Dam Concrete Automatic Transfer System

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ABSTRACT

It is a serious problem with the construction industry that there has been a growing shortage of skilled workers together with the problem of their aging. Rationalization of work, labor saving, and safety control through automation of construction equipments have also been desired. The automation of dam concrete transfer has been the urgent demand since its transfer requires skilled cable crane operators and the job itself is a typical repetitive work.

To meet such needs, the authors formed a project team in OBAYASHI Corporation since 1989 and have been engaged in system development. The project team have accomplished the full automated concrete-transfer system being centered around the cable cranes and practically applied the systems to dam construction sites.

1. INTRODUCTION

Partial automation relating to the automatic operation of dam concrete laying operations has been attempted hitherto, but this was not the full automatic operation that integrates a series of concrete transfer from a batcher plant to a concrete laying site. Especially, the automation of a cable crane in the concrete laying work was difficult because only the skills of a crane operator and a signal caller enabled the control of the swing and positioning of a bucket.

In this system, a cable crane and other equipments related to transfer of concrete are controlled by the host computer (EWS), sub-computers and programmable computers (PLC). In performing the automatic operation of cable cranes, the feed-forward control is adopted for the purpose of achieving the adequate swing control and performing the highly accurate positioning of a bucket by computing the moving locus of bucket with the EWS in advance.

Furthermore, adoption of this system has made it possible to supply concrete stably without skilled operators and with no reduction in work efficiency arising from their fatigue. As a result, great contribution has been attained towards labor saving in work, improvement in high efficiency, reduction in difficult work for workers and improvement in safety.

This paper introduces outlines of the system applied in 1992 to Chiya Dam (Okayama Pref., bank volume: 695,600 m^3) and the improved system applied in 1995 to Tomisato Dam (Water Resources Development Public Corporation, bank volume: 590,000 m^3), which is under construction work .

2. OUTLINE OF SYSTEMS

2.1 Composition of Equipments

The equipments used for this system are categorized largely into the concrete transferring machines and the controlling apparatus for automatic operation. In this connection, Fig.-1 shows the outline of the equipments which relate to transfer of concrete used for Tomisato Dam and Table-1 shows their specifications.

