Utilization of Synchronous Shutter Apparatus in the Photographic Measurement Method of Flood Flow Surfaces

Fumiaki YAMAZAKI, Masahiko HATAMOTO, Mineo KONDO
Shin Engineering Consultant Co., LTD
8-30, Sakaedori 2 chome, Shiroishi-ku,
Sapporo, Hokkaido, 003-0021, Japan
Phone: +81-11-859-2600
Fax: +81-11-859-2616
E-mail: Yamazaki@Shin-eng. co. jp

KEY WORDS: measurement of flow surface attitude, three-dimensional image processing system, flood flow, Synchronous shutter apparatus.

ABSTRACT

An aerial stereo photograph of a flood flow, which is generally covered by patterns of forms and turbid flow, was first analyzed by many researchers using the parallax method to obtain velocity distributions over the entire surface.
In this paper, we report photographing the same flood flow surface utilizing a pair of synchronous shutter apparatus and obtaining the wide-range measurement of the flood flow surface altitude with a three-dimensional image processing system (PHODIS of ZISS). Using a rectified orthophotograph; we determined the hydraulic quantity, etc. of the surface velocity vector applying the density correlation method.

1. INTRODUCTION

1.1 Necessity of Flood Observation for Japanese Rives

Rivers in Japan originate in the steep mountainous terrain of the archipelago and their courses are short, thus they have sharper channel inclinations than most rivers in foreign countries. Consequently, heavy rainfall concentrated in short periods of time, the sharply inclined topography and short courses combine to create flow volumes in excess of that capable of being held by the embankment, causing the sudden formation of flooding waters. The natural power of these flooding rivers has a severe impact along alluvial plains, which are the foundation of Japan's livelihood and where 75% its assets are concentrated.
Even though the flow of flooding waters has distinctly different properties from that of water flow during calm periods, there is still little understood regarding flows at the time of flooding. This fact leads to the necessity to observe flood flows when they occur. The measurement of flooding duration through the use of aerial photograph, as presented in this report, is a critical form of observation for learning more about flood flow phenomena.

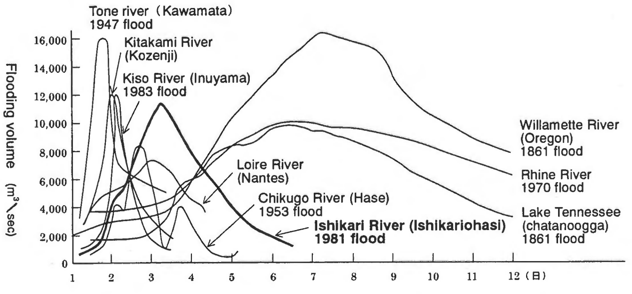

Fig.1 Flood Volume of Japanese and Foreign Rivers

1.2 Field Observation Methods

Regarding (2), (3) and (4), sufficient observations of currents around bridges / piers are available to determine influence.
However, there are no accurate measurements in Japan for locations where bridges / piers are not present. Under such conditions, in Japan, we conduct visual observations to resolve this issue.

Table 1 Description of Movement Measurements During Flooding

Description	Method
① Measurement of riverbed topography, etc.	Sonar equipment, global-positioning satellite, radio-controlled boat
② Water level	Leveling
③ Flow volume	Buoys
④ Flow velocity	Current meter
⑤ Duration of change in water surface velocity	Image analysis
⑥ Contents of flow	ADCP
⑦ Bed load	Water bottle

① Riverbed topography
② Observation position
③ Continuous water level

The simultaneous measurement of the above three parameters was made possible using a radio-controlled boat (Fig.2), sonar equipment and a global-positioning satellite.

