# History and applications of concrete steel composite structure

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**ABSTRACT**

The composite steel-and-concrete structure is a modern structure, combines the advantages of concrete and steel one. Nowadays, it is widely utilized all over the world but not much in Vietnam. Studying the history of formation and development is very meaningful in understanding and applying this type of structure in practice. This article focuses on presenting the formation and development of the composite structure and, at the same time, introduces the potential and applications of the composite structure to the current construction practice in Vietnam.

## 1. Introduction of composite structure

The composite steel-and-concrete structure is composed of concrete and steel interconnected by shear connectors to prevent separation and longitudinal slip between the two materials (Pelke & Kurrer, 2015). A composite structure consists of many components, including a composite column, steel beam, composite slab, and connectors. Composite slabs are comprised of profiled steel sheet decking and a topping of in-situ reinforced concrete (SDI, 2012). The decking acts as the permanent formwork of an in-situ cast concrete slab. Additionally, it provides a sufficient shear bond with the concrete so that, once the concrete has full strength, the two materials compositely work together (Uy & Liew, 2003).

The composite flooring system is constructed of a cold-formed, profiled steel sheet working as formwork for an in-situ cast concrete slab. In the composite stage, steel and hardened concrete elements form the composite slab, where the steel sheet is subject to tensile loading, while the concrete is compressed (Oehlers & Bradford, 1995). Then the effective depth of the slab section increases leading to higher bending stiffness and lower deflection. The profiled steels have a special shape so that concrete and steel can work together. The primary and secondary beams support the composite slab. Normally, the slab is placed perpendicular to the latter and parallel to the former. Along the beams, shear studs are welded to connect the slab and the beams (Narayanan, 1988). The beams are normally I-shaped steel and are defined as bending components. The columns support the primary beams through connections. Columns are I-shaped H-shaped steel or are combined with concrete to form composite columns. When the concrete part is constructed outside the steel, the shear stud will be constructed to link the two components together (Erkan, 2005). Columns subject mainly to compression or to both compression and bending. The last and most important part is the connection between the concrete and steel components to form the composite structure. The composite structure has the optimal working combination between the two types of reinforced concrete and steel structures. Due to its superiority, it is widely used in a variety of structures (Hicks, n.d.).

The composite structure has so far experienced a long history of formation and development (Uy & Liew, 2003). Studying the history of formation and development is very meaningful in understanding and applying this type of structure in practice (Nethercot, 2003). This article focuses on presenting the formation and development of the composite structure and, at the same time, introduces the applications of the composite structure to the current construction practice in Vietnam.

## 2. The formation and development of the composite structure

Up to the present time, the composite structure has undergone a history of formation and development for nearly two centuries. It dates back to 1808, when Ralph Dodd was granted the first patent relating to stone composite beams. It can be divided into five important phases in the history of development (Pelke & Kurrer, 2015):

- The initial phase (from 1850 to 1900) - formation of the composite beam;
- The constitution phase (1900 - 1925) - formation of the composite beam's cross-section;
- The establishment phase (1925 - 1950) - formation of the shear connector. In this phase, it is considered that the cross-section elements had to be structurally connected. The connection must be initiated as the restraint, then as the mechanical shear connector;
- The classical phase (1950 - 1975) - Development of the composite structure. In this phase, multiple forms of steel-concrete composite structures were realized in the field of bridges and industrial buildings;
- The development phase (1975 to now).

### *2.1. Initial phase (from 1850 to 1900): The formation of composite beam*

In this phase, the suspended slab was invented to cast the iron under the reinforced concrete layer. Then, the iron slabs were used to form a composite structure, typically a composite slab of Pohlmann, in 1901 (Pelke & Kurrer, 2015). The composite beam was composed of a T-shape beam with an open web and asymmetric flanges: the iron bulb flange and flat metal hoops form a shear-resistant layer connecting to the compression zone of concrete (Figure 1).

