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Construction Robots for Site Automation

Principaux thèmes abordes:

Au Japon, dans le domaine de la construction, de nombreux robors ont éré développés et utilisés avec pour objectif l'automatisation des tâches et par conséquence la réduction du personnel, notamment celui affecté à des travaux pénibles ou dangereux. Dans le présent rapport nous présentons le SSR-3, robot pour l'application de materiaux de protection ignifuges sur poutrelles metalliques, l'OSR robot de peinture pour rebord de balcon, le MTV-1 robot multitâche pour le finissage des sols et Mighty Jack, robot d'assemblage des poutrelles d'ossature metallique.

De plus sont abordés aussi les thèmes de la recherche en systèmes de production robotisés la formation des personnels à l'utilisation et à l'entrefien des robots et de l'application de nouvelles technologies.

Abstract

Many robots have been developed and used for the purpose of automating the construction site. This paper reports on the construction robots developed by Shimizu Construction Co.-- the robot for fireproofing of structural steel frames (SSR-3), the robot for condominium outer balustrade wall finishing work (OSR-1), the robot for floor finishing work (MTV-1), and the manipulator for positioning steel beams (Mighty Jack).

Themes for the future development of construction robots, the development of automated construction systems, worker training and the development of related technology are also discussed.

1. INTRODUCTION

Until recently, labor-savings and productivity enhancement in the construction industry were primarily achieved by the development of new construction methods and equipment. However, almost all such equipment was manually operated. Furthermore, traditional construction methods are designed for use by that super robot known as a human being. Using this traditional technology, automation of construction work has been difficult. As a result, construction work has not been automated until now, in spite of its inherent danger and unhealthful working conditions[1].

Construction robots, on which we have focused our development efforts for more than ten years, may be one solution to the problem of automating the construction site. This paper reports the results of our development and application of construction robots at Shimizu Construction Co. and some themes for future development.

2. DEVELOPMENT OF CONSTRUCTION ROBOTS

The industrial robot, first developed in the U.S.A. in 1962, has proliferated in Japan during the 1980s, driven by the progress of new technology, su as microcomputers and servo motors. On the other hand, the construction indus try has not been able to benefit from this technological progress, despite problems of low labor productivity, repetitive accidents and poor working conditions.

A large amount of activity in Japanese industrial robot research and devel pment stimulated construction engineers to initiate development of robots for construction. Because specific construction tasks are fundamentally different from each other, it is difficult to design a universal type of robot[2]. Henc a construction robot designer should be throughly familiar with the task to b robotized. This situation makes it difficult for a manufacturer alone to develop a construction robot. As a result, the development of construction robots has primarily been accomplished by general contractors in Japan[3].

Construction robot research was begun at Shimizu Construction Co. in 1977, with the first building construction trial achieved in 1982. This first robot called SSR-1(Shimizu Site Robot 1), was used for fireproof covering work[4]. After this, other types of construction robots were developed. However, each these robots was developed to perform a single task. Robotization of the construction system or construction method has not yet been achieved[5].

3. APPLICATION OF CONSTRUCTION ROBOTS

The construction robots listed in this section were recently developed by Shimizu Construction Co.

3.1 The SSR-3

The SSR-3 robot is designed to spray fireproofing material onto structur steel frames. This is the third model in its series, preceded by the SSR-1 a SSR-2. The SSR-1 was the first robot to successfully demonstrate the feasibi ty of using robots on a construction site. The SSR-2 successfully demonstrat the use of a position sensor to detect the distance from the robot arm to th steel beam during fireproof spraying. Although both of these robots were suc ssful prototypes, a number of problems remained from the standpoint of pract

., including:

1)The robots were too large to be transported by a lift, and had to be disassembled.
2)The operator had to be thoroughly trained to instruct the robot, as direct CP instruction cannot correct previous mistakes.
3)The cost of the robots was rather high.

The SSR-3 was developed to overcome these liabilities. A system diagram of the SSR-3 is shown in Figure 1.

The SSR-2 was driven by hydraulic servo, but the SSR-3 is driven by DC servo. Consequently, the hydraulic unit became unnecessary, further reducing the cost of the robot. In addition, controllers which were separated in the case of the SSR-2, are loaded on the SSR-3. As a result, control cables are eliminated and only the power cable is necessary.

The height and size of the steel beams to be sprayed are different from building to building. The SSR-3 can adjust the height of the manipulator arm manually using the screw jack. Height can be reduced within two meters using this jack when transported.

The SSR-3 is a numerical control robot which can be operated remotely. However, the spray nozzle attached to the manipulator is positioned away from the beam, making it difficult to instruct.

