Application of Continuous Maintenance Method for Aging Underground Powerhouse

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Abstract

An adequate management of an aging underground powerhouse is recognized to be a mandatory issue through the experience of which significant damages were happened in a few support members of approximately50-year old cavern for the powerhouse. The studies have been made to verify the soundness of the cavern by arranging two diffused laser range finders at the generator sections for monitoring the convergence, in-situ stress measurements of major concrete structures of the cavern and lift-off tests of PS anchors. Based on these results, the present soundness of the cavern was confirmed with the interpretation by the structural calculation using the simple frame model of the underground powerhouse. The management criterion was updated by applying the future scenarios of the deterioration of the cavern supports to its present structural condition. These procedures were compiled as a new management method for aging underground powerhouses, referred to as the continuous management method, which was characterized by updating periodically its management criteria aided by monitoring and structural analysis.

Following updated management criteria at the above-mentioned underground powerhouse, five-year convergence data at two generator sections has been accumulated so far. While one is stable, however another has been shortened gradually, but does not touch the warning level. In this paper, the convergence behaviors are examined from the standpoint of the availability of the monitoring device and the structural response of the cavern.

Keywords: Aging, Underground powerhouse,Management,Diffused laser range finder.

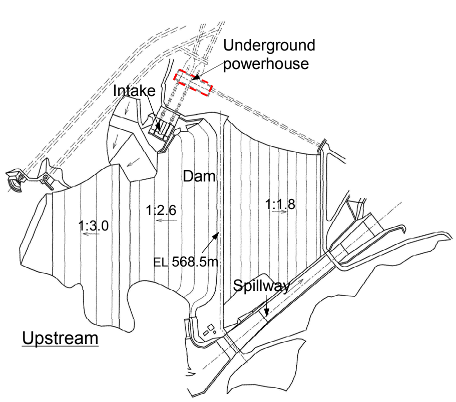
1. Introduction

Since the 1940s, more than fifty underground caverns for hydropower plants have been constructed in Japan, almost all of which have been operated for the past few decades. Monitoring the deformation of the caverns and surrounding rock, as well as the forces acting on the supports, is vital to confirm the soundness of these caverns during the construction. Because the caverns are not deemed to be exposed to any additional forces, since they also incorporate reinforced concrete as inner supports, concerns over cavern stability rarely emerge after the completion of the construction.

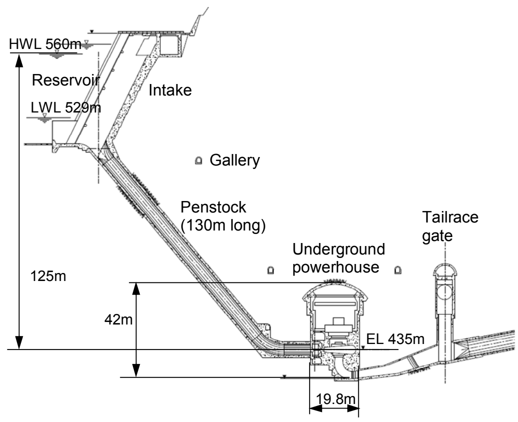
In those one during the operation for forty-six years, several rock anchors were broken, and the stability of the cavern should be re-evaluated. For this purpose, additional monitoring and numerical study (Kashiwayanagi et. al., 2009, 2011 and 2013) were conducted. This paper summarizes field measurement results and their interpretation, using diffused laser range finder, new device of convergence measurementfor the stability evolution of caverns for underground powerhouses under operation.

