

THE EXISTING STATE AND FUTURE PROBLEMS  
OF A ROBOTIZATION IN CONSTRUCTION

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ABSTRACT

This report shows the matters which are investigated and analyzed in 'Robotics Committee in Construction' of 'Japan Society of Civil Engineers'.

This Committee, consists of many authorities, has worked on a wide variety of technical problems since 1981; such as safety control and saving time in construction works, systematization, automatization and robotization of control skills. The work on this report is one of these researching activities. It can be understood the recent attitude of the Japanese construction industry toward the idea of robotization and automatization. Following describe the results of analysis on robotizations and automatizations in three different aspects.

- 1) Automatization and robotization nowadays in nine points of view.
- 2) Automatization and robotization of respective work in construction.
- 3) The analysis and future problems of automatization and robotization in construction.

1. Forword

In these days Japanese construction industry promotes actively an allied technologies, mainly electronics, and technical research and development for systematization, labor-saving and automatization in research, planning, programming, construction, maintenance and management. Especially, automatization and robotization are stimulated by the research and development of industrial robots and promoted eagerly by governments and public offices, construction companies, manufacturers, and so on. This has brought a good results. However, different from a factory production in well-arranged working conditions and environments, under severe conditions and complicated construction technologies automatization and robotization have been fairly successfully proceeded even though various problems have been caused. To improve this tendency, co-operated efforts of related industries and respective development of elemental technologies are required.

In Japan Society of Civil Engineers, in these years, Robotics Committee in Construction has taken a leading part in this project and proceeded a fact-finding investigation for automatization and robotization in construction in different aspects, and also has tried to let the participants know the state of robotics in construction, by holding many confereces and technical training seminars.

This thesis contains the result of analysis of investigated contents presented by 'Robotics Committee in Construction, Japan Society of Civil Engineers', attempting to graspe the state of automatization and robotization in construction works as precisely as possible. This investigation, though the scale is not necessarily large, consists of data prepared with detailed questions answered by engineers who take part of the development of robotics in construction, and therefore will give a sufficient knowledge of robotization in the construction fields. It is the latest report of an investigation for robotics in construction in Japan.

2. Purpose and scope of the investigation

The research and development for robotics in construction in Japan, which began at the beginning of 1980's, any longer at the stage of fumbling, but have reached the practical level. However, to promote automatization and robotization in construction fields, there are some problems which should be

resolved by considering the particularity of the works, environments and effects of investigations. Today, confronted with various difficulties, these researches and developments for numerous elemental technologies are advancing, aiming at safety-control and time-saving in construction works.

Under the present circumstances, it is important to obtain a guiding principle of effective research and development, with recognition of current situation of automatization and robotization. This is the second investigation; first one was made 5 years ago. This investigation covers at a wide range all over construction works of civil engineers including surveying, measuring and automation systems under development in order to grasp the situation of automatization and robotization as a whole.

Questions used in this investigation are on positive and negative factors for implementation and future development. There are 8 classifications selectable as shown in Table-1. Items which can not classified precisely are gathered as 'The other works'.

Study group of Robotics Committee in Construction of Japan Society of Civil Engineers confirmed the contents and items of the investigation and asked engineers who were engaged in the research and development of robotics in construction directly to make this investigation, for increasing the accuracy of the investigation. As shown in Table-2, altogether as many as 133 datas on automatization and robotization were collected from 15 representative corporations and organizations in Japan.

Table-1 Matters of works of investigation

Marks	Works	Matters
A	Earthwork and Rock works	Excavation works , Haul works , Banking, etc.
B	Earth Retaing works	Continuous underground wall method, Peristylar continuous underground wall method, Earth anchor method, Horizontal sheet-pile with perpendicular steak method, sheet-pile earth retaining method
C	Foundation works	Soft ground improvement method, Pile foundation method, Caisson foundation method, etc.
D	Concrete works	Mixing , Haul works , Placing , Compaction , Curing , Finishing , Joint works , Rainforcement works , Form works , Timbering , Repairing and reinforcement ,etc
E	Tunnel works	Mountain tunnel , Shield tunnel , Propeling , Underground cave , Trench method, etc.
F	Surveying and Measuring	
G	Under water works	Surveying , dredging , Reclamation , Foundasion works , Ground improvement , Structure , etc.
H	The other works	Pavement works , Scrap works , Cofferdam works , Temporary work , Welding , Cutting , etc.