In response to this problem, a robot programming system called the "Off-site Teaching System" was developed, consisting of a personal computer and digital cassette recorder. The action of the SSR-3 is simulated on the screen of the personal computer, from which a program of instruction is created. As the SSR-3 utilizes a digital cassette recorder for its memory, program data can be easily transferred to another cassette recorder. Utilizing this system, errors in the program can easily be corrected without changing the entire program.

The SSR-3 was manufactured in cooperation with Kobe Steel, Ltd.

3.2 The OSR-1

The ORS-1 (Ohi Saikaihatsu Robot) was designed for condominium outer balustrade wall finishing work. It moves through the condominium's corridor or balcony with its arm positioned outside the balustrade. The spray gun is attached to the arm for automatic spraying.

In conventional construction, finishing work is generally carried out by skilled workers operating from scaffolding. The introduction of this robot makes scaffolding unnecessary and decreases the exposure of workers to dangerous conditions.

The system diagram of the OSR-1 is depicted in Figure 4. The robot consists of a travelling device, control device, horizontal arm, vertical arm and guiding device. The robot is used with a material plant.

The spray gun can move up and down along the vertical arm. The spray work is carried out by this vertical action with interval travelling of the travelling device. The travelling path is controlled by the guiding device, which uses a handrail as a guide. Thus, the robot can move parallel to the balustrade. At an uneven part, the robot rotates the horizontal arm automatically according to the program.

The OSR-1 was applied to work at a condominium at Ohi in Tokyo. At this site, the process of finishing work consisted of three parts, including under coat, spray tile and top coat.

The work efficiency of this robot is $80m^2$/day by three workers. That of the conventional manual method is $80m^2$/day by four workers.

Thus, labor savings, improvement of safety and elimination of scaffolding are the advantages of this robot.

3.3 The MTV-1

The MTV-1 (Multi-purpose Travelling Vehicle-1) can execute finishing work, such as grinding and cleaning on a concrete surface automatically, addressing the need to automate not only dangerous work, but monotonous work as well.

As shown in Figure 5, the MTV-1 consists of vehicle and work module. The vehicle consists of power steering mechanisms, a control computer, sensors and batteries. The cleaning module consists of a rotating brush, filters, a dust container and the brush motor. The grinding module consists of whetstones, a gear box and driving motor. The bumper unit is designed for use in common with each work module.

There are two main characteristics of the MTV-1. One is that the work module and the vehicle are separated,so that modules for particular tasks are interchangeable. The other is that the MTV-1 can travel and avoid obstacles such as columns and walls automatically, without the use of cables.

Robot movement is controlled by data from the sensors. Travelling distance is measured by the rotary encoder connected to the measuring wheel. Direction of the robot is measured by the gyro-sensor. Ultrasonic sensors are mounted around the robot to avoid collisions.

The travelling algorithm is accomplished as the robot travels around the room to study the shape of the area. The robot then repeats its circuit as shown in Figure 7.

The MTV-1 was applied to several construction sites. The work efficiency of cleaning is about $8m^2$/min, and that of grinding is about $2m^2$/min.

New work modules are being prepared to increase the number of tasks to which the robot can be applied.

3.4 The Mighty Jack

Steel beam erection work is one of the most dangerous tasks on the construction site to be robotized. The Mighty Jack manipulator lifts two or three steel beams and sets them in the correct position by teleoperation. While setting beams, the manipulator grasps the top of the columns and doesn't need to be lifted by a tower crane. This means that the tower crane can be used for other jobs while the manipulator is working.

Although the Mighty Jack might not be called a robot, this kind of manual manipulator is also useful to advance site automation.

The Mighty Jack is comprised of two grippers to grasp columns, a lifting device and a hydraulic power unit. The positioning and assembly work of the beam is carried out by the manipulator as follows:

1)Set grippers at the suitable position
2)Put cables on steel beams
3)Position the manipulator with beams using a tower crane
4)Place the manipulator on the top of 2 columns
5)Release tower crane cables from the manipulator(manual)
6)Adjust the distance between the 2 columns
7)Set beams in the correct position one by one

8)Connect beams to columns(manual)
9)Lift the manipulator to perform the next cycle.

The Mighty Jack was applied to several construction sites. It took about 25 minutes to assemble 6 beams for this manipulator. It took about 40 minutes for the same work using the traditional method. Furthermore, assembly work can be accomplished much more safely and efficiently using the Mighty Jack.

Redesign of structural steel for automatic assembly and improving the systems versatility are the future research themes for the Mighty Jack.

4. FUTURE THEMES FOR CONSTRUCTION ROBOT RESEARCH

Future research themes for construction robot and site automation are as follows:

1) Development of robotized construction systems
Almost all construction robots are the stand-alone type designed to replace workers. Therefore, there are many restrictions against the introduction of construction robots. This is the reason why robotization could not be effectively introduced in the past.
For example, if temporary work is planned without robots in mind, the robot's working area would be constrained by scaffolding, or the robot would have to be disassembled for transfer because of the small size of the lift. To get fruitful results, a total robotized construction system, including the design and construction method, should be developed.

