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# Deterioration diagnosis-imaging technology and deterioration countermeasure technology for overhead transmission line

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## SUMMARY

Our company owns many steel towers and conductor(s), but most were constructed over 30 years ago and their equipment is aging. In addition, since equipment near the sea is prone to rapid corrosion, deterioration due to rusting among other issues has become a serious problem. Although our equipment is regularly inspected to determine its state from early state, securing the time and manpower required for such inspections has become problematic. When the inspection reveals equipment failures, they must be resolved immediately, but repairing can be very costly.
In this report, countermeasures against these challenges (image deterioration diagnosis technology and deterioration countermeasure technology), are specifically introduced as follows:

・Conductor diagnosis-imaging system using helicopter VTR and AI

To streamline VTR inspection by helicopter, which is carried out when inspecting conductor, we have developed a conductor diagnosis-imaging system. AI was constructed using deep learning, which is one of machine learning.

・Tower deterioration diagnostic method using drones and AI

To streamline efforts for check the level of deterioration of steel towers, we have established a diagnostic method using drones and AI. Utilizing commercially available drones, we have constructed AI using the same deep learning as for conductor inspection.

・Tower members repair method using carbon fiber (VaRTM method)

To repair steel tower members which cannot be easily replaced promptly or economically, we have developed a repair method using carbon fiber. This exploits scope to mold high-quality CFRP repair materials used for aircraft and wind turbine blades locally to prepare repair materials in various shapes.

## KEYWORDS

Transmission Line - Transmission Steel Tower - Conductor - Helicopter Inspection - Drone Inspection - AI Inspection - AI Deep Learning - Repairing - Carbon Fiber-Reinforced Plastic

## 1. Introduction

Our company owns around 43,000 steel towers and around 15,000 km of transmission lines, around 80% of which were constructed over 30 years ago and their equipment is aging. In addition, since equipment near the sea is prone to rapid corrosion, deterioration due to rusting among other issues has become a serious problem. Although our equipment is regularly inspected to determine its state from early stage, securing the time and manpower required for such inspections has become problematic. Equipment failures revealed by such inspections must be resolved immediately, but steel pipe members of towers are sometimes not immediately replaceable and the process can be very costly.
In this report, we introduce countermeasures (image deterioration diagnosis technology and deterioration countermeasure technology) which we have been working on to resolve these issues.

## 2. Development of a conductor diagnosis-imaging system using helicopter VTR and AI

2.1 Transmission line inspection using helicopter VTR

Since our transmission lines traverse varied terrain, from mountainous areas to urban sprawls, our inspection methods, whether ground, airborne and helicopter VTR inspections, must take prevailing conditions into account. Of these inspection methods, helicopter VTR inspection involves a worker checking and inspecting the VTR via slow-motion playback at 1/10 normal speed, which normally takes around 1,330 hours a year. The following examples show the normal and failure state of the conductor filmed via VTR (Figure 1). When compiling such VTR footage, the vast majority of transmission lines are in a normal state and very few are prone to failure. Since workers have been required to assess whether a line is normal or subject to failure while visually checking similar VTR images for extended periods, the burden on them was considerable and inspection methods like this have depended on their personal skill. This was the challenge of this method.


Normal state


Failure state

Figure 1. Normal and failure states of conductor

2.2 Development of conductor diagnosis-imaging system

In response to the challenges in the previous section, we developed an conductor diagnosis-imaging system[1]. We substituted AI for the VTR checking and transmission line inspection work performed by workers to date, to shorten the VTR inspection time, ease the burden on workers and also enhance inspection dependent on the personal skill of workers to ensure more consistent quality when assessing conductor failure.
This systemuses a cloud service to manage the data centrally and streamline the process of data sharing (Figure 2). Helicopter VTR footage is uploaded to this system, diagnosed by AI and a report is then automatically issued on parts deemed to have failed (Figure 3). Consequently, VTR checking and inspection time can be shortened.

