Original Article

Preliminary Experimental Studies on Debris Flow with Woods focusing on Difference of Specific Weight of Tree Species

Takahiro ITOH¹, Kazuhiro OGAWA², Shigeki NISHIMURA², and Senro KURAOKA²

¹ El KOEI Co., Ltd. (2304 Inarihara, Tsukuba, Ibaraki 300-1259 Japan)
² Research and Development Center, NIPPON KOEI Co., Ltd. (2304 Inarihara, Tsukuba, Ibaraki 300-1259 Japan)

There are many experimental approaches, field investigations and numerical calculations for movements of woods in a clear water and debris flow. However, treatments and evaluations for accumulated logs and interactions between a main flow and logs are not fully developed. In mountainous torrents, the logs yielding from slopes and stream beds depend on the condition of previous and present forest stands. Mitigations for woods need to be conducted taking into account tree species such as conifer and broad-leaf trees and shapes such as root swells and crown. In the present study, we focus on the differences in specific weight of conifer and broad-leaf trees with some moisture in a sediment-water mixture flow with narrow flow width. Conifer and broad-leaf tree are considered as floating and submerged solid phase, respectively. Flume tests are conducted in steady flow of clear and debris flow over a rigid bed in order to evaluate flow characteristics of clear and debris flow with woods. Debris flow is specified as flow with clear water and sediment mixture layers on a rigid bed, whose slope is 0.045. Preliminary experimental data, which suggest that influences of specific weight on logs movements are significant, has been obtained to evaluate those experimental results such as movements of floating and submerged woods and multi-layer consisted of woods and debris flow. However, detail considerations and collections of flume data are needed based on flow characteristics such as spatial eddies structures in depth-scale, diffusion/dispersion of woods, momentum transfer induced interactions between logs and mixture flow and bed conditions.

1. INTRODUCTION

There are many experimental approaches [e.g., Adachi et al, 1957; Mizuhara et al., 1979; Takeuchi et al., 1985; Mizuyama et al., 1991; Nakagawa et al., 1992; Fujita et al., 1993; Braudrick et al., 1997; Shrestha et al., 2009], field investigations [Major et al., 1986; Robinson et al., 1990; Bilby et al., 1991, Abbe et al., 2003] and numerical calculations [e.g., Nakagawa et al., 1992; Shrestha et al., 2009] for movements of woods in a clear water and debris flow. However, treatments of accumulated logs and interactions between flows and logs are not fully developed. In Japan, there are several torrents where debris flow with woods took place and detail field investigations were conducted. For example, floods disasters with woods due to heavy rainfall took place around Kobe-City in Hyogo Pref. in Japan in 1938 and the records of occurrences of numerous debris flows with woods are reported in a document [e.g., Municipal government of Kobe City, 1939].

Figure 1 shows several longitudinal bed profiles in which wood debris disasters took place previously in Japan. Photo 1 shows an example of sediment and wood debris deposition in the residential area in Kobe-City, which is shown as location (A) with 1/20
in bed slope in Fig. 1 [Municipal government of Kobe City, 1939]. It is reported that average bed slope is around 5 degrees (= 1/11) at the top of fan in the short torrents with a length less than 2000 m according to the reports in Japan [Mizuyama et al., 1991]. In Fig. 1, the inundation area and reach of wood debris deposition and formation such as deposition of logs (L) and logs dams (LD) are shown (Fig. 1). Maximum bed slope for logs deposition except formation of logs dams seems to be 1/20 (= 0.05) to 1/22 (=0.045).

In mountainous torrents, the yield of logs from slopes and stream beds depends on the condition of previous and present forest condition. Mitigations for woods need to be conducted taking into account tree species such as conifer and broad-leaf tree and shapes such as root swells and crown. It seems that there are few studies contrasting wood transport in clear-water flows and debris flows with variation in density of wood from conifers and broadleaf trees.

Recently, there are several numerical analyses by simulation focusing on movements and closeness of woods in rivers and slopes [e.g., in Japan, Shimizu et al., 2006; Harada et al., 2007; Makino et al., 2008]. However, the flow conditions by them are not our research subject investigation in the present study.