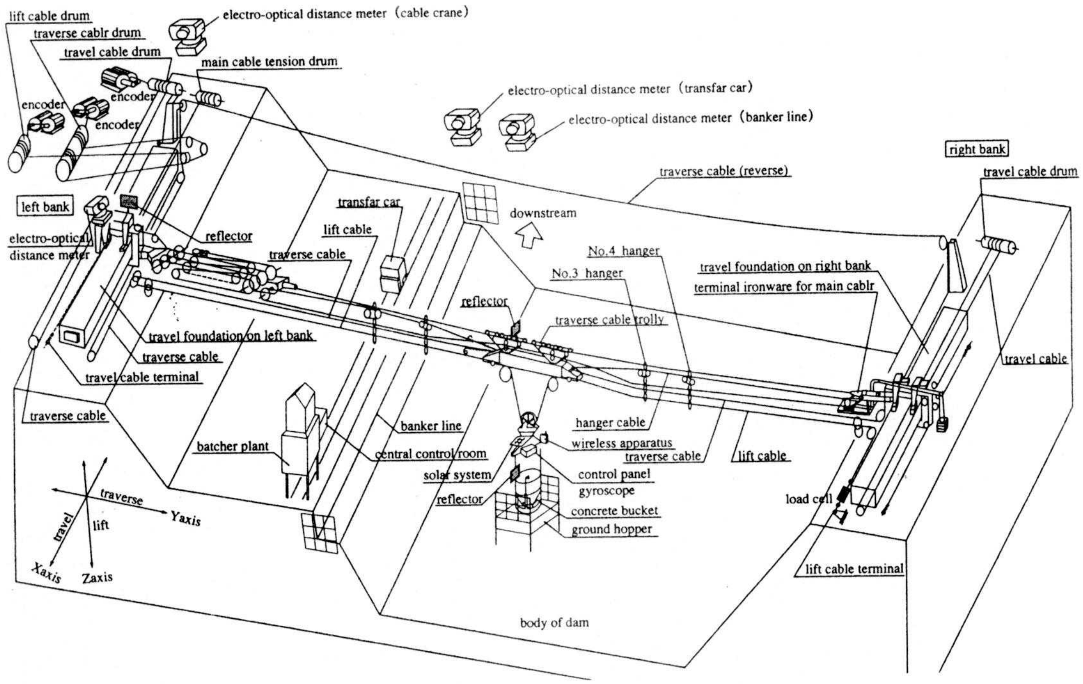


Fig.-1 Outline Drawing of Transferring Machines and Equipment

Name of unit	Specifications
Batcher plant	2-axis full automation enforced mixer 2 m^2 ×2units Mixing capacity 120 m^3/ H
Transfer car	Side chute type, Loading capacity; 6m^3, Traveling; hydraulic, Gate; air, Motor; 30kw Traveling speed; max. 120m/min.,
Double-end traveling type cable crane	Rated load; 21t Double-end traveling type, Control system, Thyristor Leonard
Wire speed	Lifting up 'and down; max. 200m/min. Traverse; max. 400m/min. Travel; max. 20m/min.
Motor capacity	Lifting up and down; max. 430kw Traverse; 313kw, Travel; 45kw×2units For main cable adjusting; 11kw
Wire	main cable; 86mmϕ,Traverse; 28mmϕ Lifting; 32mmϕ, Travel; 32mmϕ
Concrete bucket	6 m^3, air opening/closing gate type, Empty weight; 4.0t, loaded weight; 20t
Ground hopper	Air opening/closing gate type, 12m^3

Table-1 Specifications of Transferring Machines

2.2 Summary of Control

The supervisor only needs to operate the touch pad to set a coordinate (target coordinate) of the target location where concrete is discharged, and then the concrete prepared at the batcher plant is transferred via a transfer car, a bucket, and a ground hopper and is loaded on a dump truck where the concrete is laid. If it is difficult to transfer concrete by a dump truck, the concrete is directly discharged onto the concrete laying place. In this case, when the coordinate values of the 4 corners of the area are inputted, concrete is discharged onto the center of an area.

These controlling systems, as shown in Fig.-2, totally control the automatic operation units smoothly by the EWS and the PLC in the central control panel.

