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Technical Report

Development of a Construction Method That Enables Rapid Replacement of RC Decks with Advanced Steel Deck without Road Closure (STEEL-C.A.P. Method™)

Tomonori TOMINAGA*
Kohichi YOKOZEKI
Sayuri KITAICHI
Masakazu TAKENO
Junji CHO
Hiroshi IKI
Daisuke TAKEUCHI
Taro TONEGAWA

Abstract

In recent years, the replacement of RC decks has been increasing, especially on expressways. However, when RC decks are replaced with concrete type decks, the entire roadway must be closed to traffic because of the construction time required, environmental problems such as noise and vibration arise because the concrete on the girders must be removed with breakers, and the increased weight reduces earthquake resistance, requiring reinforcement of piers and piles. Thus, the STEEL-C.A.P. method™ was developed, which allows the construction of lightweight steel decks with high fatigue durability in a short time only at night by covering them while leaving the concrete on top of the main girder in place. This paper describes the features of this method, the results of the mock-up test to demonstrate its short construction period, the results of evaluation of the structural characteristics by loading tests, and the outline of the first application of this method. The practical application of this method will minimize cost, environmental impact, and social loss by enabling the renewal of decks for each lane during nighttime construction only.

1. Introduction

Recently, the deterioration of social infrastructure constructed during the high-growth period has been causing various issues in Japan. Among them, one serious issue is the replacement of reinforced concrete (RC) decks. It is estimated that the replacement of RC decks will account for more than half of the entire large-scale replacement and repair projects by the Japanese expressway companies. For deck replacement work in cities, in particular, there are demands for shorter construction periods to reduce social loss. There are also needs for construction methods in which construction work is carried out only at night by closing only one lane if possible. In the daytime during the construction period, all other lanes are required to be passable for traffic.

Meanwhile, when decks that were constructed according to old laws, regulations, and standards are to be replaced with new ones, the new laws, regulations, and standards must be naturally followed. However, if concrete-type decks are used, an increase in the dead loads is inevitable due to the influence of expansion of the road width and use of thicker decks. An increase in the decks' dead loads demands further reinforcement of the girders, which may require reinforcement of the bridge piers due to decreased earthquake resistance, which in turn demands reinforcement of the substructure due to insufficient resistance capacity.

Moreover, environmental matters are important in cities. Because construction work may be carried out at night, preventing noise and vibration is particularly important. In addition to noise and vibration, reducing dust and foul odors also needs to be considered. In conventional RC deck replacement methods, the concrete above the main girders with studs cannot be easily removed. Accordingly, such concrete must be removed by humans using break-

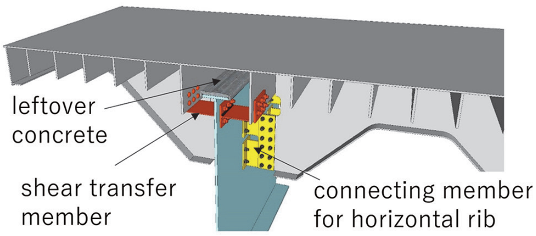
* Senior Researcher, Dr.Eng., Steel Structures Research Dept.-I, Steel Structures Research Lab., Steel Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

ers, which makes it impossible to reduce the construction time and also poses a severe environmental issue.

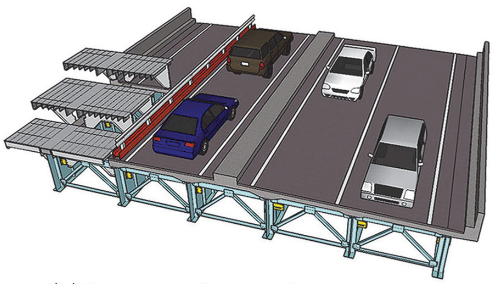
To resolve such issues, we collaborated with Yokogawa NS Engineering Corporation to develop the Steel deck Composite, Adjustable to Plate girder method (STEEL-C.A.P. method™) that realizes replacement with light-weight decks. With this method, the concrete above main girders, which is an issue, is partly left in place to shorten the construction period and resolve the environmental issue. This paper describes the STEEL-C.A.P. method's features and our work to date.

