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*Special Contribution*

# A New Stage of Construction in Japan — i-Construction

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The population projection for Japan suggests that the working-age population, ages 15 to 64, will drop to 70% or less of what it is today by 2045. In the field of construction, such a rapid reduction in the working-age population will bring about a severe loss in the number of engineers and workers as well as budget cuts for infrastructure investments due to the decrease in tax revenues. At the same time, the infrastructure which has already been created, will soon be due for maintenance as its facilities and systems are approaching their renewal dates. In addition, disaster prevention measures against active natural disasters, such as earthquakes, heavy rainfalls and volcanic activities, will need to be strengthened and/or updated. Therefore, the task of providing a stable infrastructure for society on into the future will be more difficult than ever. In the field of construction, more complex projects will have to be carried out with limited manpower and limited budgets. This problem will be addressed not only by an extension of the existing means, but also by innovations in construction technology. The Ministry of Land, Infrastructure, Transport and Tourism started a new system, referred to as "i-Construction", in April 2016 to cope with this situation. ICT (Information and Communication Technology) is one of the major measures in i-Construction; it is expected to play an important role in improving construction productivity. The present article gives an overview of i-Construction and discusses the current conditions and future prospects for a new construction model utilizing ICT in Japan.

**Keywords:** i-Construction, productivity, ICT, intelligent construction, construction robot, unmanned construction, GNSS, production cost, environmental load

## 1. Sophistication of Construction - "i-Construction"

### 1.1 Rapidly changing social conditions

Nowadays, the subject of changes in demographics is very prominent in terms of the future of Japan. Figure 1 shows a population projection published by the Statistics Bureau, Ministry of Internal Affairs and Communications [1]. The total population of Japan as of 2015 was 126,597,000, and the population between the ages of 15 and 64 (the working-age population) was 76,818,000. This projection indicates that both the total population and the working-age population will decrease in the future, and predicts that the working-age population will fall to 69.7% of what it is today by 2045. If this prediction is accurate, a working-age population of less than 70% of that of today will have to support Japanese society 30 years from now.

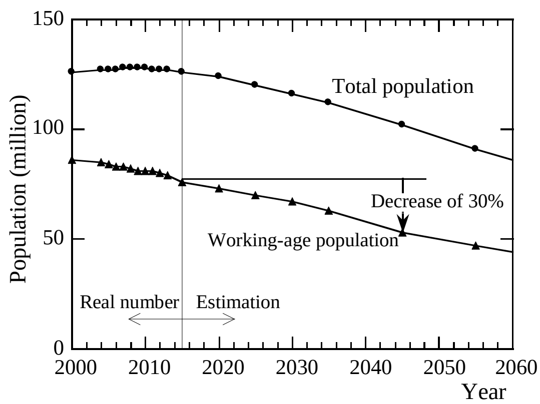



**Figure 1** Population projection in Japan

A reduction in the working-age population will have a great impact on the construction industry. There are concerns that the decrease in the number of construction engineers and workers will accelerate. At the same time, a drop in construction investments will also be a problem. That is, tax revenues and infrastructure revenues will be reduced, resulting in a forcible shrinking of budgets for public investment.

While it is predicted that the rate of new construction of the physical infrastructure will slacken as the total population of Japan decreases, the number of construction projects required to maintain the infrastructure that supports the activities and the lives of people will increase in the future. In addition, disaster prevention measures must be strengthened and/or updated in response to active natural disasters, such as earthquakes, heavy rainfalls and volcanic activities.

### 1.2 Current situation of construction industry in Japan

Figures 2 and 3 show comparisons of the average annual wages and the average annual working hours, respectively, by industry [2]. The wage level in the construction industry is sluggish at only 79% of the all-industry average. People in the construction industry work for longer hours, by 16%, than the all-industry average. Figure 4 shows the number of deaths while working [2]. It is seen that the total number of fatalities for occupational accidents in construction comprises up to

34% of all industries. Although labor conditions have improved, in comparison with the past, the construction industry can still not rid itself of this negative situation.

It is noted that the downturn in labor productivity in the construction industry is one of the major reasons. Figure 5 shows a comparison of the changes in labor productivity by industry [2]. While productivity in the manufacturing industry has more than doubled, through the introduction of factory automation technologies, that of the construction industry has continued to decline over the past twenty years. It cannot be said that the construction industry has enough potential to play an important role in providing further infrastructure to Japanese society by an extension of the existing situation.