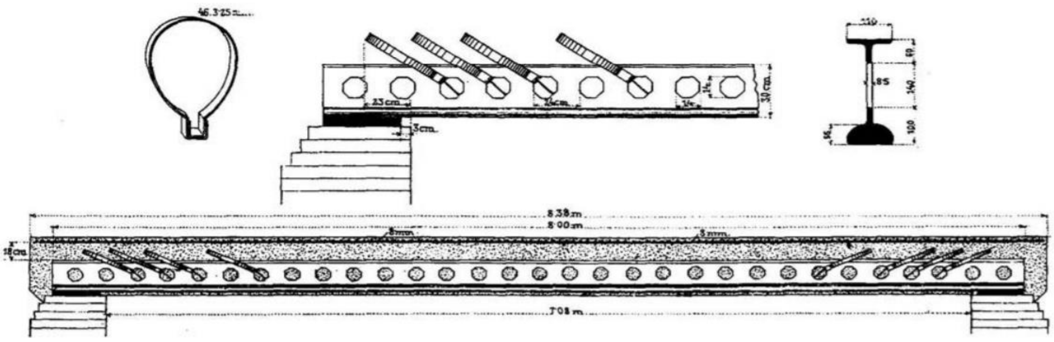

**Figure 1.** Pohlmann slab (1901) (Emperger, 1904)

### *2.2. Constitution phase (1850 - 1900): Constructional separation of steel and concrete elements of the component's cross-section*

In this phase, the differences between rigid and non-rigid reinforced concrete behaviour were realized. The connection between rigid reinforcement with concrete is much weaker than non-rigid one in terms of cohesion. The experiments of Carl on Bach from 1907 to 1909 at the Materials Testing Institute in Stuttgart - Germany, showed that the slipping resistance of steel cross-section is much lower than non-rigid round steel bars (Emperger, 2012). At that time, the role of rigid reinforcement and round steel is considered to be the same. The engineers could not explore how the round steel bars work as the transverse connections of the webs of the cross-section of the railway bridge (Figure 2). Following a long time, the shear resistance function of the connectors has been recognized.

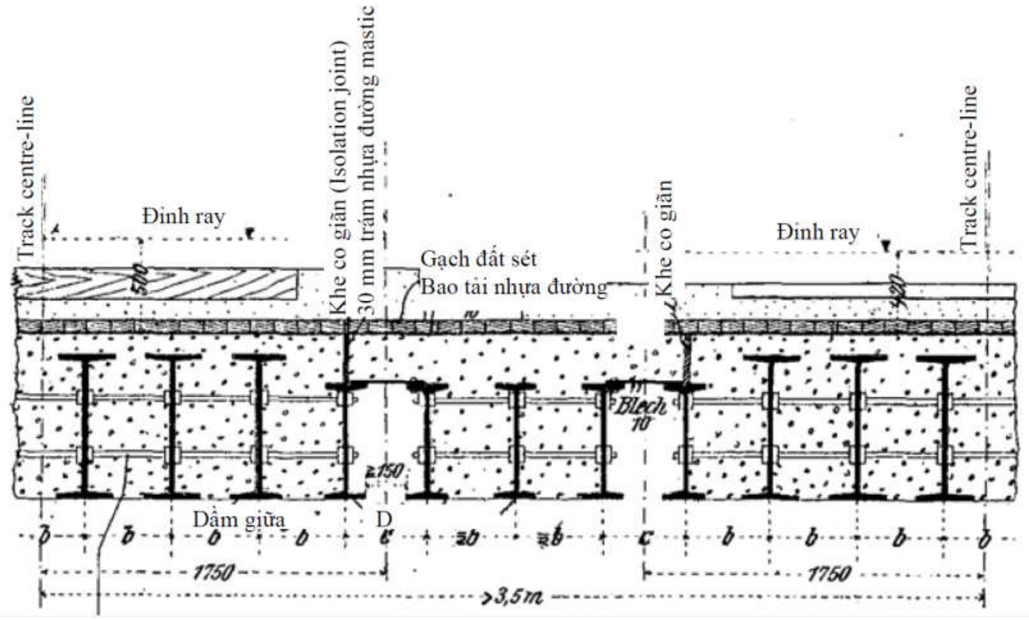


**Figure 2.** Typical cross-section of railway bridge: Rolled steel beams attached in concrete (Gesteschi, 1921)

At this time, the composite bridge structure has gradually improved. For example, Acheregg Bridge over Lake Lucerne in Switzerland was one of the first griders in Europe (Rohn, 1915). This bridge has a reinforced concrete deck supporting the load through a frictional connector. The cross-section of beam-and-slab is modern-looking with an approximately 23cm deep reinforced concrete deck on top of two 3250mm of spacing, rolled steel beams. The depth of these beams is 800mm. About 20cm of each web and the top flanges are encased into the underlayer of the deck.

