Internationales Symposion
INTERPRAEVENT 2004 – RIVA / TRIENT

# STABILITÄT, HORIZONTALES WIDERSTANDSMOMENT UND REIBUNGSKOEFFIZIENT BEI KLEINEN HOLZDÄMMEN

# STABILITY, HORIZONTAL RESISTANCE MOMENT AND FRICTION COEFFICIENT FOR SMALL WOODEN DAMS

Yoshiharu Ishikawa[1] and Mizuki Asada[2]

## ZUSAMMENFASSUNG

Die vorliegende Studie untersuchte im Rahmen von Feldversuchen die Stabilität, das horizontale Widerstandsmoment und den Reibungskoeffizient bei kleinen Holzdämmen. An sechs kleinen, im Landkreis Kioto, Japan, errichteten Holzdämmen mit einer Höhe zwischen 1,30 und 2,89 m wurden horizontale Belastungsversuche durchgeführt. Die Ergebnisse bestätigten, dass ein Design, welches eine gewisse Zugbelastung am flussaufwärts gelegenen Ende des Dammes zulässt, dazu geeignet ist, Holzpfahlwanddämmen ihre Funktion erfüllen zu lassen. Das bei horizontalen Belastungstests gemessene horizontale Widerstandsmoment der Dämme war auf Grund von Berechnungen nach bestehenden Formeln mindestens 1,50 Mal größer als das Scherwiderstandsmoment von mit Rollkies gefüllten, hohlen Stahlkonstruktionen. Diese Tests zeigten ebenfalls, dass der Reibungskoeffizient zwischen der Dammbasis und dem Fundamentboden einen Wert von mindestens 0,79 hatte. Auf Grund dieser Ergebnisse wurden rationale Bedingungen für die Berechnung der Stabilität, des horizontalen Widerstandsmoments und des Reibungskoeffizienten bei kleinen Holzdämmen vorgeschlagen.

**Key words:** kleiner Holzdamm, Stabilität, horizontales Widerstandsmoments, Reibungskoeffizient, horizontaler Belastungsversuch

1 Associate Professor, Laboratory of Forest Environment, Faculty of Agriculture, Tokyo University of Agriculture and Technology, Saiwai-cho 3-5-8, Fuchuu-city, Tokyo, 183-8509, Japan (Tel. & Fax.: +81-42-367-5826, email: y_ishi@cc.tuat.ac.jp)

2 Engineer, Fukuchiyama Regional Promotion Office, Kyoto Prefectural Government, Sinooshinmachi 1, Fukuchiyama, Kyoto, 620-0055, Japan

## ABSTRACT

This study examined the stability, horizontal resistance moment and friction coefficient for small wooden dams by field tests. Horizontal loading tests were conducted on six small wooden dams with a height of 1.30 – 2.89 m which were constructed in five streams in Kyoto Prefecture, Japan. The results confirmed that a design which allows tensile stress to occur at the upstream end of the dam is appropriate for allowing wooden crib dams to fulfill their functions. The horizontal resistance moment of the dam body measured in the horizontal loading tests was at least 1.50 times larger than the shearing resistance moment of cobblestones filled in steel hollow erosion control structures calculated by the existing formula. The tests also showed that the friction coefficient between dam base and foundation ground was at least 0.79. Based on the results, rational conditions for calculating the stability and rational horizontal resistance moment and friction coefficient of wooden dams are proposed.



**Key words:** small wooden dam, stability, horizontal resistance moment, friction coeffcient, horizontal loading test


## INTRODUCTION

There has been a growing trend in Japan towards using wood, which is ecosystem-friendly, renewable, and environmentally friendly, to build small check dams. Since, however, there had been few small wooden dams in Japan until recently; research has lagged behind the need for the establishment of standards for planning, design, construction and maintenance methods, hampering the widespread use of wooden dams. Much is yet to be known about stability, horizontal resistance moment and friction coefficient, which need to be known if safe and rational designs of small wooden dams are to be produced. In this study, horizontal loading tests were conducted on six small wooden dams of different types and heights built in Kyoto Prefecture to measure such parameters as horizontal loads applied and displacement of the dams. The field test results thus obtained were used to investigate stability, horizontal resistance moment and friction coefficient for wooden dams.