2. Outline and Main Advantages of STEEL-C.A.P. Method™

Figure 1 is a schematic drawing of the proposed structure. Removing existing RC decks above the main girders near shear connectors takes the most time and effort. Accordingly, part of the concrete on the main girders that would not be able to be cut simultaneously is left in place and steel decks are positioned so as to cover the remaining concrete. If connecting members for horizontal ribs and splice plates have been installed on the main girder webs in advance, steel deck horizontal ribs can be easily joined to the main girders by high-tensile bolted friction joints via the preinstalled connecting members for horizontal ribs. Preinstalled steel deck panels and steel deck panels to be installed later are joined by general high-tensile bolted friction joints.



(a)Connection structure of girder and deck



(b)Renewal of decks for each lane

Fig. 1 Outline of STEEL-C.A.P. method™

Thus, the existing main girders and steel deck panels transmit loads only via the bolts as their structure. Therefore, once bolt joining is completed, vehicles can travel on the steel deck panels. As described above, the removal of existing concrete decks and installation of steel deck panels can be carried out in a very short period of time. It may suffice to close one lane only at night to replace two or three panels and temporarily pave the joints between the panels; the lane can be opened in the morning.

In addition, with the lanes passable, the steel deck panels and main girders are joined with shear transfer members, which reduces stress occurring on the main girders, which in turn prevents fatigue damage. Moreover, as an option, mortar may be charged into the clearance between the concrete remaining on the main girders and the steel deck panels in the final stage of the construction work. However, this is not to enhance the strength but to prevent corrosion. Without charging mortar is also acceptable if the ease of visual inspections is prioritized.

The structure of steel deck panels used in this construction method was invented by the replacement steel deck panel study group of Tokyo City University.[1)] The deck plate thickness is 12 mm. It was verified by FEM that fatigue damage would not occur on the light-weight panels even under the heavy traffic of Tokyo Metropolitan expressways. The joint structure with main girders was also studied by FEM and it was verified that there would be no problem related to fatigue.

Table 1 lists the advantages of this construction method when comparing replacement with conventional precast concrete decks based on the features described above. The comparison shows that the more severe the construction conditions are, the more the superiority of this STEEL-C.A.P. method™ may be exerted.

Various experiments and analyses were carried out to demonstrate the performance of this construction method. Chapter 3 below describes the main such experiments and analyses.

Table 1 Advantages over conventional methods

	Precast concrete decks	STEEL-C.A.P. method™
Construction speed	Slow due to chipping, cleaning, stud re-installation, mortar hardening time required, etc. at the top of the main girder.	Fast due to concrete left on top of the main girder, bolted construction.
Noise vibration dust	Breaker work required at the chips; cleaning required.	No breaker/cleaning work required
Degree of freedom of construction	Support girders (longitudinal and transverse girders) are required depending on the slab cutting position.	High degree of freedom in cutting position
Safety	Girder generated stresses increase with each successive replacement due to weight increase	The weight is reduced as the replacement progresses, and the upper flange is not modified, which does not result in reducing load capacity.
Road widening	Even in the condition of replacing with the same width, weight is increased, thus, widening road is difficult.	Easier due to lighter steel decks
Seismic resistance	Decreased due to increased weight	Improved due to lighter steel decks
Composite girder	Stud placement in slab holes may be difficult in this case.	Possible by shear transfer members
Incidental costs	Reinforcement and environment-related costs are large.	Reinforcement-related costs are small.

