

# Effect of climate and structure on the progression of wooden check dam decay

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**Abstract** To gain better understanding of rates of decay of wooden check dams with different structures under different climate conditions, several dams of this type were examined under different environmental conditions over a 3 to 5-year period post-construction. Because a linear relationship was found between the mean ( $\mu$ ) and standard deviation ( $\sigma$ ) of pilodyn penetration depth, mean penetration depth was taken as the indicator of deterioration, and relationships with check dam structural features and climate data recorded by AMEDAS were investigated. Multiple linear regression analysis revealed that temperature, climate index (CI) computed from rain days, warmth index computed from daily and annual mean air temperature, and altitude were the climate variables with the most effect on the rate of decay. With regard to dam structural features, factors such as specific discharge rate, water through width, dam length, and dam height had the most effect. Accordingly, in an effort to summarize the effects of climatic conditions and structural features, CI, altitude, and dam height were extracted as the most significant explanatory variables, and a formula for prediction of  $\mu$  was obtained for each factor for up to 5 years post construction. The results showed that by taking into consideration regional conditions and calculating CI values from AMEDAS data,

it is possible to predict the extent of decay of wooden check dams.

**Keywords** Climate conditions · Climate index · Decay · Structural features · Wooden check dam

## Introduction

Wooden check dams are small temporary or permanent structures constructed across creeks, gullies, swales, or other mountain watercourses, primarily to restrict erosion and reduce water speed during flooding. Numerous dams of this type have been installed at such locations across Japan. Although the institutions assuming responsibility for such structures have increased over the years, future maintenance of such dams is facing increasing problems with decay. In recent years, the Japan Society of Civil Engineers (JSCE) Wood Engineering Committee has become increasingly active in response to this situation (JSCE 2010). Currently, committee members are formulating and updating maintenance-management indicators while simultaneously pursuing new design and building methods to supplement current wooden check dams.

In this study the effects of climate conditions and structural features on wooden check dam decay were examined. Such decay has previously been discussed in the literature. For example, Akita et al. (2011) investigated wooden check dams in Nagano Prefecture and showed that advanced decay could be identified up to 6 years after construction. Because the investigation process enabled the state of decay to be quantified, and because it was determined that structural design, environmental conditions, and years elapsed post construction could be factored into the distribution curve, along with the mean ( $\mu$ ) and standard

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deviation ( $\sigma$ ) of pilodyn penetration depth, it is now considered possible to predict the progress of wood dam component decay over time.

In another study, lateral loading examinations were performed on wooden check dams in Akita Prefecture by use of a procedure that included removing the lug screws used for dam construction and conducting shear tests on these screws. This additional process, which is not normally done, facilitated quantitative evaluation of dam junction safety (Noda et al. 2012).

Similarly, to reduce costs, processes have been proposed for evaluation of optimum wooden check dam design. For example, stress distribution has been investigated by use of the finite element method (FEM) for analysis of joint pins, and safety ratios and cost relationships are now regarded as essential design criteria (Chida et al. 2012). Pilodyn penetration testing has shown that wooden check dam components can be distorted by decay. More specifically, the pilodyn penetration profile correlates strongly with decay, which suggests that pilodyn penetration testing provides useful data about wood density (Tabuchi et al. 2011).

In a separate effort to clarify the decay profile of wooden check dam components in relation to environmental conditions, Akita et al. (2007) examined the relationships between component decay and a variety of environmental factors, for example component temperatures, groundwater levels, and amount of clear sky that were specific to a wooden check dam in Nagano Prefecture. Their results clearly showed that rates of decay are significantly affected by structural features and environmental conditions. In contrast, even though a relationship between decay speed and high-water levels, warmth index, and maximum depth of snow coverage has previously been reported for specific wooden check dams, and even though a significant relationship between decay speed and warmth has been accepted as part of high-water level planning and decay speed forecasting for a Kyoto Prefecture dam constructed of Japanese Cedar (*Cryptomeria japonica*), it has not been related that maximum depth of snow coverage has any effect (Dang et al. 2008). In any event, before this study all reports have focused on investigations within a particular prefecture—there have been no reports of analysis of the effect of climate conditions on wooden check dam component decay in two or more prefectures. In a semi-related study of a wooden house in Toyama Prefecture, relationships among weather climate index, wood decay, and other climate conditions were investigated (Hasegawa and Iijima 1989; Hasegawa 1996). This study showed that increases in CI tended to reduce the duration period of a timbered house.

