Development and Effects of New Method of Conveying Materials for Construction of Cast-in-place Concrete Slabs

Yu MOROYAMA, Yukihiro KURATA, Hajime YAMASHITA, and Toujyuro NISHI

Abstract—**In construction of bridges with cast-in-place concrete slabs, we often observe that materials of floor slabs are conveyed by human power in construction sites where transportation of materials by cranes or other large and heavy equipments are restrained. Since a possibility of substantial cost reduction was anticipated through rationalization of such conveyance work, we developed the new method of conveying materials for construction of cast-in-place concrete slabs. This method is to convey materials by the self-propelling carriage on monorail installed on main girder flange. This method features: installation and removal of rails are easy; the carriage can be operated in a narrow space; heavy materials can be conveyed in block; the method is applicable to curved girders and road-widening sections; and the cost is low.**

Index Terms—**Cast-in-place concrete slabs, Method of conveying materials, Monorail, Self-propelling carriage, Rationalization of construction**

I. INTRODUCTION

BRIDGES with cast-in-place concrete floor slabs are often constructed in mountainous areas, over marine waters, or in the vicinity of urban highways where lifting up and transporting materials by cranes or other large and heavy equipments are restrained. Constructions over highways in urban areas, for example, have to be conducted without obstructing traffic as much as possible, and cranes are allowed to stand only in restricted areas. In such cases, materials for construction of cast-in-place concrete slabs (for example, rebars, forms, shorings, prestressing steel wires etc.) are often conveyed by human power. A few main girders bridges with cast-in-place concrete slabs are frequently adopted in all kind of steel bridges for the purpose of reduction of construction cost. However, we cannot say that sufficient rationalization has been promoted in such bridges. Hence, we initiated development of new method of conveying materials in order to promote rationalization in construction of cast-in-place concrete slabs.

In this paper, we report about the development of new method of conveying materials for construction of cast-in-place concrete slabs [1] and the effects of this method when it was applied to actual bridge construction.

II. DEVELOPMENT OF NEW METHOD OF CONVEYING MATERIALS FOR CONSTRUCTION OF CAST-IN-PLACE CONCRETE SLABS

A. Required performance for new method

In construction of cast-in place concrete slabs, it is important to convey materials efficiently in order to reduce the material conveyance cost in construction site with different restraints. Therefore, mainly four items are required as the performance of new method as follows:

i) Vast scope of applicability

The method must be applicable to the curvature of main girders and road-widening section, longitudinal gradient and transverse gradient of floor slabs, and it must be able to take into consideration the order of concrete placing, and it must also allow traveling on concrete-placing slabs.

ii) Space saving

It is essential that the whole equipment can be placed on the main girder so that it will not disturb other works as much as possible, and it is important to be easily installed and removed.

iii) Large capacity of conveyance

It is necessary that conveying work by human power are reduced as much as possible for rationalization of works and the method can convey at least 1 ton of materials in block.

iv) Low cost

The cost must be minimized in the light of price competitiveness with other transporting methods.

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B. *Selection of structural type*

The most feasible idea is to use the space on the main girders for conveying materials, because the main girder is continuous along the entire length, and there are usually no disturbing objects placed on it. However, if the equipment straddles over the two main girders, the equipment will be affected by the transverse gradient and the linear shape, and it becomes tough to install rails, and it is also difficult to respond to the section in which the width of road changes. In addition, in bridges with a few main girders, the bearing distance becomes wider, and as a result, the cost will be increased to keep the structure to respond to such conditions. Accordingly, we devised the method in which monorail (a single rail) was installed on one main girder, a self-propelling carriage was traveled on the rail and traveled with the rack and pinion mechanism (Fig. 1). This structure would be able to manage complicated linear shapes with high longitudinal gradients and small curve radius at low cost.

