Design and Practice of Jointless Bridges in China

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ABSTRACT

This paper presents the potential variety of general jointless bridges and its application in China, based on the narration of the state of the art in the design and practice of various jointless bridges. A few examples of completed jointless bridges, including Integral Abutment Jointless Bridge (IAJB), Semi-Integral Abutment Jointless Bridge (SIAJB) and Extension Deck Sliding Jointless Bridge (EDSJB), are briefly described. Then, the feasibility and needy endeavors for wide practicing of jointless bridges in China are discussed. Finally, recent research topics in SIBERC, Fuzhou University are listed for commenting.

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INTRODUCTION

In modern transportation, the requirements for bridge and road should include, not limited to, the following aspects:

a) Smooth surface to provide safe, comfortable high speed traffic, low noise, and less impact to the pavement and structure below, as well as its surrounding environment;
b) Waterproof surface to prevent any liquid, such as water with deicing salt or even storm water, from penetrating the structure and then to protect the structure from corrosion;
c) High robustness or redundancy to supply integrity and improve fragility for structure under extreme loadings such as strong earthquake, flooding or vessel hitting;
d) Economy in both initial investment and later maintenance.

A bridge is a structure supported eventually by the earth via supporting components such as abutment, pier and then foundation. Therefore, there is a transition level between the structure and the earth, where exist the thermal movement due to material thermodynamics, as well as shrinkage and creep due to special material properties and the vehicle braking-caused movement due to external loading, etc..

All those movements between a structure and the earth should be wisely accommodated by certain a way, such that the two parts are able to work together without the potentiality of being broken up. To do so, the simplest way is to preset a gap at the each end of a bridge so that the superstructure is totally separated from its substructure. In order to meet the above requirements a)
and b), a kind of expansion device is installed inside the gap. Roughly viewing from the bridge's appearance, the whole bridge structure seems to be in integrity, but actually, the superstructure and the substructure are separated, which does not satisfy the requirement c). Besides, the presetting of the gaps and/or the installation of expansion joint devices not only cost extra expenditure and construction time, but also increase the maintenance fee and traffic disruption due to the vulnerability of expansion joint devices, which violates the requirement d) and also compromises the requirements a) and b).

His is the conventional bridge adopted all over the world for hundreds of years. Without exception, China is one of them. Some engineers realized the disadvantages of this kind of traditional jointed bridges and tried to improve the performance of the expansion joint devices. But, the above-mentioned problems are not able to be essentially solved. According to many references and statistical reports, expansion joints are recognized as the weakest, most vulnerable portions with most frequent maintenance in most short and medium bridges.

An American engineer humorously pointed out that "the best expansion joint is no expansion joint at all", which has been recognized by many bridge engineers and triggered the comprehensive research and practicing of various jointless bridges, spreading from United States to Europe, Canada and Australia, etc..

China started its mass construction of infrastructures in late 1980's. Due to the strategic emphasis of construction is only on the construction speed and the lowest cost with less consideration of its life cycle cost and long term performance, almost all bridges built are traditional bridges. Of course, some of them were built as so-called least-joint bridges by minimizing number of joints, whereas some of them were built as jointless bridges by adopting the concept of jointlessness of integral structure itself, such as arch and rigid frame. However, China seldom practiced the design and construction of modern highway jointless bridges made of steel and/or concrete.

In this paper, general type of jointless bridges is first listed and described, then individually followed by its current application in China. Finally, the feasibility and needy endeavors for wide practicing of jointless bridges in China are discussed.

GENERAL TYPE OF JOINTLESS BRIDGES AND ITS PRACTICE IN CHINA

"Jointless bridge" known to America and Europe has various types based on its structural design performance requirement. Even for a same kind of jointless bridge, taking semi-integral abutment bridge for instance, it has a numerous variety of joint configurations and limitations of applicability between countries, states or provinces. Therefore, it is also noted as different names in different references, such as "no joint bridge" , "integral bridge", "semi-integral abutment bridge", "frame bridge", "rigid-frame bridge"," U-frame bridge", etc. Generally, they are all bridges with no expansion joints on the top of bridge decks, but the bridge structures can vary from simply-supported beams, continuous beams to rigid or semi rigid frames, etc.

Based on the available references and engineering practice, jointless bridges can be classified as follows, not limited to:

Horizontal Arch Concept-based Bridge

A long horizontally curved, post tensioned concrete highway bridge 420/QEW was completed in 1975 in Ontario, Canada. The bridge is continuous over 12 spans with total deck length of 598.3 m. The radius of curvature varies from 218 m to 1165 m, Fig.1 [Campbell and Richardson, 1975].

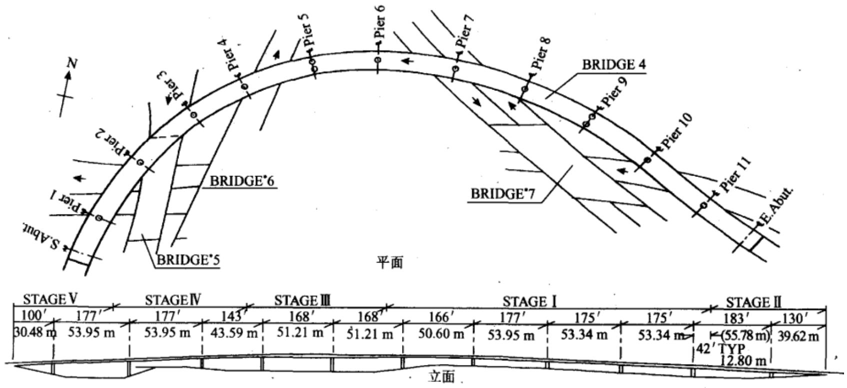


Fig.1 A long horizontally curved, post tensioned concrete highway bridge 420/QEW

No expansions joints are provided in the structure. The deck is anchored at both abutments and is free to slide in any direction at all the intermediate piers by floating bearings . And the contraction or expansion is accommodated by flexing of the curved deck in the horizontal plane. Therefore, this kind of bridge is also called "deformation self-adapting curved bridge".

Slight changes in curvature are sufficient to reduce the induced forces, due to environmental loadings, to a level which can be resisted by the abutments and the transverse flexural stiffness of the deck. Lateral forces, due to wind, centrifugal, and earthquake loading, can also be accommodated by bending of the deck and by compressive and tensile axial stresses similar to those that occur in an arch.

Another example of making use of this horizontal arch effect to accommodate thermal deformation is the State Route 50 over Happy Hollow Creek that is also an example of the upper limit of an integral abutment jointless bridge that can be achieved up to now, Fig.2 [Edward P. W.]. It is an eight-span precast / prestressed bulb-T beam bridge with composite concrete deck, completed in 1998. The structure is 358.2 m in total length on a 4° 45′ curve and 14 m in bridge deck width. The height of girder is 2.1 m and the spans vary from 36.6 m to 167.7 m. The bridge is supported by two-columned piers with their heights of 15.5 to 27.7 m.

Fig.2 Integral abutment jointless bridge on State Route 50 over Happy Hollow Creek

In addition, there are more a few integral jointless curved bridges by adopting the concept of horizontal arch, such as the curved bridge in Kuala Lumpur International Airport, Malaysia, Kalkaiji Overpass in India, the cable-stayed Sunniberg Bridge with low towers in Sweden, Yokomuki Bridge and Kujira Bridge in Japan, as well as the Island Drive Bridge in Thunder Bay, Canada (Fig.3). With its total length of 234 m, Island Drive Bridge is the longest integral abutment bridge within Canada and is believed as an integral bridge structure, in terms of the total thermal displacement, that experiences the largest overall movements of any integral abutment bridge in North America.