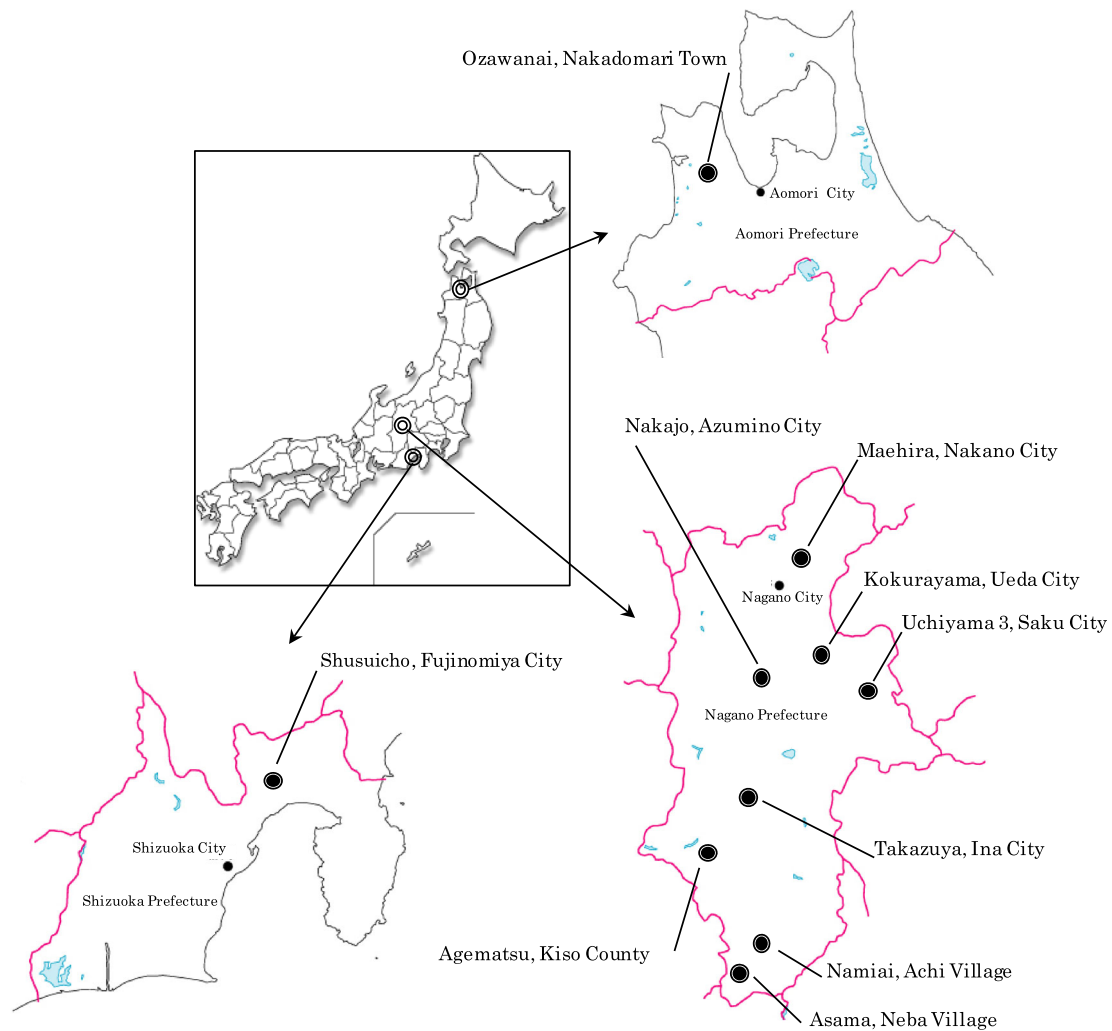
However, although progress is being made in determining wood decay profiles by examination of the history or stability of wooden check dams and homes, there have

been few investigations the decay of specific wooden check dam components, and overall relationships among climate, structural features, and decay progression remains unresolved. Accordingly, in this research, we attempted to clarify the climate conditions with the most effect on wooden check dams in the Japanese prefectures of Nagano, Shizuoka, and Aomori, which are subject to different climate conditions, and quantify the decay process of the dams inspected in those areas by means of a survey that took into consideration location climate and dam structure.

### Investigation sites

As shown in Fig. 1, we investigated wooden check dam sites in Nagano, Shizuoka, and Aomori Prefectures and studied the state of decay of dams constructed from Japanese Larch (*Larix kaempheri*) 5 years after construction and Japanese Cedar 3 years after construction. To clarify these decay states, and to assess climate and structure variables separately from the type of wood used for dam construction, we decided to combine and compare the post-construction periods for the two materials. Because all the wooden check dams examined in this study had trapezoid-type structures, it was assumed the structures would be sufficiently similar to enable investigations irrespective of the material (cedar or larch) used for their construction. During the investigation process, specimens with approximate diameters of 15.0–20.0 cm were excised from log components of the dam. It should be noted that each wooden check dam examined in our study was constructed according to standards established by the Forestry Agency of the Ministry of Agriculture, Forestry and Fisheries (MAFF), and that no significant differences in log component diameter were seen among them.

The climate conditions, structure, and materials used for each examined dam are listed in Table 1. Investigation sites were selected by examination of dam drawings, annual mean air temperatures, and annual mean precipitation, as recorded in Automated Meteorological Data Acquisition System (AMEDAS) observatory data from 2004 to 2010. Because no observatory data were available for the Asama dam site in Neba Village, Nagano Prefecture, data from the nearby Namiai Observatory were used instead. All inspected dam sites were located on mountain streams fed by contributory areas two kilometers or less in size, and where there was little constant water flow. Furthermore, the results of Akita et al. (2011) were used in investigation of two wooden check dams in Uchiyama 3 and Namiai, but results for the other eight wooden check dams are new.



**Fig. 1** Investigation sites

### Examination method

The time period covered by this study was from April 2007 to September 2011. The larch and cedar check dams had been in use for 5 years and 3 years, respectively.

To investigate soft decay, conventional penetration testing was performed by using a Proceq (Zurich, Switzerland) pilodyn to drive striker pins (max = 40.0 mm, diameter = 2.5 mm, 6 J) into the components inspected, after which radial depth of penetration into the interior of the component was measured. The pilodyn was read to an accuracy of 0.5 mm. In our study, the base recording range for pilodyn penetration was set between 1.0 and 40.0 mm. Cases resulting in penetration depths exceeding 40.0 mm were evaluated in a special category. However, it was felt that the 0–40 mm range would be sufficient for this research, which covered dams from three to five years from their construction dates, and thus in early stages of decay.

