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REDEVELOPMENT OF EXISTING DAMS TO ENHANCE FLOOD CONTROL

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INTRODUCTION

Climate change associated with global warming, as identified in the Fourth IPCC Report, will become an increasingly serious issue in the future. This is already evident from the rise in extreme weather conditions throughout Japan over recent years, such as localized torrential rainfall and severe flood damage. Analysis of national rainfall data at 1,300 monitoring stations over the last 30 years indicates a marked increase in the incidence of concentrated raifall during the last decade, with hourly rainfall volumes in excess of 100 mm more than twice as likely to occur than in the previous two decades.

There are many aspects to flood control, including river improvement work such as building up river embankments and dredging river channels, and construction of containment facilities such as dams and retarding basins. In regions affected by severe flood damage, more urgent measures are often required in order to raise flood control standards. Redevelopment of existing dams represents an immediate and effective solution. This paper discusses the flood control benefits of dam redevelopment and associated implementation issues, and examines a number of recent redevelopment projects designed to counter the effects of localized torrential downpours.

THE ROLE OF DAMS IN JAPAN IN RELATION TO RIVERS AND FLOOD PROTECTION

Japan is an archipelago defined by a ridge of mountains running down the spine, which accounts for two-thirds of the land mass. The center of the main island has many mountains of over 3,000 meters in height. As a result of the mountainous topography, rivers in Japan tend to be shorter and far steeper than in other countries. Discharge flows also tend to be very high relative to the river basin area, with a sharp waveform of short duration. Of the 30% of the national land mass considered suitable for habitation, fully one-third (or 10% of the total land mass) is classified as flood prone. Yet this area houses roughly 50% of the total population and 75% of the nation’s assets.

In cities built in flood-prone areas, river levels during flood periods will often be higher than the ground level, so embankments are used to protect residential districts. This means that an embankment breach can bring catastrophic damage.

As a result of this unique combination of topographical and social circumstances, the role of dams as a means of flood control takes on vital importance in Japan. A dam construction program has been underway since the 1950s as a means of minimizing damage associated with flooding.

As Table 1 shows, Japan has some 2,670 completed dams as of March 2006. Seven hundred of these (including 490 under the jurisdiction of the Ministry of Land, Infrastructure and Transport, excluding farmland disaster prevention dams) provide some form of flood control.

Table 1
Purpose of Japanese reservoirs

PURPOSE	SINGLE	MULTI	TOTAL
Flood-control	92	608	700
Environmental water usage	2	409	411
Agricultural water usage	1334	297	1631
Domestic and commercial water usage	110	407	517
Industrial water usage	16	145	161
Hydro-power generation	383	233	616
Total	1937	734	2671

Note:number of dams 2007

Due to the steep gradient of Japanese rivers, however, only 50 dams have storage capacity of 100 million m^3 or more, and the combined total capacity of all dams in Japan is little more than 22 billion m^3. As a result, it is often necessary to build several dams, since a single dam will not be able to satisfy the entire flood control and water use demands of the river basin.

According to a Program Evaluation conducted by the Ministry of Land, Infrastructure and Transport in 2003, the 406 flood control dams operated by the Ministry performed flood control regulatory actions on approximately 4,000 occasions over the ten-year period from 1991 to 2000. In many cases, these actions successfully prevented or minimized the extent of flood damage. Looking at return on investment, the total value of investment in 93 flood control dams (including the value of flood control aspects of multi-purpose dams) operated by the Ministry and by the Japan Water Agency is approximately ¥3.7 trillion (at 2001 rates), while the estimated financial benefit associated with prevention and minimization of flood damage was worth more than ¥4.2 trillion over the 15-year period between 1987 and 2001 alone.

Flood control programs on major rivers in Japan generally involve reservoir facilities (principally dams) and river channels. Dams generally account for 30% - 50% of the flood control burden. Given that implementation of flood control programs is only at around 60% - 70%, it will be necessary to implement further flood control strategies involving redevelopment of existing dams and construction of new dams in conjunction with river improvement works.

Many proposed new dams fail to progress beyond the concept stage due to a combination of environmental concerns and public opposition, a situation which has increased the pressure for redevelopment of existing dams.

