Partial Inspection and Dual-energy CT Material Analysis with 950keV/3.95MeV X-Band Linac

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Abstract: In situ CT application for NDE of degradation bridges is under development, with portable 950 keV/3.95 MeV X-band linac as x-ray source. Collimator is adopted to reduce scattered X-ray noise. Material analysis and erosion estimation through dual-energy CT method is integrated in order to inspect the erosion situation of inner steel rod. Reconstruction technique with incomplete projection data is studied considering limitation of projection angle range during onsite scanning. Furthermore, based on 3D model built from sectional images, mechanical characters of bridges can be evaluated referring to structural analysis with reduced stiffness

Keywords: X-band linac, NDE, Structural analysis, Scattered X-ray noise, Dual-energy CT

１． Introduction

In Japan many bridges suffering degradation problems due to long years' service which results to high demand about in situ NDE techniques. Since conventional NDE methods have limitation to inspect inner structure, Computer Tomography becomes a better choice to detect inner steel rod. Portable 950kwV/3.95MeV X-band linac would be adopted as beam source complying with that radiation source under 4 MeV is legally permitted to work outside controlled area.[1] Partial projection problem with limited scanning angle range should be studied because of constraints of bridge shape. With dual-energy CT analysis, the erosion thickness of inner steel rods can be estimated based on different density and attenuation character between iron and iron dioxide. After that, VCAD software, developed by Riken, Japan, is adopted for modeling and further structural analysis. 3D model of inspected module will be built with reconstructed sectional images so that original bridge model can be amended by substituting degradation module. Structural analysis is carried out hereafter with reduced stiffness to evaluate mechanical characters of aging structure.

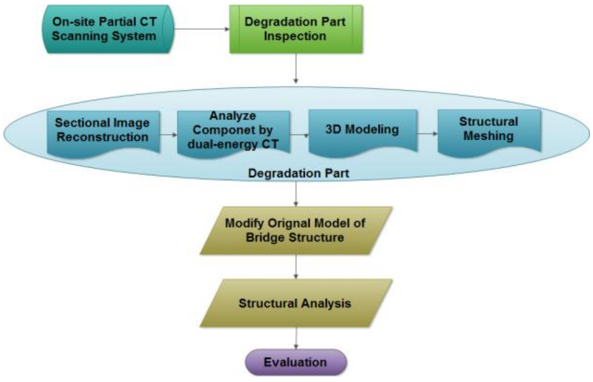

Fig.1 Schematic view of CT inspection system

In previous work, a small concrete sample with inner steel rods was scanned and CT reconstruction was carried out with Filtered Back Projection algorithm. However, due to serious noise caused by low energy scattered X-ray, the inner steel rods were not showed clear enough for 3D modeling software VCAD to distinguish the color.[2]

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New experiment adopting line sensor with collimators is implemented, as explained in next section, followed by partial CT study. Then in the fourth section, primary simulation work of dual-energy CT for component analysis is presented.

2. CT Experiment with Collimators

IIC Todai Hybrid Scintillator is a line sensor compacted with collimators to keep effective incident beam angle as showed in figure 2. The small sample is a concrete cylinder (height: 10mm; diameter: 10mm) that contains steel rods inside it and the figure 3 showed the scanning experiment layout using 3.95MeV linac.[3]

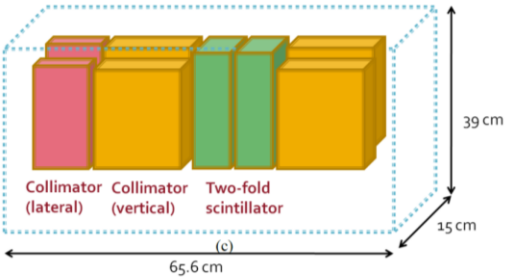

Fig.2 Line sensor with collimators

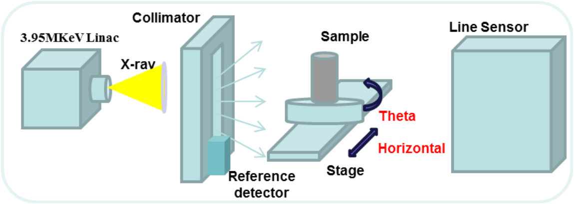

Fig.3 CT scanning experiment

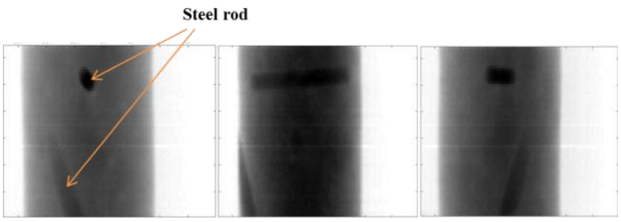

Fig.4 Transmission images in different directions

From transmission images, two steel rods can be confirmed inside the sample, one flat and the other inclined. Comparing the reconstructed images by Filter Back projection algorithm in figure 5, the steel rods have become much clearer than previous results owing to collimators effect. 64 section slices of the whole sample is reconstructed with projection data and 3D model is successfully built by VCAD software. [4]

