Product Research and Development

Exploration for New Technology of Assembled Corrugated Steel Web Composited Beam

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Abstract: Improving the prefabrication and assembly level of composited beams with corrugated steel web is key to promoting their application in bridge engineering for medium-span bridges. This paper first derives the principle of 'vertical composite force invariance' unique to composite beams with corrugated steel webs, and validates this principle using finite element structural models. Based on this, four new types of prefabricated and assembled continuous composite beams with corrugated steel webs are developed, and their respective characteristics are analyzed to provide references for other engineering practices.

Keywords: assembled; corrugated steel web composited beam; vertical assembly invariance of composite beam load-bearing state

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1 Introduction

Composite beams with corrugated steel webs are increasingly valued by the engineering community and researchers due to their advantages such as light weight, high shear strength of the web, and high prestressing efficiency [1-5]. Compared to cast-in-place construction, prefabricated composite beams with corrugated steel webs not only inherit all the advantages of corrugated steel webs but also possess the advantages of prefabricated structures. Specifically, prefabricated composite beams with corrugated steel webs have the following significant advantages:

(1) Effective solution to web cracking: The high shear strength and prestressing efficiency of the corrugated steel web significantly reduce the risk of web cracking.
(2) Fast erection: Prefabricated components can be produced in advance in the factory, and on-site installation is quick, greatly shortening the construction period.
(3) Quality control: Factory production can better control the quality of components, ensuring the precision and reliability of each step.
(4) Environmentally friendly: Prefabricated construction reduces on-site work, lowering construction noise and dust pollution, making it more environmentally friendly.

Despite the numerous advantages of prefabricated composite beams with corrugated steel webs, most bridges with spans of 30 to 60 meters currently use cast-in-place structures, resulting in a low degree of prefabrication and assembly. This severely limits the promotion and application of composite beams with corrugated steel webs in bridge construction [2]. To improve the prefabrication and assembly level of composite beams with corrugated steel webs, researchers and designers have conducted extensive studies and explorations. Reference [2] proposed the use of prefabricated I-shaped corrugated steel web composite beam units, forming a box section with external prestressed steel strands, and constructed the Zhangzhuang Village Separation Overpass with a span arrangement of 2 × 40 meters. Building on Reference [2], Reference [6-8] introduced a prefabricated corrugated steel web box girder

prefabricated bottom slab and the secondary negative moment tendons at the pier top. The characteristics of this system are:

(1) The prefabricated main beam units are lightweight and easy to transport.
(2) There are multiple plate components and numerous wet joints.
(3) Tendons are tensioned in multiple batches.

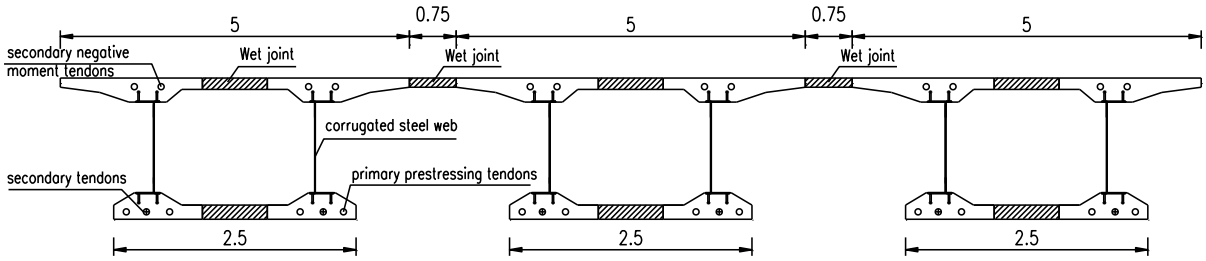

Figure 8 Schematic diagram of composite beam structure section - system I (Unit: m)

4.1.2 New Prefabricated Composite Beam with Corrugated Steel Web—System II

In the factory, the top slab with flanges, the bottom slab, and the corrugated steel web are prefabricated separately. The bottom slab adopts primary prestressing tendons. After the top slab, bottom slab, and corrugated steel web are prefabricated, they are transported to the construction site for secondary assembly. At the site, the corrugated steel web is vertically connected using bolts to form a box section. The box unit is then hoisted into place and connected using transverse wet joints. Finally, the secondary negative moment tendons at the pier top are tensioned. The characteristics of this system are:

(1) The prefabricated units are lightweight and easy to transport.
(2) There are multiple slab components, requiring secondary assembly at the construction site.
(3) High connection precision is required.
(4) Fewer tendon tensioning batches are needed.

