The 5th International Symposium on Robotics in Construction June 6-8, 1988 Tokyo, Japan

WORK STUDY FOR ROBOTIZATION OF CONSTRUCTION PROCESS

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ABSTRACT

In the development of construction robots and the designing of their operational systems, to accurately grasp the real state of the construction process and to collect extensive data as well as to be well prepared for various conditions is indispensable. This study, on work study for robotization of construction process examines its fundamental concept, role, and the various points at issue concerning site survey. According to surveys conducted on the burden on the laborers, the course of the member's movement and speed, work particulars as well as input and output information, the technique's effectiveness in experimental application to steel frame erection has been confirmed. In addition, the study has clearly defined the problems arising from surveying technique and utilization of survey data.

1. Introduction

The success of the introduction of robots into general manufacturing springs from the fact such conditions as (1) the particulars of on-site work constantly grasped and (2) standardization of work conditions introducing for robots were already present at the start of mechanization and automation. However, there has always been a tendency in the construction industry to leave the actual work up to the laborer; this results in the understanding of actual work conditions being neglected.

In the past, F. B. Gilbreth, analyzing the motions of bricklaying, defined the "therblig". The technique he applied was one which improved the motions of hand process. But, when constructing a work system for a robot the number and variety of data to be collected are many, and the consequential accuracy is also high.[1] At a time when we are entering the age of robots, the necessity to develop corresponding new techniques is immense.

2. Work Study for Robotization

2.1 Understanding the Actual Work Conditions

In understanding actual work conditions, the gathering of basic data in each step of the construction process is required. This collection has two basic goals:

(1) To improve the work for adapting it for a robot to do, extensively studying the present work situation and points at issue.

(2) To clarify practical work requirements for robot design minutely pursue work details.

There is a great difference between (1) and (2) above as regards topics for research, methodology, and data processing. Especially when doing research from the design viewpoint ((2) above), a conversion from the ill structured to the well structured is necessary. Developing a survey technique that will allow conditions for work systems and robot design to be derived quantitatively is indispensable. In such a case, more precise measurements (e.g., that for work that does not change whether done by man or robot) and items not considered important for case (1) above are an important factor.

2.2 Objective of Work Study

2.2.1 Selection of Work Objects

A selection is made of the work to which robots are to be applied, investigating the requirements of robotization according to an analysis of the physical and psychological burden on the laborer and attitude to manual labor. It is necessary to simultaneously understand the real state of affairs of the work in question so a target can be fixed and assessment criteria for the work system can be defined. In selecting suitable work for robotization, but avoiding partial optimization, (1) critical work, (2) work that entails relatively long hours, and (3) work that is technically simple to robotize, are to be abstracted.

2.2.2 Designing a Robotized Operation System

A. Investigating the Adaptability of Robotization

To clarify items to be investigated about presently available materials, construction methods, building structure, etc. when judging the adaptability of robotization.

B. Clarification of Limits

To identify the limits of work space, the work environment must be evaluated in terms of its effect on the robot's size as well as on the selection of list/arm module.

C. Collection of Basic Data for the Allocation of Function Between Man and the Robot

It is difficult to conceive that construction work will be totally automated in the foreseeable future. To collect data for the purpose of allocating functions between man and the robot taking into consideration their respective characteristics.

D. Collection of Basic Data for Designing Robots

To clarify, quantitatively, the various conditions that will affect the work that the robot will perform, much data are required for the design of the robot's moving and holding functions, locomotive functions, measuring and recognizing abilities, and control functions.

2.2.3 Evaluation of Robotized Work Systems

Through analysis of facts such as percent of robot utilization and the required man-hour, to evaluate the system's efficiency and detect points which can be improved in robot hardware by precisely measuring robot motions.

2.3 Problems Encountered in Work Study

2.3.1 Characteristics of Construction Work

Construction work is varied in many ways, and it is this factor that obstructs robotization in this field. The main items are as follows:

(1) Work conditions are not always the same, and it is necessary for laborer to exercise one's skill accordingly.