***2.3. The phase of establishment (1925 - 1950): The formation of structural connection of steel and concrete elements - shear connector to resist displacement***

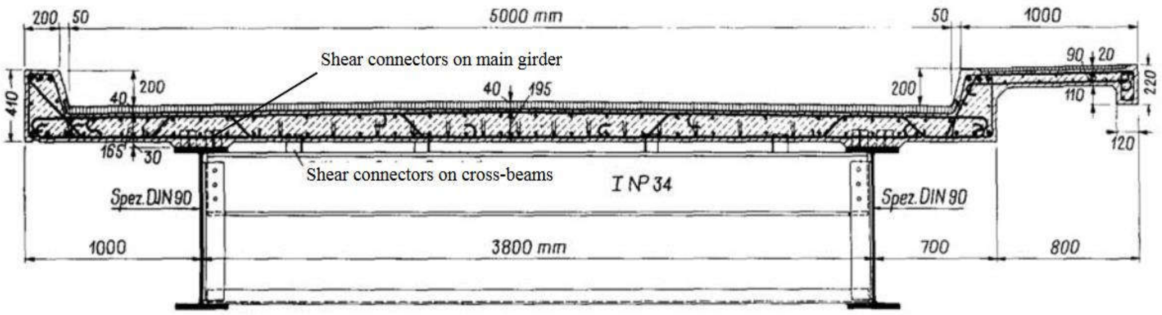


**Figure 3.** Cross-section of Willerzell Viaduct bridge on Sihl lake (1936) (Rohn, 1915)

At this stage, it was confirmed the role of the shear-resistance connector, and the theory of composite structure was also completed. Initially, European studies still focused on the friction/adhesion bond between concrete and steel until Otto Schaub proposed an effective connector by curved round steel reinforcing bars, applying for the Willerzell Viaduct bridge on Sihl lake in Switzerland, 1936 (Figure 3).

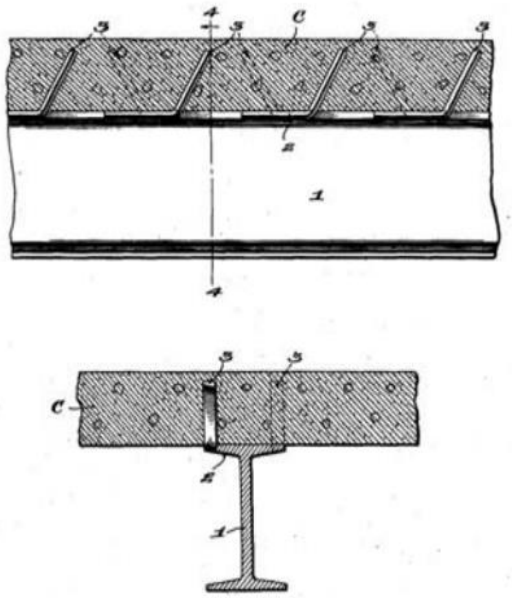

**Figure 4.** Kahn composite beam 1926 (Julius, 1926)

**Figure 5.** Typical composite structure of commercial building in UK 1900s (Erkan, 2005)

In the USA, in 1921, Julius Kahn registered a patent for a composite beam and then granted it in 1926. In this structure, the modern style cross-section of the steel-concrete composite structure is formed by an alternating arrangement of bent-up flange cut-outs to connect the beam and reinforced concrete deck (Figure 4).

***2.4. Classical phase (1950 - 1975): Quantification of the connection of the cross-section's elements and the vital of the construction of steel-concrete composite structure***

At once, in the USA, there was the first successful steel-concrete composite bridge with 06 and 24m length spans in the form of slab and multi-beam bridge. In these straight beam-and-slab bridges with closely spaced steel beams, the reinforced concrete slab is mostly against the transverse loads and resists the heavy vehicles dynamic loads. In 1938, Newmark proposed a theoretical basis for this bridge type. From this theory, in 1943 he published his first design concept (Newmark, 1949). Following extensive tests, Newmark, together with Richart and Siess completed the practical design concept shortly after World War II. In 1944, theAmerican Association of State Highway Officials (AASHO) published the first design provisions standardizing the steel-concrete composite bridge for the first time in the USA.

