A STUDY ON THE VISUAL EFFECT OF LIGHT SCATTERING REFLECTED BY THE WATER SURFACE ON WATERSIDE SPACE DESIGN

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Waterside space provides a good landscape and a relaxing space in urban areas. However, some people are vulnerable to the reflected light from the water surface. Some children have a weak tolerance to scattering light, and some elderly people are vulnerable to glare from strong light. The only medical advice to the weak in response to such light could be to teach them not to approach waterside spaces. At present, there is no fundamental solution, and the situation requires assistance from engineering technology. In this study, we tried to obtain basic knowledge to control the characteristics of reflected light from the water surface by conducting hydraulic experiments. Also, we investigated the condition of waterside space using a structure with water flow in urban space. Based on the results, a method for designing waterside space was considered from the viewpoint of human visual effects.

Key Words: waterside space, urban spatial design, handicapped person, universal design, visual effect

1. INTRODUCTION

In recent years, the installation of structures using water flow has been recognized in creating places for relaxation in public spaces. It is considered that the installation of such structures can generate the murmuring sounds or the sound of falling water, and mitigate the noise from the surroundings. Also, it can be inferred that the installation of structures using water flow has the same effect of being able to enjoy the actual sound of flowing water. It is pointed out that the waterside is a visually pleasing space for people owing to the water flow in an otherwise boring landscape. In many cases, therefore, a structure that utilizes water flow has positive effects, both visually and audibly. However, for some people, the reflected light from the water surface in the waterside space may have an undesirable effect on the visual system as shown in Fig. 1.

Fig. 1 (A) shows what has become widely known globally as the “Pokemon seizure incident” (referring to the Pokemon program episode that aired on December 16, 1997), where some children were affected by the flashing light emitted by the TV images. Incidents regarding consciousness disorders (onset of epilepsy) were reported. This phenomenon may also occur when strong light, such as sunlight, enters a place where water surface is present, even if the light is diffusely reflected from the water surface.

Fig. 1 (B) shows that for elderly people, when strong light is incident on the retina, glare is induced and causes difficulty in obtaining proper visual information. The unexpectedly strong luminescence increases the risk of glare for the elderly. No visual information can be obtained during the recovery time from glare. For this reason, it may cause a fall acci-
dent or a traffic accident. The only medical advice for the safety of people who are vulnerable to light, even when using optical aids, is to “keep away from waterside spaces.” Therefore, at present, there is no fundamental solution to this problem. No engineering approach has been taken to improve this situation. On the other hand, many studies have been conducted to utilize the waterside for urban landscapes that use reflected light from the water surface as a flowing water expression. For example, “Waterfront Landscape Design” is a pioneer manual in Japan for designing waterside spaces. This manual describes the usefulness of river landscapes. Also, design considerations have been pointed out so that people would positively view river landscapes. Besides this manual, there are other studies that relate water flow to landscape. Ichimaru and Shinohara have proposed a method for predicting the types of water flowing landscape by using existing hydraulic formulas for small dams. Hoshino and Shinohara and Aizawa and Shinohara conducted a study on a method of designing a flowing water landscape by computer graphics based on the knowledge from hydraulic experimental results. They have proposed a design method that takes into account the situation of falling water in the existing drop structures. Furthermore, Aizawa organized previous studies in order to provide a conceptual framework for the expression of falling water. Then, he summarized the design policy on the water flow appearance of the various situations. Gotou has proposed that the numerical analysis technology has been used effectively for waterside space design so that artistic designers can easily use the knowledge of hydraulics to be difficult to understand. As mentioned above, several hydraulic and landscape engineering studies on the flow situation of structures in urban areas have been made, and designs of waterside have been made to make people appreciate the water surface. Therefore, no consideration for visual impairment has been given in past studies. “River Landscape Guidelines” edited by the Ministry of Land, Infrastructure, Transport and Tourism describes the concept of river landscape design. This document does not mention the control of the reflected light from the water surface. As a result, even basic design considerations have not been clarified yet. In the future, in order to gain knowledge for safe and secure waterside space design, including those affected by light stimuli, a water engineering approach is essential. We deeply recognize that the results of this research are significant from the engineering aspect. Therefore, in this report, in order to obtain basic knowledge, we assumed the two cases as shown in Figs. 1 (A) and 1 (B) and arranged medical information on the visual stimulus of the reflected light from the water surface. An experimental study was performed to gain basic knowledge on the characteristics of the reflected light from the water surface. Also, a survey was conducted to determine what types of flows are frequently used in monumental structures using water flows in urban spaces. Field experiments at the actual space were conducted on the characteristics of the reflected light from the water surface in structures using various types of water flow. Furthermore, the characteristics of the reflected light from the water surface were clarified from the field survey and field experimental results.