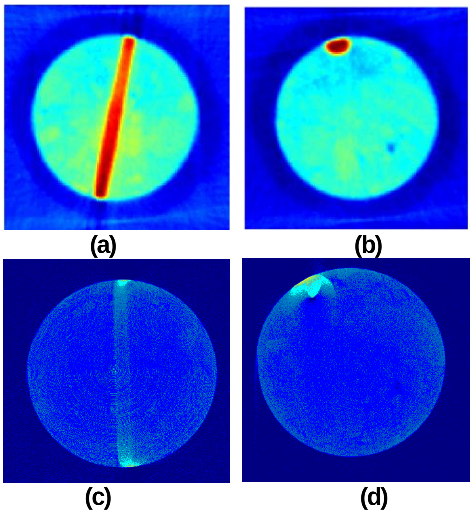

Fig.5 Reconstructed sectional images

(a,b: with collimator; c,d: without collimator;

a,c: flat inner steel rod; b,d: inclined inner steel rod)

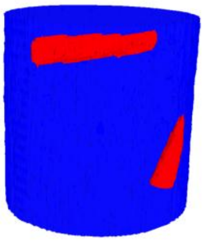

Fig.6 3D model of scanned sample

(red: steel rods; blue: concrete)

3. Partial CT Reconstruction

When reconstructing with incomplete projection data, artifacts would deteriorate image quality. Partial CT reconstruction is studied with experimental data to explore how much influence there is for inner steel rods.

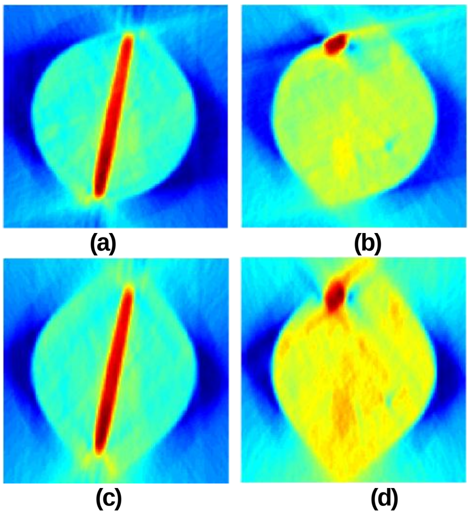

Fig.7 Reconstruction with limited angle range

(a,b: 120 degree; c,d: 90 degree;

a,c: flat inner steel rod; b,d: inclined inner steel rod)

When reconstructing with data of limited projection angle range, the sample edge shape was damaged seriously and apparent shadow appears around missing angles. The inclined steel rod was damaged a little more serious than flat steel rod with shadow because it located near edge.

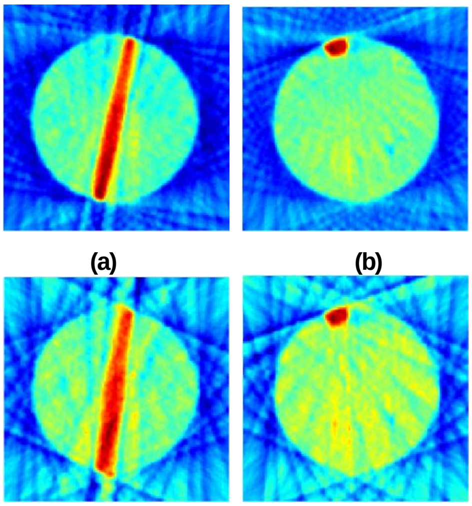
(a) (b)
(c) (d)

Fig.8 Reconstruction with few projections
(a,b: 8 degree increment; c,d: 16 degree increment; a,c: flat inner steel rod; b,d: inclined inner steel rod)

When increasing projection increment and reconstructing with data of fewer projections but still covering full angle range, apparent line shadow due to incomplete data appears. The steel rod's diameter and shape was affected especially as increment increased.