(2) There is little work done at any fixed location, so considerable locomotion is often required.

(3) Because construction is usually outdoors, it is greatly affected by the weather and frequently affected by circumstances beyond anyone's control.

(4) Repetitions standard work is scarce; work is often done by a small number of grouped laborers.

(5) Because of the uniqueness of many materials involved and their processing, more restrictions apply to working time and the work's quality.

2.3.2 Difficulties of On-Site Surveys

The working environment at a construction site is invariably special (very high, underground, under water, etc.). The drafting of a thorough plan for the study (schedule, preparation of measuring instruments, role assignment of participants, etc.) is vital. Concerning difficulties for surveying the site, the following data can be quoted:

(1) For large-scale research, 7 to 10 surveyors would be required, the presence of whom in a limited space could interfere with the laborers.

(2) Work at a construction site does not always go according to schedule and it is difficult to confirm the execution date of some work that is the object of a survey in advance.

(3) Various materials are scattered on the floor, resulting in uneven footing. Hazards are everywhere, space is limited for the surveyors, and it is doubtful whether there is an ideal spot for taking photos.

(4) Measuring instruments are affected by rain, wind, dust, and noise so the instruments would have to come with a protective devices, be durable, and have anti-shock features.

(5) Instruments to measure characteristics of a living body (such as electrocardiogram, electromyogram) are designed for use in a hospital or at least indoors, so many of them require special measures or certain improvements.

3. Application of Work Study to Steel-Frame Erection

3.1 Object of Survey

For column and girder erection work, a survey was conducted at a steel-frame reinforced-concrete construction site.

3.2 Items and Method of Survey

A. Heart Rate and Work Posture

Using telemetry, heart rate of erecter (skilled laborer who is engaged in steel-frame erection) was taken before and during work. His postures had been previously categorized, and by visual observation, the types and the time factors were recorded.

B. Movement, Course, and Speed of Steel Members

The movement of girder raised by cranes were recorded by two VTR cameras and, using a video position analyzer, three-dimensional coordinates of the girder were sought. The rotation of the crane's cable drum was also recorded, and its rate of rotation sought.

C. Substance of Erecter's Work

The work of a erecter installing a girder was observed in its entirety and recorded.

D. Input/Output Information on Laborers

While recording the work situation of the erecters and crane operator, their expressions, motions, the focus of their eyes, etc. were observed and the results recorded. Again, conversations between the laborers were recorded on tape. Furthermore, the laborers whose work was recorded were interviewed at a later date, when they were shown the recordings of their work.

3.3 Use of Survey Results

A. Burden on Laborers

Figure 1 shows the transition (timewise) of the change in heart rate of the erecter installing a girder. The average count is 101.7 beats per minute, an increase of 33.8% over his resting heart rate. A periodic fluctuation can be observed in the heart rate and, when the erecter is hammering in the drift pin, it exceeds 130/min., a very high figure indeed.

Figure 2 shows the types of postures and their respective proportional times, according to action. Various postures are required for work on the girders and, particularly when engaged in web work, an extremely exhausting forward-bent posture is required.[2]

In consequence, work that is physically difficult can be abstracted and it is possible that such work will be robotized eventually.

B. Course of Movement and Speed of Steel Members

The three-dimensional coordinates of moving a girder at 10-second intervals are given on Table 1. Figure 3 is the result of plotting the course of movement based on the Table 1 data.[3] Figure 4 shows the speed of the crane's rotating drum when adjusting position of girders. Converted to lowering speed of girders, it comes to 7.3 cm/sec. for the larger girders and 13.4 cm/sec. for the smaller ones. Note that the weight of the girder affects the operation of the crane.[4] This results make it possible to obtain basic data for the study of arm/list structure of the robot and control of its movement.