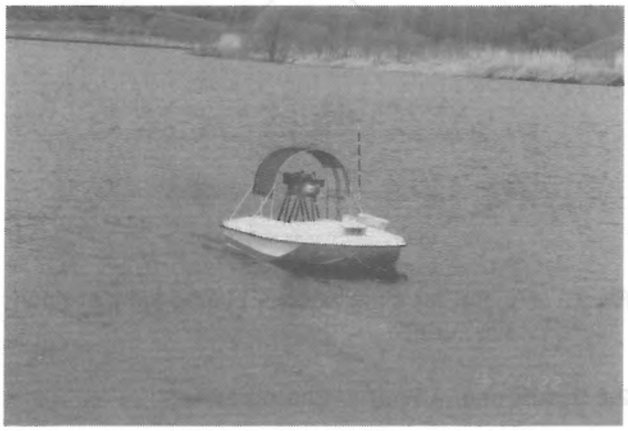

Fig.2 Radio-controlled observation boat

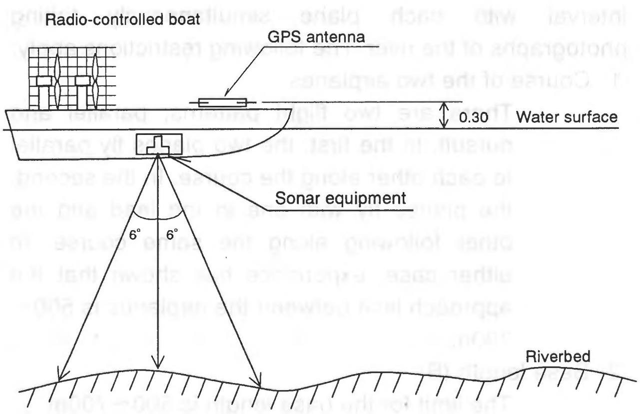

Fig.3 Measurement method using radio-controlled boat

The results of the measurements gathered enabled us to draft The contour line map of flood flow surface (Fig.4) and The contour line map of flood flow riverbed channel (Fig.5) for the same observation point. Additionally, by integrating The contour line maps together it was possible to create 3D image of flood flow surface (Fig.6) and 3D image of flood flow riverbed channel (Fig.7). Reconfiguring the information as three-dimensional data enables us to give an image as if viewed from the air. In other words, topography that is normally invisible because it is underwater can be expressed three-dimensionally. This is possible because the data from GPS measurements includes changes in water surface such as rising falling, etc.

To measure the water level across the width of a river takes 1-2min. Consequently, there is no problem in the observation if the flow volume remains steady. However,