## OUTLINE OF WOODEN DAMS

The six small wooden check dams studied are located in Kyoto Prefectural University (KPU)'s Kuta research forest in Sakyo Ward, Kyoto City; KPU's Oe research forest in Nishikyo Ward, Kyoto City; and Tango Town, Maizuru City and Keihoku Town, all in Kyoto Prefecture (Figure 1). Table 1 summarizes data on these wooden dams. Horizontal loading tests were conducted on all of the wooden dams shown in Table 1, and earth pressure and water pressure measurements were conducted at the dams in Tango Town and Keihoku Town. Details of the earth pressure and water pressure measurements have already been reported (Ishikawa *et al.*, 2000, 2002). All dams listed in Table 1 were built with thinned Japanese cedar (*Cryptomeria japonica*) or Japanese cypress (*Chamaecyparis obtusa)*. The Tango-town dam is a λ–shaped type filled with crushed stones; the dam in the Oe research forest is a single-wall type filled with locally available silty gravels; and the other dams are typical double-wall type wooden crib dams filled with a mixture of cobbles and rubble plus a small quantity of crushed stones.

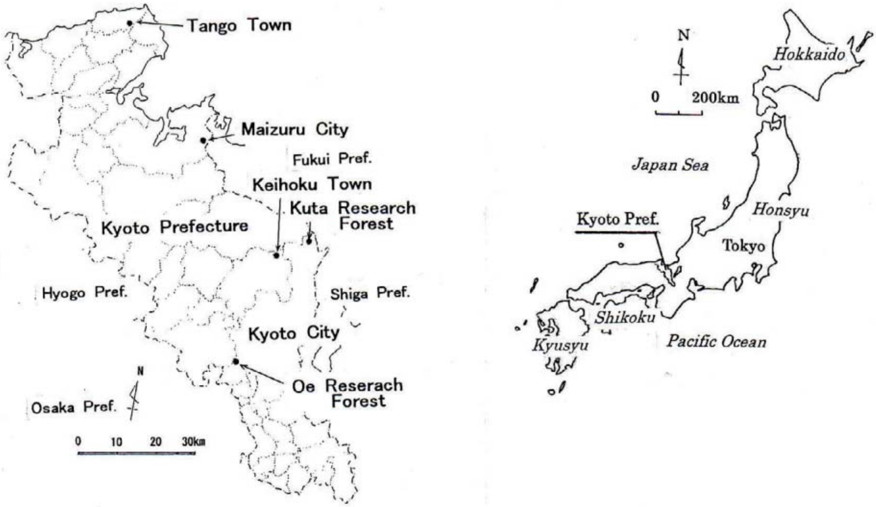


**Abb.1:** Lage der Holzdämme im Landkreis Kioto

**Fig.1:** Locations of wooden check dams in Kyoto Prefecture

**Tab.1:** Zusammenfassung der Daten 6 kleiner, im Landkreis Kioto errichteten Holzdämme

**Tab.1:** Summary of data on six wooden crib dams built in Kyoto Prefecture

| FY of completion | 1998 | 1999 | 1999 | 1999 | 2000 | 2000 |
|---|---|---|---|---|---|---|
| Site of dam | Kuta | Tango | Keihoku(A) | Oe | Maizuru | Keihoku(B) |
| Type of dam | Triple-wall | λ-shaped | Double-wall | Single-wall | Double-wall | Double-wall |
| Height of dam(m)<br>(in test) | 1.50<br>(1.40) | 2.21<br>(1.87) | 1.87<br>(1.87) | 1.30<br>(1.15) | 2.55<br>(2.55) | 2.89<br>(2.55) |
| Length of dam(m)<br>(in test) | 5.15<br>(1.75) | 21.5<br>(2.0) | 18.5<br>(2.0) | 5.8<br>(2.15) | 12.0<br>(2.0) | 16.0<br>(2.0) |
| Total width of dam(m)<br>(in test) | 1.8<br>(1.4) | 4.4<br>(1.8) | 2.0<br>(1.8) | 2.0<br>(1.75) | 2.0<br>(1.8) | 2.0<br>(1.8) |