In Germany, in April 1948, there was the reconstitution of The German Committee for Structural Concrete (DASt). Due to the situation after the war, Wilhelm Klingenberg led the DASt to set up its "Composite Beam" subcommittee. The first draft of a code of practice for the "design of composite beams for road bridges" was submitted as in 1950. Also, DIN 1078 (steel-concrete composite bridge beams) in 1955 and DIN 4239 (composite beams in buildings) in 1956 were introduced inspiried by the code drafting work of Klingenberg.

In Japan, the composite structure first appeared in 1910, widely applied to the skyscraper, especially after the second World war. It was considered that the composite structure is most effective for 05 - 20 storey buildings; even for more than 20 storey buildings, the lower floors were made up of composite structures. In 1958, Japan published its national standard of a composite structure called the SRC standard (Steel Reinforced Concrete).

***2.5. The development phase (1975 to now): The development of morden composite structure***

In this phase, the composite structure is widely applied to high-rise buildings. After the earthquake in 1978 in Miyagiken - Oki - Japan, it was seen that the capacity of earthquake resistance of the composite structure is better than a conventional reinforced concrete one.

Nowadays, the theory of composite structure is completed. Many countries have given design standards for this structure, for example:

- Eurocode 4: Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings (BEng & Park, 1994).
- Australian standard AS 2327.1-2003: Composite structures - Part 1: Simply supported beams (Uy & Hicks, 2014).
- Australian standard AS 5100.6-2004: Bridge design - Steel and composite construction (Hicks, Uy, & Kang, 2017).
- Japanese standard: SRC (Steel Reinforced Concrete).
- American Institute of Steel Construction (AISC) (2000): Code of Standard Practice for Steel Buildings and Bridges. American Institute of Steel Construction, Inc. Chicago, IL (American Institute of Steel Construction, 2000).
- American National standards institute/ steel deck institute - C - 2011 Standard for Composite Steel Floor Deck - Slabs (SDI, 2012).

**3. Application of composite structure**

In its history, the composite structure was initially applied for buildings, then widely used for bridges and industrial structure. However, after 1975, the composite structure's important role in civil and industrial buildings was proved, especially in multi-storey buildings and factories (Pelke & Kurrer, 2015).

***3.1. Composite structure in civil constructions***

In the world, composite structure is widely used in civil construction, especially in high-rise buildings. Composite structure meets the requirements of bearing capacity with compact structures, moderate cross-section and fast construction speed (Figure 5).

In the USA, Comerica Bank Tower in Dallas (Texas) - a 60-storey skyscraper with a height of 240m constructed from 1985 to 1985, is a typical example of a composite structure being used as a skyscraper. Its structure is made up of a reinforced concrete core combined with steel columns and steel beams (Hart, Henn, & Sontag, 1978). The total floor area of the building is 142,233m$^2$. The 89$^{th}$ highest building in North America, 49$^{th}$ highest in the USA, thi$^{rd}$ highest in Dallas, and sixth highest in Texas.

A composite structure was also used for Millennium Tower (Vienna - Austria) constructed from 1997 to 1999 (Rubin & Tschemmernegg, 1999). The tower consists of 50 floors, 171m high. The floor plan of the tower has an area of 1080m$^2$, the form of two overlapping circles for the office block and the concrete core in the middle. The tower is designed using a typical composite structure with composite columns and thin welded T-shaped composite beams combined to form a composite frame with semi-rigid connections between beams and columns. The tower has a fantastic construction speed: from 2 to 2.5 floors in a week.