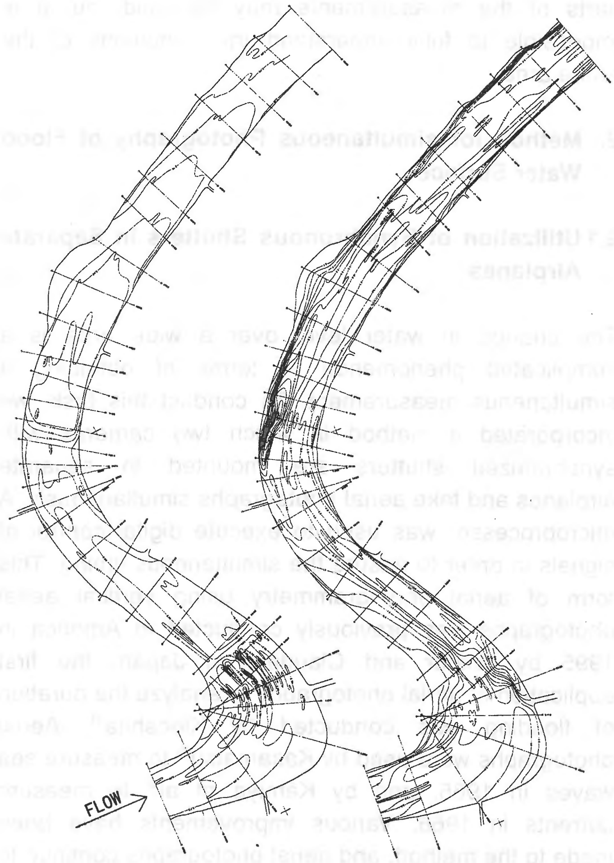

Fig. 4 The contour line map of flood flow surface

Fig. 5 The contour line map of flood flow riverbed channel

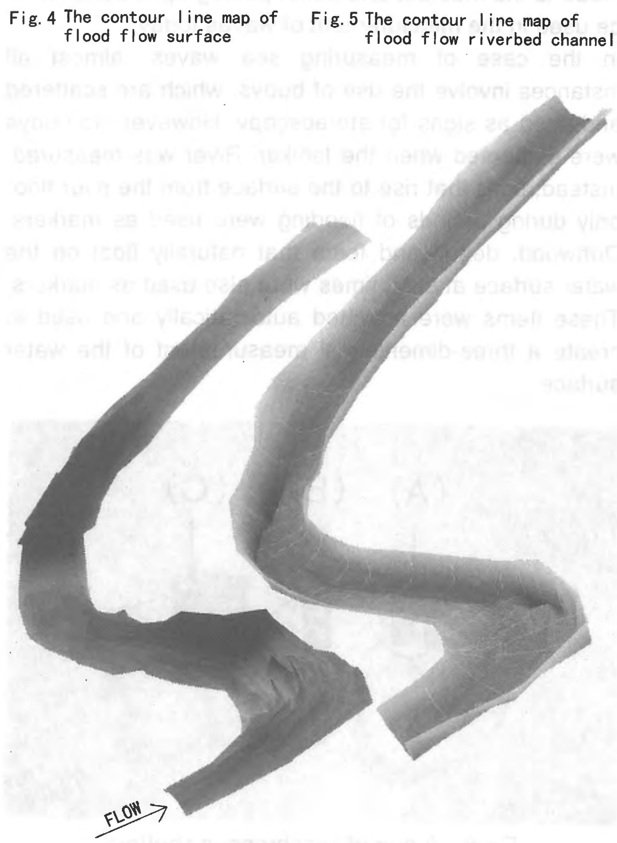

Fig. 6 3D image of flood flow surface

Fig. 7 3D image of flood flow riverbed channel faults may occur when there is a substantial change in flow volume over the full 2.5km area. At such times, parts of the measurements may be valid, but it is impossible to fully understand the conditions of the entire area.

2. Method for simultaneous Photography of Flood Water Surface

2.1 Utilization of Synchronous Shutters in Separate Airplanes

The change in water level over a wide area is a complicated phenomenon in terms of obtaining a simultaneous measurement. To conduct this task, we incorporated a method in which two cameras with synchronized shutters are mounted in separate airplanes and take aerial photographs simultaneously. A microprocessor was used to execute digital control of signals in order to ensure the simultaneous timing. This form of aerial photogrammetry using vertical aerial photographs was previously conducted in America in 1995 by Wilber and Claude[1]. In Japan, the first application of aerial photography to analyze the duration of flooding was conducted by Kinoshita[2]. Aerial photographs were used by Kasamatsu[3] to measure sea waves in 1965, and by Kamiya et al[4] to measure currents in 1966. Various improvements have been made to the method, and aerial photographs continue to be used in the measurement of waves today.
In the case of measuring sea waves, almost all instances involve the use of buoys, which are scattered and used as signs for stereoscopy. However, no buoys were dispersed when the Ishikari River was measured. Instead, boils that rise to the surface from the river floor only during periods of flooding were used as markers. Driftwood, debris and foam that naturally float on the water surface at such times were also used as markers. These items were matched automatically and used to create a three-dimensional measurement of the water surface.

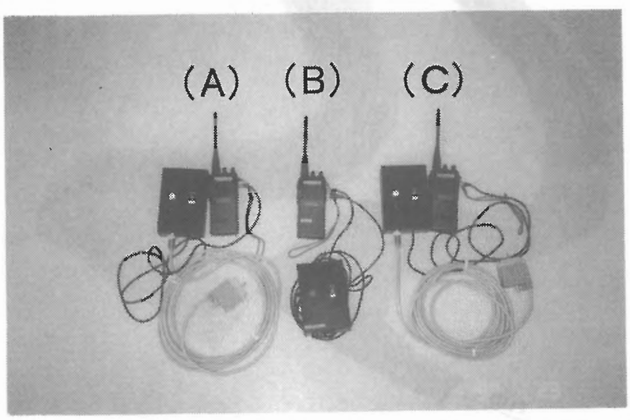

Fig.8 A pair of synchronous shutters
(A),(C) Pair of synchronous shutters
(B) Synchronous shutter transceiver (master)

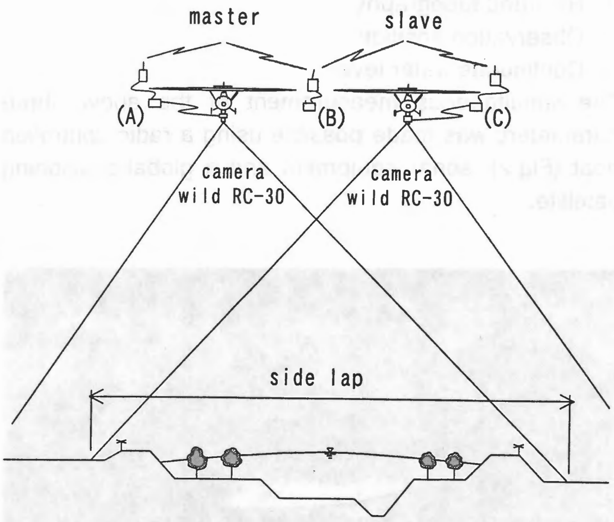

Fig.9 Method for simultaneous photography of flood water surface

2.2 Synchronous Shutter Photography

The procedure for synchronous photography requires two airplanes to fly over the same course at a fixed interval with each plane simultaneously taking photographs of the river. The following restrictions apply:

① Course of the two airplanes
There are two flight patterns, parallel and pursuit. In the first, the two planes fly parallel to each other along the course. In the second, the planes fly with one in the lead and the other following along the same course. In either case, experience has shown that the approach limit between the airplanes is 500~700m

② Base length (B)
The limit for the base length is 500~700m

③ Photography overlap
Since the difference in the elevation of the water surface on the river is small (within 1.0~2.0m), a overlap of 55~60% is better than 80% in order to simplify reading.