REDEVELOPMENT OF EXISTING DAMS FOR FLOOD CONTROL

Redevelopment of existing dams commonly involves heightening of dams, upgrading discharge facilities, reallocating storage levels and better coordinating the distribution of reservoirs within groups of dams. Discharge facilities will often be upgraded or extended in conjunction with improvements to flood regulation and water utilization methodology.

Tables 2 and 3 show heightening of concrete and fill dams respectively. a of Table 2 shows cases where a new dam is built downstream of the existing dam, with the axis of the new dam in alignment. b shows cases where the new dam is built directly below the existing dam and with the axis on the same dam site; in some cases the new dam covers part of the existing dam while in other cases it is a fully independent structure. Although case-a tend to be more common, case-b is becoming more popular because it allows greater flexibility to cope with flood incidents during construction.

Table 2
Examples of heightening of concrete gravity dam

NAME OF DAM	EXISTING DAM			ESTABLISHED DAM			
	Dam height	Effective capacity	completion	Dam axis	Dam height	Effective capacity	completion
Odomari	60.0	13,000	1935	a	70.5	26,100	1959
Mikawa	48.0	8,880	1959	a	53.0	12,306	1974
Kawakami	46.5	5,880	1962	a	63.0	13,500	1980
Kuroda	35.0	4,500	1935	a	45.2	10,000	1981
Shin-Nakano	53.0	600	1960	a	74.9	2,820	1985
Kayaze	51.0	2,610	1961	a	65.5	5,940	2000
Shimonoharu	30.6	1,319	1968	a	36.5	2,182	2006
Hikawa	56.5	5,100	1974	a	58.5	5,900	2002
Shin-Maruyama	98.2	38,390	1956	b	122.5	105,220	u.c.
Tsugaru	58.0	33,000	1959	b	97.2	127,200	u.c.
Shin-Katsurazawa	63.6	81,800	1957	b	76.0	136,400	u.c.
Yubari-Shuparo	67.5	80,500	1959	b	110.6	367,000	u.c.

Units 1: dam height (m)
Units 2: effective capacity (thousand cubic meters)

Table 3
Examples of heightening of fill-dam

NAME OF DAM	EXISTING DAM			ESTABLISHED DAM		
	Type	Height	Completion	Type	Height	Completion
Oyachi	Earth-fill	15.0	1953	Earth-fill	23.0	1991
Shirakawa	Earth-fill	27.6	1933	Earth-fill	30.0	1996
Sayama-lke	Earth-fill	17.4	616	Earth-fill	18.5	2001
Sannoukai	Earth-fill	37.4	1952	Rock-fill	61.5	2001

Units:height(m)

Yet another approach involves building a much larger dam at a separate site some distance downstream of the existing dam, which is then submerged. A typical example of this approach is the Isawa Dam, which when completed will submerge the Ishibuchi Dam. While this is not heightening of the existing dam, it is still considered redevelopment of the reservoir, which constitutes a precious and finite resource, thereby satisfying demands in relation to flood regulation and water utilization. In terms of compensation for submergence of the existing dam, this approach is also superior to building a totally new dam.

Table 3 shows heightening of fill dams. All of these are earth fill dams; many were built a considerable time ago and the original design and construction documents are no longer available. A thorough study of the existing embankment and foundations is required before heightening. For example, the heightening of the ancient Sayama-ike dam (completed in the year 616) was raised successfully for the purpose of improved flood control on the basis of an exhaustive investigation of the embankments.
Table 4 shows some common examples of upgrading of discharge facilities. These include boosting the discharge capacity, building additional discharge facilities at lower elevation, and providing extra water treatment systems in reservoirs and downstream rivers.

Table 4
Typical examples of functional reinforcement of outlet works

FUNCTIONAL REINFORCEMENT OF THE OUTLET WORKS				ESTABLISHMENT OF SELECTIVE-WITHDRAWAL EQUIPMENT AND SURFACE-WITHDRAWAL EQUIPMENT	
lmprovement of spillways		lmprovement of outlet works for water utilization			
Fujiigawa *	1955-1975	Asahikawa	1954-1983	Shimokubo	1968-1976
Sasougawa **	1956-1976	Fukuchi	1974-1983	Ogochi	1957-1977
Kasabori	1965-1979	Akiha *	1958-1989	Asahikawa	1953-1983
Fukuchi	1974-1983	Naiba	1952-1989	Matsubara	1972-1984
Tase *	1953-1990	Yoroibata *	1957-1991	Sugano	1966-u.c.
Ikari *	1956-2003	Sugano*	1966-u.c.	Ikari	1956-u.c.
Amagase **	1964-u.c.	Ikari *	1956-u.c.		
Tsuruta	1966-u.c.				
Nagayasuguchi	1956-u.c.				
Kanogawa	1959-u.c.				