C. Erecter's Work Contents

The actual work sequence as confirmed by visual observation is plotted in Figure 5.[5] From the top, a erecter's work are listed in the order which they occur whereby a girder is installed without a hitch. Work steps as they occur and their sequence change due to (1) the direction of the girder at time of work relative to guiding it, (2) the plumb of the column already constructed, and (3) the shape of the part of the column and the girder that is to be connected. From such results, it is possible to extract work conditions that require preparation and study at time of robotization.

D. Laborers' Input and Output Information

The pattern in information conveyance between the crane operator and the erecter is shown in Figure 6.[6] As for output information, instructions to the crane operator and relevant requests, and reports of location, direction, and plumb are most common, but a different pattern is observed for different work. Figure 7 shows the erecter's input information, items of recognition and judgment, motion and output information when installing a girder. There are also many input information on the girder's location/direction and the relative location of the girder and bracket.

From data made available in respect of information processing by the laborer at time of work, it is possible to come up with basic data for designing the measuring and recognizing ability and control function for robotized work systems.

4. Conclusion

This report has summarized work study for robotization of construction work. The reasons why the technique introduced herein has not been effectively adopted into the development of construction robots is that previously outlined characteristics of construction work has made it difficult to do on-site surveys and that applicable concrete methods are still to be established to the point of ensuring reliable results. These studies on robotization have just begun, and there are still a number of problems to overcome. The main problems are as follows:

(1) To miniaturize and reduce the weight of measuring equipment and to simplify and standardize survey methods.

(2) To automate and speed up data processing and analysis.

(3) To quantify survey data and improve its reliability, which would lead to work systems and the laying down of specifications for robots.

(4) To clarify and utilize a laborer's skill.

(5) To introduce a knowledge-engineering approach to the recognition, classification, etc. of work conditions.

(6) To collect input data for computer simulation, required for designing work systems and assessments, and for developing a data base.

To plan the establishment of the technique in question, further research must be done hand-in-hand with the development and manufacture of an actual working robot.

(Acknowledgements)

This research is being conducted as a link in the WASCOR Project. We wish to express our profound appreciation to the companies and individuals participating in this project who have helped us every possible assistance and cooperation.

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5) ibidem 4)

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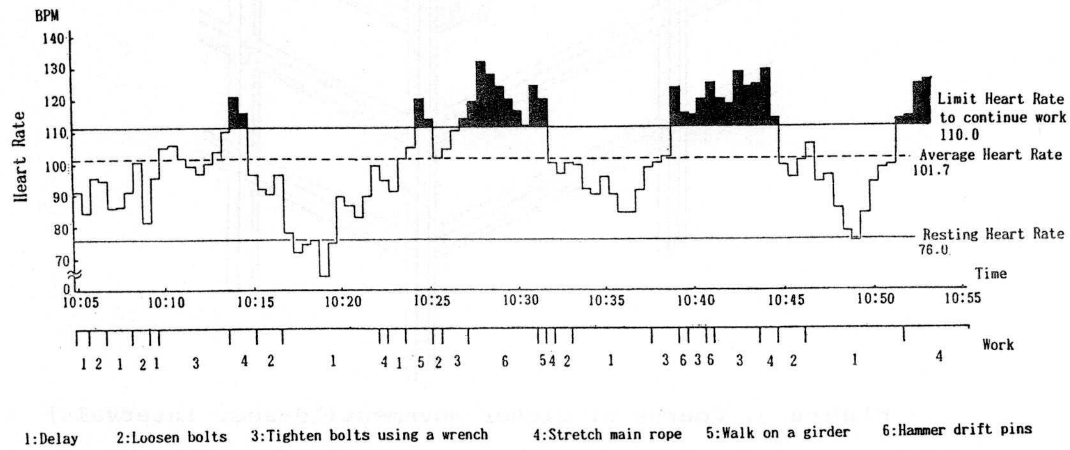