2. METHODOLOGY

In this study, we conducted a literature survey on medical findings focusing on the relationship between waterside space and human vision. Next, a hydraulic experiment in the laboratory was conducted to obtain basic knowledge on the characteristics of light reflected from the water surface. Then, the installation condition of the structure using water flow in the urban space was investigated, and the characteristics of the reflected light from the water flow surface on the various structures were examined. The methodology is described below.

(1) Literature survey on the relationship between people with visual disabilities and waterside spaces

In the case of Fig. 1 (A), it was difficult to search for cases due to the personal information protection in Japan, so information was mainly gathered from the technical book of “Photosensitive Epilepsy” by Hardings and Jeabons. Also, additional information was gathered by referring to the guidelines published by the Japan Epilepsy Society and various other sources.
ous medical journals. In the case of Fig. 1 (B), information was obtained from various medical journals too, and largely from “Human Measurement Handbook (Popular Edition)” 5) and “Low Vision Care Manual” 14), 15).

(2) Experiments in laboratory basic channel
The experiments were performed by using the rectangular horizontal channel measuring 80cm wide and 15m long as shown in Fig. 2. In the experiment, a simple flow was formed without any model placed on the channel. Especially, a sluice gate was used to form the supercritical flow, and the measurement location was set to a region where the turbulent boundary layer was sufficiently developed 16). The experimental cases are as shown in Table 1. The water depth was measured using a point gauge (readable by 0.1mm), and the light source used was an electrodeless lamp considered to be relatively close to natural sunlight. The height of the electrodeless lamp was set as close as possible to the water surface by devising fixtures allowing the light to be reflected sufficiently on the water surface. The height of the video camera and the luminance meter were adjusted by considering the average height of a 10-year-old child (the height of both boys and girls is about 137 cm) 17), which is the age at which epilepsy tends to occur. In order to observe the reflected light from the water surface, some fine adjustments on the height of the camera and the luminance meter (adjusted in the range of 117 cm to 143 cm) and the distance between the camera and luminance meter and the light source (adjusted in the range of 350 cm to 380 cm) were made. After the adjustment, it was checked whether the projection angle was at an angle (30° to 40° from the horizontal) that would not eventually result in unnatural viewing.

Then, the luminance of the reflected light from the water surface was measured ten times with the luminance meter (Konica Minolta’s Luminance meter LS-100 (response mode: High) and LS-150 (response mode: automatic)), and the average value was used as the measured value. An image of the reflected light from the water surface was acquired with the video camera (SONY HDR-CX670; frame rate 60 frames/s). For the measured images by the video, the image analysis software Image-Pro Premier 9.1 (manufactured by Media Cybernetics Co., Ltd.) was used to calculate the RGB gradation average value (hereinafter referred to as RGB value. R: red, G: green, B: Blue (the average value of these values is 0 for black and 255 for white)). For this reason, analysis was not performed separately for each of the light components R, G, and B.

Next, as shown in Fig. 2, in order to know the characteristics of the water surface conditions recorded in the video, time-series data of water surface fluctuations were acquired with the ultrasonic water-level meter (HM-002 manufactured by Tokyo Keisoku Co., Ltd.; Installation height from water surface about 10cm, measurement time 30s, sampling interval 10ms). The illuminance \(I\) in the laboratory was measured with the illuminometer (ILM 1332A man-

![Fig.2 Experimental apparatus.](image)

Table 1 Experimental condition.

| Run No. | \(F_{r}\) Number | \(Re_{f}\) Number \(\times10^4\) | Flow Rate \(m^3/s\) \(\times10^2\) | Water Depth (cm) | Illuminance \(I\) (lx) |
|---|---|---|---|---|---|
| Case 1 | 0.702 | 11.2 | 9.855 | 14.65 | 628 |
| Case 2 | 0.697 | 12.5 | 10.806 | 15.65 | 710 |
| Case 3 | 0.569 | 10.0 | 8.663 | 15.46 | 575 |
| Case 4 | 0.434 | 7.5 | 6.513 | 15.32 | 387 |
| Case 5 | 0.327 | 5.7 | 4.910 | 15.33 | 464 |
| Case 6 | 0.270 | 4.7 | 4.026 | 15.24 | 336 |
| Case 7 | 0.141 | 2.5 | 2.120 | 15.35 | 160 |
| Case 8 | 0.077 | 1.3 | 1.157 | 15.39 | 137 |
| Case 9 | 0.050 | 0.9 | 0.762 | 15.41 | 110 |
| Case 10* | 0 | 0 | 0 | 12.05 | 110 |
| Case 11 | 1.71 | 9.8 | 8.600 | 7.38 | 754 |
| Case 12 | 1.99 | 9.8 | 8.600 | 6.67 | 933 |
| Case 13 | 2.57 | 9.8 | 8.600 | 5.63 | 1268 |
| Case 14 | 3.14 | 9.8 | 8.600 | 4.92 | 990 |
| Case 15 | 3.57 | 9.8 | 8.600 | 4.52 | 1071 |
| Case 16 | 4.11 | 9.8 | 8.600 | 4.12 | 1062 |