Fig.3 Island Drive Bridge, the longest integral bridge in Canada

The integral bridge with curvature in plan has unique characteristics. If appropriately designed, curved integral abutment bridges can be constructed longer than the straight counterpart. It can be explained as following reasoning.

The curved deck moves alike an arch in plan against temperature change. The constraint stresses due to temperature change, creep and shrinkage, etc. are released by the escaping horizontal movement in plan (Fig. 4) [Akiyama, 2008], though transverse bending moment would be generated in the deck/girder. The “arch effect” makes the constraint stresses of the deck lower and enables longer integral bridge construction than straight counterparts.

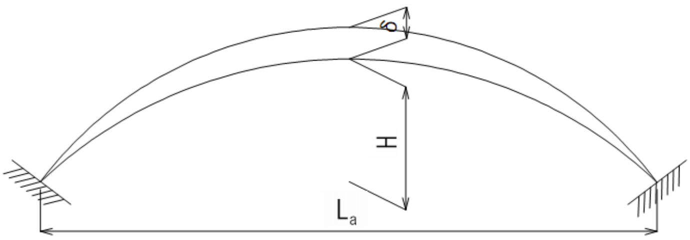


Fig.4 Horizontal deformation due to temperature rise

In China, this kind of concept has been used in the design and construction of traditional jointed bridges, but nothing in jointless bridges.

Arch bridges

Changing a horizontal curve into a vertical curve, the corresponding horizontal curve bridge becomes an arch bridge which undoubtedly owns the arch effect and the merits it brings. In ancient times, people only used the compression characteristics in an arch to cross a river or a valley by using natural materials such as stone and bricks, with no intention to make use of the arch effect to reduce the constraint stresses in the structure caused by thermal change and/or creep and shrinkage. But, at that times, people intuitively also made use of the “arch effect” also to eliminate the need of expansion joints for arch structure without horizontal deck (Fig. 5 a) and arch bridge with deck supported by solid earth spandrel (Fig. 6). In modern arch bridge, high requirements for deck needs the installation of expansion joints similar to other kind of traditional bridges, which lose the merits of curved structures in reducing thermal stresses and deformation. Based on available references, the former two kinds of arch structures are jointless, whilst the latter is almost similar to any traditional jointed bridges, with only one except of the Ashtabula Bridge (Fig. 5 b), which is a partially jointed or quasi-integral arch bridge built in 1926 in USA. The innovative feature is that the traditional joints over piers were eliminated and the deck was kept jointless with only expansion joints over abutments reserved.

a) Stone arch bridge with no horizontal deck b) Modern steel arch bridge with horizontal deck

Fig. 5 Arch bridges

Therefore, in modern bridges, arch bridge cannot make full of the vertical curve to reduce the horizontal deformation due to temperature change, creep and shrinkage, vehicle braking

and so on. However, the slender flexibility of some piers can be used up to accommodate this kind of deformation in the way done in the Ashtabula Bridge. This is one of our research targets because arch bridge is one of main bridge types and a lot of arch bridges will be built and renovated. How can we make them jointless as much as possible?
Followings are some examples of jointless arch bridges in China as well as other countries:

Small span of masonry arch bridge with horizontal deck on solid spandrel

This kind of jointless bridge is pretty similar to culvert and its thermal movement is accommodated by earth. It has been constructed for thousands of years and will be built for pedestrians and light vehicles. Fig. 6 shows jointless singe span and jointless multi-span masonry arch bridges with horizontal decks on solid spandrels.

a) Single span arch bridge b) multi-span continuous arch bridge

Fig. 6 Masonry arch bridges with horizontal decks on solid spandrels (also for vehicles)

Small span of masonry arch bridge without horizontal deck (for pedestrians only)

This is the very traditional jointless arch bridge with very long history. Most of the thermal deformation is absorbed by curvature change of the arch itself upwards or downwards. Fig. 7 shows jointless single span and jointless multi-span masonry arch bridges with no horizontal decks.

a) Single span arch bridge b) multi-span continuous arch bridge

Fig. 7 Masonry arch bridges with no horizontal decks (for pedestrians only)

Slip joint concept-based jointless bridge

Zuk (1981) proposed a kind of jointless bridge with continuous Jointless deck-slip joint concept-based jointless bridge, Fig. 8.

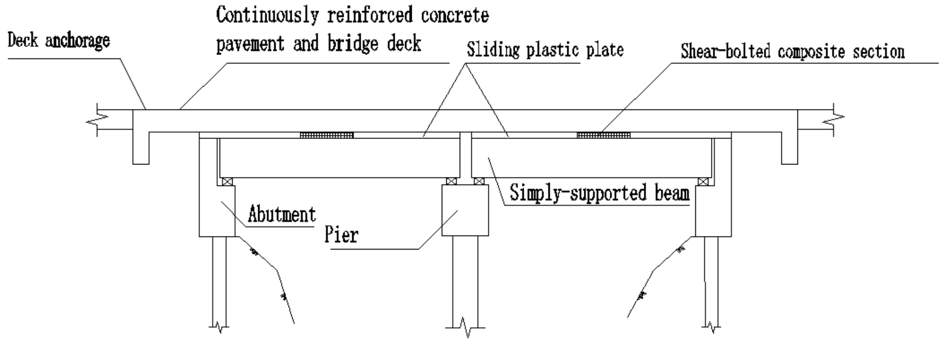


Fig. 8 Slip joint concept-based jointless bridge

The concept was proposed initially for the continuously reinforced pavement to extend across bridge structure with no joint interruption. To allow for expansion and contraction of the bridge girder, they should be designed as simply supported members supported by flexible bearings as elastomeric pads. However, to take advantage of composite action between the girder and the deck slab, the central region of the girder, which carries the maximum bending moment, is compositely joined to the slab. The end regions of the girder are designed so as to allow slip at the interface between the girder and the slab. Several layers of plastic sheets at the interface are suggested to provide a slip plane. The bridge slab is expected to develop narrow, closely spaced, transverse cracks, but, if the reinforcing steel is epoxy coated, no special problems are foreseen.

This method would allow bridges of any length to be constructed with absolutely no joints in the deck. In addition, there are no joints between the bridge deck and the roadway pavement. Stresses induced in the slab and girder in the longitudinal direction are not excessively high, and with the proper amount and type of material (steel or concrete), these stresses can be easily accommodated. The large forces on the connectors between the girder and the slab could present a problem, however. The theory developed assumes that the interface force is concentrated at one point, whereas due to stress redistribution, this force may be spread out over some distance. With the redistribution, the magnitude of the stress level in the connectors is considerably decreased [Zuk, 1981].

This kind of jointless bridge was ever tried a while in Texas, USA in 50-60's of 20th century, and then was aborted because of the occurrence of serous cracking in the slab over abutment and abutment itself. However, the concept of slip-joint was used in Qurnah, Iraq during late 1950's [Wolde-Tinsae, 1987].

Ordinarily, a composite deck would have been specified in the design, with the deck acting as the top flange of the steel girders. The high temperature ranges in Iraq forced the bridge designers to use a semi-composite deck, which acted as sway bracing without carrying any stresses

To my knowledge, there is no such a kind of application in any Chinese bridges.

Abutmentless bridge

In a bridge with its superstructure of cantilever beam or a rigid frame bridge, the beams are directly connected to road embankment with no abutment supports (Fig. 9). The bridge end has an unconventional configuration that connects the end of the bridge to the base of pier with prestressing strands. The deformation of beams is absorbed by the preset joint at the end of bridge or the end of between approach slab and road pavement. This kind of abutmentless bridge is mostly used in overpass above highway. Abutmentless bridge is very uncommon in U.S. However, eight jointless bridges were designed without abutments in Australia, with the longest bridge of 88.7 m.