2. Outline of an underground powerhouse studied

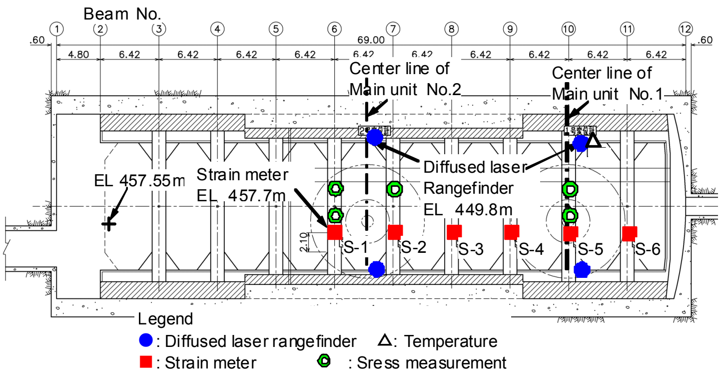
The underground powerhouse studied in this paper, locates in central part of Japan, includes output of 220 MW, two generator units and discharge of 266 m^3/s, with completion in 1968. Its characteristics are shownin Fig. 1. Some damaged pre-stressed anchors were recently identified, while no other deterioration in the cavern was found. It is considered that the damages to the support did not affect the stability of the cavern. However additional monitoring, which involves measuring the tension stress of existing anchors and monitoring the cavern convergence and major structural beams, is planned to clarify its long-term performance. Monitoring plan is shown in Fig. 1 and Table 1. The convergence is monitored using a new device using the diffused laser beam, referred to as the diffused laser range finder (DLRF), which consisting the laser transmitting and receiving unit and the reflecting board. The distance between the unit and the board is continuously measured in a precision of 0.1 mm with any interval. The overview of DLRF is shown in Fig. 2. The monitored convergence performed in four years is examined in this paper from the mechanical view point of the cavern behavior.



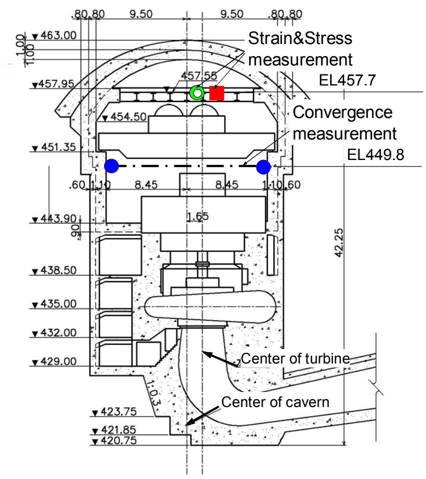
(a) Layout of powerhouse



(b) Longitudinal section of waterway



(c) Plan of underground powerhouse



(d) Section of underground powerhouse

Fig.1. Underground powerhouse and monitoring arrangement

Table 2. Monitoring plan (Refer to Fig. 1)

Monitoring items	Descriptions
Convergence	Diffused laser rangefinder (Meiji Consultant Co., Ltd.), consisting laser transmitting and receiving device and reflecting board, as shown in Fig.2, Two sections, Monitored from Feb. 2010
Strain of RC beams	Six sections, Monitored from Feb. 2010
Stress of RC beams	Three sections, Monitored on Dec. 2010
Axial force of rock anchors	All pre-stressed anchors constructedalong the cavern surface
Observation of cracks	All surfaces of the underground powerhouse

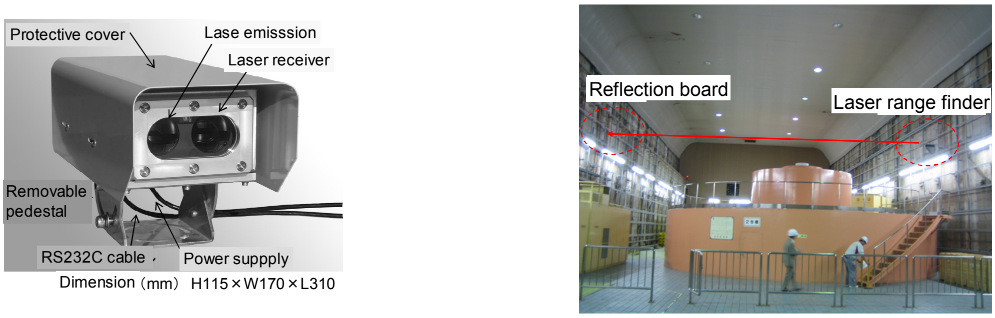


Fig. 2. Diffused laser range finder (DLRF)

3. Convergence monitoring

3.1 Monitoringresults

Monitored convergences of the underground powerhouse at two sections are shown in Fig.3 with its conditions of the reservoir water depth and the ambient temperature of the powerhouse, shown in Fig.4. The reservoir water depth shows several cyclic fluctuations a year, while the temperature in the powerhouse fluctuates once a year. The convergence at the No.1 unit section (referred to as the No.1 section hereinafter) fluctuates several times a year with constant a 0.3mm convergence occurringat the beginning of the monitoring. The significant convergence in August 2014 is supposed to be false behavior due to the stain of the reflecting board ofDLRF. The convergence at the No.2 unit section (referred to as the No.2 section hereinafter) shows minor, but continuous convergence with smaller and similar fluctuationsof one of the No.1 section. Both convergences involve scattering of approximately 0.2 mm. The relations between the convergences and their circumstances of the reservoir water depth and the ambient temperature of the powerhouse are studied in the following sections.