When components for measurement were selected, those arranged parallel to the direction of water flow (Fig. 2) were designated vertical components whereas those arranged perpendicularly to the water flow were classified as transverse members. Transverse members of the dam wing were chosen for decay investigation in this research. Because it was believed that running water affects the advance of the decay of a dam body, it was not chosen for measurement.

To compute a climate index, we totaled annual mean air temperatures, annual mean precipitation rates, and rain days per year from AMEDAS data collected nearest to the examination sites, as was mentioned in the previous section in which climate conditions were discussed. When creating a summary, the period 3–5 years post construction was totaled as the decay investigation time. Clear sky measurements were produced by averaging the total amount of sky visible in upward-directed photographs taken from each side of the wooden check dam, after which coverage

**Table 1** Inspection sites

Prefecture	Site	Structure of wooden check dam				Location and climate conditions				AMEDAS observatory			
		Completion year	Investigation year	Dam width (m)	Dam height (m)	Altitude (m)	Catchment area (km <sup>2</sup> )	Average annual temperature (°C)	Average annual precipitation (mm)	Average annual rain days (day)	Name	Altitude (m)	Distance to dam site (km)
<i>Larix kaempferi</i> , after 5 years													
Nagano	Uchiyama 3	2003	2008	8.5	2.1	850	0.17	10.8	956.8	102.8	Saku	683	11.4
	Kokurayama	2005	2010	17.5	3.2	520	3.90	12.2	958.1	109.4	Ueda	502	3.2
	Nakajo	2006	2011	9.0	2.1	620	0.05	12.2	1,118.3	108.0	Matsumoto	610	11.4
	Takazuya	2005	2010	19.5	3.1	1,080	0.09	11.8	1,627.9	126.0	Ina	633	7.8
	Agematsu	2006	2011	8.7	2.5	800	0.02	11.0	1,905.0	138.0	Kisofukushima	750	14.8
	Namiai	2003	2008	16.0	2.0	1,090	0.07	9.5	2,322.2	144.0	Namiai	940	2.7
<i>Cryptomeria japonica</i> , after 3 years													
Nagano	Maehira	2003	2006	8.5	2.1	660	1.25	11.5	1,395.9	169.8	Iiyama	313	19.3
	Asama	2004	2007	12.5	3.1	810	0.94	9.5	2,322.2	144.0	Namiai	940	25.7
Shizuoka	Shusuicho	2008	2011	15.0	3.0	600	0.33	16.3	2,363.0	132.0	Fuji	66	20.1
Aomori	Ozawanai	2006	2009	10.5	2.1	20	0.65	10.8	1,287.7	187.3	Goshogawara	9	19.4

computations were performed by use of analysis software (CanopOn2 and URL:<http://takenaka-akio.cool.ne.jp/etc./canopon2/>). In addition, wooden check dam structural features and type of wood were checked from drawings of the structure and of the planned vertical sections.

**Results and discussion**

Evaluating the progress of wooden check dam decay

In this research, the probability-distribution technique described by Akita et al. (2011) was used to evaluate wooden check dam decay. Because the state of decay can be predicted from the distribution curve of pilodyn penetration depth, the relationship between specific climate conditions and the mean and standard deviation of the distribution curve was investigated. According to Akita et al. (2011) pilodyn driving depth probability is normally distributed immediately after construction but becomes log normal after decay. Moreover, for wooden check dams in which decay was present the distribution curve is distorted in the positive direction. Equations (1) and (2) show the formulas for normal and log-normal distribution, respectively. Here,  $\mu$  is the mean value,  $\sigma$  the standard deviation, and  $x$  is class value of pilodyn penetration depth.

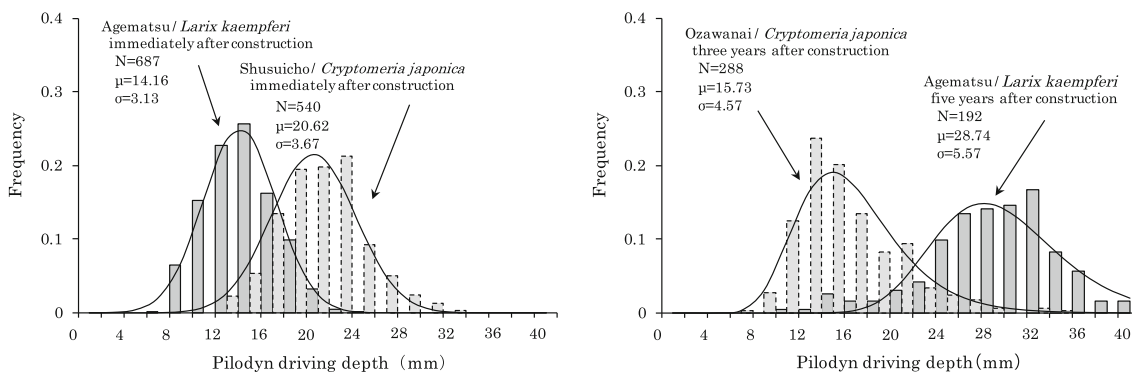
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{1}$$

$$f(x) = \frac{1}{\sigma x\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln x-\mu}{\sigma}\right)^2} \tag{2}$$