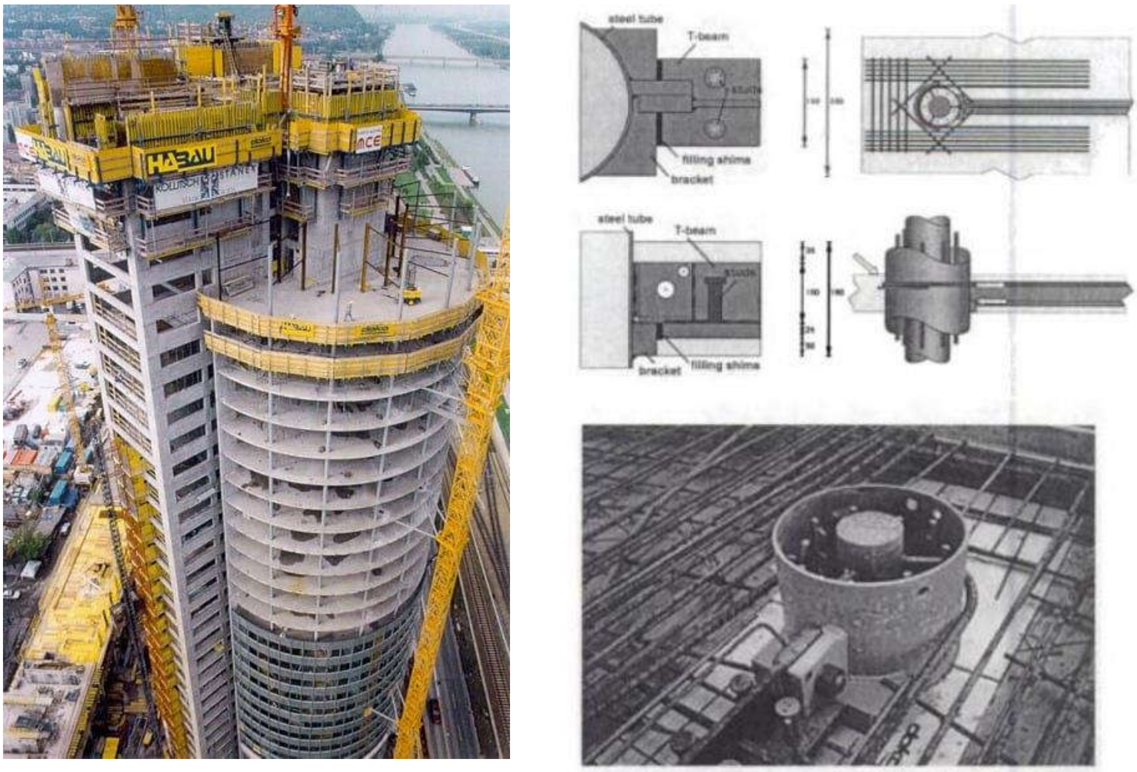


**Figure 6.** Millennium Tower (built in 1997 - 1999) by composite structure having 50 floors with 171m high (202m including antenna) and typical column beam connection (Rubin & Tschemmernegg, 1999)

In Vietnam, composite structures have also been used for a long time for buildings. Before 1975, the Nguyen Kim apartment building was designed and built with this structural form. After that, the Diamond Plaza building, a very famous high-rise building in Ho Chi Minh City, was also completely built with a steel-concrete composite structure. Recently, the Bitexco Financial Tower project also applied the form of a frame structure, columns, and steel-concrete composite floor for the podium. Bitexco Financial Tower holds the record for many years as the tallest building in Ho Chi Minh City after giving it to Landmark 81.


**Figure 7.** Kim Thanh international border gate, Lao Cai province using composite slab, supported by four 150 x 50cm steel primary beams with a span of 24m

In 2010, a composite structure was used at Block B, Kim Thanh international border gate in Lao Cai (Figure 7) with a span of 24m; the structure was designed by the lecturers of the Department of Civil Engineering and Technology, Thuyloi University. Also, this year, the 68-

storey Vietinbank Tower project using a composite structure was started. After completion, this project will be the largest project in Vietnam using a composite structure.

The composite structure is also the solution to renovating and raising old houses instead of conventional structures (Figure 8). Accordingly, the old building is an atrium laboratory with an area of about 600m$^2$, which needs to be renovated into a number of classrooms on the upper floor. Due to the entanglement of experimental equipment (not allowed to move, not to damage equipment), a composite structure was selected. After that, the auxiliary beam system is placed on top, then proceed to install steel corrugated iron, and finally cast the concrete floor. Due to the narrow space, the main beam system was divided into small pieces (although it caused a weak reduction in the beam structure) and then reassembled using bolts. The construction was carried out quite smoothly; the composite structure solution is suitable in this case.

**Figure 8.** Composite structure used in renovating of Hydraulic laboratory of Thuyloi University

### *3.2. Composite structure in transport construction*

Medium span composite bridges are typically constructed from welded or composite sheet steel beams and wide reinforced concrete floors, as shown in Figure 9a. Box girders, as shown in Figure 9b, look good but are more expensive and are used less often. For smaller spans, from 20 to 35m, hot rolled steel sections are commonly used in combination with concrete slabs or placed in concrete (above flanges and girders). Figure 10 illustrates hot-rolled steel sections used in this way, which can be curved if required.