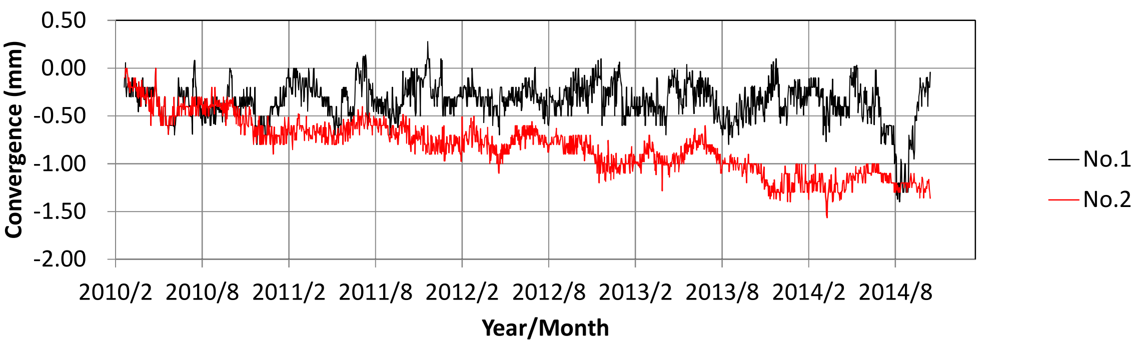


Fig.3. Convergence at No.1 and No.2 unit sections
(Negative values correspond to narrowed sections.)

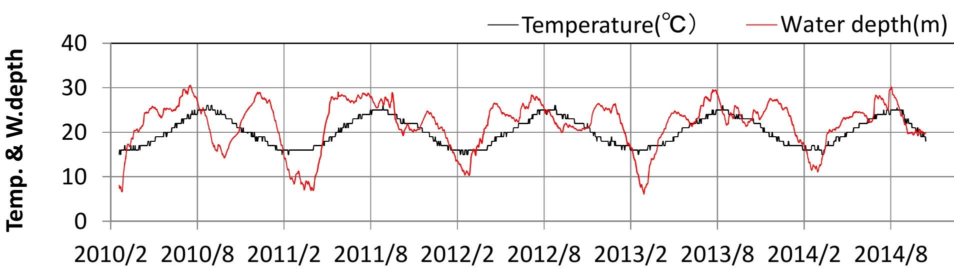
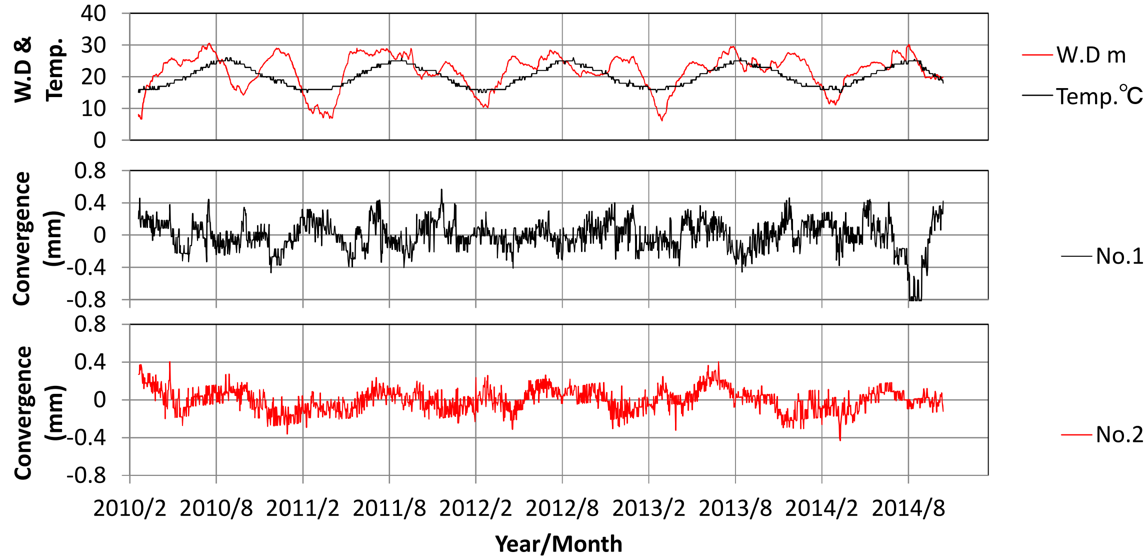