Note) In case 10, water is not supplied.
ufactured by ISOTECH Co. Ltd.). In order to reduce the influence of the lighting installed in the laboratory, the lighting near the experimental area was turned off, thus relying mainly on natural sunlight from outside. For this reason, the illuminance $I$ shown in Table 1 has changed slightly. The relationship between the luminance $L$ and the illuminance $I$ is determined using Equation (1).

$$L = \frac{P_r}{\pi} I$$

Since the reflectance $P_r$ of water is 0.02 (when light is incident perpendicular to the water surface), if the illuminance $I$ is converted into the luminance $L$, the maximum illuminance of 1268 lx in Table 1 is 8.1 cd/m$^2$. In the case of the minimum illuminance of 110 lx, it becomes 0.7 cd/m$^2$. Since the magnitude of the illuminance $I$ is less than 1/50 in all the measurement cases with respect to the magnitude of the measured luminance $L$ described later, the effect of the light in the laboratory against the luminance was considered negligible.

3. RESULTS AND DISCUSSION

The results obtained from literature surveys on the effects of reflected light from the water surface on vision, hydraulic experiments in the laboratory, surveys of actual conditions of structures in the field, and hydraulic experiments in the field are described below.

(1) Results of literature survey on visual effect of reflected light from water surface

a) Results of the literature survey on consciousness disorders caused by flashing light stimulating vision

In the case of Fig. 1 (A), cases have been verified by multiple researchers. Tsuboi and Nielsen 22) reported light-evoked EEG abnormalities in Turner syndrome patients (five cases, chromosome type unknown) with mental retardation. Three of them developed epilepsy and showed irregular spike and slow wave complex (hereafter referred to as spike wave) in brain waves in both occipital regions. It was shown that the seizure wave was further increased by light stimulation. In light-sensitive epilepsy, seizures and seizure waves are induced by light stimulation. In everyday life, it is conceivable that a television image (including a game) causes a flashing stimulus of light or a state of flickering due to the presence of the sunlight. In particular, it has been pointed out that the latter is mainly triggered by the reflection of sunlight on the water surface19). Some of the epileptic seizures caused by sunlight reflected from the water surface are shown below3).

Case 1) Age: 8 years old Gender: male
Symptoms: The boy frequently had epileptic seizures while watching TV. Spike waves in epilepsy observed by using an electroencephalogram (EEG). Not only when watching TV, but several times, the boy also showed a short consciousness disorder at the poolside. The doctor diagnosed that the epileptic seizure in the outdoors was due to the boy seeing the reflected light scattering of sunlight from the water surface.

Case 2) Age: 15 years old Gender: male
Symptoms: The boy had a seizure at 12 years of age. His two-year-old brother also had seizures at the age of 14. The boy had been taking anti-epileptic drugs to control seizures since the first seizure. Although he regularly went through EEG tests, he had
no clinical record of light sensitivity. However, spike waves have been sporadic in EEG recordings at the age of 15 in IPS (light stimulation diagnosis by EEG examination) with eyes open and closed on EEG examination. A few months later, the boy developed an epileptic seizure when he saw the scattering sunlight reflected from the water surface while fishing in the outdoor.

In addition to the light from television images, the main light scattering is mainly caused by sunlight. In the “Pokemon” anime incident, epileptic seizures were triggered by the flashing light created by artificially inserting color filters. However, epileptic seizures are originally induced by sunlight having a continuous wavelength component existing in nature. When a patient moves outdoors, an example of light from above is light that enters through a gap between equally spaced trees planted on a roadside. While indoors, light enters through vertical bar structures, such as handrails installed on promenades. Also, examples of light from below are diffusely reflected light from water surfaces of ponds and monumental structures in public spaces, such as rivers and lakes and artificial waterside spaces in cities. There have been many reports of cases that cause epilepsy.

There are also cases of seizures at beaches and seaside parks as a result of visual observation of the reflected light from the surface of the swaying waves.

On the other hand, the following points were pointed out in the guideline on diagnosis and treatment of photosensitive epilepsy by the Japan Epilepsy Society. “Many mild photosensitizers are potential photosensitizers who may not be aware of their photosensitivity unless they have the opportunity to undergo electroencephalography. Thus, they do not care about epileptic seizures. The frequency of light-sensitive epilepsy is as low as 1 in 4,000. However, the frequency of photosensitizers is quite high, including those with potential constitutional photosensitivity. In Europe and the United States, the ratio is 8.9% for children and 0.5% for men. In the anime “Pokemon” in 1997, 76% of cases where a light-sensitive seizure was induced were potential light-sensitive individuals. The frequency of occurrence in Japan is unknown because it is a population survey, but it indicates that there are potentially many photosensitive individuals.” In addition, children refer to those under the age of 15. Thus, it is necessary to understand that light sensitivity is not uncommon and has a complex relationship with the epilepsy syndrome.

