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CHANGE OVER TIME OF SABO STRUCTURES USING NATURAL MATERIALS
– RESULTS OF A SURVEY OF THE INUYAMA DISTRICT, WHICH IS IN AN AICHI PREFECTURE FOREST OWNED BY THE UNIVERSITY OF TOKYO –

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ABSTRACT

Between August 1999 and January 2000, we conducted a survey on the changes in the 33 existing traditionally designed Sabo structures that were built using natural materials. They are located in the Inuyama District, which is in an Aichi Prefecture forest owned by the University of Tokyo. These Sabo facilities were constructed between 1920 and 1950 in order to prevent the formation of sediment and its discharge from barren ground. Their foundation is comprised of earth dams, and their spillways are covered with either stones, steel wire gabions, or concrete. Although approximately 50 to 70 years have passed since the Sabo facilities were constructed, the ones that had their spillways covered with stones or concrete have not been damaged. On the other hand, all but one of the 19 Sabo facilities that had used steel wire gabions to cover their spillways had not been damaged. The damages to the steel wire gabions were broadly categorized into 2 conditions: one, corrosion of the steel wires which caused the stone filling to collapse; and two, deformation or destruction of the gabions, which were caused by debris flows and other external forces. No relationship was found between the cause of the damage and the degree of corrosion of the steel wire in the second condition. However, in the first condition, the corrosion of the gabions was found mostly in three places-areas close to the ground, in the joints between the gabions, and the areas that were at water level. It was assumed that all areas had constant exposure to high humidity. The wire gabions, which were 4.2 millimeters in diameter and made from galvanized wire, had completely corroded over a period of 40 or 50 years, resulting in the gabions losing their ability to contain the stone filling. However, in some cases, the fine grain sediment between the individual stones has stayed securely in place so that the shape of the top of the spillway has not deformed even though the steel wire has corroded over time. A study of the nearby vegetation revealed that a stratified structure had formed in the area surrounding the steel wire gabions some 70 years after the completion of the Sabo. The tree layers of the stratified structure included red pines and Quercus serrata. The above findings have confirmed that the Sabo facilities that were constructed using steel wire gabions are not suitable for passively resisting the movement of sediment. However, they are capable of functioning as temporary structures preventing the motion of surface sediment for a certain period of time. In this manner, they help in the recovery of vegetation, and temporarily prevent sediment deposits from moving any further.

KEYWORDS: function of steel wire gabion, service life

INTRODUCTION

The number of sabo structures constructed using natural sand and gravel generated from sabo work sites is increasing (Minami et al. 2000). Although concrete is widely used to construct sabo structures since it is superior to natural sand and gravel in wear resistance and watertight performance (Minami et al. 2000), there are

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advantages in using natural sand and gravel generated from sabo work sites: structures constructed using them have superior dynamical characteristics and higher work efficiency can also be achieved. Therefore, they are suitable for the construction of dams and earth structures. Unlike concrete lumps, sludge, and other byproducts from work sites, natural sand and gravel can be used as construction materials without additional processing and therefore they are higher-grade recyclable construction materials (Minami et al. 2000). Specifically, the use of sand and gravel generated from work sites has the following advantages:

(1) Because the volume of locally generated soil from work sites can be decreased, the volume of both locally generated soil taken out of work sites and concrete carried into work sites can be decreased and therefore the effects of work vehicles on the natural environment can be reduced.

(2) Because forms do not need to be used when doing the work of material placing, the level of work safety can be increased and labor can be reduced at the same time.

(3) Because costs of aggregate and other material costs become unnecessary, substantial cost reductions are possible.

(4) Because the curing period can be cut down, the construction period can be decreased (Minami et al. 2000).

Therefore, natural sand and gravel generated from work sites will be more widely used to construct sabo structures and the work method is expected to become established as a major sabo work method. However, there are still some uncertain points that remain to be clarified, i.e., the durable lives and functionality of sabo structures built using natural sand and gravel in the natural environment, and other uncertainties related to their practical performance.

Earth dams were once constructed using only soil, sand or gravel from the mountainside and some of such earth dams constructed more than 50 years ago exist today. We conducted field surveys on existing earth dams in the Inuyama research forest in the Aichi Experimental Forest owned by the University of Tokyo, verified the conditions of maintenance of their dam functions, and compiled the results of field surveys into this report. The period when the field surveys were conducted is from Aug. 1999 through Jan. 2000.

SURVEY PROCEDURE

Records of the past sabo works done by the Aichi Experimental Forest Office of the University of Tokyo (hereafter called the office) were examined prior to conducting the field surveys. At the office, the records of sabo works done in the Inuyama research forest during the period from 1922 to 1961 are retained (see Fig. 1). We examined these records and identified the work methods used, completion years, work scale, work locations, etc., for 33 sabo structures. We conducted field surveys on these 33 sabo structures to verify their existing conditions. Sabo structures constructed in and after 1962, however, were not surveyed since sabo works were done using mainly concrete in and after 1962 and the office does not retain the work location map due to the transfer of sabo works to the forest department of Aichi Prefectural Government.

