IPA News Letter Volume 5, Issue 3 September 2020

Reports

Recent technological development at Japan Construction Method and Machinery Research Institute

Hiroyuki Takenouchi

Engineering Adviser
Japan Construction Method and Machinery Research Institute

Outline of Japan Construction Method and Machinery Research Institute

History and research philosophy

Japan Construction Method and Machinery Research Institute (JCMMRI) was established in October 1964 as an affiliated organization of Japan Construction Machinery and Construction Association (Photo 1). The purpose of its establishment is to contribute to our nation's economic development by promoting technology improvement and rationalization of construction projects through research and testing in the area related to construction machinery and mechanized construction works.

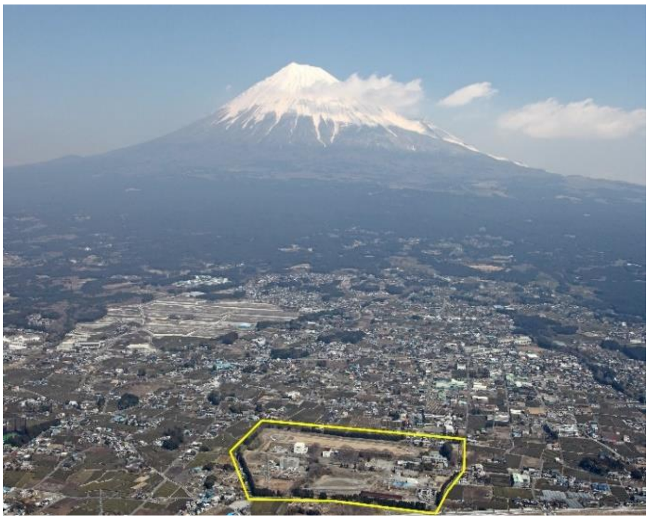

Photo 1. JCMMRI at the foot of Mt. Fuji

Ever since the establishment, commissioned by related organizations such as the national government and private companies, we have been conducting various tests, surveys and researches on construction method and machinery in wide diversity of works and projects such as roads, bridges, tunnels, and dams, including notable major projects in Japan for more than half a century. We have also focused on construction safety and environmental issues such as noise, vibration, and exhaust gas countermeasures.

We are determined to play the leading role as Japan's only comprehensive testing and research institute for construction machinery and mechanized construction, while maintaining the tradition of "think with our own head, investigate with our own feet, and test with our own hands" from the beginning.

Activities

The work carried out by JCMMRI covers a wide range of fields, such as research and study, performance test and evaluation, technology development, and technical support. In addition to on-site survey and experiments using test facilities, we also perform all kinds of work related to construction technology which requires advices and judgment as the third party, such as surveying and analysis on construction productivity data and equipment ownership cost for construction cost calculation.

Photo 2. 4MN fatigue testing machine

Researches and studies have been conducted on various issues related to construction methods, maintenance of structures, and construction machinery throughout construction work. As the recent tendency, the number of researches related to maintenance, repair and reinforcement is increasing, as the importance of maintenance has been strongly called out again. As for bridges, for examples, we are taking measures to prevent fatigue damage to steel decks, fatigue durability of bridge expansion joints and PC decks used for floor deck replacement work (Photo 2). As for tunnels, field verification of Robot technology for the purpose of inspection developed by private companies was carried out (Photo 3).

For construction machinery, we have been conducting research on performance improvement and development of new models in the fields of disaster prevention and restoration measures, environmental measures and safety measures. Performance tests, evaluations and ratings are also conducted. Automatic control and remote operation have become recent important issues for snow removal work (Photo 4) and early recovery work from natural disasters to reduce social impact. With regard to information and communication technology-oriented construction, so called ICT-construction, which has been strongly promoted by the Ministry of Land, Infrastructure, Transport and Tourism, we have been providing support for the vision and strategy, and spreading the actual practice in construction field (Photo 5). We also have been engaged in the establishment of technical standards for ICT-construction by making use of our accumulated knowledge on elemental technologies such as machine control and machine guidance and 3D measurement technology.

Photo 3. Verification test in the simulated tunnel

Photo 4. Automatic control of snow removal work

Photo 5. Hands-on workshop for ICT-construction

Technology development such as new models, new methods and new materials has been conducted through joint research projects with construction companies and private companies handling construction machinery and materials, in addition to contracting from the ordering party. In this report, two cases of recent technical development through joint research with private companies and universities are introduced.