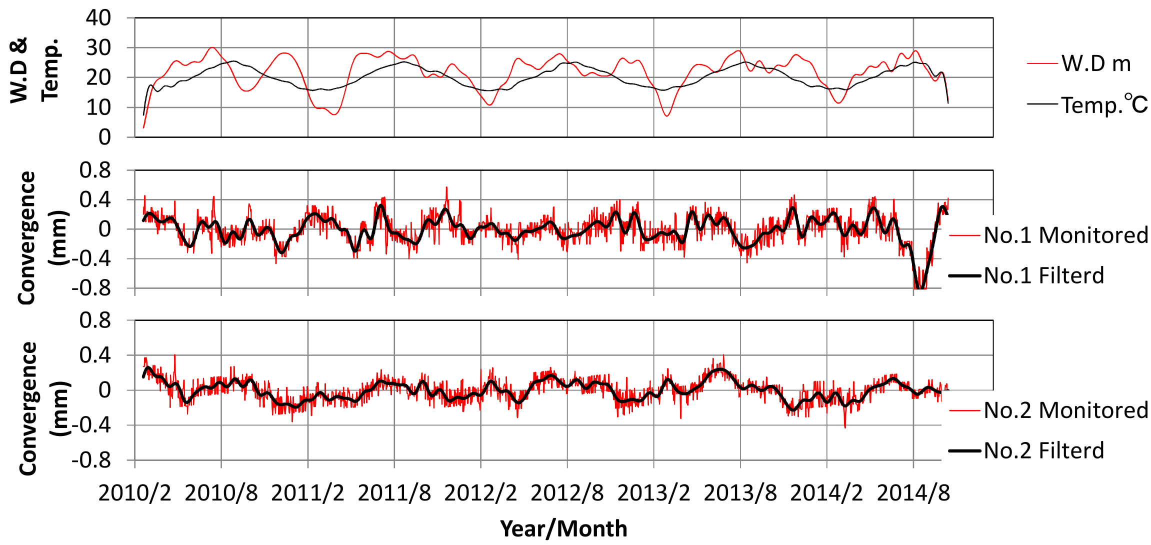
Fig.4. Temperature and reservoir water depth

3.2 Data analysis and discussions

Eliminating the long-term trend and short-term variation, the convergences at No.1 and No.2 sections are compared with the reservoir water depth and the ambient powerhouse temperature. The data processing is conducted by the filtering methods of high pass filter for the long-term trend firstly and low-pass filter of 0.033 /day for the short-term variation. The monitored convergences are transformed to approximately monthly averaged data without the trend. The processed data are shown in Fig.5. The convergence of the No.1 and No.2 sections shows the 0.3 mm and 0.2 mm amplitudes with 0.1 mm to 0.2 mm variation, respectively.



(a) Trend treatment



(b) Filtering (Low pass filter: 0.0033 /day)

Fig.5. Convergence without long period trend and short period fluctuation

The frequencycharacteristics of monitored data are shown in Fig.6. The significant periods of these data are summarized in 1 year, 0.5 year and 120 days for the reservoir water depth, 1 year for the ambient powerhouse temperature, 0.5 year and 120 days for the No.1 section and 1 year and 120 days for the No. 2 section. These facts may indicate that the reservoir water depth and the ambientpowerhouse temperature cause the convergence of the cavern. By illustratingthe relation between the convergences and the other data in Fig. 5 (a), the convergence of the No.1 section shows the slight negative relation to both, while the convergence of the No.2 section showspositiverelation only to the ambient powerhouse temperature as shown in Fig. 7. However in those figures, the short-term variations prevent the apparent relations.