2)Training of workers
Unfortunately, the education level of construction workers is not so high in Japan. In order to introduce robots for common use on a construction site, it would be necessary to train operators and maintenance workers for robot operation.
The operation of construction robots should basically be easy.
However, it will be different from that of conventional construction equipment, such as a bulldozer or a crane. There will be special technology for robot maintenance. Consequently, training will be necessary. Furthermore, the training of workers should be discussed.

3)Development of new technology
There are many obstacles to the development of construction robots. It is necessary to develop new technology to overcome these difficulties.
For example, mobility is important for construction robots. Precise positioning technology, mobility technology for irregular roads and mobility technology for vertical or inclined walls, needs to be developed.
Vision systems are also an important theme for construction robots. Development of fast processing technology for pattern recognition and image processing, or the development of various sensors, should be pursued.
In addition, each of these technologies should be economical and reliable.

5. CONCLUSION

The period in which construction robots are adopted as a curiosity is almost over in Japan. Most construction robots in the early days were trial manufacture, so it is hard to say that they produced effective results.

The need for effective construction robots has now been demonstrated. The first step is to introduce stand-alone types of construction robots on a trial basis. The next step is to develop a robotized construction system using the know-how gained from the trial. It will take a long time to complete the system, because the development of a robotized construction system includes modifications of structural design, development of new construction methods, materials and so on.

Construction sites will be changed dramatically when robotized construction systems are introduced.

6. ACKNOWLEDGEMENT

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REFERENCES

1)Y.HASEGAWA :"Robotization of Reinforced Concrete Building Construction", Proceedings of 11th ISIR, Tokyo, 1981.

2)A.WARSZAWSKI :"Economic Implications of Robotics in Building", Building and Environment, Vol.20, No.2, pp.73-81, 1985.

3)S.SUZUKI, T.YOSHIDA, T.UENO :"Construction Robotics in Japan", Proceedings of Second Century of the Skyscraper, Chicago, IL, 1986.

4)T.YOSHIDA, T.UENO, M.NONAKA and S.YAMAZAKI :"Development of sprayrobot for fireproof cover work", Proceedings of Workshop Conference on Robotics in Construction, Carnegie-Mellon University, Pittsburgh, PA, 1984.

5)K.KOBAYASHI :"Development of advanced system for construction technorogies with proper use of electronics", Proceedings of 15th ISIR, Tokyo, 1985.