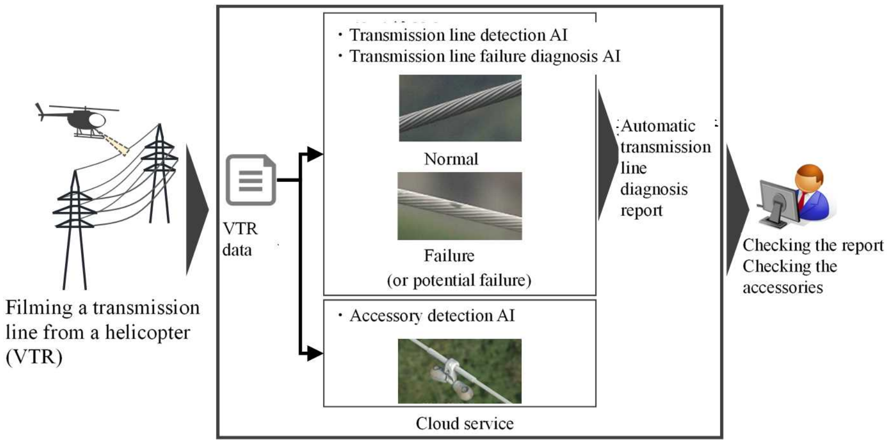


Figure 2. Overview of conductor diagnosis-imaging system

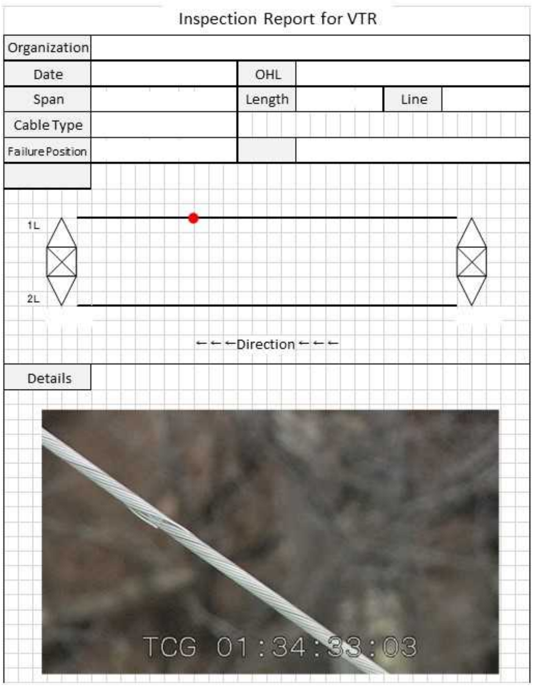


Figure 3. Inspection report

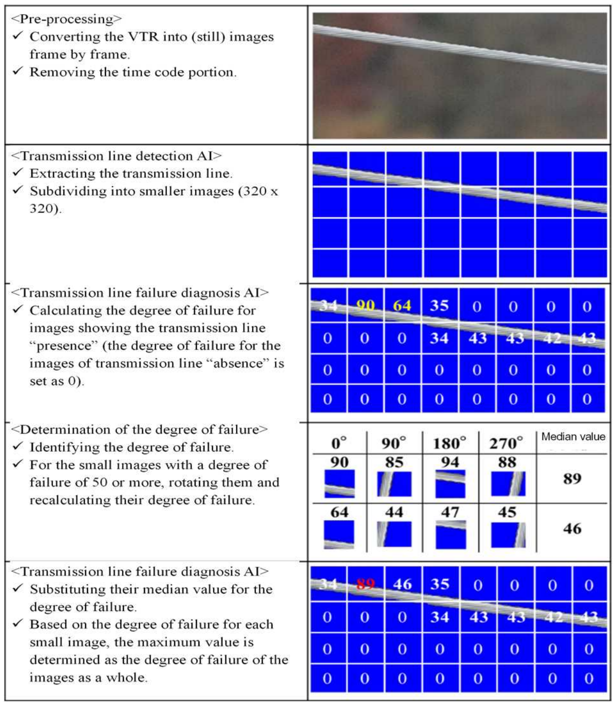


Figure 4. The procedure of the conductor failure diagnosis

AI was constructed using deep learning, which is a type of machine learning. The conductor detection AI used to identify the position of conductor in the image was trained and constructed based on U-Net, which is a convolutional neural network that was developed for biomedical image segmentation, one of the neural networks for segmentation. Conductor failure diagnosis AI which calculates the failure degree of conductors was trained and constructed by performing transfer learning based on the general-purpose image recognition model VGG16. VGG16 is a simple and widely used Convolutional Neural Network (CNN) Architecture used for ImageNet, a large visual database project used in visual object recognition software research.