You can realize that tunnel works is an overwhelming majority, followed by concrete works and underwater works. This shows the present circumstance of these research and development straight forwardly.

Table-2 A number of matters of automatization and robotization of investigation

	A	B	C	D	E	F	G	H	Total
Ports and Harbours Bureau Ministry of Transport							10		10
Nippon Telegraph and Telphon Corp.					4				4
Ohbayashi Corporation	4	1	1	2	4	1	1	1	15
Okumura Corporation		2			5			3	10
Kajima Corporation		1		5	6		1	2	15
Kumagai gumi Co.,Ltd				2	6			1	9
Ministry of Construction							1	1	2
Simizu Corporation		1	1	3	4		2	5	16
Taisei Corporation				2	4	1		2	9
Takenaka Doboku Co.,Ltd	1	1			2		1	1	6
Toyo Construction Co.,Ltd					3		6		9
Japan Development and Construction Co.,Ltd		1	1	1	2			1	6
Hazama-Gumi ,Ltd		1	1	2	4	5	1		14
Fudo Construction Co.,Ltd	1				4		1		6
Mitsui Construction Co.,Ltd	1							1	2
Total	7	8	4	17	48	7	24	18	133

Notes : A, B, C, ....., H in table is equivalent to marks in Table-1

### 3. Automatization and robotization in respective works.

We have analysed the data described previously in nine different questions. This is to show when, who, in what field, for what purpose and how automatization and robotization in construction field has been proceeded. The following show results.

#### 3.1 What field is automatized and robotized ?

Three types of works occupy 67% of the entire 133 samples; Tunnel works: 48 (36%), Underwater works:24 (18%), Concrete works:17 (13%). Regarding other works; earth retaining works:8 (6%), earthwork, rock works, serveying and measuring works:7 (5%). It shows that the types of works, which require automatization and robotization or which are technologically advanced, are in common.

### 3.2 What is the purpose of the research and development ?

The purpose of this research and development is depend on their kinds of works and environment. A high rank 6 items as the advantage of automatization and robotization are as follows;

- ① Labor-saving is successful.
- ② Accuracy of construction has been progressed.
- ③ Quality of construction has been progressed.
- ④ Production has increased.
- ⑤ Safety control have improved.
- ⑥ Working conditions have been improved.

Higher priority in a younger numbers.

Be equivalent to these 6 items, the disadvantage are as follows;

- a. Quantity and number of working process have increased.
- b. Accuracy of construction has been deteriorated.
- c. Quality of construction has been deteriorated.
- d. Production has decreased.
- e. safety have declined.
- f. Environments have deteriorated.

Only ① is pointed out as an advantage as the purpose of the research and development. That is to say, the research and development for automatization and robotization are achived for the purposes grasping functions which are going to be developed sucessfully. But the purpose of development and the order of above stated 6 items as the advantages and disadvantage, have brought the results as expected.

On the one hand, while a great interest in labor-saving, little interst is shown in other items; energy-saving, resource-saving and Haul of the heavy-weights. This result shows a strong need for labor-saving in construction field, even if the resource and energy is over-consumed. Labor-saving is shown as the highest rank of advantage which is brought by automatization and robotization, however, a shortage of specialists and operators or a cost increase for constructions are pointed out as disadvantages. It shows the complexity of the research and development in construction technics.

### 3.3 Have safety controls and enviroment in construction have improved by automatization and robotization ?

In this type of works; earth, rock, concrete, temporary, tunnel, and earth retaining ; the improvement of safety control and environment have been proceeded actively through automatization and robotization. Especially earth, rock, earth retaining, concrete, and tunnel works are listed as the work where safety control has been improved. And in tunnel works and concrete works environment has been improved. On the other hand, it is said that danger has increased by automatization and robotization in earth retaining works and tunnel works. That is minor but an attention should be paid to this problem.

There is no sample that environment deteriorated by automatization and robotization. Generally speaking that has been improved. And we cannot afford to overlook the fact that foundation works and underwater works have not aimed at the improvement of safety control. That is why technical developments in these works have not reached the level as is needed the improvement of safety control and environment.