Figure 1. Time-wise transition of erecter´s heart rate while engaged in girder installation

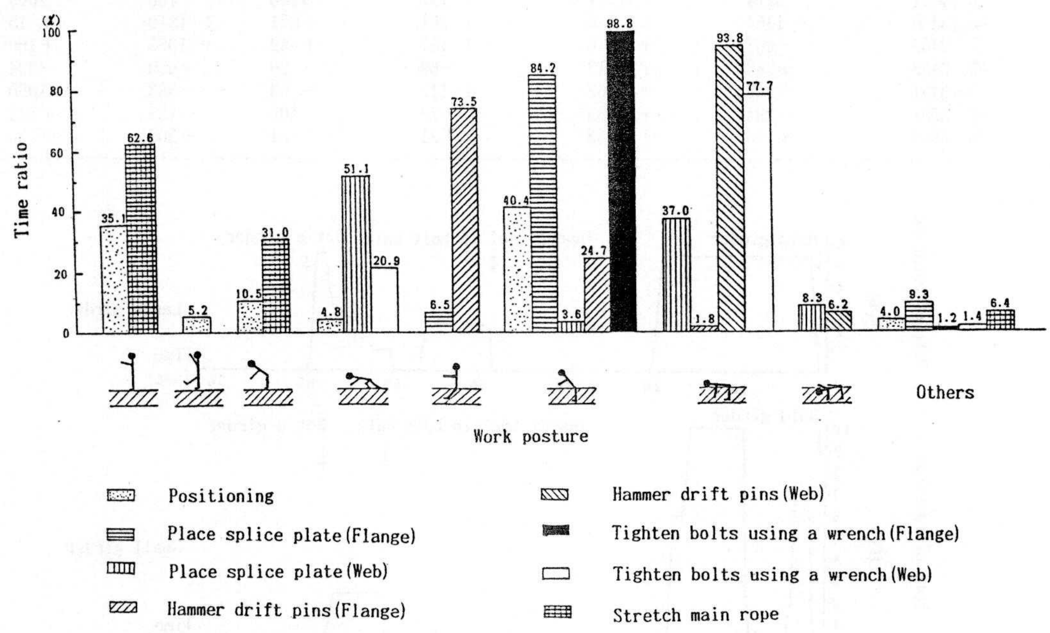


Figure 2. Work postures and proportional times for each action in girder instllation

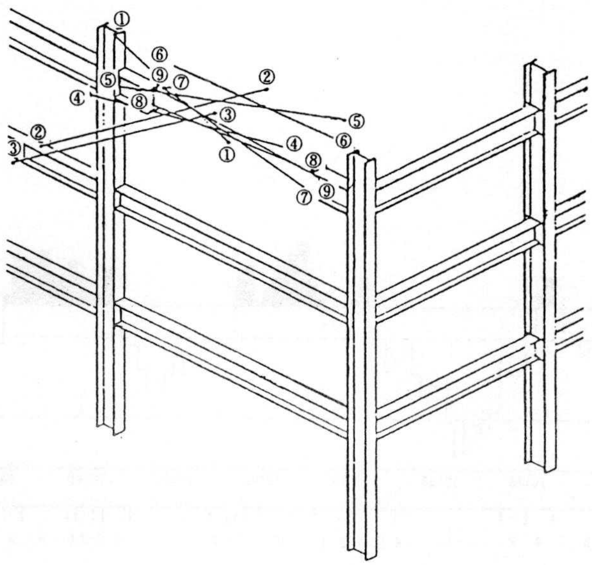


Figure 3. Course of girder movement(10-sec. intervals)