C. *Examination of application to actual bridge*

1) *Installation and removal of rails*

The constructional situation of cast-in-place concrete slabs changes variously along the schedule of construction (Fig. 2), such as: (a) State of only steel girders placed (or state of safety passages provided at the side of the upper flange); (b) State of forms and shorings installed; (c) State of rebars and prestressing steel wires placed; (d) State of concrete placed. Further, the any one of the above states irregularly take place along the bridge axis due to the order of concrete placing. We considered that rail installing work should be conducted within the safety passages to meet those constructional situations, and we contrived the system so that rail could be placed on the main girder flange when the safety passage had been provided after the main girder was erected as shown in Fig. 3. In addition, we took consideration so that rebars and prestressing steel wires might be placed with the rail kept placed. Regarding removal of rail, all railing materials could be removed, and no foreign objects would be left in concrete. Stanchions would be replaced with T-shaped ones, and the rail would be able to be placed again without problems also on concrete slabs after placing as shown in Fig. 4.

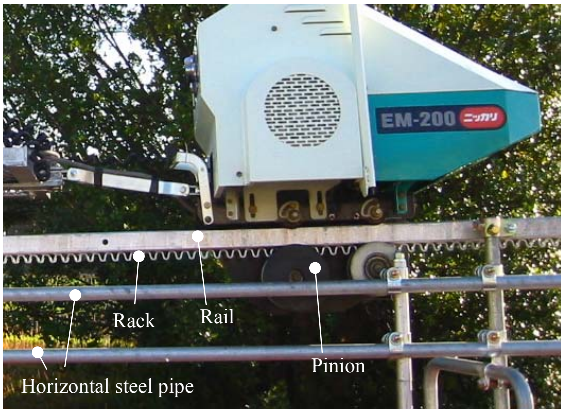

Fig. 1. Rack and pinion mechanism

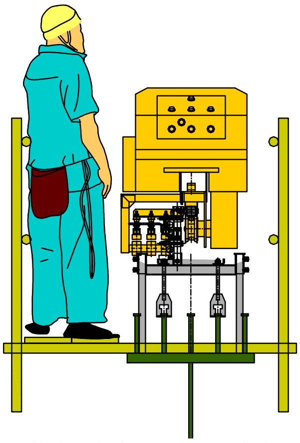

Fig. 3. Installation (before concrete placing)

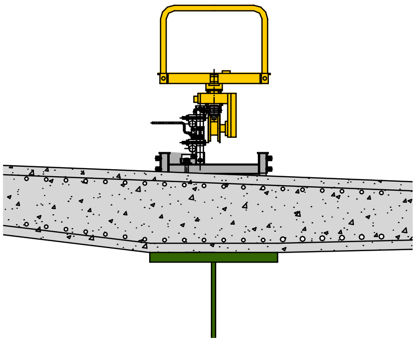

Fig. 4. Installation (after concrete placing)