Inner steel rod is still discernible in reconstructed images under partial projection conditions but the shape is deteriorated to some extent especially under severe lack of projection data. Increasing projection increment properly could be one approach to reduce scanning time but the increment degree should be well controlled. On the other hand, some improvement for projection data recovery algorithms is under discussion such as iterative analytic reconstruction.

4. Dual-energy CT simulation

4.1 Method of Material Estimation by Dual-energy CT

CT image is representation of linear attenuation coefficient μ, which denotes how strongly the media material absorbs or scatters beam light. This character can be described by the mass attenuation coefficient μ / ρ where ρ is the density.[5]

Each kind of element media shows distinctive mass attenuation coefficient. For heterogeneous material, the mass attenuation coefficient is defined as below and W_i is fraction by weight of i_{th} atomic constituent:

$$\mu_m = \sum_i W_i \left(\mu/\rho\right)_i \rho_i$$

At different energy level, the measured μ value would vary for same media. Therefore for μ_1 and μ_2 at two different energies, we have

$$\frac{\mu_1}{\mu_2} = \frac{f_1(Z)}{f_2(Z)} = F(Z) \qquad \Rightarrow \qquad Z = F^{-1}\left(\frac{\mu_1}{\mu_2}\right)$$

Here

$$f_i(Z) = \int w_i(E)\left(\frac{\kappa}{\rho}\right)(E,Z)\,dE$$

F(Z) shows as monotonic function with μ_1/μ_2, so we can get $Z=F^{-1}(\mu_1/\mu_2)$ through numerical interpolation. Relatively, density can be obtained by

$$\rho = \frac{\mu_i}{f_i(Z)} = \frac{\mu_i}{f_i\left[F^{-1}\left(\mu_1/\mu_2\right)\right]}$$

For heterogeneous material, atomic number Z and density ρ include effectiveness of all compound elements:

$$\rho = \sum_i \rho_i \qquad Z^k = \frac{\sum_i Z_i^k \rho_i}{\sum_i \rho_i}$$

4.2 Simulation of Dual-Energy CT

In the simulation sample there is one steel rod inside concrete with erosion coating with thickness of half its radius. The model is similar with figure 3 and EGS5 simulation is calculated about spectrum and detector efficiency. Noise elimination in air region is realized by reset μ value of air.

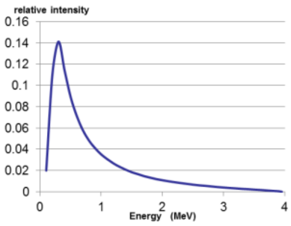

Fig.9 Spectrum energy

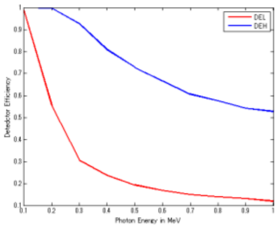

Fig.10 Detector efficiency

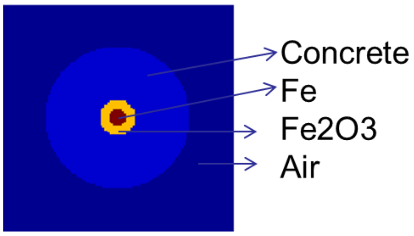

Fig.11 Simulation sample

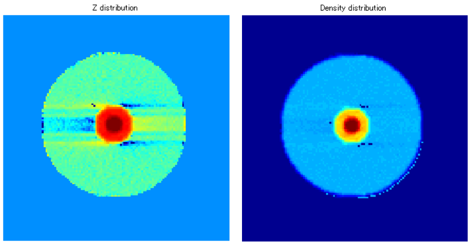

Fig.12 Estimation result

(left: atomic number; right: density)

For steel rod with erosion coating Fe and Fe_2O_3 can be identified. The estimation accuracy is acceptable, for estimation of material atomic number Z within 0.2-0.5 and for density ρ within 0.3 g/cm^3. Validation with Experimental data is expected in future work.

5. Conclusion

The linac CT system for in situ NDE of bridge is improved for reducing low energy scattered X-ray noise by collimator. Through reconstruction with incomplete projection data, the identification of steel rod is discussed. Lack of data would cause artifacts and shape of inner steel rod would be deteriorated seriously when too much projection data is missing. Data recovery algorithm will be added to the system. Additionally, material estimation with dual-energy CT is programed and tested that Fe and Fe2O3 can be well identified for erosion evaluation. Relative experiment is under plan.

References

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