3. Main Experiments

3.1 Mock-up test and proof-loading tests using an actual vehicle

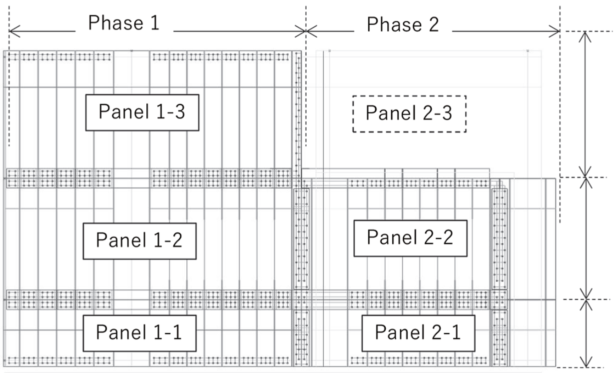
To confirm the concept of this construction method and verify the floor panel model used for the study, a mock-up test and proof-loading tests using the mock-up test specimen and an actual vehicle were performed.

According to the standard bridge structure for urban expressways (simply-supported, composite, 6-main girder bridge, span length ≈ 40 m), the mock-up test specimen shown in **Fig. 2** was fabricated, which simulated two lanes on the one side of the bridge (Fig. 1 (b)) cross-section and three steel deck panels in the bridge longitudinal direction. The mock-up simulated an RC deck composite girder involving shear studs as an existing structure before re-decking. The steel decks for the replacement widened the cross-section by extending the cantilever length outside the G1 girder by approximately one meter compared with the RC deck.

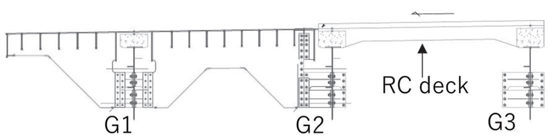
The decks were replaced from lane 1 by placing steel deck panels one by one until three panels were installed, followed by final tightening of the high-tensile bolts. Then the decks of lane 2 were replaced with new panels. The construction time for each fabrication phase was measured.

Figure 3 shows panel erection. All phases were smoothly implemented without any problems such as fit-up issues in connections and shortage of the workspace. An additional measurement for minimization of the fit-up issue was also successfully implemented without significant delay, whereby in-situ drilling of the bolt hole was conducted at the connection between steel deck transverse ribs and split T-shaped mounting parts preinstalled on the main girders. The construction time calculated based on this test is shown in **Fig. 4**, by comparing with the general precast deck replacement time when two panels are replaced at night[2]. It indicates that construction work is feasible by one-lane closure only at night. It also means that more panels can be replaced in the case of the STEEL-C.A.P. method™ when the construction time is the same.

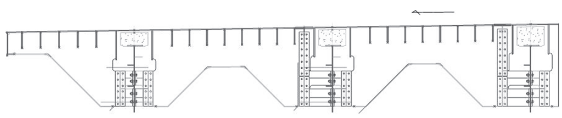
Moreover, the proof-loading test using an actual truck (**Fig. 5**) was carried out at each phase: after the first lane was re-decked; after the second lane was re-decked but before mortar charge to the space between the main girders and the steel deck; and after the curing of charged mortar. The proof-loading test results demonstrate that even the minimum erection system (state in Fig. 2 (b)) can secure sufficient safety and verify the FEM model used for numerical studies for this series of research and development.



(a) Ground plan (phase 2 almost completed)



(b) Cross section (phase 1 completed)



(c) Cross section (phase 2 completed)

Fig. 2 Outline of mock-up test specimen

3.2 Performance of girder in which shear transfer member is installed

A distinctive part in this structure is the shear transfer member

Fig. 3 Panel erection in mock-up test

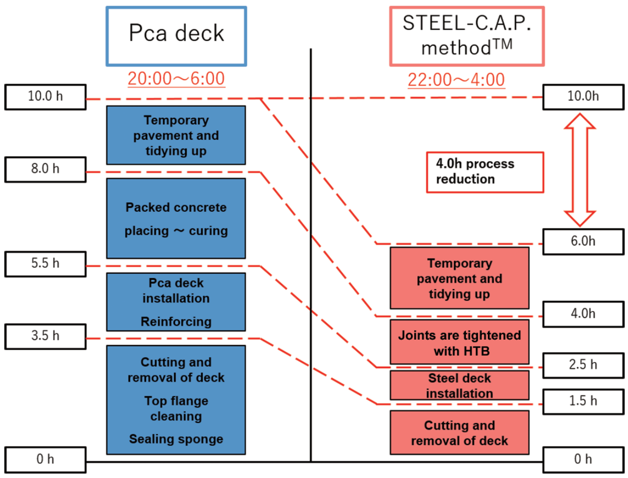


Fig. 4 Comparison of required construction time[2]

Fig. 5 Proof-loading test using the mock-up test specimen

shown in Fig. 1 (a). A girder loading test was carried out to study the appropriateness of the design method and demonstrate the shear transfer member's effect on reducing the main girder's sectional force. Moreover, by applying up to the maximum load finally, the ultimate state as a result of the STEEL-C.A.P. method™ was investigated.