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ROBOT DE CONSTRUCTION POUR L'AUTOMATION DES SITE

CONSTRUCTION ROBOTS FOR SITE AUTOMATION

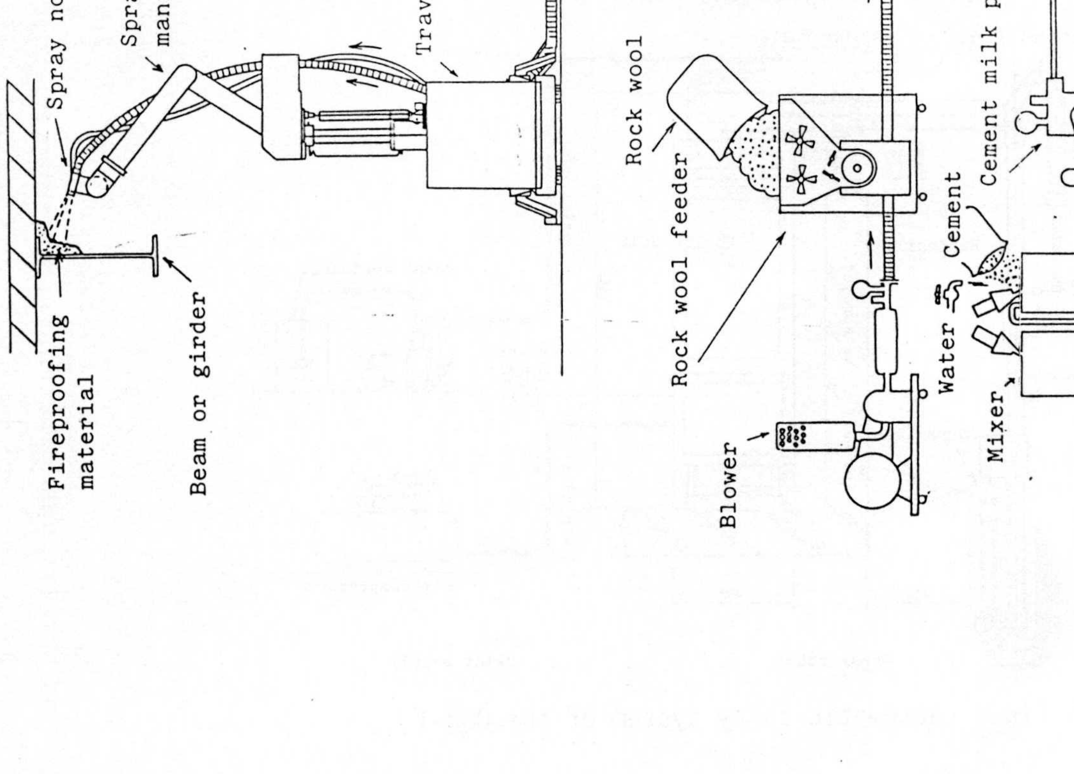


Fig.1 Rock wool spray system of the SSR-3