## METHOD OF HORIZONTAL LOADING TESTS

Horizontal loading tests were conducted to investigate the strength of the six wooden dams against sliding and toppling. The test method is as follows. After completion of the dam body, a jack and a load cell were installed on the upstream face of the dam. Horizontal displacement measuring instruments were installed in the highest, upper, middle-upper, middle, middle-lower, lower and lowest parts of the downstream face of the dam, and vertical displacement measuring instruments were installed at the upstream and downstream ends of the dam. In the tests, horizontal loads applied by the hydraulic jack were increased in increments of 4.9 kN (0.0, 4.9, 9.8, 14.7 kN and so on), and the horizontal displacement of the downstream end of the dam and the vertical displacement of the top of the dam were measured with the instruments installed on the dam. As an example, Figure 2 is a schematic of a wooden dam constructed in Maizuru City, and Figure 3 is a schematic of the horizontal loading apparatus used for the dam. Figure 4 was taken during the horizontal loading test conducted at the same dam. On the basis of the relationship between horizontal force acting on the dam and horizontal displacement, the strength and other characteristics of the dam were investigated.

## RESULTS OF HORIZONTAL LOADING TESTS AND DISCUSSION

The stability of each wooden dam, the horizontal resistance moment of the dam, and the coefficient of friction between the underside of the dam and the foundation ground were investigated on the basis of the results of the horizontal loading tests and of the current design methods and the design guidelines for existing concrete dams and steel dams. The methods of study used for the six dams subjected to the horizontal loading tests are almost identical. As an example, therefore, this section reports on the wooden dam in Maizuru City, which is a double-wall type crib structure, the most common type among the six wooden dams considered here.