### 3.4 Have quality and accuracy of construction been improved ?

For the purpose of the improvement of quality and accuracy of construction, there is the type of works which has proceeding automatization and robotization, positively as follows; earth retaining, foundation, tunnel, surveying and measuring, and underwater works. In earth retining works, foundation works, tunnel works, and surveying and measuring works, the improvement of quality and accuracy has been highly appraised. On the other hand, the improvement has not reached at the sufficient level in underwater works. Generally saying, there are few samples which report the deterioration of quality and accuracy of

construction. In this aspect, the disadvantage of the research and development is hardly seen.

On the other side, the improvement of quality and accuracy of construction has not been proceeded in earth and rock works and concrete works. It is pointed out that in these two works the improvement of quality and accuracy of construction cannot be expected as the effects of automatization and robotization. In these works which deal with a large quantity, labor-saving is an urgent requirement and the improvement of quality and accuracy of construction is might be a future problem.

### 3.5 Have working conditions been improved ?

The improvement of working conditions by automatization and robotization has been aimed in various works. Above all, labor-saving has been realized as expected and the improvement of working conditions has been successful in these works as follows; earth and rock work, tunnel works, foundation works, concrete works, surveying and measuring works, and etc. It shows that in earthwork and rock works, in particular, the improvement of working conditions has been obtained sufficiently by automatization and robotization more than expected. On the other hand, it is pointed out that labor-saving has been unsuccessful in earth retaining works, temporary works and underwater works. In earth retaining works, in particular, labor-saving has not been valued and the improvement of working conditions by automatization and robotization has not been contributed.

By automatization and robotization, more or less, labor-saving has been proceeded and the improvement of working conditions has been successful. A new problem for automatization and robotization of construction technology is pointed out, for example, lack of a great deal of expenditure for development and lack of elemental technic, short of specialists for robot-controlling and maintenance, and so on.

### 3.6 Have resource-saving and energy-saving been successful ?

Examples of automatization and robotization resource-saving and energy-saving have not yet seen. In other words, though there is no sample of the advantage that resource-saving and energy-saving has been promoted by automatization and robotization. It is not report that the consumption of resource and energy have increased. Therefore, we cannot refer to the relation between 'resource-saving and energy-saving' and 'automatization and robotization'.

### 3.7 Have cutdown, curtailment of the completion for construction, and productivity been improved ?

Three factors of cutdown, curtailment of the completion for construction, and productivity, brought by automatization and robotization have always attracted engineers who work for technological development of robots in construction. Even though these are the ultimate purpose in the actual construction field, they have not yet been practically in effect. This is because that more interests are taken in improvement of labor-saving, accuracy of construction and quality of products, status of a company, safety control, environment and management than cutdown and curtailment of the completion for construction. It is too early to discuss the effects. Following describe in details.

With regard to cutdown, the number of people who recognize effect is equal to who do not. On the other hand, regarding curtailment of construction, productivity, and working condition, the number of people who do not recognize effects is twice as many as who do. Concerning about speculation effect depending on expenditure for development, there is no significant differences in amount of money. Generally speaking, there are more expenditures of over 10,000,000 yen than below 10,000,000 yen. 10,000,000 to 50,000,000 yen speculation occupies one third. 50,000,000 to 100,000,000 yen speculation and over 100,000,000 yen are almost the same. In the case of below 10,000,000 yen speculation effective is not so much considered.

Strong interest is taken in cutdown, curtailment of construction and

productivity at concrete works, tunnel works, underwater works, and so on, while little interest is taken at earthwork and rock works, earth retaining works, foundation works, and surveying and measuring works. As concerns developing organization above three items have the same purpose of other development. Developments are mainly organized by their own construction companies and co-operated development with manufacturers. Self-development are seen most frequently. This may be the typical of Japan's developing organization of constructing technologies. The advantage and disadvantage of automatization and robotization for the purpose of cutdown, curtailment of construction and productivity are as follows; in all the three items the disadvantages are that more specialists, operators, and auxiliary devices are needed, and the increase of resources, energy consumption and expenditure in productivity. Little interest is taken in other disadvantages. This has the same tendency as the improvement safety, quality, accuracy, labor-saving, environment, energy-saving, resource-saving, the feed-back to design and implementation, status of company and management. Deterioration on productivity and delay of construction period are not pointed out, but increase of expenditure is pointed out as a disadvantage. This disadvantage is as serious as that more specialists, operators and auxiliary devices are needed.