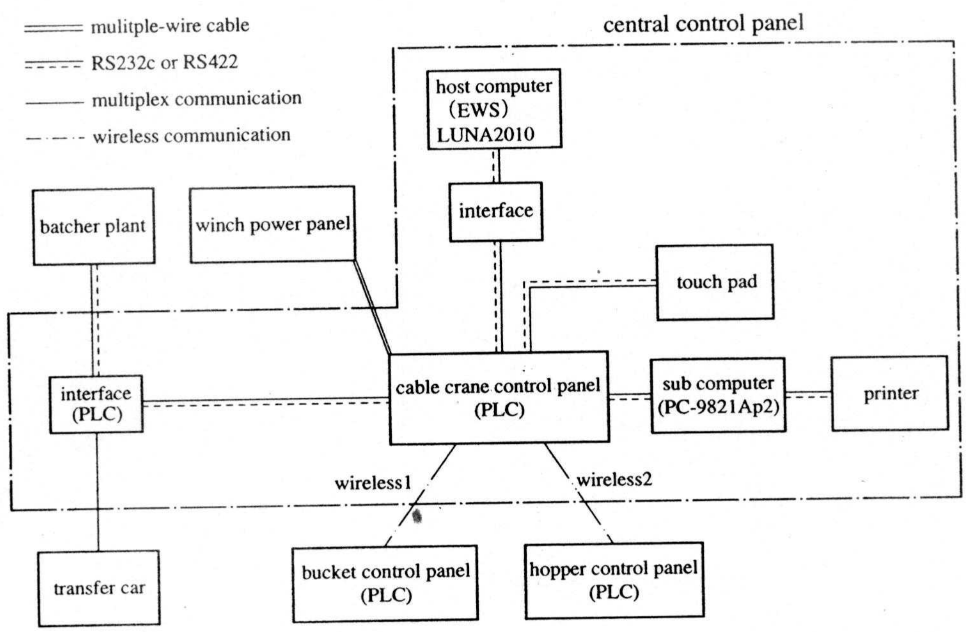


Fig.-2 Drawing of Configuration of Control System

2.2.1 Automatic transfer system for a transfer car

The transfer car is loaded with concrete prepared at the batcher plant and starts moving forward at a high speed as soon as it receives the start signal. Thereafter, from the central control room it receives a signal of position coordinate of banker line where a bucket arrives, then it calculates its position by using an encoder. It stops when the light of the optical sensor of the bucket is detected. At same time, it automatically gets the air to operate the bucket gate and discharges concrete. Then it goes back to the batcher plant and starts the next loading process.

2.2.2 Cable crane automatic operation unit

The cable crane is the equipment that transfers concrete which is loaded into a bucket at the banker line as far as the target position where concrete is unloaded. As shown in Table-1, it used to be extremely difficult for the automatic operation control by the feedback control to stop a bucket in its target position without swinging and with accuracy, because, as shown in Fig.-3, a heavy substance (20 t) is transferred using flexible wire ropes as a guide for a long distance at high speeds (traverse; max. 400 m/min. and lifting up and down; max. 200 m/min.).

This system uses the EWS to compute the movements of a traverse cable trolley and a bucket in advance and performs automatic operation by the feed-forward control. In this connection, the two-dimensional double-end fixed type crane with traverse and lift up and down operations as illustrated in Fig.-3 is to be examined to explain the algorism for the reduction of the swing and the positioning logic of a bucket.

(1) Movement Model

We decided to analyze the movement of bucket by assuming a model in which the traverse cable trolley moves along the main cable and the bucket swings as a pendulum of which fulcrum is located at the traverse cable trolley.

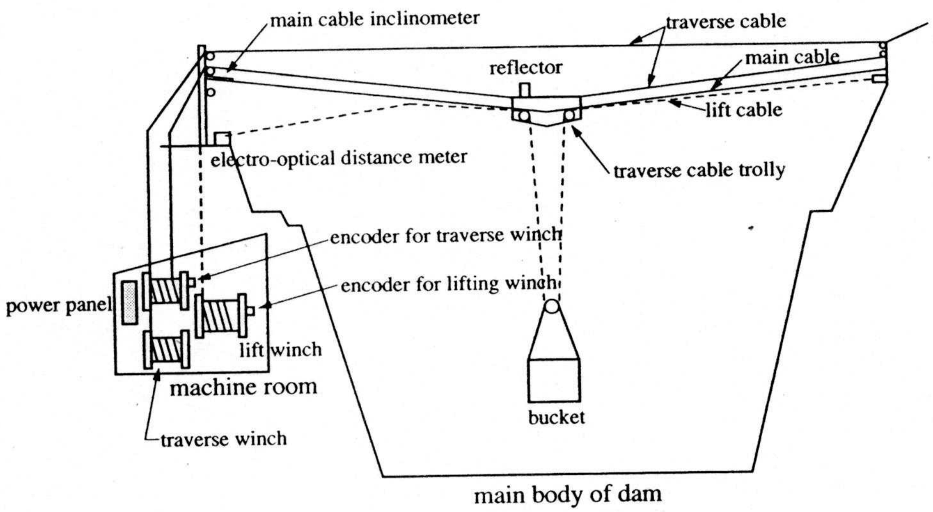


Fig.-3 Drawing of Outline of Cable Crane

(2) Calculation of Locus of the main Cable

First of all, deflection of the main cable caused by the movement of traverse cable trolley is calculated. As shown in Fig.-4, when the static balance between the traverse cable trolley and the main cable is taken into consideration, Formulas ①,②,③ are obtained.