Figure 4 shows the procedure of the conductor failure diagnosis. First, a full high-definition format VTR is converted into a still image, which is then subdivided into smaller images of 224 x 224 pixels. Next, the conductor detection AI determines the presence or absence of the conductor against such small images and calculates the degree of failure for images determined as having the conductor "presence". For smaller images where the set threshold value of failure has been exceeded, however, they are rotated into four patterns of 0, 90, 180 and 270 degrees respectively, the degree of failure in each state is recalculated and the median value thereof is adopted as the degree of failure of the small images. When the degrees of failure for each small image are compared, the peak value is deemed to equate to the degree of failure of the image.

2.3 Judgment rate

For conductor failure data, 594 cases (conductor breakages, discharge marks, corrosion, frays, outer flaws, foreign matter adhesion, etc.) were extracted from VTRs filmed by helicopter during the period 2013 to the first half of 2017, 471 of such cases were used for an AI learning model and 123 cases were used for verification. As normal images, 34,000 normal parts were randomly extracted from filmed VTRs of 471 cases and then assessed under this system. The indicators of the judgment rate were categorized as the non-detection and false detection rates (Table I).

Non-detection rate = FN / (TP+FN) ……(1) False detection rate= FP / (TN+FP)……(2)

The non-detection rate means the ratio of conductor failure cases that were undetectable by conductor failure diagnosis AI and was applied to the judgment rate of failure images. The false detection rate means the ratio of images that did not correspond to conductor failure but were mistakenly assessed as such by the conductor failure diagnosis AI and was applied to the judgment rate of the normal images. The changes in the non-detection and false detection rates with respect to the degree of failure in 123 cases for verification are shown in the following (Figure 5).
Both the non-detection and false detection rates should be as low as possible, although their relationship is an inversely proportional trade-off. It was confirmed that the threshold value to determine the degree of failure was 62 or less when the non-detection rate was set to 5% or less to reduce the non-detection rate. In this case, the false detection rate was 6% and it was hypothesized that applying this system, even given the need to tolerate some non-detection and false detection, would save significant inspection time compared to conventional inspection methods using VTR slow-motion playback. In future, a further reduction in the non-detection rate can be expected by applying additional learning to the conductor failure diagnosis AI.

Table I. Items to judge the conductor failure diagnosis

| | | Predict | |
|---|---|---|---|
| | | Failure | Normal |
| Actual measurement | Failure | TP (True Positive) | FN (False Negative) |
| | Normal | FP (False Positive) | TN (True Negative) |

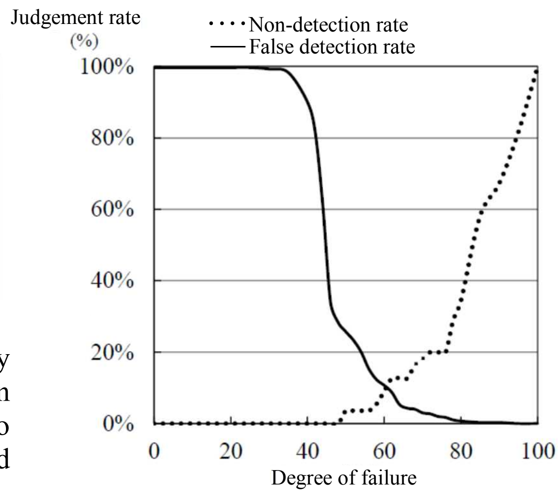

Figure 5. Judgment result of the conductor failure diagnosis

We developed an conductor diagnosis-imaging system by combining helicopter-assisted transmission line inspection technology and AI (deep learning) technology accumulated to date. The judgment rate of failure diagnosis AI suggested potential to further streamline conventional inspection methods using this system. Previously, around 1,330 hours a year were needed for inspection work, which involved by playing back the filmed VTR in slow motion and checking failures of conductor, but using this system, this work is expected to become about 660 hours a year and its efficiency is improved by about 50%.

## 3. Development of steel tower deterioration diagnostic method using drones and AI

3.1 Traditional steel tower deterioration diagnosis

We carry out work to check the deterioration of all steel towers (tower deterioration diagnosis). This involves multiple workers climbing up to the transmission line and visually assessing the deterioration of towers (presence or absence of rusting and degree thereof) and ranking it on a five-point scale. This is done for around 1,200 towers a year and is very time-consuming. Moreover, since this is work at elevation, it involves the risk of electric shock, crashing and falling down. Furthermore, since the evaluation of the deteriorated state was left to the judgment of the worker, it was also a challenge that this method depended on the personal skill of the workers.