An example of the application of probability distributions to a wooden check dam for which advanced decay was recorded immediately after construction is shown in Fig. 3. Although the figures for immediate post-construction larch lumber dams were obtained from this result of research records and Akita et al. (2011), all results for post-construction cedar dams were collected during this study. Also immediately after construction of cedar dams, pilodyn driving depth can be expressed by a normal distribution, and decay grade can be evaluated from  $\mu$  and  $\sigma$  of the distribution curve. When larch and cedar post-construction distribution curves were compared, the difference between the values of  $\sigma$  was 0.54 mm (Shusuicho: 3.67 mm, Agematsu: 3.13 mm), which is quite low, whereas the difference between the values of  $\mu$  was approximately 6.5 mm (Shusuicho: 20.62 mm, Agematsu: 14.16 mm). Thus, it is believed there is a  $\mu$  difference of approximately 6.5 mm between the two types of wood. In Fig. 3, the 3-year post-construction value of 15.73 mm shown for a cedar dam in Ozawanai, Aomori Pref., is lower than its immediate post-construction value, and is comparable with the immediate



**Fig. 2** Positions of the components for which decay was measured (Shusuicho Dam, Fujinomiya City, Shizuoka Prefecture)



**Fig. 3** Distribution of pilodyn pin penetration depth

post-construction Shusuicho value of  $\mu$  (20.62 mm). Although it is believed that the density of a healthy wood component is affected by decay from the beginning of the post-construction period, the value also adds accuracy to analysis of relationships between rate of decay and specific climate conditions and structural features, because it is believed that the  $\mu$  value recorded 3 years post construction would be small, thus indicating that decay speed is also slow. Because wooden check dam decay can be approximated by use of a log-normal curve that now includes similar cedar dam measurements, the  $\mu$  and  $\sigma$  values can also be used for decay evaluation.

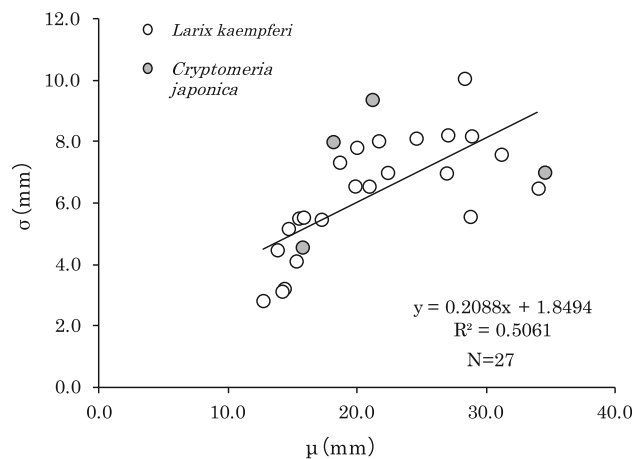
The new results obtained in this study and previously recorded data from Akita et al. 2011 and other locations are combined (2) in Fig. 4, where the relationship between  $\mu$  and  $\sigma$  is also shown.

$\mu$  and  $\sigma$  for pilodyn penetration depth are given by:

$$\sigma = 0.2088(\mu) + 1.8494 \tag{3}$$

$$R = 0.71^{***} \quad P = 0.0005 \quad (P < 0.001)$$

When  $\sigma$  increases slowly,  $\mu$  also increases. Because there is a linear relationship between  $\sigma$  and  $\mu$  we decided to use a broad range of values of  $\mu$ , 10–40 mm, for evaluation of the state of decay of wooden check dams.



**Fig. 4** Relationship between  $\mu$  and  $\sigma$  for pilodyn penetration depth

**Relationship between wooden check dam decay and climate conditions**

Calculation of climate index

To clarify the climate conditions with the greatest effect on the advance of wooden check dam decay, a variety of

climatic indices were compiled by use of climatic factors and AMEDAS data. Because amounts of wood decay depend on such weather indexes as the aridity index (AI) and the warmth index (WI) by Hasegawa (1996), it can be assumed that CIs are highly relevant. Theodora (1971) first defined CI as an overview that includes elements of each climate factor and used it to calculate the active mass of a wood-rotting fungus from the product of calculations involving temperatures and rain days. The AI was created by Martonne (1942) to improve the rainfall factor (RF) calculation of Lang, and it is used to express the soil climate conditions. In forestry science, WI is a general index mostly used to express the correlation of vegetation and temperature. Because significant activity occurs in both categories under the high-temperature environmental conditions when wood-rotting fungus is present, it was decided to summarize and compute the relationship of these data with others. Equations (4), (5), and (6) cover the various climate factors used in this study. Here, the  $t$  of Eq. (4) is the monthly mean temperature (°C), and  $d$  is the monthly total of rain days (day). In Eq. (5),  $P$  is the annual precipitation (mm),  $T$  is the annual mean temperature (°C). In Eq. (6),  $a$  is the monthly mean temperature (°C).

$$\text{Climate Index (CI)} = \frac{\Sigma(t - 2.0)(d - 3.0)}{16.7} \tag{4}$$

$$\text{Aridity Index (AI)} = \frac{P}{T + 10.0} \tag{5}$$

$$\text{Warmth Index (WI)} = \Sigma(a - 5.0) \tag{6}$$

Various climate conditions and decay

Our calculation results, including  $\mu$  and  $\sigma$  values, CI, and the amount of clear sky, are listed in Table 2, and the