④ Photography scale (S)
The maximum photography scale is determined after the base length and overlap rate are determined; S = B / 0.23 (1.0 - 0.6)

⑤ Photography width (W)
The necessary river width required to be photographed is determined using the base length and other information. The formula is W = S×0.23.

⑥ Determining the photography course
When determining courses for Japanese river widths, the standard base length is 500~700m. Therefore, navigation aspects taken into consideration, it is difficult to use the pursuit course, and the parallel course is

usually judged as most appropriate due to safety factors. However, there are times when this course doesn't result in good image quality due to the direction of sunlight and / or direction of location to be photographed.

2.3 Apparatus Characteristics

- When photographing, the transceiver sends a 1,200bps digital signal at 3ms pulse widths three times.
- The signal from the receiver switches between a resistance value of infinity and 50ohms. These signals are used to control shutter speed by switching between the L and H shutter instruction circuits in the cameras.
- All signals are digitally controlled using a single-chip microprocessor.
- A photo MOS IC relay is used rather than a mechanical relay, which is known to have a rather high error level. The signal delay of the IC, at 18ms, is much smaller than the approximate 100ms of the mechanical relay, and the disparity between the two receivers is small enough to be ignored.
- The power-supply is 100% internal, and therefore is not subject to airplane flight or maintenance inspections.
- Since the single transceiver and two receivers operate at sub-frequency levels, there is no need to file an application based on the Radio Law. Neither is there any influence on airplane navigational instruments.

The speed of the simultaneous transmission, reception and shutter action of the camera has been calculated to have a precision of 1/1,000s or better. However, in reality the shutter systems within the individual cameras cause a slight time lag. Therefore, the simultaneity between the main and secondary cameras is reduced; judged to be approximately 1/100s at the greatest. This results in a movement disparity of about 0.5m when photographing at an airspeed of 180km/h. When the maximum water surface flow during a flood is 5m/s, the surface distance traveled in 1/100s is 0.05m. Therefore, this is can be ignored when measuring the volume of flooding.

3. Method for Measuring Water Surface Elevation

3.1 Snow-melt flood flow of the Ishikari River

Figure 7 shows the peaks of snow-melt flooding on the Ishikari River, a major river in Hokkaido, on April 13 – 14 of year. The equipment and conditions utilized during the photography session were as follows:

· Photograph scale	1 / 8,000
· Photograph site	Ishikari River, Hokkaido
· Photography elevation	1,224m, 1,223m
· Camera	wild RC30, RC30
· Overlap	side 60%, over 60% (actual 80%)
· Shutter speed	1/500s, 1/500s
· Filter	420nm, 420nm
· Shutter synchronizer	Synchronous shutters (digital)
· Film width	240mm
· Focus	wide-angle f=3D 152.99, wide-angle f=3D 152.82
· Motion correction device	None
· Film	EK-AREOCOLOR
· Shutter interval Δt	10.21s, 10.27s (60%)

3.2 Elevation Measurement

The Measurement of water surface elevation was conducted with the utilization of a digital image processing system; the process of which is indicated in the following flow chart.