Table 1. Three dimensional coordinates of girder

Pos.X	Pos.Y	Pos.Z	Speed	dX	dY	dZ
①−2632	− 3061	+13422				
②−3176	− 3107	+12434	+ 113	−543	− 47	−989
③−4321	− 3274	+11371	+ 157	− 1146	−166	− 1063
④−3450	− 1464	+11386	+ 201	+871	+ 1810	+ 15
⑤−3408	−407	+11546	+ 107	+ 42	+ 1056	+160
⑥−3438	+243	+11312	+69	− 29	+650	−234
⑦−3491	−140	+10262	+ 112	− 53	−383	− 1050
⑧−3597	−294	+10383	+22	−106	−153	+121
⑨−3648	+ 16	+10363	+31	− 51	+309	− 20

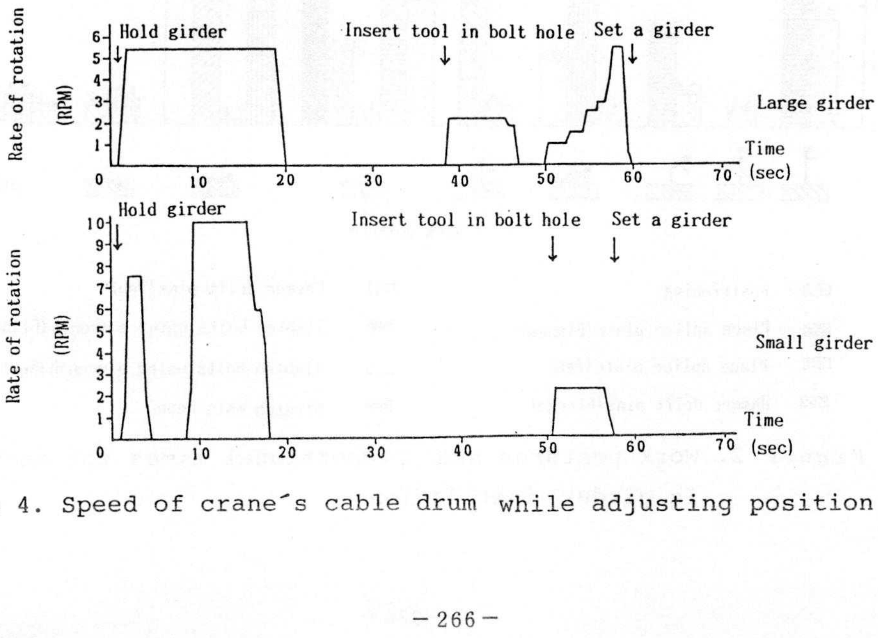
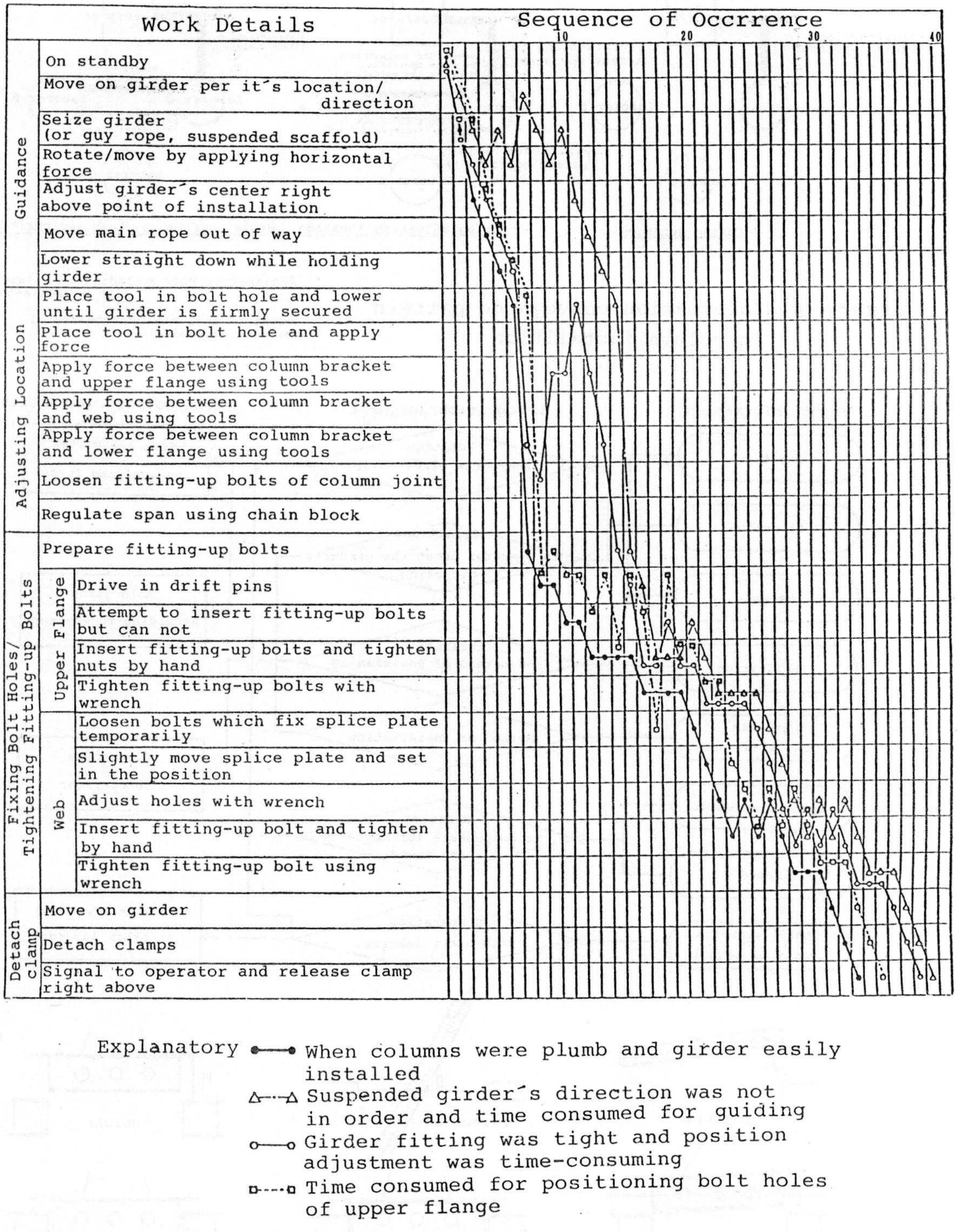