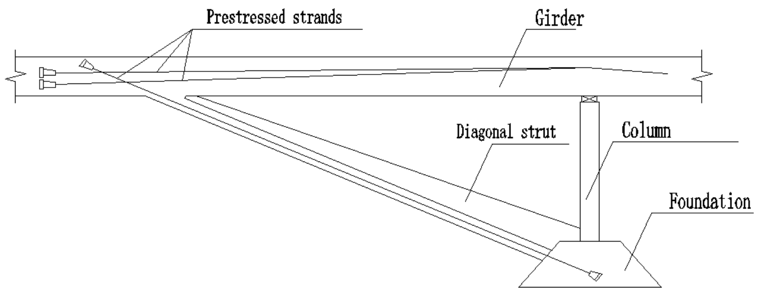


Fig. 9 Abutmentless bridge end details [Wolde-Tinsae, 1987]

In china, similar abutmentless bridge was ever designed and built, which is a kind of cantilever beam bridge with approach slabs connected directly to road embankments and with no abutments. However, this kind of bridge is only used for overpass with light traffic due to the drawbacks of both the large amount of workload on side slope paving and the occurrence of bumping at the bridge ends.

An alternative for this series of abutmentless bridges is called slant-legged rigid frame bridge as shown in Fig. 10. The recorded example of such a kind of fully jointless bridge is the Jingji bridge built in 1988 in Er Zhou city. This bridge has a single span of 20 m, the total length of 30.5 m and the width of 9 m [Wang, G.D., 2000].

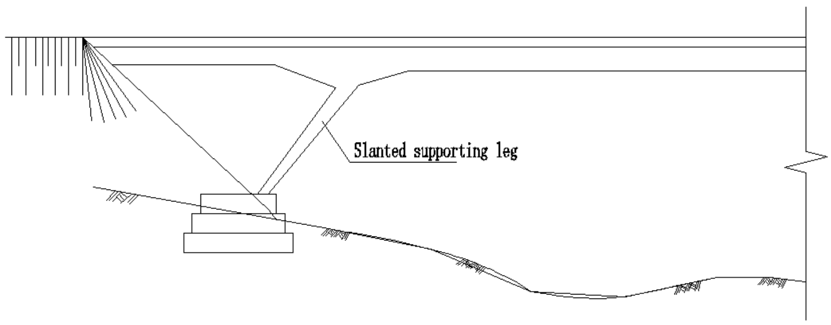


Fig.10 The fully jointless Jingji bridge with no abutments

The performance of this hybrid structure is between beam bridge and arch bridge, depending on the inclination of the supporting columns or the slanted legs. This kind of bridge enables traffic to have more space below. But at the ends of bridge, because of the low bearing capacity of soil, abutments are mostly still needed, and therefore, actually the bridge is not a jointless bridge any more.

Therefore, only for light traffic bridge and/or on the condition of having very good soil load-bearing capacity at two sides of a bridge can abutments be eliminated, as well as, can bridge beams be directly seated on the compacted soil and merged into roads. Fig. 11 shows two jointed overpasses with slanted leg supports and abutments.

a) Overpass over a highway

b) Overpass over a river

Fig. 11 Two jointed overpasses with slanted legs and abutments

Jointless bridge with continuous jointless deck and jointless bridge with continuous span

The purpose of adopting continuity of deck and/or span is to minimize the number of expansion joints in a long bridge. The more ideal case is that all joints are eliminated over piers, with only one or two expansion joints reserved over abutment(s), or even eliminated (the way the most ideal fully jointless bridge does).At the bridge ends, the horizontal deformation can be accommodated in many ways such as expansion joints (similar to traditional bridges), extension deck sliding (EDS), flexible pile swing (IAJB) and end-diaphragmed girder sliding over traditional bearings (SIAJB), etc. The latter three are the working mechanisms of most popular three jointless bridges described in the following context more detailedly.

Because the expansion joints at bridge ends (over abutments) are still remained, especially for multi-span long bridges, and therefore, this kind of bridge is not the fully jointless bridge and we call it “least joint bridge” in China. The superstructure can be simply-supported or continuous or simple for dead load and continuous for live load. In USA and other countries, the simply-supported structure with continuous jointless deck is named as partially-continuous span, while the continuous structure with continuous jointless deck is called continuous span.

The continuity of the superstructure in this type of bridge will benefit from both the reduction of expansion joints and the reduction of the maximum mid-span moment. The former can lower the cost of expansion joints investment and its maintenance and also can provide with a smooth riding surface and a protection roof for girders and superstructure from any deterioration due to the penetration of harmful liquid. On the other hand, the latter enables adoption of less cross section and brings with obvious economy. Continuous jointless deck concept is widely used in the world, suitable for both new construction and rehabilitation of existing structures.

In China, three major configurations are adopted for the connection between adjacent decks and this connection is usually called general link slab.

Elastic-plastic material—TST

When the total expansion and contraction stroke is small, taking 5 mm for instance, that bridge deck pavement can be continuous by setting saw cuts at the supposed expansion joint locations, Fig. 12. Saw-cutting is provided to absorb the expansion and contract deformation and to avoid the occurring of irregular cracking in the deck pavement. The normal width of saw-cutting is around 5 mm and the depth is around 30～50 mm, inside where sealing material is filled. This joint sealer must be soft enough and must satisfy required specifications. It could be asphalt with rubber mixture, or TST with the combination of rubber, plastics and asphalt mixture.

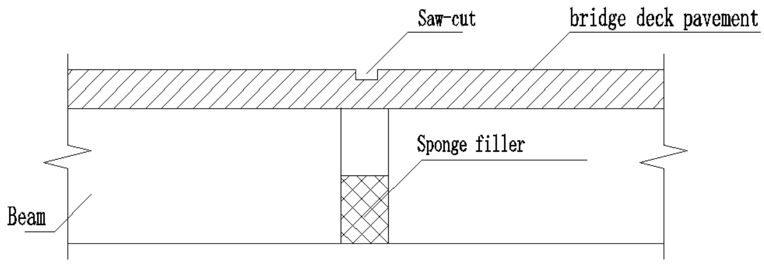
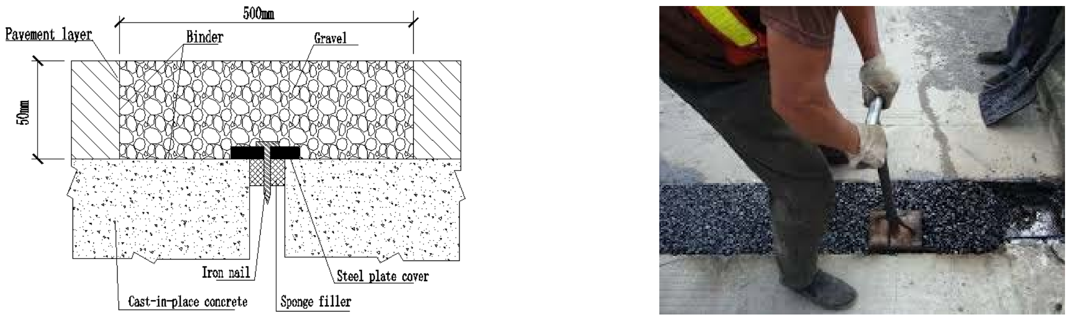


Fig. 12 Saw-cutting

For bridges with relatively larger expansion and contraction stroke than those suitable for saw-cutting, joint-sealers such as TST can be directly paved at the supposed expansion locations to form a pseudo-link slab which connects the adjacent pavements together, Fig. 13. This special "expansion joint" is called "hidden expansion joint". Small span of conventional simply-supported bridge is usually built with no expansion device or only with continuous jointless deck, which is so-called hidden expansion joint bridge.



a) Configuration b) Under Construction

Fig. 13 TST hidden expansion joints

This kind of bridge is very popular and very cheap in maintenance. But, it is only suitable for bridges with small expansion and contraction deformation. Besides, the low durability of TST material is a big concern which needs frequent repair or mostly complete replacement.

