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CASE ANALYSIS OF SEDIMENT BYPASS TUNNELS (SWITZERLAND, TAIWAN, JAPAN)*

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SUMMARY

Until now, the planning and design of SBT has been performed individually, in accordance with the circumstances of a particular dam. In order to systematize design methods for SBT, with this research we created a database of the purpose and specifications of SBT. We then applied classifications by structural types, and analyzed related characteristics. The target was a set of 15 SBT in

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* *Analyse de cas des tunnels de dérivation de sédiments (Suisse, Taiwan, Japon)*

Switzerland, Taiwan and Japan. Classification of structures was performed based on the sediment discharge form, the purpose of the dam, and the main purpose of the SBT. Here, the sediment discharge form refers to whether or not sediment entering upstream of the reservoir is passed through the reservoir. For the analysis of SBT characteristics, we analyzed the tunnel design discharge, the tunnel structure, and the target grain size of sedimentation, based on the prior structural classifications. We then organized considerations to be taken into account with future SBT planning and design.

RÉSUMÉ

Jusqu'à présent, un TDS (tunnel de dérivation des sédiments) était planifié et conçu en fonction de la situation de chaque barrage. Cette étude, qui a pour objectif de systématiser les méthodes de planification des TDS, a créé une base de données relative aux objectifs et aux diverses spécifications des TDS. Elle a classé ceux-ci selon les différents types d'installations et analysé leurs différentes caractéristiques. 15 TDS situés en Suisse, à Taiwan et au Japon ont été étudiés. La classification des installations a été effectuée sur la base de la forme d'évacuation des sédiments, la finalité des barrages, ainsi que l'objectif principal des TDS. On entend ici par forme d'évacuation des sédiments l'existence ou non d'un passage des sédiments en amont du bassin de rétention à travers celui-ci. Basées sur le classement des installations obtenu précité, les analyses des caractéristiques des TDS qui ont été effectuées comprennent les analyses des caractéristiques sur le volume de décharge planifié des galeries, de la structure des galeries et du diamètre des grains de sédiments qui s'écoulent. Ensuite, les points à retenir ont finalement été donnés pour la planification et la conception des futurs TDS.

Keywords: Tunnel, Specification, Sedimentation, Density Current, Discharge, Drainage Channel.

1. INTRODUCTION

The execution of a suitable countermeasure for sediment is essential for maintaining the reservoir function of a dam over a long period of time. A Sediment Bypass Tunnel (SBT) can become a remarkably effective permanent countermeasure for many dams, providing a sediment discharge effect, reduction of environmental impacts on downstream river channel, and ecosystem support. The SBT can also be considered a contributing resource for sustainable development in the surrounding region. However, in actual fact, SBT constructed up until the current time have been designed as tunnels or open channels in response to the circumstances of each individual dam. Going forward, it will be important to systematize the SBT design method in order to efficiently construct SBT for a variety of dams.

Based on the state of affairs described above, with this research we first characterized an SBT as a structure that takes sediment that enters a reservoir and diverts it around the dam structure and then directly into a downstream river channel. Then we compiled a database (Table 1) of the purpose and specification of a specific SBT, for a total of 15 dams in 3 countries and regions (Switzerland, Taiwan and Japan) that maintain multiple prototypes of an SBT.[1] [2] [3] [4] Thereafter, we extracted points for consideration during SBT planning and design by using the database to classify by facility type, perform detailed analysis of design discharge, tunnel structure, and target grain size of sedimentation.

2. CLASSIFICATION OF SBT

The SBT of each dam having specifications organized in Table 1 can be classified into different types by each factor. The following classification categories are offered, and the results of classification are shown in Table 2.

2.1. Sediment discharge form

The currently targeted SBT were classified into 2 major types by their sediment discharge form.

SBT (Sediment Bypass Tunnel, in narrow sense)
A structure that diverts sediment, which enters the watershed upstream of the reservoir, into a downstream river channel, without passing through the reservoir. [Structures in Switzerland and Japan]

SST (Sediment Sluicing Tunnels)
A structure that passes fine sediment, which has been deposited in the area immediately upstream of the dam structure, to a location downstream of the dam structure, by means of density current discharge. [3 structures in Taiwan]

The broader meaning of SBT, mentioned earlier, was given as “a structure that takes sediment that enters a reservoir and diverts it around the dam structure and then directly into a downstream river channel.” However, here we are intending the narrow sense given above.

Fig. 1 presents an illustration that includes each type. Additionally, Fig. 2 shows Koshibu Dam in Japan, as an example of SBT, and Fig. 3 shows Tsengwen Dam in Taiwan, as an example of SST.