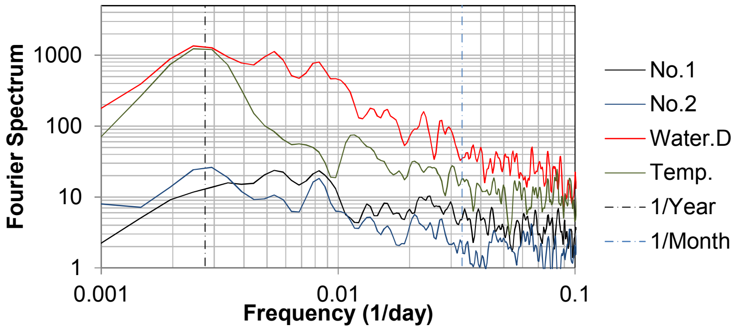
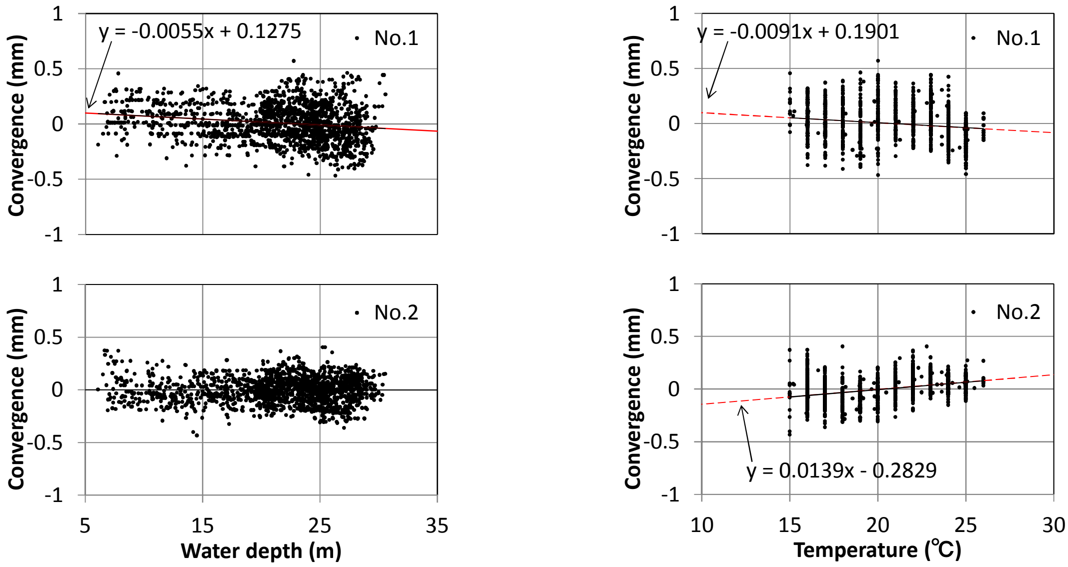


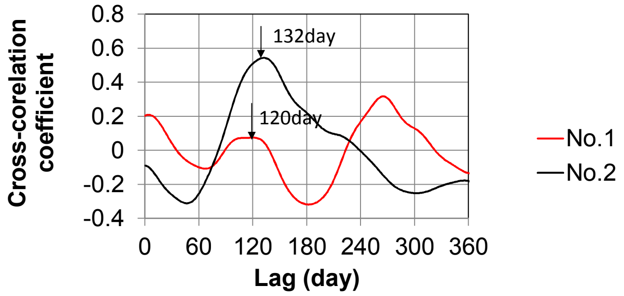
Fig.6. Frequency characteristics of monitored data



