Safety Measures for Coordination Between Man and Machine
- Case Studies of Dam Concrete Placement -

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Synopsis *: Automation and robotics in construction fields are being undertaken in views of shortage and aging of construction workers and skilled workers, improvement of working environment and maintenance of good conditions free from hard work and danger. In-depth examination has been carried out at almost all the sites and surveyed as to performance, operability and working environments to secure safety control, prior to automation or use of robots in dam construction which combines manpower and machines. On the other hand, there are worries about safety on construction sites . Focusing on dam concrete placement, this paper reports on the present condition of dam construction sites from a viewpoint of safe operation, that is, "Coordination between Man and Machine". This paper also describes the direction of functions and element technologies required in automation and development of robotics, makes suggestions as to the future implementation systems and examines issues of promotion and support of automation in the institutional context.*

Keywords: *dams, concrete placement, automation, safety measures, coordinated operation*

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1. Introduction

Automation and robotics in construction fields are being undertaken in views of shortage and aging of construction workers and skilled workers, improvement of working environment and maintenance of good conditions free from hard work and danger. This paper reports on information and opinions about automation and robotics (hereinafter called as automated machines) in dam construction works, which were obtained through a questionnaire sent out to 28 dam construction sites in Japan. This survey was carried out to address the present problems in views of safe operation and "Coordination between Man and Machine" by the Building Frame Subcommittee (hereinafter called as Subcommittee) in Construction Robotics Committee of Japan Society of Civil Engineers. This paper describes the future direction and the favorable form of automation, and examines its implementation in both technical and institutional contexts.

2. Present conditions and problems of automation and robotics in dam construction

2.1 Survey on automated machines

The Subcommittee carried out survey on the following items : Adoption of the automated machines, safety measures taken prior to adoption, the operability of the automated machines, their appraisals, and requirements of safety measures for the automated machines. The questionnaires were sent out to gravity concrete dam sites completed after 1980 or still under construction, for a variety of construction methods such as RCD (or RCC), extended layered construction method, and conventional block type of construction method.

2.2 Adoption of automated machines

It shows that automated machines have now been widely used in concrete dam construction since they are adopted in 21 dam sites in some ways among 22 replies collected. The main reason for adoption and expectation through the use of them, is to save manpower in all the 21 dam sites as shown in Fig. 1. The next reason is safety improvement, followed by cost