Note 1:(*) drilling for concrete dam body
Note 2:(**) tunnel spillway
Note 3: completion of existing dam-completion of reinforcement project

Table 4 also shows flood control strategies. At the Sasogawa and Kasabori dams, for instance, the spillways were upgraded following several floods that exceeded the original design specifications. At the Yoroihata and Ikari dams, meanwhile, the spillways were modified or upgraded when construction of a new dam upstream necessitated changes to the flood regulation methodology.

Urgent work is also underway at the Tsuruta Dam, Nagayasuguchi Dam and Kanogawa Dam following recent flood damage. This involves reallocation of storage levels and modification of discharge facilities and discharge capacity in order to improve flood regulation at these dams. Further details are provided later in this paper.

Alternation of the purpose of the reservoir offers an effective solution for ensuring optimum utilization of existing dams. Reallocation also involves measures to reduce silting, which can generate additional storage.

Another approach is to improve the coordination and distribution of reservoirs within a group of dams or between new and existing dams. As mentioned earlier, reallocation and redistribution often requires associated modification and/or construction of additional discharge facilities in response to changes in reservoir operation with respect to flood control and water utilization.

The Nagasaki Flood Damage Emergency Dam Project, undertaken in response to extensive flood damage in the city of Nagasaki in July 1982, serves as a good example of redistribution of storage levels between several dams. The project involved a major overhaul of flood control measures along the Nakashima and Urakami rivers, which suffered the greatest flood damage, including reinforcement of dams and installation of flood regulation facilities at the Nishiyama and Urakami dams, which supply drinking water to Nagasaki. New multi-purpose dams were also built on the nearby Yukinoura and Nakao rivers, both of which were affected by the floods, in order to supplement the drinking water supply and improve flood control.

Yet another example is the proposed reconfiguration of six dams in the upper reaches of the Tonegawa River: the Aimata, Fujiwara, Sonohara, Shimokubo, Naramata and Yagisawa dams. The project, still at the concept stage, involves coordination and reallocation of storage levels within the dam group to enhance flood control and water utilization efficiency. As a general rule, dams sited beneath large catchment areas are better suited to flood control, while dams with guaranteed water resources in the form of melting snow are considered best for water supplies. Thus, the proposed reconfiguration seeks to redistribute the storage levels in accordance with the characteristics of each dam in order to improve the overall efficiency of flood control within the group.

RECENT DAM REDEVELOPMENT PROJECTS PROMPTED BY DAMAGE FROM TORRENTIAL RAINS

As mentioned earlier, in recent years Japan has experienced localized torrential rainfall on an unprecedented scale, resulting in considerable flood damage. It is clear that urgent action is needed, especially in the worst affected regions, in order to provide higher levels of flood control. Redevelopment of existing dams offers an immediate solution. This section looks at several recent dam redevelopment initiatives and considers implementation issues.

Tsuruta Dam redevelopment project

The Tsuruta Dam, as shown in Figure 1, is a multi-purpose dam built in 1966 for both hydroelectric power generation and flood control.

Fig.1 Tsuruta Dam

Following extensive flood damage in 1969, 1971 and 1972, the initial flood regulation storage level of 42 million m^3 was increased to 75 million m^3 via reallocation of the water supply to the hydroelectric facility. However, record rainfalls associated with the seasonal rain front over a five-day period in July 2006 saw the Sendai river basin area in Kagoshima prefecture deluged with 1,165 mm — nearly 50% of the total annual rainfall for the region. Although flood regulation at the Tsuruta Dam helped to mitigate the extent of damage, the dam was simply unable to cope with flood levels well in excess of the original design standards. The incident prompted the adoption in October 2006 of the Special Emergency River Disaster Countermeasures Project, setting out a range of urgent riparian works over a period of five years. In light of the inherent limitations of river improvement works, it was also necessary to upgrade the flood regulation storage of the Tsuruta Dam. The dam is located on the main stream of the Sendai River with a catchment area of 805 km^2, roughly half of the total river basin area of 1,600 km^2. Thus, the Tsuruta Dam plays a vital role in regulating flooding in the downstream river basin.

