Technical Report

Development of High-performance Steel Decks and Design Support Tools

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Abstract

Nippon Steel Metal Products Co., Ltd. (hereafter referred to as NSMP) has developed and introduced various steel decks into the market to support steel structure. In recent years, we have developed a high-performance steel deck that is different from the conventional concept. We are also developing not only hardware, but also software. In order to improve the work efficiency of structural engineers, we will introduce the automatic layout system of steel decks using BIM (Building Information Modeling) and the new functions added to the NSMP steel decks design support system.

1. Development of High-performance Steel Decks (Cynos deck™)

1.1 Introduction

The technology of steel decks for composite slab (hereafter referred to as composite floor decks) was introduced by the US in the 1970s, and subsequently, triggered by the establishment of coatless refractory technology, composite floor decks have spread widely in this country for use mainly in steel structure. From the very beginning, Nippon Steel Metal Products Co., Ltd. has continued to uniquely promote product development, starting with the composite floor deck “E deck (EV50)”, improved type “Super E deck (EZ50, EZ75)”, a current major product, and in 2005, the 120 mm in height type “HYPERDECK™” compatible with long span. Furthermore, regarding the formwork use, NSMP developed the “SF deck™” in 1992, its improved type “SF Eco™” in 2015, and “Akros Deck™” for long-span use in 2016. Thus NSMP continues to grasp the changing times and customers’ needs and continues to introduce new products.

Recently, in order to solve the problem of concrete cracking, a problem of the deck composite slab that takes place due to sections of unequal thickness, and to improve dwelling performance, the development of “Cynos deck™”, the composite floor deck having sections of equal thickness, was promoted and was placed on the market in 2018. This report introduces the “Cynos deck™.”

1.2 Product concept

The sectional configurations of the conventional composite floor decks are shown in **Fig. 1**, wherein the repeating parallel configuration is generally adopted prioritizing practicality, and special unevenness is provided in order for the concrete to be composite with the deck. Herein, practicality means primarily the economic rationality to promote weight reduction by reducing the amount of concrete while maintaining the form-working performance. However, there are problems: cracks tend to develop on the surface of the floor slab due to the difference in concrete contraction speed, and the deterioration of sound insulation performance due to weight reduction.

“Cynos deck™” is a reverse type of formwork use, and is a product in which the composite effect with concrete is secured by the embossed vertical ribs buried in concrete. The aforementioned formwork uses steel “Akros Deck™” for long-span usage is utilized reversibly, and is an unprecedented steel deck that can be used for two applications with only one sectional configuration.

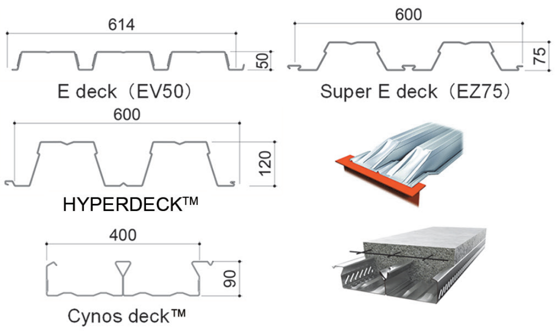

Fig. 1 Composite floor decks

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1.3 Public authority

The appraisal of the designated performance appraisal institution was obtained in 2002 with respect to the conformity as steel deck to notification No.326 of the Ministry of Land, Infrastructure, Transport, and Tourism, and additionally, with respect to the security of the structure and the safety in construction conforming to the Design and Construction Manual for Steel Deck Structure (edited by the Japanese Society of Steel Construction)[1]. Furthermore, for steel structure usage, two-hour fireproof approval was obtained for both normal-weight concrete and light-weight concrete, and applications in a wide range of within a maximum load of 35 kN/m^2 (177% increase from the conventional product) and a maximum span of 4.5 m (125% similarly) have become feasible.

1.4 Cracking test (test of application of repeated wheeling load)

Wheel load traveling tests simulating the traveling of forklifts on the floor slabs in physical distribution facilities, for instance, were conducted, and changes in crack width and deflection with time were measured.