(b) Convergence and water depth
(c) Convergence and temperature

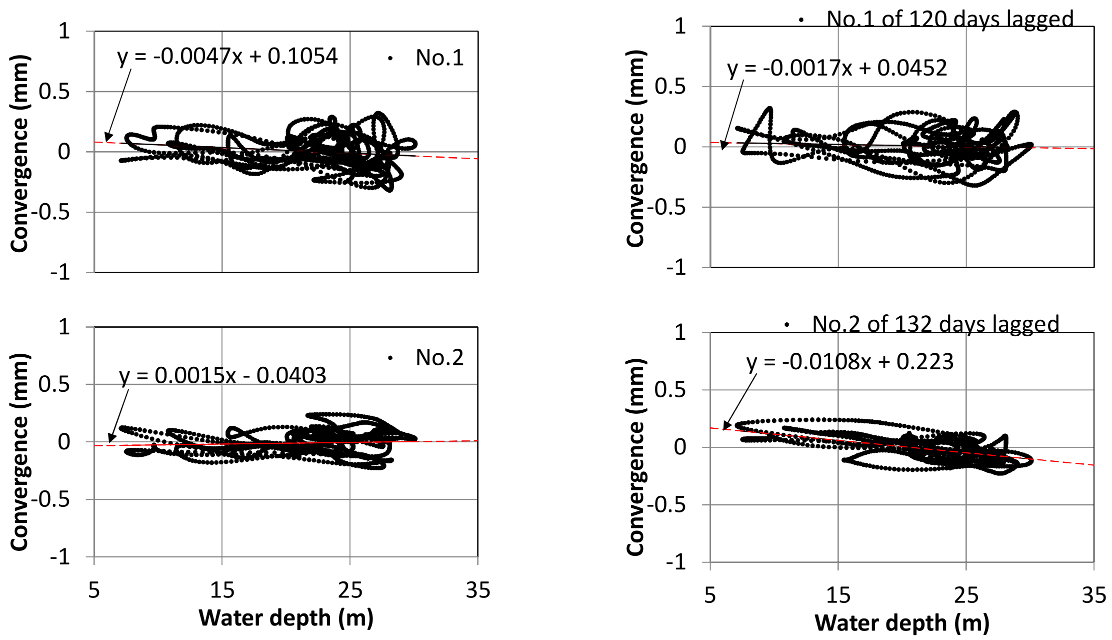
Fig.7. Relations on convergence(without data after Aug. 2014)

A change in the ambient temperature causes deformation of the concrete structures in the powerhouse, which resultsin the convergence of the powerhouse. These phenomena can happen in a short time without the lag time of the change in the temperature. The fluctuation of the reservoir water depth may have a longer lag time to cause the powerhouse convergences due to the infiltration process as underground water. In this context, the cross correlation between the convergences and the reservoir water depth was examined. The data shown in Fig.5 (b) are applied with eliminating 100 days data at the beginning and the end of the total data to avoid thecomputational error of data processing. The cross-correlation coefficient of the convergencesand the reservoir water depth are shown in Fig.8, showing the peak at 120 and 132 lag days for the No.1 section and No.2 section, respectively. Based on the results, the relations are shown again in Fig.9 and Fig. 10 with lag days comparedthose of no lag days. The lagged convergence time history of No.1 and No.2 sections are shown in Fig.11 with comparing to the reservoir water depth, showing good agreement in each behavior.



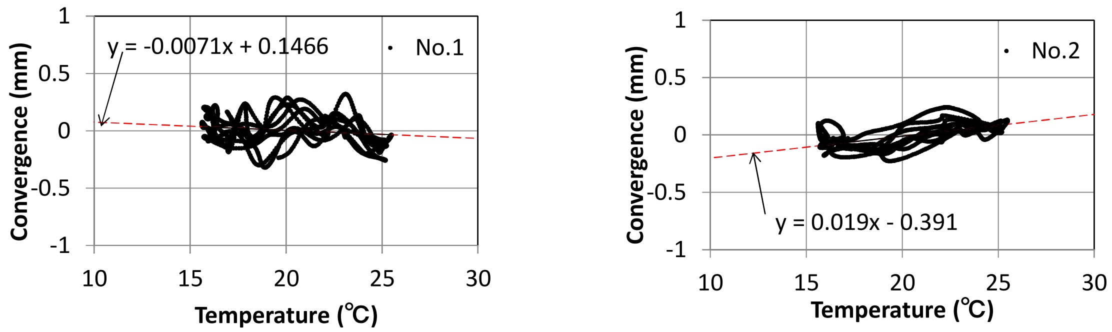
Note: Each convergence data are processed by the trend elimination and filtering.