b) Literature survey results on difficulties in acquiring visual information due to visual stimuli caused by strong light

In the case of Fig. 1 (B), for the elderly, the intense light incident on the retina induces glare (photophobia) due to the diffusion of light in the eyeball, making it difficult to obtain appropriate visual information. And, the time required for recovery to obtain visual information accurately tends to be long. Elderly people, more than young people, are more likely to experience discomfort glare, and the permissible limit luminance of discomfort glare for elderly people is about 54% lower than that of young people. It has been reported that cataract, one of the causes of visual impairment in the elderly, occurs in 70% of people in their 60s and more than 90% in their 80s. And in cases involving cataracts, the elderly may complain of glare instead of visual impairment. In that case, it is pointed out that it is necessary to pay attention not only to sunlight but also to the strong light reflected from the water surface, and to use an optical aid that can achieve appropriate contrast and glare reduction.

Based on the contents of the above literature, it can be seen that a considerable number of people are living with daily attention to the reflected light from the water surface or away from the environment with water surface. It is also understood that there are potentially many people who can experience seizures due to light reflected from the water surface.

(2) Result of experiments in basic laboratory channel

a) Discussion of dominant factors on illuminance from the water surface

Under the experimental conditions, it is inferred that the explanatory variables representing the characteristics of the light reflected from the water surface consist of the dimensionless quantity of the flow and the physical quantity representing the properties of the light. Therefore, it is considered that there is a relationship as shown in Equation (2).

\[ L, RGB = f \left( F_r, Re, We, P_g, k_s, h, I, t \right) \]  

where \( F_r \): Froude number \( (= V / (gh)^{1/2}) \); \( V \): averaged velocity \( (= Q/Bh) \); \( g \): gravitational acceleration; \( h \): water depth; \( Q \): flow rate; \( B \): channel width; \( Re \): Reynolds number \( (= Vh/v) \); \( v \): kinematic viscosity coefficient; \( We \): Weber number \( (= ph V^2/\sigma) \); \( p \): liquid density; \( \sigma \): surface tension; \( P_g \): pressure gradient in the direction for the downstream; \( k_s \): channel bottom roughness; \( I \): illuminance; and \( t \): time. Here, regarding Weber number \( We \), if the liquid is water, \( We \) is generally expressed by \( F_r \) and \( Re \). Regarding Reynolds number, \( F_r \) is superior to \( Re \) as a dominant factor because it targets flows with water surfaces where gravity and inertial force are dominant. Regarding the pressure gradient \( P_g \), the flow is not uniform flow but is a gradually varied flow with hydrostatic pressure distribution. In this experiment, for subcritical flows, the averaged water surface
gradient toward the downstream is about 1/10000. For supercritical flows, the averaged water surface gradient toward the downstream is about 1/100.)). Regarding the channel bottom surface roughness $k_s$, the channel sidewalls and bottom surface of the experimental channel has been dealt with smooth. Regarding the illuminance $L$, the average illuminance in the experiment was 606 lx during the experiment time, which is the same range as that of a general gymnasium (500 lx) e.g.31). Considering the above, it is inferred that the characteristics of luminance $L$ and RGB values in this experiment mainly change with $F_r$ and $t$ as shown in Equation (3).

$$L, \text{RGB} = f(F_r, t) \quad (3)$$

In a structure using a water flow in an actual urban space, in addition to the effects shown in Equation (2), in the case of channels, the water surface is affected by (1) an upwelling flow due to the channel sidewall roughness and the unevenness at the channel bottom, (2) the shock wave formation due to channel curvature, and (3) mixed supercritical and subcritical flows due to the change of longitudinal slope. Also, in the case of ponds, the water surface is affected by the disturbance due to the falling water. As mentioned above, it is thought that the characteristics of the light reflected from the water surface change due to the influence of various disturbances. Here, we considered this hydraulic experiment as the first step in obtaining basic knowledge about the reflected light from the water surface. From this, a simple hydraulic experiment was intentionally performed to reduce the explanatory variables for the objective variables.

b) Experimental results and discussion

Fig. 3 shows the relationship between the values of the time-averaged luminance $L$ and RGB (measurement time 30s) obtained from the experiment based on the time averaged $L$, $\text{RGB} = f(F_r)$. As shown in Fig. 3, in the range of the subcritical flow ($F_r<1$), the values of the time-averaged $L$ and RGB decrease as the value of $F_r$ increases. Also, the value of the time-averaged luminance $L$ becomes smaller in the case of the supercritical flow region than in the case of the subcritical flow region, and shows an almost constant value. It is shown that the glare caused by the reflected light from the water surface can be greatly reduced by flowing down with the supercritical flow as compared with that in the case of the subcritical flow. Therefore, it is understood that for elderly people suffering from glare, creating a water stream instead of nonmoving water is an effective way to design the waterfront.

