CRACK INSPECTIONS USING "KUMONOS", A TOTAL STATION EQUIPPEDWITH A BUILT-IN CRACK SCALE

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This paper describes KUMONOS, which is a total station equipped with a built-in crack scale. Using this system enables one to accurately measure the width of cracks in structures from a distance. When compared to the traditional inspections based on hand-sketches, the advantages of the inspections using KUMONOS are high precision, safety and economic performance. Therefore, KUMONOS can be expected to perform a constructive role in maintaining structures.

KEY WORDS: Social capital, life cycle cost, maintenance, cracks, total stations

1. Introduction

1.1. Background of the development

Many structures were built between 1960 and 1980 in Japan. As Table 1 shows, the number of the structures which exceed 50 years since their construction will increase dramatically in the next 20 years. This rapid deterioration of social capital stock increases the cost for maintenance and renewal of the structures. On the other hand, as Figure 1 shows, the construction cost in Japan continues to drop from its peak in the fiscal year of 1992, and fell to about half of the peak in the fiscal year of 2010. This situation calls for the extension of structures' life-spans and systematic renewal of existing structures. Therefore, it is crucial to regularly detect signs of deterioration and to accurately monitor and record them in order to accurately assess the deterioration of structures, and determine the appropriate timing for repair.

Table1.The number of infrastructures exceeding 50 years since their construction
(Source: "White Paper on Land, Infrastructure, Transport and Tourism in Japan" [1])

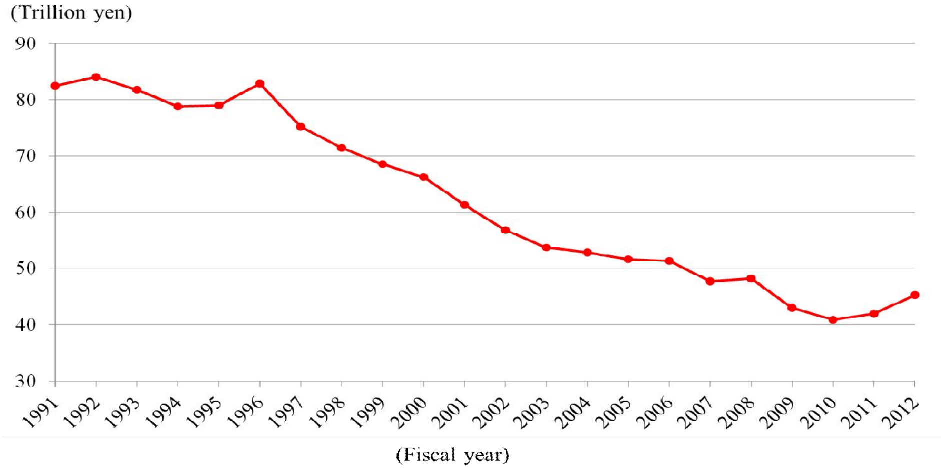
	2010	2020	2030
Road bridge	Approx. 8%	Approx. 26%	Approx. 53%
Drainage pump station, floodgate etc	Approx. 23%	Approx. 37%	Approx. 60%
Sewer culvert	Approx. 2%	Approx. 7%	Approx. 10%
Port quay wall	Approx. 5%	Approx. 25%	Approx. 53%

Various phenomena such as dry shrinkage, deflection under load, water leaks, corrosion, and rust can cause deterioration to structures. These causes can be identified from the position, shape, and direction of cracks which have emerged on the structures. Also, cracks are easy to inspect because they appear on the surface of the structures. It is a relatively easy and legitimate inspection to regularly and accurately monitor the progress of cracks.

In this paper, we introduce KUMONOS, which is a total station equipped with a built-in crack scale, as an instrument which can accurately measure cracks in structures, and record their growth.