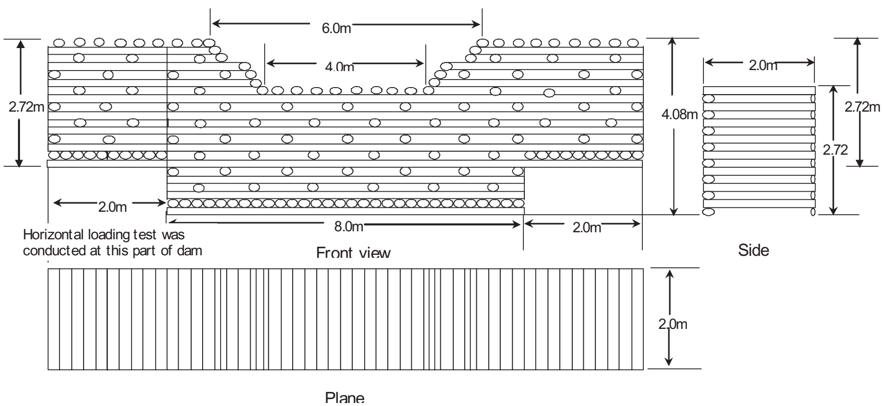


**Abb.2**: Schematische Darstellung des in Maizuru errichteten Doppelwand Holzpfahldammes

**Fig. 2**: Schematic figure of double-wall type wooden crib dam built in Maizuru

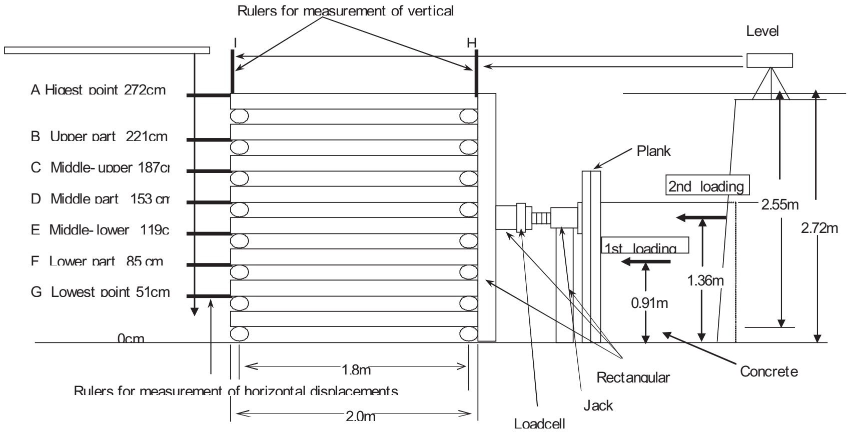


**Abb.3:**Schematische Darstellung der horizontalen Belastungsversuche am in Maizuru errichteten Holzpfahldammes

**Fig. 3:** Schematic figure of horizontal loading tests of a wooden crib dam in Maizuru

**Abb.4:** Horizontale Belastungsversuche an einem in Maizuru errichteten Holzpfahldammes

**Fig.4:** Horizontal loading tests of a wooden crib dam in Maizuru

## Test results for the wooden dam in Maizuru City and stability of the dam

Figure 2 is a schematic of the wooden dam built in Maizuru City, and Figure 3 is a schematic of the loading test. Figures 5 to 8 show the relationship of the loading moment (horizontal load applied times the loading height from the timber base) with horizontal displacement and vertical displacement. Figures 9 and 10 show the relationship between the applied load and horizontal displacement. In the first loading, the horizontal displacements of the upper and lower parts of the dam were as large as more than 50 mm, so it is likely that sliding occurred. It was observed in the test that since the timber base and the sill bracing were connected by cramps alone, the sliding at the final stage of the first loading occurred between the timber base and the sill bracing. In the second loading, displacements in the upper part of the dam were large, while horizontal displacements in the lower part of the dam were small. In the second loading, uplift (of more than 40 mm) also occurred at the upstream end of the dam. This indicates that toppling began at the final stages of loading. The inspection of the wooden dam conducted after the horizontal loading test revealed no marked deformation or damage, and the dam was found to be functional.