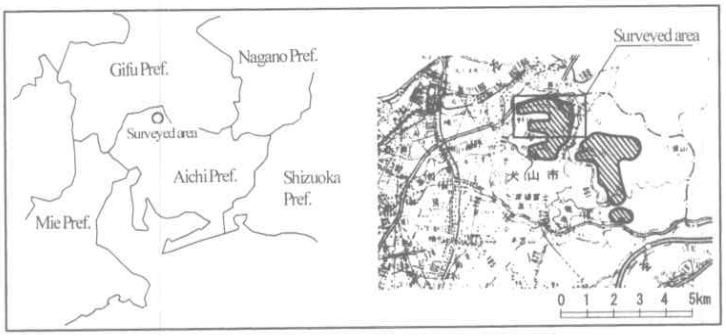


Fig.1 Location map of the surveyed area (the shaded area is the Inuyama research forest)

BACKGROUND TO THE SURVEYED AREA

The Aichi Experimental Forest of the University of Tokyo (hereafter called the Experimental Forest) was established in 1922 as the ground for experiments on or practical exercises for the use of forest water or the erosion control engineering. An area in this forest on which the field surveys were conducted is called the Inuyama research forest located on a hill at the height of 70 m to 218 m, the ground of which is mainly new tertiary deposits. When the Aichi Experimental Forest was established, the ground of this Inuyama research forest was nearly bare ground with only a small number of trees growing along mountain streams. Because hillside and mountain stream works were done, the ground is today fully covered with greenery. According to the records of the office, the following works were done during the period from 1922 to 1961:

* Hillside foundation works
  Small check dams (wire-gabion earth dams, stone-masonry earth dams, and concrete-block earth dams), water channels (stone pitching, etc.)
* Hillside planting works
  Stepped dams (terracing with planting, simple terracing with silver grass, etc.), planting (planting of young trees)
* Mountain stream works
  Dams (wire-gabion earth dams, stone-masonry earth dams, and concrete-block earth dams)

CHARACTERISTICS OF SABO STRUCTURES AND EXISTING CONDITIONS

Specifically, the thirty-three sabo structures surveyed are the earth dams with their spillway crowns and downstream faces of slopes covered with wire gabions, stones or concrete. They were constructed as small check dams in order to prevent the runoff of sediment from hillsides, beds of mountain streams or river channels (to pool sediment). In this report, small check dams and other types of dams constructed using each specific type of material are referred to as wire-gabion dams, stone-masonry dams, and concrete-block dams.

Structures of small check dams and other types of dams constructed using each specific type of material can be outlined as follows:

Wire-gabion earth dams

The structure of one wire-gabion earth dam is shown in Fig. 2.

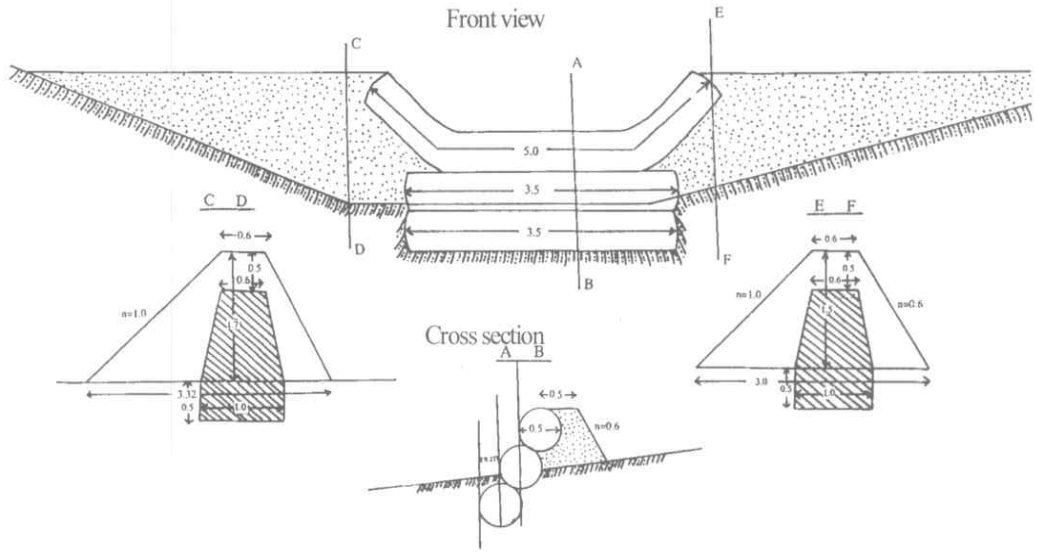


Fig. 2 Typical structure of the wire-gabion earth dams constructed in the Aichi Experimental Forest of the University of Tokyo
Source: Design document for the wire gabions installed in the drainage basin VI issued in May 1934, owned by the Aichi Experimental Forest Office of the Agricultural Department, the University of Tokyo

Wire gabions are used at the spillway crowns and downstream faces of the slope of the earth dam. As a result of a review of design-related data on wire gabions kept by the office, it is presumed that laying a cylindrical wire gabion shown in the A-B cross section at an angle of 60 degrees on the downstream face of the slope was practiced as a standard wire-gabion laying procedure in the Experimental Forest.

