform coverage of floating logs on standing impounding water, whereas the rate in Figure-22 is around 80% to the water surface in the experiment.

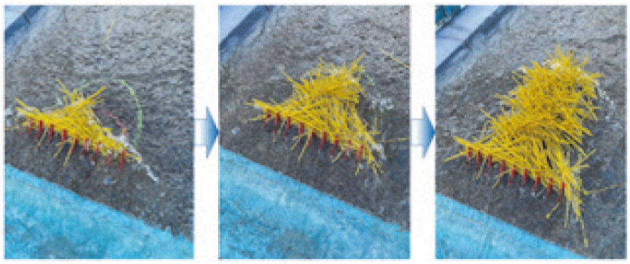


Fig.24 Driftwood capturing condition at running water section

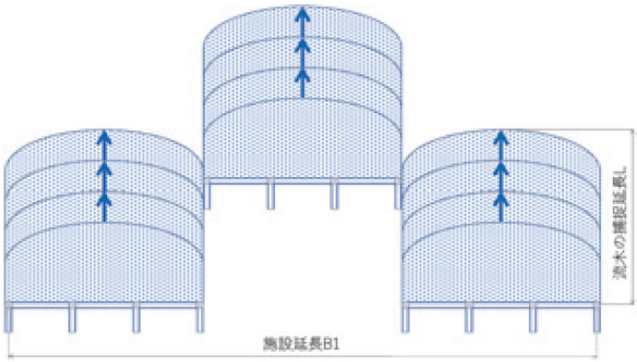


Fig.25 Amount of captured driftwood in a running water

5.2 Flowing case in bedload section

To date, planned driftwood entrapped volume has been estimated following the formula of impounding area times floating log diameter. Experimental result suggested that no floating was observed unless impounding standing water conditions occurred. When planners try to entrap driftwood in running water of bedload section, with blocking setting in at entrapment faces, the accumulation process extends in a upstream direction. Note that, with the advancement of driftwood accumulation, entrapment mechanism gets unstable, allowing release of captured logs, etc. once entrapment expanse goes beyond facility expanse. Thus, entrapment expanse L is hypothetically estimated in a reverse way using equation (2), to obtain the equivalent volume of planned driftwood entrapment volume (impounding area times floating log diameter) (Figure-25). Note that entrapment has been assumed under the water surface whereas actually driftwood is captured over the water surface, leading to a larger volume than estimated by the formula. Nonetheless, here the assumption remains intact, to be under water because the protrusion over the water surface depends on water depth, facility height, and length of logs.

$V = B_1 \times h \times L \times \gamma$ (2)

Where, V: Entrapped driftwood volume (m^3)

B_1: Facility expanse (m)

h: water depth (m)

L: driftwood entrapment expanse (m)

γ : spatial density (filing rate) (0.3)

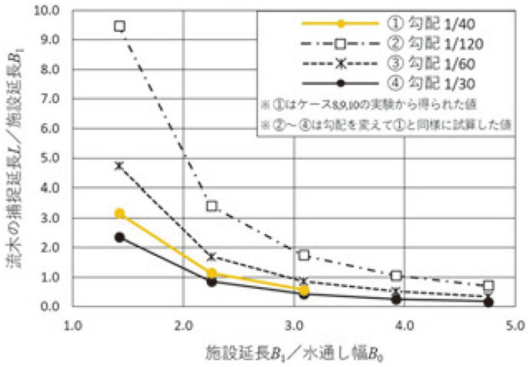


Fig. 26 Total length of captured driftwood L/facility length B_1– facility length B_1/channel width B_0

For analysis, driftwood entrapment configuration of equation (2) is set to represent real driftwood entrapment volume (facility expanse x driftwood entrapment expanse x depth x spatial density). Then, as in the previous section, planned (estimated) driftwood entrapment volume (impounding area times floating log diameter) is utilized to derive driftwood entrapment expanse (circumferential length of L) in a reverse manner, where floating logs are uniformly distributed on the impounding surface.

Figure-26 is a plot where facility expanse B1/spillway width B0 is the horizontal axis and driftwood entrapment expanse L / facility expanse B1 is the vertical axis. Note that L is a driftwood entrapment expanse, assuming current code-based estimated entrapment volume. Stream bed gradient 1/40 in the figure is that for experiments in the study. Calculation is made for gradient of 1/30, 1/60, and 1/120 for comparison, under the assumption of the similar driftwood entrapment situation. For example, horizontal value =1 represents those driftwood entrapment works (reapers) with the same width as the spillway. Those with the horizontal values of 2 through 3 represent driftwood entrapment extended broader than the spillway width. According to the result for case of 1/40 gradient, at the horizontal axis value of unity, planned entrapment volume is obtained with at least with entrapment expanse L to be double (2.0). By setting the horizontal axis value to be 2 through 3, namely extending the facility expanses over the spillway width, entrapment expanse of driftwood is expected to go below 1.0. This calculation suggests that a broader facility expanse is needed at the lower gradient. The proposed types of structures extended over the spillway width would have equivalent storing and entrapping functions as current technical code effectively, if it is planned in the stream gradient of 1/40, where driftwood storage space may be available up to the same distance in the upstream direction as across the stream.

6. Conclusion

Driftwood entrapment function of driftwood reapers, together with their reducing effect on backwatering, is examined by hydraulic model tests, which have been supplementarily added in the upstream zone of existing non-consecutive non-permeable sabo facilities, slightly off on the sediment reservoir or adjacent to the main weir. Several insights obtained in the process are summarized as follows:

1) Once entrapment is initiated, clogging logs boost blocking in a self-inducing way, preventing trapped logs from slipping through the entrapment faces. Planners can duly expect this entrapment function by keeping a rule-of-thumb as "facility expanse > spillway width," regardless of upstream water being standing or running (assuming a bedload section).

2) When facility expanse (projected total stretch of driftwood entrapment works onto longitudinal direction) is greater than the spillway width, progress of backwatering is regulated. In order to ensure the durability of this suppression, planners are advised to set "effective spillway width > 3 times of the spillway width," again despite the flowing conditions on sediment reservoir.

3) Driftwood entrapment faces tend to get clogged by incoming sediment in the initial stage with assumed movable bed stream, resulting in backwatered impoundment, which self-regulates further sediment transportation and allows planners to assume a fixed-bed stream channel in the latter stages.

4) Once water depth is risen through backwatering under an impounding condition, incoming driftwood starts floating on water surface and being stored, instead of reaching entrapment faces with clogging logs. Regarding storage as an adds-on to entrapment, aggregated driftwood entrapment is greater for straight layout than for convex layout of the entrapment works, whose suppression impacts are almost the same.

5) Equivalence of backwatering suppression impacts in running water in bedload section, to the corresponding standing water state, is ensured by keeping effective spillway width large, which is attained by increasing unit components as in convex layout. Prevention of backwatering and suppression of water level rise are achieved by arranging entrapment faces in the area upstream of weir wings, rather than on the main spillway channel.

6) Driftwood evasion, an occurrence of fleeing floating logs through spacings, drained down, can be prevented by arranging unit components up to the full stretch of facilities, for hydraulically non-consecutive sabo weir/dams.

7) Driftwood entrapment reapers with a proposed layout on the upstream sediment reservoir area, with a greater expanse than the spillway can effectively exert the equivalent entrapment function as estimated in the current technical code up to stream gradient of 1/40, so long as the stream-wise dimension of the storing zone can be extended up to or more than the total facility expanse across the stream.

8) Experimented cases show the coverage rate of driftwood to be 80%, in relation to presumed stored volume under the assumption of a uniform distribution on impounding water surface.

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