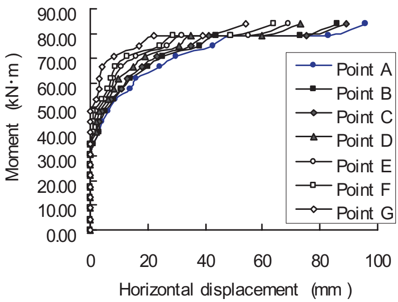


**Abb.5:** Momente und horizontale Verlagerungen bei horizontalen Belastungsversuchen (Maizuru, erste Belastung)

**Fig.5:** Moment and horizontal displacement in the horizontal loading tests (Maizuru, 1st loading)

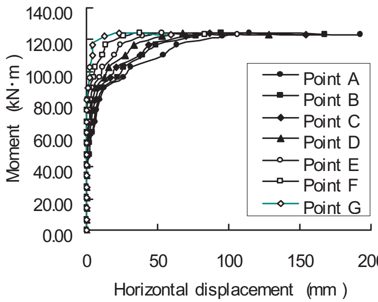


**Abb.6:** Momente und horizontale Verlagerungen bei horizontalen Belastungsversuchen (Maizuru, zweite Belastung)

**Fig.6:** Moment and horizontal displacement in the horizontal loading tests (Maizuru, 2nd loading)

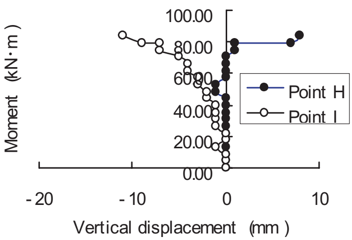


**Abb.7:** Momente und vertikale Verlagerungen bei horizontalen Belastungsversuchen (Maizuru, erste Belastung)

**Fig.7:** Moment and vertical displacement in the horizontal loading tests (Maizuru, 1st loading)

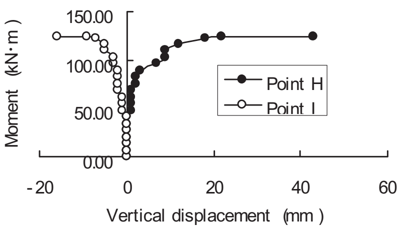


**Abb.8:** Momente und vertikale Verlagerungen bei horizontalen Belastungsversuchen (Maizuru, zweite Belastung)

**Fig.8:** Moment and vertical displacement in the horizontal loading tests (Maizuru, 2nd loading)

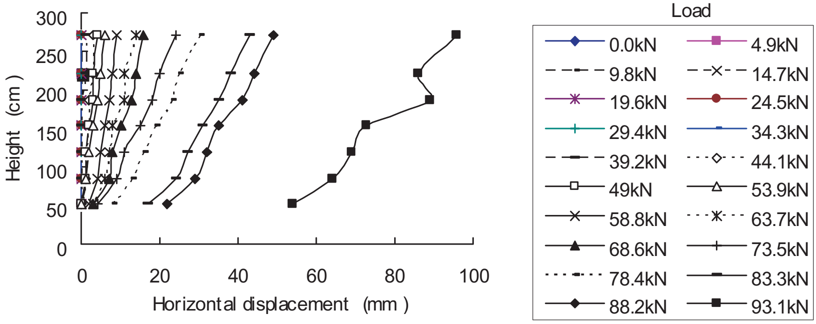


**Abb9:**Belastung und horizontale Verlagerungen bei horizontalen Belastungsversuchen (Maizuru, erste Belastung)

**Fig.9:** Load and horizontal displacement in the horizontal loading tests (Maizuru, 1st loading)

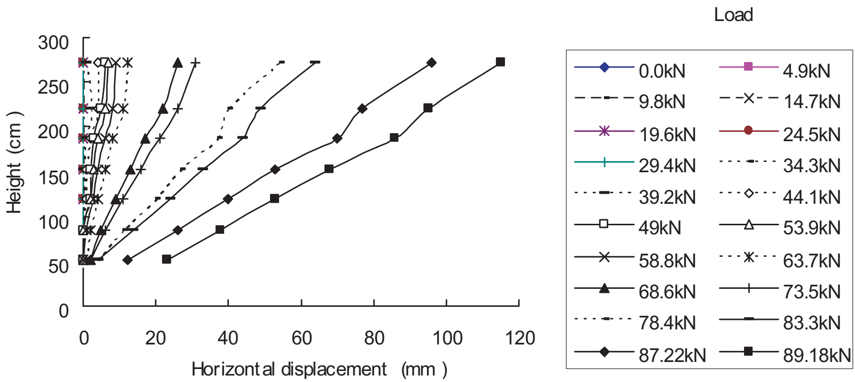


**Abb.10:**Belastung und horizontale Verlagerungen bei horizontalen Belastungsversuchen (Maizuru, zweite Belastung)

**Fig.10:** Load and horizontal displacement in the horizontal loading tests (Maizuru, 2nd loading)

As shown in Figures 5 to 10, the maximum moment per 2.0 m of length was 121.41 kN·m (second loading), and the maximum horizontal load was 93.17 kN (first loading). These translate to a maximum moment of 60.71 kN·m per meter of dam length and a maximum horizontal load of 46.59 kN per meter of dam length.

The average diameter of the logs used was about 0.25 m. Since the logs were sawn on two sides so that the sawn logs became 17 cm thick, the average cross-sectional area of the timber used was 0.039 m$^2$. The measured unit weight of the timber, $r_L$, used was 5.88 kN/m$^3$, and the measured unit weight of the cribfill, $r_S$, was 18.34 kN/m$^3$. Since the volume ratio between the timber and the cribfill stones was 0.24 : 0.76, the average unit weight of the dam, $r_D$, was 15.35 kN/m$^3$.