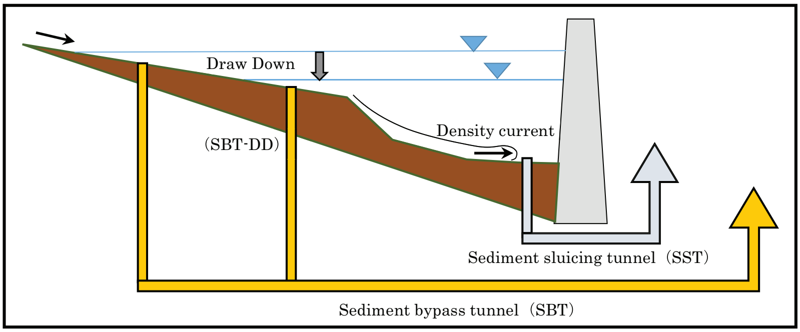


Fig. 1
Illustration of SBT and SST as classified by sediment discharge form (Also see section 2.5 Reservoir Level Operation in regards to the term SBT-DD.)
Illustration de SBT et SST distingués selon la forme d'évacuation des sédiments (voir la section 2.5)

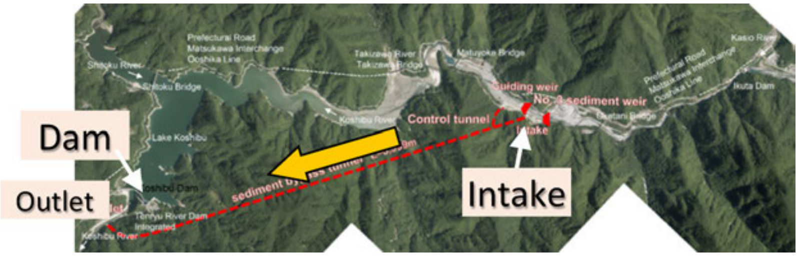


Fig. 2
Example of SBT (Koshibu Dam in Japan)
Exemple de SBT (barrage de Koshibu, Japon)

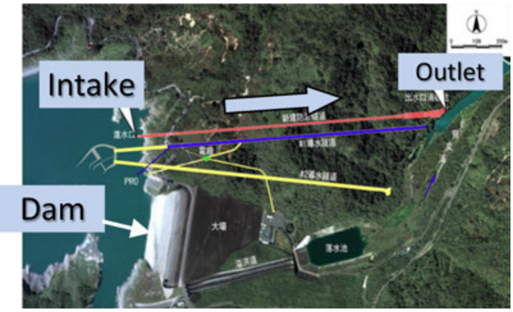


Fig. 3
Example of SST (Tsengwen Dam in Taiwan)
Exemple de SST (Tsengwen, Taïwan)