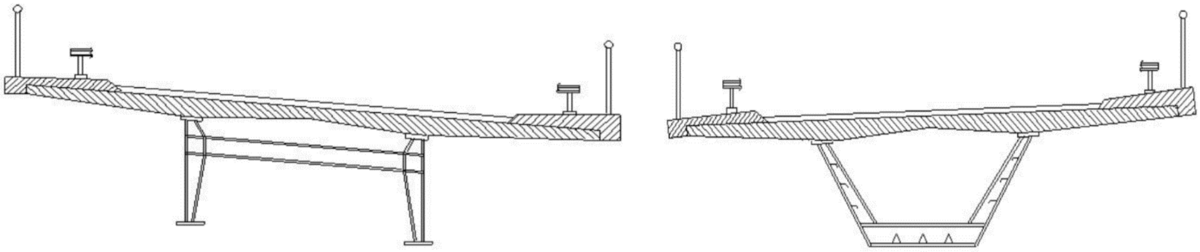

**Figure 9.** Typical cross-sections for bridge girders using composite structures: a) composite steel plate girders in Europe; b) box girders (Erkan, 2005)

Since the 1950s, several composite bridges have been built on the continuous high-span highway. In the years immediately following the Second World War, steel was very expensive, so the composite structure took advantage of its lightness and less steel usage to save material costs. Today, bridge cross-sections are more compact and simpler and do not have too many auxiliary beams, supports, and stiffeners. This structural form helps to save design and construction costs.