Table 2 shows forces acting on unit length of the wooden dam (dam height: 2.55 m, total height: 2.72 m) at the time of its completion. The forces were calculated using the method proposed by Ishikawa et al. (2002). Horizontal moment and horizontal force acting on the main structure of the dam per meter of length due to the earth pressure acting on the upstream side of the dam are 22.69 kN·m and 24.15 kN, respectively. Let us determine whether the resultant of the forces acting on the dam under the influence of the self-weight of the dam and overflowing water, and earth pressure is located with the middle third of the base width (*B*) of the dam. $1/3 \times B = 0.60$ m $< X = 95.66/81.08 = 1.18$ m $< 2/3 \times B = 1.20$ m, therefore, the resultant mentioned above is located within the middle third of the base width of the dam, indicating that the dam is sufficiently safe against toppling. In this case, the factor of safety against toppling was 72.97/22.69=3.22.

Next, let us consider stresses acting at the downstream end and the upstream end of the dam base. The stresses acting at the upstream end and the downstream end of the dam are $\sigma_d = -86.94$ kN/m$^2$ (compression) and $\sigma_u = -3.15$ kN/m$^2$ (compression). Since these values are smaller than the bearing capacity (with a specified factor of safety) of the ground of 250 kN/m$^2$, the dam can be deemed safe. The factor of safety against sliding, if the coefficient of friction is 0.70, is $F_s$=81.08×0.7/24.15=2.35, which means the dam is safe against sliding. The factor of safety is 2.01 (i.e., the dam is safe) even if the coefficient of friction is 0.6. The shear deformation resistance moment of the cribfill is, when calculated by using Kitajima's formula (Kitajima 1962) used in *Guidelines for Design of Steel Sabo Structures* (Committee of Steel

**Tab.2:** Auf den Holzpfahldamm in Maizuru einwirkende Kräfte und Momente (pro Meter Länge, Einheiten: kN, m)

**Tab.2:** Forces and moment acting on wooden crib dam in Maizuru (per 1m length, Unit;kN,m)

| | Symbol | Equation | Vertical force | Horizontal force | Distance | Moment |
|---|---|---|---|---|---|---|
| Weight of dam body | $W_d$ | 1.8×2.55×15.35 | 70.46 | | 0.90 | 63.41 |
| Weight of over-flow water | $W_w$ | 1.8×0.5×11.8 | 10.62 | | 0.90 | 9.56 |
| Thrust due to earth pressure | $E_1$ | (1/3)×2.55 ×0.5×11.8 | | 5.02 | 1.28 | 6.43 |
| | $E_2$ | (1/6)×2.55$^2$×17.65 | | 19.13 | 0.85 | 16.26 |
| Total | | | ΣV=81.08 | ΣH=24.15 | | ΣM=95.66 |

Sabo Structures 2001), is 33.41 kN·m. Since rubble was used as cribfill, the internal friction angle $\varphi$ of the cribfill was assumed to be 40 degrees in the calculation. The factor of safety associated with the shear deformation resistance moment of the cribfill is $F_d$=33.41/22.69=1.47, which means a safe condition because it is greater than the criterion value of 1.20.

The coefficient of friction measured in the horizontal loading test of the wooden dam in Maizuru City was f'=46.59/70.46=0.66. Our observation revealed that because the timber base and the sill bracing were connected by cramps alone, the sliding at the final stage of the first loading occurred between the timber base and the sill bracing. This coefficient of friction, therefore, can be considered to indicate the coefficient of friction between wood surfaces.

Consequently, the coefficient of friction between a wood surface and the ground surface should be greater than 0.66. The measured value of shear deformation resistance of the cribfill per meter of length was 60.71 kN·m, which is considered to be rather great because it is 1.82 as large as the theoretical shear deformation resistance of 33.41 kN·m calculated by Kitajima's formula. After the test, no major damage was found on the dam, so the wooden dam in Maizuru City was judged stable.

