DEVELOPMENT OF A NON-DESTRUCTIVE INSPECTION SYSTEM FOR INDUSTRIAL AND SOCIAL INFRASTRUCTURES WITH 950 keV/3.95 MeV PORTABLE X-BAND LINAC BASED X-RAY

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Abstract

We applied the X-ray source based on a portable Linacs for NDT on industrial and social infrastructures and conducted a real bridge inspection at the middle of Japan. We got transmission images of the inner part of the experimental bridge, from which we calculated the residual durability of this bridge by a simple beam theory. The bridge will be decommissioned in two years. We confirmed a reasonable plan of decommissioning by the calculation result. For further precise testing, CT and tomosynthesis is to be adopted for this system.

BACKGROUND

In Japan, some disastrous accidents have occurred and killed people because of over aging and insufficient maintenance. In addition, bridges aged over 50 years have fallen due to large earthquakes such as the ones in 2011 and 2016 at east north Japan including Fukushima and Kumamoto in Kyushu. For the bridges that have not fallen yet, we have to estimate the damage of the shaking. As well as Japan, aging of bridges is also a problem in other countries such as America suffered from a big large fall shown in Fig. 1.

Then the demand for reasonable NDT techniques is growing rapidly not only in the nation but all over the world. We suggest a NDT system with high energy X-ray based on 950 keV/3.95 MeV Linacs. Table 1 shows the information of 950 keV linac. What is characteristic of this linac is that it has a specially small accelerator tube of 12 cm which makes it possible to makes the linac smaller with its weight under 100 kg including RF source. With this light weight, we can bring it to on-site inspection. Further information is in [1]. The reason we use Linacs in this energy lies in Japanese regulatory rules of radiation. Precise description of these safety rules are shown in the 4th section of [2].

Table 1: 950 keV Linac Information

950 keV Linac	
RF source	9.3 GHz Magnetron
Input RF power	250 kW
Pulse width, Repetition	3 μs, 330 pps
X-ray intensity	> 50 mGy/min @ 1 m
Electron gun voltage	20 kV
Length of accelerator tube	125 mm
Weight	49.5 kg (RF) + 44 kg (Accelerator tube)

Figure 1: Fall of aged bridge accident in America [3].

We have conducted some on-site experiments with these Linacs at PWRI (Public Works Research Institute) or NILIM(National Institute for Land and Infrastructure Management). The experiment of 3.95 MeV Linac on 27th July, 2015 was the first on-site usage of a radiation generator with over 1 MeV energy.

The purpose of this research is that to invent an X-ray NDT system that gives us good materials for judging if we can use infrastructures longer or what to do for safer usage of them.

REAL BRIDGE EXPERIMENT

We have conducted an experiment on a real bridge on use. The location of this bridge is presented in Fig. 2 with the locations of major earthquakes that happened in these days.

The bridge is about 50 years old, to be decommissioned in two years and consists of 4 parts with 5 legs, we choose the middle of the first part for experimental area where some PC wire faults have been detected by former inspections. It has an empty space at the center of it, where we put the experimental instrument and radiated X-ray in the lower direction and put the detector at the surface of the reverse side from the X-ray source. Figure 3 shows a schematic view of this experiment and the scenery of the inner part of this bridge is presented in Fig. 4, in which we can see a 300 kV X-ray tube that is so small that we can use it where 950 keV Linac cannot move around.

First, we use a FPD that can display on-line pictures for checking if the position of detector in the right place, then determine where to put the imaging plate that gives higher contrast pictures than FPDs do because of longer X-ray detection integral time of IP. Each radiation time was 3-10 minutes. The radiated plate has 36 pre-stressed concretes set perpendicular to this paper.

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Figure 2: Location of the real bridge experiment.

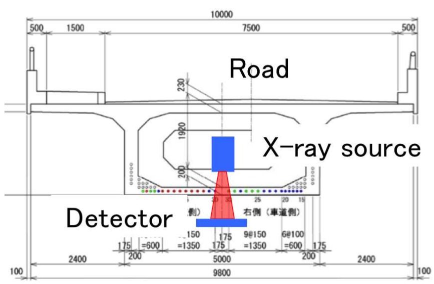

Figure 3: Schematic view of this experiment.

One of the resulting X-ray pictures is shown in Fig. 5 in which we can see a loosing of a PC wire numbered 28 while 29 and 30 keep being tightened together. Other status for the left side of the bottom plane was gained through. We estimated the residual cross section of each wire by eye. The estimated result is shown in Table 2.