Figure 6 shows the loading state. **Fig. 7** shows the arrangement of shear transfer members. **Figure 8** shows the results of the test and FEM analysis. The rigidity obtained by the FEM analysis well matches that measured in the test, which confirms the appropriateness of the design method of the shear transfer member and girder stress reduction effect. Moreover, a test to check the ultimate state was performed in the final stage when the shear transfer members were sparsely arranged as TYPE-2. The test demonstrated that even when the upper flanges of the main girders buckled, the steel decks transfer the stress and thereby the load does not decrease. The FEM analysis results shown in Fig. 8 also show that for TYPE-0 in which no shear transfer members are arranged, when the upper flanges of the main girders buckled, the load decreases; and for TYPE-1 in which the members are densely arranged, the flange buckling itself does not occur because the reduction of the stress generating on the main girders is large.

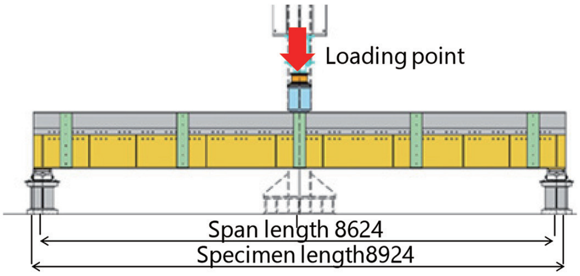


Fig. 6 Outline of girder loading test

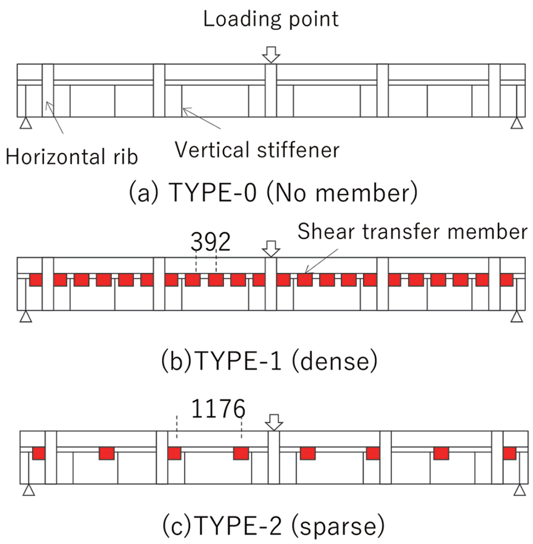


Fig. 7 Arrangement of shear transfer members

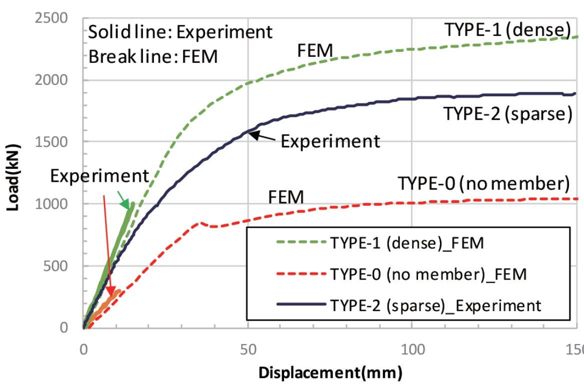


Fig. 8 Results of girder loading tests and FEM analysis

4. Construction Work for the First Application and Expectations for the Future

In the previous development of products for bridges, such as Kakuta Bridge™, Panel Bridge™, and nickel-added weather-proof steel, etc., facilities in Nippon Steel Corporation were used to conduct first applications. The STEEL C.A.P. method™ was applied to the Midorikawa bridge owned by Kyushu Works with completion of the construction planned in January 2023. For the steel deck panels, Corrosion Resistance Steel for Painting Cycle Extension (CORSPACE™) was adopted for the first time in Kyushu. CORSPACE™ extends the intervals between recoating and thereby contributes to LCC reduction. Newly developed high-tensile bolts with the CORSPACE™ specification were adopted for the first time.