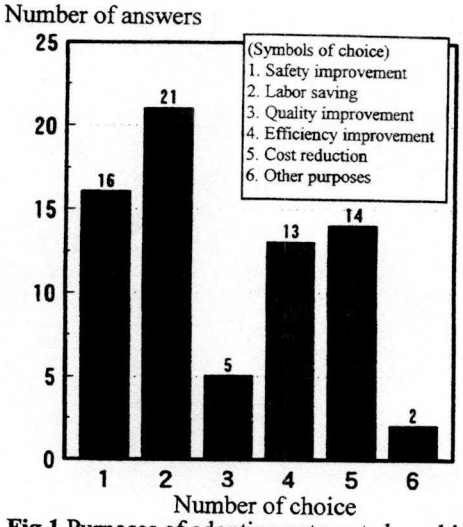


Fig.1 Purposes of adopting automated machines

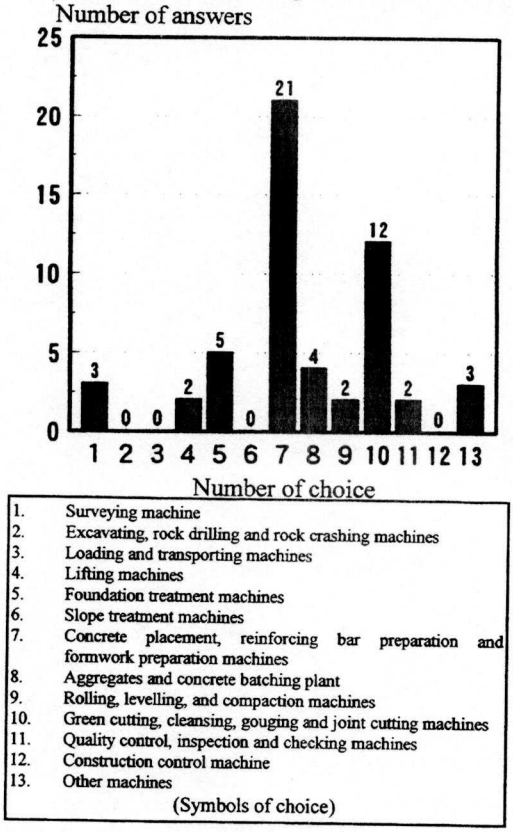


Fig.2 Types of automated machines adopted

reduction and enhancement of productivity. These results seem to reflect the present labor issues.

As shown in Fig. 2, the types of automated machines adopted are concrete placement machines employed in 21 dam sites, followed by concrete finish machines for green cutting, cleansing, gouging, joint cutting, etc. employed in 12 dam sites, foundation treatment machines in 5 dam sites, and concrete aggregates and concrete batching plants in 4 dam sites. The adoption of these automated machines are encouraged by efforts of private enterprises in research and development and introduction of the official technical certification system by the Ministry of Construction.

2.3 Safety measures prior to adoption

Safety measures had been considered in more than 80% of the sites in some ways prior to their adoption as seen from Fig. 3. The number of automated machines adopted was 35, which demonstrated a fact that automated machines are employed with deliberation.

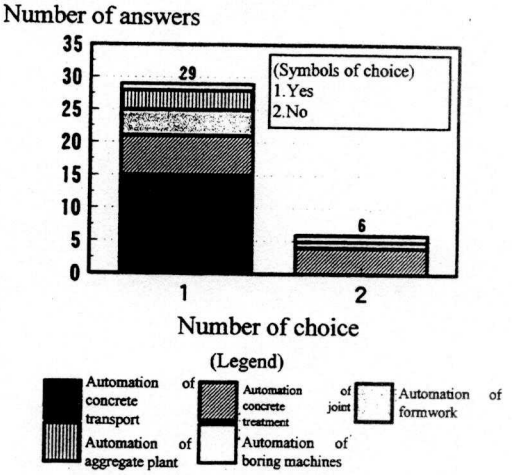
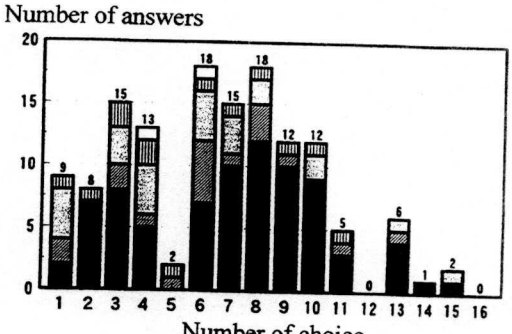


Fig.3 Prior examination in adoption

Fig. 4 shows the details of safety measures taken prior to adoption. As seen from the figure, concrete transporting machines in particular, are regarded to give a serious and direct impact on jobs on site if they break down or cause accidents. Therefore, all the dam sites took various safety measures for the concrete transporting machines, such as the installation of safety devices, interlock circuits, various censors and safety walkways. For automatic formwork, manual checking is carried out, risk of mishandling is studied, and safety training is provided for workers. Because green-cutting (concrete joint treatment) involves combined work of men machines and safety measures prior to adoption for this job is placed with education of workers.



[Note]: Legends are the same as those of Fig.3.