It has therefore been decided to undertake a further redevelopment of the Tsuruta Dam, based on a redistribution of hydroelectric and dead water storage to boost flood control storage capacity by around 30% from the current 75 million m^3 to 98 million m^3. Two or three additional discharge gates will also be built in the lower part of the dam to enable more effective flood regulation, as shown in Figure 2.

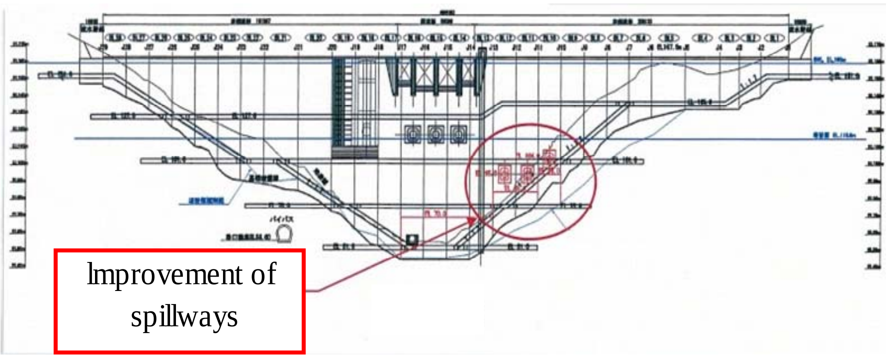

Fig.2 Tsuruta Dam View from Upstream Side

The redevelopment project also calls for the installation of large discharge pipes in the lower part of the dam. A preliminary investigation will be required for stress concentrations in the vicinity of large openings. Hydraulic modeling will also be needed to determine the impact of additional energy dissipaters that are to be built adjacent to the existing ones to accommodate the extra discharge flow.
Finally, it will be necessary to consider the structure of the deep-water cofferdam and other key design issues. A survey of the foundation is required in order to ascertain the impact of installation of the discharge pipes on the dam blocks. However, the available data on the foundation data from the time of construction, more than 40 years ago, is considered inadequate, so new boring studies will need to be conducted.

Nagayasuguchi Dam upgrade project

The Nagayasuguchi Dam in Tokushima prefecture, shown in Figure 3, is a multi-purpose dam built in 1956 to provide water for hydroelectric power generation and irrigation as well as to boost flood regulation capacity.

Fig.3 Nagayasuguchi Dam

The dam is situated on the Nakagawa River, a Grade 1 river which flows through Tokushima prefecture on the island of Shikoku. The Nakagawa River has a primary channel length of 125 km and the associated river basin area is 874 km^2. It is the only dam in the region suitable for flood regulation. However the riparian safety level is less than that of other rivers, and flooding occurs almost every year. Despite its limited capacity, the Nagayasuguchi Dam serves as the sole source of water supply for the region. The river water intake level is frequently subject to restrictions during water shortages, which impacts directly on agriculture and industry.

A radical solution was proposed in the form of the Hosogochi Dam, a multi-purpose facility on the Nakagawa River designed for both flood regulation and water supply. However, negotiations with local governments and other interests dragged on for many years without agreement, and the project was eventually abandoned in November 2000. This decision increased the pressure for an immediate review of the operation of existing facilities.

Recent problems associated with the Nagayasuguchi Dam include major flood damage caused by Typhoon No. 23 in October 2004, and the impact on local industry and agriculture of water restrictions associated with the 2005 drought. Industry alone is estimated to have lost some ¥6.85 billion as a result of the restrictions.

Work eventually got under way in FY2007 on redevelopment of the Nagayasuguchi Dam to boost the flood regulation capacity and improve the consistency of water supplies. For the purpose of this project, the Ministry of Land, Infrastructure and Transport took over authority for the dam from the Tokushima prefectural government.