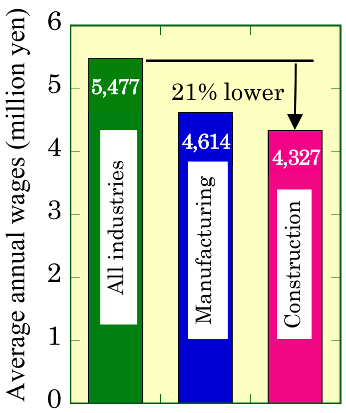



Figure 2 Comparison of average annual wages by industry

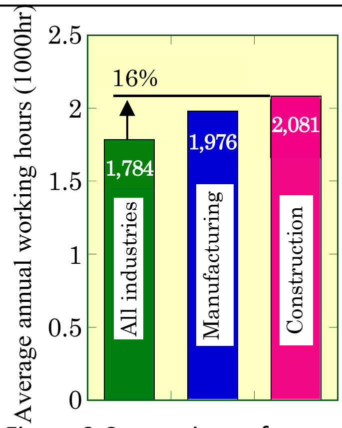



Figure 3 Comparison of average annual working hours by industry

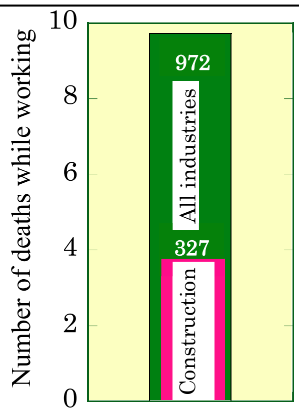



Figure 4 Number of deaths while working

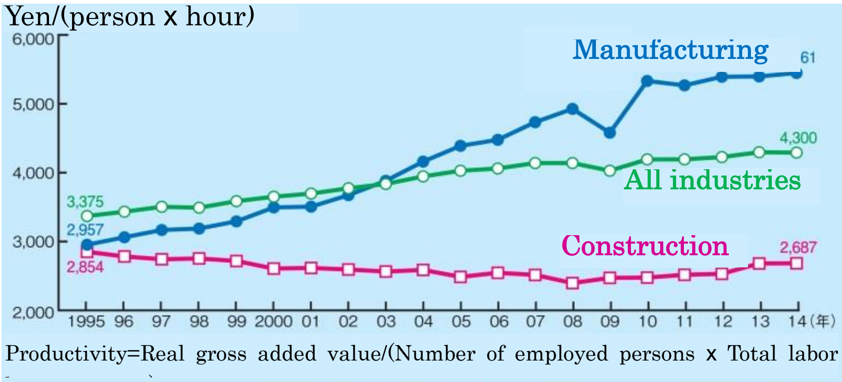



**Figure 5** Comparison of changes in labor productivity by industry

### 1.3 Three major strategies in i-Construction

Under such a situation, the Ministry of Land, Infrastructure and Transport started a new policy of i-Construction [3], in which high wage levels, sufficient holidays and a safe labor environment can be realized through remarkable improvements in productivity. The ministry established three major steps for such improvements, namely, the aggressive use of ICT in construction, the standardization of the specifications used in construction to avoid the inefficiency caused by single-item production and the balancing of orders throughout the year regardless of the season. Among these steps, advanced construction technology utilizing ICT is expected to play the most important role in realizing the final goal. This report introduces the present situation and future prospects of ICT utilization in i-Construction.

## 2. Utilization of ICT in Earthwork

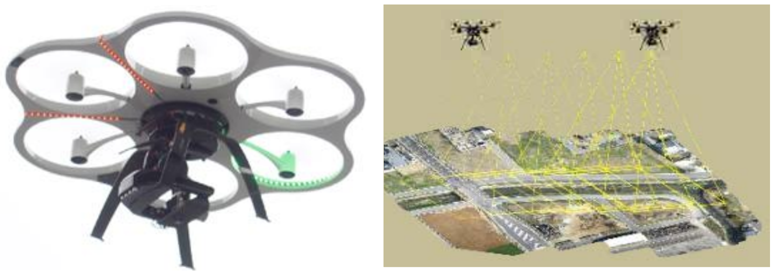
Earthwork is a generic name for the works in which soil and rock are moved for excavation, transportation, compaction and so on in order to build earth structures, such as roads, fill-type dams and levees. Figure 6 shows the stages of the earthwork process, which consists of surveying, design and construction planning, construction, inspection and maintenance.


**Figure 6** Stages of earthwork process

In i-Construction, the configuration information of earth structures is grasped and treated as 3D data and various ICT tools are effectively introduced at each stage of the earthwork process to deal with the 3D data, as follows.

**2.1 ICT in surveying**

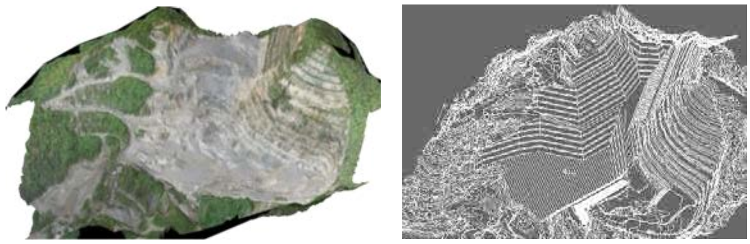
The configuration data of earth structures are grasped as 3D data through 3D laser scanner surveying or aerial surveying with a UAV. UAV is the abbreviation for unmanned aerial vehicle. Figure 7(a) shows an example of a UAV. One type of UAV, called a "drone", is often employed to examine structures, such as bridges, which are difficult to approach due to being located at high elevations. Figure 7(b) shows aerial surveying with a UAV. The 3D configuration data of a landform are measured with the principle of photogrammetry by overlapping photographic shots taken with the UAV.



(a) Unmanned Aerial Vehicle (b) Principle of photogrammetry

**Figure 7** Aerial surveying with UAV

Figure 8 shows the 3D landform data for an excavation site obtained by UAV aerial surveying. A UAV can execute 3D surveying from comparatively low-flying heights; and thus, it is able to accurately measure small areas. Through the periodic measuring of a site, changes in the landform can be grasped and the volume of soil to be excavated can be recalculated during the construction progress.



(a) Landform of site (b) Quantification of landform

**Figure 8** Aerial surveying of landform with UAV

**Table 1** Effect of introduction of UAV in surveying（Kajima Co. Ltd.）

| Methodology | Area | Time | Human works | Cost |
|---|---|---|---|---|
| UAV | 2ha | 1hour | 1 man day | 1 |
| 3D Laser scanner | 2ha | 1day | 2 man day (2days) | 4.0 |
| Electro-optical measurement | 2ha | 3day | 10 man day（5days） | 5.6 |

Table 1 shows a comparison of UAV surveying and other surveying methods. The case here involves the surveying of a 2ha land area. It is seen that time, labor and costs can be remarkably reduced by UAV surveying.