1.2. Problems of conventional crack inspection

Using the common crack inspection method, one must chalk cracks in order to indicate their shape, measure their widths using a special ruler called a crack scale, and then write the values of the width on a concrete surface. Finally one must visually check and sketch their shapes in order to take the data of the cracks.



* The numbers for FY2010 and FY2011 are prospective and for FY2012 is forecasted.

Fig. 1. Transition of Construction Investment
(Source:"Estimate of Construction Investment" [2])

One must approach cracks in this method, but most of concrete structures are in places where one must set up scaffolds or use a boom-lift to inspect cracks. Because of these reasons, this method requires cost for scaffolds or a boom-lift. Also, one is unable to conduct inspections in places where one cannot set up scaffolds or use a boom-lift. Additionally, the data of the inspections are based on hand-sketches, which vary depending on the inspectors. Hand-sketches make it difficult to record accurate data of inspections, and analyze changes over time.

2. "KUMONOS", crack inspection system

2.1. Outline of KUMONOS

KUMONOS is a system which consists of a surveying instrument called a total station, a built-in crack scale and special onboard software (Figure 2). A 42X telescopic lens is mounted on KUMONOS so that the operator can measure the shape and the width of cracks from a distance. The measured data is recorded with 3D positional coordinates. It is no longer necessary to use scaffolds or a boom-lift which was used in the past to approach cracks. It reduces cost and dramatically improves measurement accuracy compared to hand-sketched data. Additionally, the data of positional coordinates acquired from measurements can be instantly plotted out via the special software once it has been installed in a computer. Therefore, the man-hours needed for preparing drawings after measurements are also significantly reduced. Also, the positional coordinates contained in the measurement data enable comparison and analysis by overlapping the new data with the previous data, which was too difficult to do using the conventional method. By making comparisons and analyses, it is possible to quantitatively assess changes such as the growth of cracks, and the extent of the area of rust and water leaks over time.

KUMONOS can measure the shape of the structures themselves, areas of damages such as rust and water leaks as well as cracks because KUMONOS has the standard functions of a total station to measure vertical and horizontal angles, and the slope distance and derivation of 3D coordinates. That is, KUMONOS can record the condition of the target structures and their deterioration as highly accurate 3D information. Because of this, it is easy to compare the new data with the previous data, and to quantitatively analyze changes over time which had been too difficult using the conventional method.

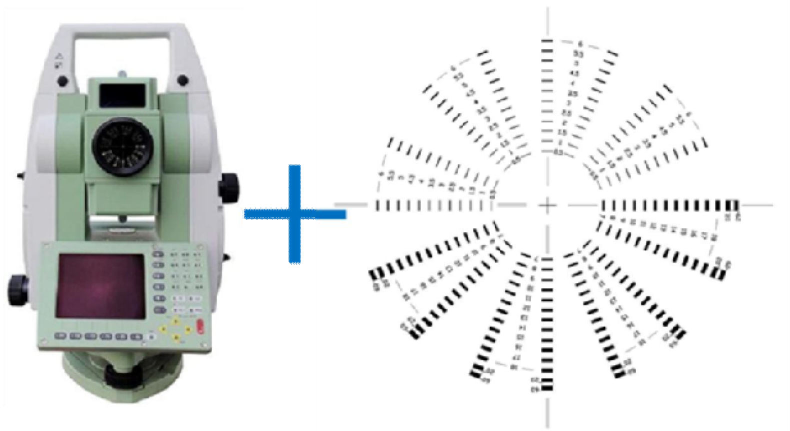


Fig. 2. The main unit of a total station and a built-in crack scale

2.2. How to measure cracks using KUMONOS

The way to measure cracks using KUMONOS is as follows;

I. Select the gauge number which matches with the crack's width using the built-in crack scale in the reticle of the total station.

II. Measure the distance and the angle between the instrument and the position where the crack's width is measured.

III. The actual crack's width is automatically calculated from the gauge number and the measured distance and angle, and then show up on the liquid crystal screen of the instrument.