A wire-gabion earth dam at the time of completion is shown in Photo 1 and the present conditions of this dam are shown in Photo 2. The number of small check dams and other types of dams constructed using wire gabions is 19. All these dams except one were damaged. Conditions of the damage will be described later in detail. Wires used to make wire gabions are galvanized steel wires 4.2 mm in diameter (#8). The sediment on the beds of mountain streams where wire-gabion earth dams were constructed consists of fine particles without exception; boulders that are as large as the human head and can cause damage to wire gabions could not be found during field surveys.

Photo 1 Example of a wire-gabion earth dam at the time of completion (owned by the Aichi Experimental Forest Office of the University of Tokyo)

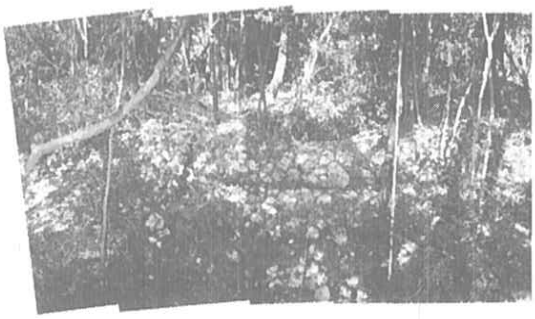
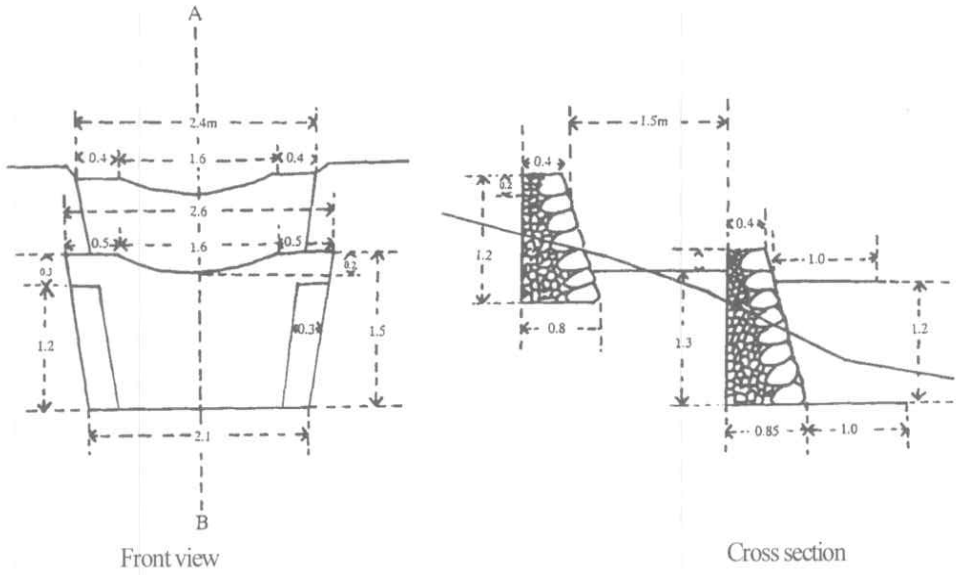


Photo 2 Present conditions of wire-gabion earth dam

Photo 3 Present conditions of a dry-masonry check dam

Stone-masonry earth dams

The structure of one stone-masonry earth dam is shown in Fig. 3. As a result of a review of data on stone masonry works kept by the office, it is presumed to be a typical stone masonry structure of stone-masonry dams constructed in the Experimental Forest. The number of surveyed stone-masonry earth dams is seven dry-masonry dams and two wet-masonry dams (including a dry-masonry dams with its spillway crown covered by concrete). With all these stone-masonry dams, no damage was noted at the stone-piled portions. The present conditions of one dry-masonry earth dam are shown in Photo 3.



Front view Cross section

Fig. 3 Typical structure of a stone-masonry dam (check dam) constructed in the Aichi Experimental Forest of the Agricultural Department, the University of Tokyo

Source: Report on the completion of a new stone-masonry dam, the 5th drainage basin Aza Taihan No. 31 issued in 1945, owned by the Aichi Experimental Forest Office of the Agricultural Department, the University of Tokyo

Concrete-block earth dams

The structure of one concrete-block earth dam is shown in Fig. 4. Concrete blocks are laid to a thickness of 30 cm on the spillway crown, the downstream face of the slope, and the front apron of the concrete-block dam. The number of surveyed concrete-block earth dams is four. All these dams were not damaged. One of these dams at the time of completion is shown in Photo 4.