Figure 4. Speed of crane's cable drum while adjusting position of girder



Explanatory ●—● When columns were plumb and girder easily installed
△-·-△ Suspended girder´s direction was not in order and time consumed for guiding
○—○ Girder fitting was tight and position adjustment was time-consuming
□----□ Time consumed for positioning bolt holes of upper flange

Figure 5.Seqence of work in girder installation

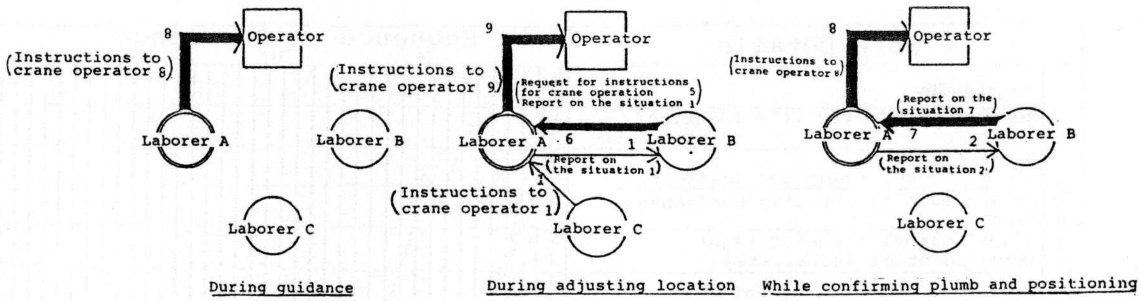


Figure 6. Information conveyance pattern in column installtion

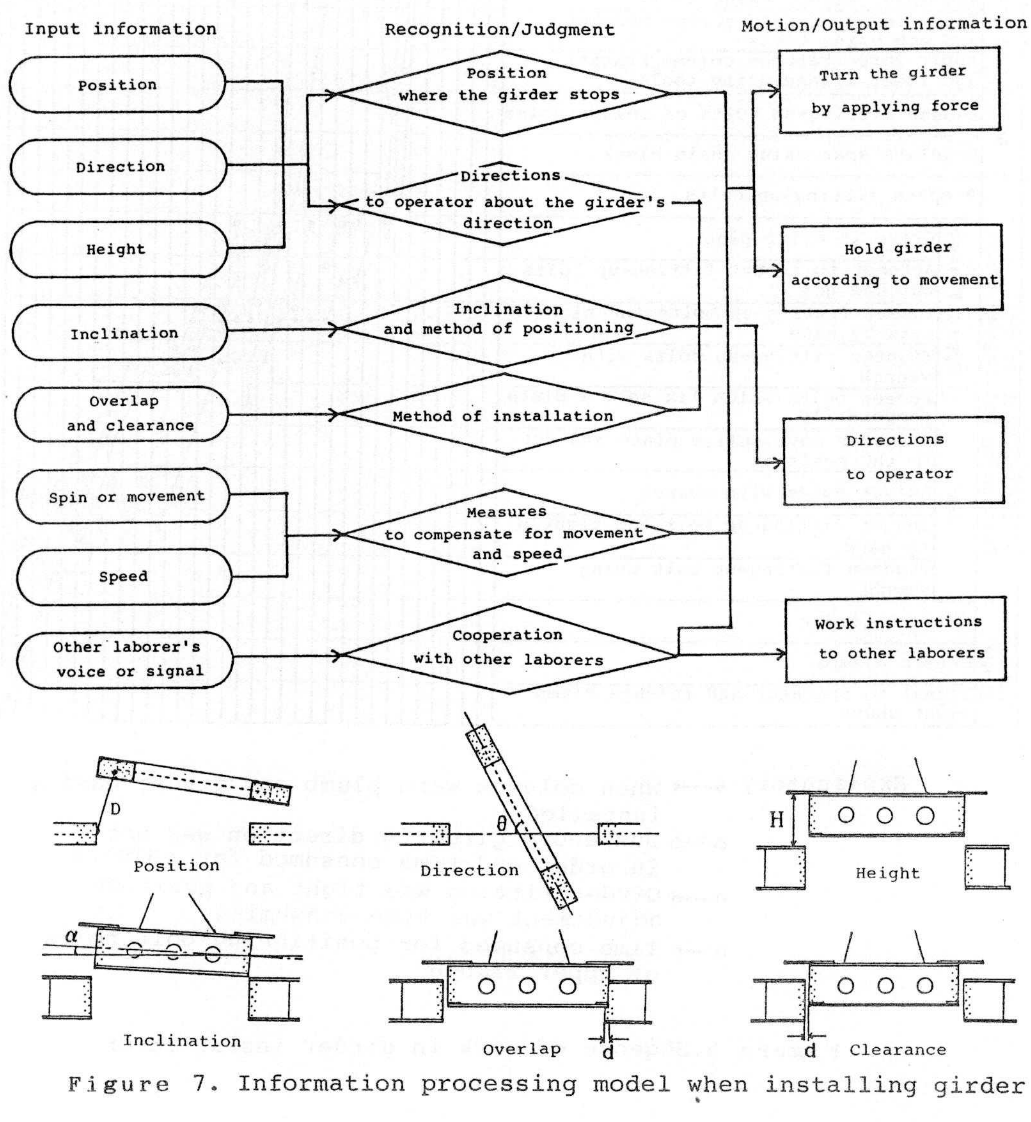


Figure 7. Information processing model when installing girder