Case (1) Development of Multi-divided Precast Lining System for Mountain Tunnel

Background and purpose

It is assumed that securing labor will become more difficult due to the shortage of manpower in the construction industry from now on, and improving productivity to reduce the number of workers in construction is one of the urgent tasks to be tackled today. In the construction of mountain tunnels, there often occurs cases where rapid construction of the entire tunnel work is required to shorten the construction period or to recover the process delay. For such cases, in general, application of precast lining can be considered as a rapid lining work. But, in the current precast lining work, the size of precast members is significantly large because the lining is commonly divided into two sections. This leads to the difficulty of transportation, loading, and erection of precast members during excavation work going on at the same time. And so, the applicability in a narrow tunnel space becomes an issue. With these backgrounds, aiming at significant improvement of the productivity of the lining concrete construction, the joint research team has been developing Multi-divided Precast Lining System that enables more than double the speed of conventional construction.

Outline of Multi-divided Precast Lining System

Multi-divided Precast Lining System was developed for highway tunnels with two lanes where the general cross section is about 80 m^2. The basic structure of multi-divided precast lining consists of 6 pieces for 1 ring with the width of 1.0 m. The arc length of one piece is reduced to about 2.8 m, one-third of the conventional one, so that workability of transportation, loading and erection can be greatly improved. For the purpose of quick assembly, the wedge joint between pieces and the pin insertion joint between rings are adopted, which are common in shield tunnel construction (Fig. 1).

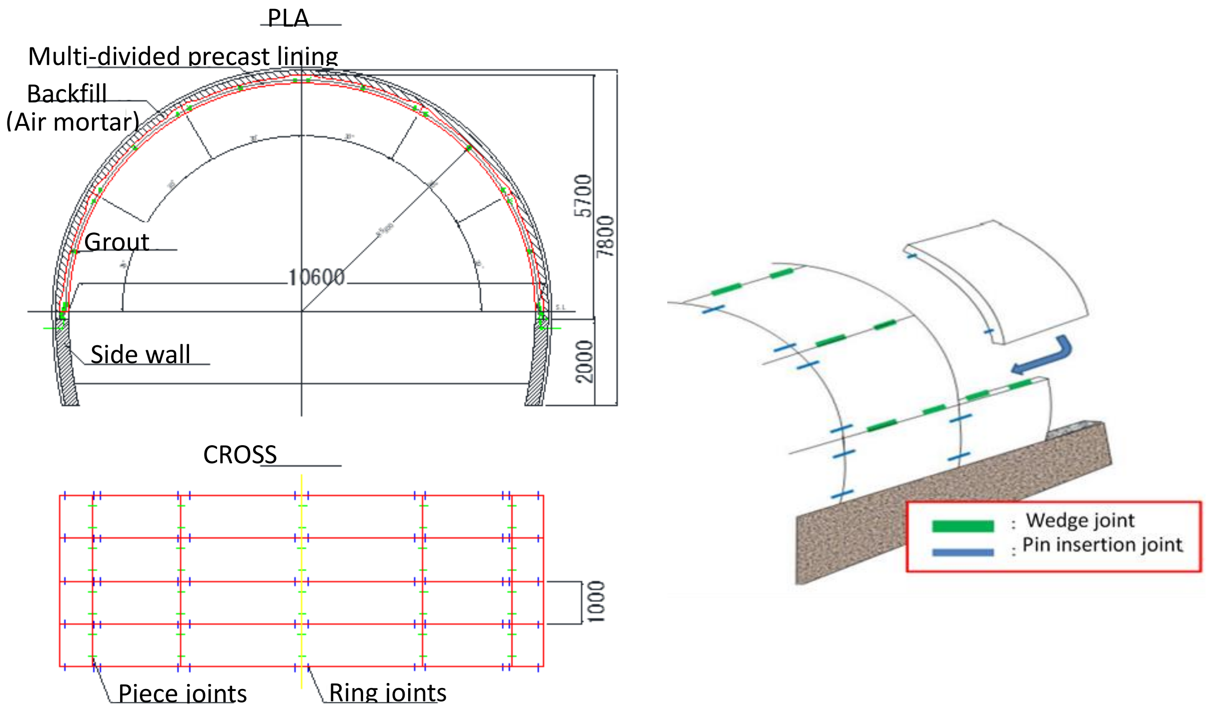

Fig. 1. The basic structure of multi-divided precast lining

The connecting part of the leg of the side wall concrete is designed as a pin structure, and the wedge joint between the pieces is designed as a rotating spring structure. As for the ring arrangement in the tunnel axial direction, the straight joints arrangement was adopted after the study on both of staggered arrangement and straight joints arrangement. Regarding the structural stability, following three states were examined; the self-supporting state after the ring was erected, the biased pressure loading state during backfilling performed from the grout holes of each piece, and the loading state of the ground load after backfilling.

The erection machine for the multi-divided precast lining system is a gantry type, unlike conventional heavy machines, that allows other vehicles to pass through the lower space. Therefore, excavation work and lining work can be done in parallel. This erection machine is composed of an erector-equipped assembly device and a shape retention device for retaining the ring shape after assembly (Photo 6). It travels on rails installed on the tunnel roadbed in the same manner as the travelling arch center. Multi-divided precast linings are erected by the assembly device in order from one side, and the shape of the erected linings are maintained by the shape retention device immediately after erection.