3.2 Development of tower diagnostic method using drones and AI

In response to the challenges in the previous section, we established a new diagnostic method[1]. By using AI to replace the work involved in checking and determining the level of deterioration of steel towers performed by workers to date, to reduce the workload and ease the burden on workers, eliminate risks and also assess any deterioration more accurately and consistently rather than simply depending on the personal skill level of workers.
This new diagnostic method involves filming steel towers using commercially available drones, then using AI to quantitatively evaluate the deterioration from the footage (Figure 6), which can significantly reduce the work time.

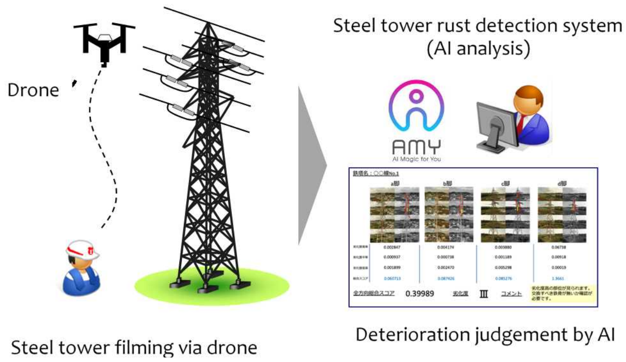


Figure 6. Steel tower deterioration diagnosis method using drones and AI

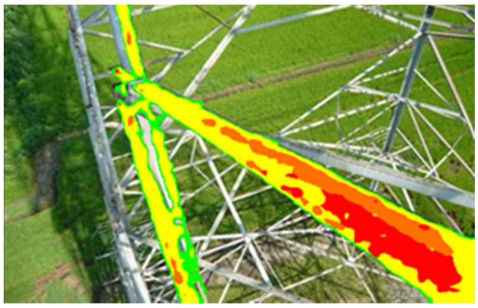

Figure 7. Visualization of the rust (deteriorated parts) by AI

3.3 AI model

This AI model is constructed by additionally learning images of rusting on 22 steel towers as part of a versatile rust detection approach, which involves the AI deep-learning numerous rust images of all kinds. This AI can detect deteriorated (rusted) portions of a steel tower from images, in pixel (px) units. Any rust detected in pixel units from the image is color-coded and visualized in three stages according to the degree of rusting, which allows us to check rusted parts at a glance (Figure 7). It has been confirmed that the accuracy of this AI involves a recall rate of 97% or more and precision of 91% or more (Table II).

Table II. Accuracy of AI

| | |
|---|---|
| Recall rate (probability of finding rust without missing it) | 97.66% |
| Conformity rate (probability of the existence of actual rust in target points where existence is predicted) | 91.91% |

In addition, this AI includes a function allowing steel towers to be determined from imagery. Since towers have a skeleton structure, the background occupies most of the image when they are filmed via drones. Steel materials such as fencing and guardrails are also included in the background to such images and cases in which they were mistaken for steel towers were confirmed. Accordingly, by developing and installing an AI function to pinpoint towers, areas of rust other than on the tower can be automatically removed, whereupon rust on towers can be detected, irrespective of the background. An example involving extracting a steel tower by AI is shown below (Figure 8).

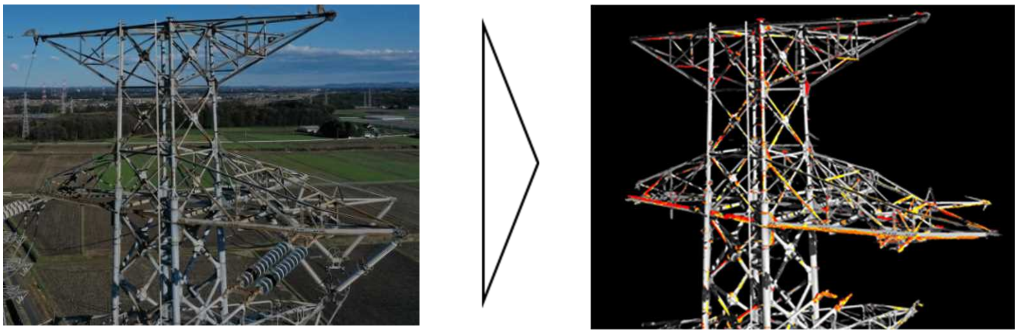

Figure 8. Example of rust extraction on the steel tower by AI

3.4 Summary of this part

We have developed AI which detects rust on steel towers via drones and AI, which we expect to help streamline conventional diagnostic work. Although around 1,490 hours a year have been required for such work to date, we predict scope to reduce such inspection time to 315 hours a year, which represents an efficiency improvement of about 80%.