**2.2 ICT in design and planning**

Figure 9 is the completed drawing of the interchange of a highway. This figure is not a bird's-eye-view, but a plan made with the accurate coordinates of all the points.

**Figure 9** Utilization of 3D data in design and planning（from web site of NPO Cooperation Green Earth）

The design and construction planning stage has been made with 2D planar draughts of cardinal points. Although no difficulties may be encountered in the case of a simple straight alignment, the engineers have done the job by imaging 3D conceptual drawings from many 2D plans in the case of a complicated structure, as seen in Figure 9. By using a 3D data set, not only can the 3D conceptual drawing be directly obtained, but the 3D data can also be used for various applications. For example, 3D images can be obtained precisely for each step of the construction. Through their use, the steps of the construction can be confirmed in advance, and the design and construction planning stage can be made to be more exact by finding defects which are likely to occur at a certain stage of future construction and addressing them beforehand. The images can also be used to explain the construction to people residing near the site, showing them the visual 3D images of each step of the construction. These uses are the target of CIM（Construction Information Modeling）*; and thus, it is said that i-Construction is a system which includes the concept of CIM.

* CIM is referred to as BIM (Building Information Modeling) in many foreign countries.

### 2.2 ICT in construction

A typical example of the ICT introduction to construction is the sophistication of machine control, which can be classified into MG and MC. MG is the acronym for Machine Guidance; it is the technology with which the ease of machine operation or the accuracy of the construction can be improved by supplying the information on the construction to operators. MC is the acronym for Machine Control; it is the technology with which some parts of machines are automatically controlled.

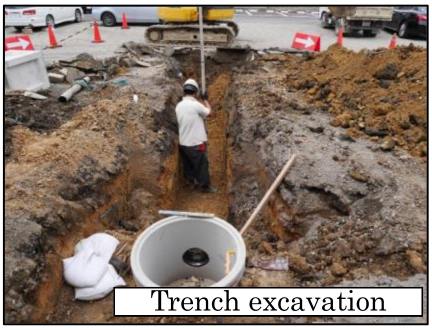




**Figure 10** Typical works with hydraulic shovel

Figure 10 shows typical jobs that are done with a hydraulic shovel. In the laying of sewage pipes, for example, the workers must confirm the depth and the inclination of the trench through surveying and then give the shovel operator the precise modifications for the excavation. In completing the excavation of slopes, workers set the finishing stakes to inform the operator of the working form of the slope.

Figure 11 presents a hydraulic shovel with the MG function. This shovel is equipped with GNSS (Global Navigation Satellite System) for grasping its accurate position in the field and sensors to measure the inclinations of the bucket, arm and boom. The accurate position and inclination of the bucket are displayed on a monitor in the cabin. The shovel is also equipped with a computer into which the data with the working form of the structures are input; they are also shown on the monitor. Therefore, the operator can control the machine by confirming the relative positions of the working form and the bucket, which means that no additional surveying or finishing stakes are necessary at the construction site.

Figure 12 presents a bulldozer that has a function to control its blade by using RTK-GNSS (Real Time Kinematic-GNSS). This bulldozer has an in-vehicle PC that is inputted with data for the final finished surface of the site. The bulldozer also has the MC function that measures the positions and the inclinations of the bulldozer and the blade, one of the bulldozer's working parts, using GNSS and a sensor, and controls the blade so that the final ground shape is automatically formed [4].

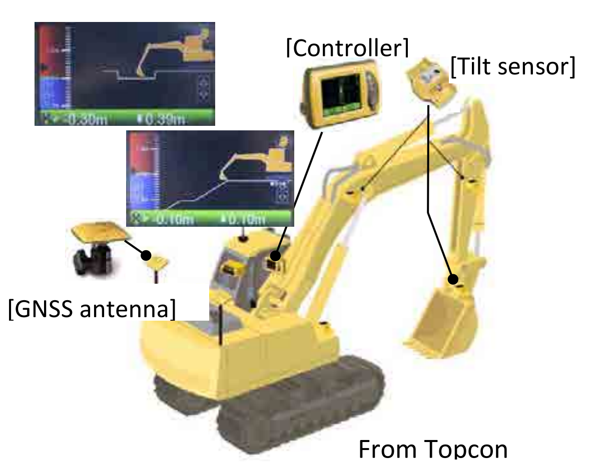



**Figure 11** Example of shovel equipped with MG function

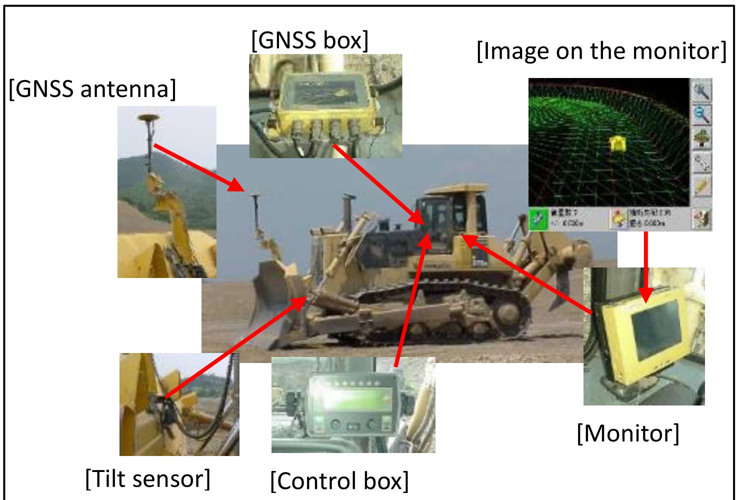



**Figure 12** Blade automatic control system in bulldozer

These types of machines not only bring about a big improvement in efficiency, accuracy and working time, but also a reduction in the environmental impact caused by the construction. Figure 13 shows the results of a field experiment in which the working times for a soil-spreading job were compared between manual control by an operator and an MC machine [5]. In the experiment, the working times were measured for a skilled operator and an unskilled one under the same field conditions to discuss the effect of the difference in experience on the results.