(Symbols of choice)

1. Obtained operation manual and safety check manual, and checked whether the machine was suitable for the conditions of the job site.
2. Checked if there would be risk of computer crash in view of the operation conditions of the site (e.g. rainfall, wind, sunshine and thunders).
3. Studied how the machine would function for all the possible operational situation.
4. Checked the risk in case the machine is mishandled by the operator.
5. Checked if there would be a damaging impact on the surrounding (e.g. noise, vibration and dust particles).
6. Educated the workers for safe operation (including management) of the machine through test execution.
7. Installed various interlock circuits on the automated machine for safe operation.
8. Installed several devices (e.g. emergency stop switches, alarm lamps, alarm tone and caution signs) for safe operation.
9. Installed various censors (e.g. for obstacle recognition, failure detection and metal location) for safe operation.
10. Installed safety walkways, emergency passes and guard fences as a means of dealing with crashing of the machine and prevent the workers working nearby from being caught by the machine.
11. Installed a device such as touch bumper to stop the machine automatically in case touched by an obstacle or a worker.
12. Provided workers with a portable device which can automatically recognize and prevent the danger of approaching the machine too closely.
13. Made a daily maintenance inspection record and/or monthly inspection record dedicated to the machine implemented.
14. Adjusted the operational speed of the machine to a slower mode until workers get used to it.
15. Appointed resident maintenance staff on site dedicated for the machine implemented.
16. Other safety measures

Fig.4 Prior examination in adoption

2.4 Present situation on operation of automated machines

Those who answered they had some apprehension over the use of automated machines were 8 out of 33. The rest, 25 dam sites, answered they were confident. Looking at this result alone might lead a conclusion that detailed safety measures prior to adoption made such confidence possible. On the other hand, they seem to regard automated machines as same as conventional machinery for temporary works when handling them; as seen from Fig. 5, what made them anxious were mainly machines themselves and the operators who handled them. It seems to show that they are not totally confident about the reliability of safety devices such as censors, and, to a certain extent, they are worried if operators would mishandle them or could not adapt themselves to such high-tech machines. As for types of machines that caused anxiety, concrete transporting machines (shuttle train line) and green cutting machines accounted for more than 70% of the total machines; automation of travelling machines are found to cause particular worries over safety.

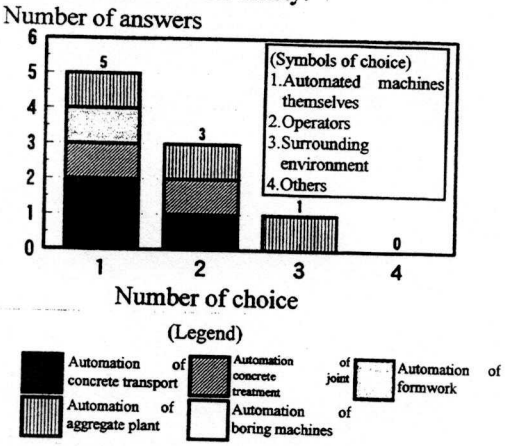


Fig.5 Systems that caused anxiety

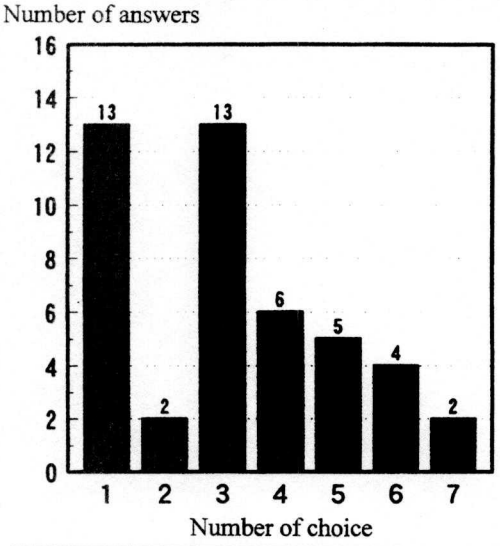
2.5 Opinions about automated machines

As a result of adoption, 22 dam sites out of 25 answered that automated machines would improve safety as opposed to 3 who could not determine whether it would improve safety or not. Thus, an overwhelming majority was found to consider that automated machines help improve safety. In answering the purpose of adoption, the choice of "safety improvement" came after "labor saving", chosen by almost 80% of the whole dam sites. It demonstrates that automated machines are regarded to be a valuable safety measure.