Photo 6. Erection machine for multi-divided precast lining

Full-scale verification experiment

2 rings of full-scale precast lining were assembled on the steel pedestal to check the assemble performance. And, assembled precast lining was jacked down to stand by itself to confirm the stability in the state (Photo 7). No significant deformation was observed in the self-supporting state.

Photo 7. 2-ring assembled precast lining

In addition, the bending test of the joint specimens of 2 pieces was carried out, and it was confirmed that the breaking load was higher than the design bending proof load specified by the material.

Future outlook

Currently, in parallel with the experiment, we are comparing the performance of the multi-divided precast lining and the conventional lining by non-linear analysis. Demonstration tests are now being carried out in the full-scale simulated tunnel to confirm the workability (Photo 8). After the experiment, we plan to apply this system to new tunnel constructions and renewal projects that require rapid construction of lining concrete.

This research and development have been carried out by the joint research with Shimizu Corporation and IHI Kenzai Kogyo Co., Ltd.

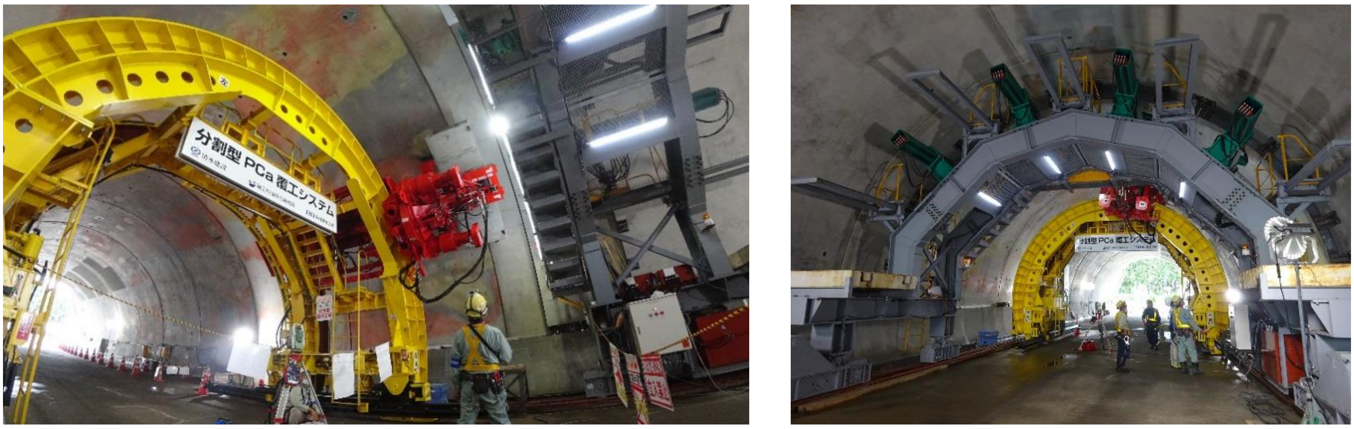

Photo 8. Demonstration test in the simulated tunnel at JCMMRI

Case (2) Development of On-Site Shot Printer

Background and overview

In the field of concrete, as one of the three pillars of i-Construction undertaken by the Ministry of Land, Infrastructure, Transport and Tourism, precast construction with factory products is being promoted. But there still exists more room left for research and development in this field, compared to productivity improvement in other fields. The joint research group has reached to the idea that the technology improvement required by the present society for the concrete field is not only the shift from on-site casting to application of precast factory products, but the development of a concrete structure manufacturing technology based on a completely new concept. Based on this idea, the group has been promoting research and development focusing on the resent 3D printing technology. In this research, we proposed a technology to build concrete structures by direct print modeling on-site, namely On-Site Shot Printer system. This technology is a combination of 3D printing technology and ICT construction technology, which have been active in recent years. In order to realize this system, the spraying technology of cement-based material, which is indispensable to this system, was deeply studied and succeeded to develop a new hybrid spraying system that has the advantages of conventional technologies of both "dry mix shotcrete" and "wet mix shotcrete".

Hybrid Spray System

Direct print molding on-site requires long-distance transport of material for molding. At the same time, it is important to secure the strength of the shaped article as a structure. The "dry mix shotcrete", in which the materials are individually conveyed and mixed and sprayed at the nozzle, is advantageous for long-distance transport. On the other hand, the "wet mix shotcrete", in which premixed materials are directory sprayed from the nozzle, is effective to obtain secure strength. Since both performances are necessary for the On-Site Shot Printer, we have developed the new Hybrid Spraying System that has the advantages of both technologies (Fig. 2).