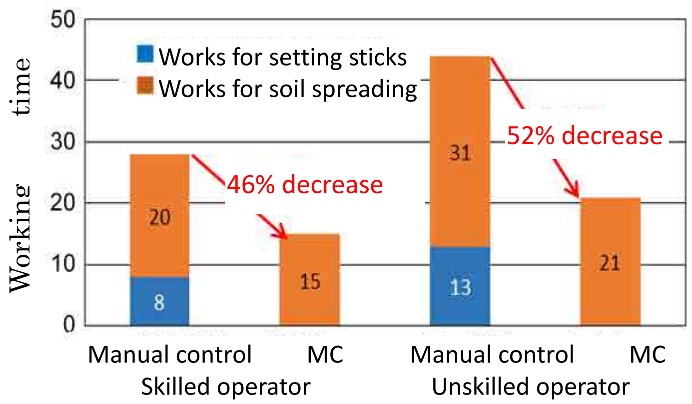



**Figure 13** Comparison of working times in soil-spreading job

The results clearly show that the time for the spreading job is reduced by appropriately half in the case of the MC bulldozer regardless of the skill of the operator. This experiment proves that even an unskilled operator can level the ground with almost the same accuracy as a skilled operator.

It is seen that the productivity in construction can be remarkably improved by utilizing ICT from different viewpoints than those introduced above. In this report, the precise management of construction through the effective utilization of ICT and the introduction of robot technologies to construction will be presented with some examples.

### 3. Enhanced Management in Construction

The infrastructure in Japan has been developed based on a systematized concept of structural design according to thorough construction standards and manuals. Thanks to this concept, Japan has efficiently accomplished infrastructure development with a uniquely high level of quality. This is undoubtedly a benefit of across-the-board controls using standards and manuals. At the same time, however, across-the-board control methods are problematic in terms of excess, resulting from the unavoidable unpredictability of uncontrollable factors, because across-the-board controls must comprehend the effect of indefinite factors, such as weather and geological conditions, the performance of the machines and so on. Therefore, plans made through across-the-board control methods should offer assurance that jobs can be completed even if the real construction conditions are not favorable. This means that a margin of error must be built into the plans. However, even when the construction conditions are not so unfavorable, it is not unusual to pump in more materials, more machinery and/or more labor than is actually necessary, according to the original plan. If the real on-site conditions can be grasped and the original plan can viewed with some flexibility, based on the real conditions, the input of materials, machinery and labor can be reduced to the true level of necessity, as shown in Figure 14.

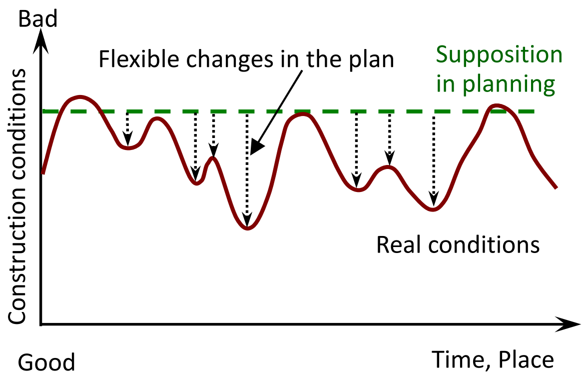



**Figure 14** Graphic image of flexible responses using information

Today, there are increasing demands for the efficient use of limited resources, the mitigation of the environmental effects from construction work and an improvement in the quality of structures. Across-the-board controls based on standards and manuals are not enough to meet these demands. Following the standards and manuals is important, but relying too much on them should be avoided. Flexibility is necessary for construction works to be as sophisticated as on-site situations demand. By using a variety of sensors and other ICT devices to grasp the specific situations at a site, intelligent construction can induce work that conforms to each unique site. Summaries of some successful introductions of intelligent construction tools at work sites are herein presented in accordance with this principle.

#### 3.1 Introduction of intelligent construction into large-scale earthwork [6]

The above-mentioned principle was introduced to a large-scale earthwork. Figure 15 shows an outline of the construction process. At the site, a hill was excavated by blasting or by mechanical excavation using hydraulic shovels. The excavated soil was loaded on dump trucks with loaders or shovels and then carried to crushers. The rock masses, larger than 20 cm in size, were crushed by the crushers and then carried to a pier for loading onto a ship by a conveyer belt. The soil was loaded on barges and then transported to the construction site of an offshore airport. The size of the construction site was 2 km in length by 1 km in width. The total field area was 149 hectares and the total volume of excavated soil was 50 million $m^3$.

In general, the work efficiency at earthwork sites depends on various factors, such as weather, geological conditions, geographical features and machine performance, and these factors can change in an unsteady manner with the progress of the construction work. To improve the work efficiency, it is necessary to flexibly change the construction methods, such as the arrangement of heavy machinery, the blasting method and so on, in accordance with the changes in the above factors. Doing so requires the creation of a system that collects information on the construction site conditions in real time and supports the site engineers in making good decisions for improving the construction method properly and flexibly, corresponding to the changeable site conditions.