In present study, we focus on the differences in specific weight of fresh (green wood’s) conifer and broad-leaf tree in a sediment-water mixture flow, supposing that conifer and broad-leaf tree are considered as floating and submerged, respectively. Flume tests were conducted in steady flow of clear and debris flow over a rigid bed. Herein, debris flow is consisted of clear water and sediment-water mixture layer, and the bed slope is 0.045. The movements of woods such as closeness and rotation of logs are reproduced and evaluated in a narrow flume.

2. FLUME TESTS

2.1 Experimental flume

Referring to previous documents for debris flow with woods, the flow width of channel prototype is specified as 10 to 15 m and flow regime is the clear water and debris flow with clear water layer with woods such as conifer, broadleaf tree and those mixtures. The reason is why influences of the differences in specific weight between conifer and broadleaf tree on flow structure need to be evaluated qualitatively and is why vertically and cross sectionally extreme movements of woods as seen in wide channel need to be avoided in this flume tests.

Photo 2 shows the experimental flume, which is 20.0 cm wide, 80.0 cm high and 10.0 m long. In the upstream reach, a debris flow with characteristics as required for tests can be produced by water and sediment supply. Water is steadily supplied in case of clear water flow. Sediment bed is set up smoothly by using a larger size sediment (5 mm) than the material of the supplied debris flow body, and the bed slope is 0.045 (= 2.58 deg.), which is adjusted to the equilibrium slope, corresponding to the sediment supply.

2.2 Experimental conditions, sediment and woods model

Supposing that watershed area is 1.0 km², peak
discharge rate, $Q$, is 25 m$^3$/s and mean sediment diameter, $d_{60}$, is 85 mm in mountainous region, where sediment disasters took place previously [e.g., Mizuyama et al., 1991], clear water discharge rate and sediment size in 1/50 a model is $Q = 1.42$ l/s and $d_{60} = 0.17$ cm, respectively using Mizuyama et al.’s flume tests [1991].

Experimental runs are shown in Table 1. A uniform grain size, $d_{60}$, of 0.183 cm is used to form the debris flow in all cases. Inflow sediment and water mixture discharge rate, $q_m$, is set at a constant value at the upper boundary where dry sands are mixed with supply water to produce a required debris flow using sand feeder. Flux sediment concentration, $c_f$, of supplied debris flow is set at 0.012 by volume to maintain equilibrium sediment concentration for bed slope (0.045= 2.58 degrees) [Egashira et al, 1997]. Herein, flux sediment concentration, $c_f$, is defined as $c_f = q_s/q_m$ in which, $q_s$ is the sediment discharge rate in unit width.

Physical parameters of sediment are as follows: The mean value of the internal friction angle of sediment particles of $d_{60} = 0.183$ cm, $\phi_s$, is 37.4 deg., specific weight is 2.63 and the volumetric sediment concentration in sediment deposition layer, $c_s$, is 0.535.

Three kinds of wood, which are conifer (C), broadleaf-tree (B) and mixed tree, were used for flume tests. Logs mixtures are set as C: B = 1: 0, C: B = 0: 1 and C: B =1: 1 where C: B is the ratio between conifers and broad-leaf trees in the numbers of logs. Wood debris of fresh wood (green wood) was modeled by plastic sticks with densities representing those of conifers and broad-leaf trees as shown in Table 2. Polyethylene, in which specific weight is 0.952, is used for fresh conifer model, and Polymethyl methacrylate, in which specific weight is 1.20, is used for fresh broadleaf tree model. Log diameter ($d_{log}$) is 0.61 cm. The length of log, $l_d$, was specified as 20 cm (See Photo 3). The values of fresh wood of specific weight of conifers and broadleaf trees were specified using the values examined by Yazawa [1941, 1951] and documents

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### Table 1 Experimental runs

<table>
<thead>
<tr>
<th>Feeding rate of driftwoods (logs/s.)</th>
<th>Conifers</th>
<th>Broadleaf trees</th>
<th>Mix</th>
<th>Conifers</th>
<th>Broadleaf trees</th>
<th>Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (50 logs)</td>
<td>Run 1</td>
<td>Run 4</td>
<td>ditto</td>
<td>Run 9</td>
<td>Run 12</td>
<td>ditto</td>
</tr>
<tr>
<td>6 (300 logs)</td>
<td>Run 2</td>
<td>Run 5</td>
<td>Run 7</td>
<td>Run 10</td>
<td>Run 13</td>
<td>Run 15</td>
</tr>
<tr>
<td>10 (500 logs)</td>
<td>Run 3</td>
<td>Run 6</td>
<td>Run 8</td>
<td>Run 11</td>
<td>Run 14</td>
<td>Run 16</td>
</tr>
</tbody>
</table>