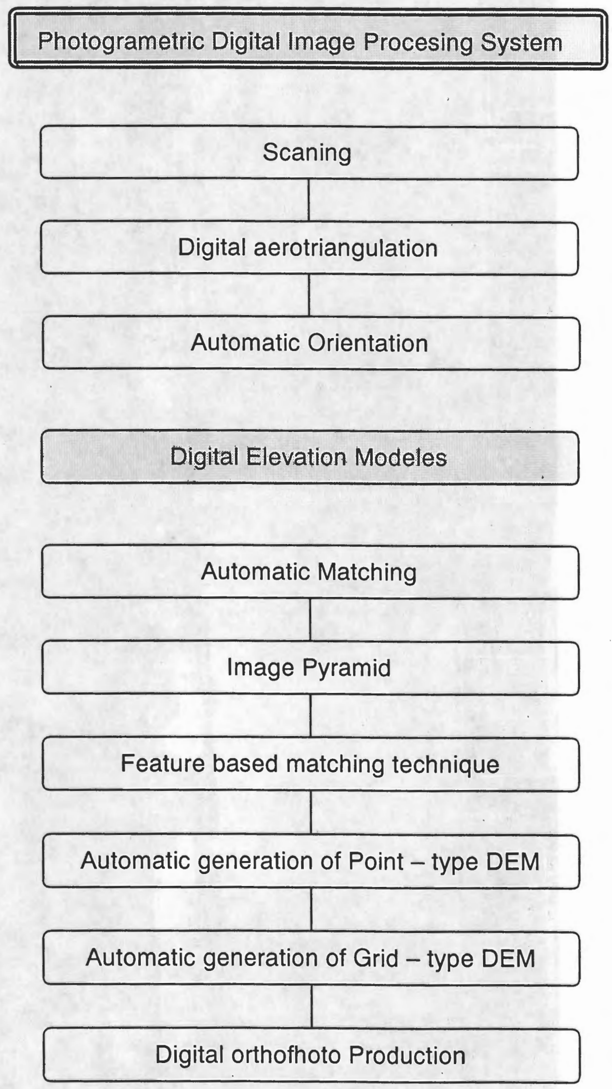

Fig.10 Flow chart of photogrammetric digital image processing system

Photograph site : Ishikari River in Hokkaido

FLIGHT DATE : 14 APRIL 1998

OVER LAP : SIDE 60% , OVER 60%

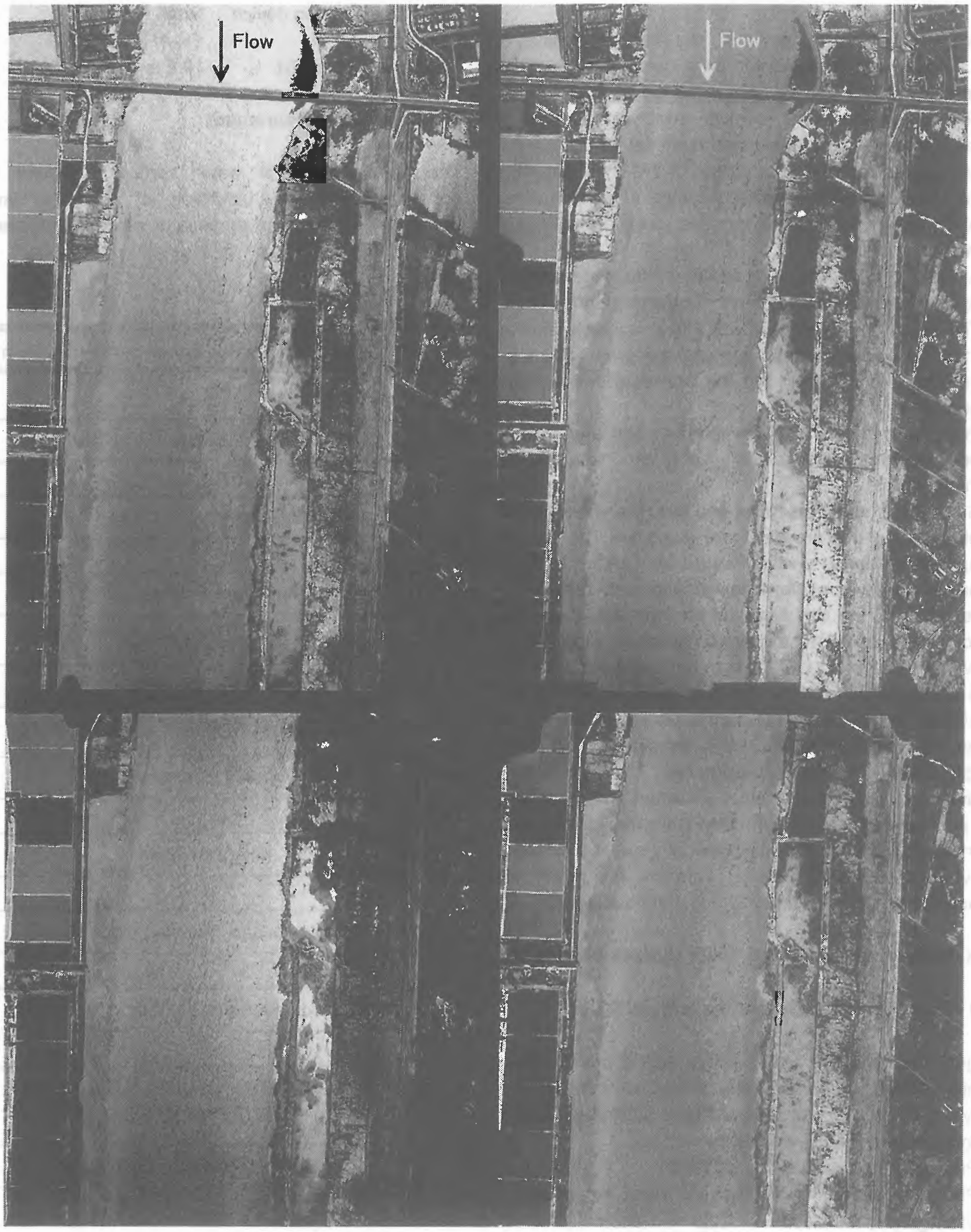

Fig.11 Synchronous shutter aerial photographys of snow-melt flood

3.4 Explanation of flow chart

① Scanning
Each pair of aerial photographs was digitalized at 8 bits. In order to increase automatic matching precision, it was important to construct the boil configurations using several pixels. Since boils are circular in shape with diameters of 5 ~ 6m, their sizes are equivalent to 0.625mm in a photograph (1/8,000). Therefore, photographs were directly scanned from the negatives at a pixel interval of 21 μm. Twenty-one micrometers are equivalent to a surface measurement of 0.20m.