Photo 4 Concrete-block earth dam at the time of completion (in the Aichi Experimental Forest of the University of Tokyo)

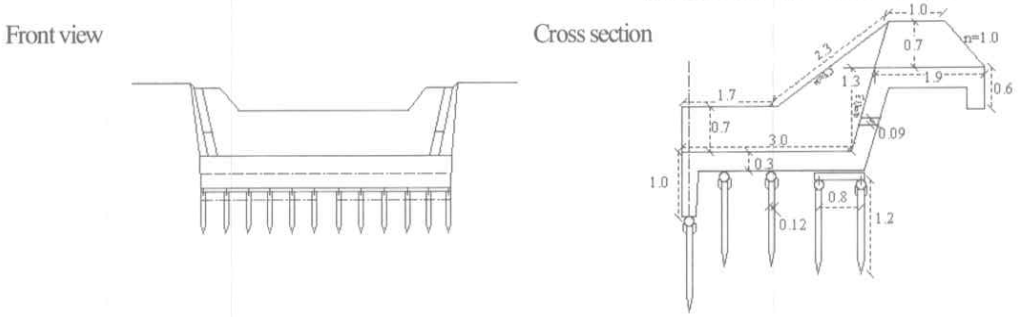


Fig. 4 Typical structure of a concrete-block earth dam constructed in the Aichi Experimental Forest of the Agricultural Department, the University of Tokyo

Source: Design document Nanzan B (second volume) concerning concrete-block earth dams, owned by the Aichi Experimental Forest Office of the Agricultural Department, the University of Tokyo

Materials used to construct earth dams and the construction method

We could not find literature that can readily inform us of the materials and construction method used to build the earth dams shown in Fig. 2, 3 and 4. However, there is the following explanation given in "Erosion Control for the 21st Century" (Aichi pref., 2000) and "Water Use and Erosion Control Engineering - Engineering Works" (Moroto, 1971) and it might help us to infer what materials and construction method were used:

"In the initial stage of the development of the construction method, a dam structure was constructed by tamping down the soil from the mountainside to a height of about 30 cm with a downstream slope set at angles

of 9 to 11 degrees and an upstream slope set at 6 degrees. The center of a dam structure was called core earth and an impervious core wall was built using the clay that was obtained by digging the base of a bank more than 90 cm wide and more than 90 cm deep. The slope on the upstream side was called side earth and its surface was finished using clay to make it impervious to water. Because the function of earth dams constructed this way was different from that of storage dams, the gradient on the downstream side was decreased to about 6 degrees. Also, core earth and dam strengthening earth were not prepared except when large-scale earth dams were to be constructed. The whole of a slope on the downstream side was sodded while the crown and the slope on the upstream side were sodded at regular intervals. Flood channels were designed with a width and depth that meet existing flow rates and they were usually formed into a trapezoidal cross section. At the toe of a slope on the downstream side of a flood channel, piles were driven and base lumber was laid on top of the piles. The crown of a flood channel and the slope on the downstream side were lined with stones in alignment with the piles and base lumber installed. The front apron was made into a box-shaped framework; it was dug more than 90 cm deep, posts were driven around the front apron at the interval of about 182 cm, and piles were installed to secure the posts in position. Track shims were made by splitting wood pieces vertically. They were installed in such a manner as to pinch each post. Each post together with track shims were then fastened using bolts. On the downstream side and on both right and left sides, piles were laid in two levels while on the upstream side they were laid in one level. The base of each post was tamped down using clay and stones were piled on the base. Although stones, bricks, earthenware, rubble stones, and other various materials were used to make flood channels, stones were mainly used." (Aichi pref., 2000)

"The gradient of an earth dam was set at more than 11 degrees on the downstream side and at more than 6 degrees on the upstream side. Mountain soil, sand and gravel were gathered, piled 30 cm deep, and tamped down. After digging of ground was completed, the width and height were uniform at all points of the dug area. As soil, sand and gravel were piled to the height where they reach a high-water level. Viscous mountain soil was used on both front and back sides and was applied to a thickness of 30 cm to 90 cm, depending on ground conditions. Because a flood channel must be set in the center, the whole of the slope on the downstream side was sodded, except this section. The crown was sodded at the interval of about 60 cm while sod was laid in three strips on the slope on the upstream side.

A flood channel was set at a 9-degree gradient or at a gradient equal to that of the dam. Three piles (pine trees each of 182 cm in length and 12 cm in diameter) were driven in two rows at the interval of 182 cm. This set of piles (three piles × two rows) was fastened using a #8 steel wire of about 182 cm in length, and base lumber of about 12 cm in diameter was set on top of these piles. Fifteen soil retaining piles (green pinewood of about 150 cm in length and 6 cm in diameter) were driven every 182 cm and stones or bricks were laid on these piles. In spaces between laid stones or bricks, a well-kneaded mixture of granitic sediment (called seed soil) and lime was filled. If stones were laid, this mixture was filled to a thickness equal to the size of stones. If bricks were laid, this mixture was filled to a thickness of about 18 cm. Spaces between filled stones or bricks were plastered up using mortar.

In preparing the mortar, 10.8 liters of cement and 21.6 liters of sand per 3.3 m^2 were mixed if stones were to be laid while 180 liters of cement and 540 liters of sand per 1,000 bricks were mixed if bricks were to be laid. Earthenware tiles, bricks or other materials with smooth surfaces should not be used to make a flood channel since such materials are not effective in decreasing the speeds of water flow.