## 4. Development of tower member repair method using carbon fiber (VaRTM method)

4.1 Pitting of a steel pipe member

Hot-dip galvanized steel is generally used for steel towers to ensure long-term rust prevention performance. Steel pipes are often used for large steel towers given their mechanical strength but pitting in members due to the progressive corrosion inside steel pipes, presumably due to defects during manufacturing and aging, have been confirmed (Figure 9). Steel pipe members affected by pitting should preferable be replaced with new equipment, given the potential for a significant decline in strength, but the need to temporarily release stress and high cost of replacement are problematic. Accordingly, technology allowing members subject to pitting to be repaired on site economically and promptly was sought.

Figure 9. Pitting of a steel pipe member

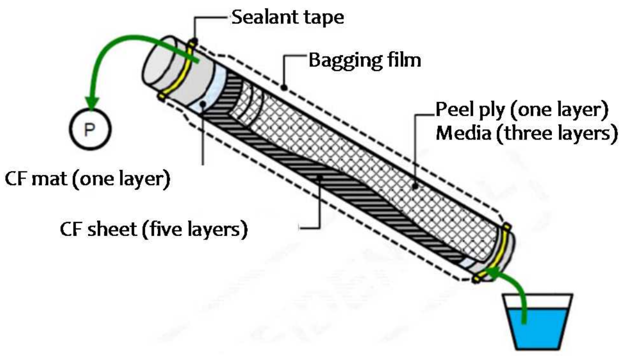


Figure 10. Overview of the VaRTM method

4.2 Repairing method using carbon fiber

Repairing method using carbon fiber-reinforced plastic (CFRP) has been adopted for concrete structures since the 1990s, with many current examples. Recent years have seen the applicable scope expand to include repairs to steel structures and girders. This time, we examined the applicability of a repair method applying VaRTM (Vacuum-assisted Resin Transfer Molding) to aviation and wind blades, to form high-quality CFRP on site[2]. The VaRTM method is outlined in Figure 10. A carbon fiber-reinforced plastic is formed by enclosing a reinforcing fiber film on the outside of a steel pipe subject to pitting, then injecting a liquid resin via vacuum suction. Consequently, the proof stress of the steel pipe member is restored.

4.3 Examination toward application

With the application of the VaRTM method in mind, we organized and examined the necessary items as shown in Table III.

・Examination of the repairing effect

The adhesive properties of CFRP and hot-dip galvanized steel bonded by the VaRTM method were tested (material adhesion test, double patch test) and analyzed (finite element analysis) and the fixing length and adhesive strength of the resin were confirmed. Other tests (to determine tensile proof strength and compressive proof strength) were also conducted with the steel pipe size and slenderness ratio as parameters and their predetermined reinforcing effect as shown in Figure 11 was confirmed.

Table III. Examined items and their contents

| Item | Examined contents |
|---|---|
| Repairing effect<br>(Performance aspect) | (1) Confirmation of the repairing effect against the hot-dip galvanized steel pipe<br>• Fixing length and adhesive strength of resin<br>• Repairing effect in terms of proof strength tests of members<br>(2) Confirmation of long-term performance and feasibility as a permanent measure<br>• Weather resistance of paint to be applied to the CFRP surface<br>• Fatigue resistance performance against repeated loads |
| Scope of application<br>(Design aspect) | (3) Repairing quantity calculation formula according to the member state<br>• Validity confirmation of the design formula by comparing CFRP reinforcement design formula and proof stress test result<br>(4) Arrangement of the repair design method and applicable scope of the VaRTM method |
| Construction method<br>(Construction aspect) | (5) Establishing construction procedures and management standards to ensure top quality<br>• Establishment of a construction method via the workability confirmation test with an actual steel tower |