② Digital aerotriangulation
Bundle-block calculations were utilized as photographs were taken with the airplanes flying a parallel course.

③ Automatic orientation
With the utilization of 200 tie points, it was possible to create a stereoscopic model with a 3~5 μm remnant-vertical parallax. There is a tendency for the relative orientation of vertical parallaxes to increase slightly due to Δt; thus care should be given to reducing Δt.
Interior, relative and absolute orientation are performed either automatically or semi-automatically. Particularly for the water surface portion, as the images change little in many cases, it is necessary to confirm the residual utilizing epipolar images after relative orientation, and then delete and add information.
The orientation process is as follows: ① interior orientation transforms the image pixels for the fiducial marks into camera coordinates; ② relative orientation determines the relationship between the left and right image tie points within a three-dimensional coordinate system; and ③ absolute orientation matches the results with the geodetic coordinates.
Orientation was conducted using a multistage area-matching method. The Lagrange least-squares matching method was applied as the arithmetic process to designate similarities within the windows. Clear positions of the riverbank were extracted from the photographs and established as additional points for relative for improving the accuracy of water surface measurements.

④ Digital elevation model (DEM)
Stereo matching of six-stage epipolar images (21, 42, 84, 168, 336 and 672 μm) was utilized to attain the DEM for this report.
First, for the rough, coarse 672 and 336 μm images, only large, clear reference points were retrieved using feature-based matching. Next, for the images ranging from 168~21 μm, only the first item of similarity was retrieved from the small-area image information. This was done using defined-area matching. The corresponding points retrieved through these matching methods were randomly located; however, they were interpolated into a 5m grid in the end.

3.4 DEM Verification

The accuracy of the DEM determined was verified using leveling at the riverbank. The results of leveling were approximately 0.07~0.28m higher than the measured results. The desired accuracy for this type of measurements is 0.05 ~ 0.10m. On the other hand, through experience it is understood that the height accuracy for this imaging system is 0.1‰~0.3‰ of the flying attitude. Since the height of the airplanes' course at the time of photographing the water surface 1,200m, the error in measurement 0.12~0.36m.
There is no way to verify the results of DEM measurement of the center section of the river channel. However, it is judged that the relatively good results obtained for the riverbank are the result of manual tie-point addition and pricking during the relative orientation and absolute orientation processes.

3.5 Error Factors During Three-Dimensional Measurement

The following error factors should be considered when measuring rivers.
① Poor clarity of water surface patterns
② Unevenness in stereo photograph images due to the influence of halation
③ Use of film unsuitable for three-dimensional measurement
④ Measuring system
⑤ Relationship of base length, flight altitude and resolution

3.6 Visualizing Water Flow

3.6.1 Water Surface

Figures 12 show the contour of the water surface at the peak instant. This is the same shape as that recorded for the Shiribetsu River (Fig.6) when measured using a GPS system. The water surface level rose an average of 0.21m as the difference between the riverbank and flow center. The slope in the upper and lower flows of the water surface was approximately 1/810. In contrast, the lateral-direction slope of the water surface was 1/500, which is approximately one and six times greater than the longitudinal slope.
Ordinarily, in such a case, this would be illogical unless the flow is divided laterally from the center of the stream towards the riverbanks. However, in reality, the flow moves almost entirely towards the lower reaches. Although the lateral surface indicates a gentle arc, a close analysis of the changes indicates slight rising and falling. Utilizing pattern relationships, this movement was judged to be due to boils and other turbulence.

3.6.2 Kinetic Energy

Figures 13 show the movement of matter floating naturally, indicated in the longitudinal course shown earlier in fig.11. From observation of the two figures, the time for movement was roughly 5.5~5.6s. The velocity of the flow is expressed as a distribution. The values are obtained by respectively dividing the levels by the shutter time (Δt=5.5s), which is the absolute velocity of the flow vector.
Additionally, the area of energy concentration seems to be directed downward and toward the right shoreline while changing shape in a complex manner. However, a close analysis of Fig.13 reveals that this area is also connected to the are of concentration at the centerline of the river. It was therefore judged that the areas of concentrated energy were connected by eddy currents. It is believed that visualization of the flow phenomena using this photography technology will play a critical role in providing an understanding of the complicated factors related to discharge duration.

