Current Developments and Issues in Construction Robot Technology

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1. WHY CONSTRUCTION ROBOTS ARE NEEDED

The population of Japan is expected to age rapidly in the coming decades, and the years until the early 21st century are a critical period for expanding housing and other societal infrastructure. A planned boost in the master plan for infrastructural investment which will bring investment in public works in the years 1995 through 2005 to a total of 630 trillion yen, and this will also lead to a concomitant need to improve the efficiency of maintenance work, as the overall stock of societal infrastructure increases.

The low productivity of labor in the construction industry has long been a problem; now that a rise in the average age of construction laborers and shortages of skilled laborers and technicians are expected, this problem must be urgently solved. Improvement in work conditions and work environments — i.e. long hours, low wages, and high risks — has lagged, and this is also a significant problem as it has caused job-seekers to be attracted less and less to the construction industry.

The causes for these matters lie in the outdoor nature of production in the construction industry, the peculiarity of work conditions being different for each project, and the large number of on-site workers required. In other words, compared to other manufacturing industries, standardization of products and across-the-board mechanization and robotization have been difficult.

In the year 2000, the investment in construction is expected to be 1.2 - 1.6 times as large due to the implementation of the master plan for investment in public works, and working hours will have been cut down to 1,800 hours per year. An equation was derived from correlations of the relationship between construction work and the required number of workers, using data spanning the past twenty years. From this is it was estimated that the number of workers required in 2010 will be 4.8 million; according to estimations by a think tank on hiring policy, the supply of workers will be 3.5 million, signifying a shortage of 1.3 million. In order to pursue the expansion of housing and other societal infrastructure, large-scale labor-savings and robotization of construction are an urgent issue.

2. MEASURES INSTITUTED BY THE MINISTRY OF CONSTRUCTION

To comply with these demands of the day, the "Basic Policy on Research and Development Aimed at Higher Efficiency in Construction," which presented a basic policy on technologies for improving efficiency in construction and popularization measures, and the "Vision for Technology Development Aimed at Higher Efficiency," which conceptualized the construction site of the 21st century and presented the necessary objectives, were formulated by the Construction Technology Development Council of the Ministry of Construction, in 1988 and 1989, respectively.

The "Vision for Technology Development Aimed at Higher Efficiency" covered almost all of the construction industry, as indicated by the 10 categories of work and 34 work techniques, shown in Table 1.

Table 1 Scope of the Vision for Technology Development Aimed at Higher Efficiency

Work Category	Content
Montane tunnelling	Blasting, free cross-section TBMs, full cross section TBMs
Shield tunnelling	Slurry shields, EPB shields, directly placed concrete linings
Dams	Concrete dams (RCDs, columnar work)
Road pavement	Asphalt road construction, asphalt maintenance work, prefabricated pavement
Construction	Underground work, framework, finish work, installation work
Earthwork	Conventional excavation, embankments, slopes, mixed fill work
Foundation work	Caisson (pneumatic caissons, open caissons) work, contiguous diaphragm walls, earth drill work, reverse cast-in-place work
Concrete work	Sewage treatment plans, common ducts, large-scale underground tanks, pumping and placement, quality control
Underwater work	Dredging, bridge construction, caisson foundation work
Installation work	Block installation work, drainage work

In the formulation of the vision, the current state of all work procedures in all work categories was carefully studied, and it was decided to 1) reduce dangerous work, 2) reduce work in tiring or taxing conditions, 3) take measures against the labor shortage, 4) improve work performance.

Based on this vision, technology development was pushed ahead in both the private and public sectors. The Ministry of Construction implemented a general technology development project (GTDP), carried out mainly at the Public Works Research Institute and called the "Development of New Construction Method Technology (1990-1994)."