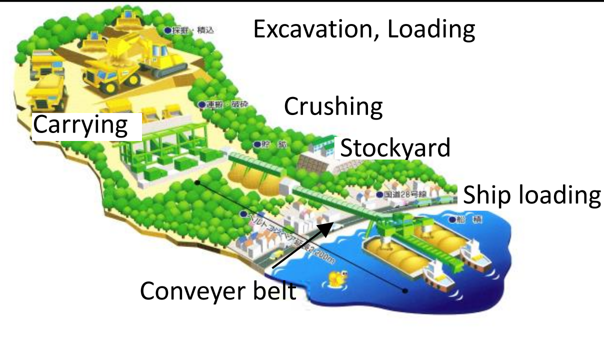



**Figure 15** Outline of construction process

A great deal of information on the geological conditions, the geographical features, the working performance of the machines and other construction conditions at the site was precisely collected by the ICT tools equipped on the construction machines or at the site, and then commonly shared with a plural number of offices and site stands related to the construction after being unified and analyzed by the construction management system shown in Figure 16.

This system brought about quick decisions regarding the improvement of the construction process, and it produced good results in terms of improvements in construction efficiency and a reduction in the environmental impact brought about by the earthwork.

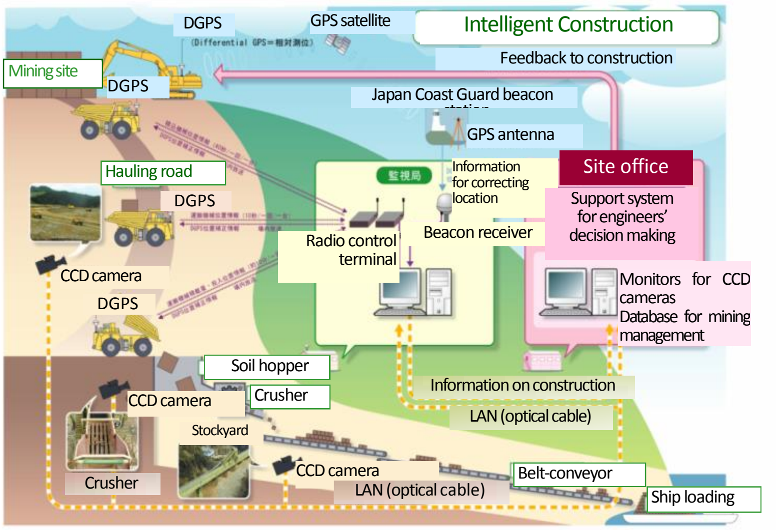
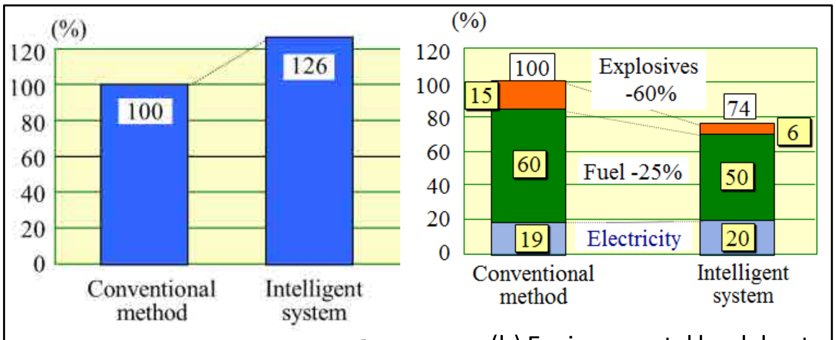



**Figure 16** Information and communication equipment introduced into large-scale soil collection and construction work

Figure 17(a) shows the production volume per day. The results are presented as a comparison of the intelligent construction method to the conventional method employed before implementing the new system. It can be clearly seen in this figure that the daily supply volume increased by 26%. In addition, as shown in Figure 17(b), there was a 26% reduction in environmental impact (emission of $CO_2$) through the efficient operation of the construction machinery and by saving on the amount of explosives.




(a) Production volume per day

(b) Environmental load due to construction work

**Figure 17** Effect of introduction of intelligent construction

### 3.2 Introduction of intelligent technology into tunnel construction

To maintain a proper working environment inside a tunnel that is under construction, ventilation is necessary. Ventilation is conducted with a large fan by circulating the air between the inside and the outside of the tunnel; the fan must work constantly. However, the air quality, or the cleanliness, depends on the type of work being done, namely, blasting, shotcrete, mucking or other types of operations. Therefore, the air volume of the ventilation facility at a site needs to be adjusted according to the type of work being done inside the tunnel, based on the measurement results for $CO_2$, the dust volume, the oxygen concentration, poisonous gas and so on (Figure 18). The electric energy consumed in a ventilation facility can be successfully reduced by controlling the air volume at an output of 100% only when the tunnel air is dirty and at 70% when it is less dirty [7].