1.4.1 Test specimen

In these tests, two slab types are compared; one is the composite deck slab using “Cynos deck™” with a floor slab thickness of 180 mm (hereafter referred to as Cynos), and the other is the conventional floor slab (RC slab). The parameters of the test specimens are shown in **Table 1**, and the profile and the size are shown in **Fig. 2**. Concrete of nominal strength of 18 N/mm^2 was positioned so that the compressive strength at the time of test start becomes about 24 N/mm^2 (**Table 2**). The reinforcing bars of the conventional floor slab were D10@200 (SD295), and single-layer bars were arranged in Cynos. In the conventional floor slab, bars were arranged doubly, one on the top side and the other on the bottom side. In the conventional floor slab, headed studs were used for connection.

1.4.2 Loading method

Loading was applied by using a self-running type moving wheel load exerting device. The wheeling load of the test device was 70 kN, and in order to simulate the condition of a 20 kN forklift (vehicle gross weight: 53 kN inclusive of load weight) running on the floor slab two million times, and converted by the power law of multiplication by 12.7 times, evaluation was conducted at a converted 60 thousand times of running (2 million times/(70 kN/53 kN)$^{12.7}$ ≈ 60 thousand times).

Table 1 Test parameters

Specimens	Slab thickness	Reinforcement	
		Entire floor	Above the beam
Composite slab of Cynos deck™	180 mm	D10@200 Single	D10@200, L=1 100 mm
RC slab	180 mm	D10@200 Double	D10@200, L=1 100 mm

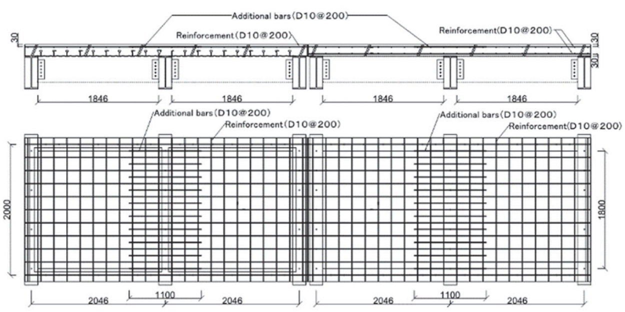

Fig. 2 Specimens profile and size (Left: Cynos, Right: RC slab)

1.5 Result of test

1.5.1 Crack width

Figure 3 shows the cracking states at the 20 000th running and 60 000th running. On the upper surface of the floor slab, cracks running along the center beam in either specification are observed. Cracks progressed in the entire width in the short side direction during the period from ten thousand times running to twenty thousand times running (reversely converted equivalent to 680 thousand times running). However, after that, cracks did not progress noticeably, and the crack width in either specimen converged to about 0.2 mm at the 70 000th time running (reversely converted equivalent to 2 400 thousand times).

1.5.2 Deflection amount

Figure 4 shows the change of the elastic deflection at the center of the floor slab (actually measured maximum value) over time. The vertical axis shows the deflection in the center of the floor slab, and the horizontal axis shows the running frequency. In Cynos, deflection rapidly increases until it reaches a little less than 1.0 mm at the 1 000th running frequency, and after that, gradually increases and reaches about 1.5 mm at the 60 000th running (reversely converted equivalent to 2 050 thousand times running). On the other hand, in

Table 2 Concrete and reinforcement test results

Test date	σ_c (N/mm^2)	Ec (N/mm^2)	Type (SD295)	σ_y (N/mm^2)	σ_u (N/mm^2)	Elongation (%)
Start date	25.3	25 500	D10	335	488	18.2
End date	30.0	25 300				