This technology is mostly used in the rehabilitation and strengthening of short and medium span of existing bridge with their expansion joint structure aligned to the level of bridge deck. This general link slab here can definitely improve the riding comfort, but the difference of material properties between TST and bridge deck greatly discounts the improvement of riding quality due to the potential roughness and differential settlement or rutting; besides, the color contrast affects the bridge appearance.

RC link slab

For multi-span bridge with large expansion and contraction deformation, a kind of RC link slab is post- cast in place at the locations over piers and used as a special expansion joint.

Because of its functional requirement, its peculiarity is featured by its different configuration from normal bridge deck. In China, mainly, there are two types of standardized and legalized configurations as shown in Figs. 14 and 15.

Fig. 14 shows the configuration of a so-called rigid link slab where more reinforcement is laid out. Two saw cuts with filled soft wooden plugs are set at the end bottom of the link slab. This rigid connection slab is liable to cracking due to the large tensile stress around the joint in the slab, which causes the penetration of water and resulting in corrosion of steel rebar and substructure.

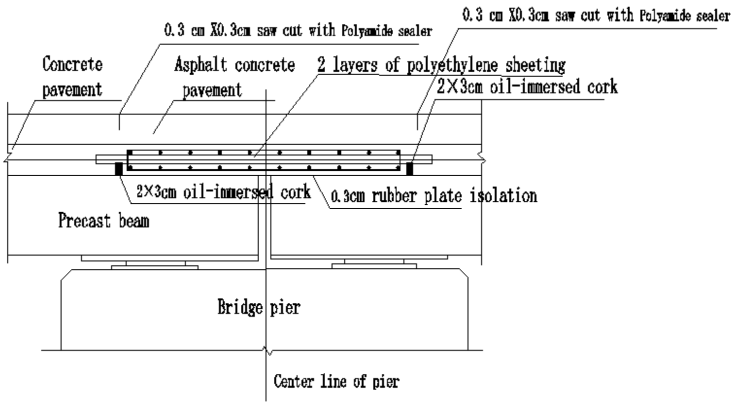
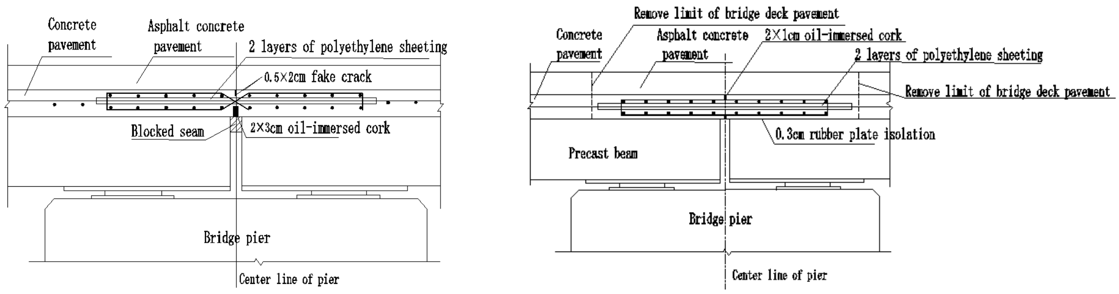


Fig. 14 Configuration of rigid link slab

Another kind of RC link slab is shown in Fig. 15 as tie-bar and saw cut link slab which can be also classified into two subclasses: non-moment-resistance(Fig. 15 a) and moment-resistance (Fig. 15 b). In the middle position of joint, link slab is saw-cut at both top and bottom along the depth.



a) Non-moment-resistance b) Moment-resistance

Fig. 15 Configurations of tie-bar and saw-cut link slabs

RC Link slab is a way to make bridge deck jointless while keeping the performance of simply-supported bridge structure unchanged. Both the horizontal deformation and the rotation at beam ends force the link slab to be in an extraordinarily complicated status of stressing that is not considered in its original design and construction. Besides, no corresponding measures are taken, which results in the serious cracking on the top of link slab. Early cracking of pavement on link slab and concrete spalling at the beam ends are found very soon after bridges with those kinds of link slabs are open to traffic. Those early distressed concrete will develop into crushing fragment and pot hole as the time is collapsing, which in turn aggravates the impact to bridge itself. Cyclically, this distress seriously affects the performance of bridge and safety of vehicle riding, especially being worse for highway bridges. Fig. 16 shows the damaged pavement around the top of a link slab in a multi-span simply-supported bridge with RC link slab connection over piers.

Fig. 16 The damaged pavement around the top of link slab

Combination of multi-jointless bridges

For very long bridges, based on concept of RC link slab connection, least expansion dams or joints may be set somewhere above certain intermediate piers in addition to two joints above abutments in two bridge ends. Between any two joints, the bridge is jointless with the span number maximized.

Full integral bridge or portal bridge

In a full integral bridge, girders are monolithically connected with piers and abutments, where end diaphragms are also functioned as both abutments and concrete pile caps supported by one row of piles, Fig. 17.

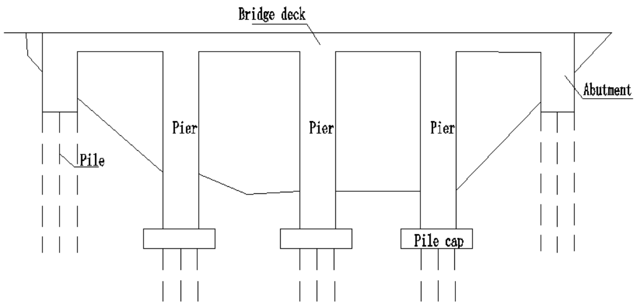


Fig. 17 Full integral bridge or portal bridge

Another full integral bridge is just the rigid frame bridge, whose abutments are mostly thin walls or ribbed plates (Fig. 18). This kind of jointless is pretty close to culvert, and therefore, also called culvert-typed jointless bridge (Fig. 19). It is only suitable for very short span of crossing. The horizontal thermal deformation is accommodated by the flexible thin wall-abutment and, in some cases, the hinges at the bottom of walls.

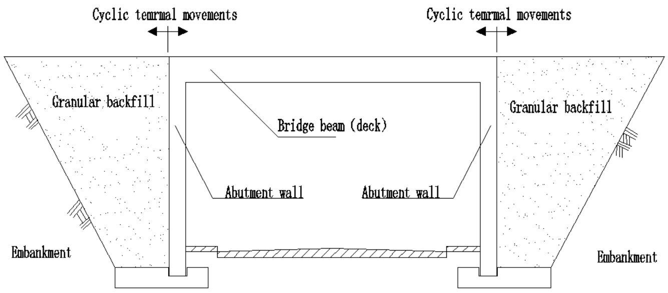


Fig. 18 Rigid frame bridge

a) Multi-span of rigid framed jointless bridge   b) Single span of rigid framed jointless bridge
Fig. 19 Culvert-typed or rigid framed jointless bridges

Very familiar to all of you, three dominant jointless bridges are IAJB, SIAJB and EDSJB (Extension Deck Sliding Jointless Bridge) which are widely used in American, Europe, Canada and Australian, etc. Therefore, their concepts and configurations are not described here in details, except for their applications in China.

