AUTOMATISATION OF REINFORCEMENT WORK IN HIGH-RISE REINFORCED CONCRETE BUILDINGS

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SUMARRY

Ohbayashi Corporation has been engaged in the construction of a block of flats which, upon its completion, will be the tallest reinforced concrete building in Japan. A computerised comprehensive control system was developed for the reinforcement work for efficiency in the management work and, at the same time, mechanisation and automatisation of processing and assembly were promoted to ensure precision and reduction of labour. The level of automatisation has not been as high as it could have been, but the system has been functioning well as a total system aimed at CAD/CAM and has been of effect in raising the quality and reducing labour and term of works.

Keywords: CAD/CAM, data base, automatisation, reinforcement work

1. INTRODUCTION

The MKO Group (consisting up of Ohbayashi Corporation and two other companies) received the top prize in the design competition for urban housing estate projects held by Osaka City in 1986. The design was for a housing estate for 1,100 households accompanied by cultural, commercial and health facilities to be constructed on a 4.6 ha site. There will be eleven buildings in all, of which the tallest is the 41-storey block of flats. Ohbayashi Corporation is responsible for the execution design and construction of this building. (See Figure 1)

This was the first time a reinforced concrete building exceeding 40 storeys was to be built in Japan and there still remained a number of unsolved problems concerning its design and execution. These problems were finally solved and construction began in January 1989. The most difficult part of the work on this occasion was the reinforcement work, for which an automatic system aimed at CAD/CAM was developed in response to the strong demands for high quality and reduction of labour.

2. OUTLINE OF WORK

The building is a block of flats catering for 304 households, 41 storeys above ground with a single-storey basement and with an eaves height of 130 m. To allow for variation in layout of flats, a double-tube, pure-frame structure was used, removing all columns and beams protruding into the living spaces. (Figure 2)

The basic principles in construction have been the guarantee of high quality, reduction of labour and reduction of term of works. Frames