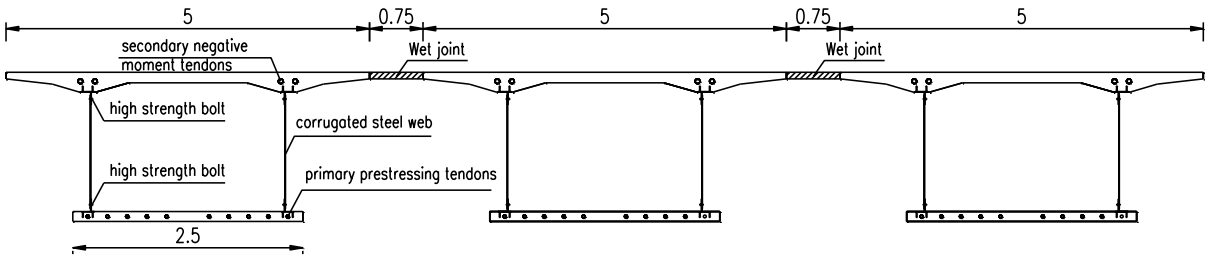

Figure 9 Schematic diagram of composite beam structure section – system II (Unit: m)

4.1.3 New Prefabricated Composite Beam with Corrugated Steel Web—System III

In the factory, the top and bottom slabs with shear key slots and the corrugated steel web units are prefabricated. The bottom slab adopts primary prestressing tendons. After the prefabricated units are completed, they are transported to the construction site for secondary assembly. At the site, concrete is poured into the shear key slots to form a box section. The box unit is then transported to the final position and hoisted into place, and connected using transverse wet joints. Finally, the secondary negative moment tendons at the pier top are tensioned. The characteristics of this system are:

(1) The prefabricated units are lightweight and easy to transport.
(2) There are fewer slab components, reducing the number of on-site connections.
(3) Slightly higher connection precision is required at the construction site.
(4) Fewer tendon tensioning batches are needed.

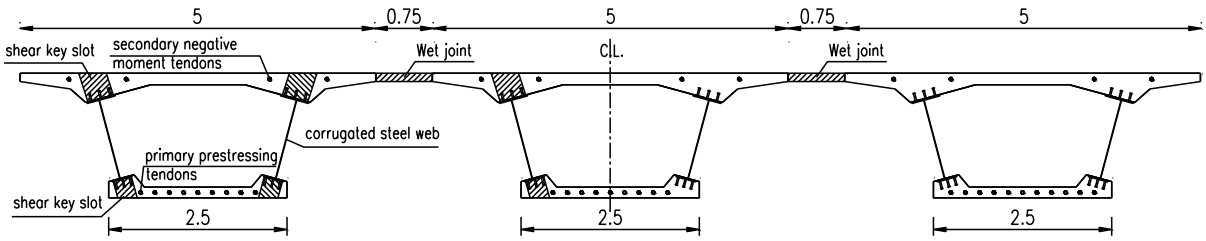

Figure 10 Schematic diagram of composite beam structure section – system III (Unit: m)

4.1.4 New Prefabricated Composite Beam with Corrugated Steel Web—System IV

In the factory, U-shaped beams and waffle top slabs are prefabricated separately, with the bottom slab of the U-shaped beam adopts primary prestressing tendons. After the prefabricated units are completed, they are transported to the construction site. The U-shaped beams and waffle top slabs are then hoisted into place sequentially and connected using transverse wet joints. Finally, the secondary negative moment tendons at the pier top are tensioned. The characteristics of this system are:

(1) The prefabricated units are heavy, and the U-shaped beams are inconvenient to transport.
(2) There are fewer plate components, reducing the amount of on-site work.
(3) Moderate on-site work is required.
(4) More tendon tensioning batches are needed.

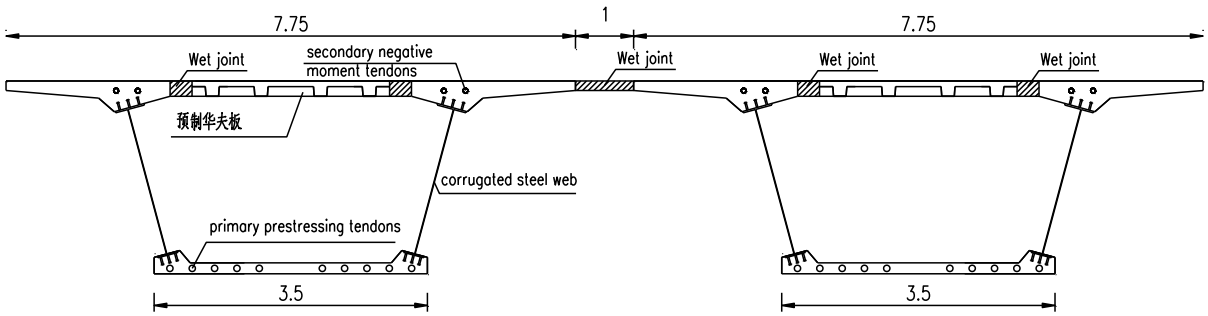

Figure 11 Schematic diagram of composite beam structure section – system IV (Unit: m)

4.2 Comparison of Four Types of New Prefabricated Composite Beams with Corrugated Steel Webs

All four types of new prefabricated composite beams with corrugated steel webs use internal prestressing tendons. They differ in terms of bottom slab prestress, structural integrity, and construction convenience. The specific differences are as follows:

(1) Bottom Slab Prestress Form:

System I: The prefabricated bottom slab uses primary prestressing tendons to resist the self-weight and construction equipment loads during the girder erection stage. After forming the box section, secondary prestressing tendons are tensioned in the bottom slab to resist the loads during the bridge completion stage. System I is suitable for a wide range of spans.