### Table 2 Some examples of plastic specific weight for fresh wood (green wood) model

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Specific weight</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polycetal</td>
<td>1.41 to 1.42</td>
<td>Maximum value for broadleaf tree</td>
</tr>
<tr>
<td>Polymethyl methacrylate</td>
<td>1.17 to 1.20</td>
<td>Mean value for broadleaf tree</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0.91 to 0.97</td>
<td>Mean value for conifer tree</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0.90 to 0.91</td>
<td></td>
</tr>
</tbody>
</table>

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![Photo 3 Driftwood model using plastic material](Image)

![Fig. 2 Empirical relationship between the numbers of yielding logs and watershed area](Image)
Table 3 Examples of specific weight of green woods

Japanese red pine [Yazawa et al., 1951]

<table>
<thead>
<tr>
<th></th>
<th>Trunk</th>
<th>Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Side wood</td>
<td>Haert wood</td>
</tr>
<tr>
<td>Fresh (green) wood</td>
<td>Range</td>
<td>Mean value</td>
</tr>
<tr>
<td></td>
<td>1.077−0.686</td>
<td>0.933</td>
</tr>
<tr>
<td>Dry wood</td>
<td>Range</td>
<td>Mean value</td>
</tr>
<tr>
<td></td>
<td>0.593−0.318</td>
<td>0.437</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>Range</td>
<td>Mean value</td>
</tr>
<tr>
<td></td>
<td>216.8−75.5</td>
<td>145.0</td>
</tr>
</tbody>
</table>

Examples of specific weight of woods (g/cm³) [Yazawa et al., 1941]

<table>
<thead>
<tr>
<th>Woods in a air</th>
<th>Fresh wood (Green wood)</th>
<th>Conifer/ Broadleaf tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrophulariaceae</td>
<td>0.300</td>
<td>0.559</td>
</tr>
<tr>
<td>Yew</td>
<td>0.061</td>
<td>0.709</td>
</tr>
<tr>
<td>Magnolia</td>
<td>0.062</td>
<td>0.752</td>
</tr>
<tr>
<td>Walnut</td>
<td>0.521</td>
<td>0.758</td>
</tr>
<tr>
<td>Buckeye</td>
<td>0.571</td>
<td>0.800</td>
</tr>
<tr>
<td>Japanese red pine</td>
<td>0.529</td>
<td>0.800</td>
</tr>
<tr>
<td>Tung</td>
<td>0.420</td>
<td>0.800</td>
</tr>
<tr>
<td>Larch</td>
<td>0.062</td>
<td>0.813</td>
</tr>
<tr>
<td>White birch</td>
<td>0.610</td>
<td>0.820</td>
</tr>
<tr>
<td>Alder</td>
<td>0.521</td>
<td>0.833</td>
</tr>
<tr>
<td>Ash</td>
<td>0.699</td>
<td>0.833</td>
</tr>
<tr>
<td>Chestnut</td>
<td>0.610</td>
<td>0.847</td>
</tr>
<tr>
<td>Japanese cypress</td>
<td>0.541</td>
<td>0.862</td>
</tr>
<tr>
<td>Painted maple</td>
<td>0.709</td>
<td>0.862</td>
</tr>
<tr>
<td>Japanese cedar</td>
<td>0.441</td>
<td>0.877</td>
</tr>
<tr>
<td>Castor aralia</td>
<td>0.571</td>
<td>0.877</td>
</tr>
<tr>
<td>Hornbeam</td>
<td>0.752</td>
<td>0.901</td>
</tr>
<tr>
<td>Ash</td>
<td>0.690</td>
<td>0.901</td>
</tr>
<tr>
<td>Magnolia</td>
<td>0.500</td>
<td>0.917</td>
</tr>
<tr>
<td>Nettle tree</td>
<td>0.699</td>
<td>0.943</td>
</tr>
<tr>
<td>Maple</td>
<td>0.680</td>
<td>0.952</td>
</tr>
<tr>
<td>Mimosa</td>
<td>0.571</td>
<td>0.962</td>
</tr>
<tr>
<td>Weeping willow</td>
<td>0.549</td>
<td>0.962</td>
</tr>
<tr>
<td>Japanese apricot</td>
<td>0.870</td>
<td>0.971</td>
</tr>
<tr>
<td>Japanese black pine</td>
<td>0.658</td>
<td>0.971</td>
</tr>
<tr>
<td>Camphor tree</td>
<td>0.420</td>
<td>0.971</td>
</tr>
<tr>
<td>Storax</td>
<td>0.680</td>
<td>0.971</td>
</tr>
<tr>
<td>Dogwood</td>
<td>0.599</td>
<td>0.990</td>
</tr>
<tr>
<td>Beech</td>
<td>0.719</td>
<td>1.00</td>
</tr>
<tr>
<td>Apple</td>
<td>0.671</td>
<td>1.01</td>
</tr>
<tr>
<td>Bayberry</td>
<td>0.952</td>
<td>1.02</td>
</tr>
<tr>
<td>Ash</td>
<td>0.079</td>
<td>1.02</td>
</tr>
<tr>
<td>Oak</td>
<td>0.730</td>
<td>1.02</td>
</tr>
<tr>
<td>Pear</td>
<td>0.699</td>
<td>1.05</td>
</tr>
<tr>
<td>Zelkova</td>
<td>0.077</td>
<td>1.06</td>
</tr>
<tr>
<td>Oak</td>
<td>0.084</td>
<td>1.08</td>
</tr>
<tr>
<td>Oak</td>
<td>0.085</td>
<td>1.09</td>
</tr>
<tr>
<td>Fir</td>
<td>0.481</td>
<td>1.10</td>
</tr>
<tr>
<td>Deutzia</td>
<td>0.741</td>
<td>1.10</td>
</tr>
<tr>
<td>Holly</td>
<td>0.917</td>
<td>1.12</td>
</tr>
<tr>
<td>Red Oak</td>
<td>0.909</td>
<td>1.15</td>
</tr>
</tbody>
</table>
Sediment Control Division, National Institute for Forestry Research Institute, 1967]. A part of those values are shown in Table 3. The ratio of flow width to log length in the experiments is set as unity.