3.8 Main obstructive factors are as follows:

- ① High cost of developing expense.
- ② Retrieving of expense.
- ③ Element technology.
- ④ Transport ratio of developed equipment.
- ⑤ Environmental proof technologies e.g.vibration,water,pressure and fire.
- ⑥ Developing expense is excluded from constructing expense.
- ⑦ Present technology level.
- ⑧ Developing period.
- ⑨ Increase of general expenditure.
- ⑩ Individual talent.
- ⑪ Order system for construction.
- ⑬, ⑥, ④ are all related to ②.

In other words, ② occupies 25.9% of the entire obstructive factors.

① and ②, which are financial factors, make 55.5%. It is the critical obstructive factor for automatization and robotization that the expense cannot be retrieved, therefore it is necessary to search seriously solution. Secondly, technological obstructive factors occupy 19.3 % by element technology, environmental and present technology level. That means that 'retrieving of expense', 'technological difficulty' are the most important factors.

Tunnel works and concrete works have been developing in wide varieties, and so obstructive factors have also wide varieties.

Unsignificant obstructive factors are as follows;

- ① Unefficiency.
- ② Problem on safety control.
- ③ Difficulty in educating employees.
- ④ Engineers for development cannot be increased.
- ⑤ Parts supply is difficult.

When these are not regarded as obstructive factors, automatization and robotization are well approved.

3.9 What do we consider the cost and organization of this project ?

So far as developing expense as a whole is concerned below 10,000,000 yen takes 12%, 10,000,000 to 50,000,000 yen takes 40%, 50,000,000 to 100,000,000 yen takes 30%, over 100,000,000 yen takes 18%. This means that over 50,000,000 yen takes nearly 50%. Also, Respective works have the same tendency, for instance, in the case of tunnel works 8%, 44%, 27%, 21%, and in underwater works case, 5%, 38%, 19%.

It can be understood that large amount of developing cost, which are

speculation on technological development and retrieving developing expence, obstructs automatization and robotization. Therefore, the most important matters are lowering developing expence and including developing expence in constructing expence.

Regarding developing organization, self development occupies 47% co-operated development with manufacture occupies 41%, making 90% by these two. In tunnel works, concrete works and earth retaining works self-development is main organization, to the contrary in underwater works, earth and rock works do not mainly discerned.

Regarding responsibility for the expence, 74% of the developing expence is supported by each constructing companies and 19% is supported by co-operated organization. This explains that constructing companies are mostly responsible for developing expence, even when development performed with cooperative manufacturer, and so it can be said that current developing organization is construction company dominant type of co-operation.

#### 4. Automatization and robotization nowadays in respective works

##### 4.1 Earthwork and Rock Works

It is natural that time and money saving is one of the purposes for automatization and robotization, but it looks peculiar that resource-saving and energy-saving are not recognized as a point of technical development. Advantages of automatization and robotization are labor saving and minimizing management purposes for development being achieved. Actual elements are decrease of prices, improvement of environment proof and introduction of sensor, control system and movement system.

On the other hand, disadvantages are increase of cost, specialists and operators, leaving financial and operational problems to be solved. As technological development for automatization and robotization is mostly yet in process, judgement should not be made until later. So far as now, it is more financial and operational problems than technological level, that prevents promoting automatization and robotization. Development expenditure is mostly supported by constructing companies and excluded from constructing expence. this is the major problem of Japan's constructing industries.

##### 4.2 Earth Retaining Works

The improvements of quality and accuracy construction are two main aims of automatization and robotization. What should be performed are introduction of a direction controlling system and automatic meter for excavation and boring. However, what actually performed are mixture of complete and semi automatization. The most outstanding of all is a robot for continuous underground walls.

The advantages obtained by automatization and robotization are improvement of productivity, accuracy and status of company, while the disadvantages are increase of specialists, operators and auxillary devices. In many cases, automatization and robotization has been at the implementation level since 1980 to 1983.

The development system and expenses ranges from 100,000,000 yen to 50,000,000 yen mostly supported by self-development of construction companies. The characteristic is that investment on development is lower than the other industries and price decrease is intensively desired.