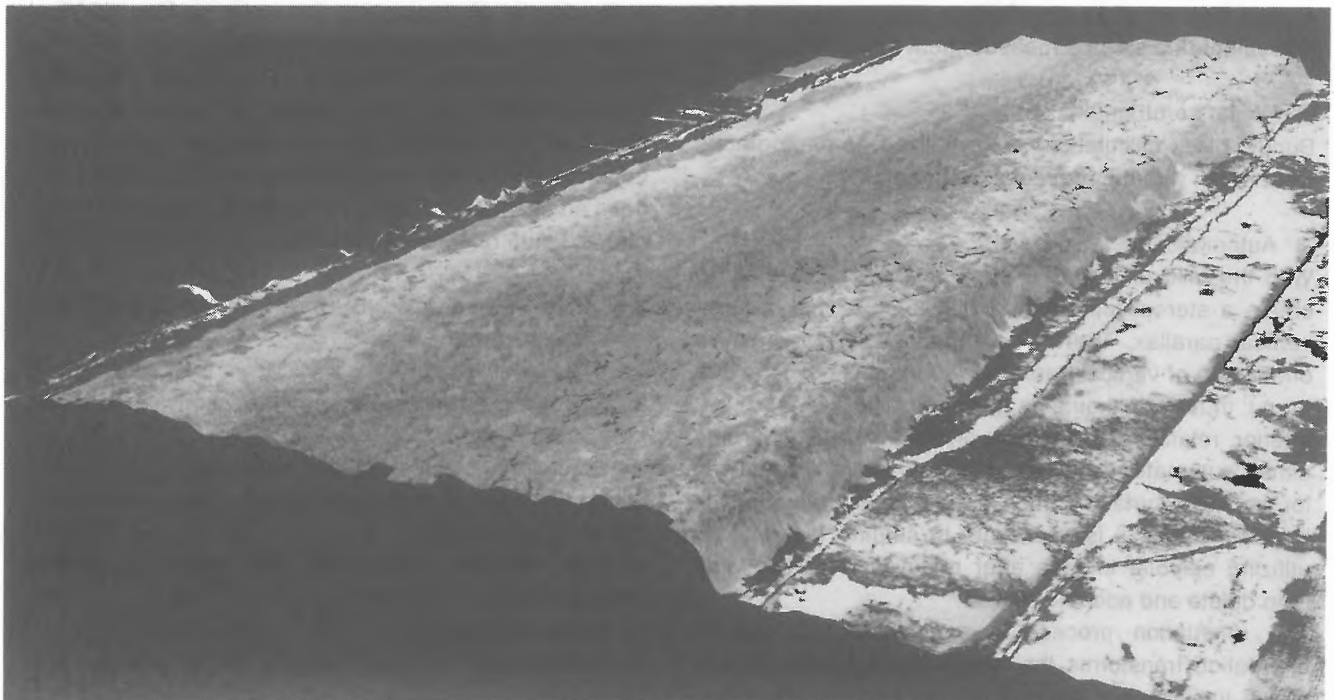

Fig.12 Orthophoto birds-eye view photograph of flood flow emphasized the height changes in surface of the water