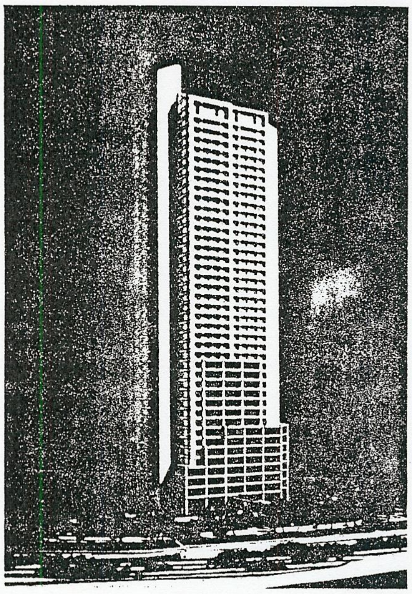


Figure 1:MKO Project

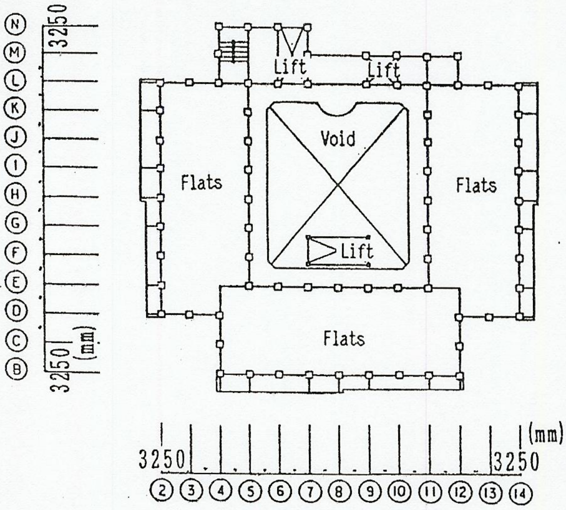


Figure 2:Plan of Standard Floor

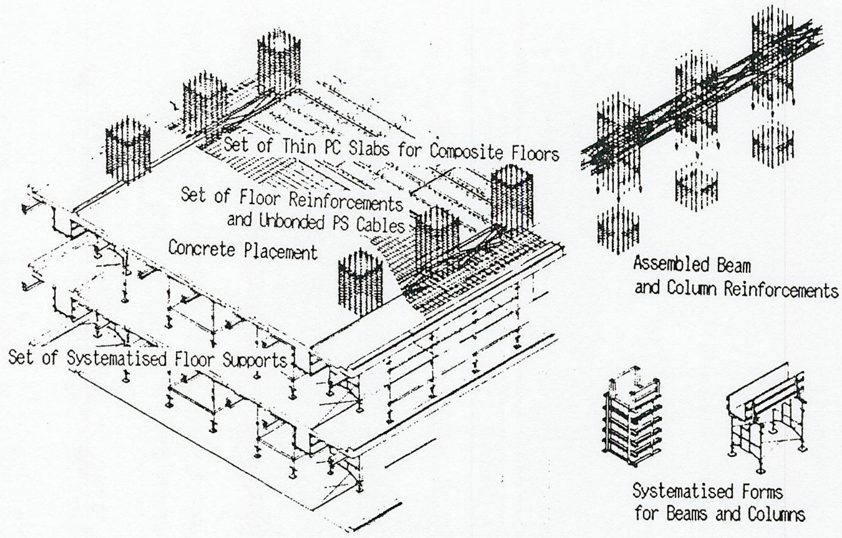


Figure 3:Concept of Construction Method

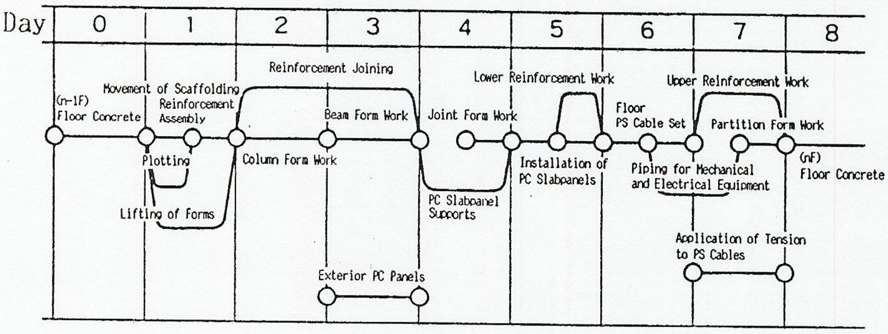


Figure 4:Work Schedule for Standard Floors

of high quality and precision are obtained through measures such as diagonal arrangement of some of main reinforcements to raise toughness of short beams, assembly of reinforcement bars for columns and beams into blocks on the ground, adoption of thin PC slabs for composite floors with voids and of systematised forms, placement of high-strength concrete, introduction of strict quality control.(Figure 3) Automatisation have been applied to such items of work as processing and assembly of reinforcement bars, installation of piles for slurry walls, placement of concrete, application of tension to PS cables, installation of outside PC panels and construction of inside wall boards, with the aim of reducing labour. The total term of works is 38 months and eight days are allotted to construction of each storey.(Figure 4)

3. AUTOMATISATION OF REINFORCEMENT WORK

3.1 Requirements in Development of Automatised System

Special features of the reinforcement work include use of reinforcement bars with large diameters (D29 to D41), processing of bars in small lots, processing of bars into complex shapes and high-density arrangement of bars.To fulfil the following conditions required for implementation of highly precision and highly efficient processing and construction of reinforcements, it was judged to be necessary to introduce the use of computers and automatised devices and to develop a management system for comprehensive control of the reinforcement work.(Figure 5)

- Preparation of accurate drawings for processing and assembly and reduction of labour in preparation of drawings
- Checking beforehand that reinforcement bars converging on joints between beams and columns do not interfere with each other
- Ordering and careful management of stock to avoid waste
- Delivery on time
- High level of precision in processing and construction and reduction of labour

3.2 Comprehensive Control System for Reinforcement Work

3.2.1 Composition of System

An integrated project data base for the reinforcement work was created and was used for a wide variety of purposes including CAD and CAM. The project data base was created by using existing systems for the earlier processes of structural design and estimation and reprocessing the data from these in the later processes. Besides the use of CAD in preparation of processing and assembly drawings for the reinforcement bars, computers were used throughout the process from ordering, storage, processing, assembly on ground and installation. The composition of the comprehensive control system is shown in Figure 6. Two small business computers were used to allow creation and updating of the data base and preparation of drawings to be carried out simultaneously and a plotter was introduced for CAD. One of the on-site supervisors has been made responsible for the operation of the system.

