

Shortened Construction Period with No Need for Lowering of Roadbed

Excellent reinforcing effect exhibited in narrow tunnels Partially thin PCL method

When a previously constructed tunnel is internally reinforced with high-performance PCL (Precast Concrete Lining) panels, the diameter of the tunnel is reduced. To address this issue, IHI Construction Materials Co., Ltd. has developed a construction method intended to increase the strength and reduce the thickness of part of a PCL panel to make it possible to reinforce tunnels without having to lower the roadbed.

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Partially thin PCL work



Erection of partially thin PCL panel

Clearance limit — Barrier to reinforcement —

In Japan, approximately 10 100 road tunnels are in service with a total length exceeding 4 300 km (as of 2015), and the number of road tunnels will be increasing in the future. Among these tunnels, those that have been in service for more than 50 years account for about 10% in terms of total length, and some of them have become deformed due to

causes attributed to external factors (external forces, environments) and internal factors (materials, construction, design), requiring that measures be taken. For tunnels suffering such deformations, various reinforcement measures are being implemented with the aim of improving their load-carrying capacity. To date, however, it has been difficult to implement adequate reinforcement measures because roadbeds had to be lowered, i.e., digging had to be done to lower the road surface to meet the clearance limit, which

contributed to prolonged construction periods and increased costs. For this reason, we have developed the partially thin PCL method as a measure for tunnels whose cross-sections are not large enough to meet the clearance limit based on the conventional PCL method, which has been used in tunnel reinforcement measures, through joint research with the Public Works Research Institute (PWRI), which is a National Research and Development Agency, and four companies affiliated with the PCL Association (IHI Construction Materials Co., Ltd. (IKK) serves as the Secretariat of the PCL Association).

What is the PCL method?

The PCL method collectively refers to the design, manufacture, and execution methods related to the lining method that uses a concrete panel intended for the interior wall, finish, repair, or reinforcement of tunnels. As illustrated below, a concrete panel constitutes a three-hinge structure having one hinge each at the top joint, at the connection with the left-side wall, and at the connection with the right-side wall. Specifically, work is executed as follows. With reference to the springline of a tunnel (the line in the cross-section of a tunnel at which the arch of the upper-half starts), side walls are constructed using the cast-in-place concrete method to form the lower half. After a waterproof sheet has been attached to the inner surface of the existing lining concrete of the upper half of the

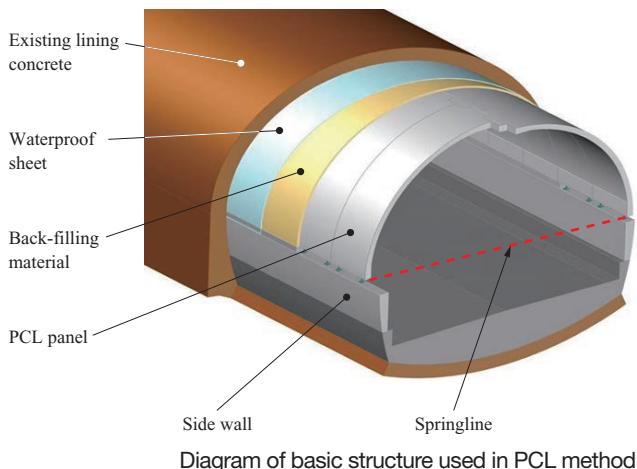
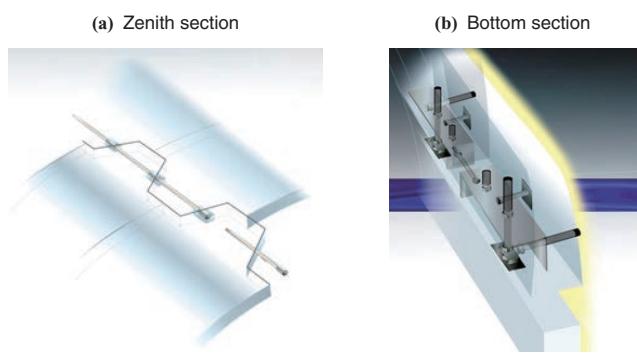
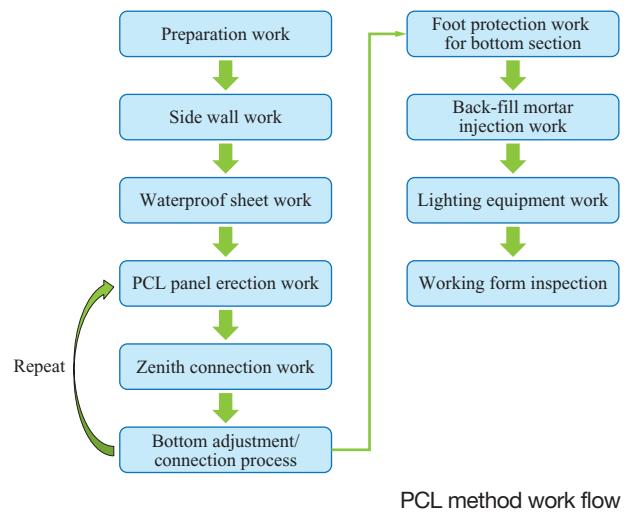