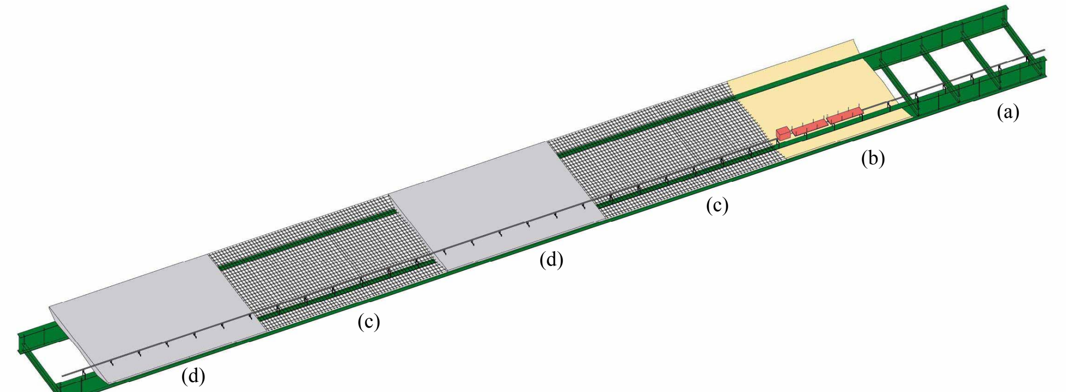

Fig. 2. Construction of cast-in-place concrete slabs

2) Rail structure and structure of matching parts between rail and main girder

The specific way of installing rails was: to provide a steel bar with its top and bottom threaded (hereafter referred to as "threaded steel bar") at the position of measurement bar on the main girder flange, and cover that steel bar with a steel pipe stanchion for rail installation, and fasten them with a nut from the top, and fix the railing materials to that steel pipe stanchion, and repeat this procedure (threaded steel bar will be available as a measurement bar after rail removal) (Fig. 5). Consequently, there is no need to do centering and mark-off work that were required in conventional rail installation work. In addition, we adopted the structure of fastening steel pipes with bolts without welding work as a whole, and therefore, all kinds of installation work became available for simple manual operation, and the efficiency of installation and removal of rails were dramatically improved.

For prevention of rails falling, two horizontal steel pipes were provided with steel pipe stanchions in the bridge axis direction, while, in the direction perpendicular to the bridge axis, sway brace pieces were provided as side anchor consisting of a beam member and a stanchion member. Prevention pieces for vertical shaking up were provided to fix stud dowels and sway brace pieces (Fig. 6).

3) Performance of conveyance

As shown in Fig. 7, the self-propelling carriage, which travels on the rail, consisted of the drive section (power section plus generator) and a trolley section. The trolley section could be connected by linking trolleys in tandem, and three trolleys could convey rebars of about 12m long, and five trolleys could convey prestressing steel wires of about 20m long. Forms, shorings and other materials could be conveyed as well. One trolley unit could convey materials of 300kg, and the entire trolleys could convey 1 ton in total (depending on the performance of drive section). The running speed of carriage was expected up to 40m/min or so. Thus, this method provided conveyance of large weight and large capacity in block.

4) Safety measures

The carriage was operated by a pendant controller, and a four-stage brake system was integrated on board, including an emergency stop device. And there was no concern about derailing because the rack and pinion mechanism was adopted. As a safety check for operation, the alarm rolls when the carriage starts run.

D. Travel tests

Travel tests were conducted in the test field for the purpose of confirming rail installation work and travel performance. The tests revealed that this method was satisfactorily available in straight bridges with longitudinal gradient of 6% and transverse gradient of 8% and in curved bridges with radius of 50m.