Fig. 4 is an example of the time-series changes in RGB values for the subcritical flow (in the cases for small value of $F_r$ and large value of $F_r$) and the supercritical flow. As shown in Fig. 4, when the flow is the subcritical flow under the condition of the small Froude number ($F_r = 0.050$), flickering occurs under a bright state that is dominant continuously, and when the flow is the subcritical flow under the condition of large Froude number ($F_r = 0.697$), blinking occurs under a dark state that is dominant. In the case of a supercritical flow ($F_r = 4.11$), fine flickers occur continuously. This means that as $F_r$ becomes larger, water surface fluctuations and fine standing waves from the channel sidewall are induced, and they intersect on the water surface. It is considered that the water surface has irregularities and the characteristics of the light reflected from the water surface change. Also, standing waves are fine waves that are constantly formed due to small unevenness on the sidewalls, and they flow and propagate along the water surface and cross each other. As it will be described later, especially in the case of a supercritical flow with a developed turbulent boundary layer, the reflected light from the water surface is considered to be fine because the water surface irregularities are always formed with minute water surface fluctuations. From these characteristics, it is considered that the “glareness” decreases as $F_r$ increases.

Regarding concerns about impairment of consciousness caused by flashing light, as shown in Fig. 5, it has been pointed out that the frequency of dangerous flashing light is generally in the range of 8 to 50 Hz in tests on patients with factors of photosensitivity2). A light-sensitive response is a constitution sensitive to light stimulation. A patient with that constitution may have a seizure by looking at some type
of light. In particular, as mentioned above, there are findings by light stimulation\(^2\). Therefore, in order to examine that children are more susceptible to photosensitivity the flickering characteristics of the reflected light from the water surface, Fourier transform was performed on the time series data of RGB values with 1024 data. \textbf{Fig. 6} shows the Fourier amplitudes divided into the supercritical and the subcritical flows as a function of \(F_r\). As shown in \textbf{Fig. 6}, all frequency components are present in any case of \(F_r\). Therefore, it is necessary to pay attention to the flashing light in the case of children. In this experimental range, it is suggested that the Fourier amplitude (intensity on the luminance) increases with increasing \(F_r\) in the case of the subcritical flow and with decreasing \(F_r\) in the case of the supercritical flow. In such a case, it is desirable to take measures such as reducing the incident light by creating a waterway under the tree or under the roof.

In order to further clarify the fluctuation characteristics of RGB values, the power spectrum at each \(F_r\) was calculated, and an example of the results is shown in \textbf{Fig. 7}. In the past, the relationship between \(1/f^\lambda\) fluctuation and the biological stimulus in the power spectrum of various fluctuations felt by the living body has been investigated by Musha\(^3\), \(^4\). Musha pointed out that \(\lambda = 1\) is close to many natural phenomena, and when \(\lambda = 1\), he mentioned that biological stimulation is more comfortable for humans. It has been considered that as the value of \(\lambda\) is closer to 0, the noise becomes white noise and the stimulus fluctuates more strongly for the living body, and as the value of \(\lambda\) becomes larger than 1, it becomes monotonic fluctuation with less stimulus to the living body.

\textbf{Fig. 8} shows the values of \(\lambda\) calculated as an example in \textbf{Fig. 7} for each \(F_r\). As shown in \textbf{Fig. 8}, in the case of the subcritical flow with a small value of \(F_r\), as the value of \(\lambda\) is equal to about 1.3, the flashing light becomes monotonous. On the other hand, when the value of \(F_r\) is large, even if the subcritical flow is formed, the value of \(\lambda\) is smaller. Furthermore, if the value of \(F_r\) becomes large for the supercritical flow, the stimulus against the living body becomes a strong fluctuation. In addition, in the flow of \(F_r < 2\) as seen in a general water park, the value generally shows \(\lambda=0.5\) to 1.5. Therefore, considering the opinion of Musha, it is inferred that the flowing waterside is a comfortable space for those who are not sensitive to light stimulation.

\textbf{Fig. 9} shows an example of time-series data for water surface fluctuations on the subcritical and the supercritical flows measured to examine the characteristics of the water surface where light is reflected. \textbf{Fig. 10} shows the result of the quantities dividing the standard deviation of the water surface fluctuation \(h'\) by the water depth as a function of the Froude number.