In order to confirm the performance of the Hybrid Spray System, we conducted a spraying experiment aiming at the material transport distance of 160 m (the maximum performance of the system is 300 m) under the conditions that discharge volume is 18 kg / min and mortar flow is 170 mm. As the result of this experiment, it was confirmed that the mortar was stably supplied and sprayed with expected quality by the Hybrid Spray System.

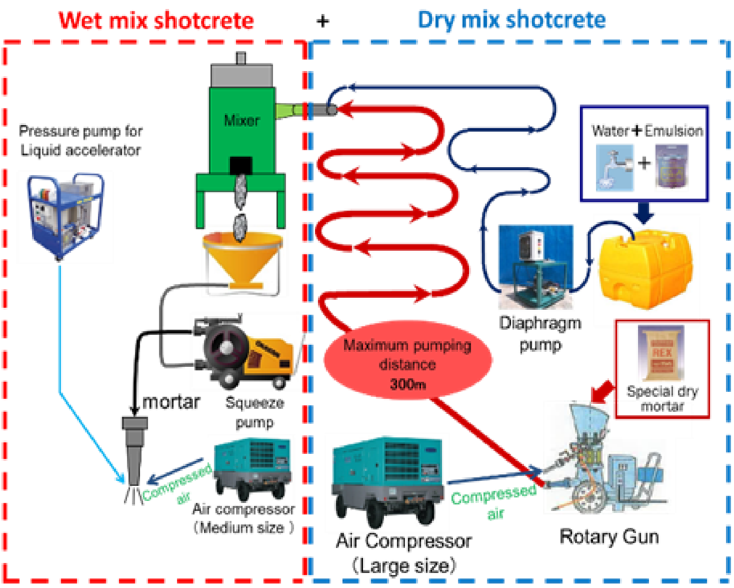

Fig. 2. Hybrid Spray System

Direct print molding on-site by utilizing ICT construction machinery

In order to build concrete structures by direct spraying on-site, the position and the movement of the spray nozzle must be properly and precisely controlled automatically. For this control, ICT construction equipment was decided to be utilized because they can be controlled by the computer program and is resistant to sever site conditions such as rain, wind and dust. The spray nozzle is attached to the bucket of the ICT aided hydraulic excavator. The position and the movement of the spray nozzle are controlled by the design data created and input to the ICT aided hydraulic excavator. By utilizing these ICT construction machine technologies, we succeeded in direct printing and molding concrete structures assuming walls and buried formwork at present.


Photo 9. Direct print molding of a wall


Photo 10. Direct print molding of buried formworks

Demonstration experiment was conducted at the field of JCMMRI. In this demonstration experiment, it was confirmed that a wall with about 1 m height and about 1.8 m width can be formed in about 60 minutes (Photo 9). Photo 10 shows a molding situation assuming buried formworks to be placed on the outer surface of a rectangular pillar with 1 m width × 1 m depth ×2 m height. It was molded up to a height of 1.5 m on each surface in about 25 minutes. These specimens were successfully constructed by direct print molding without any material crushing or peeling off.

Target utilization scene

At the present stage, the feasibility of using it as a buried formwork has been mostly verified, and the following uses are envisioned as directions for future research and development.

Phase1: Current stage
Buried formworks, especially for construction with difficulty in material transportation
Phase 2: Accurate and safe control stage (Fig. 3)
Large structural members of substructure such as abutment, pier, caisson, etc.
Phase3: Delicate control stage (Fig. 4)
Structural members of bridge superstructures such as floor slabs, guard walls, etc.

This research and development have been carried out by the research and development group consisting of Gifu University, JCMMRI, Sumitomo Osaka Cement, Shimizu Construction, NIPPO, Maruei Concrete Industry and FTS. It is supported by the Construction Technology R & D Grant System of 2019 (the Ministry of Land, Infrastructure, Transport and Tourism).

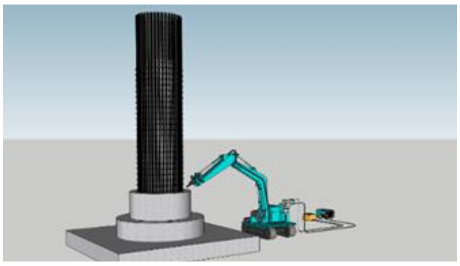

Fig. 3. Image of Phase 2

Fig. 4. Image of Phase 3

◆ A brief CV of Mr. Hiroyuki Takenouchi

Hiroyuki Takenouchi is the engineering adviser of Japan Construction Method and Machinery Research Institute. He joined the institute upon graduating from the Department of Civil Engineering of Tokyo Institute of Technology in 1974. Since then he has engaged in a number of research and development works on wide variety of construction method and machinery. He specializes in strength and durability technology of structures such as bridges. He is also the President of MK Engineering Inc., engaged in consulting business to protect infrastructure with knowledge, practice, and industry-government-academia networks.