The front-apron box framework must be installed at the base of a slope of a flood channel to prevent discharged water from digging the front apron and causing damage to the dam structure. After ground was dug to make a space for the front apron, prefabricated post shores (green pinewood of 270 cm in length and 12 cm in

diameter) were set up every 182 cm and piles (green pinewood of 15 cm in diameter) were installed to secure the post shores. Each pile was split in two and set in such a manner so that it pinches each post shore, and bolts were then installed to secure the pile to the post shore. The piles were installed in two levels on the front, left, and right sides of the box framework. On the rear side of the box framework, they were installed in one level at the upper part. Soil retaining piles (green pinewood of about 150 cm in length and 6 cm in diameter) were then set up (15 soil retaining piles were set up every 182 cm or plates each of about 182 cm in length, 4.5 cm in center thickness and 9 mm in both edges were laid in an area of 3.3 m^2). Clayey mountain soil was laid to a thickness of more than 30 cm and the bottom ground of the box framework was tamped down. Stones or bricks were then placed in the box framework and a well-kneaded mixture of granitic sediment (seed soil) and lime was filled in spaces between stones or bricks. The thickness of this mixture should be equivalent to that of the mixture used for a flood channel." (Moroto, 1971)

In 1914 a different type of earth dam called the check dam with a water path was developed. In constructing this dam, clay was not used as core earth. Instead, rubble or concrete was used to build a flood channel (Aichi pref., 2000) and the size of the front apron was made smaller; stones were laid and piles were driven only at the end of the front apron where running water falls (Aichi pref., 2000). Because the construction work for this dam could be done more easily than that for concrete-block earth dams, the gradient on the downstream side was decreased to 6 or less degrees. The work was done to make the front apron level and to make it 1.5 to 2 times longer than the fall (Aichi pref., 2000). In early stages of development of dam construction methods, large-size dams were constructed at the lower part of main streams to pool a large quantity of sediment at each dam location. Their size, however, was gradually reduced and many earth dams were constructed near the mountain foot in order to adjust the gradient of mountain streams. The gradient of the sand deposition slope was set at around 2 degrees (Aichi pref., 2000).

With 25 out of 33 sabo structures surveyed, the inside of earth dams with their wings uncovered was exposed. Although the conditions of damage could not be clearly identified due to thickly grown trees, slight surface erosion, or sediment accumulating on the upstream side, we could verify that two earth dams were heavily damaged. It is presumed that the damage occurred under the conditions shown below:

- Collapse occurred due to the seepage water that ran on the slope in the wing portion on the downstream side.
- Damage occurred when sediment being carried with running water directly hit the earth dam.

CHANGE OF CONSTRUCTION METHODS

Years when the 33 sabo structures surveyed were constructed are shown in reference to each construction method used and intended dam function in Fig. 5. Until 1938, all check dams and other types of dams were constructed using wire gabions. It is in and after 1939 that dry- or wet-masonry methods came into use. It is in 1950 that disaster restoration works began and concrete-block earth dams were first introduced. Check dams designed to prevent the runoff of sediment were constructed in 1929, 1939, and 1950, and during this period the construction methods changed from wire-gabion to wet-masonry to concrete-block methods in order to make dams more resistant to wear and corrosion. It is presumed that better construction methods were pursued this way on the recognition that the dams constructed to prevent the runoff of sediment must be more resistant to wear and impact than the dams constructed to restrain the sediment yield. Also, high costs of stone materials (Aichi pref., 2000) are considered to be a cause of a shift in materials used from stone to concrete.

Dam heights can be summarized as follows:

* 0.5 m average for the dams constructed to restrain the sediment yield on hillsides

* 0.7 m average for those constructed to restrain the sediment yield on the beds of mountain streams
* 1.5 m average for those constructed to prevent the runoff of sediment

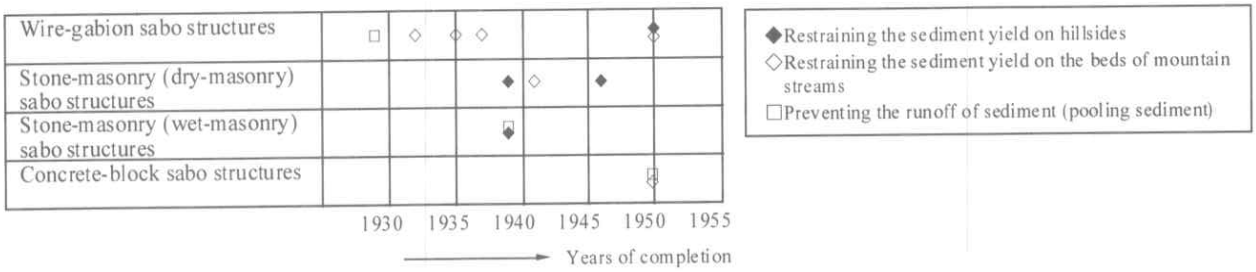


Fig. 5 Intended functions of sabo structures in relation to used construction methods
* Because more than one sabo structure was constructed to achieve the same function in the same year, the number of sabo structures indicated by symbols is smaller than 33.