Diagram of basic structure used in PCL method



Detailed view of connection of PCL panel



PCL method work flow

tunnel as a water leak prevention measure, separate parts of a PCL panel — two parts, in principle — are erected, with the zenith and bottom sections bolted together. Then, the gap between the waterproof sheet and the PCL panel is filled with a back-filling material such as mortar. The main features of a PCL panel are as follows.

- (1) It is a high-quality product that is produced at a factory under strict quality control.
- (2) Since the gap between a PCL panel and the existing lining concrete is filled with a back-filling material, high stability can be expected against unforeseeable loads as well.
- (3) Since a single-purpose erection machine is used, construction periods can be shortened.
- (4) Erection work can be executed while one lane is open for one-way alternating traffic although the work involves temporary lane control.
- (5) Since the PCL panel is only connected to the side walls of the existing tunnel, preparation work is easier.
- (6) Compared with the conventional technique (lining reinforcement with the cast-in-place concrete method), the PCL method enables cost reduction by 30% for 30 m of work area.

A typical workflow of the PCL method is shown in the figure above.

The most appropriate method can be selected according to on-site conditions

The method of erecting a PCL panel (erection machine) can be selected with consideration given to traffic conditions, the weight of the PCL panel, the total length of the work area, economic efficiency, and so forth in a comprehensive manner.

The following are the standard methods of erecting a PCL panel.

- (1) Self-propelled single-purpose machine mode
- (2) Forklift mode
- (3) Truck-mounted simple erection machine mode
- (4) Self-propelled assembly platform mode



Self-propelled single-purpose machine mode



Forklift mode

- (5) Platform towing mode
- (6) Side wall running mode
- (7) Single-purpose erector mode

The self-propelled single-purpose machine mode and the forklift mode, which are generally used, are exemplified on the top of this page.

Works can be executed with a tunnel open for traffic (one-way alternating traffic)

When construction work is executed in a tunnel, it is difficult to construct an alternative arterial road that is essential for local living or an adequate bypass in neighboring areas. It is therefore needed to execute the work while the tunnel is open for traffic (one-way alternating traffic). The PCL method uses an erection machine specifically for PCL construction work to enable such works to be executed with one-way alternating traffic, thereby reducing the inconvenience to local residents and road users.

Partially thin PCL method

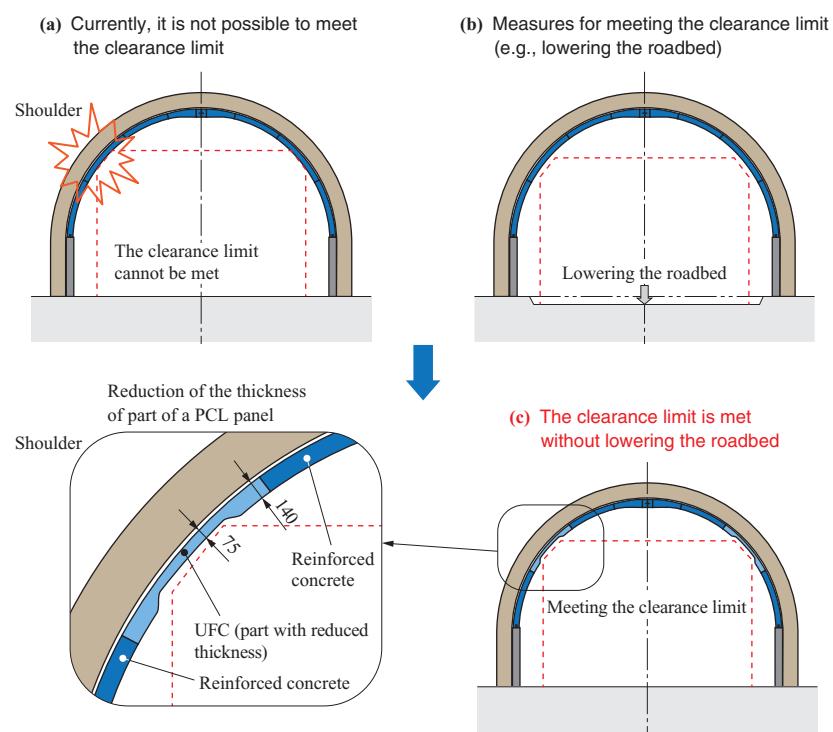
Some tunnels showing deformity were constructed many years ago and have a cross-section that is not large enough to meet the clearance limit. The PCL method, in which an arc-shaped precast concrete panel is erected, is a reinforcement method that effectively provides compression force under these conditions. In some cases, however, even if the PCL method is adopted, the existing roadbed needs to be lowered so that the shoulders of the PCL panel meet the clearance limit. Therefore, we have developed the partially thin PCL method, which is designed to reduce the thickness of part of the left and right shoulders of the upper arch, which are

bottlenecks to meeting the clearance limit.