Integral abutment and jointless bridge (IAJB)

Abutments in an IAJB are supported by flexible H steel piles which are not acceptable in most developing countries including China. For that reason, people have been endeavoring to use (P)RC piles to replace steel piles by predrillng a larger hole and then filling the gap with soft material around pile at the top portion with certain a depth to reduce the lateral flexural rigidity. According to available references, only one Integral abutment and jointless bridge using RC piles was built and is in good service, which is the Shang Ban Large Bridge (No.7 in the table 1) in Yongchun, Fujian, China and designed by Fuzhou University. It is the longest integral abutment bridge in China up to now with the bridge length of 137.1 m and width of 7.5+2×0.5 m. Its design load is truck-20 t, tractor trailer-100 t. The superstructure is of prestressed concrete T beams with 4×30 m span arrangement and with the beam height of 1.8 m. The piers are of two reinforced concrete columns. Its two abutments are reinforced concrete integral abutments with their support of rectangular RC piles. The overall layout and appearance of this bridge are shown in Figs. 20 and 21.

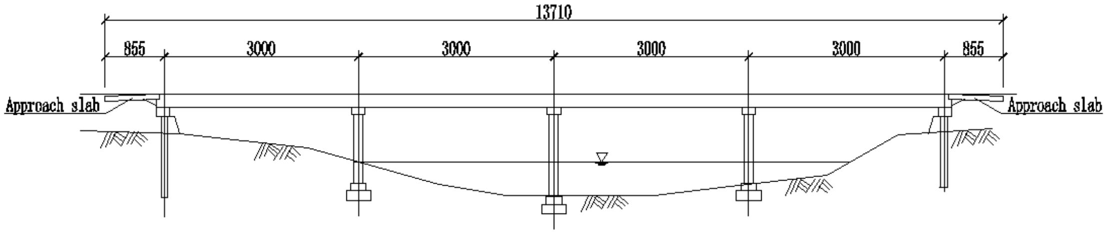


Fig. 20 Overall layout of the bridge (cm)

Fig. 21 Bridge in service

The beam, pier and foundation in this bridge are similar to a traditional jointed bridge. Here is only the introduction to the main parts in a jointless bridge, such as abutment, foundation and approach slab.

Fig. 22 shows the structural configuration of an integral abutment. To avoid the occurring of adverse forces in the abutment foundation due to the bending moment caused by the self-weight of the superstructure before they are integrally connected, the beam was first hinged on the abutment, and then the shadow portion was concreted in place to monolithically connect the superstructure and substructure.

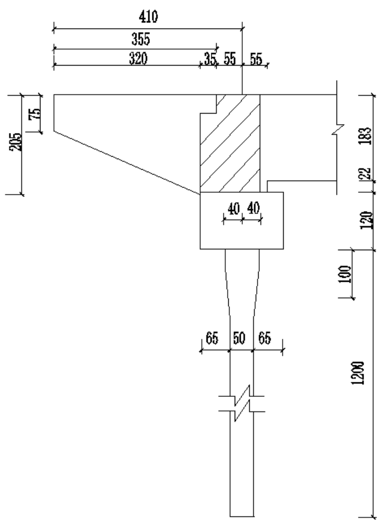


Fig. 22 The configuration of an integral abutment (cm)

From economic consideration, H steel piles were seldom used and always replaced by concrete piles. Because the lateral rigidity of concrete pile is relatively very large and its deformation capacity is low, it is not suitable to be applied in integral bridge. This integral bridge adopted a single row of four RC rectangular piles along their weak bending axis, with each pile's cross-section of 70×50 cm.

To improve the flexural capacity of the connection between pile and abutment, as well as to avoid the stiffness mutation from pile to abutment, the pile size increases from 70×50 cm to 70×70 cm in the upper 1 m of pile top. The total bridge length of 137.1 m would produce large shear force on the top of pile due to thermal effect. Although construction of rectangular column is more complicated than circular column, rectangular column would increase the shear capacity of pile by laying inclined steel bars, which brings with larger shear capacity. This is the reason for adopting the rectangular columns in this integral bridge.

Pile is inserted into tuff layer of 6 m deep, using artificial hole-digging construction method. For increasing the flexibility of pile to reduce the force of the superstructure caused by the temperature changing, holes size is bigger than the pile size. After concrete pouring of pile is completed and reaches certain intensity, loose sandy soil is filled in the remaining space of holes. The connection between abutment and pile is also the key of bridge design. In order to ensure abutment rigidly connected with pile, the main steel bar of the pile is embedded into the abutment of 1 m deep.

After cancelling the expansion joint, the superstructure deformation due to the temperature changes is the key to the design of bridge structure. Therefore, a two-stage slab was designed as shown in the Fig. 23. Temperature deformation of superstructure could be accommodated by the two 2 cm wide asphalt-filled joints on the sleeper beams.

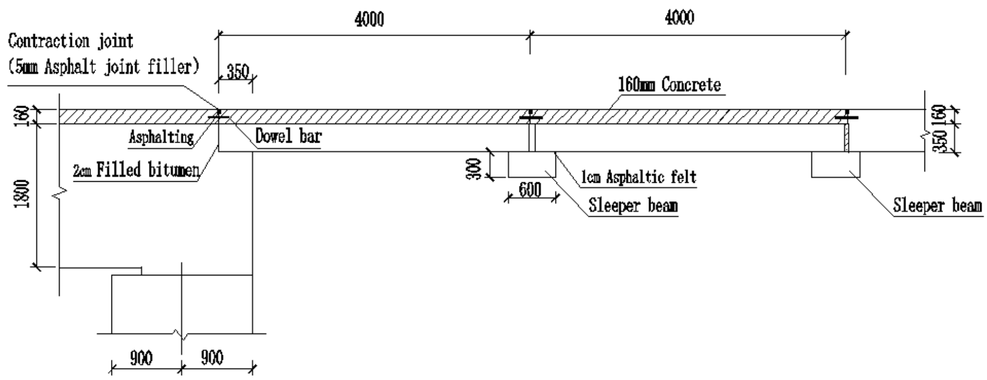


Fig. 23 The layout of the approach slab

Moreover, due to the use of concrete deck in the Shang Ban Large Bridge, in order to avoid the potential cracking in the deck, 5 mm wide traditional contraction joints were set at the connection of slab and abutment as well as in the concrete pavement above sleeper beams.

Except for reducing the length of approach slab, the two-staged approach slab can also solve some common distresses existing in general bridge, which manifests as natural subsidence of backfill behind abutment and slab damage due to the cavity below caused by the repeated displacement of abutment. Permeable gravel soil was adopted as backfill material behind abutment to reduce natural subsidence and ensure smooth drainage. The layered compaction of backfill material was conducted synchronously with the abutment construction, and the compaction degree requires not less than 95%. The maximum elevation difference of backfill between two sides of the bridge should not exceed 0.5 m to ensure force symmetry to the structure.

The bridge was completed in January 2004. The full-bridge static and dynamic load tests were carried out by Fuzhou University before the traffic opening. Since the opening, bridge performance has been in good condition with smooth driving on the deck, and no cracking phenomenon has been found at abutments and concrete deck pavement. The practice has proved that this integral abutment bridge design is feasible and successful.

To understand the working conditions and problems that may occur after the running for more than seven years, a field survey of the bridge was conducted on April 14, 2011. The conclusions by visual inspection are as follows:

As shown in Figs. 24 (a) and (b), stringer structure under deck and overall abutment structure are still as good as new without any abnormal situation, even without any signs of leakage.