3.2.2 Reinforcement Arrangement Simulation

The positions of the main reinforcements in beams and columns were altered to avoid interference between the reinforcements. Optimum positions for the reinforcements were obtained ensuring there was no

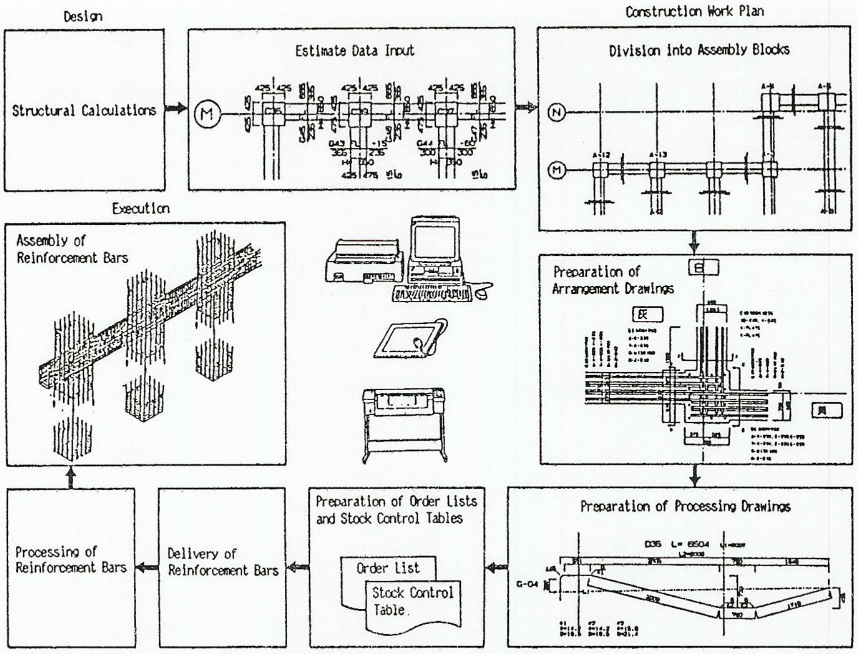


Figure 5:Concept of Processes in Comprehensive Control System for Reinforcement Work