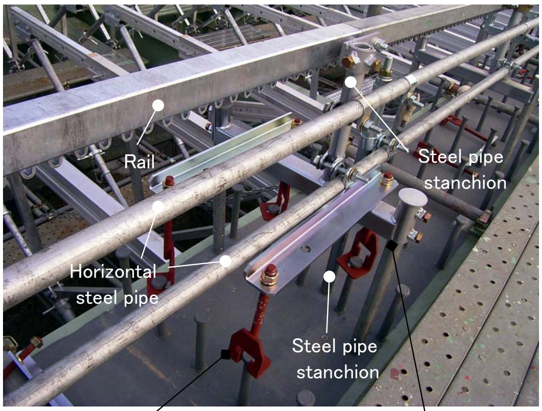

Fig. 5. Rail structure

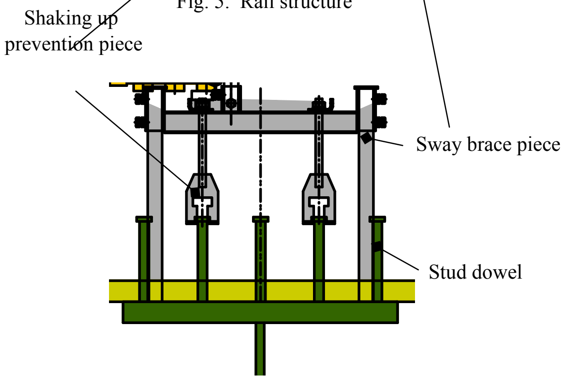

Fig. 6. Falling prevention structure

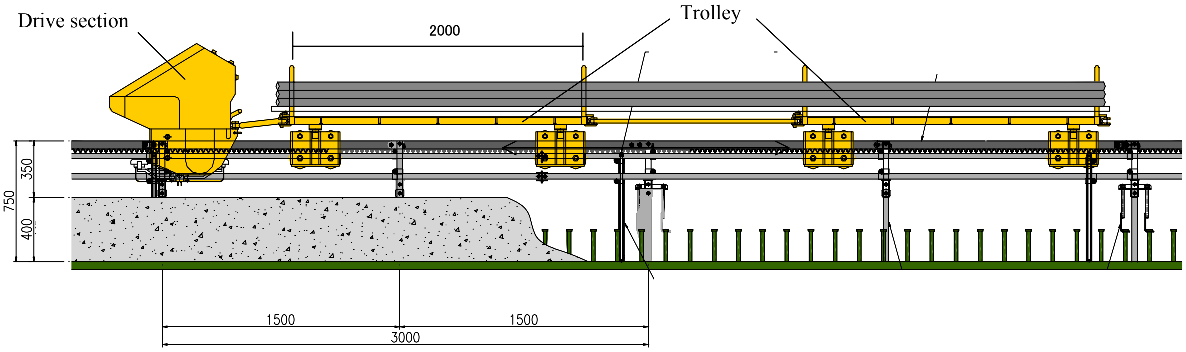

Fig. 7. General view of self-propelling carriage

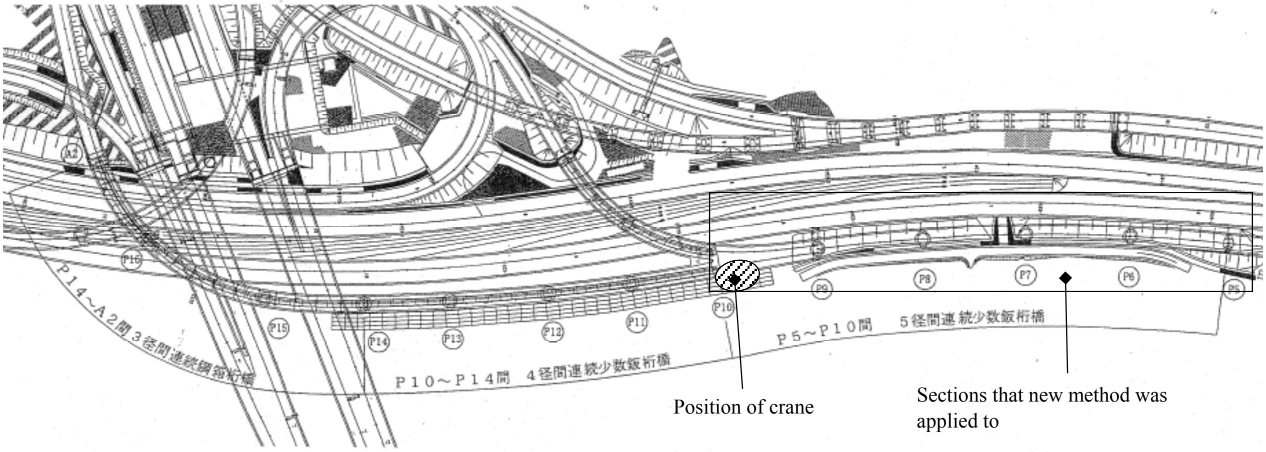

Fig. 8. Schematic view of A-Bridge

III. APPLICATION OF DEVELOPMENT OF NEW METHOD OF CONVEYING MATERIALS FOR CONSTRUCTION OF CAST-IN-PLACE CONCRETE SLABS TO THE ACTUAL BRIDGE

A. Outline of actual bridge for application

The longer is the section of human-power conveyance, the more this method provides its effects in locations where transporting materials by crane or other heavy equipments are difficult due to the restraints in construction sites. Hence, we verified the produced actual effects for trial in the bridge that this method was expected to be sufficiently effective (hereafter referred to as “A-Bridge”). Figure 8 illustrates the schematic view of A-Bridge. In the sections between P5 and P10, A-Bridge had a space for a crane to stand only in the vicinity of P10. In those sections, therefore, materials for floor slabs were unloaded onto P10, and then they were carried by human power. Thus, we decided to apply our method to the sections between P5 and P10.