EVALUATING THE DEGREE OF DAMAGE OF WIRE GABIONS

In all 33 sabo structures surveyed, no damage was found with the sabo structures constructed using stones or concrete. Damage was noted, however, with all sabo structures constructed using wire gabions except one. Conditions and causes of damage of wire gabions were investigated closely.

We examined the conditions of damaged wires as well as the coming of stones off wire gabions and evaluated them according to four different degrees of damage, as shown in Fig. 6. Wire gabions evaluated and classified this way are shown in Photo 5, 6, and 7 that correspond to the first, second and third degrees of damage, respectively. The wire gabion in the second degree of damage is corroded and damaged to the extent that it can no longer retain the stones filled in it. However, sediment filled the spaces between stones over years, allowing the stones to be bound together and consequently the dam structure to be maintained. The degrees of damage of 19 wire gabions surveyed are shown in Fig. 7. As shown in this figure, wire gabions in the second degree of damage account for more than 40% of all 19 wire gabions. Those in the second degree of damage together with those in the third degree of damage account for about 80% of all 19 wire gabions. The surveyed wire gabions are all cylindrical wire gabions. It is presumed, therefore, that in the case of cylindrical wire gabions the original forms of both wire gabions and dams can be maintained in the majority of cases though corrosion and damage of wire continue to develop.

Corrosion and/or wear of wires develops over time. It was expected, therefore, that certain correlations between the degrees of damage of wire gabions, the elapsed number of years after they were constructed, flow rates, external forces applied, etc., could be found, as shown in Table 1. Significant correlations, however, could not be found. Relationships between the degrees of damage and catchment areas are shown in Fig. 8 (in the data, data obtained regarding earth dams constructed using different construction methods is included). It is presumed that the wire gabion (No. 29) in the fourth degree of damage shown at the extreme left in Fig. 8 was directly hit by sediment and was destroyed because the conditions shown below were noted on-site:

* The whole dam structure, including the wing portions, was almost buried in sediment.
* Projections that are seen with accumulations in debris flow were found on sediment, indicating that the sediment quickly formed instead of accumulating little by little.

It is evident from these facts that the sabo structures using wire gabions cannot withstand the direct hit of sediment even if the catchment area is small.

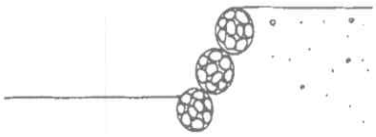
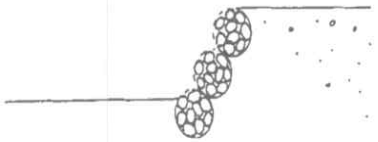
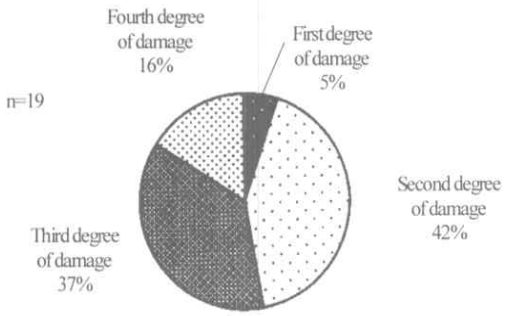
Degree of damage	Conditions of wire gabions
First degree of damage	 Wire gabions are not damaged or they are slightly damaged. They are able to retain the stones filled in them.
Second degree of damage	 Although wire gabions are corroded and damaged to the extent that they are partly unable to retain the stones, the stones do not come loose since sediment in the form of fine particles filled otherwise vacant spaces between stones over years, allowing the stones to be bound together and the forms of wire gabions to be maintained.
Third degree of damage	Wire gabions are corroded and damaged to the extent that they can no longer retain stones. The collapse of the spillway crown, however, does not yet occur.
Fourth degree of damage	Stones are coming off and the runoff of sediment is in progress. As a result, the spillway crown collapsed.

Fig.6 Definitions of the degrees of damage of wire gabions used on spillways and downstream slopes

Photo 5 Conditions of the wire gabion classified as the second degree of damage

Photo 6 Conditions of the wire gabion classified as the third degree of damage

Photo 7 Conditions of the wire gabion classified as the fourth degree of damage



	The number of wire gabions	Percentage
First degree of damage	1	5%
Second degree of damage	8	40%
Third degree of damage	7	35%
Fourth degree of damage	3	15%

Fig. 7 Distribution percentage of damagedwire gabions

Table 1 Coefficients of correlations between the degrees of damage of wire gabions, the elapsed number of years after construction, and the catchment areas

	The elapsed number of years after construction	Catchment area
Degree of damage	-0.06278	0.10790