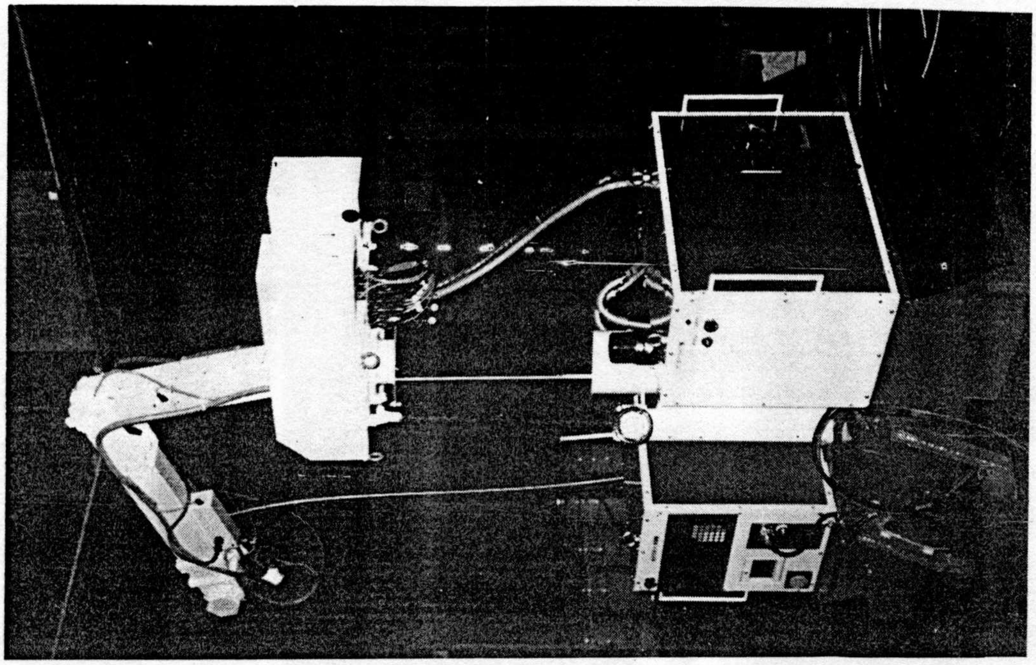


Fig.2 The SSR-3

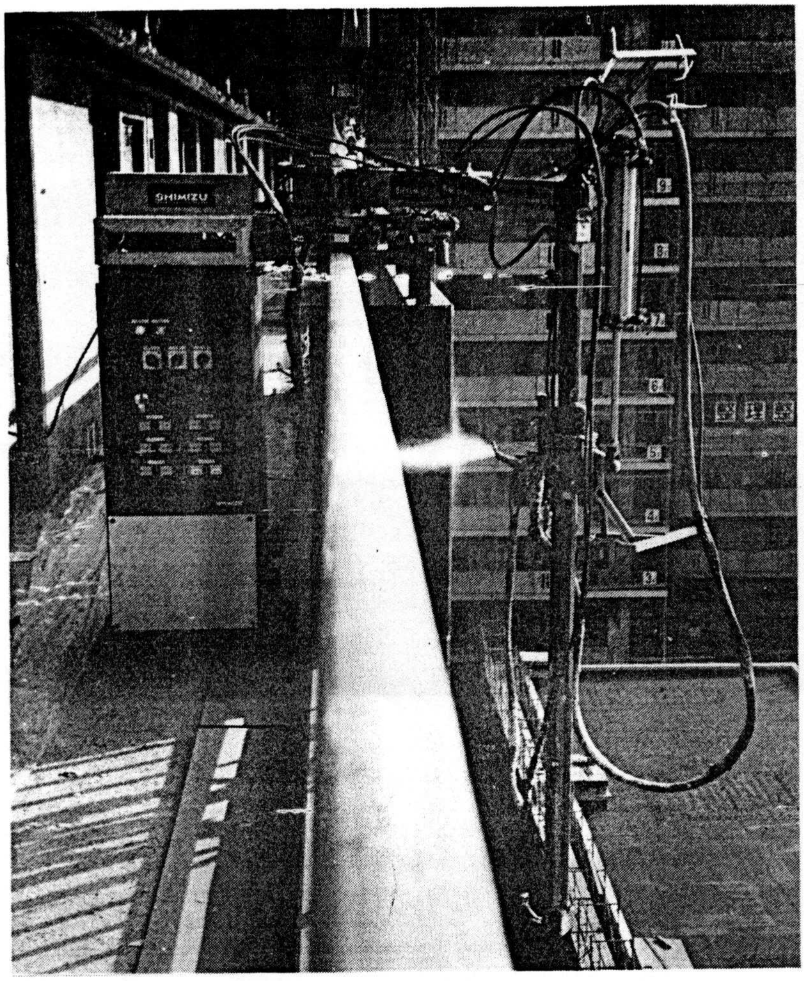


Fig.3 The OSR-1

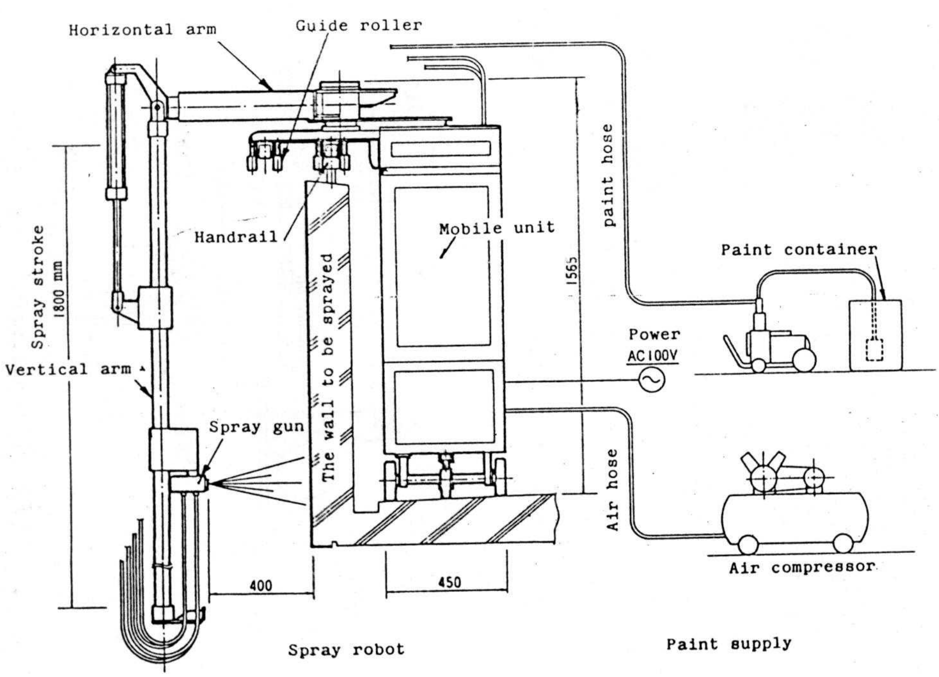
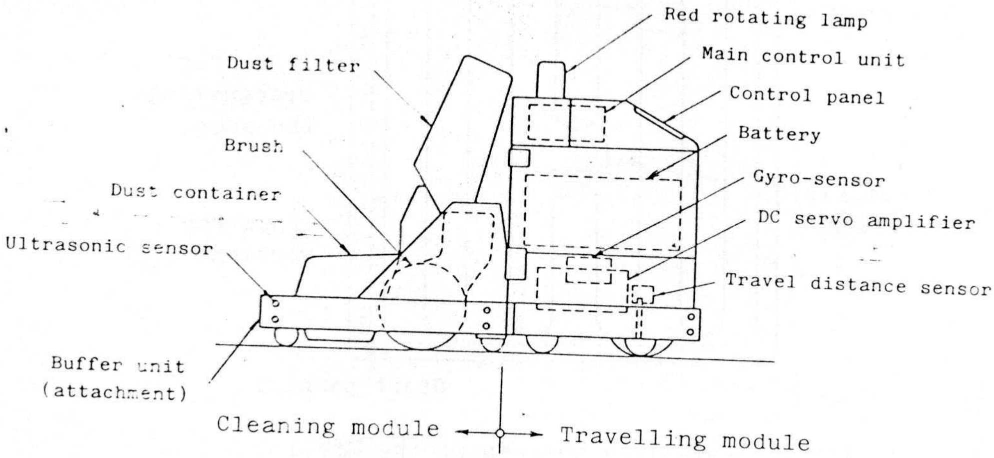