3. Comparison of KUMONOS and the conventional method

3.1. Comparison in measurable range and safety

For example, when we check a cable-stayed bridge like that in Figure 3 using the conventional method with visual check and hand-sketch, we need to approach under the bridge by inserting the wagon of a boom-lift between the cables of the bridge. However, if the spaces between the cables are narrow, it is impossible to insert the wagon. Also, it is too difficult to check under the bridges, because it is impossible to set up scaffolds in a running river. Figure 4 shows a butane storage base. It requires a boom-lift to check the base. However, the entrance of the base is too narrow to bring a so big boom-lift that can reach the 30 meters height into the base.

On the other hand, we can conduct measurements from a distance using KUMONOS. To inspect the bridge in Fig. 4, we can set up an instrument on the opposite shore and make measurements from there. Also, it is possible to measure the ceiling of the butane storage base in Fig. 4 from the ground, because we can measure targets which are right above us by attaching the special eyepiece to the instrument. Moreover, we can remotely and safely measure objects which are not only in places we cannot physically approach, but also in places too dangerous to approach such as places which have the possibility of land slides.

Thus, KUMONOS enables one to measure the area which had previously been unmeasurable due to locational conditions, conformation, and dangers, and to comprehensively assess the current condition and determine whether it needs to be repaired. We can conduct measurements without the use of scaffolds even in places where scaffolds were once used. No need to use scaffolds ensures the safety of workers and third parties such as pedestrians.

Fig. 3. A cable-stayed bridge

Fig. 4. A butane storage base

3.2. Comparison in cost and man-hours

Table 2 shows a comparison in cost and man-hours for inspecting 1000 m² of a tunnel as an example. The inspection using KUMONOS reduced the cost by approximately 20% and man-hours by approximately 41% compared to the conventional method.

Table2. Comparison of new and conventional methods in cost and man-hours

	New method	Conventional method	Reduction rate
Cost	564,250 JPY	710,500 JPY	20.58%
Man-hour	7 days	12 days	41.67%

Especially when drawing figures, using the conventional method, one must scan the hand-sketches and then trace them using CAD. However, using KUMONOS, the special software automatically connects the measured points with lines, and instantly draws a figure. Although editing work is still necessary such as adding numbers and writing the length, required hours are dramatically shorten compared with the conventional method.

Not a boom-lift, but scaffolds are commonly used for inspecting bridges and retaining walls. Scaffolds cost 1,300 JPY per 1 m² on average (Commonly based on a monthly contract). On the other hand, KUMONOS does not require the use of scaffolds, which reduces the cost. Moreover, the area which the instrument occupies is so small that traffic control is rarely needed.

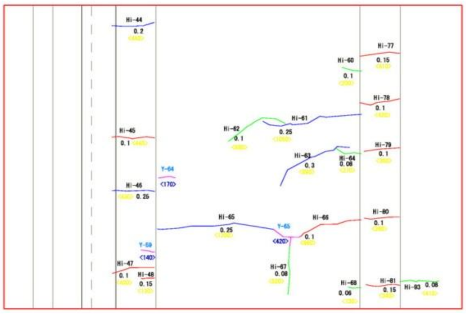
3.3. Analyzing deterioration over time

The positions of cracks are recorded with accurate positional coordinates in the inspections using KUMONOS. This is why it is possible to analyze changes in damages over time such as the growth of cracks and expansion of damaged areas. Figures 5 and 6 show a measurement case of Oshima Bridge in Yamaguchi Prefecture, Japan as an example of analyzing changes over time.