2.6 Request for safety measures

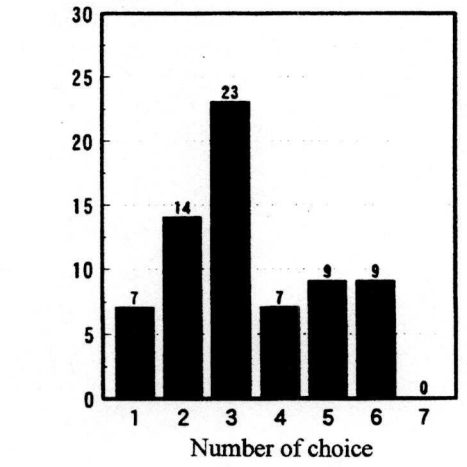
Present and/or future problems of safety management addressed are given in Fig. 6. Absence of safety standards, inadequacy of safety measures such as censors and safety circuit installed within automated machines and durability technology were pointed out by 13

dam sites each. Next came the inadequacy of manuals, which was followed by the absence of safety liability and operation licensing systems.



1. No adequate safety standards have been established.
2. It is difficult to explain the machine to authorities adequately.
3. Safety technology (e.g. censors, safety circuits and durability) of the machine does not seem to be sufficient.
4. No adequate safety manuals have been provided.
5. No clear liability has been indicated in case of an accident.
6. Operation licensing systems should be established.
7. Other problems

Fig. 6 Problems of safety management



(Symbols of choice)
1. Users should not have to appoint dedicated maintenance staff for the machine.
2. Machines should be able to predict (detect or locate) danger and prevent it themselves.
3. Machines should have perfectly-fail-safe functions, i.e. should be able to stop safely in case of failure.
4. Safety standards should be established for automated machines.
5. Liability should be defined in case an accident happens (e.g. manufacturer's liability or user's liability or supervisor's liability, etc.)
6. Adequate safety management manuals should be established so that they can be submitted to authorities.
7. Other requests

Fig. 7 What is required for automated machines concerning safety

The answers indicated, as seen from Fig. 7, that automated machines are required to possess perfectly-fail-safe functions and be able to predict and prevent danger themselves.

2.7 Other free opinions

The following free opinions about automated machines were obtained:

(1) Opinions about operation of automated machines

1) While it is not too difficult to give sufficient training for handling automated machines, there is still a danger of suspension of business unless the breaking-down of machines are coped with through a relevant operation and maintenance system with high technological knowledge. Dam sites are already short of technicians who can deal with usual operation and maintenance, and therefore immediate actions should be taken.
2) The ultimate aim of automation is not to save labor but carry out no-man operation. However, it would be extremely difficult to make dam construction works completely unattended by men; therefore the working environment of dam

construction sites inevitably involves combined work of men and machines. It means that it is necessary for dam construction sites to revise both construction schedule and scheme of execution in order to separate non-automation works and automated works.

3) As present automated machines require assistant workers, new type of dangerous jobs may be involved in their operation. In addition, because automated machines need a variety of censors, defects in their durability and performances often cause inefficiency of construction works.

(2) Opinions about the development of automated machines

1) Automated machines to be newly developed are required to: replace aging skilled workers and unskilled workers; put emphasize on safety and rationality; have simple trouble-free configuration requiring simple operation; be reasonable; and be re-usable for other conditions.
2) The development of an automated machine, which involves a series of work from researches to implementation, is extremely costly. Therefore, the central government should designate such development as a pilot project and give financial support or consideration for cost estimation.
3) Because machinery used in a dam site tends to be re-used in other sites, the development of automated machines should also take into account that they will be re-used widely in other sites. Furthermore, they are often modified through actual construction works, their development should be recognized as the responsibility of the whole dam construction industry.
4) Automated machines should enable workers with no specialized knowledge to cope with troubles of computer control by immediately switching to manual operation. In addition, when an automatic controller covers a wide range of functions, a fail-safe system should be developed by dividing them into smaller functions, each of which with its own fail-safe mechanism.