$$T_3 \sin\phi_1 = F\cos(\theta_0 + \theta_1) \qquad \text{-----①}$$

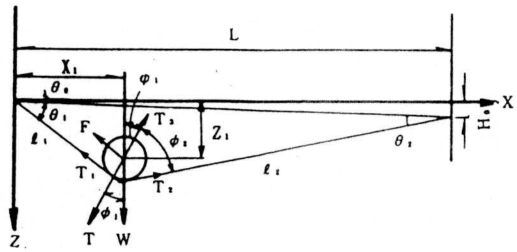
$$T_3 \cos\phi_1 = F\sin(\theta_0 + \theta_1) = W \qquad \text{-----②}$$

$$T_1 \cos\phi_2 = T_2 \cos\phi_2 \qquad \text{-----③}$$

Neglecting the frictional force between the main cable and sheave, assuming the sheave diameter to be zero and developing the foregoing formulas, then the X-coordinate (x_1) of the traverse cable trolley becomes the function of the Z-coordinate (z_1) of the traverse cable trolley by use of $\theta 0$ and $\theta 1$. Then, z_1 is to be calculated by applying a constant to x_1. The locus coordinates of the main cable is calculated by applying several constants to the formula.

(3) Bucket Coordinate Calculation

The bucket coordinate is, as shown in Fig.-5, calculated as a model in which a bucket is hung from the traverse cable trolley and swings without any restriction assuming that its fulcrum is positioned at the traverse trolley.



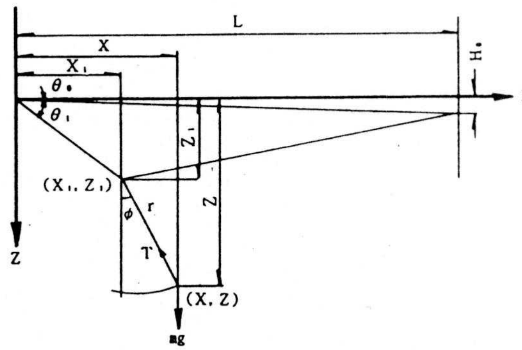


Fig.-4 Main Cable Coordinate   Fig.-5 Bucket Coordinate

The motion of bucket is calculated by the following formulas:

$m\ddot{x} + T\sin\phi = 0$ -----④

$m\ddot{z} + T\cos\phi = mg$ -----⑤

And, assuming the bucket coordinate to be (x,z) and the traverse cable trolley coordinate to be (x_1, z_1), we obtain the following:

$x = x_1 + r\sin\phi$ -----⑥

$z = z_1 + r\cos\phi$ -----⑦

where x_1, z_1 and r are assumed to be functions of time t only. From Formulas ④ through ⑦, the next formula is obtained:

$r\ddot{\phi} + 2\dot{r}\dot{\phi} + (g - \ddot{z}_1)\sin\phi + \ddot{x}_1\cos = 0$ -----⑧

The bucket coordinate at time .t is obtained by dispersing formula ⑧, conducting numerical integration, and examining it with the main cable locus calculation.

(4) Elimination of Bucket Swinging and Its Positioning

As mentioned above, the swing of bucket can be simulated when a winch is operated and a traverse cable trolley is moved. A lot of simulation results show that it is possible to stop a bucket at a designated position without any swing of a bucket by changing the speed of traverse cable trolley as required. The swing of a bucket arising from acceleration or deceleration of the trolley can be eliminated by sequentially accelerating and moving at a same rate the trolley, or decelerating and moving at a same rate the trolley.

(5) Measures against Disturbances

The operation distance of a bucket slightly differs every time due to slips between a winch and wire, and elongation of wire deriving from change in atmospheric temperature. On account thereof, it is designed that the present system performs position adjustment every time at the start point. The starting point of a bucket is adjusted every time by taking measurements of angle of elevation of the main cable with a main cable inclinometer and the traverse cable trolley position with an electro-optical distance meter.