FIg.4 Automatic spray system of the OSR-1

Cleaning work



Grinding work

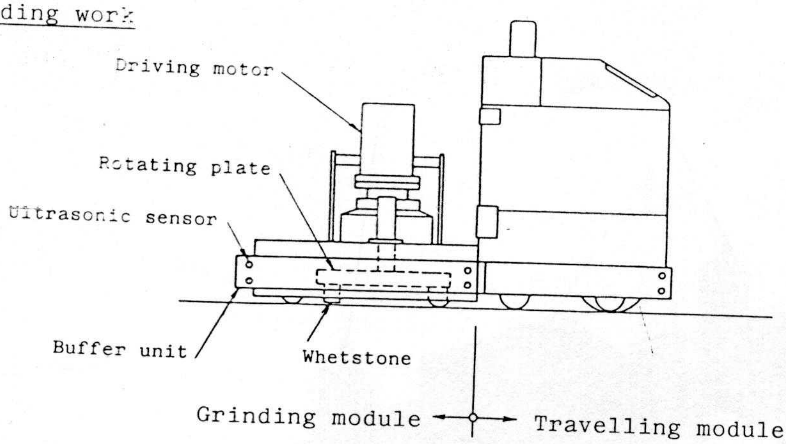


Fig.5 Components of the MTV-1

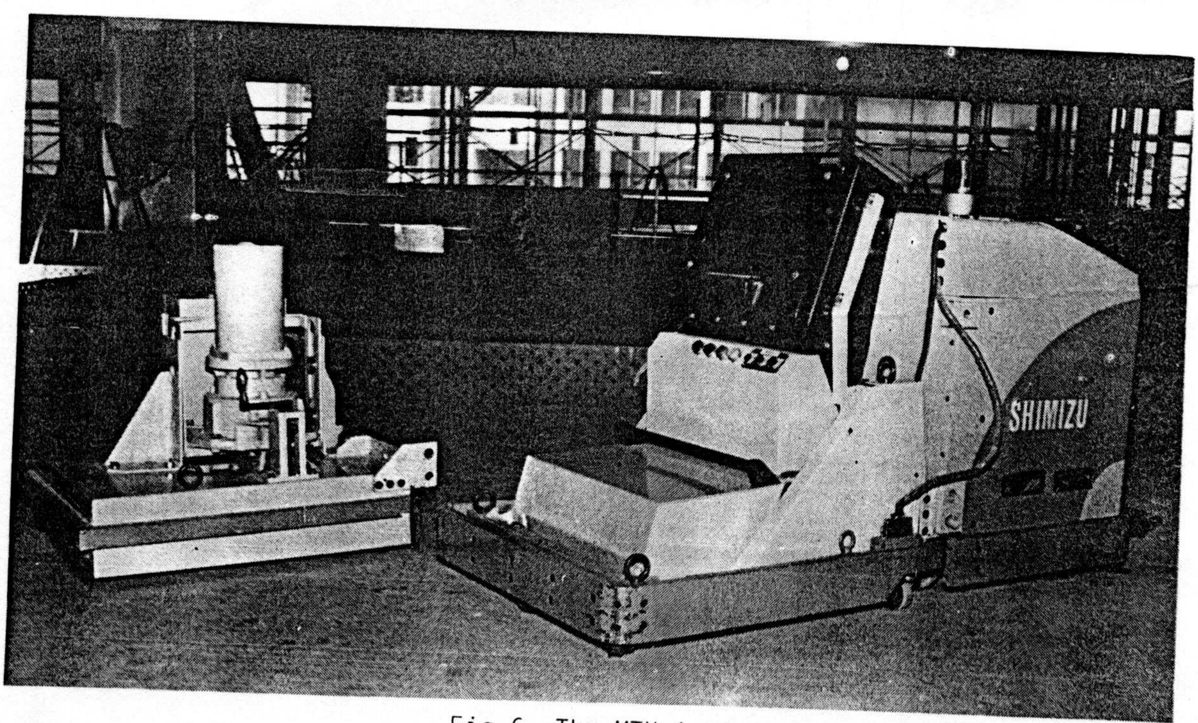