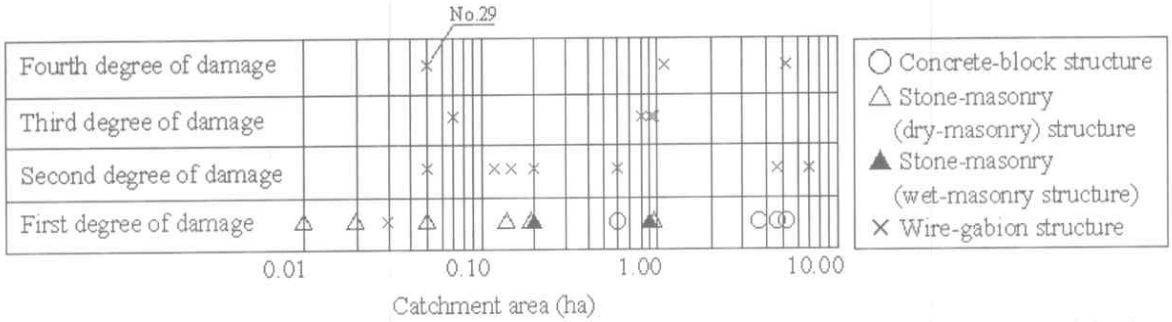


Fig. 8 Relationships between the work methods used to install protective coverings on spillways, catchment areas, and the degrees of damage

CORRODED OR DAMAGED PORTIONS OF WIRE GABIONS

Corroded or damaged portions of wire gabions can be summarized, as shown in Table 2.

Table 2 Summary of damaged portions of wire gabions

No.	The number of years elapsed after construction	Portions damaged by wire corrosion						Degree of damage of wire gabions	Remarks on the portions damaged by corrosion and the damage conditions
		Edge of ground	Water path that runs from the crown to the downstream face of slope	Where wire gabions are in contact with each other	Spillway crown (where the spillway crown is in contact with sediment at the back)	Overall wire gabion structure (surface corrosion)	Wire gabions in lower levels		
31	45							2	No corrosion
30	45	×						3	Edge of ground
29	45	×	×					4	Water path and the edge of ground. The wire gabion was totally damaged by floods.
25	50							1	No corrosion
12	50		×					2	Water path in the spillway
26	50		×					2	Narrow portions in the water path
28	50		×	×				4	Water path, where wire gabions are in contact with each other. The wire gabion was totally damaged by floods.
23	50			×	×			4	Spillway crown and where wire gabions are in contact with each other
21	50			×	×			3	Water path and where wire gabion are in contact with each other
14	50	×		×	×			3	Spillway crown, where wire gabions are in contact with each other, the edge of ground
16	50	×			×			2	Spillway crown, the edge of ground
18	50	×			×			2	Spillway crown, the edge of ground
22	50	×		×	×			3	Spillway crown, where wire gabions are in contact with each other, the edge of ground
13	50		×			×		2	Water path in the spillway, the whole of the left bank
11	63	×	×	×		×		3	Water path and the overall wire gabion structure
9	65	×	×	×		×		3	Water path and the overall wire gabion structure
8	68	×	×	×		×		3	Water path and the overall wire gabion structure
19	71		×	×			×	2	Water path, where wire gabions are in contact with each other. The wire gabions are more heavily corroded at the lower part on the downstream slope.
20	71		×	×			×	2	Water path, where wire gabions are in contact with each other. The wire gabions are more heavily corroded at the lower part on the downstream slope.

If some wires of wire gabions were washed away and lost, conditions of remaining wires were examined to identify the corroded portion that caused the runoff of wires. Damaged portions of wire gabions can be classified as follows in descending order of the number of damage identified:

· Water path that runs from the spillway crown to the downstream slope

- Where wire gabions are in contact with each other
- The edge of ground
- Overall wire gabion structure
- Wire gabions in lower levels in the dam structure

In the case of the wire gabions of the dams constructed 45 to 50 years ago, corrosion of overall gabion wires and subsequent runoff do not yet occur though wires are broken along the edge of ground, water paths, and where wire gabions are in contact with each other. In the case of the wire gabions of the dams constructed more than 60 years ago, surface corrosion and runoff of wires were noted. Overall, the breakage of wires occurred at not only the portions subjected to constant frictional force from the sediment running downstream but also the portions where humidity always remains high due to the seepage water or the wet soil at the back. It is presumed that the same or similar conditions can be observed with rectangular wire gabions now being widely used for sabo structures. Although soil pH is not yet measured, the ground of the surveyed area consists of new tertiary deposits and is not a hot spring region. It is presumed, therefore, that the soil acidity is not high.

CONCLUSIONS

Construction methods, sabo structures to which they can be applied effectively as well as the conditions for the use of such construction methods are summarized as follows:

Wire gabions

In the case of check dams and other types of dams whose spillways or downstream slopes are made of wire gabions, damage quickly develops if sediment runoffs directly hit them or if other external dynamic forces are applied, consequently their intended functions will be lost. However, damage slowly develops if they are subjected to the running water of small- to medium-scale floods (see Fig. 9).