B. Outline of application

Fig. 9-12 illustrate how our method was applied in this construction sections. The total length of rail installed between P5 and P10 was 225m(Fig. 9). Since floor slabs were already constructed in the sections between P10 and P14, rail was placed on the completed floor slabs between P10 and P11 with some 25m overhung, and this location was assigned as the materials loading space (Fig. 10). Using a crane, we lifted up materials, and then put them directly into the trolleys, performing highly efficient loading and conveying materials (Fig. 11).

Fig. 9. Rail installation

Fig. 10. Installation on existing floor slabs

Fig. 11. Loading of materials

Fig. 12. Conveyance of materials

Rails were installed in the phase when the safety passage was provided at the side of the main girder, and therefore, the applied method could conduct conveyance of almost all kinds of materials for construction of floor slabs, such as shorings, forms, rebars, prestressing steel wires, and other small auxiliary items as bolts and nuts (Fig. 12).

C. Result of application

We divided the installation of applied method into “Rail installation” and “Other operations” (conveyance of materials, installation and adjustment of self-propelling carriage etc). Since the number of workers and operation hours varied with the operation days, we firstly converted all operation hours into the hour values when all operations were performed by a single worker, and we calculated the value of man-days from the converted hours for evaluation. Here, ‘man-day’ was taken as 1 when a single worker worked 1 day (converted into 8 hours). As a result, it was confirmed that rail installation and other operations spent 11.8 man-days and 4.4 man-days, respectively. The length of installed rail was 21.2 m by 1 man-day. Here, supposed that those operations were performed by 4 workers every day (in actual installation, operations were performed by 3 to 6 workers per day), rail installation took about 3 days, other operations took about 1 day, and all operations were completed within about 4 days. The length of installed rail would be 85m per day.

D. Effects of application

To evaluate the effects of the applied method, we compared the results of construction between A-Bridge and the bridge of similar scale to A-Bridge, in which materials were conveyed by human power (hereafter referred to as “B-Bridge”). The operation items for our comparison included “Shoring assembly”, “Form assembly“, “Rebar assembly“ and “Prestressing steel wire assembly”, each of which comprised operations of “Conveyance” and “Installation (or Placement)”.

The number of operation days in both bridges was 35 days for A-Bridge and 85 days for B-Bridge, indicating A-Bridge was constructed in a rather shorter period than B-Bridge. Here the “operation day” denotes the number of days from the start of shoring assembly to the day of completed rebar assembly in construction of floor slabs (immediately before concrete placing). Next, we had to put the data in order by the unit operation quantity in order to compare the operation efficiency. Here the “unit operation quantity” denotes the value of man-day divided by the quantity of each operation item, indicating the man-day spent to construct a unit quantity. TABLE I shows the quantity by each operation item, spent man-hours and unit operation quantity. TABLE II shows the value of the unit operation quantity in B-Bridge divided by the unit operation quantity in A-Bridge to indicate the specific values of improved efficiency of operations by adoption of this method. Those values reveal that remarkable improvement of efficiency in operations was achieved through the adoption of this method, namely, 3.1 times in shoring assembly and 2.7 times in form assembly. In rebar assembly and prestressing

TABLE I
MAN-DAYS AND UNIT OPERATION QUANTITY

A-Bridge (Bridge length: 220m, operation day: 85days)

Operation item	Quantity	Man-day	Unit operation quantity
Shoring assembly	2,877 m^2	413	0.144 / m^2
Form assembly	2,877 m^2	337	0.117 / m^2
Rebar assembly	295 ton	508	1.72 / ton
Prestressing steel wire assembly	30 ton	144	4.85 / ton
Total	-	1402	-

B-Bridge (Bridge length: 245m, operation day: 35days)

Operation item	Quantity	Man-day	Unit operation quantity
Shoring assembly	2,169 m^2	100	0.046 / m^2
Form assembly	2,169 m^2	95	0.044 / m^2
Rebar assembly	200 ton	251	1.26 / ton
Prestressing steel wire assembly	13 ton	40	3.13 / ton
Total	2,169 m^2	486	-