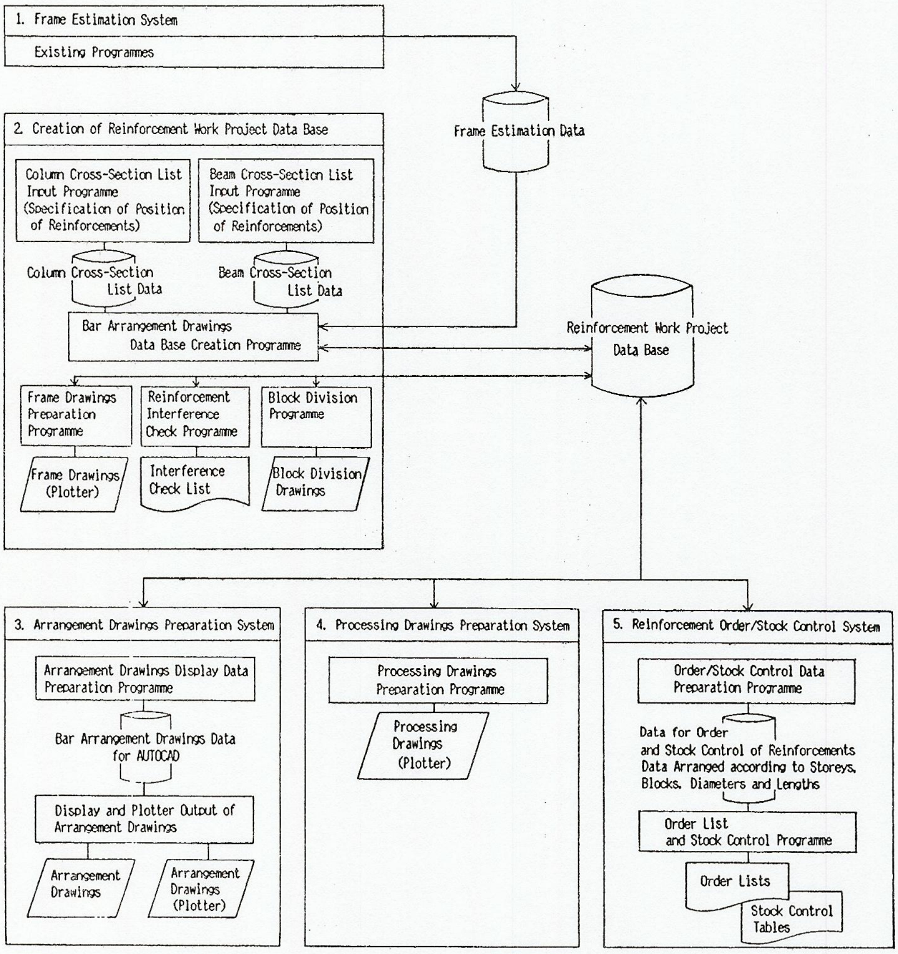


Figure 6:Composition of Comprehensive Control System for Reinforcement Work

interference throughout all the floors. The divisions between the blocks were made carefully to make the blocks as large as possible while minimising the variation in lengths of reinforcements.

3.2.3 Preparation of Reinforcement Arrangement Drawings

Drawings for the arrangement of the reinforcements were prepared automatically for each block of reinforcements from the data stored in the completed data base using a general-purpose personal computer CAD software. To raise the level of efficiency in processing and assembly of the reinforcements on the ground, different colours were automatically used for bars belonging to different beams and columns, making the divisions clear as shown in Figure 7.

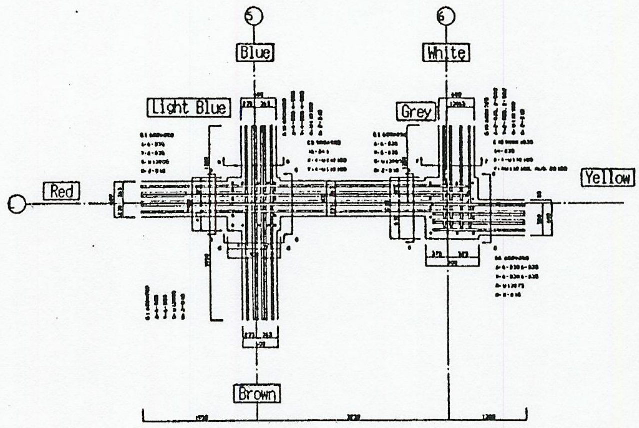


Figure 7:Reinforcement Arragement Drawing

3.2.4 Preparation of Reinforcement Processing Drawings

The drawings for processing of the reinforcement bars were prepared on the plotter, adding information for controls on the processing machines and check dimensions for after processing to the processing dimensions and angles for each of the main reinforcements comprising the blocks. Reinforcement processing lists were also outputted, dividing all the reinforcement bars into processed and straight bars and displaying the diameters and dimensions of each bar,as well as the coloring mentioned above. (Figure 8)

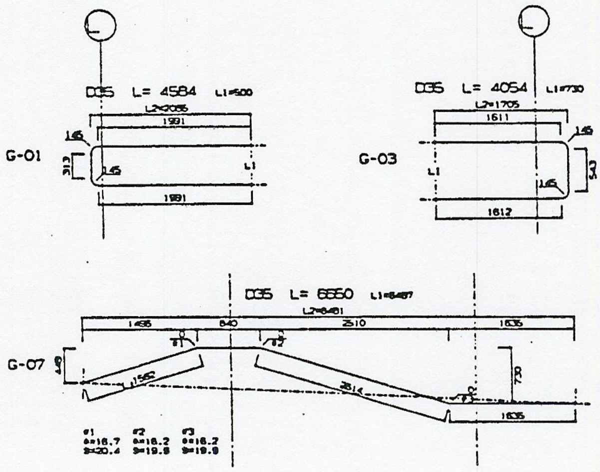


Figure 8:Reinforcement Processing Drawing

3.2.5 Ordering and Stock Control of Reinforcements

The order lists for reinforcements are prepared by putting together the member lists of reinforcements stored in the project data base. Numbers of reinforcements are given in the order lists according to storeys, members, diameters and dimensions (lengths in millimetres). Reinforcement bars are ordered in units of four storeys at a time using these lists. Approximately 300 different types of reinforcement bars are delivered at a time, bundled together according to members, daiameters and dimensions.