Table1: Specifications of dam and sediment bypass tunnels

	Name of Dam	Dam Specifications							Bypass Tunnel Specifications																	Note
		Completion Year	Purpose/Shape*1	Dam Height (m)	Catchment Area (km^2)	Design Flood Flow (m^3/s)*2	Flood Control Plan*3		Completion Year	Purpose*4	Tunnel Specifications				Flow Discharge				Design Velocity (m/s)	Operation frequency (/year)	Intake Specifications			Outlet Energy Dissipator	Target Grain Size (mm)	
							Inflow (m^3/s)	Outflow (m^3/s)			Cross Section Shape	Length (m)	Longitudinal Slope	Curved Section	Design Discharge (m^3/s)	Specific Discharge ($m^3/s/km^2$)	Design Discharge Return period*5	Percentage in Reservoir Maximum Outflow			Intake Position in Reservoir	Flow Control	Reservoir operation during sediment discharge			
Japan	Nunobiki-Gohonmatsu	1900	W/G	33.3	10.7	—	—	—	1908	S, W	Hood-type 2.9m×2.9m	258	1.3 (1/75)	No	39	3.64	—	—	—	—	Up Stream end	No gate	Keeping water level	No	—	
	Tachigahata	1905	W/G	33.3	18.9	—	—	—	1905	S, W	—	—	—	—	—	—	—	—	—	—	Up Stream end	—	—	—	—	Karasuhara Reservoir
	Miwa	1959	F.N.P/G	69.1	311.1	1,200	1,200	500	2005	S	Horseshoe shape 2r=7.8m	4,308	1.0% (1/100)	Yes	300	0.96	1/4.3 year	60.0%	10.8	1 - 2 times	Mid to up Stream	Gate	Flood control	Yes	Wash load	
	Asahi	1978	P/A	86.1	39.2	1,200	1,200*	1,200*	1998	S	Hood-type 3.8m×3.8m	2,350	2.9% (1/35)	Yes	140	3.57	1/0.5 year	11.7%	11.4	16 times	Up Stream end	Gate	Keeping water level	No	dm: 50 d90: 300	
	Koshibu	1969	F.A.P/A	105.0	288.0	2,160	1,500	500	2016	S, (R)	Horseshoe shape 2r=7.95m	3,999	2.0% (1/50)	Yes	370	1.28	1/6.2 year	74.0% (Currently) 100.0% (Planned)	15.8	—	Up Stream end	Gate	Flood control	Yes	dm: 10 d90: 70	Started operation in 2016
	Matsukawa	1975	F.N.W/G	84.3	60.0	560	440	200	2016	S, (R)	Hood-type 5.2m×5.2m	1,417	4.0% (1/25)	Yes	200	3.33	1/25.1 year	100.0%	15.0	—	Up Stream end	Gate	Flood control	Yes	dm: 10 d90: 60	In operational test
Switzerland	Egschi	1949	P/G	45.0	109.0	464	464*	464*	1976	S	Circle 2r =2.8m	360	2.6% (1/38.5)	Yes	50	0.46	—	10.8%	10	10 days	Up Stream end	Gate	Keeping water level	No	dm: 100 d90: 300	
	Palagnedra	1952	P/G	72.0	138.0	2,380	2,380*	2,380*	1977	S	Horseshoe shape 6.2m×6.1m	1,760	2.0% (1/50)	Yes	250	1.81	—	10.5%	13	2 - 5 days	Up Stream end	Gate	Keeping water level	No	dm: 74 d90: 160	
	Pfaffensprung	1922	P/A	32.0	30.0	530	530*	530*	1922	S	Horseshoe shape 4.7m×4.8m	282	3.0% (1/33.3)	Yes	220	7.33	—	41.5%	14	ca. 200 days	Up Stream end	Gate	Keeping water level	No	dm: 250 d90: 2,700	
	Rempen	1924	P/G	32.0	82.7	257	257*	257*	1986	S	Horseshoe shape 3.4m×3.4m	450	4.0% (1/25)	Yes	80	0.97	—	31.1	12	1 - 5 days	Up Stream end	Gate	Keeping water level	—	dm: 60 d90: 200	
	Runcahez	1961	P/G	33.0	50.0	343	343*	343*	1962	S	Hood-type 3.8m×4.5m	572	1.4% (1/71.4)	Yes	110	2.20	—	32.1	9	4 days	Up Stream end	Gate	Keeping water level	No	dm: 230 d90: 500	
	Solis	1986	P/A	61.0	900.0	1,000	1,000*	1,000*	2012	S	Hood-type 4.4m×4.7m	968	1.9% (1/52.6)	Yes	170	0.19	1/5 year	17.0	11	1 - 10 days	Mid Stream	Gate	Drawdown	—	dm: 60 d90: 150	
Taiwan (R.O.C.)	Shihmen	1964	F.W.A.P.R/R	133.0	763.4	13,800	14,500	14,149	2012	S	—	—	—	—	380	0.50	1 - 2/1 year	2.7%	—	—	Directly up stream of dam	Gate	Flood control	—	dm: 0.004 - 0.008 d90: 0.05	Modifying existing release pipe
									In plan	R, S	Hood-type 8.0m×9.0m	3,685	2.86% (1/34.9)	No	600	0.79	1 - 2/1 year	4.2%	10-20	—	Mid Stream	Gate	Flood control	No	dm: 0.04 (Density flow)	
	Nanhua	1994	F.W/E	87.5	108.3	4,332	5,379	5,500	2018	R, S	Horseshoe shape 9.5m×9.5m	1,287	1.85% (1/54.1)	No	1,000	9.23	1/5 year	18.2%	24.5	—	Mid Stream	Gate	Flood control	Yes	dm: 0.02 (Density flow)	Under construction
	Tsengwen	1973	F.W.A.P/E	133.0	481.0	9,470	12,430	12,966	2017	R, S	Horseshoe shape 9.5m×9.5m	1,235	5.32% (1/18.8)	No	995	2.07	1/2 - 3 year	7.7%	18-30	—	Directly up stream of dam	Gate	Flood control	Yes	dm: 0.005 (Density flow)	Under construction

*1 Purpose(F : flood control、N : normal function of the river water、A : agriculture、W : water supply、P : power generation、R : recreation)
Shape(G : concrete gravity dam、A : concrete arch dam、E : earth dam、R : rock-fill dam)

*2 The design flood flow for the Swiss dams are sum of the release capability of the spillway and bottom outlet.

*3 Water utilization dams are arranged with "Design flood flow = Planned maximum inflow = Planned maximum outflow."

*4 Purpose of bypass tunnel (S: sediment discharge, W: water utilization, R: increase release capacity or flood control)

*5 The probability value for designed flow of dams in Japan is calculated using the "Hydrology Statistics Utility."
Furthermore, the probability distribution with highest suitability (SLSC becomes minimum) was used. (Miwa Dam: Gev. Asahi Dame: LogP3. Koshibu Dam: LN2PM. Matsukawa Dam: Exp.)