![The main frequency causing photosensitivity epilepsy](image)

\textbf{Fig. 5} Percentage of patients (N=170) who caused a light response to flashing light at different frequencies during electroencephalography with flashing light stimulation (This figure has been re-created and edited by the author based on reference 2)).
Fr. As shown in Figs. 9 and 10, the surface fluctuation water surface fluctuation differs in the case of the supercritical and the subcritical flows, and the water increases as the value of Fr increases. Also, as shown in Fig. 10, the magnitude of the water surface fluctuation is almost the same as the value pointed out by the research results of Miyamoto and Shimoyama\cite{35} and Nakase et al.\cite{36}. In the case of the subcritical flow, the fluctuation intensity is less than 1% of the water depth, and in the case of the supercritical flow, the fluctuation intensity is 1% to 2% of the water depth. From the appearance of such water surface fluctuations, the characteristics of the reflected light from the water surface will cause slow monotonous fluctuations in the case of the subcritical flow. On the other hand, in the case of the supercritical flow, it is thought that a strong fluctuation due to the glittering stimulus is generated.

(3) Results of investigations on installation of structures using water flow in urban areas and field experiments on characteristics of light reflected from the water surface

From the experimental results in the basic channel, the basic knowledge of the reflected light from the water surface was obtained, thus the flow condition on the structure installed outdoors was investigated to extend the knowledge for design. As a result of the reconnaissance, 114 structures using water flows were found. Table 2 shows the list and the classification results of flow types. As shown in Table 2, the types of flow are “still water”, “a pond with a fountain” (hereinafter abbreviated as “fountain”), “water channel” (hereinafter abbreviated as “channel”), “falling water”, “sheet flow”, and “stepped channel flow” (hereinafter abbreviated as “step”). Fig. 11 shows the percentage based on this classification. As shown in Fig. 11, it can be seen that there are many “fountains”
in urban spaces. In the case of a “fountain”, it is thought that not only visual effects but also audible sounds are generated, and in summer, the surrounding air is also cooled and is preferred as a child’s playground item.

Based on these classifications, we decided to extend the knowledge of the basic indoor waterway and investigate the visual effects of the reflected light from the water surface of each flow. Time-series data on the image of the light reflected from the water surface on the flow over the structure were obtained except for the “still water” (which is no flow), and “st-

Table 2  Results of field investigation on installed structures in urban area using water flows.

| No. | Investigation Place | Kind of Flow Types | No. | Investigation Place | Kind of Flow Types |
|-----|---------------------|-------------------|-----|---------------------|-------------------|
| 1   | Wadakura Fountain Park | Fountain 58 | Shinjuku Park Tower | Still water |
| 2   | Falling Water 59 | Shinjuku Central park | Still water |
| 3   | Still water 60 | Omotesando Hills | Sheet flow |
| 4   | Step 61 | Shinjuku Central park | Still water |
| 5   | Shinagawa season Terrace | Still water 62 | Omotesando Hills | Sheet flow |
| 6   | Falling Water 63 | Yoyogi Park | Sheet flow |
| 7   | Still water 64 | Channel |
| 8   | Falling Water 65 | Still water 66 | Sheet flow |
| 9   | LaQua | Fountain 67 | Falling Water |
| 10  | DisneySea | Still water 68 | Sheet flow |
| 11  | Falling Water 69 | Still water 70 | Sheet flow |
| 12  | Sheet flow 71 | Ours Inn Hankyu | Sheet flow |
| 13  | KISPIARI | Step 72 | Sheet flow |
| 14  | Toranomon Hills | Still water 73 | Falling Water |
| 15  | Fields Toyosu | Still water 74 | Gate City Oosaki | Falling Water |
| 16  | Still water 75 | Nippori South Park | Still water |
| 17  | Falling Water 76 | Still water 77 | Sheet flow |
| 18  | Still water 78 | Shinjuku OIOI | Sheet flow |
| 19  | Falling Water 79 | Falling Water 80 | Sheet flow |
| 20  | Tokyo Dome City | Falling Water 81 | Sheet flow |
| 21  | Sheet flow 82 | Falling Water 83 | Sheet flow |
| 22  | Tokyo Mid-Town | Falling Water 84 | Falling Water 85 | Sheet flow |
| 23  | Sheet flow 86 | Shinjuku News Paper SBS Building | Still water |
| 24  | Jinocho Mitsui Building | Sheet flow 87 | Hamamatsucho Building | Sheet flow |
| 25  | Nomura Co. Ltd. Head Office | Falling Water 88 | Fukuoka City Oosaki | Sheet flow |
| 26  | Sendai-Dono-Flow Park | Channel 89 | Shiodome Building | Still water |
| 27  | Higashi-Chofu Park | Channel 90 | Still water 91 | Sheet flow |
| 28  | Tokyo Mid-Town | Falling Water 92 | Falling Water 93 | Sheet flow |
| 29  | Palace Building | Falling Water 94 | Falling Water 95 | Sheet flow |
| 30  | Oosaka Waterfront Park | Falling Water 96 | Falling Water 97 | Sheet flow |
| 31  | Ueno Park | Falling Water 98 | Falling Water 99 | Sheet flow |
| 32  | Edogawa-Sougou Park | Falling Water 100 | Falling Water 101 | Sheet flow |
| 33  | Shin-Nagashima Waterfront Park | Falling Water 102 | Capital Mark Tower | Sheet flow |
| 34  | Shin-Koiwa Park | Falling Water 103 | "Senzoku nagare" | Sheet flow |
| 35  | National Park | Falling Water 104 | Channel |
| 36  | Shin-Koiwa Park | Falling Water 105 | Channel |
| 37  | Shin-Koiwa Park | Falling Water 106 | Still water |
| 38  | Shin-Koiwa Park | Falling Water 107 | Still water |
| 39  | Shin-Koiwa Park | Falling Water 108 | Still water |
| 40  | Shin-Koiwa Park | Falling Water 109 | Still water |
| 41  | Shin-Koiwa Park | Falling Water 110 | Still water |
| 42  | Shin-Koiwa Park | Falling Water 111 | Still water |
| 43  | Shin-Koiwa Park | Falling Water 112 | Still water |
| 44  | Shin-Koiwa Park | Falling Water 113 | Still water |
| 45  | Shin-Koiwa Park | Falling Water 114 | Sheet flow |
| 46  | Shin-Koiwa Park | Falling Water 115 | Sheet flow |
| 47  | Shin-Koiwa Park | Falling Water 116 | Sheet flow |
| 48  | Shin-Koiwa Park | Falling Water 117 | Sheet flow |
| 49  | Shin-Koiwa Park | Falling Water 118 | Sheet flow |
| 50  | Shin-Koiwa Park | Falling Water 119 | Sheet flow |
| 51  | Shin-Koiwa Park | Falling Water 120 | Sheet flow |
| 52  | Shin-Koiwa Park | Falling Water 121 | Sheet flow |
| 53  | Shin-Koiwa Park | Falling Water 122 | Sheet flow |
| 54  | Shin-Koiwa Park | Falling Water 123 | Sheet flow |
| 55  | Shin-Koiwa Park | Falling Water 124 | Sheet flow |
| 56  | Shin-Koiwa Park | Falling Water 125 | Sheet flow |
| 57  | Shin-Koiwa Park | Falling Water 126 | Sheet flow |