TABLE II
MAN-DAYS AND UNIT OPERATION QUANTITY

Operation item	Improved efficiency of operations
Shoring assembly	3.1
Form assembly	2.7
Rebar assembly	1.4
Prestressing steel wire assembly	1.6

TABLE III
REDUCED MAN-DAYS AND RATIO OF REDUCTION

Operation item	Man-day		Reduced man-day	Ratio of man-day reduction (%)
	A-Bridge	B-Bridge		
Shoring assembly	100	311	211	68
Form assembly	95	254	159	63
Rebar assembly	251	345	94	27
Prestressing steel wire assembly	40	62	22	35
Total	486	972	**486**	**50**

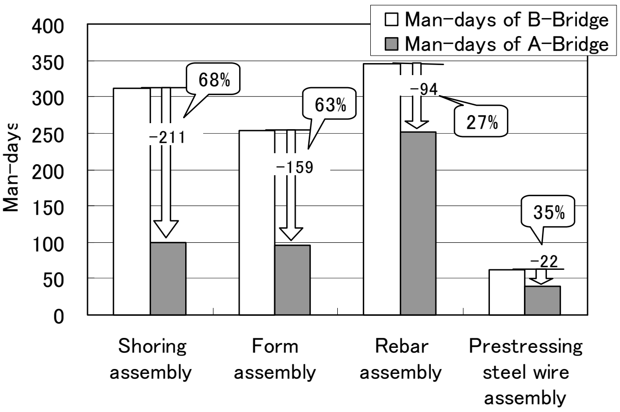

Fig. 13. Comparison of man-days

steel wire assembly, an efficiency improvement of about 1.5 times was observed, not such high values as in the above two items because of the troublesome operation in laying out and tying.

TABLE III and Fig. 13 show the reduced man-day and the ratio of man-day reduction through the adoption of this method. The "Ratio of man-day reduction" means reduced man-day divided by B-Bridge's man-day. As indicated by those values, we could obtain more than 60% reduction of man-day in shoring assembly and form assembly and man-day reduction of 30% or so in rebar assembly and prestressing steel wire assembly, resulting in 50% man-day reduction in total.

As mentioned above, it is demonstrated that the adoption of this method brought us the significant shortening of construction term and the reduction of man-day at the same time.

IV. CONCLUSION

This section summarizes the features and effects of our newly developed method of conveying materials for construction of cast-in-place concrete slabs as follows:

1) Introduction of self-propelling carriage traveling on monorail by means of the rack and pinion mechanism enabled us to convey materials on the main girder flange that involves curvature (radius of 50m or so), longitudinal gradient (6% or so) and transverse gradient (8% or so), and on the concrete slabs after placing.
2) A steel bar, with its top and bottom threaded, was provided in the position of measurement bar on the main girder flange and rail was fixed to it, therefore, there is no need to do centering and mark-off work and all kinds of installation work became available for simple manual operation.
3) The self-propelling carriage could be connected by linking trolleys in tandem, and three trolleys could convey about 12m long rebars, and five trolleys could convey about 20m long prestressing steel wires. A single trolley could convey 300kg load, and the entire trolleys could convey a weight of 1 ton in total. Thus the carriage could convey materials of large weight and large capacity in block.
4) We applied this method to the actual bridge having a rail installation length of about 220m, and verified the effects of this method. The improvement of efficiency in operations was found to be 3.1 times in shoring assembly, 2.7 times in form assembly, and 1.5 times or so in rebar assembly and prestressing steel wire assembly. The ratio of man-day reduction was proved to be more than 60% in shoring assembly and form assembly, around 30% in rebar assembly and prestressing steel wire assembly and 50% in total. Great reduction was also verified in the number of operation day.

V. FUTURE DEVELOPMENT

The result of our study demonstrated that this method could produce sufficient effects in rationalization and cost reduction of construction of cast-in-place concrete slabs. In the future, we would like to consider actively applying this method to other styles of bridges such as box girder bridges, truss bridges, arch bridges and so on in addition to a few main girders bridges if there are restraints on transporting materials in their constructions.

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