2.2. PURPOSE OF DAM

For the “purpose of dam,” we applied the following two classifications.

Excluding one structure (Asahi Dam), the structures in Japan and Taiwan were all classified as “Multipurpose” (M) dams. The structures in Switzerland and the Asahi Dam in Japan were classified as “Water Utilization” (W) (power generation) dams.

M (Multipurpose): A multipurpose dam having a flood control function and a water utilization function.
[Structures in Japan (excluding Asahi Dam) and 3 structures in Taiwan]
W (Water Utilization): A dam having only a water utilization function.
[Structures in Switzerland and the Asahi Dam in Japan]

2.3. PURPOSE OF SBT

We further classified the “main purpose of SBT” to the following two types.

The structures in Japan and Switzerland were classified as type “I” (sediment discharge), with the main purpose being to discharge sediment. In comparison, many dams in Taiwan have insufficient ability to release water in times of flooding, which has become frequent in recent years. For that reason, the SBT were planned and constructed having not only the purpose of sediment discharge but also the purpose of augmenting water release capability, and these structures are therefore classified as type “II” (sediment discharge + water release).

I (sediment discharge): Main purpose of SBT is sediment discharge
[Structures in Switzerland and Japan]
II (sediment discharge + water release): Main purpose of SBT is sediment discharge and increase in water release capability.
[3 structures in Taiwan]

2.4. TARGET GRAIN SIZE OF SEDIMENTATION

The currently targeted SBT were classified into the following 2 major groups by the target grain size of the sedimentation.

(1) Structures that set only grain size equal to or smaller than silt as the target.
[3 structures in Taiwan and Miwa Dam]
(2) Structures that include grain size larger than silt as the target.
[Structures in Switzerland and Japan (excluding Miwa Dam)]

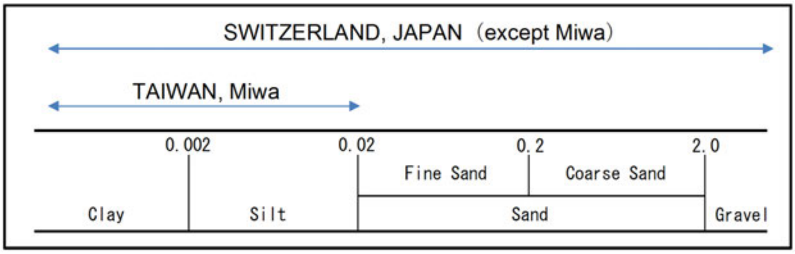


Fig. 4
Grain size (mm) of sediment set as the main target for each SBT
Diamètres des grains des principaux sédiments qui pour chaque SBT (mm)

Fig. 4 presents the grain size classes set as the main target for each SBT.

2.5. RESERVOIR LEVEL OPERATION

During sediment discharge at the Solis Dam, the reservoir water level is lowered to below normal (draw down operation). This arrangement allows the SBT intake position to be placed at a location nearer the dam structure, and in turn this allows the tunnel length to be made shorter.

The presence of such an arrangement allows a further SBT classification. Here, we have classified this as SBT-DD.

2.6. SBT CLASSIFICATION RESULT TABLE

We first offered a major classification for SBT by focusing on “sediment discharge form,” “purpose of dam” and “main purpose of SBT,” which can be thought to have the largest influence on setting of the design discharge.

This allowed classification to 3 types, as shown in Table 2.

- Major classification
  - Type A: SBT (narrow sense), with multipurpose dams having a flood control function and a water utilization function.
  - Type B: SBT (narrow sense), with water utilization dams having only a water utilization function.
  - Type C: Sluicing tunnels (SST)

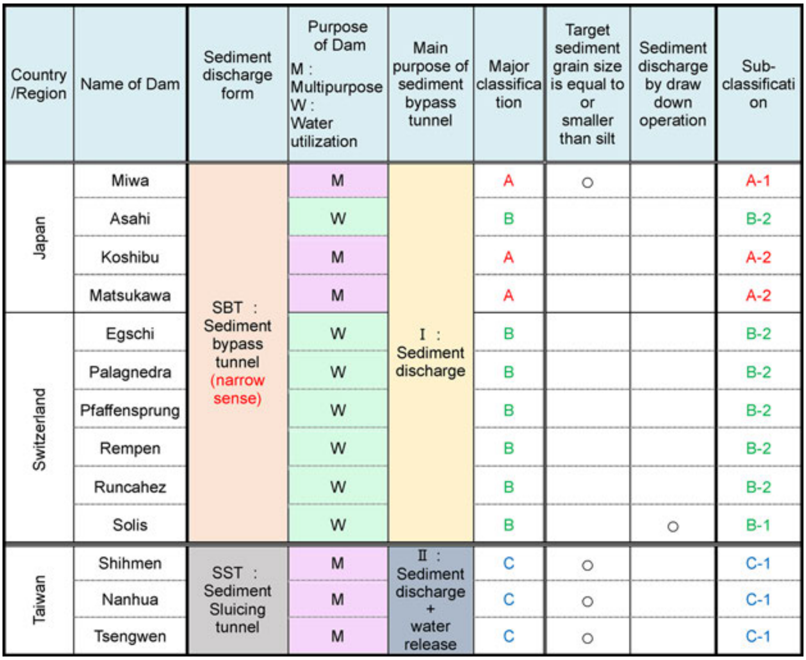
We then established sub-classifications by looking at whether or not only grain size equal to or less than silt was made the target sediment grain size and whether or not sediment discharge was performed by a draw down operation. These sub-classifications were incorporated into Table 2.