(3) Opinions about adoption

1) It is a desirable trend that automation is reducing danger and hard work, ultimately aiming at leading them disappear all together. However, implementation of automated machines which cannot be operated without specialized knowledge such as on computer is, in fact, demanding for dam sites in terms of personnel matters.
2) The problem of aging skilled workers and the decrease in the number of skilled workers is prominent in the construction industry. Consequently, it would be an inevitable trend for the construction industry to implement automated machines. Although teething pains with some anxiety are inevitable, the implementation should be vigorously undertaken.
3) If automated machines are made the most of, safety will be dramatically improved.

3. Safety technology required for automated machines in dam construction

3.1 Trend in automation and robotics in dam construction

In the dam concrete work, the whole successive jobs from manufacturing to finishing have been automated and systemized. The survey revealed that work sections involving concentration of work force and/or hard work are ahead of other sections in adopting automated machines. In view of the above, it is clear that the adoption of automated machines has been undertaken based on the expectation that automation of dam construction works will effectively improve the work environment on dam sites.

3.2 Technologies for safe operation

From the survey, the following insights into safety concerning automated machines were obtained:

(1) Issues to be solved concerning safe operation in dam construction works

At present, measures are being taken for safe operation prior to adoption, and safety management is also being exercised during operation, especially when operating automated travelling machines. It is, on the other hand, a fact that there are anxieties over safety management as to whether safety devices would function

properly, whether there is any danger of failure, and whether the automated machine could injure workers or damage itself when mis-handled. Consequently, development of perfect fail-safe mechanism within machines and autonomous function of predicting and preventing danger are regarded urgent.

(2) Basic safety measures in dam construction

The basic idea of safety measures common to all the automated machines used in dam construction are as follows:

1) Safety during operation of automated machines

In the case of automated travelling systems, there is a difference between the safety measures for track-mounted machines in dam construction such as shuttle train lines and those of unconfined machines. The basic concept of safety measures for track-mounted machines is the designation of prohibited areas, that is, to divide the area of the machine to move about by fences, preventing men and machines from working together during the operation. On the other hand, safety measures for the automation of unconfined travelling machines are far more serious and highly-complicated because the machines can travel anywhere, creating working environment where both men and machines work together. In such a case, the machines should be kept away from workers during operation and the machine's travelling areas should be limited by mobile barricades that can prevent the burning-up of the machine, dividing the work space for men and the machine locally.

2) Safety during inspections and repairing

An accident happens most often when a worker enters an automated machine's travelling area for inspection, repair, adjustment or refueling. Therefore, much care should be taken to ensure safety in such a case. For example, because a machine has to be run for confirmation when adjustment is being made, the machine should possess an extremely-slow-mode function, or a pair-working principle should be exercised so that one worker is always ready to stop the machine in case anything unusual occurs.

3) Inspection of automated machines before commencement of work

Like the case of conventional machines, it is essential to confirm the condition of automated machines before commencement of work to prevent malfunctioning. In practice, however, it would be difficult to predict malfunctions; it is nevertheless very important to check if there is a fault that can lead to malfunctions and if the emergency stop mechanism works properly.

(3) Basic concept of technology concerning safety

Generally speaking, there are two patterns of operational condition: a condition in which safety is being confirmed; and a condition in which a hazard is being detected. Furthermore, there is another pattern between these two: a condition where it is difficult to determine if it is safe or hazardous, that is, when it is not clear if the censor is functioning properly or when a situation has arisen that is not mentioned in the manual. Where there is any doubt, operation should be stopped and the following safety confirmation system and technologies need to be implemented:

1) Configuration of the safety confirmation system

The present systems used for safety assurance are categorized into the following: the safety confirmation type and the hazard detection type. The difference between these two types are demonstrated in Figures 8 and 9 where the photo switch and the safety confirmation interlock circuit are taken as examples. The safety confirmation type runs only when safety is assured, and it goes off when any danger is detected.