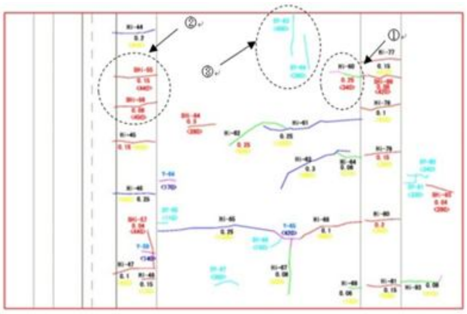
The figures below show a part of plotted out drawings of the pier of Oshima Bridge. Fig. 7 is a damage map from the measurement conducted in the first year. Fig. 8 is from the second year, which shows the same area as Fig. 7. By overlapping these two drawings, we can quantitatively assess the growth of the cracks and the generation of new cracks.

Fig. 5 and 6. Measuring Oshima Bridge

For example, the crack numbered 1 in Fig. 8 has already shown up in Fig. 7. Its length was 200 mm and its width was 0.1 mm in the first year, and the crack grew to a length of 340 mm and a width of 0.25 mm in the second year. Also, the crack numbered 2 in Fig. 8 does not exist in Fig. 7. It means that it is a newly emerged crack. The damage numbered 3 in Fig. 8 is the area of an efflorescence, which is the decalcified concrete aggregate which has come up to the surface. The efflorescence itself does not have a negative effect to the structural durability, but it has been recorded as a change on the surface. Using KUMONOS, it is possible to measure not only cracks but also other changes, and also to analyze the changes in them over time.



(1st year)
Fig. 7. Damage map of Oshima Bridge



(2nd year)
Fig. 8. Damage map of Oshima Bridge

There are generally both times when cracks grow rapidly and slowly, and then their growing speed tends to converge. Although it depends on the condition of the concrete, in the case of Oshima Bridge, it has been considered that it is efficient on a cost-benefit basis to repair the bridge when the cracks' growth stops. Therefore, the timing for repair is determined by quantitatively analyzing the growing speed of cracks, which is based on the comparison of the results of measurement using KUMONOS. Moreover, it is easy to estimate the appropriate quantity of repairing materials because the inspections using KUMONOS are able to quantitatively and precisely assess the width and length of cracks and the other deteriorated areas.

As mentioned above, we can precisely assess the deterioration at the time the inspection is carried out by regularly conducting an inspection, comparing the new data with previously accumulated data, and analyzing changes over time. Moreover, analyzing the process and the tendency of the deterioration enables one to predict future deterioration. By doing so, we can make a prioritization for repair and renovation according to the degree of hazard. Precise prioritization based on the quantitative data leads objective determination for repair and renovation.

4. Conclusion

This system enables one to accurately measure cracks from a distance. Compared with the conventional visual and hand-sketch inspection, the inspection using KUMONOS is vastly superior in terms of safety, accuracy and economic efficiency. Also, one can measure the area which we could previously not be measured. While the number of structures which need maintenance is currently increasing, this system is expected to contribute considerably to planning repair and maintenance of social capital, because it can accurately and easily measure cracks.

As of December 2012, we have introduced approximately 180 sets of KUMONOS to the Japanese market. Of the inspections using KUMONOS, Kansai Construction Survey Co., Ltd. alone has conducted over 1000 inspections. The types of target structures vary such as bridges, tunnels, dams, retaining walls, and buildings. We would like to make more efforts to expand KUMONOS in order to contribute to the appropriate maintenance of social capital.

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ОБСЛЕДОВАНИЕ ТРЕЩИН С ПРИМЕНЕНИЕМ УСТРОЙСТВА «KUMONOS», ОБОРУДОВАННОМ ВСТРОЕННОЙ МАСШТАБНОЙ СЕТКОЙ

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Статья описывает работу с «KUMONOS», которое представляет собой современнейшую установку с встроенной масштабной сеткой. Используя эту установку, можно определять ширину трещины, появившуюся в конструкции, с большого расстояния. Сравнивая представленный метод и традиционные ручные замеры ширины раскрытия трещин, можно убедиться, что предлагаемое обследование трещин намного точнее, безопаснее и экономичнее. Таким образом, можно ожидать, что «KUMONOS» выполнит важную конструктивную роль в обеспечении безопасности сооружений.