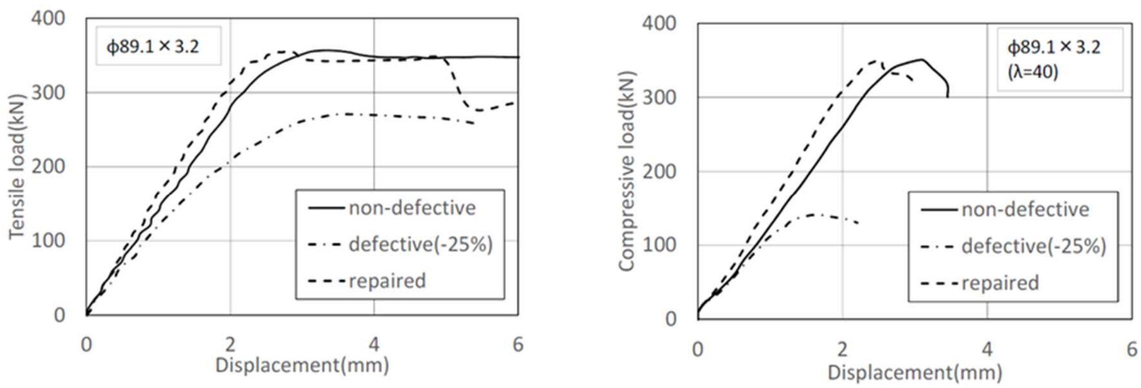

Figure 11. Proof strength test results of steel pipe members

・Examination of the applicable scope

After evaluating the validity of the calculation formula for CFRP repairs applied in other fields, the veracity of the formula was confirmed, likewise its accuracy to within tolerance of 10%. Accordingly, it was confirmed that this calculation formula could be applied to steel pipe members of steel towers. The need to consider the rusting proof stress of steel pipes to be repaired before the actual repair was also acknowledged.

・Examination of construction method

A workability test was conducted on site and it was confirmed that stable construction quality could be ensured, even at the top of the tower. Based on the test results, construction management standards were established.

4.4 Summary of this part

With the need to repair pitted steel pipe members economically and promptly in mind, the applicability of the VaRTM method as one of the repair techniques using CFRP was examined from performance, design and construction perspectives and the feasibility of the approach was confirmed. Conventionally, when replacing a stressed steel pipe member, the stress must be released temporarily, which generally involves 12 months of construction and a cost of seven million yen, including the preparation of jigs to release stress. However, the new construction method proposed eliminates the need to release stress, allowing repairs to be completed in just two months and for two million yen.

## 5. CONCLUSION

This report introduces measures in response to challenges encountered while inspecting and repairing transmission equipment (image deterioration diagnosis technology and deterioration countermeasure technology). The specific details are as follows:

・We have developed conductor diagnostic system by combining helicopter-based transmission line inspection technology and AI (deep learning) technology accumulated to date. Based on the judgment rate achieved by failure diagnosis AI, we see potential to further streamlining conventional inspection methods using this system. Previously, around 1,330 hours a year were needed for inspection work, which involved playing back the filmed VTR in slow motion and checking for failure in conductors. However, using this system, the work is expected to take about 660 hours a year, boosting efficiency by about 50%.

・We have developed tower deterioration diagnostic method using drones and AI, which we expect to help streamline conventional diagnostic work. By using AI to replace the work involved in checking and determining the level of deterioration of steel towers performed by workers to date, to reduce the workload and ease the burden on workers, eliminate risks and also assess any deterioration more accurately and consistently rather than simply depending on the personal skill level of workers. Although around 1,490 hours a year have been required for such work to date, we predict scope to reduce such inspection time to 315 hours a year, which represents an efficiency improvement of about 80%.

・We have developed tower menbers repair method using carbon fiber (VaRTM method). We need to repair pitted steel pipe members economically and promptly in mind, the applicability of the VaRTM method as one of the repair techniques using CFRP was examined from performance, design and construction perspectives and the feasibility of the approach was confirmed. Applying VaRTM method allows construction in about 1/6 of the original time, at about 1/3 of the cost.

In future, we plan to study the feasibility of further expanding the applicable scope of AI (conductor accessories, insulators, conductor fittings) and developing construction methods that allow repairs to be done more economically and promptly.

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