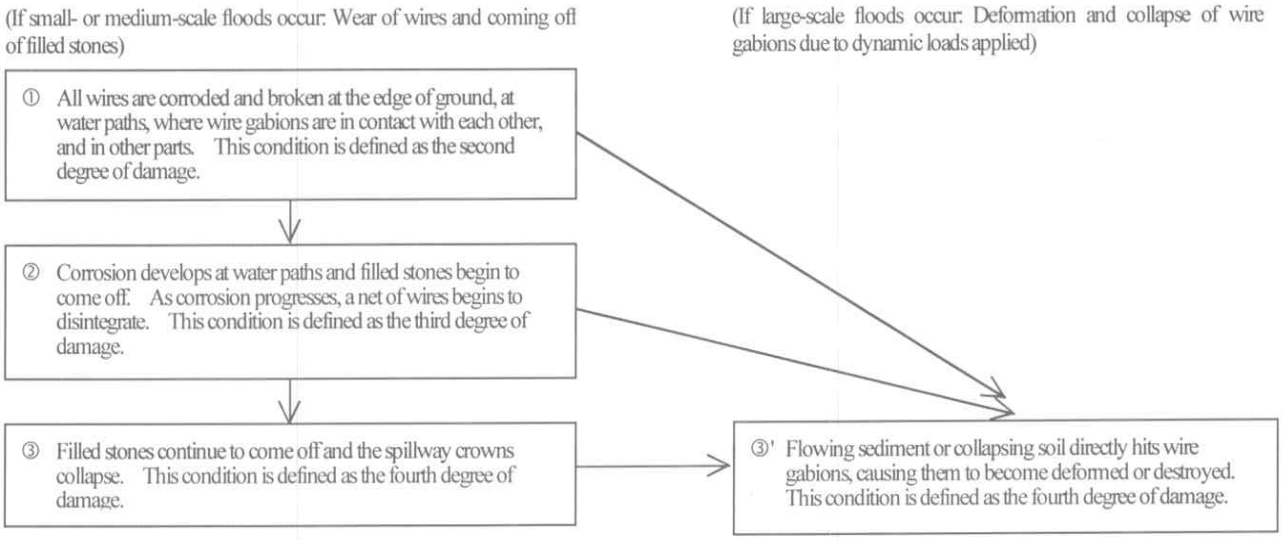


Fig. 9 Process of damage caused to the earth dams with their spillways covered with wire gabions

If sabo structures are constructed to prevent surface erosion, it is thought that they can perform their functions as long as they remain in the third degree of damage (see Fig. 6) where the height of the spillway crown can be maintained. Considering that many sabo structures remain in the third degree of damage after about 50 years from when they were constructed, as shown in Table 2, they are thought to be able to restrain the movement of surface soil and thereby restore ground to vegetation or to temporarily retain sediment runoffs if requirements for making wires resistant to breakage can be met, namely, if they are constructed on slopes on hillsides or in small

mountain streams where there are no boulders or water.

Stone masonry

No damage was observed with the surveyed check dams constructed using the stone-masonry construction method. This is thought to be due to the factors shown below:

* Loosening of the rock work that may destroy the stability of a stone-piled structure hardly occurred since all those check dams were constructed on solid gravel ground where there is no running water.
* Because they were constructed as earth-retaining dams, they were not directly affected by sediment runoffs.

It is thought that the stone-masonry construction method can be used even today if the conditions of a construction site are appropriate. Under the circumstances, however, it is considered impracticable in terms of availability of materials and expertise to achieve the same results using this method as those in the days past since stones and specialists in stone masonry are no longer available in plenty.

Earth dams

The functions of earth dams constructed as the wing of a dam structure were maintained except two earth dams that collapsed due to seepage water or were destroyed by the direct hit of sediment runoffs. (We noted that some earth dams had damaged wings and that running water might fall from portions other than their spillways if a flood occurs. We judged that such earth dams are unable to perform their functions.) The INSEM method and other new construction methods are now being introduced to utilize the sand and gravel generated from work sites. The results of the present surveys indicate the possibility that small-scale check dams built to restrain the sediment yield on hillsides can readily maintain their given functions if they are designed with a size appropriate for prevention of surface erosion and if they are constructed using cement mixed in proportions appropriate for maintenance of the designed strength (using the INSEM method, for example).

CLOSING REMARKS

Because relevant data and literature were scattered and lost and trees and vegetation were thickly grown, it was much more difficult than expected to identify the sabo structures that were constructed by the early Showa period using the methods of traditional erosion and sediment control works. In our effort to find stepped dams and other sabo structures constructed using construction methods other than stone masonry, we could only identify the traces of stepped ground. The surveyed area retains nothing of the special catchment area that it used to be.

We also conducted similar surveys in the upper reaches of the Kizugawa River. In some areas shown on the drawing owned by the Kizugawa Work Office where sabo structures were constructed in the past, large-scale residential districts and golf courses are developed. Therefore, we could only identify the remnants of earth dams (the dam crowns were not protected) and the traces of steps made on hillsides in areas that escaped development.

In conducting a series of surveys, we could obtain cooperation of many people. We would like to express our sincere appreciation to them.

REFERENCES

Minami N. and Tomita Y. (2000) Locally generated soil use for erosion and sediment control facilities, *Technical Memorandum PWRI*, No. 3730, p.1-37.

Aichi Prefecture (2000) *Erosion Control in the 21st Century - History of Wasted Forests and Restoration in the Owari Region*, p.1-239.

Moroto H. (1917) *Water Use and Sabo Engineering - Work Procedure*, p.201-203.