Reallocation of storage levels will see the flood regulation capacity increase slightly, from 10.96 million m^3 to 12 million m^3. Although the capacity cannot be raised any further due to the level of demand for water supplies, a new spillway will be constructed to improve the spillway discharge flow in conjunction with the capacity increase, as shown in Figure 4. Together with river improvement works downstream of the dam, the new discharge facility will enable better flood regulation through improved operational procedures.

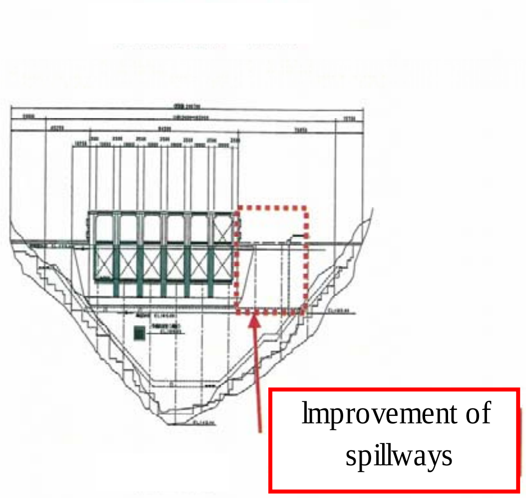

Fig.4 Nagayasuguchi Dam View from Upstream Side

Priority will be given to downstream industrial and agricultural applications and river flows rather than hydroelectric power generation, as was previously the case, in order to provide greater stability in water supplies.

As a result of sediment flows during flooding, particularly in the major floods of 1976 and 2004, sediment buildup in the Nagayasuguchi Dam has exceeded the original design specifications by around 180%, causing major problems for the ongoing operation of the facility. A major element of the redevelopment project will be the removal of sediment from the upper section of the reservoir.

As the amount of excavation to build new spillway is so large, a careful investigation into construction methodology will be required. Furthermore, the dam is required to remain operational throughout the redevelopment project, so it is important to ensure the safety of ongoing construction and installation work. The design of the spillway, particularly its scale and type, must reflect these key considerations. Furthermore, the steep-sided valley in which the dam is situated imposes various restrictions on the placement of temporary construction facilities.

Kanogawa Dam upgrade project

The Kanogawa Dam, shown in Figure 5, is a multi-purpose dam on the Hijikawa River, constructed in 1959 for flood control and hydroelectric power generation. Also located on the Hijikawa River is the multi-purpose Nomura Dam, completed in 1982, which is used for flood control and also supplements drinking water and irrigation water supplies. The proposed Yamatosaka Dam on the Hijikawa River will be a multi-purpose facility providing flood control and supplying water to boost river flows.

Fig.5 Kanogawa Dam

The Hijikawa River is a Grade 1 river that runs through the south-western region of Ehime prefecture on the island of Shikoku. It has a river basin area of 1,210 m^2 and a primary channel length of 103 km.

The middle course of the Hijikawa River brings together several tributaries in the Ozu Basin region. The topography between the Ozu Basin through the lower reaches to the coastline is defined by a gentle riverbed gradient in a confined area. This makes the river highly vulnerable to flooding, as occurred in July 1995 from the seasonal rain front and again in 2004 following three typhoons in succession.

May 2004 saw the release of a new plan for the Hijikawa river system designed to reduce the incidence of flood damage in the region. The plan calls for a target flow of 5,000 m^3/s at the reference point of Ozu, of which 1,100 m^3/s will be regulated by dams within the river basin area (taking into account the feasibility of river improvement works).

However, the combination of the existing Kanogawa and Nomura dams and the new Yamatosaka Dam will not of itself be sufficient to prevent flooding. Although the new dam will have a flood regulation storage of 14 million m^3, this will need to be augmented through redistribution of storage and upgrading of spillways at the Kanogawa Dam.

The flood regulation capacity of Kanogawa Dam will be increased from the current 16.5 million m^3 to 23.9 million m^3 via reallocation of water for hydroelectric power generation. However, this will not be enough to enable effective flood regulation, since only four crest gates are available for discharge during flood periods. Enhancing flood regulation capability by redistributing of storage capacity and lowering the water level at commencement offers only limited improvement in discharge capacity during the initial period of flooding.

It is therefore planned to build a new tunnel spillway on the right bank of the reservoir that will bypass the dam and enable faster discharge at lower water levels.