- Sub-classification 1
    - A-1, C-1: Structures that set only grain size equal to or smaller than silt as the target.
    - A-2, B-1, B-2: Structures that include grain size larger than silt as the target.

- Sub-classification 2
    - Dams that arrange to lower the reservoir level, using the SBT, to below normal, during sediment discharge. (SBT-DD)
    - A-1, A-2, B-2, C-1: Dams that do not provide the above described arrangement.

The classification targets have become 13 dams from among the 15 dams shown in Table 1 because sufficient information could not be collected for 2 of the dams in Japan (Nunobiki-Gohonmatsu and Tachigahata [Karasuhara Reservoir]).

Table 2
Result of classifying SBT



Country /Region	Name of Dam	Sediment discharge form	Purpose of Dam M : Multipurpose W : Water utilization	Main purpose of sediment bypass tunnel	Major classification	Target sediment grain size is equal to or smaller than silt	Sediment discharge by draw down operation	Sub-classification
Japan	Miwa	SBT : Sediment bypass tunnel (narrow sense)	M	I : Sediment discharge	A	○		A-1
	Asahi		W		B			B-2
	Koshibu		M		A			A-2
	Matsukawa		M		A			A-2
Switzerland	Egschi		W		B			B-2
	Palagnedra		W		B			B-2
	Pfaffensprung		W		B			B-2
	Rempen		W		B			B-2
	Runcahez		W		B			B-2
	Solis		W		B		○	B-1
Taiwan	Shihmen	SST : Sediment Sluicing tunnel	M	II : Sediment discharge + water release	C	○		C-1
	Nanhua		M		C	○		C-1
	Tsengwen		M		C	○		C-1

The next chapter analyzes design discharge, tunnel structure and target grain size of sedimentation, and organizes the respective characteristics, based on the 3 types A, B and C of the major classification.

3. ANALYSIS OF CHARACTERISTICS BASED ON SBT CLASSIFICATIONS

3.1. DESIGN DISCHARGE

First we analyzed design discharge as a way of understanding how much sediment discharge capability was inherent in the SBT of each dam.

Fig. 5 presents the relationship between the design discharge and the SBT completion year. This confirms the historic growth of SBT. In order to examine geographic trends, we also plotted the relationship of catchment area to design discharge (specific discharge) in Fig. 6. Furthermore, Fig. 7 presents the relationship between the design discharge (specific discharge) and the return period.

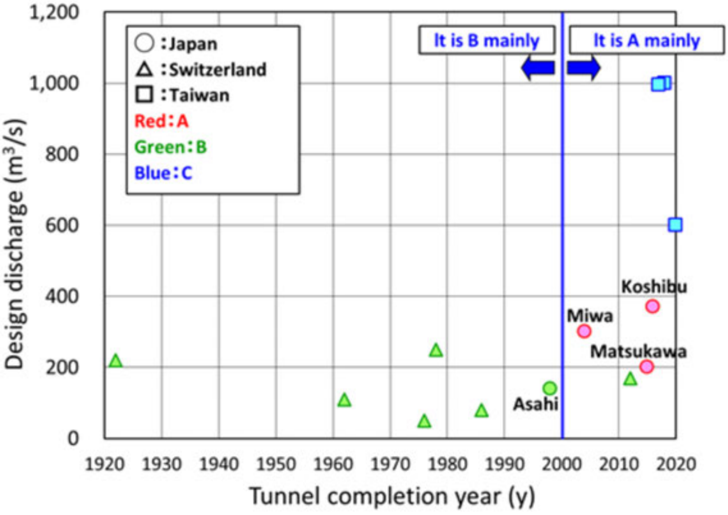


Fig. 5
Relationship between SBT completion year and design discharge
Relation entre l'année d'achèvement d'un SBT et le volume de décharge planifié de la galerie