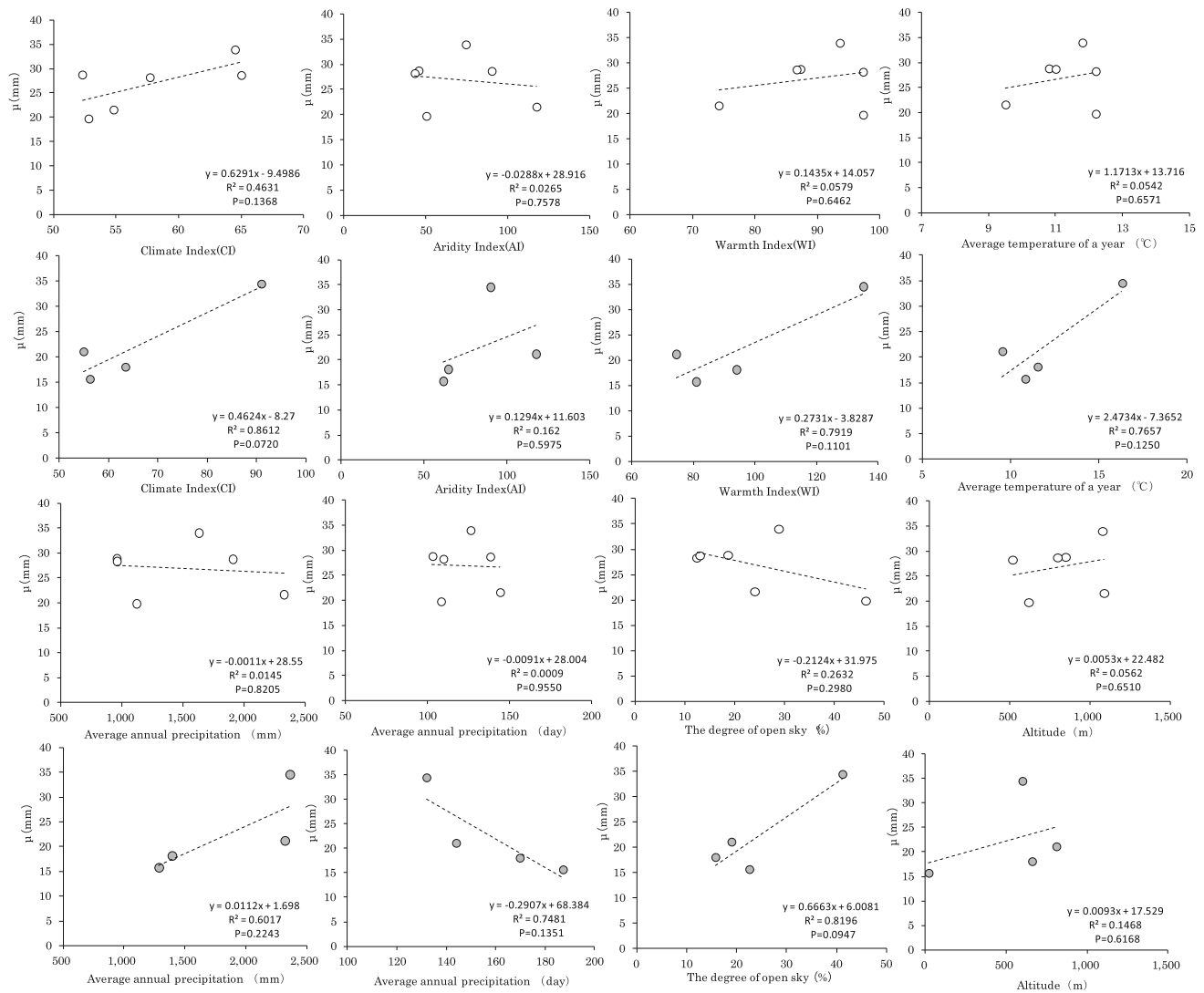
relationships between wooden check dam decay and different climate conditions are shown in Fig. 5. For Japan’s CI distribution, Hasegawa (1996) showed a Scheffer distribution map of the Nagano area with ranges of 50–60 and 70–80 near Shizuoka and 40–50 in Aomori Prefecture. These values are in agreement with our results.

The relationship between CI and  $\mu$  tends to be very strong, and for wooden check dams of larch and Japan cedar  $\mu$  increases as CI increases. A relationship between  $\mu$  and WI is also observed for larch. However, because the only numerical values available for this material were collected from Nagano Prefecture, the WI range was narrow and the relationship results were deemed inconclusive. However, it does seem that  $\mu$  also increases. Accordingly, these data were added to the national cedar data. However, no clear relationship could be detected between  $\mu$  and AI. No effort was made to examine precipitation, rain days, and the amount of clear sky, even though unused climate could be expected to be related to the  $\mu$  value. The upward right slanting tendency has been checked against annual means for air temperature and altitude. Snowfall and rain days are also included in the AMEDAS precipitation data, and it is expected that they would have similar effects.