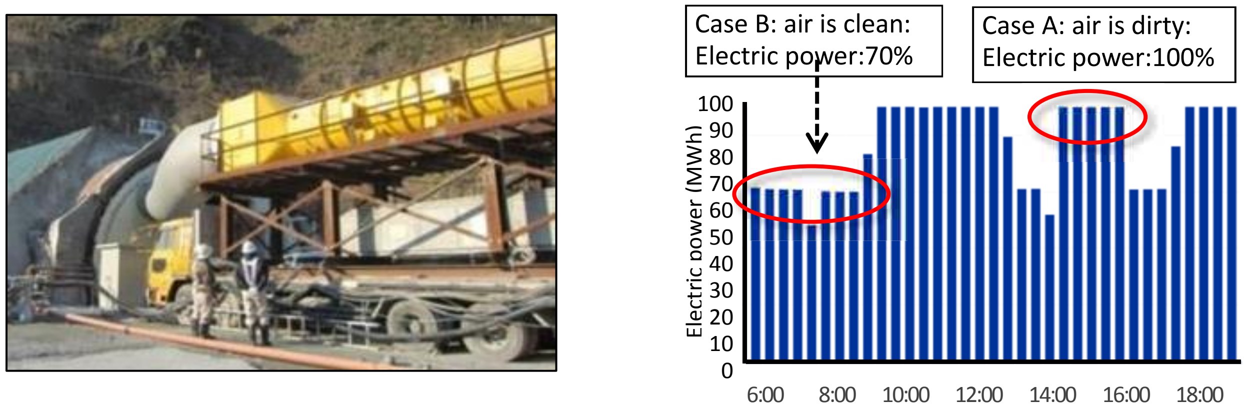



**Figure 18** Control of air volume in accordance with air environment inside tunnel （Shimizu Co. Ltd）

Other than that, a $CO_2$ reduction was achieved at this site by introducing energy-saving awareness through the visualization of various work situations, such as helping the dump truck operator understand how braking and acceleration impact energy efficiency [7].

Due to the introduction of intelligent construction, detailed control of the construction, based on the situation at the site, generally promotes work efficiency and reduces the environmental load resulting from the construction. Significant costs are usually incurred for general manufacturers to achieve energy savings. However, improvements in productivity and savings in energy can occur simultaneously by introducing the idea of individual evaluation into across-the-board controls in the field of civil engineering. Depending on the focus, there are many opportunities to utilize new technologies.

### 4. Introduction of Construction Robots

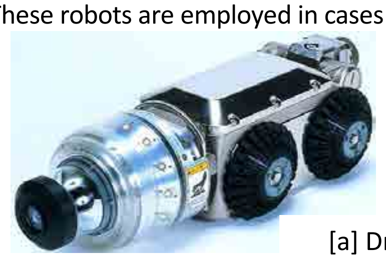
The introduction of robots in construction is said to lag behind that of manufacturing by 20 or 30 years due to the unpredictable situations in construction. Figure 19 shows the difference in working conditions between manufacturing and construction.

In manufacturing, the form and the materials are clearly specified in the design of products and the working environment is stable because the work is done indoors. Objects come to robots on a conveyer; and thus, robots do not need to move around in the factory. In construction, on the other hand, the materials are soil and rocks; and thus, their properties are not constant, but variable. Machines must work outdoors, and the working conditions are very much affected by the weather. For example, machines cannot move smoothly across muddy soil after a heavy rain. The working objects are mountains, rivers and so on; and thus, the machines arrive at them after traveling across a huge field. Therefore, the robots in construction should have a function to determine their own action flexibly and in accordance with the situation at each construction site. This means that it is much more difficult to introduce robots to construction than to manufacturing.


**Figure 19** Difference in working conditions between manufacturing and construction

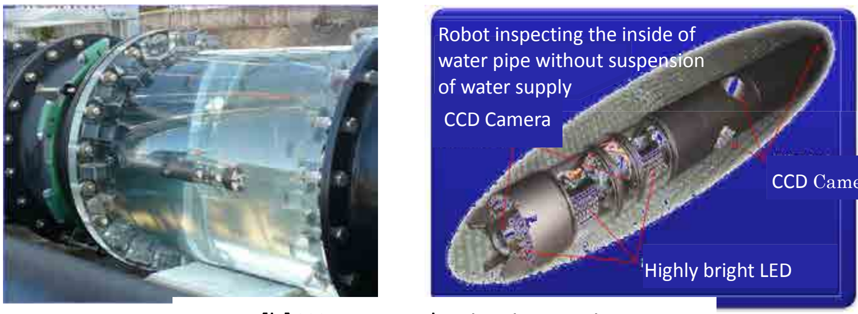
### 4.1 Progressing introduction of construction robots

In spite of the difficulties of introducing robot technology to construction, some robots have been practically used at construction sites. Figure 20 shows some examples of robots used in the field of maintenance. [a] and [b] are inspection robots for drain and water supply pipes, respectively. [c] is a UAV used for checking the heights of the slabs of bridges, etc. [d] is a robot that searches for any faults on the surface of a spherical gas tank, sticking and moving along it with suckers. These robots are employed in cases where people cannot enter or approach the site for reasons of narrowness or danger.




[a] Drain pipe inspection

[c] UAV for height inspection




[b] Water supply pipe inspection


**Figure 20** Robots used in field of maintenance of infrastructure

Figure 21 shows robots used at the recovery construction site of a natural disaster. In the case of a slope failure due to an earthquake or heavy rain, etc. or in the case of an area being covered by ashes or earth and sand due to a volcanic eruption, the ashes or earth and sand must be removed immediately for lifesaving or retrieval purposes. However, if the situation continues to be dangerous after the occurrence of a disaster, no one will be allowed to enter the site in order to prevent a secondary disaster. In such a case, an unmanned construction system is often employed. The heavy machinery applied for such work is operated from a control room, located at a distance from the site, using visual information transmitted from the site and displayed on monitors. These kinds of unmanned construction systems have become popular and reports of their track records have increased. It is said that these systems comprise indispensable technology for Japan where various natural disasters often occur all over the country.