Figure 9 shows the current state of the Midorikawa bridge and a general drawing after the construction work. In this construction work, the road is expanded and the newly developed deck replacement machine shown in **Fig. 10** is applied to further improve the construction efficiency. **Figure 11** shows the replacement work. The photograph shows that although the site is narrow, construction is carried out in one lane by a single machine that does all the tasks of RC deck removal, steel deck panel installation, and transfer of the

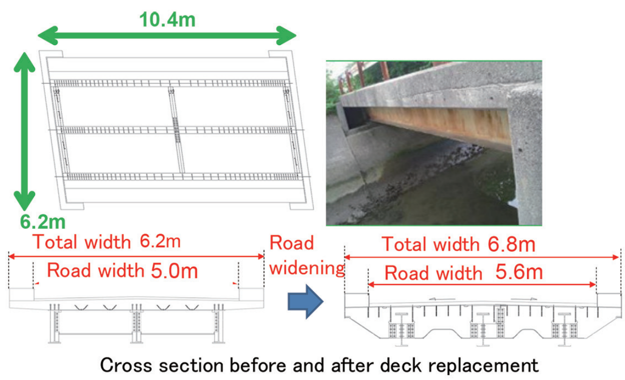


Fig. 9 Outline of Midorikawa bridge

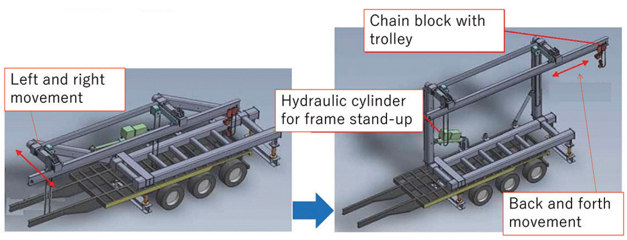


Fig. 10 Deck replacement machine

Fig. 11 Midorikawa bridge under deck replacement work

materials.

Realization of this construction method makes deck replacement work on expressways where no detours can be constructed possible and also enables renewal (deck replacement) of bridges on general roads in short construction periods. It used to be necessary to reconstruct such bridges from the foundations to replace the decks. This method could minimize costs and social loss.

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1) Yokozeki, Yokoyama, Tominaga, Miki: Fatigue Enhancement of Longitudinal-to-transverse Rib Connection in Orthotropic Steel Deck. Journal of Japan Society of Civil Engineers A1. 73 (1), 206–217 (2017)
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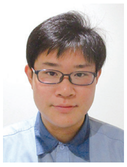
Tomonori TOMINAGA
Senior Researcher, Dr.Eng.
Steel Structures Research Dept.-I
Steel Structures Research Lab.
Steel Research Laboratories
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

Kohichi YOKOZEKI
Senior Researcher, Dr.Eng.
Steel Structures Research Dept.-I
Steel Structures Research Lab.
Steel Research Laboratories

Sayuri KITAICHI
Researcher
Steel Structures Research Dept.-I
Steel Structures Research Lab.
Steel Research Laboratories

Masakazu TAKENO
Senior Manager
Project Development Engineering Dept.
Project Development Div.



Junji CHO
Equipment Div.
Kyushu Works

Hiroshi IKI
General Manager
Plate Technical Service & Solution Dept.
Plate Technology Div.
Plate & Construction Products Unit

Daisuke TAKEUCHI
Executive officer, Dr.Eng.
Yokogawa NS Engineering Corporation

Taro TONEGAWA
Dr.Eng.
Yokogawa NS Engineering Corporation