Stock control is implemented by comparing the order list data with the documents confirming the use of the reinforcements sent back to the construction site from the reinforcement processing yard.

3.2.6 Processing and Construction

As the reinforcement bars are processed at a yard 25 km away from the construction site, there is a need to ensure that the bars are delivered at the specified time and date to enable one to commence assembly of the blocks on the ground. Directions on reinforcements required for ground assembly in three days' time, including block arrangement drawings, processing drawings, processing lists, confirmation of use of reinforcements and directions on time and date of delivery, are sent every day from the construction site to the processing yard.

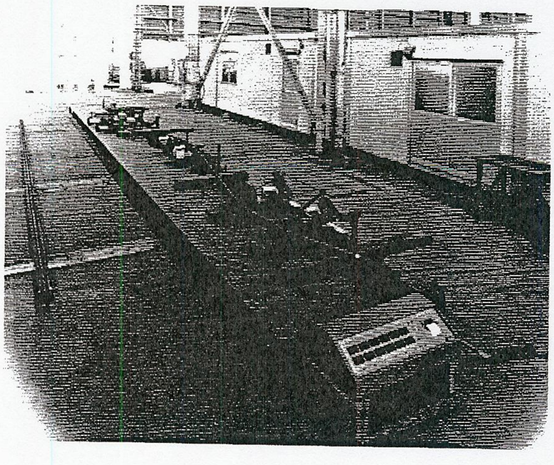
At the yard, the reinforcement bars required are taken out of the stock as stated in the reinforcement processing lists and bound with the vinyl tapes of the specified colours, on which are also marked the processing numbers. The reinforcement bars are then processed into the forms as given in the processing drawings using the automatic processing machine. After processing, the processed and unprocessed reinforcement bars are collected in pallets according to blocks and sent to the construction site together with the instructions.

The reinforcements delivered at the construction site in block units are assembled into blocks either for beams and columns alone or blocks combining beams and columns.

3.3 Processing and Assembly Devices

3.3.1 Automatic Processing Machine for W-Shaped Reinforcement Bars

The newly developed automatic processing machine for W-shaped reinforcement bars are capable of bending thick bars of D29 to D41 at a maximum of six points and consists of six electrohydraulic benders capable of independent movement on the base and a control device. (Figure 9) Following the reinforcement processing drawings, the benders are set in the initial positions and the stroke data are inputted for each bender. The machine is then switched on and a bar is bent



Dimensions	W=1,500mm ,L=12,500mm ,H=320mm
Benders	6 Portable Electrohydraulic Bender: 100V 15A Propulsion: 13tons Traction: 10tons With casters
Shifting Device	Screw-driven feed mechanism
Reinforcement Bars	D29 to D41
Bending Range	0 to 20°
Control Method	Variable sequence Stroke Control: Setting; 3 figures (XX.X) Accuracy; 0.5 mm
Operation Methods	Manual: control board attached to each machine Automatic: centralised operation (capable of bending at maximum of 6 points)

Figure 9:Automatic Processing Machine for W-Shaped Reinforcement Bars

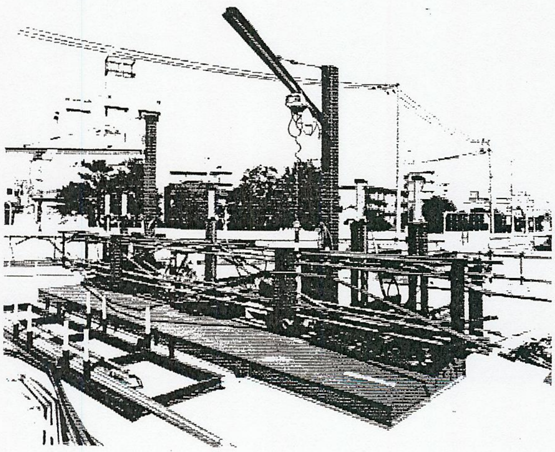
simultaneously at several points at the required angles. The bar is taken out and the benders will automatically move back into the initial positions. The whole process is controlled by two workers.

3.3.2 Automatic Processing Machine for U-Shaped Reinforcement Bars

A mobile positioning device for ends of reinforcement bars was developed and attached to an automatic processing machine for bending reinforcements at right angles sold on the market to reduce the time required for preparatory work. The processing machine consists of a reinforcement feeder, a device for bending of a bar and a control device. The processing machine is operated by two workers.