**Horizontal loading test results for the six wooden dams and evaluation of their stability**

Table 3 summarizes the horizontal loading test results for the six wooden dams and the results of evaluation of the stability of those dams. As Table 3 indicates, only in the case of the wooden dam (dam height: 2.89 m, total height: 3.06 m) built in Oshio, Keihoku-cho, in 2001, the resultant of forces acting on the dam does not fall within the middle third of the base width. This indicates that tensile force acts on the upstream side of the dam. This tensile force ($F_t$=0.54kN/m), however, is smaller than the allowable tensile stress per meter of length (about 27.5 kN/m) for the steel connecting bolts (diameter: 16 mm) and the allowable compressive force (3.6 kN/m) for the bolts to prevent them from sinking into the wood. In addition, in the horizontal loading test, loads exceeding the design horizontal moment were applied, but the dams showed no sign of abnormality. Small wooden dams may be designed, therefore, so that the occurrence of the allowable tensile stress is permitted on the upstream side. For all wooden dams tested, the factor of safety against toppling turned out to be 1.5 or more, and the factor of safety against sliding and the factor of safety associated with the shear deformation resistance moment of cribfill were 1.2 or more. The coefficients of friction between wood surfaces at the dam base and between the underside of the dam and the ground surface were greater than 0.6 and 0.7, respectively. For comparison, Table 3 shows the values indicated in existing design and technical guidelines for concrete and steel dams.

As can be seen from Table 3, the six wooden dams subjected to the horizontal loading tests are safe with respect to (1) toppling, (2) sliding, (3) the bearing capacity of ground, (4) stress in the dam (stability of members and connection) and (5) shear deformation of cribfill, and are safe on the whole, too.

**Tab.3:** Ergebnisse der horizontalen Belastungsversuche

**Tab.3:** Results of horizontal loading tests

| Site of dam | | Kuta | Tango | Keihoku(A) | Oe |
|---|---|---|---|---|---|
| Horizontal loading tests | Maximum Moment (kN·m/m) | 16.7 | 21.08 (wing) | 34.33 | 13.13 |
| | Maximum load (kN/m) | 21.8 | 24.03 (wing) | 45.61 | 29.19 |
| | Friction coefficient | 0.91 | 1.11 (wing) | At least 0.87 | 1.08 |
| | Average unit weight of dam(kN/m$^3$) | 12.26 | 9.26(wing),11.19(dam body) | 15.61 | 13.37 |
| | Measured / Calculated reisistance moment | 2.07 | 2.72(wing) | At least 1.50 | 1.98 |
| | Outside appearance of dam after tests | Sound | Sound | Sound | Sound |
| Design of wooden dam | Moment (kN·m/m) | 4.20 | 15.46 | 9.84 | 3.27 |
| | Horizontal load(kN/m) | 7.80 | 18.72 | 13.97 | 6.71 |
| | Middle third of dam base | Inside | Inside | Inside | Inside |
| | Stress on downstream end of dam base(kN/m$^2$) | (Compression )33.2 | (Compression )21.24 | (Compression )53.69 | (Compression )28.02 |
| | Stress on upstream end of dam base(kN/m$^2$) | (Compression )8.3 | (Compression )29.15 | (Compression )16.49 | (Compression )14.76 |
| | Safety factor for overturning | 4.84 | 16.15 | At least 5.78 | 10.08 |
| | Safety factor for sliding | 2.61 | 3.96 | At least 3.16 | 8.01 |
| | Safety factor for shear deformation | 2.10 | 3.02 | At least 2.33 | 2.49 |
| | Synthetic judgment for stability of dam | Safe | Safe | Safe | Safe |