Jointless deck of the four-span continuous bridge is still smooth with no cracking or cambering phenomenon. Both pavements behind the abutments suffer from different degree of damage and subsidence, which causes a slight bumping problem for vehicles. It can be seen from Fig. 24 (c) and (d) that the pavement condition in the northern end of the bridge was better than the southern end. In addition, there was a crack appeared in the stone revetment under the southern end abutment, shown in Fig. 24 (e). This phenomenon may be caused by the new road constructed in the west side of the bridge, whose embankment directly constrains the west end of the bridge abutment and makes the abutment under an uneven deformation state. When the bridge has a longitudinal displacement, the abutment will follow the longitudinal movement as well as the rotation. This explanation has been proved by the following facts: the pavement behind the southern abutment was resurfaced in Dec. 2011, but two 2 cm deformation joints were not correctly set according to the original design requirements. After the traffic opening, two inclined cracks appeared on the pavement, as shown in Fig. 24 (f), which apparently was caused by the rotation of the abutment.

(a) West side

(b) East side

(c) Northern end

(d) Southern end

(e) Stone revetment at the southern end abutment

(f) Resurfaced pavement behind the southern end abutment

Fig. 24 Current situations of Shang Ban Large Bridge

Overall, nearly a decade since the completion of this bridge, except for a pavement resurfacing conducted at the southern end of the bridge in order to improve driving condition, everything is normal elsewhere, with no maintenance, which fully embodies the advantages of the integral bridge. It should also be noted that the normal operation and future repair of the integral bridge must comply with its working principle and design intent, not being processed as a conventional bridge.

Besides, there are 2 more integral bridges with shorter bridge length. One is the Cheng Nan Road Viaduct (No. 2 in the table 1) only with its east abutment being integral, shown in Fig. 25. This bridge was analyzed and investigated in details as a research project. See reference [Jin and Shao, 2002] for details.

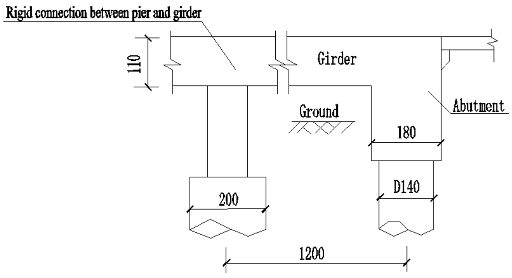


Fig. 25 East end elevation of the Cheng Nan Road Viaduct

Another one is the Si Jiu Medium Bridge (No. 4 in the table 1), which has both integral abutments like most jointless bridges. The integral abutment is the series combination of pile and thin wall to gain enough lateral flexibility, Fig. 26. See reference [Jin, 2000] for details.

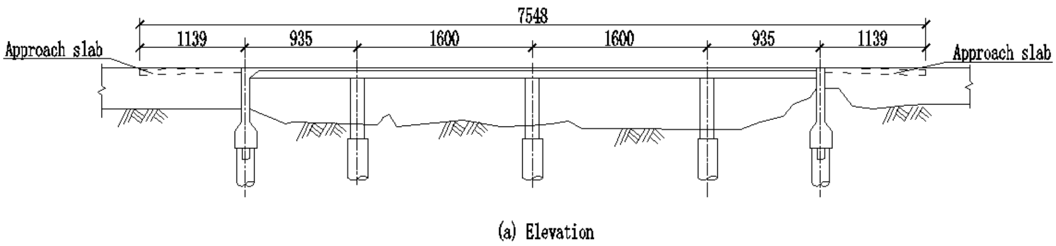


Fig. 26 Elevation of the Si Jiu Medium Bridge

Semi-integral abutment and jointless bridge (SIAJB)

In the above described IAJB, girder is rigidly or monolithically connected with abutment, which induces significant crack-causing negative moment at the top of bridge deck and the connection of abutment and supporting pile. Accordingly, a kind of semi-integral or semi-rigid abutment was figured out with various configurations (not listed and described here in details). SIAJB is developed based on IAJB, but with more constraint release between abutment and girder, which allows the rotation and translation between them, and therefore, reduce the moment. As a result, SIAJB has wider application and longer bridge length. This is one of main reasons why the jointless bridges in table 1 are almost semi integral abutment bridges.

Undoubtedly, semi integral abutment bridge also realizes the purpose of being jointless and owns almost all advantages of IAJB. Besides, it has more advantages such as applicability for bridges supported by both flexible foundation and rigid foundation. However, it has obvious drawbacks such as low integrity and aseismicity.

Here is an example of a newly constructed semi-integral abutment bridge- Guan Bian Bridge, located in Hu Zhou City, Zhejiang province, designed by Fuzhou University and Hu Zhou Design Institute of Transportation Planning.

Guan Bian Bridge is a skewed (30°) semi-integral jointless bridge of 112 m long. The superstructure of the bridge uses post-tensioned concrete hollow slab with 7×16 m span arrangement. The superstructure adopts a structural system of simply supported for dead load and continuous for live load. The substructure uses capped pile piers with bored pile foundation. Clearance under the bridge meets the section requirement of flooding discharge, shown in Figs. 27 and 28.

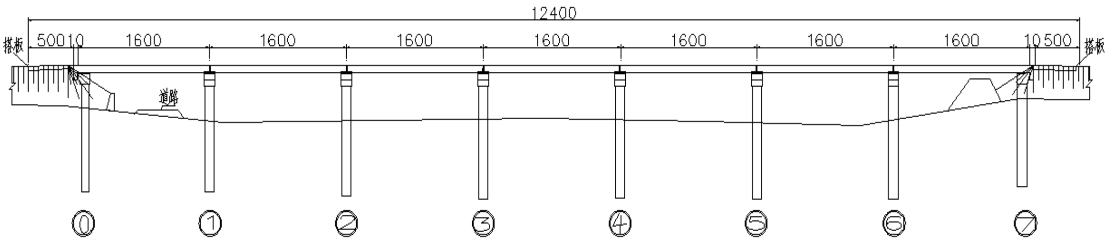


Fig. 27 Layout of Guan Bian Bridge

Fig. 28 Photo of Guan Bian Bridge

The technical features of the bridge include two items. The first one is its composite backfill behind the abutments. In order to avoid mutation of vertical compressive stiffness behind abutment, a transition layer of gravel was adopted (Fig. 29). Due to the light weight and sufficient strength of aerated concrete, it can effectively reduce soil subsidence behind abutment, especially on soft soil base. In addition, for reducing the sliding friction coefficient at the approach slab bottom and efficiently absorbing the temperature deformation from the main deck without significant forces induced in the slab, a 20 cm thick of medium-coarse sand layer was paved.