The partially thin PCL method has the following features.

- (1) Ultra-high strength Fiber reinforced Concrete (UFC) is used as the material for the part with a reduced thickness to ensure rigidity and load-carrying capacity.
- (2) This method can be used for tunnels that cannot meet the clearance limit without lowering the roadbed.
- (3) The erection method used in the conventional PCL method can be used without modification.

UFC is an ultra-high strength cementitious composite material reinforced with fiber and has a compression strength of UFC 150 N/mm².



Schematic diagram of partially thin PCL panel (unit: mm)



Full-scale test

Compared with ordinary concrete, UFC has much lower permeability, air-permeability, and chloride ion diffusion coefficient while having excellent salt-damage resistance, abrasion resistance, and shock resistance.

Doubled load-carrying capacity, shortened construction periods, and cost reductions

With the objective of verifying the performance of partially thin PCL panels, we conducted a reinforcement experiment in which a partially thin PCL panel was compared with conventional cast-in-place lining concrete using a full-scale device for loading tests of lining owned by PWRI.

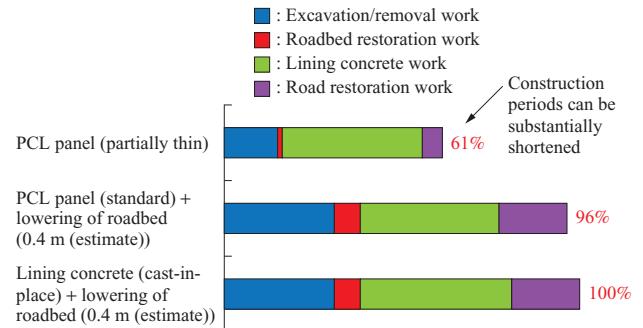
The results demonstrated that the partially thin PCL panel had about twice the load carrying capacity of the cast-in-place lining concrete.

The adoption of the partially thin PCL method eliminates the need for lowering roadbeds to meet a clearance limit. Given this, it is estimated that construction periods will be shortened by 39% compared to when the conventional cast-in-place concrete lining is used (about 36% compared to the conventional PCL method).

In addition, it is also estimated that the partially thin PCL method will reduce costs by 12% compared to the conventional cast-in-place concrete lining (however, the partially thin PCL method is comparable to the conventional PCL method in terms of cost).

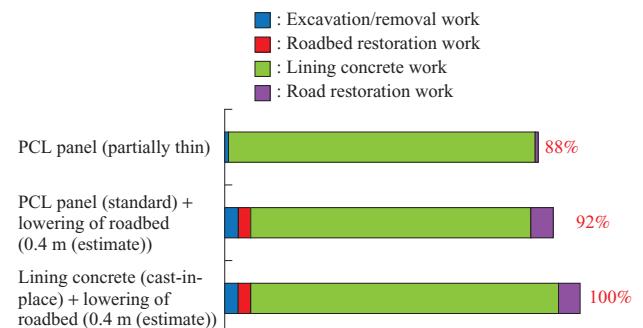
Future development

The developed partially thin PCL method achieved a larger scope of application than that of the conventional PCL method. In addition, the partially thin PCL method was confirmed to be comparable to the conventional PCL method in terms of total construction cost. However, with respect to the manufacturing cost of PCL panels, the partially thin PCL method has a challenge. Specifically, that the UFC parts of the partially thin PCL panels with a reduced thickness need to be manufactured at specialized factories; thus, the cost of transportation between the UFC factory and the concrete factory arises. Moreover, two forms — one for parts with a reduced thickness and the other for standard parts — are needed. Consequently, the manufacturing cost is higher,



- (Note) Conditions assumed for comparison
 - Total length of work area $L = 30.0\text{ m}$
 - Section subjected to lowering of roadbed : 90.0 m (consideration given to transition area)
 - Height reduced by lowering of roadbed $h = 0.4\text{ m}$

Comparison of construction periods (example)



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Comparison of costs (example)

compared with conventional PCL panels.

We hope to select a new material and develop a new type of partially thin PCL method, which will use a composite structure consisting of steel plates and concrete in order to achieve further cost reductions, thereby providing customers with satisfactory products.

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