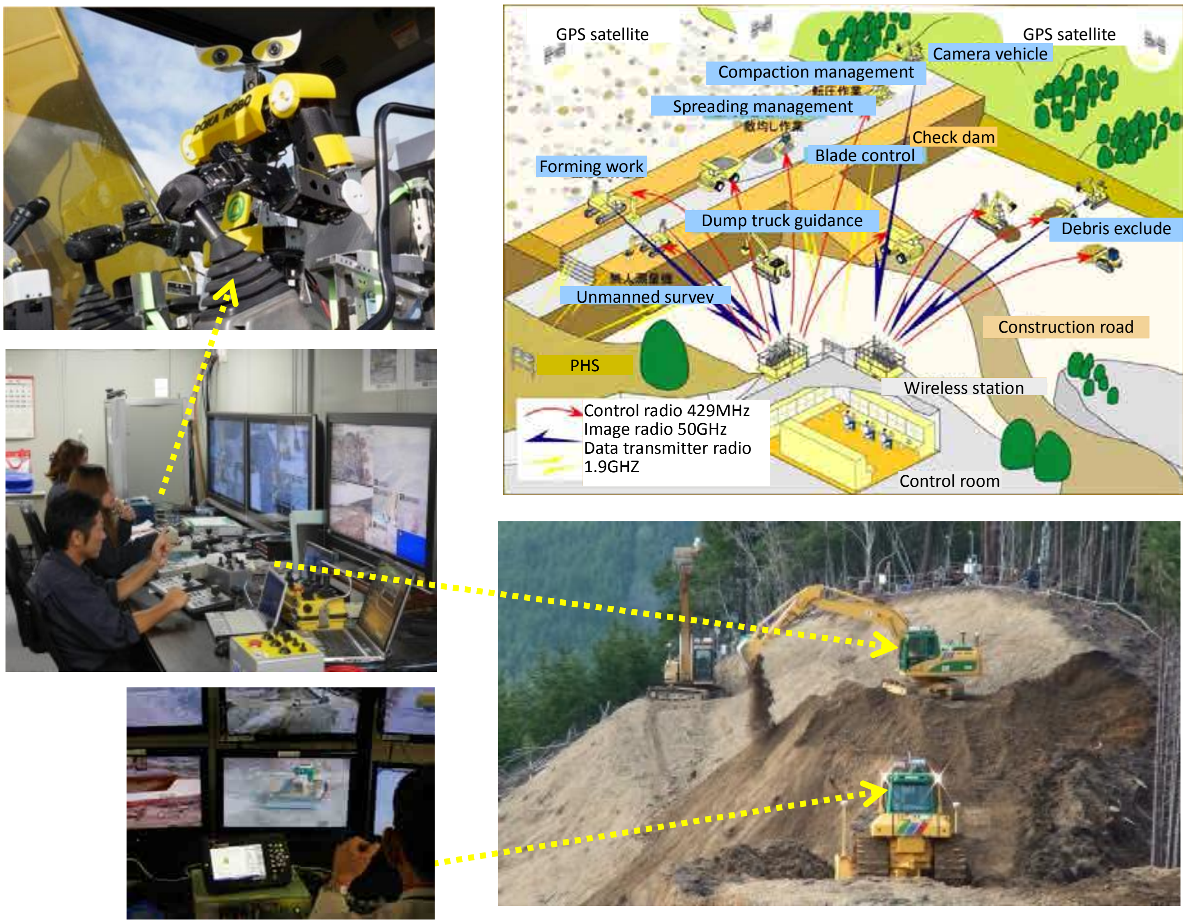



**Figure 21** Robots used in the recovery works from natural disaster

Figure 22 shows a comparison of the rate of the budget for research and development to gross sales by industry. The pharmaceutical industry spends more than 12%, while the manufacturing industry spends about 4% of their gross sales for the research and development of new products. On the other hand, the construction industry spends just 0.4% of its gross sales for the development of new technologies. In spite of the small budget for research and development, various advancements have been made in construction, as shown in Figures 20 and 21.

In the construction industry, the development of new technologies has often been tackled during actual construction projects with their budget. Therefore, the technologies developed here must certainly serve the projects well and lead to the development of extremely practical technologies rather than the development of highly sophisticated technologies. This is the reason that most construction robots can be effectively used in actual construction projects.

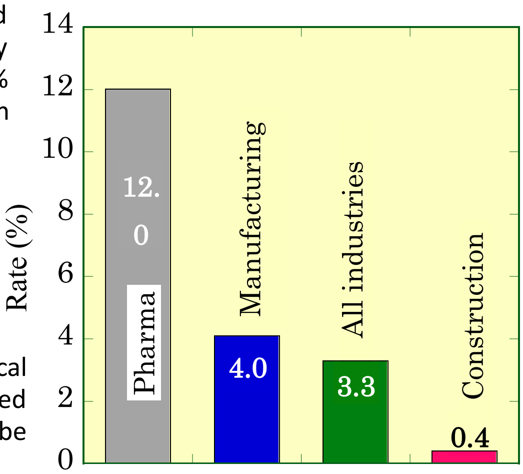



**Figure 22** Comparison of rate of budget for research and development to gross sales by industry.

**4.2 Recovery project from volcanic disaster in Mt. Unzen Fugen**

When the development of unmanned construction systems is discussed, the recovery project from the volcanic disaster at Mt. Unzen Fugen should not be excluded.

In November 1990, Mt. Unzen Fugen suddenly erupted. In the aftermath of this eruption, many researchers and mass media personnel came to investigate the volcano. Unfortunately, due to a second eruption in 1991, 43 of these people either lost their lives or went missing. The Ministry of Land, Infrastructure and Transport made a plan for sediment control work in which a check dam would be constructed at the foot of the mountain to protect the neighboring villages from the ensuing debris flow. However, the dangerous situation continued due to the potential for a sudden succeeding pyroclastic flow and people were prohibited from entering the site. Thus, it was requested that a construction method be developed whereby a dam could be built at the site while keeping people out of the area. The development of the unmanned construction system, explained in Figure 21, was started in 1993. It has been continued for more than 23 years and has led to improvements in technologies which have been applied to actual construction jobs at dam sites. These efforts have made this system quite practical, and its usefulness was clearly proven after the accident at the Fukushima nuclear power plant due to the tsunami disaster following the Great East Japan Earthquake of 2011. The unmanned construction system was introduced to the site just after the accident and it worked smoothly to remove debris and to demolish a damaged house, as shown in Figure 24. It is said that the system's technologies had been refined while being used in an actual construction project; and thus, it could be used quite smoothly as an extension of the existing technologies. This means that the technologies generally used as common methods are really effective in emergency situations; and therefore, efforts should be made to refine all technologies even in the usual works.