Table 2: Estimated Residual Cross Section

Number	Decrease
30–29	0%
28	100%
27	70%
26–22	10%
21	50%
20	0%

STRENGTH CALCULATION FROM X-RAY IMAGES

From the resulting X-ray images in section 4, we calculated the strength of this bridge based on the fiber model for numerical calculation and on the simple beam theory. In the fiber model program, we can get a moment-curvature curve like Fig. 6. The moment at which slope of this curve changes is the yield moment and gives the bending stiffness which shows the strength of this structure. When a moment as large as yield moment is put on a bridge, the concrete part of the bridge starts cracking, which indicates of the danger of falling.

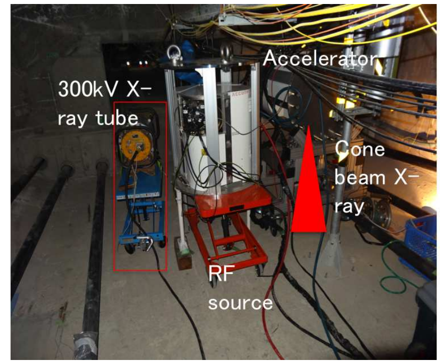

Figure 4: Experimental system in the bridge.

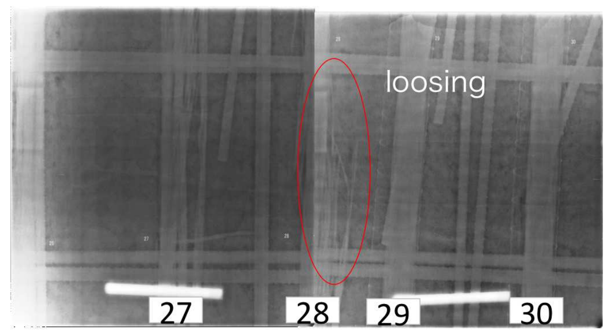

Figure 5: Transmission X-ray image of the bottom part of the bridge.

Then we calculated the difference of acceptable load between the data set of original design and of X-ray inspection by putting a intensive and uniformly distributed load. The latter load is fixed at the a constant value that is employed in designing a bridge in order to agree with Japanese law.

The calculation flow is as below:

1. Make a fiber model constructed with simple rectangular pieces like Fig. 7 from the original design,
2. Put the PC wire information in the calculation sheet,
3. Run the calculation program giving the yield moment and bending stuff for the input,
4. Calculate the moment to a intensive load with uniformly distributed load, seeing the bridge as a simple beam by Newmark's moment calculation,
5. Increase the intensive load an re-calculate the moment,
6. Repeat 1-4 until the moment by the intensive load reaches the yield moment. Save this final moment as residual durability.

This calculation gives the residual durability for two cases; PC wire information of original design and that of estimated value from the X-ray pictures. We can see about 5% difference of the residual durability in Table 3. According to Prof. Maekawa of Department of Civil engineering, the University of Tokyo, this 5% decrease of durability is so serious in terms of bridge maintenance that the plan of decommissioning can be thought to be reasonable.

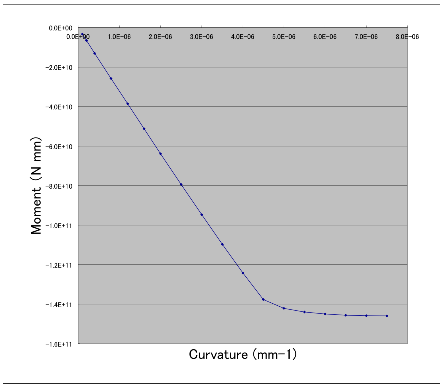

Figure 6: Curvature-moment curve calculated by the data set of original design.

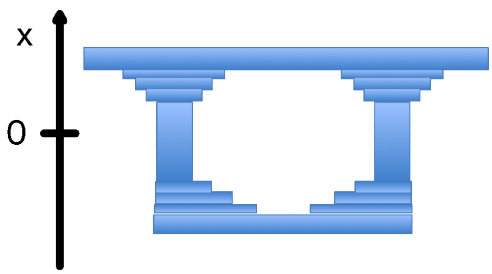

Figure 7: Fiber model for numerical calculation. The zero-point is set at the balancing point.

Table 3: Yield Moment and Maximum Load Calculated by the Data of Original Design and X-Ray Pictures

	Before inspection	**After inspection**	**Variation (%)**
Yield Moment (kN m)	$1.42 * 10^2$	$1.37 * 10^2$	3.7%
Maximum load (kN)	$8.75 * 10^3$	$8.30 * 10^3$	5.4%

CONCLUSION

We have managed to get transmission images of a real bridge and to find PC wire faults. It was also achieved to calculate 5% decrease of the durability and to verify a reasonable plan of decommissioning of the object bridge. However our estimation of PC wire state is done by human eye, which makes the resolution in order of 10%. Therefore it is desirable to precisely qualify the state by CT (computer tomography) or tomosynthesis reconstruction methods that can give cross sectional view of objects, which makes it possible to gain qualitative residual cross section of each PC wires.

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