##### 4.3 Foundation Works

Nothing in particular is listed up as automatization and robotization in the foundation works, but automatic meter or measuring management are desired in contact with the above earth retaining works. The purposes for automatization and robotization are improvement of quality, accuracy of process, productivity, labor saving, specially process accuracy is achieved more than the expectation.

Obstructive factors of automatization and robotization are increasing developing cost, difficulty of retrieving it, while advantages are improvement

of mechanical functions and reliability. This ascribes to versatility of measuring equipment and progress of electronic technology.

Disadvantages are increase of specialists, operators, auxiliary devices, the number of working process and amount of works, and delay of construction period.

Technical development is concentrated from 1980 to 1986 and the development organization is co-operation by constructing company and manufacturer. Desired elements for development are more sophisticated automation, higher accuracy and weight-decrease.

#### 4.4 Tunnel Works

The mechanization is most advanced in this field and further progress of automatization and robotization have been introduced. The purposes for technological development are improvement of accuracy of construction, quality, labor saving and safety control which have given result as expected. Obstructive factors are as follows ;

- ① increase of developing expense, difficulty in retrieving it which caused expanded facilities.
- ② difficulty in elemental technology such as environmental proof technology.
- ③ low efficiency of developed devices.

Regarding disadvantages, increase of cost, specialists and operators are typical in this field. What required are retrieving the developing expense establishment of estimation on developed technology for improvement of equipmental efficiency and expanding the facility for education. Other requirements are lower price, higher accuracy, more sophisticated automation and improvement of sensor technology.

#### 4.5 Concrete Works

Concrete works occupy 13% of the entire construction field, half of the companies working on automatization and robotization. 17 samples of concrete works for automatization and robotization are form works:5, haul works:4, compaction:2, finishing:2, jointing:2, repairing and reinforcement:1, reinforcing bar:1.

Main purposes for development are labor saving and safety control. Advantages as expected are labor saving, safety control, accuracy of construction and productivity. Disadvantages vary wide ranges. The worst one is 'increase of expense' which is common in all the fields. Positive factors are economical advantages, efficiency, improvement of mechanical reliability and function. Negative factors are increase of developing expense, prices of products, and difficulty in retrieving, and decrease of efficiency. What required are more sophisticated automation and lowering cost.

#### 4.6 Surveying and Measuring

Main purposes of automatization and robotization are automatization of surveying operation for construction and ground. Samples are; earthquake observation:3, geological surveying:1, construction experiment:1, building maintenance:2. Similar to earth retaining works previously described, measuring control is a main matter. Some of the measuring are only semi-automatic.

Successful result is obtained in improvement of quality and labor saving, but costs are not lowered successfully because of increase of workers for maintenance and auxiliary equipments. Automatization and robotization in this field is expected to bring improvement of intelligent processing technology, communication technology and mechanical functions as well as progress of systemization technology.

#### 4.7 Underwater Works

Automatization and robotization in underwater works are mainly achieved in the three field: surveying, dredging and ground improvement mostly aiming at labor-saving. Advantages are labor-saving, increase of accuracy and so on. Disadvantages are increase of specialists, operators and auxiliary equipments.



By improvement of element technology such as intelligence processing and sensor automatization and robotization is expressed to be advanced even more.

#### 4.8 The Other Works

In this investigation, temporary works, cofferdam works, welding, cutting, scrap works, pavement works are gathered in one field. This makes operational contents complicated, and so there is no definite tendency observed. This field is not suitable for automatization and robotization, therefore it is necessary to improve construction method for automatization and robotization. Different from other field, interests in labor saving are not quite strong.

#### 5. General Thought

##### 1) Attempt of automatization and robotization

It is long since automatization on construction technic and operation began. Automatization has been proceeded little by little in each function in necessity of the constructing field. With the technical development in electronics, not only mono-functional robots but multi-functional robots and even intellectual robots have been utilized in the constructing field. This field has made efforts more eagerly on automatization and robotization than the other fields.

It is caused by typical backgrounds as:

- ① skilled workers are short.
- ② constructing workers are aging.
- ③ working environments are inferior and possibility of accidents is high.
- ④ productivity is low.