Systems II to IV: The prefabricated bottom slab uses primary prestressing tendons, which are fully tensioned during the bottom slab prefabrication stage, greatly simplifying the on-site prestressing tendon tensioning process. This makes the construction procedures simpler and more economical. However, Systems II and III are more suitable for shorter spans, while System IV, with its partially prefabricated waffle top slab and wider box cells, is suitable for longer spans.

(2) Structural Integrity:

System I and IV: The horizontal direction has two wet joints, resulting in poorer structural integrity. The age difference between the wet joint concrete and the

prefabricated concrete, along with the difficulty of ensuring on-site concrete quality, can lead to potential issues.

Systems II and III: These systems offer better structural integrity than Systems I and IV, but special attention must be paid to the construction quality of bolts and shear keys.

(3) Construction Convenience:

System I: Requires casting two wet joints in the top and bottom slabs, increasing the formwork workload and making construction less convenient. Additionally, temporary supports are needed during the main beam installation stage to prevent lateral tilting.

Systems II and III: Require secondary assembly in the factory, including bolt assembly and shear key concrete pouring, to ensure smooth connections between prefabricated components. High precision is required for both prefabrication and construction.

System IV: Only requires casting the top slab wet joint, making construction more convenient. However, the prefabricated U-shaped beams are irregular components, making transportation difficult and requiring high lifting capacities during erection.

Table 5 Comparison of characteristics of four types of new prefabricated composite beams with corrugated steel webs

System No.	Block forms	Assembly method	Prestress forms		Structure features
			Bottom slab	Top slab	
System I	Two prefabricated I-beams	Horizontal wet joints	Primary prestressing tendons + secondary tendons	Post-tensioned negative moment tendons	Can apply prestress according to construction load requirements.
System II	Prefabricated top and bottom slabs with flanges; Prefabricated corrugated steel web	Vertical bolt assembly	Primary prestressing tendons		Good Structural Integrity of top and bottom slabs; Can eliminate corbel for the prefabricated bottom slab
System III	Prefabricated top and bottom slabs; Prefabricated I-beam with corrugated steel web	Horizontal wet joints	Primary prestressing tendons		Connected using bundled shear studs; Can use inclined web plates, providing good torsional resistance and aesthetic appearance.
System IV	Prefabricated U-shaped beams; Prefabricated waffle slab	Horizontal wet joints	Primary prestressing tendons + secondary tendons		Suitable for wider box sections; Uses waffle top slab for high section efficiency; Can use inclined webs, providing good torsional resistance and aesthetic appearance.

Compared to conventional bridge schemes, composite beams with corrugated steel webs offer economic advantages [12]. Since the structural differences among the

four types of new prefabricated composite beams with corrugated steel webs are minimal, their economic differences are not significant. The analysis of applicable spans, construction, and aesthetics is provided in Table 6.

Table 6 Comparison of four types of new prefabricated composite beams with corrugated steel webs

System No.	Applicable span (m)	Single beam lifting weight (t)	Construction features and difficulty	Aesthetic effect
System I	30~60	120~240	On-site casting of 8 wet joints, tensioning of secondary tendons and negative moment tendons; many procedures, large workload, low construction difficulty.	Middle
System II	30	230	Secondary assembly required, casting of 3 wet joints, tensioning of negative moment tendons; many procedures, large workload, high construction difficulty.	Poor
System III	30	230	Secondary assembly required, on-site casting of 3 wet joints, tensioning of negative moment tendons; slightly more procedures, slightly larger workload, slightly higher construction difficulty.	Good
System IV	60	500	On-site casting of 5 wet joints, tensioning of secondary tendons and negative moment tendons; slightly more procedures, moderate workload, low construction difficulty.	Best

Through the comparison of the four types of new prefabricated composite beams with corrugated steel webs, it is evident that different structural systems are suitable for different bridge spans, construction equipment, and construction techniques. Each system has its own characteristics and can be selected based on the specific project requirements.

5 Conclusions

Improving the prefabrication and assembly level of composite beams with corrugated steel webs for spans of 30 to 60 meters is key for promoting their application in bridge construction. This paper first derived and proved the unique "vertical assembly invariance of composite beam load-bearing state" principle of composite beams with corrugated steel webs. Based on this, four new prefabricated composite beam systems with corrugated steel webs were proposed. The characteristics of each system were analyzed in terms of structural form, construction advantages and disadvantages, and applicable spans, aiming to provide references for related engineering practices and research.

Conflict of interest: All the authors disclosed no relevant relationships.

Data availability statement: The data that support the findings of this study are available from the corresponding author, Zhang, upon reasonable request.

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