It should be noted that the CI is a product of monthly mean temperature and monthly rain days. Thus, it is directly associated with wood decay via the factors of temperature and moisture. The relationship between CI and  $\mu$  shows that decay relationships among different independent factors are better than those using a single factor alone. Dang et al. (2008) reported no relationship between WI and decay speed, but when their data were compared with results from a study in Nagano Prefecture, a slightly weak but identifiable relationship was observed between WI and wooden check dam decay. Next,  $\mu$  was correlated

**Table 2** Calculation results

Site	$\mu$ (mm)	$\sigma$ (mm)	CI	AI	WI	Average annual temperature (°C)	Average annual precipitation (mm)	Average annual rain days (day)	Amount of clear sky (%)	Altitude (m)	AMEDAS observatory
<i>Larix kaempheri</i> , after 5 years											
Uchiyama3	28.85	8.19	52.3	45.5	87.3	10.8	956.8	102.8	18.7	850	Saku
Kokurayama	28.30	10.07	57.7	43.1	97.3	12.2	958.1	109.4	12.5	520	Ueda
Nakajo	19.81	6.56	52.8	50.2	97.4	12.2	1,118.3	108	46.3	620	Matsumoto
Takazuya	34.01	6.49	64.5	74.3	93.6	11.8	1,627.9	126	28.9	1,080	Ina
Agematsu	28.74	5.57	65.0	90.1	86.7	11.0	1,905.0	138	13.1	800	Kisofukushima
Namiai	21.64	8.03	54.8	117.4	74.2	9.5	2,322.3	144	24.1	1,090	Namiai
<i>Cryptomeria japonica</i> , after 3 years											
Maehira	18.11	8.01	63.3	64.4	93.8	11.5	1,395.9	169.8	15.7	660	Iiyama
Asama	21.15	9.38	54.8	117.4	74.2	9.5	2,322.3	144	18.9	810	Namiai
Shusuicho	34.51	7.01	90.9	89.9	135.1	16.3	2,363.0	132	41.2	600	Fuji
Ozawanai	15.73	4.57	56.1	61.4	80.7	10.8	1,287.7	187.3	22.5	20	Goshogawara



**Fig. 5** Relationships among wooden check dam decay and climate conditions. *Open circles, Larix kaempferi* after 5 years; *filled circles, Cryptomeria japonica* after 3 years

with the amount of clear sky and altitude. Although a relationship with altitude was observed, temperature, precipitation, and amount of clear sky did not have strong effects. Because sudden temperature falls and high levels of precipitation typify high-altitude environments, it was thought likely that wooden check dam decay would advance easily in such locations.

### Relationship between wooden check dam decay and structural features

#### Wooden check dam structural features

To clarify the relationship between wooden check dam decay and structural features, previously established

wooden check dam data, for example water throughway width and dam length, were obtained from structure drawings and planned vertical section drawings. In particular, water depth (uniform flow depth) was based on flood flow computed by use of a rational method based on time at a specific discharge rate during flood conditions. To calculate flood flow, by use of formula, from intensity of rainfall applicable to each area, the probability of excessive rainfall was defined as 100-year exceedance probability rainfall for every area, after which flood times and average rainfall intensities were calculated. By use of Manning formula calculation for processing uniform flow depth, the relative roughness coefficient was found to take the average value of the mountain land channel, 0.03–0.05 (see Ministry of land, infrastructure, transport and tourism 2012), and a value of 0.04 was applied.

### Relationship between structure and decay

Wooden check dam structural features and their related  $\mu$  and  $\sigma$  values are listed in Table 3, and the relationship between structural features and wooden check dam decay is shown in Fig. 6. Because numerous wooden check dams have been constructed across small mountain streams below a first order valley, specific discharge levels are usually approximately  $7.1\text{--}34.4 \text{ m}^3 \text{ s}^{-1} \text{ km}^{-2}$ , which is regarded as small, and uniform flow depths are normally 1.0 m or less.

However, some dam sites have numerous steep slopes because they are located in the upper regions of river basins. Under such conditions, when different structural features are compared with  $\mu$ , a faint relationship with specific discharges can be observed. However, these relationships were not accepted as typical for stream bed slope and uniform flow depth. Furthermore, although the relationship between dam wing height and  $\mu$  is weak, an increase in  $\mu$  is also observed, enabling its use to enlarge a scale that includes water through width, dam length, and dam quantity. Because it is evident that wooden check dam structural features are directly related to the water environment, and a relationship is seen between specific discharge rates, it is apparent that water factors, for example contributory area and precipitation, affect decay rates. On the other hand, because the uniform flow depth is weakly related to streambed slope and  $\mu$ , the effect of this factor on decay rates is small. Furthermore, because relationships between  $\mu$  and factors such as water throughway width, dam length, and dam quantity have been demonstrated, the scale of a wooden check dam itself can be said to affect its rate of decay. When the river at a dam site is wide, and when a dam body is constructed to a specific height, high humidity will be maintained within the sleeve and it is believed such conditions facilitate decay. When dam length is 15 m or more and dam height is 3 m or more the rate of decay becomes large.