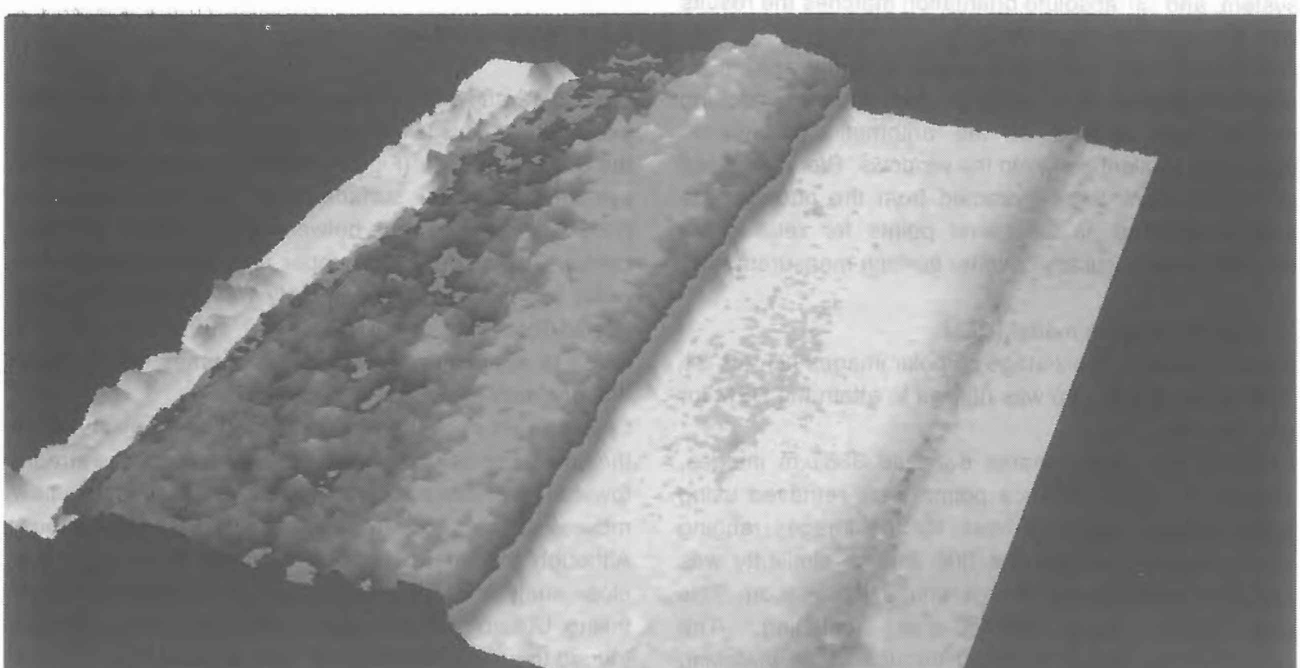

Fig.13 Birds-eye view of kinetic energy in the flow

4. Conclusion

From the standpoint of measuring moving bodies, the effectiveness of measuring the flood phenomena unique to Japanese rivers using digital photography was confirmed.

1) Riverbed topography and water surface, which constantly change during flooding, were successfully measured three-dimensionally and simultaneously. Consequently, the previously hypothesized but never proven phenomenon of arc-shaped rising of the water surface in a straight river channel was observed.
2) It is necessary to improve the correction method for kinematics in order to increase the precision of measuring water surface height when utilizing a GPS system.
3) It was confirmed that simultaneous photography utilizing a synchronous shutter system mounted in two airplanes is an effective method for measuring moving bodies.
4) Taking into consideration the river flow characteristic of uncertainty of current direction, the shutter interval speed had to be increased.
5) It was confirmed that the stereoscopic visualization of flow phenomena using three-dimensional digital image processing is effective for understanding flood waters as a moving body.
6) It is recommended that global research be conducted for the purpose of improving the precision of elevation measurement in numeric topography models that utilize three-dimensional digital imaging systems.

ACKNOWLEDGMENT

I wish to express my sincere thanks to Koichi Endo of Kimoto K. K., and Takaharu Kotaki, Nobuaki Horie, Atsushi Konno, Qiu Tong, Carl Zeiss and Silke Jud for their enormous help concerning attempts toward the cutting-edge practical application of the systems in this research and development. I would also like to note my sincerely gratitude to the staff of Code Photography K. K. for their assistance in developing the synchronous shutters and photography work.

REFERENCES

Wilber Marks, F Claude Rome: Aerial stereo photography and ocean waves, Photogrammetric Engineering, XXI – 1, 1955, PP.107 – 110, 1995.

Ryosaku KINOSHITA: Measurement of flood water surface velocity and direction using aerial photogrammetry, and the relation between distribution and riverbed formation, collection of Eighth Hydraulics Seminar Lectures, PP.65 – 66, 1963. (in Japanese)

Ryosaku KINOSHITA: An analysis of the movement of flood waters by aerial photography concerning characteristics of turbulence and surface flow, Journal of the Japan Society of Photogrammetry, VOL.6. NO.1, PP. 1 – 17, 1967.

Kiyoshi KASAMATSU; Contour map of the waves, Journal of the Japan Society of Photogrammetry, VOL.4. NO.4, PP. 165 – 169, 1965.

R. KAMIYA, T. TAKAHASHI, K. TANAKA: Current survey by use of air photographs, Journal of the Japan Society of Photogrammetry, VOL.5. NO.4, PP. 159 – 164, 1966.

Fumiaki YAMAZAKI, Ryosaku KINOSHITA, Kazuo SHIMURA: Hovercraft utilization for the riverbed sound Investigation at the Time of Flood, Annual Journal of Hydraulic Engineering, JSCE, VOL.35. 1991. PP. 691 – 694, 1993.

Karl Klaus, P. Baldheusel: Photogrammetry, 1993

Tadashi UTAMI, Tetsuo UENO, Ryosaku KINOSHITA: A study of the structure of flood flow by picture processing of aerial photographs, International Association for Hydraulic Research, PP. 721 – 727, 193.