An safety confirmation type interlock circuit is a system which does not give permission of operation, not only when there is no order of operation but also when the safety device itself goes wrong. The distinctive feature of the above safety confirmation type devices is that they regard a fault in itself as a danger and stops the operation, putting users to be on the safe side.

On the other hand, the danger detection type does not work unless a hazard is detected. This system is off when safety is assured, which is confusing for users as it could mean either safety or a malfunction of the system itself. Therefore, this type should not be used to ensure safety.

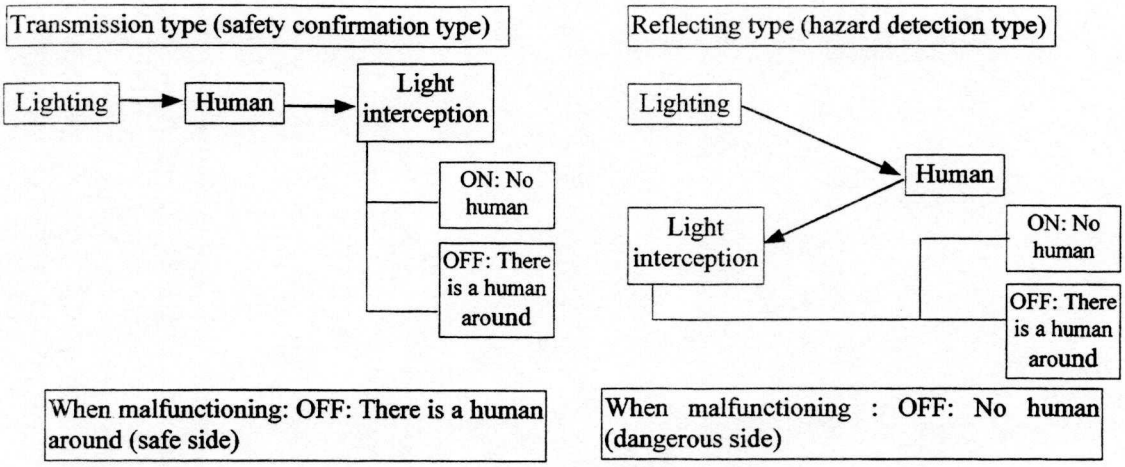


Fig. 8 The safety confirmation type and the hazard detection type

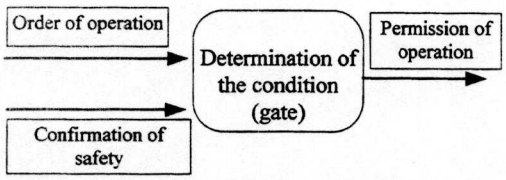


Fig. 9 Safety confirmation type interlock circuit

2) Fail-safe technology

In addition to the above safety devices, there is a technology called as "fail-safe technology" which equips automated machines with special system and configuration to stop them when anything wrong is found with them. Through the use of this fail-safe technology, a device can run only when all of its components are all right and safety is confirmed by safety devices. It is a technology that should be applied to automated machines.

4. Future perspective of the system of dam construction

Fig. 10 is the conceptual drawing of a future dam construction system which fulfills the idea of safety measures described above. This is a no-man operation system in which concrete is placed automatically by an all-weather, jacket-type concrete placement machine travelling on the surface to be concreted. Machines are remotely controlled by the central control room built on the jacket, and workers do not have to enter the working space of machines during the operation.

5. Towards the materialization of an execution system for the next generation

In order to materialize the system proposed above, the following various steps should be taken.

5.1 Steps to be taken in the technology field

The major tasks concerning technology are summarized as follows:

(1) Technology of processing and controlling information

Automation systems should be of remote control type or semi-automation type or full-automation type, the decision of which depends on the functions and the operation levels of the machines. These control types need to be systemized so as to coordinate one work operation with others for safety and to save labor. Furthermore, in order to run every machines efficiently, such systems as the centralized control system and distributed autonomous controllers should be implemented.