The number of supplying logs was set as 50, 300 and 500 representing a range of log yields to channel in a drainage area of 1 km² (Fig. 2) [Erosion and Sediment Control Division, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport, Japan, 2007]. Prototype supplying time is set as 6 min taking into account sediment volume and hydrograph, which results in 50 sec of supplying time in model scale.

The supplying rate was set at 1, 6 and 10 logs/sec., respectively. Model logs were supplied randomly.

### Table 4 A part of hydraulic conditions for experiments

<table>
<thead>
<tr>
<th>n (Clear water)</th>
<th>B (cm)</th>
<th>Q (l/s)</th>
<th>c_f</th>
<th>c</th>
<th>h_0 (cm)</th>
<th>h_0 / d</th>
<th>h_0 / d_l</th>
<th>τ_c</th>
<th>Fr</th>
<th>Re</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0176</td>
<td>20.0</td>
<td>1.42</td>
<td>0.012</td>
<td>0.049</td>
<td>1.47</td>
<td>8.12</td>
<td>2.41</td>
<td>0.224</td>
<td>1.85</td>
<td>7070</td>
</tr>
</tbody>
</table>

Figs. 3 Temporal changes of runoff logs at downstream end
in orientation in the upstream reach of a channel.

Table 4 shows a part of experimental conditions, in which $n$ is the manning type’s bed roughness [m$^{1/3}$/s], $B$ is the flow width, $c$ is the cross sectional mean sediment concentration, $h_0$ is the uniform flow depth in a clear water flow, $d_{50}$ is the relative depth to diameter of sediment, $d_{50}$, $\tau_*$ is the non-dimensional shear stress, $Fr$ is the Froude number and $Re$ is the Reynolds number.

Several runs are performed in the same experimental condition in order to obtain reliable data. In all cases, sediment and water mixture discharge at the lower end of the flume was measured using bucket, flow depth without woods was measured using a point gauge at a fixed point 100 cm upstream from the lower end. Spatial and temporal changes of flow regime and runoff discharge rate of woods at the lower end were measured by recording the flow with digital video camera and analyzing the images.