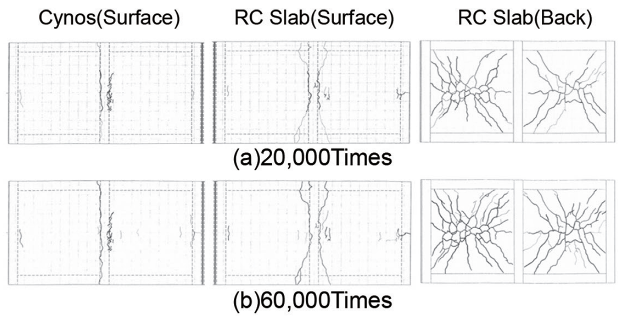

Fig. 3 Cracking diagram

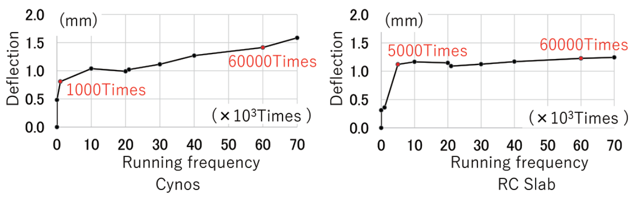

Fig. 4 Change over time of elastic deflection

the conventional floor slab, deflection rapidly increases to about 1.2 mm at 5 000 times (reversely converted equivalent to 170 thousand times running) and maintains a constant value afterward.

The above result confirmed that the cracking character of Cynos developed by traveling of wheel load does not differ greatly from that of the conventional floor slab.

1.6 Establishment of a design method for reinforced concrete structure

As a new market for "Cynos deck™," application to reinforced concrete structures like that of apartment houses is promoted. Upon application, ① elongation of span length, and ② high dwelling performance are required, and security of higher sectional stiffness is essential. In the current composite deck slab design system, the upper limit of the effective concrete thickness is 100 mm above the top of the deck, and design by using an effective equivalent section is implemented. Then, reexamination of the effective concrete thickness, and the establishment of the design method using overall equivalent sections incorporating groove reinforcing steel bars were studied.

The specification of the test piece is shown in **Table 3**, and the slab section and the bending aspect are shown in **Fig. 5**. A reinforcing bar (D10) is arranged in each valley of the steel deck, and bending tests were conducted, taking support span, shear span, and the floor slab thickness as variables. **Figure 6** shows the load-deflection relationship obtained from the test (selected from A3.0-200). In this test, in order to make the floor slab thickness uniform, concrete was placed by using a support when the test piece was manufactured. The result of the measurement of the deflection due to self-weight when the support was detached and the ratio of the self-weight vs. long-term allowable load are shown together. Herein, the remaining strength of the long-term allowable load (W_a) reduced by the self-weight (W_{DL}) is defined as the long-term allowable live load (W_{aLL}). In all test pieces, the test values of stiffness exceed the calculated values, and it is confirmed that within the range below $W_{aLL}/3$, the stiffness progresses with the overall equivalent section stiffness. Furthermore, with respect to the effective concrete thickness, the design of a composite deck slab up to a total thickness of 250 mm

Table 3 Test specimens

Names	Support span (m)	Shear span (m)	Width (mm)	Slab thickness (mm)	Concrete strength (N/mm²)	Deck YP (N/mm²)	Test weight (kN/m)
A3.0-200	7.0	3.0	800	200	33.4	314	3.92
B3.0-200	7.0	3.0	800	200	16.4	314	3.93
A3.0-250	7.0	3.0	800	250	33.4	314	4.89
A2.0-250	5.0	2.0	800	250	33.4	314	4.90

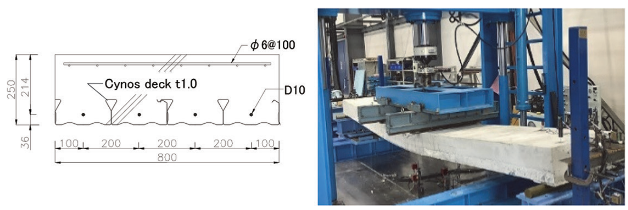

Fig. 5 Slab section and bending test

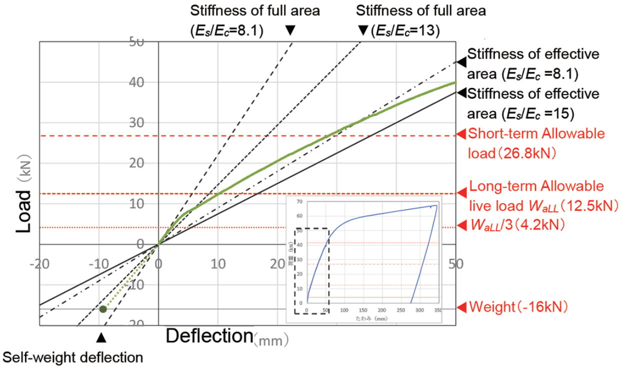

Fig. 6 Load-deflection relationship

with 160 mm above the top is feasible. As the condition of employing moment of inertia of area of the overall equivalent section for the study of the deflection, although the upper limit value (56%) is imposed on the "self-weight/long-term allowable live load" in order to limit the study to the range verified by the experiment, with this, the design of a composite deck slab of up to a maximum of about 7 m is possible. Further, this design method has obtained the appraisal of the designated performance appraisal institution.