In the previously described 'What fields are actually automatized and robotized' and 'What is the purpose of the development', we can observe many samples which contain the above problems.

First of all, labor-saving is pointed out as most important aim in every field and it is followed by progress of accuracy of construction, quality, productivity, and safety control. There left haul of the heavy-weighted, resource-saving, energy-saving, cutdown and curtailment for constructions what are not easy to resolve in automatization and robotization. This means that the construction industry has reached only the stage of improving the quality and accuracy for automatizing manual works, but not yet the stage of propheting the effects like resource-saving, curtailment, cutdown, resolving the problems particular for construction industry like haul of the heavy-weighted.

When we look on the purpose in automatization and robotization in respective works, there is no specific tendency, but the ratio of working condition is rather high in concrete works and tunnel works. It shows that lack of skilled workers in reinforcement and form works is getting a significant problem.

##### 2) What fields are actually automatized and robotized ?

The works which actually automatized and robotized in each construction field are, for example, exavation, haul and placing in the tunnel works. What is distinct about the underwater works is that 10 samples out of 24 are automatized and robotized for the purpose of prompting 'construction system'. This may because, in the underwater works, manual operation itself is difficult, therefore it is required to automatize not only mono-functional works but also the system that controls the entire construction works, as well as to reconsider construction methods. Various different operations are needed for building a construction, therefore, it is necessary to consider construction procedures as a whole system using an appropriate approach.

Besides, automatic measuring and measuring control are regarded as aims for surveying and measuring. Necessity for automatization of measuring works will be increasing and there might appeared the robots specially designed for measuring.

##### 3) Automatization and robotization(period, level, and stage of development)

The technic of construction has been developed in either hardware, that is, utilization of large machines, or in software, that is, the development of new construction method including standardization of design. Mechanization of constructing works has rapidly developed since 1970's automatization. Toward the end of 1970's by remote controlling system of bulldozers and shovels was forwarded but automatization and robotization has drastically improved since 1980's. In our research, it shows that 91% of samples appeared after 1980, 65% are after 1984, while only 7% existed before 1979. This shows that the interest in automatization and robotization is recently raised.

Out of 133 samples, 49(37%) are complete automatization, 48(36%) are semi-automatization, 25(18%) are automatization exclusively for measuring, and 12(9%) are remote controlling. We are now in the half-way through from semi-automatic to complete automatic age. Even though automatization and robotization have been expanded for these several years, it is still at the stage of bringing it into practice for constructing fields, particular problems not yet being resolved. So we are now at the stage of searching the way, investigating the applicability of automatization and robotization by the prototype.

#### 4) The direction in future

Automatization and robotization in construction have been effectively used for the progress in quality, safety control, and labor-saving. On the other hand, there are some problems, such as; increase cost for development, lack of element technology, and increase of the number of skilled operators and workers for maintenance. As we can see in our research, 'What are the obstructive factors?' and 'What is needed for promoting automatization and robotization?', the cost is very much concerned.

There are obstructive factors which increase the cost;

- ① The respective work at which robots are good is not available enough because standardization is not completed.
- ② The construction locations are always moved and so the conditions and types of works should be changed accordingly.
- ③ Construction methods in general are invented to be performed by men and therefore too complicated for robots.
- ④ A robot is required to feature a transportation function.
- ⑤ A robot is required to handle the heavy-weighted as well as determine the positioning.

To develop and settle down automatization and robotization in construction, it is important how to solve problems like;

- ① to raise the money for development.
- ② to include the cost in calculation of expense.
- ③ to establish the evaluation for the developed systems and machines.

Automatization and robotization are organized by the construction company alone, and it is inevitable because the procedures of construction is so complicated that each company has to select the necessary function in co-operation with the manufacturer.

#### 6. Conclusion

The interest in constructing robots seems to be declined in recent years, but it actually shows the robots are no longer just current topics of 1980 onward. As a matter of fact, we are now on a changing period which we have never experienced, as technics of electricity has been progressed, the computers are getting smaller but they can hold the larger amount of messages and it has influenced to the world of construction, too. We are looking forward to seeing some robots which we cannot believe to exist but in science fictions.

This is the summary of 'The Existing State and Future Problems' (Sept. 1987) that is reported by study group of 'Robotics Committee in Constructions' of 'Japan Society of Civil Engineers'.