Notes) In the case of the “channel”, the classification of the supercritical flow and the subcritical flow is not performed because the classification becomes complicated.
ep”. Regarding the condition of each measured location, in the case of “fountain” as shown in Fig. 12, the water depth was 16.0cm, the flow velocity was 6.6 to 6.8 cm/s, and the Froude number was approximately $F_r = 0.053$ to 0.054. In the case of “channel” as shown in Fig. 13, the water depth was 13.8cm, the flow velocity was 0 to 5.6 cm/s, and the Froude number was approximately $F_r = 0$ to 0.048. In the case of “falling water” as shown in Fig. 14, the falling height was 5.5m, and the flow rate fluctuated with time, thus detailed measurements could not be made. In the case of “sheet flow” as shown in Fig. 15, the water depth was about 2mm, and the speed of the roll waves was 1.75 to 1.95m/s from the image. Ishihara et al.\textsuperscript{21)} stated that the average flow velocity was smaller than the velocity of the roll waves, and the velocity of the roll waves was 1.5 to 1.6 times the average flow velocity $V$. Although the slope of channels in the experimental conditions of Ishihara et al. differs from the slope of this channel (the magnitude of slope $\theta$ is about 40°), using this knowledge, if the roll wave speed is divided by 1.6 and the Froude number $F_r = V/(gd \cos \theta)^{0.5}$; $d$: water depth on the slope, $\theta$: channel inclination angle), the value of $F_r$ is 8.9-9.9.

Based on the obtained time-series data on each flow, Fourier transform was performed with 2048 data, and the power spectrums for each flow were calculated. The calculated results are shown in Figs. 12 to 15. As for the structure of “step”, the flow condition is completely different depending on the angle of inclination for the downstream, the step height, and the flow rate, and it is considered that systematic study is necessary to obtain the characteristics\textsuperscript{37)}. Therefore, it was not measured this time. As shown in Figs. 12 to 15, it is considered that the glare is reduced by the turbulence of the water surface even when the water flows over any structure. However, it is understood that caution is required for flashing light for children, since all the frequency components of the disturbance

![Graph](image1)

**Fig. 11** Ratio of the installed situation on structures using water flow.

![Graph](image2)

**Fig. 12** Power spectrum on reflected light from the water surface disturbed by “Fountain” (the water erupt height is about 8.5m at the biggest fountain, $h$ is approximately equal to 16.0cm, $V=0.066-0.068\text{m/s}$, $F_r=0.052-0.054$).