This GTDP involved the automation and robotization of new construction and construction process technologies for tunnelling work, pavement work, foundation work, and dam construction, which make use of more efficient design technologies in concrete work, the latest electronics, and sensors. Additionally, new construction and construction process support technologies were developed for working on large-scale structures. Research and development was also carried out on a wide range of fields, such as development of precast concrete formwork conducive to the introduction of robots, developing streamlined production processes for secondary products and public works structures, and also development of technologies for improving the safety of construction work.

3. ON PROJECT RESEARCH FOR NEW CONSTRUCTION METHOD TECHNOLOGY DEVELOPMENT

(1) CONCRETE WORK

In the GTDP, research was carried out on reinforced concrete structures that allow automation and robotization. Simultaneously, technical standards were reviewed, and design standards and standard design drawings were revised. Important research topics were as follows:

1) Simplification of the shape of concrete structures; standardization of dimensions

2) Standardization of reinforcements

3) Development of preassembled reinforcement

4) Increasing the size of precast members

5) Development of formwork for prestressed concrete

Of particular note is research on preassembled reinforcement, which involved the development of methods for joining reinforcement and solutions for dealing with the concentration of splicing to one cross-section. After verification through strength tests, this technology was put into service.

In regard to large-scale prestressed concrete material and prestressed concrete formwork, single shear tests and tension tests were carried out to investigate the bonding with secondary concrete and the joints between prestressed concrete formwork. It was found that the quality matches that of concrete poured on-site.

(2) MONTANE TUNNELLING

Robotization is considered particularly necessary for that tunnelling work involving blasting, which is dangerous due to falling rocks, face collapse, inflow, and explosions. In this GTDP, the automation of charging and other issues were tackled, as follows:

1) Prelocation technology and technology for predicting ground expansion

2) Automation of surveying and marking

3) Automation of charging and blasting

4) Automation of the mucking shovel

Triangulation surveying systems, CCD camera measuring systems, and stereo photography surveying systems using laser beams and CCD cameras were developed as efforts to automate marking in surveying. It has become possible to drill holes with an accuracy of ± 5 cm, using automation machinery for a heavy drifter with an adjustment mechanism possessing five degrees of freedom. A prototype of a robot that charges and blasts automatically was developed, and verification tests were carried out to confirm the safety of all aspects of work.

(3) FOUNDATION WORK

Automation is necessary because of the adverse work environment and safety levels when workers have to work deep underground, during caisson work or deep foundation work. In this GTDP, the remote control and monitoring of excavation or raising work in open caisson work or pneumatic caisson work were carried out; data on excavation conditions was gathered throughout. In open caissons, it was possible to achieve 10 - 12 m3/h in sandy clay, and the work accuracy was also extremely high. Full-scale tests were carried out for pneumatic caissons. It was found that the required accuracy and excavation performance were satisfied, and the applicability of the technology to practical situations was thus verified.

(4) DAM CONSTRUCTION

Dam construction has long been the subject of mechanization, and automation has progressed for dump trucks, rolling compaction machines, and greenery carts. In this GTDP, concrete mixing was automated through the continuous measurement of water content using radioisotopes, in order to automate the quality control of concrete ingredients. Additionally, robots were developed for inspecting and cleaning the dam itself, and a machine which automatically prepares concrete samples was also developed. It was thus possible to improve precision of concrete quality, and to work around risks posed by maintenance work.

(5) PAVEMENT WORK

In this GTDP, an automatic tracking total station was used to determine the three-dimensional location of the finisher, and steering and work position were automatically controlled in three dimensions to adhere to a work plan input in advance. In terms of performance, this automatic finisher achieves a mean locationing error within 50 mm and a height error of approx. 10 mm; it has thus good chances of practical application. A roller which automatically controls compaction was developed. It comes with an automatic vibration device which works according to data on the location of the roller, obtained using an encoder and gyrocompass, and data on the state of roller-compaction, obtained using dispersion radioisotope measuring instrument. This research has presented the possibility of eventual practical application.

(6) EARTHWORK

Earthwork can be divided into the four phases of (1) preparation (surveying and work planning), (2) excavation, (3) earth transportation, and (4) embankment work.