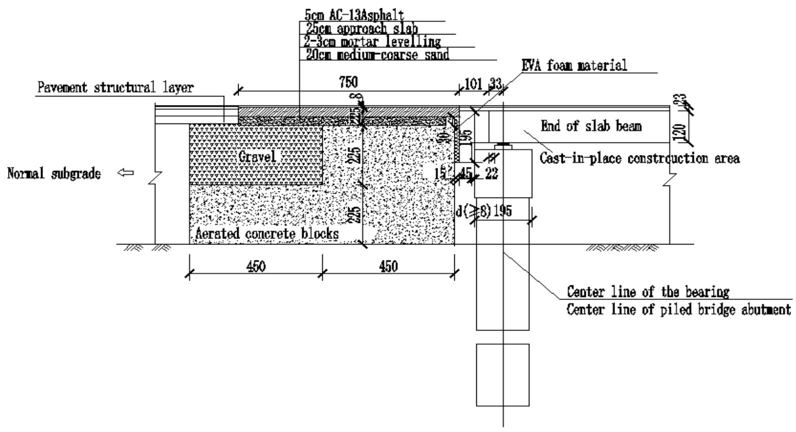


Fig. 29 Cross section of the composite backfill

The second feature of the bridge is that X-type reinforcement is adopted at the connection between abutment and approach slab to ensure the connection hinged. When there occurs any external loading, such as thermal effect or slab settlement, it only transmits horizontal force without bending moment resisted. (Fig. 30)

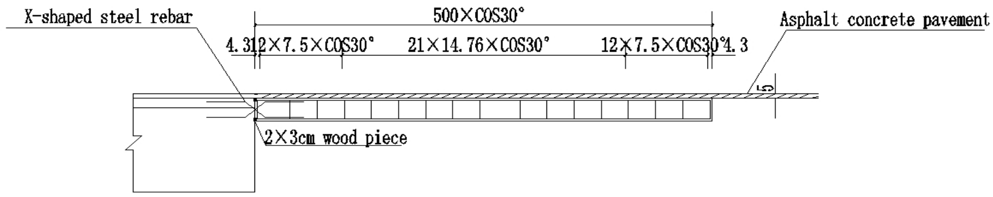


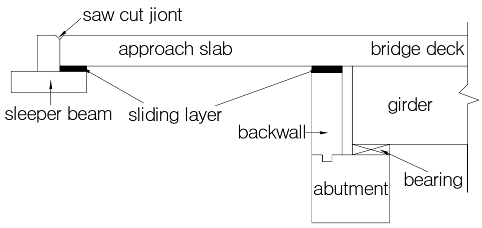
Fig. 30 Sectional structure of approach slab area

To investigate the accommodating capacity of thermal deformation of this semi-integral bridge system and the influence of skew angle on its performance, some strain gauges were embedded in various points in an approach slab to monitor its mechanical behavior. Currently, a long-term observation, including overall deformation, slab strain and general behavior of the structural system, is being conducted.

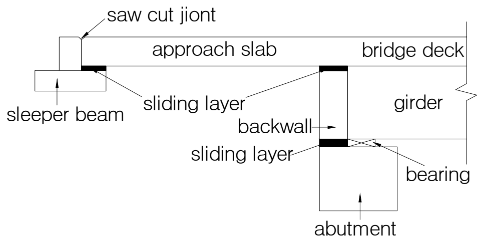
Extension Deck Sliding Jointless Bridge (EDSJB)

EDSJB is built by extending bridge deck crossing over the top of back wall and being connected with approach slab. By doing so, the normal expansion joint is moved back to the end of approach slab which is also supported by a sleeper beam. Eventually, the superstructure is protected from any corrosion. EDSJB is widely used in North America (NA), especially in Michigan State. It is one of three major jointless bridges and its applicability in China is much wider than NA or Europe because it is suitable not only for new bridges but also for existing bridges (Table 1).

General speaking, EDSJB is adopted only when IAJB or SIAJB cannot satisfy the particular design requirements（for example, bridge length or skew angle exceeding limitations）, or for rehabilitation of existing structures. Fig. 31 shows two kinds of most popular EDSBs. Most of projects done and being done are related to EDSJBs because of its easiness for both new construction and existing rehabilitation.



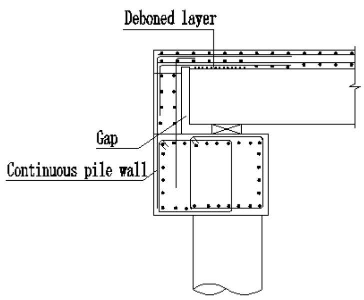
a) Independent deck sliding



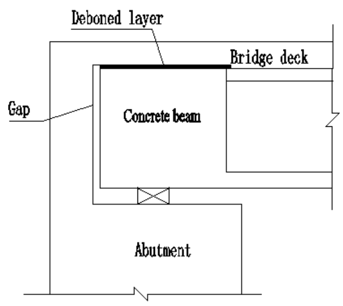
b) Dependent deck sliding

Fig. 31 Two kinds of most popular EDSJBs

Here is an example of special EDSJB, Hong Yu Medium Bridge in Fuzhou (No. 25 in table 1). The bridge is designed as a peculiar SIAJB as shown in Fig. 32. The constraint between girder and abutment is larger than semi-integral abutment bridge, but it is still classified as a SIAJB.



(a) Cross section



(b) Appearance view

Fig. 32 Australian configuration between semi and full integral abutment

Hong Yu Medium Bridge is a 20 m long of PRC hollow slab simple bridge supported by columned piers with bored pile foundation. Fig. 33 shows its cross section.

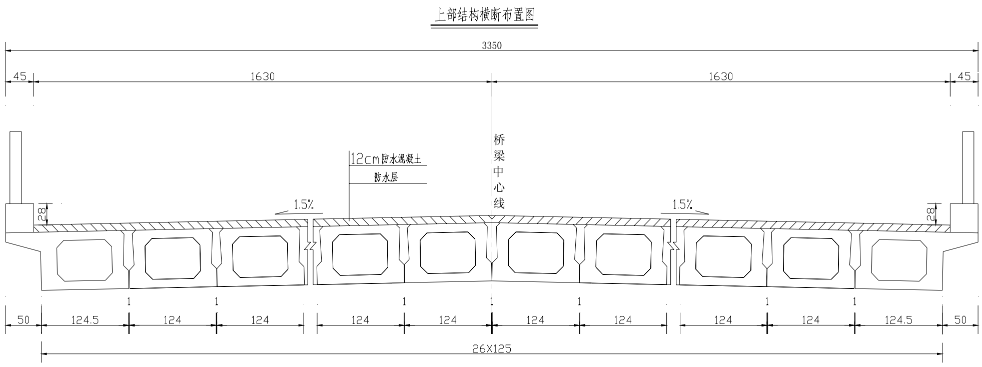


Fig. 33 Cross section of Hong Yu Medium Bridge (unit: cm)

After 3 years' service, there exist lots of distresses, with most of them being the serious damage of concrete and debris clogging in both expansion joints which lower the riding comfort and even safety. Therefore, the owner asked Fuzhou University to rehabilitate the bridge into a jointless bridge. As a new trial, an Australian semi integral abutment bridge is being carried out. Fig. 34 shows its design of approach slab and Fig. 35 shows the configuration of the Australian semi integral abutment. The construction of the bridge rehabilitation will be started next month.