3.3.3 Ground Assembly Device for Longitudinal Beam Reinforcements

Thick reinforcements over 10 m in length weigh over 100 kg and their arrangements tend to be complex. An assembly device for longitudinal beam reinforcements was developed with the aim of reducing labour and raising accuracy in ground assembly of beam reinforcements. The device consists of an assembly base made up of five sets of supporting arms for the reinforcements, simple jib cranes, a hydraulic pump unit and a control board.(Figure 10) Following the reinforcement arrangement drawings, the positions and the heights of the supporting arms are adjusted. The main beam reinforcements arranged in four layers, including W-shaped reinforcements, are inserted in order from the side and placed. The spiral stirrups are inserted into the main beam reinforcements from both ends while making the arms expand and contract. The spiral stirrups are set at the specified intervals and fixed in position. The device is operated by two workers.



Dimensions	W=1,750mm ,L=8,000mm ,H=2,020mm
Supports	5 Stands with 4 cantilever arms Vertical Movement of Arms:Hydraulic Cylinders ;St.380mm Expansion of Arms:Hydraulic Cylinder;St.620mm Hydraulic Unit: 200V, 1.5kw, 60ℓ/min.
Shifting Device	Screw-driven feed mechanism
Reinforcement Bars	Main Reinforcements: D29 to D41 Spiral Stirrups: D9 to D13 Longitudinal Beam ≦10m
Simple Jib Cranes	2 cranes: 200kg Working Radius: 3,500mm Post Height: 3,450mm
Operation Method	Manual

Figure 10:Ground Assembly Device for Longitudinal Beam reinforcements

3.4 Effects of Implementation

a. The use of the project data base enabled one to determine the optimum positions of the reinforcements and to prepare data for use in the ordering, processing, assembly and stock control of the reinforcements.

b. Because accurate quantities of the reinforcements required were ascertained at an early stage, all the main reinforcements were delivered in the lengths required down to the nearest millimeters, making cutting on site unnecessary and thus leading to a significant reduction in labour and costs.

c. Drawings that can be prepared automatically using the data stored in the project data base include those for the concrete frame, block layout, reinforcement arrangement and reinforcement processing. The total number of these drawings is expected to reach 2,000 and their automatic preparation will result in significant reduction of labour in comparison with draughting them by hand. The high-quality CAD drawings containing large amounts of information received high appraisal from the reinforcement workers.

d. The automatic processing machines have made precision bending of large-diameter reinforcements possible. The cycle time for processing of U-shaped bars is approximately two minutes per bar, while that for W-shaped bars is approximately five minutes per bar. Both the processing machines can be operated easily by unskilled workers and have led to a significant reduction of labour.

e. The ground assembly device for longitudinal beam reinforcements has been of great effect in complex and high density assembly of heavy reinforcements on the ground. The amount of necessary work for assembly of a block of beam reinforcements is around 250 man-minutes (approx. 2 workers x 2 hours). The level of precision in the assembly of bars on ground is high and there has been no need for correction in the work of assembly of blocks and joining of reinforcements on floors so far.

3.5 Tasks for Future

It would have been possible in the CAM to provide data on floppy disks from the project data base to the automatic processing machines and to use them as control data. It was judged, however, that the processing of bars in small lots according to blocks would lead to a low level of cost-effectiveness and, consequently, a decision was taken not to combine the CAD and the CAM. Standardisation of materials and design will be necessary before implementation of CAD/CAM.

On this occasion, the comprehensive control system and the automatic devices were developed by Ohbayashi Corporation and used by the subcontractor for reinforcement work. Much of this, however, was work which was properly in the domain of the subcontractor and the implementation of the work in the form that it took led to blurring of the ranges of responsibilities of the general contractor and the subcontractor. It is hoped that, in the future, the standard form will be for the subcontractor to receive information that will be of use in the production from the general contractor or the architect and to make use of it in their own CAM.

4. CONCLUSION

As the automatic system described here was developed for a special case of a high-rise reinforced concrete building, there will be difficulties in applying the system to more ordinary reinforcement works but given the general tendency towards CAD/CAM, efforts should be made to apply CAD/CAM to construction works in the future.

REFERENCE

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