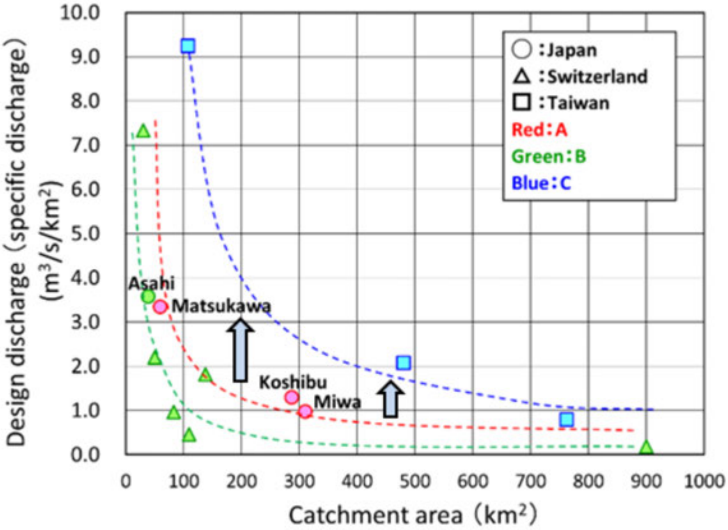


Fig. 6

Relationship between catchment area and design discharge (specific discharge)

Relation entre la superficie du bassin versant et le volume de décharge planifié de la galerie (décharge spécifique)

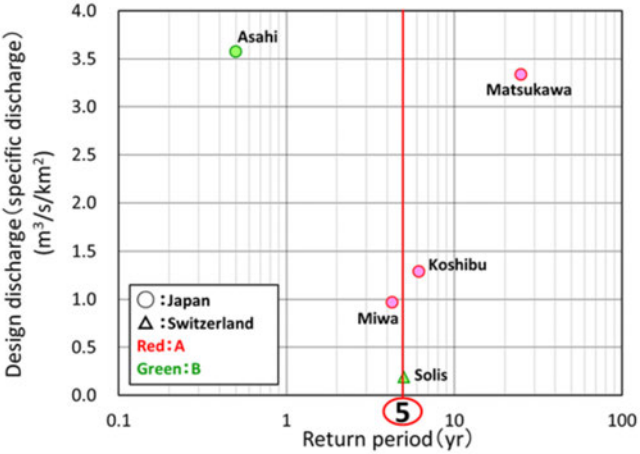


Fig. 7

Relationship between the return period and design discharge (specific discharge)

Relation entre la période de retour du volume de décharge planifié de la galerie et son volume de décharge planifié (décharge spécifique)

The trends and characteristics derived from these figures are given below.

- Many type B dams (water utilization) have an old completion year, and type A dams (multipurpose) have been increasing since the year 2000.
- In conjunction with the shift from type B to type A, the design discharge has become larger and large-scale SBT are being built.
- Design discharge (specific discharge) for a given catchment area may differ according to the type of SBT or may reflect local geographic characteristics, but that is not clear due to the small sample size of this analysis.

  However, type C (dams in Taiwan) were intended to increase release capacity as well as sediment discharge. Accordingly, if local geographic characteristics can be assumed to be similar among the types, the design discharge of type C is expected to be about the sum of the design discharge of type A (3 dams in Japan), which is intended mainly for sediment discharge, and the increase in release capacity.
- In Fig. 7, the return period for design discharge, excluding type C which differs in sediment discharge form, showed variation in the range of 0.5~25 years. Even so, when excluding Matsukawa Dam and Asahi Dam, the return periods of 3 dams are around 5 years.

  The return period for Matsukawa Dam was high, at 25 years, but that is due to having planned to use the SBT of the dam for flood control. The design discharge for the Matsukawa Dam is the planned maximum release flow for the dam (equivalent to a 25-year return period relative to the scale of the inflow amount). The catchment area of the Matsukawa Dam is approximately 60km^2, and the expected maximum flooding can be controlled by the SBT, thereby enabling use of this method.

  The return period value for the Asahi Dam was small, at 0.5 years, but this is because the SBT is also used during normal periods as a structural countermeasure for turbid water by releasing clean water. Furthermore, the Asahi Dam is located in a region with much rainfall, so a flow at the level of a 0.5-year return period is appropriate.

  Based on the reasons given above, the reasonable return period for the design discharge of a standard SBT is impacted by regional characteristics, but it can be presumed to be around a 5-year return period for the dam inflow amount

3.2. TUNNEL STRUCTURE

We then focused on structural aspects of each tunnel and analyzed tunnel diameter, longitudinal slope, and intake structure. This allowed us to gain an understanding of the approximate scale and range of conditions that applied at construction of existing structures. Fig. 8 shows the relationship between design discharge and tunnel diameter. Fig. 9 shows the relationship between tunnel longitudinal slope and design velocity. We also considered the intake structure based on the SBT specifications presented earlier in Table 1.