| Site of dam | | Maizuru | Keihoku(B) | Technical standard (Standard-1)* | Technical standard (Standard-2)** |
|---|---|---|---|---|---|
| Horizontal loading tests | Maximum Moment (kN·m/m) | 60.71 | 50.43 | | |
| | Maximum load (kN/m) | 46.59 | 55.41 | Gravel layer | |
| | Friction coefficient | 0.66(between logs) | 0.79 | 0.5 - 0.6 | 0.6 - 0.7 |
| | Average unit weight of dam(kN/m$^3$) | 15.35 | 15.35 | | |
| | Measured / Calculated reisistance moment | 1.82 | 1.51 | More than 1.20*** | More than 1.20**** |
| | Outside appearance of dam after tests | Sound | Sound | | |
| Design of wooden dam | Moment (kN·m/m) | 22.69 | 31.83 | | |
| | Horizontal load(kN/m) | 24.15 | 30.25 | | |
| | Middle third of dam base | Inside | Outside | Inside | Inside |
| | Stress on downstream end of dam base(kN/m$^2$) | (Compression )86.94 | (Compression )108.90 | Within allowable bearing capacity | |
| | Stress on upstream end of dam base(kN/m$^2$) | (Compression )3.15 | (Tension )8.38 | No tensile stress occurs | |
| | Safety factor for overturning | 3.22 | 2.56 | More than 1.5 | |
| | Safety factor for sliding | 2.35 | 2.09 | More than 1.2 | More than 1.0 |
| | Safety factor for shear deformation | 1.47 | 1.22 | More than 1.20*** | More than 1.20**** |
| | Synthetic judgment for stability of dam | Safe | Safe | | |

* Ministry of Construction(1997) Manual for River and Sabo Works in Japan
** Forest Agency(1999) Explanation of Technical Standard for Erosion Control
*** Committee of Steel Sabo Structures(2001) Guidelines for Design of Steel Sabo Structures, Sabo Technical Center
**** Institute of Forest Science(2000) Tentative Guidelines for Design and Construction Productivity of Forest Civil Engineering Wooden Structures

## CONCLUSION

In this study, horizontal loading tests were conducted to investigate stability, horizontal resistance moment and friction coefficient for wooden dams.

The horizontal loading test results showed that the shear deformation resistance moment of the cribfill (rubble) against forces external to the dam is at least 1.5 times as large as the value obtained from Kitajima's formula for calculating the shear deformation resistance moment of cribfill (rubble) against external forces. Thus, since measured values turned out to be considerably greater than calculated values, it is necessary to reconsider calculation methods.

The horizontal loading test results indicate that, with the exception of the coefficient of friction between sliding wood surfaces observed at the wooden dam in Maizuru City, the coefficient of friction between the underside of a wooden dam and ground surface is not smaller than 0.79, which is greater than the current standard values of 0.5 to 0.6. Unlike concrete gravity dams, double-wall type wooden dams can be designed permitting a certain degree of tensile stress if the timber on the upstream side of the dam is vertically interconnected by bolts or other means.

The results of the on-site horizontal loading tests showed that all wooden dams tested are safe. As a next step, it is necessary to continue studies and research on other types of wooden dams in order to develop rational design methods. It will also be necessary to investigate the influence of decreases in strength due to the decay of timber on structural stability.

The authors sincerely thank the Forestry Agency, the Department of Agriculture, Fisheries and Forestry of Kyoto Prefectural Government, Kyoto Prefecture Association of Forest Owners' Cooperatives, and Sabo Technical Center for their generous support and cooperation with this study.

## REFERENCES

Committee of Steel Sabo Structures (2001): Guidelines for Design of Steel Sabo Structures, *Sabo Technical Center,* 22-26 and 45-49

Forestry Agency, Japanese Government (1999): Explanation of Technical Standard for Erosion Control,189-201

Institute of Forest Science (2000): Tentative Guidelines for Design and Construction Productivity of Forest Civil Engineering Wooden Structures, 5-12

Ishikawa Y., Asada M., Mizuhara K. (2002): A Design Method for Small Wooden Dams Based on Field Tests, *Proceedings of Interpraevent 2002 in the Pacific Rim*, Vol.2,773-784

Kitajima S. (1962): Study on the Stability of Cellular Bulkheads, *Report of Transportation Technical Research Institute, Ministry of Transportation ,* Vol.12 (3), 1-77

Ministry of Construction, Japanese Government (1997): Manual for River and Sabo Works in Japan, Design Ⅱ,*Sankaido,* Tokyo,4-19