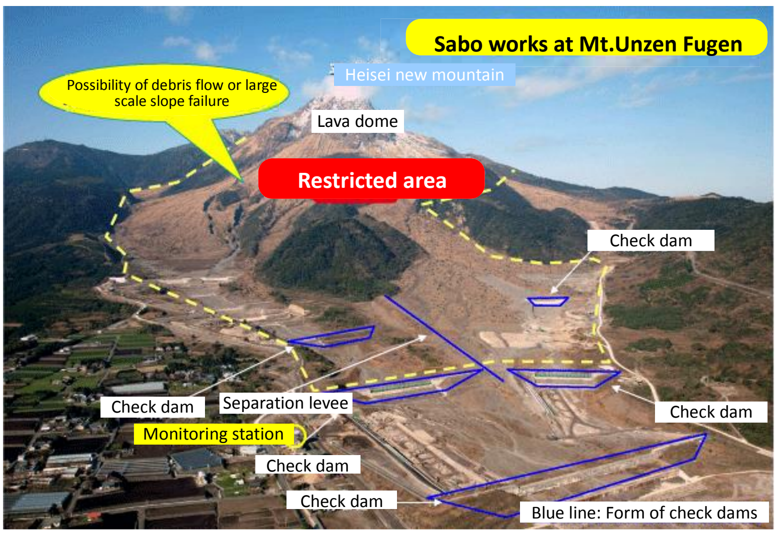




**Figure 23** Recovery project from volcanic disaster at Mt. Unzen Fugen.

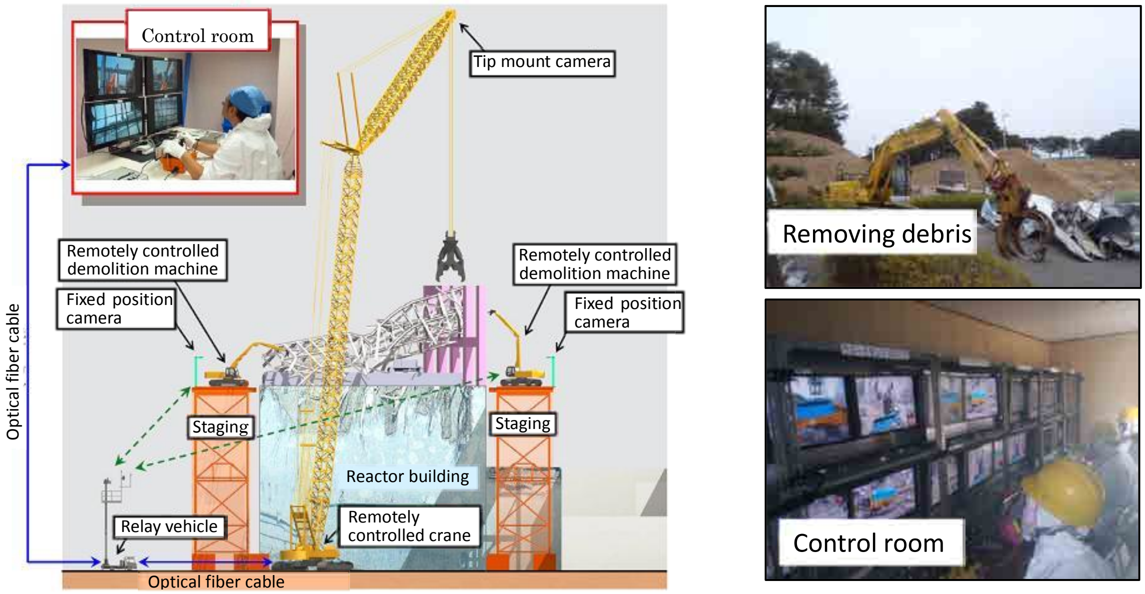



**Figure 24** Unmanned construction system employed in accident of Fukushima nuclear power plant.

## Conclusion

In the promotion of the i-Construction policy, it is worthy of special mention to state that the criteria and manuals for this policy have been largely modified. Although intelligent construction was introduced more than 10 years ago, it has not sufficiently prevailed because these criteria and manuals had not been modified. It has been impossible to adequately demonstrate the high ability of ICT under the conventional criteria and manuals. The new criteria and manuals have been introduced by assuming the utilization of ICT; and thus, the potential of ICT can now be demonstrated sufficiently. However, both ICT tools themselves and the way in which they are to be used have not yet been established. In the near future, however, they will be established for practical construction sites. It is highly anticipated that technological development in this area will soon gather momentum at construction sites.

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## ◆A brief CV of Dr. Kazuyoshi Tateyama

Dr. Kazuyoshi Tateyama is a professor in the college of science and engineering and an executive trustee of Ritsumeikan University, Japan. He graduated from Kyoto University with Bachelor in Civil Engineering and took the Doctoral Degree in Kyoto University in 1988. He has taken on the research and development on the rationalization of construction for many years and engaged in a lot of committees of governments and academic societies. He is now the chairperson of the committee for construction robotics in Japan Society of Civil Engineers and Council for Construction Robot Research.