Although it is difficult to set up measures against influence from the swing by wind load because the bucket controlled by the aforementioned logic. In actual work, the influence is negligible, because the traverse-wise force on the bucket by wind at a speed of 10 m/sec. is 55 Kgf while the vertical load of an empty bucket is 4 tf. The upper part of bucket is equipped with a vibration gyrocompass to detect its inclination, and it is designed to interrupt the control when its inclination exceeds the limit.

3. POSITIVE ACHIEVEMENTS AND EFFECTS

This systems was adopted at Chiya Dam (Okayama Pref., gravity-type dam with bank volume of 695,000 m^3) and have been adopted at Tomisato Dam (Water Resources Development Public Corporation). This system has had positive achievements of concrete laying amounting to 670,000 m^3 at Chiya Dam and amounting to 140,000 m^3 as of January 1996 at Tomisato Dam, accomplishing the initial objectives stated in the aforementioned section 2. The main introductory effects of this system are as follows:

(1) Labor saving

The conventional systems used to require 6 to 9 skilled workers who are engaged in operation of transfer equipment, while adoption of this system has made it possible to conduct the foregoing work by 2 supervisors.

(2) Improvement in work efficiency

Adoption of this system has made it possible to supply concrete on a stable basis while the concrete transferring capacity is either equal to or better than the conventional method by operator's operation. The data on practical cycle time are shown in Fig.-6 and Fig.-7.

Comparison with the conventional method has been obtained by examining the two-way travel of the cable crane. Table-2 shows an example of the results.

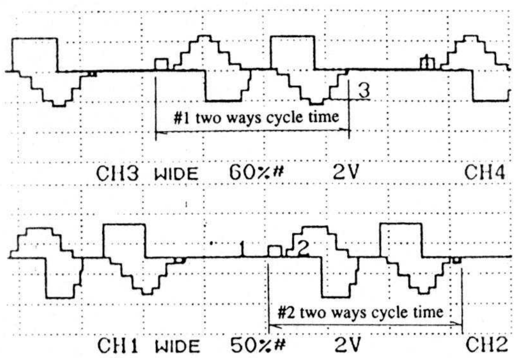


Fig.-6 Cycle Time (Chiya Dam)

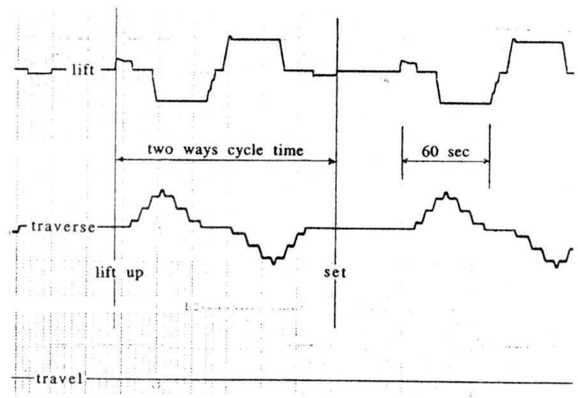


Fig.-7 Cycle Time (Tomisato Dam)

Name of crane	Distance from bucket yard		by conventional method (sec)	by automatic system (sec)
	L (m)	H (m)		
Chiya No.1 Unit	140.5	65.1	163	156
Chiya No.2 Unit	134.1	65.1	161	149
Tomisato	79.3	50.6	155	151

Table-2. Example of Measured Cycle Time

(3) Improvement in safety

Owing to the automatic operation, all kinds of manual work have been eliminated, and accordingly, no direct contact of workers with the concrete laying machinery has made this work much safer.

4. CONCLUSION

Development of this system has made it possible to fully automatize concrete transferring work for dam construction, and it has been demonstrated that labor saving and improvement in safety can be achieved at dam construction sites where this system is put to use. Thereby we believe that we have presented one system that can dissolve the aforementioned problem. In our future we will improve this system so that they can be applied to cranes of more degree of freedom. In applying this system to construction sites, we received advice and cooperation from the construction office of Chiya Dam in Okayama Pref. and the construction site of Tomisato Dam by Water Resources Development Public Corporation. The authors would like to express their deep gratitude for the advice and cooperation.