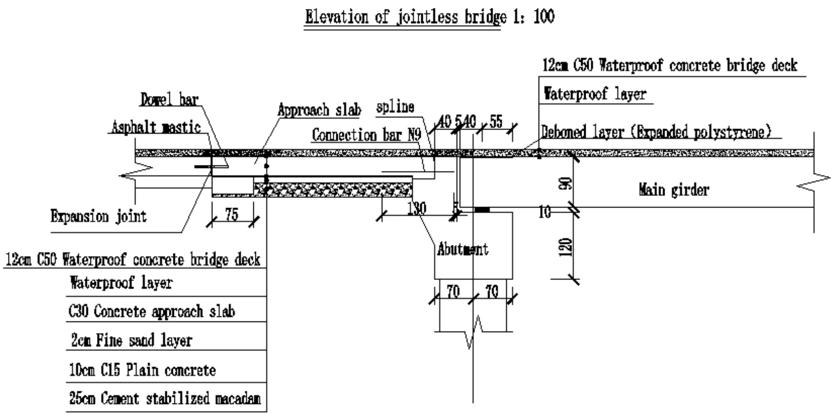


Fig. 34 Design of approach slab

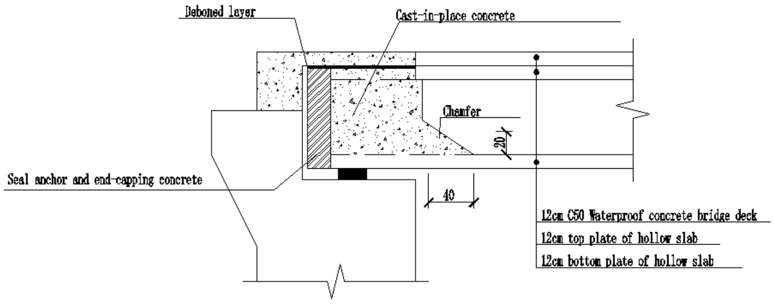


Fig. 35 Design of Australian Semi integral abutment

TABLE 1 LIST OF ALL JOINTLESS BRIDGES BUILT AND BE BUILT IN CHINA (UP TO MARCH 1,2014)
(ONLY ON IAJBs, SIAJBS AND EDSJBS)

No	Bridge Name	Location	Span Arrangement and	Structural Type	Year of Bridge Completion	Note
1	Overpass	Yi-Chang Highway	11.4+33.2+11.4 m, continuous beam	SIAJB	1998	
2	Cheng Nan Road Viaduct	Changsha City	14+2×20+25+4×20+12 m continuous beam	East end: Integral abutment, West end: Traditional gravity abutment	1999	Curved
3	Bao Zheng Gang Bridge	Shanghai Chongming	2×12＋20+2×12 m Hollow slab, continuous deck	Pile foundation and approach slab	1999	Skewed 10°
4	Si Jiu Medium Bridge	Qingyuan, Guangdong	10+2×16+10 m RC continuous rigid frame	IAJB Total bridge length of 75.48 m	2000	Skewed 15°
5	Li Guan He Bridge	Zhoukou, Henan	3×16 m, precast PRC hollow slab, simply-supported, continuous deck	SIAJB, Total bridge length of 67.96 m	2000	Skewed 15°
6	Shi Long He Bridge	National highway 207	4×16 m, precast PRC hollow slab, simply-supported, continuous deck	SIAJB, Total bridge length of 84 m	2000	Skewed 15°
7	Shang Ban Large Bridge	Yongchuan, Fujian	4×30 m, precast PRC continuous T girder	IAJB	2004	
8	Na Jiao Bridge	Nayou, Guangxi	4×20 m, precast PRC simply-supported, continuous beam	SIAJB， one end: gravity abutment, another end: light abutment	2005	
9	Da Shui Ting Bridge	Heng-Da Highway	4×16 m, precast PRC hollow slab, simply-supported	SIAJB	2005	Skewed 35°
10	Da Pu Ramp Bridge	Heng-Da Highway	3×25 m, precast PRC hollow slab, simply-supported	SIAJB	2005	Curved
11	Long Tang Bridge	Qingyuan, Guangdong	2×11.4+11.1+11.65+4×9.15 +2×13.55 m, simply-supported beam	SIAJB	2006	Rehabilitation, curved
12	He Kou Medium Bridge	Tianling, Guangxi	4×20 m, PRC continuous box girder, four spans between expansion dams	SIAJB	2010	Curved and skewed
13	Kou Meng Small Bridge	Ningming，Guangxi	16 m, RC hollow slab	SIAJB, U gravity abutment	2010	
14	Kui Gu Small Bridge	Ningming，Guangxi	10 m, RC hollow slab	SIAJB, U gravity abutment	2010	
15	Xin Yu Small Bridge	Ningming，Guangxi	16 m, RC hollow slab	SIAJB, U gravity abutment	2010	
16	Kui Luo Small	Ningming，Guangxi	10 m, RC hollow slab	SIAJB, U gravity abutment	2010	

	Bridge					
17	Yan Ke Medium Bridge	Ningming，Guangxi	20 m, RC hollow slab	SIAJB ,U gravity abutment	2010	
18	Na Mai Small Bridge	Ningming，Guangxi	10 m, RC hollow slab	SIAJB, U gravity abutment	2010	
19	Ban Kan Medium Bridge	Ningming，Guangxi	2×16 m, PRC hollow slab	SIAJB, U gravity abutment	2010	
20	Li He Cun Bridge	Kunming, Yunnan	4×20 m, PRC hollow slab, continuous for live load, four spans between expansion dams	SIAJB，gravity abutment	2010	
21	No.1 Xing Long Bridge	Kunming, Yunnan	3×20 m, PRC hollow slab, continuous for live load，three spans between expansion dams	SIAJB，gravity abutment	2010	
22	No.2 Pei Hong Gou Medium Bridge	Yinchuan, Ningxia	4×20 m, PRC continuous box girder	Ribbed plate abutment	2012	Curved and skewed
23	Guang Bian Bridge	Huzhou, Zhejiang	3×16+4×16 m, Precast PRC hollow slab, continuous deck with one link slab in the middle	EDSB，continuous for live load	2012	
24	Shi Li Bridge	Zhangzhou, Fujian	6×16 m, PRC hollow slab, continuous deck	SIAJB，System transformation from simple to continuous	Under construction	
25	Hong Yu Medium Bridge	Fuzhou,Fujian	20 m, PRC hollow slab, simply-supported	SIAJB，System transformation from simple to jointless	Under construction	Australian configuration, between semi and full integral(Fig. 23)
26	Liu Er Ying Medium Bridge	Gaoyu ,Hebai	2×20 m prestressed concrete composite box girder	SIAJB，System transformation from simple to jointless	Under construction	
27	Yong Nian Medium Bridge	Yongnian, Hebai	20 m prestressed concrete composite box girder	SIAJB，System transformation from simple to jointless	Under construction	
28	A highway bridge	Shenzhen, Guangdong	A single span curved ramp bridge	IAJB	In planning	
29	A Highway Bridge	Shenzhen, Guangdong	and a multi-span of T girder bridge	EDSB	In planning	
	15 bridges to be jointless	Xian, Sanxi	9-existing, 6-new	SIAJBs and EDSBs	In design	

CONCLUSIONS AND REMARKS

From 1990's，Fuzhou University and Hunan University, etc., have been working on jointless bridges with many research paper publication and project completion. Up to an incomplete statistics, there are only 23 jointless bridges built in China, with most of them being short span of SIAJBs or EDSJBs. Under the endeavor of SIBERC, Fuzhou University, there are yet almost 20 bridges (new design and existing bridge rehabilitation) engaged in design and construction as jointless bridges with most of them being still short spans and non-IAJBs (Table 1). According to a report, China is now a country with most number of bridges, exceeding USA. However, the number of jointless bridges is far less than America, Canada, Australia, and most countries in Europe. This mismatch was produced partially by the strategy of "Great leap" as a developing country, which results in short lifespan, frequent repair or rebuilding, and even collapsing of a large number of bridges.

Along with the economic development and social maturity, the safety, life cycle cost and sustainability of infrastructures have been gradually recognized and emphasized as the strategy of a country's development. For bridges, jointlessness is one of limited ways to fulfill this strategy.

Recently, SIBERC of Fuzhou University has started the series research on, not limited to:

- Aseismicity of micro pile supported semi-integral abutment bridge
- Static and shaking table dynamic tests on pile-soil interaction
- High toughness cementitious (HTC) link slab jointless bridge with HTC approach slab
- Reactive Powder Concrete(RPC) pile supported IAJBs
- Dynamic damage mechanism of approach slab

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