Fig.6 The MTV-1

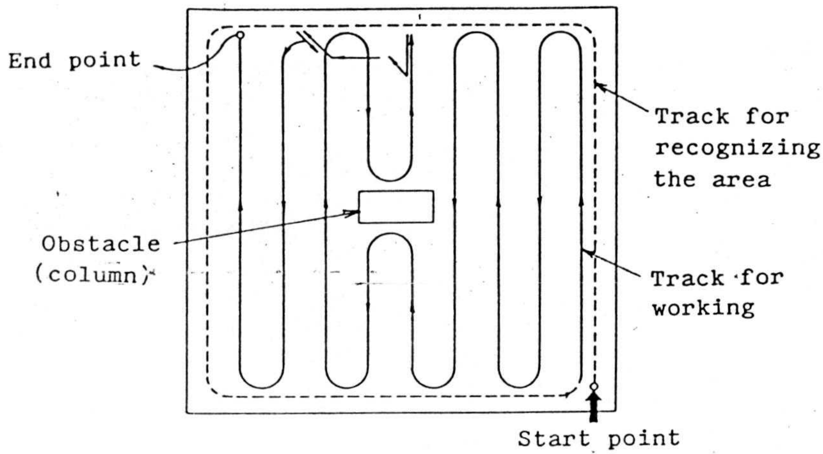


Fig.7 Travelling pattern of the MTV-1

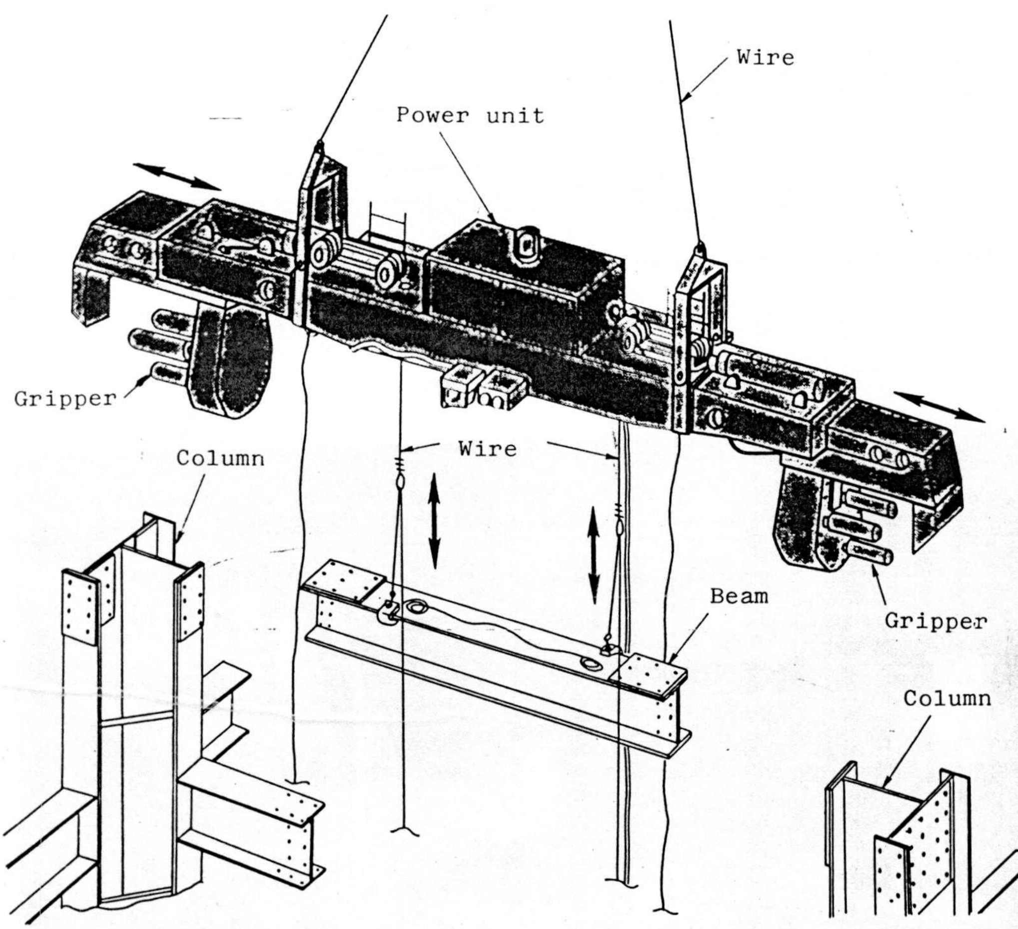


Fig.8 Components of the Mighty Jack