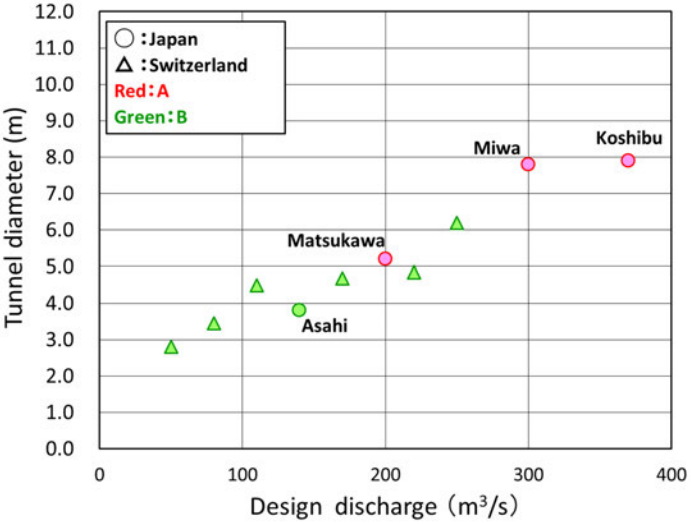


Fig. 8

Relationship between design discharge and tunnel diameter

Relation entre le volume de décharge planifié de la galerie et son diamètre

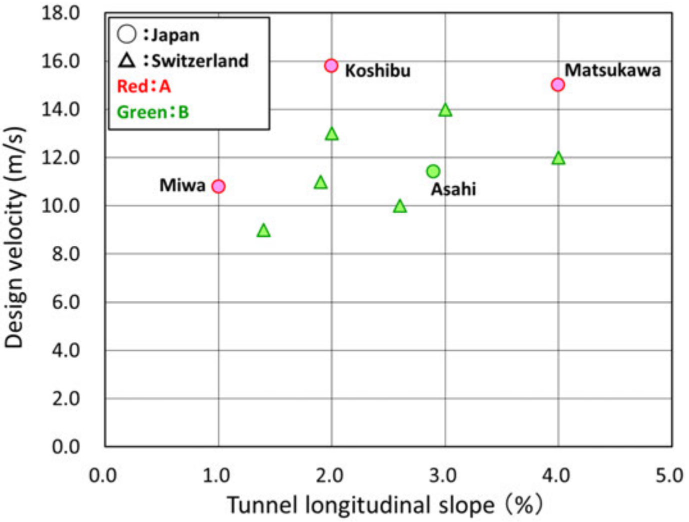


Fig. 9

Relationship between tunnel longitudinal slope and design velocity

Relation entre la déclivité longitudinale de la galerie et la vélocité prévue

The trends and characteristics derived from these figures are given below.

- Maximum tunnel diameter was approximately 10m, and minimum tunnel diameter was approximately 3m. There is a proportional relationship between tunnel diameter and design discharge with free flow tunnel, which are in the Swiss and Japanese dams. Based on these results, from the perspective of execution, it can be thought that tunnel diameter of approximately 3m to 10m is the standard.
- Maximum longitudinal slope was approximately 5% or less, and minimum longitudinal slope was approximately 1%. From the perspective of sediment discharge efficiency, hydraulic stability, and sediment abrasion countermeasure, SBT longitudinal slope of this range is the standard.
- With type A dams (multipurpose), a gate for flow control is established at the tunnel intake.
- At the Miwa Dam, a check dam positioned upstream of the reservoir captures coarse gravel, and only wash loads become the target of the SBT. The SBT intake is placed at a diversion weir downstream from the check dam. This is directly below a stockyard that collects fine sediment dredged from the reservoir, and it is positioned in the reservoir midstream.
- Looking at the example of the Solis Dam, it is possible to place the intake position near the dam structure as a measure to lower the reservoir water level at time of sediment discharge. This method allows shortening of the tunnel extension and raising of the sediment discharge efficiency, but an assessment of the risk of failure to recover the reservoir water level will be necessary.
- When we checked the horizontal alignment of the tunnel using a plane drawing of each dam, we confirmed a curved section in all but the Nunobiki Gohonmatsu Dam in Japan and the three dams in Taiwan. The curvature radius of the tunnel curved section in Palagnedra Dam in Switzerland was the smallest.

3.3. TARGET GRAIN SIZE OF SEDIMENTATION

Lastly, we analyzed the SBT target grain size, and we confirmed the relationship between target grain size of sedimentation and design velocity (Fig. 10).

The trends and characteristics derived from these figures are given below.