Potential alternatives to the new tunnel spillway included lowering the crest gate foundations and notching through the bulkhead section. However these were dismissed in favor of the tunnel spillway option due to concerns about the impact of floods that may occur during construction, and also due to restrictions on positioning of construction equipment.

Design specifications for the tunnel spillway are now being prepared. As Figure 6 shows, it will be 420 meters long and will support a discharge rate of 1,000 m^3/s at the commencement level. It will consist of an inlet channel, pressure tunnel of diameter 11 – 14 meters, high-two pressure roller gates measuring 6 meters high by 4 meters wide and a discharge tunnel of width 20 meters.

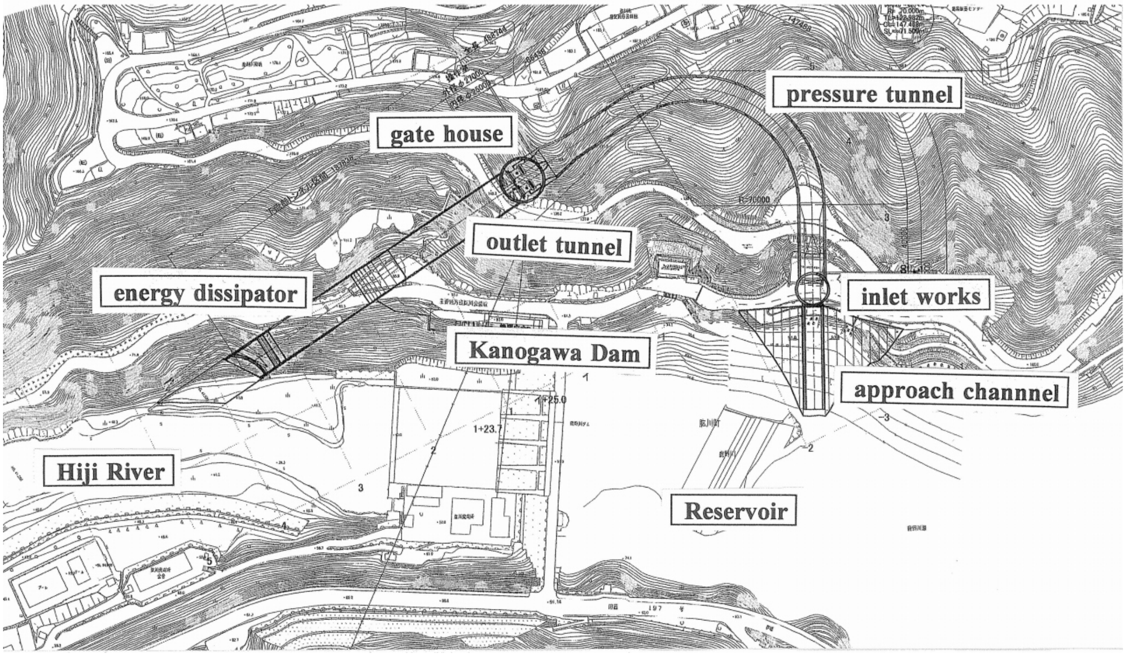

Fig.6 Tunnel spillway project of Kanogawa Dam (plan)

CONCLUSIONS

Japan builds many dams in order to provide secure water supplies for the nation and to mitigate the impact of floods. Dam construction has become an increasingly lengthy process, due to the requirements of environmental assessment processes as well as measures to minimize impacts on social environments. Dam construction programs have also been affected by funding issues.

In recent years, Japan have suffered extensive flood damage due to the increased incidence of localized torrential rainfalls. Countermeasures to mitigate flood damage are urgently required in these regions. Redevelopment of existing dams has been identified as an effective solution and has already been applied to a number of dams.

Redevelopment of existing dams offers several advantages over construction of new dams: it requires less compensation for submerged land; the environmental impact is less; reaching consensus is generally easier; and it is faster and less expensive. It is therefore expected that dam redevelopment projects will become increasingly popular as a means of making more effective use of existing infrastructure.
On the other hand, many dams will be required to remain operational during the redevelopment period, and this imposes additional restrictions on the design and construction processes.

In order to ensure the safety, efficiency and economic viability of dam redevelopment projects, it is important to build up a body of knowledge and expertise through the sharing of design and construction technology, with reference to overseas case studies and experiences where relevant.

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