Fig. 8. Cross correlationcoefficient between convergence and reservoir water depth



(a) Original data (b) Processed data

Fig.9. Correlation between convergence and reservoir water depth



(a) No. 1 unit section (b) No.2 unit section

Fig.10. Correlation between convergence and temperture

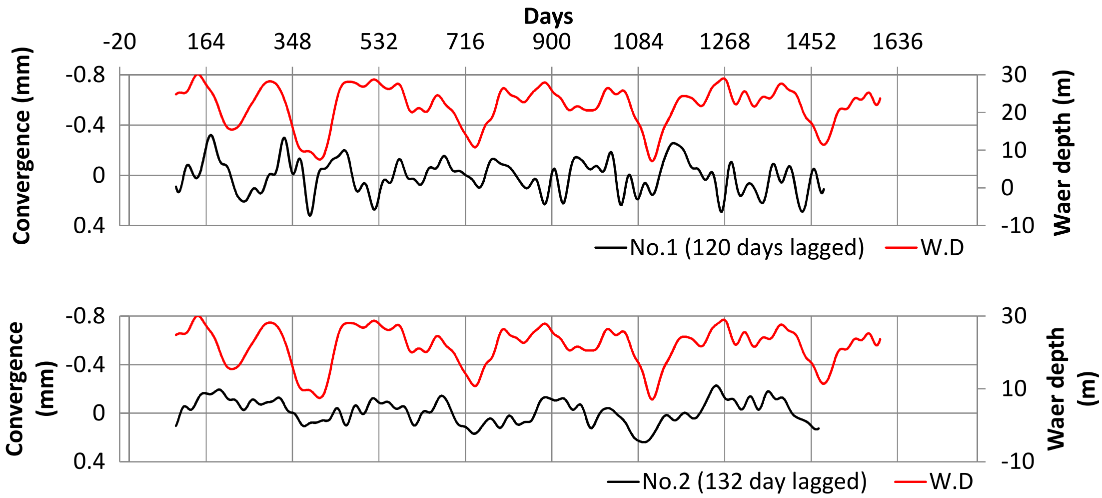


Fig. 11. Lagged time histories of convergences

The convergence of the No.2 section shows a negative relation to the reservoir water depth with132 lag days, while less relation in no lag days, and a positive relation to the powerhouse ambient temperature. These relations suggest that the higher water pressure around the cavern and the decreasing of the temperature may cause the convergence of the cavern and the contraction of the concrete structure, and resultsin the negative convergence, respectively. The monitoredbehavior of the convergence of No.2 section is considered to be reasonable. The fluctuation of the underground water pressure and the ambient powerhouse temperatureis one of the major causes of the behavior of long-term operated underground powerhouses. The behavior of the No. 1 section shows the wider scattering even after introducing the 120 lag days and the negative relation to the ambient powerhouse temperature. Further studies are necessary to explorethe behavior of the No.1 section.

The continuous increasing of the convergence of the No.2 section shown in Fig. 4 is not studied in this paper. The plastic characteristics of the surrounding rock at the No. 2 section may be the causes of such behavior. Further study including the survey work of the surrounding rock of the cavern is necessary.

4. Conclusions

As a continuousmaintenance method of an aging underground powerhouse proposed by the authors (Kashiwayanagi, et. al., 2013), detailed monitoring has been conducted due to the damages of several PS anchors in an underground powerhouse that has been operated for approximately 50 years. This paper focuses on the behavior of the convergencemonitored by the new device of the diffused laser range finder. The convergence behavior is studied in relation to the fluctuations of the reservoir water depth and the ambient powerhouse temperature. The conclusions are summarized below.

(1) The convergences of the underground powerhouse are precisely monitored and showreasonable behavior againstthe fluctuation of the reservoir water depth and the ambient powerhouse temperature even though the convergences fluctuate within 1 mm as shown in Fig. 3.

(2) The convergences monitored do not exceed the warning level of 2.5 mm (Kashiwayanagi, et. al., 2013). Therefore it is considered that soundness of the cavern is ensured and that the current management should be continued as a continuous maintenance method for theunderground powerhouse.

(3) The fluctuation of the underground water pressure and the ambient powerhouse temperatureis one of the major causes of the behavior of agingunderground powerhouses.

(4) The applicability of the diffused laser range finder for the monitoring of the underground powerhouse is credible from the perspective of the monitoring precision andstable operation.

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