(2) Censor technology

A censor in a construction site must possess strength to withstand severe conditions, and be stable, reliable and durable against long-term use, noise and dirt so as not to malfunction in such conditions. Automatic travelling machines, in particular, need censors that can recognize real-time information on its course and position, anything unusual, and obstruction such as a human.

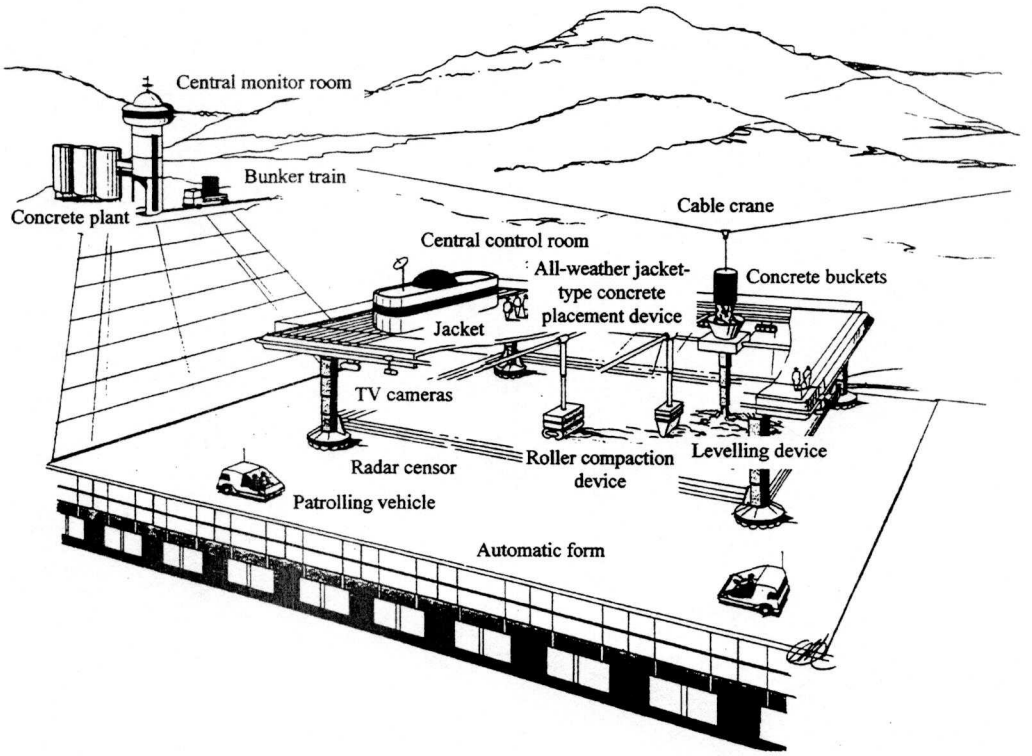


Fig. 10 Conceptual drawing of future dam construction system

(3) Telecommunication technology
It would be better to implement a radio system for exchanging information as a wide working area has to obtain information in a dam construction site. Particularly when machines are remotely controlled or automatically run, a highly-reliable telecommunication system will be needed, which can quickly process a vast amount of information in the form of numerical values, images and sound without disturbances even when billions of pieces of information are being exchanged.

(4) Maintenance technologies
Because of the increasingly-advanced mechatronics technology, there are cases where workers in charge cannot cope with machine troubles, operation and maintenance properly. In order to operate automated machines safely, efforts should be made to go a step further in simplifying operation methods and mechanism of machines, making them free from maintenance. Meanwhile, it is equally important to educate operation and maintenance staff with specialized knowledge.

(5) Hard wares
As machines are required to perform in a small area, it needs to be small and light-weight, being agile in its movement and capable of a small sharp turn. Moreover, because there are cases where they are operated in a wild land open to wind and rain, they also need to be capable of functioning properly under such severe conditions.