- The target sediment grain size was finer with type A dams (multipurpose), and it tended to be coarser with type B dams (water utilization). With multipurpose dams, installation of a regulating function (gate function) must be considered, which seems to be a trend for targeting sediment of fine grain size.
- In comparison, when focusing only on sediment discharge, as with the type B SBT, sediment with coarse grain size can be set as the target. However, in

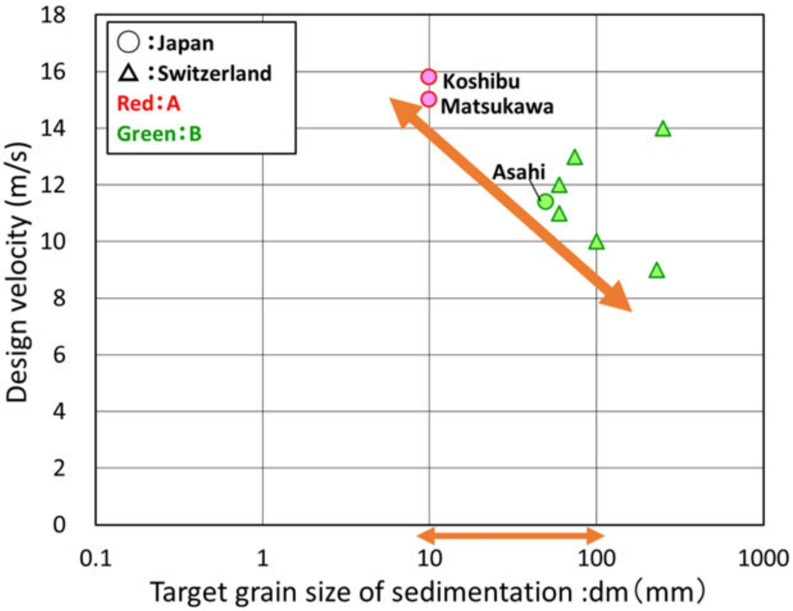


Fig. 10
Relationship between target grain size of sedimentation (dm) and design velocity
Relation entre la taille (dm) moyenne des grains de sédiments et la vélocité prévue

this case abrasion countermeasures will be necessary and a tunnel with a long overall length will be unsuitable.

In addition, except for the Miwa Dam, which sets only grain sizes equal to or smaller than silt as the target, we were able to confirm the following tendency, based on the relationship between target sediment grain size and design velocity. Namely, that design velocity is set smaller the larger the target grain size, within a range of 10mm~100mm or greater.

- As shown in Table 3, abrasion countermeasures are implemented with dams that target coarse grain sediment.

4. CONCLUSION

This research analyzed 13 dams in Switzerland, Taiwan and Japan in regards to SBT, for which structure planning and design were previously conducted

Table 3
Examples of abrasion countermeasures for sediment bypass tunnels

EXAMPLES	
Koshibu	• Tunnel lining thickness was set while considering an abrasion allowance. (50mm at invert section) • Used high strength concrete at invert section.
Asahi	• Tunnel lining thickness was originally regular concrete but was later replaced with high strength concrete. (100mm at invert section)
Egschi	• Original lining was with quartzite plate but granite blocks were later placed over the entire invert.
Palagnedra	Originally there was no lining, but a steel lining was later placed at the acceleration section of the entrance.
Pfaffensprung	Reinforced with 0.5m thick granite blocks.
Rempen	Protected with basalt concrete.
Runcahez	Local experiment confirmed high abrasion resistance of polymer concrete and steel fiber concrete.

according to the situation with each individual dam. The SBT were then classified into three types, according to the sediment discharge form, the purpose of the dam, and the main purpose of the SBT.

For each type, we additionally analyzed factors such as design discharge, tunnel structure and target grain size of sedimentation. The resulting characteristics were used to formulate points to consider, given below, in the planning and design of SBT.

[Based on analysis of design discharge]

- The approach to setting of design discharge differs by the type of SBT. It must be set after considering the sediment discharge form.
- There is a possibility that the return period of an efficient design discharge should target approximately 5 years. However, attention must be given to the individual design approaches and impact of regional factors such as rainfall patterns.

[Based on analysis of tunnel structure]

- Maximum tunnel diameter was approximately 10m or less and minimum tunnel diameter was approximately 3m, and this range can be considered a standard for execution.
- Approximately 1%~5% is the standard for tunnel longitudinal slope, but attention must be given to sediment discharge efficiency, hydraulic stability and sediment abrasion countermeasures.
- It is possible to increase sediment discharge efficiency by shortening the SBT length and by performing reservoir water level adjustment at time of sediment discharge, as with the Solis Dam. However, an assessment of the risk of failure to recover the reservoir water level will be necessary.

[Based on analysis of target grain size of sedimentation]

- With SBT targeting grain size larger that coarse grain sediment, abrasion damage to the tunnel interior is marked. Abrasion must be considered, with an action such as shortening the tunnel length or devising another abrasion countermeasure.

The result of each type of analysis given here can be expected to form a valuable basis for establishing planning and design systems for effective SBT.

Furthermore, the number of SBT examples we collected for this research is still not sufficient. It is therefore important that we continue to collect examples as much as possible, and improve the accuracy and reliability of the analysis, so we will make further data collection efforts.

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