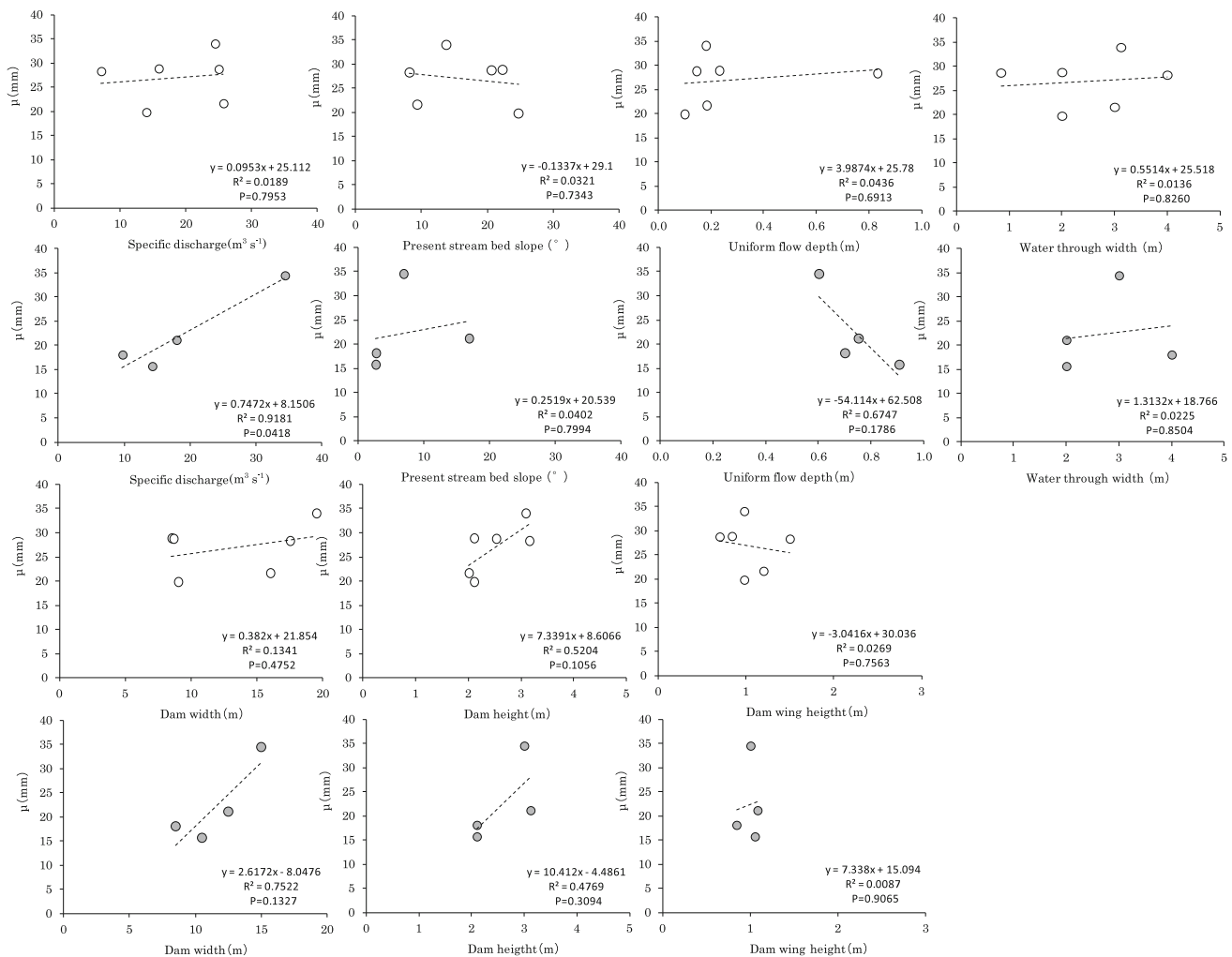
### Multiple linear regression analysis

To consider relationships among wooden check dam decay, climate conditions, and structural features, we conducted multiple linear regression analysis for each combination of factors to clarify effects on  $\mu$  values. Because multiple linear regression analysis is based on a step-down method, by conducting multiple linear regression analysis using all climate conditions and structural features as explanatory variables, factors with little effect are gradually removed, leaving the final explanatory variable. For climatic index, relevant CIs were chosen on the

**Table 3** Wooden check dam structural features

Site	$\mu$ (mm)	$\sigma$ (mm)	Catchment area (km <sup>2</sup> )	Probable daily rainfall (mm day <sup>-1</sup> )	Flood flow (m <sup>3</sup> s <sup>-1</sup> )	Specific discharge (m <sup>3</sup> s <sup>-1</sup> )	Stream bed slope (1 n <sup>-1</sup> )	Stream bed slope (°)	Uniform flow depth (m)	Water through width (m)	Dam width (m)	Dam height (m)	Dam wing height (m)
<i>Larix kaempferi</i> , after 5 years													
Uchiyama3	28.85	8.19	0.17	191.30	2.70	15.9	2.4	22.3	0.23	2.00	8.50	2.10	0.84
Kokurayama	28.30	10.07	3.90	138.47	27.80	7.1	7.0	8.2	0.83	4.00	17.50	3.15	1.50
Nakajo	19.81	6.56	0.05	146.85	0.70	14.0	2.2	24.7	0.10	2.00	9.00	2.10	0.98
Takazuya	34.01	6.49	0.09	252.88	2.20	24.4	4.1	13.8	0.18	3.12	19.50	3.08	0.98
Agematsu	28.74	5.57	0.02	227.93	0.50	25.0	2.7	20.6	0.15	0.84	8.65	2.52	0.70
Namiai	21.64	8.03	0.07	252.88	1.80	25.7	6.1	9.4	0.18	3.00	16.00	2.00	1.20
<i>Cryptomeria japonica</i> , after 3 years													
Maehira	18.11	8.01	1.25	156.69	12.10	9.7	21.0	2.7	0.70	4.00	8.50	2.10	0.84
Asama	21.15	9.38	0.94	252.88	16.80	17.9	3.3	16.9	0.75	2.00	12.50	3.12	1.08
Shusicho	34.51	7.01	0.33	384.53	11.20	34.4	8.3	6.9	0.60	3.00	15.00	3.00	1.00
Ozawanai	15.73	4.57	0.65	200.86	9.20	14.2	21.4	2.7	0.91	2.00	10.50	2.10	1.05





**Fig. 6** Wooden check dam decay and relationships with structural features. *Open circles, Larix kaempferi* after 5 years; *filled circles, Cryptomeria japonica* after 3 years

basis of multicollinearity because of overlap of temperature and rain days, used as factors of CI.