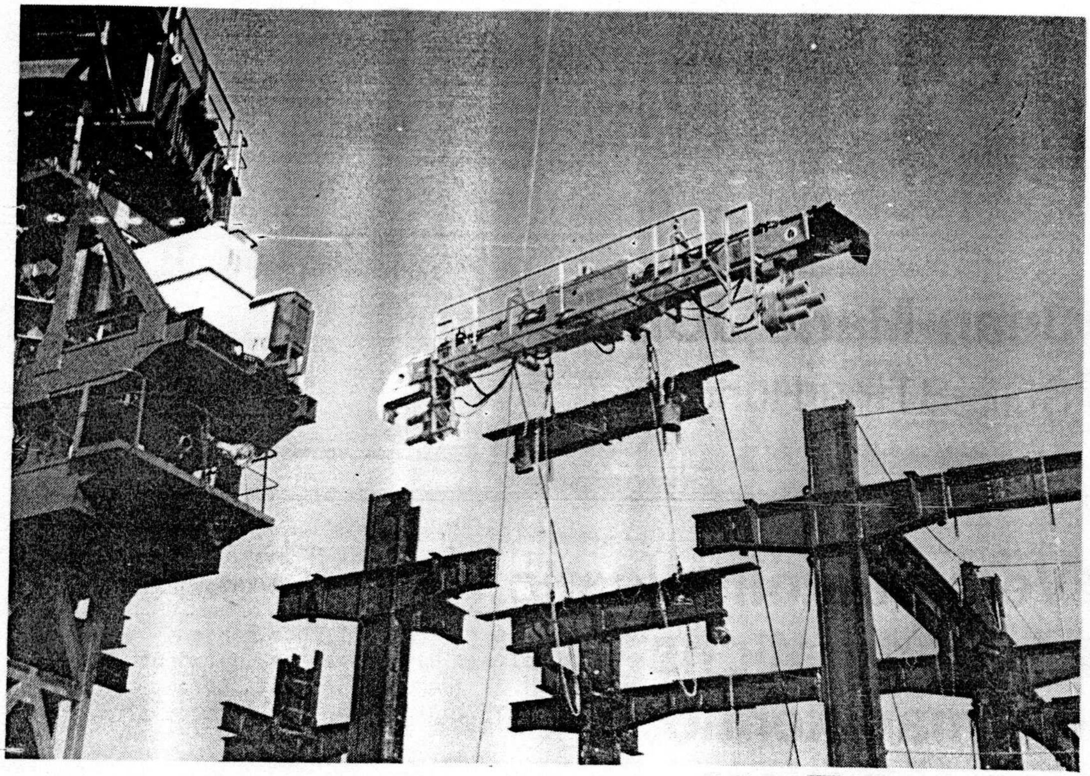


Fig.9 The Mighty Jack

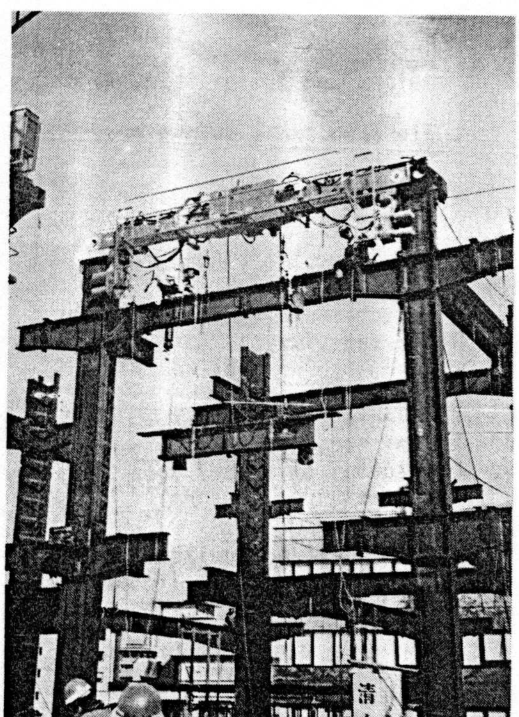


Fig.10 Fixing upper beam

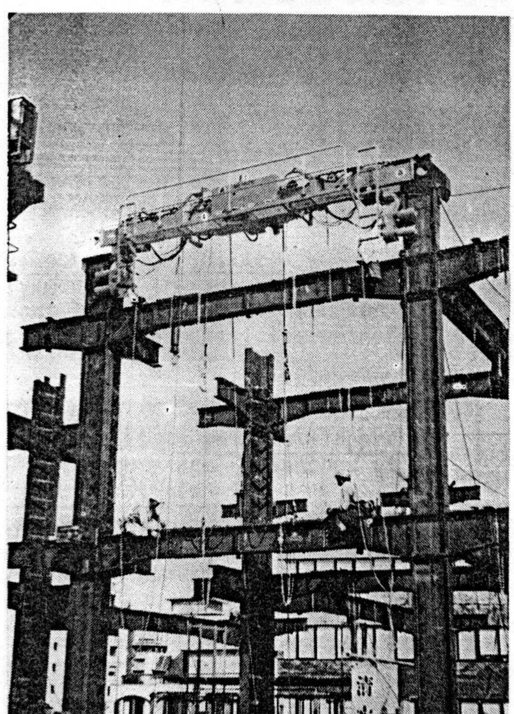


Fig.11 Fixing lower beam