The automation of civil engineering construction machinery includes the simplification of machinery operation, block stacking, blade control, automated measurement of roller compaction and compaction, and remote control (as was carried out at Unzen-Fugendake). In this GTDP, development work was carried out on unmanned earth transportation, a non-prism automated optical accounting control system, and a system for integrating GPS locationing and radioisotope compaction measurement. In addition, work planning and work process control systems utilizing these automatic measurement systems were developed, and practical application tests were carried out. Unmanned vehicles had a maximum course deviation of less than 1 m at 15 km/h, and satisfactory results were obtained on automatic steering, vehicle guidance, surroundings awareness, and collision prevention. It was found that application to large dump trucks is possible. Research on work information control systems is being expanded to CALS (Continuous Acquisition and Lifecycle Support).

(7) TECHNOLOGY FOR IMPROVING SAFETY

Accidents in the construction industry have gradually decreased over the years, thanks to improvements in various safety measures. While the number was more than 2,000 persons in 1965, this fell to less than 1,000 persons in 1985. The accident occurrence rate is still higher than in other industries, however, and has not decreased since. To cope with this situation, in this GTDP development work was carried out on preassembled scaffolding, contact-safe backhoes, and technology to prevent mobile cranes from toppling. Contact-safe backhoes have safety support systems which detect ultrasound waves emitted by transponders attached to machinery and workers, and are designed to sound alarms, slow down and stop when there is a risk of contact. No significant deterioration in work efficiency was observed during field trials, while safety was found to have improved. The newly developed crane-toppling prevention technology adds detection of outrigger reaction during work to the moment limiters (which already existed). Hence the concentration of loads is determined to judge the safety condition of the vehicle. Trials using actual machinery found that the determination of the center of gravity using the measured value of outrigger reaction can be considered valid.

4. ISSUES AND DEVELOPMENT FOR PRACTICAL APPLICATION

Some new technologies and work techniques, construction robots in particular, have been developed but are not in actual use. The reasons for this are that there is no legislation, no precedent, no standard for cost appraisal, and that the costs are high. The Ministry of Construction is thus determined to promote the measures given below to popularize the technologies.

(1) LEGAL MEASURES

The legality of the charging and blasting robot for tunneling work is currently being considered according to the Explosives Control Law. No complications for these robots is expected, however, and legal approval is expected soon.

(2) SUPPORT SCHEMES

There are several schemes directly promoted by the Ministry of Construction to popularize the active utilization of new construction technology, as follows:

1) Technology Utilization Pilot Programs

2) Designated Technology Utilization Pilot Programs

3) Field Testing Programs

4) Tax Relief Scheme for Construction Robots (tax alleviation for small and medium sized contractors, for six types of construction robot)

5) Labor Saving Investments Financing Scheme
Low-interest loans for the financing of labor-saving equipment, such as construction robots, small-size backhoes.

(3) SUPPLY OF INFORMATION ON CONSTRUCTION ROBOTS

To aid in the on-site operation of construction robots, information on construction robots is provided. This allows costs of conventional construction methods and the use of construction robots to be readily compared. The information provided is as follows:

1) Initial cost for construction robots

2) Time and personnel required for moving the equipment on-site, assembling, work, and dismantling.

3) Amount of work per construction robot, required number of personnel

4) Miscellaneous

(4) DEVELOPMENT OF RESEARCH THEMES AT THE MINISTRY OF CONSTRUCTION

Of those aforementioned research themes of the GTDP, prototypes were developed for earthwork, planning systems, and process control systems. Research was subsequently continued in the GTDP on the unification of construction information (the development of CALS), which commenced in 1995. Incorporation is planned in the construction machinery CALS which use IC cards, which started in 1996. The improvement of safety technology will be effected by the use of safe backhoes at road construction sites, and research to confirm the practicality of this, which will start in 1996. Basic research will involve remote control technology and studies to tackle automation and division of labor between man and robots, from the perspective of man-machine interfaces.