### 3. INFLUENCES OF SPECIFIC WEIGHT ON MOVEMENTS OF WOODS

Figures 3 (a)–(d) show temporal change of the numbers of runoff woods at the downstream end. Photos 4 show flow patterns in case of Run 3, 6, 8 (Clear water flow) and 16 (Debris flow). Photos 5 show several examples of formations of log dams in case of Run 11, 14 and 16 (Clear water flow) and Run 3, 6 and 8 (Debris flow) when the supplying rate is 10 logs/sec. Figures 4 (a) and (b) shows flow angle of logs at the section of 2.0 m from lower end in case that the logs supplying rate is 6 and 10 logs/sec. Figure 5 shows relations between trap rate of logs in a channel and relative flow width ($= B/l_0$). Table 5 shows parts of experimental data and the numbers of trapped woods in a channel, the formation of logs dam, surface velocity of clear water and debris flow and mean velocity of woods are shown in the table. The table shows one example for total runoff rate of logs at downstream end, though the runoff rate of logs needs to be evaluated in arbitrary section in a flume. Herein,

![Frequency](image1)

**Incidence angle of driftwood to a main flow (deg.)**

(a) 6 logs/sec.

(b) 10 logs/sec.

**Figs. 4** flow angle of logs at 2.0 m from downstream end

![Photos 4](image2)

**Examples of flow patterns of wood debris in a flume (Supplying rate= 10 logs/s.)**
trapping rate of woods is calculated by the ratio of logs remaining in a channel for supplying logs [Mizuyama, 1991]. Table 6 shows the velocity of free surface and logs which are measured at the section of 2.0 m from downstream end.

Conifers tend to have some ranges of flow angle to main flow and broadleaf trees tend to move along main flow, and those tendencies become remarkable in case of debris flow (Figs. 4, Photos 4). In comparison to clear water flow, as surface velocity of debris flow is fast at the same bed slope, the tendency results in increasing rotational movements of conifers due to velocity gradient of sectional velocity distribution near free surface (Figs. 4, Photos 4 and Table 6).

On the other hand, movements of broadleaf tree tend to maintain such that flow direction of logs is parallel to main flow direction, and the logs of broadleaf tree does not tend to be captured in a channel (Figs. 3, 4 and Photos 4). In case of clear water, the movements of broadleaf trees are affected by bed roughness and the range of the closeness of logs is wide due to effects of specific weight and bed roughness (Photos 4). In case of debris flows, the logs of submerged broadleaf tree are located on the debris flow (in other words, “the sediment and water mixture layer” or “interface”), and it seems that the flow nature on the interface prevents the logs from...

Photos 5 Examples of formations for logs dams in a flume
Table 5 Trap rate of logs in a flume

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Sediment water mixture flow (surface velocity: ( u_s = 79.5 \text{ cm/s} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding speed of logs</td>
<td>Conifer</td>
</tr>
<tr>
<td>1 (Run 1)</td>
<td>4</td>
</tr>
<tr>
<td>(total: 50)</td>
<td>4 logs</td>
</tr>
<tr>
<td>6 (Run 2)</td>
<td>177*</td>
</tr>
<tr>
<td>(total: 300)</td>
<td>177*</td>
</tr>
<tr>
<td>1 (Run 3)</td>
<td>1</td>
</tr>
<tr>
<td>(total: 500)</td>
<td>1</td>
</tr>
<tr>
<td>10 (Run 4)</td>
<td>323*</td>
</tr>
<tr>
<td>(total: 500)</td>
<td>323*</td>
</tr>
<tr>
<td>223*</td>
<td>0.446</td>
</tr>
<tr>
<td>(total: 500)</td>
<td>223*</td>
</tr>
<tr>
<td>190*</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Star, *: Formation of dams (*: 1 dam, **: 2 dams)
In debris flow, conifers on the free surface become a kind of trigger of closeness of woods because of increase of rotational movements, while broadleaf trees tend to be parallel to main flow (Figs. 3, 4 and Photos 4). As a result, woods tend to be easily captured in a channel in case of debris flow. However, in case of conifer and broadleaf tree mixtures, trapping rate of logs in a debris flow is larger than that in clear water flow at a supply rate of 6 logs/s. At a supply rate of 10 logs/s, trapping rate in debris flow becomes small. The multi-layers constituted of conifers, broad-leaf trees and sediment-water mixture flow are formed (e.g., Photos 5(f)). Interaction between conifers and broadleaf trees appears if more logs than some value of supplying rate of logs are given in a channel.