![Graph](image3)

**Fig. 13** Power spectrum on reflected light from the water surface disturbed by “channel” ($h=3.8\text{cm}$, $V=0-0.056\text{ m/s}$, $F_r=0-0.048$).
exist. In the case of “still water”, the water surface becomes like a mirror, thus it is expected that the glare can be greatly reduced by a little contrivance such as disturbing the water surface by the falling water due to the fountain. As in the case of the basic channel in the laboratory experiment, the results of calculating the value of $\lambda$ on the flow in various structures are listed in Table 3. As shown in Table 3, in the slow-flowing “water channel” and “fountain”, the values of $\lambda$ are 1.88 and 1.65 respectively, and the reflected light in each case is relatively monotonous.

As shown in Fig. 15, in the case of “sheet flow”, a flow condition considered to be roll waves are formed, so that a certain frequency is dominant. However, on average, the value of $\lambda$ is close to 1, and is similar to “falling water”. In the case of “water channel”, the value of $\lambda$ is larger than that of subcritical flow in laboratory experiments. The reason for this result is considered to be the measurement under the influence of wind and the environment where the flow velocity is 0 to 5.6 cm/s and the flow velocity is not constant. In the case of “sheet flow”, the value of

**Table 3** Values of $\lambda$ on reflected light from the water surface with various structures in urban spaces using water flow.

| Kinds of structures and installed place | $\lambda$ |
|----------------------------------------|-----------|
| Ponds disturbed by fountain             | 1.65      |
| Channels(subcritical flow)              | 1.88      |
| Falling water (before water flows as particle-like) | Measured at Wadakura Fountain Park | 1.06 |
| Falling water (after water flows as particle-like) | 1.12 |
| Sheet flow                              | 1.26      |

Fig. 14 Power spectrum on reflected light from the water surface disturbed by “falling water” (Falling height is about 5.5m).

Fig. 15 Power spectrum on reflected light from the water surface disturbed by “sheet flow” (h is approximately equal to 2mm, $V$=1.17-1.22 m/s, $F_r$=8.9-9.9, channel slope 40 in degree).
\( \lambda \) is larger than the value of that in the case of the supercritical flow in the laboratory experiments. It is considered to be due to the formation of the roll waves on the sheet flow. In the case of such a complicated flow, it is necessary to extract explanatory variables appropriately according to the case and to conduct a systematic investigation.

As described above, similar to the considerations obtained from the experimental results in the basic channel, even in many actual waterside spaces, if the inference of Musha is quoted, the waterside spaces in urban spaces have been well designed for those who do not have photosensitivity. Therefore, as a result, it is presumed that watersides in urban spaces are relaxing spaces.

(4) Consideration points for designing waterside space in urban spaces taking into account people with visual disabilities

From the findings obtained from the literature survey in the medical field and the experiments in the laboratory and in the field, the points to consider in designing the waterside space in urban space are described as follows;

- Assuming a scattering light for children, regardless of the type of water flow, it is not possible to prevent the generation of dangerous frequency components of the scattering light from the water surface, so it is necessary to reduce the incidence of light from the sky as much as possible. Therefore, when installed indoors, it is possible to control the incident light. However, if structures such as water monuments installed at outdoors, a shade by using trees can be used to suppress the incidence of light from the sky, or a roof that blocks sunlight can be used. As mentioned above, at the water side space, it is desirable that there be installation of a shape-like structure which blocks the sunlight incidence.
- Assuming glare for elderly people, it is desirable to generate as much flow as possible to avoid the water surface becoming like a mirror. In particular, it is effective to design waterside spaces by forming supercritical flows. In places where the flow velocity cannot be increased, it is desirable to reduce the intensity of light reflected from the water surface by disturbing the water surface with fountains, falling water and etc...
- If the various measures mentioned above are not possible, it is advisable to give publicity to call attention.

4. CONCLUSION

The conclusions of this study are summarized as follows:

- Regarding the visual stimulus caused by blinking lights on children, it is assumed that as the velocity of the flow increases, not only does the flashing light have high frequency component, but also the flashing light has high frequency component. Therefore, care in designing the structure is necessary. In particular, when the supercritical flow with the small Froude number and the subcritical flow with the large Froude number is formed, it is desirable to take measures, such as placing trees or a roof, etc. around the waterside space to reduce harmful incidents. By these measures, the condition of the waterside space will be improved around the water flow channels.
- When the influence of glare due to a strong light is assumed, the flow causes the water surface to fluctuate and minute standing waves are formed from the channel sidewalls, so that the reflected light from the water surface is dispersed. It has been clear that the formation of such a flow reduces glare. In addition, still water can possibly cause glare to elderly people, thus it is desirable to disturb the water surface appropriately using a fountain and similar structures.
- As for the visual stimulus to a healthy person, the shape of the power spectrum of the fluctuation of the reflected light from the flowing water surface has a shape close to 1/\( f \). Therefore, it was suggested that the reflected light from the water surface could be a pleasant stimulus for healthy people. In other words, it was inferred that waterside installations in urban spaces provided a comfortable and fluctuating landscape where people could relax.

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