5.2 Steps to be taken in design and structural stages

In order to bring out the maximum performance of automated machines, consideration should be given at design stage and execution methods need to be improved.

(1) Steps to be taken at design stage
In order to rationalize dam construction works, a notion of rationality needs to be fully recognized from the design stage, construction work to operation. It is particularly important to include the implementation plan of automated machines in a comprehensive design plan so as

not to have to select them at construction stage only when they are thought suitable for design specifications.

(2) Steps to be taken in execution methods
From the viewpoint of automation, execution methods need to be simplified. To be concrete, following the way RCD or RCC Construction Method has been transformed into a more advanced system, conventional methods also need to be revised. In so doing, more simplified execution methods without complicated operations such as formwork and green cutting can be implemented, an example of which would be the use of soil-cement-like materials or new materials instead of concrete.

5.3 Steps to be taken concerning regulations and legislation

Present legislation does not touch upon matters concerning automated machines, and thus need revision.
For example, the Ordinance on Industrial Safety and Health prescribes that the erection and demolition of formwork supports should be carried out under the supervision of an operations chief who has attended relevant skills tuition. Licensing and qualifying are also prescribed in operating almost all construction machinery, and in addition, regular voluntary inspections are mandatory. Construction machinery becoming more advanced, it is now necessary to revise the qualifications of operations chiefs, skills tuition programs, systems of licensing and qualifying, and inspection system of safety devices.
Furthermore, it is proposed that regulations and standards concerning automated machines should be established, involving issues specific to them, such as fail-safe mechanism.

5.4 Other supports and promotions

In order to enhance the implementation of automated machines, the following supports and promotions need to be provided:

(1) Development system
The present situation concerning the development of automated machines is that every private enterprises are investing heavily on similar development and competing with each other. It is true that free competition invigorates the industry, but, because the development of an automated machine needs heavy investment and the development does not necessarily lead to direct cost reduction, a system of cooperative development needs to be established.

(2) Supporting systems

1) Financial support for development
Considering the decrease in the number of workers in construction works, automation and robotics are an inevitable trend which should be implemented with the cooperation of all interests involved in the society. It is proposed that pioneers in this field should be entitled to receive a variety of financial support, such as tax preference, subsidies and re-evaluation of construction cost when applying a new technology.

2) Promotion of pilot projects
At present, it is difficult to put a newly-developed technology and/or machine into practice because its workability and performance may not be fully recognized by users and owners. In this respect, new policies are needed to promote more pilot projects.

3) Revision of cost estimation system
Only a small number of automated machines are given a dedicated estimation standard and a hire-calculation system at present. More machines need to have the equivalent systems through the assessment of pilot projects and actual construction performance records. In addition, it is proposed that safety issues should be included in the economic evaluation of a project, so that the evaluation properly takes into consideration the reduction in accidents on duty due to automation to reflect it on cost estimation.

(3) Promotion of automated machines

1) Bringing up engineers and technicians
An automated machine is a collection of element technologies. At its development stage, therefore, leader engineers are needed who are well-informed about every element technologies and integrate them systematically. Needs at construction stage are technicians who can

deal with operation, daily maintenance and failure of automated machines. Bringing up these engineers and technicians should be undertaken with the cooperation of all the interest parties in the construction industry, academic institutions and the government.

2) Information disclosure

To reduce unnecessary development and achieve more efficiency, it is proposed to develop an Electronic Data Interchange (EDI) System through which data of newly-developed technologies and actual execution examples are exchanged and utilized by all the parties working on the development of automated machines. Close cooperation of various academic and industrial societies would be necessary to facilitate such a system.

6. Conclusive remarks

It would be best for the construction industry, with all the problems of work environment, to transform all the manual jobs into no-man operations. In practice, however, majority of construction works involve both men and machines working together, often in one operation. Given this situation, the authors have attempted the establishment of safety measures in view of "Coordination between Man and Machine" in this study. Although the measures proposed in this study are not sufficient, the data and opinions obtained through the survey will be used as a valuable basis for future researches.

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