Because the purpose of this study was to clarify the environmental conditions and structural features that have the greatest effect on wooden check dam decay, the different examination periods (3 years for cedar and 5 years for larch) were not taken into consideration. It was also believed there were few samples of cedar and larch for statistical analysis. However, multiple linear regression analysis was conducted to unify such data. These results, with a climate condition  $\mu$  value for each structural feature, are shown in Table 4. At this point in the step-down method, two factors, CI and altitude, remained. These are given in Eq. (7), where  $x1$  is CI and  $x2$  is altitude.

$$\mu = 0.35x1 + 0.01x2 - 3.44 \quad (7)$$

$$R = 0.75 \quad P = 0.0571 \quad (p < 0.1)$$

CI and altitude selected as predictor variables are significant at the level  $p \leq 0.1$ . The  $p$  value for Eq. (7) showed that  $\mu$  was affected by CI. Because increasing altitude is usually associated with temperature reduction of  $0.6 \text{ }^\circ\text{C}/100 \text{ m}$ , and because precipitation increases with altitude, it partly overlaps the CI.

At this point of our examination of structural features, two factors, specific discharge rates and dam height remained. These are shown in Eq. (8), where  $x1$  is the specific discharge and  $x2$  is the dam height.

$$\mu = 0.36x1 + 6.83x2 + 1.07 \quad (8)$$

$$R = 0.76 \quad P = 0.0511 \quad (P < 0.1)$$

Specific discharge and dam height selected as a predictor variables are significant at the level  $p \leq 0.1$ . The  $p$  value for Eq. (8) showed that  $\mu$  was affected by dam height.

**Table 4** Multiple linear regression analysis results combining climate and structural features

Item	Symbol used in multiple regression formula	Regression coefficient	<i>t</i>	<i>p</i>	Simple correlation coefficient		
					$\mu$	CI	Altitude
Section		-3.44	-0.34	0.74			
$\mu$	<i>y</i>				1.00		
CI	<i>x1</i>	0.35	2.41	0.05	0.59	1.00	
Altitude	<i>x2</i>	0.01	1.84	0.11	0.44	-0.04	1.00

Item	Symbol used in multiple regression formula	Regression coefficient	<i>t</i>	<i>p</i>	Simple correlation coefficient		
					$\mu$	Specific discharge	Dam height
Section		1.07	0.12	0.90			
$\mu$	<i>y</i>				1.00		
Specific Discharge	<i>x1</i>	0.36	1.79	0.12	0.56	1.00	
Dam height	<i>x2</i>	6.83	2.04	0.08	0.61	0.21	1.00

The different examination periods (3 years for cedar and 5 years for larch) were not taken into consideration

**Table 5** Integrated results from multiple linear regression analysis

Item	Symbol used in multiple regression formula	Regression coefficient	<i>t</i>	<i>p</i>	Simple correlation coefficient			
					$\mu$	CI	Altitude	Dam height
Section		-8.46	-0.91	0.40				
$\mu$	<i>y</i>				1.00			
CI	<i>x1</i>	0.23	1.71	0.14	0.59	1.00		
Altitude	<i>x2</i>	0.01	1.70	0.14	0.44	-0.04	1.00	
Dam height	<i>x3</i>	5.04	1.41	0.21	0.61	0.42	0.13	1.00

The different examination periods (3 years for cedar and 5 years for larch) were not taken into consideration

Multiple linear regression analysis conducted with explanatory variables chosen from climate conditions and structural features led to Eq. (9), where *x1* is the CI, *x2* is altitude, and *x3* is dam height. Because the *p* value was low, specific discharge was removed from Eq. (9).

$$\mu = 0.23x1 + 0.01x2 + 5.04x3 - 8.46 \tag{9}$$

$$R = 0.82 \quad p = 0.691 \quad (P < 0.1)$$

The final results from multiple linear regression analysis are listed in Table 5. CI, altitude, and dam height, selected as a predictor variables, are significant at the level  $p \leq 0.1$ . The *p* value for Eq. (9) showed that  $\mu$  was affected by CI and altitude. Climate conditions are believed to have a greater effect than structural features on the decay of wooden check dams. Therefore, the state of decay of wooden check dams can be obtained by calculating CI from AMEDAS observatory data and use of the multiple regression formula for  $\mu$ .

**Conclusions**

During the course of this study it was sometimes necessary to conduct wide-ranging on-site investigations of wooden check dams, and to collate the data obtained for use and storage in another prefecture where CI(s) differed. The multiple regression formula for  $\mu$  can be used for wooden check dams constructed from either Japanese cedar and larch for approximately 5 years after construction. Although, by use of multiple linear regression analysis, it is possible to predict some decay behavior on the basis of three factors, data are accumulated strictly on the basis of wood type or time, so efforts to improve the accuracy of prediction will be necessary in the future.

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