2. Development of Deck Plate Design Support Tools

2.1 Automatic layout system of steel decks for BIM model

2.1.1 Background and objective

Recently, the introduction of the workflow employing Building Information Modeling (BIM) as the platform of the architectural production process has been spreading, and the effective utilization of the morphological information and the attribute information of material components is under examination.

Herein, for the deck plate used as the floor slab of steel structure, conventionally the template expressing only rough morphologic information is provided, and sufficient attribute information to be effectively utilized in structural design, fireproof design, and materials management has not been provided.

Composite decks consist of pluralities of sub-materials such as cracking growth-suppressing reinforcing bars and spacers in addition to deck plates and concrete. In the construction of deck plates, unit decks of a standard width (600 mm or 400 mm) are laid all over the width with each unit deck plate fitting each other. Depending on the gap with respect to the beam at the end of laying, a deck plate of half the width of that of the standard plate (half plate) or a width adjustment plate (100 to 250 mm wide) is used so that all of them are laid out without a gap. In this regard, before starting construction, a layout chart that specifies the arrangement of such is to be completed, based on which the length and number are calculated, and a detailed construction plan is devised in the subsequent process. Currently, streamlining of the downstream process by means of front loading utilizing BIM is in progress, and the improvement of operational efficiency is promoted by developing an automatic layout system of steel decks using BIM.

2.1.2 Overview of automatic layout system of steel decks

The developed automatic layout system is intended for the all-purpose BIM software, and by using a Geometric Description Language (GDL) object, the regulation that is the basis of the automatic layout system is implemented as a script, and thus unnecessary data growth, a problem of BIM is prevented.

Figure 7 shows the judgement flow of flushing for the adjustment at the completion side of laying deck plates. As for the entire width for laying L_w, the laying of the standard plate is started at the laying-starting side and continued. n is taken as the number of the already laid deck plates when the remaining gap width becomes less than the standard deck plate width. Then, corresponding to the remaining gap width $_sL_w(n)$, whether a half plate is required or not, or how many width adjustment plates are required is judged according to the flow.

Figure 8 shows the result of the implementation of the automatic layout system with BIM. On the planar display, deck plates can be automatically laid out by designating the layout range. In addition, at the same time, the system is designed to be an object capable of presenting other materials of components that constitute the floor slab such as concrete, reinforcing bar, and spacer (**Fig. 9**). When the layout of deck plates is completed, the composite deck slab modeling is completed simultaneously, and the separate work for modeling concrete and reinforcing bar is saved. Calculation of the amounts of various constituent materials is also possible.