### Table 6 Measured velocity of free surface and logs

<table>
<thead>
<tr>
<th></th>
<th>Clear water</th>
<th>Debris flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 logs/s</td>
<td>6 logs/s</td>
</tr>
<tr>
<td>Conifer (C)</td>
<td>Run1 67.6</td>
<td>Run2 66.7</td>
</tr>
<tr>
<td>Broadleaf tree (B)</td>
<td>- 34.4</td>
<td>Run5 38.9</td>
</tr>
<tr>
<td>Surface</td>
<td>74.3</td>
<td>Run7 39.3</td>
</tr>
<tr>
<td></td>
<td>75.7</td>
<td>Run9 72.3</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Run11 38.6</td>
</tr>
</tbody>
</table>

Fig. 5 Relations between trap rate of logs in a channel and relative flow width

Fig. 6 Schematics for sediment and water mixture flow with logs which are consisted of conifer and broadleaf tree rotating (Figs. 4, Photos 4).
Photo 6 shows an example of “multi-layer flow”, which is formed due to densities differences of materials and which is constituted of floating conifers, submerged broad-leaf trees and debris flow. Those flow characteristics are modeled as shown in Fig. 6 before formation of logs dams.

Conifers tend to align at a range of flow angles to the main flow, and those are always floating logs. Broadleaf trees can pass through closeness of conifers, supposing that logs dam is formed in a channel as shown in Photos 5(f). In this case, occurrence of sudden destruction of a dam or broad-leaf trees and sediment runoff can take place, and the huge floods due to break of logs dam can be formed.

Sudden decreasing of runoff rate of logs at downstream reach depends on the formation log dams in a channel (Figs. 3, Photos 5 and Table 5). The formation of dams and closeness of logs do not depend on flow velocity but on the supply rate of logs and a mixture of conifers and broadleaf trees (Figs. 3, Photos 5 and Table 5), while those characteristics and physical mechanism need to be precisely clarified.

In addition, Mizuhara [1979] suggested the possibility of effects of specific weight of logs on the number of captured logs in a check dam based on the experimental data obtained in clear water flow. Present experimental data support his experimental results in case of clear water flow and debris flow.

According to those experimental data, influences of specific weight of wood on flow characteristics of mixture flow are significant and it seems to be quite important to take into account the differences of conifer and broadleaf tree for countermeasures against debris flows with woods. In addition, we will propose governing equation’s sets and flow model for the multi-layers flow based on experimental data and flow patterns in order to estimate several kinds of debris flows constituted of logs, sediment and water.

4. CONCLUSIONS

The present study examined the flow characteristics of clear water and debris flow with clear water layer with woods focusing on specific weight of woods. The results obtained in present study are summarized as follows:

1. Conifers tend to align at a range of flow angles to the main flow and broad-leaf trees tend to parallel tp the main flow, and those tendencies become stronger in debris flows. Influences of specific weight of wood on flow characteristics of mixture flow are significant.
2. Multilayer flow of sediment, water, conifer and broadleaf tree are formed due to differences of specific weights and those interactions. In debris flows, conifers on the free surface aggregate because of an increase of rotational movements, though broadleaf trees tend to be parallel to main flow. Woods tend to be easily captured in a channel in case of debris flows. However, in case of conifer and broadleaf tree mixtures, trapping rate in debris flow becomes small when supplying rate is 10 logs/s..

Especially, it seems that the interaction between conifers and broadleaf trees appears at some supply rate of logs.

The jamming and closeness of woods does not seem to depend on velocity of flow. Detailed considerations and collection of flume data on flow characteristics such as spatial eddy structures, diffusion/ dispersion of woods, momentum transfer induced by interactions of logs, mixture flow, and bed conditions are needed in order to evaluate those experimental data on movement of floating/submerged woods and the formation of multilayer.

ACKNOWLEDGMENTS: Parts of this study are supported by Research Budget from Research and Development Center, NIPPON KOEI Co., Ltd (Research theme: Modeling for debris flow with woods and their applicability).

REFERENCES