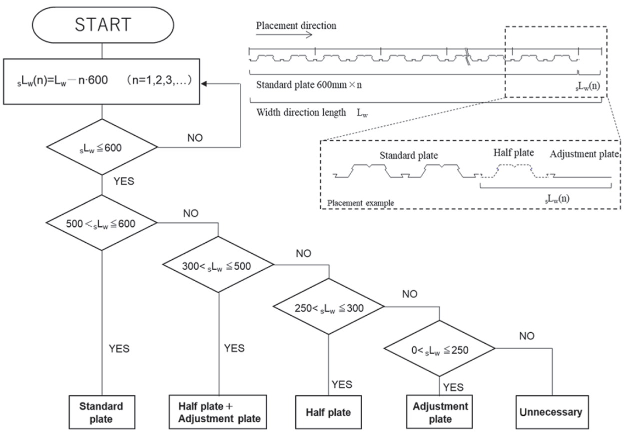

Fig. 7 Judgment flow of flushing for the adjustment

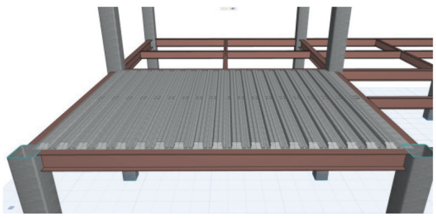

Fig. 8 Example of steel deck layout

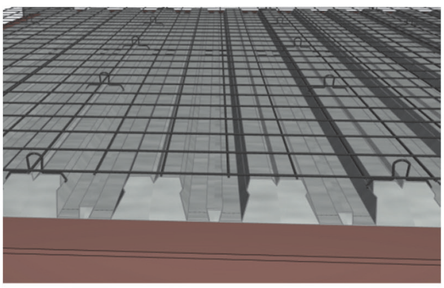

Fig. 9 Example of component display

2.1.3 Function of automatic layout system

The distribution of the automatic layout system was started in September 2019, and the expansion of the function is underway to incorporate market needs, of which the following are representative functions.

1. Correspondence to inclined slab
2. Preparation of opening (rectangular, circular)
3. Correspondence to cutout around a column
4. Correspondence to diagonal beam
5. Addition for formwork use to lineup

Improvement intended for the enhancement of usability and the streamlining of the entire architectural production process will be promoted continuously.

2.2 Specification output function of deck plate design support system

2.2.1 Background and problem

With regards to the floor slab employing deck plate represented by the composite deck slab, design is promoted by conducting structural calculation and specification checks at each stage of construction, completion (with regards to fireproofing and structure), and earthquake. In September 2009, Nippon Steel Metal Products started to supply the cloud type "Nittetsu Deck Plate Design Support System" as the design support system for the implementation of the examination of the abovementioned series. By taking advantage of the usability of the system used on WEB, examination without reinstallation is possible based on the continuously updated information.

However, after designers made adaptive judgement with the said system using the conventional floor slab design flow, in order for the design and construction specifications to be attached to the design documents, there was a process in which items incorporated in the specification have to be manually filled in with the selected deck plate type and fireproof grant number, and the elimination of the work, as well as the mistakes in checking due to human error, are problems that must be addressed.

2.2.2 Specifications output function overview

The said system was equipped with "Design and Construction Specifications Output Functions" as a new function in December 2022. After adaptive judgement as conventionally implemented, by executing "Specification DXF output," the adaptability-confirmed design and construction specifications are automatically transferred to the specifications, and incorporated into the design documents as they are without selecting specifications and check of the design specifications (Refer to **Figs. 10**, **11**).

The output format is of the DXF format and has high interchangeability with all-purpose CAD software. Furthermore, it is also possible to integrate pluralities of design specifications into a single sheet specification, and at that time, the corresponding design and construction specifications are automatically differentiated. If there is a deck composite slab emitting an NG adaptive judgement signal, an alert message is displayed, and output is not issued under the inadaptive situation due to the structure of the system.

With the mounting of this function, a sequential integrated implementation from the selection of floor slab specification, structural calculation, and fireproof design, up to the description in design and construction specifications has been realized, and even when the design specification is changed, modification is simple.

Fig. 10 Interface of design support system of steel decks

3. Conclusion

We introduced a new concept Cynos deck™ and the steel deck design tool intended for improvement of usability. Hereafter, we are determined to correspond to the changes in social needs such as increasing operational efficiency and labor-saving, and to promote the development of new products welcomed by end users and share new values and relevant application technologies both in hardware and software aspects.

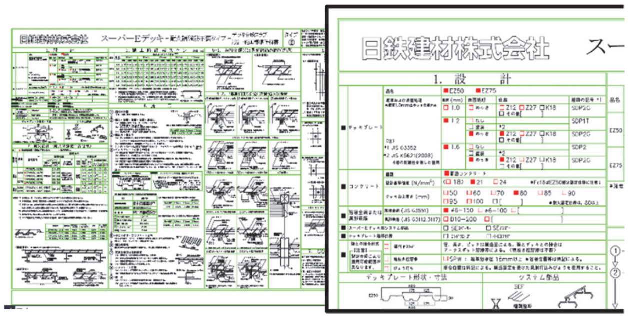

Fig. 11 Example of specifications output function

Reference

1) Japanese Society of Steel Construction: JSS III01-2018 Design and Construction Manual for Steel Deck Structures, 2019

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