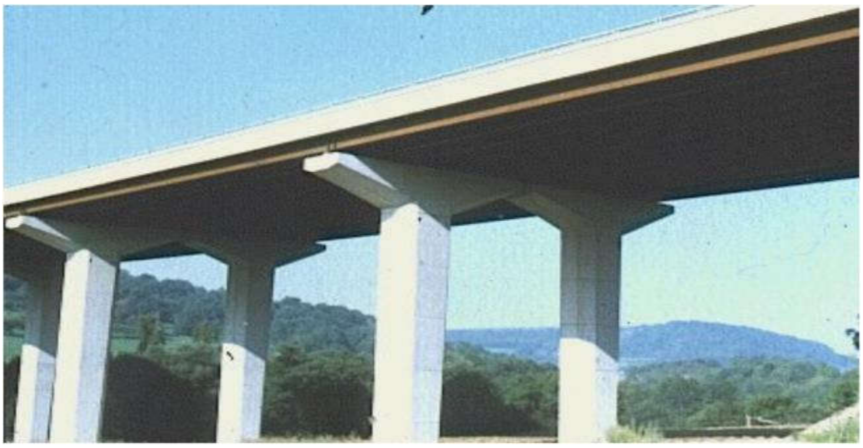

**Figure 10.** Typycal medium span composite bridge (Erkan, 2005)

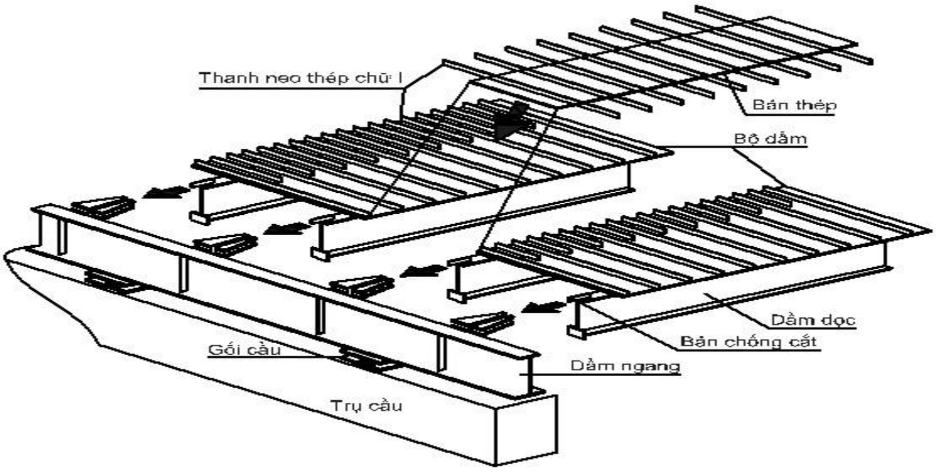


**Figure 11.** New type I composite grider structure (Nguyen & Mac, 2015)

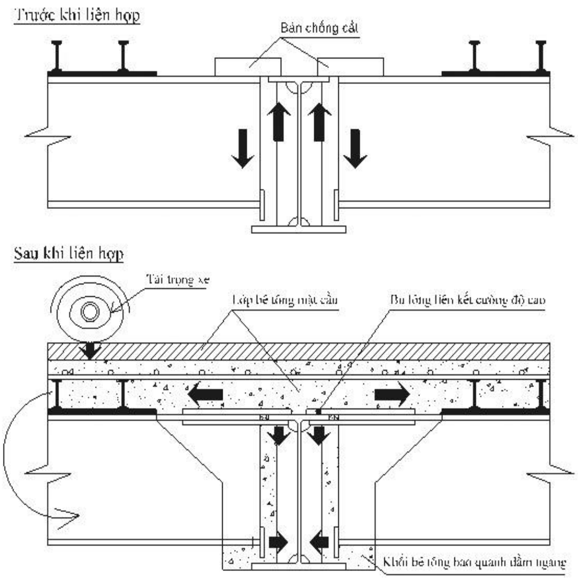


**Figure 12.** Transverse beams before and after composited (Nguyen & Mac, 2015)

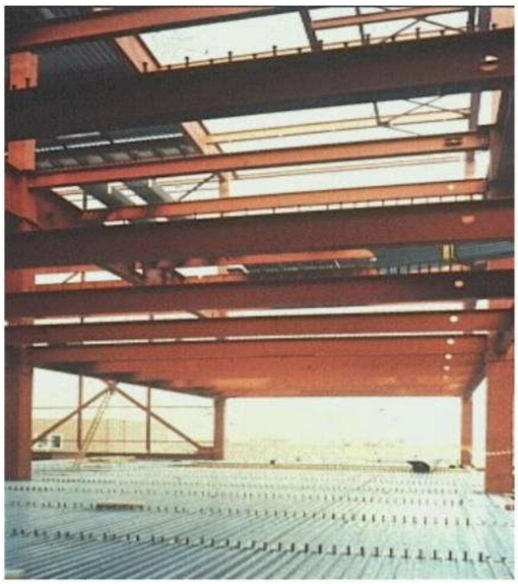

**Figure 13.** Typical composite multi-storey composite steel frame structure for automobile factories in Germany (Erkan, 2005)

In some Asian countries, such as Japan, I Panel girder - a new type of composite I-beam without a transversal girder is used quite commonly, such as Kimitsu, Tosu, and Shimohag. This type of bridge does not arrange intermediate transverse girders; only transverse beams are arranged at the two ends of the main girder at the abutment and pier positions; the transverse beam is placed directly on the pin and connected to the main girder. In order to increase the stiffness of the transverse beam, vertical reinforcement ribs can be arranged. In addition, to further increase the local shear strength at the bearing position, one can cast concrete enclosing this beam (Figure 11 and Figure 12).

### *3.3. Composite structure in industrial*

Industrial plants can use a composite structure for a high-bearing capacity structural solution that can support loadings on the floor as well as heavy equipment loading. At the same time, it can meet the construction schedule or provide effective construction solutions in difficult locations such as conventional concrete structures. Figure 13 shows an industrial building using a composite structure in Germany.

In Vietnam, steel structures are used a lot in industrial buildings due to their flexibility, good bearing capacity, ease of fabrication, and ease of construction. With many advantages, since the 2000s, composite structure has been widely used in industrial buildings. Industrial plants widely use composite structures, especially on the upper floors where it is not possible to construct reinforced concrete with conventional formwork such as roof floors of cement silos or silos containing raw materials of Cement Plants Binh Phuoc (2009), Bim Son Cement Factory (2016), Tan Thang – Nghe An Cement Factory (2017), Hoang Thach Cement Factory (2018), Xuan Thanh Cement Factory. Silo in cement plants according to technology imported from European countries and solutions for the structure as well as composite structure solutions for roofs are also according to European consulting units (FLSmith - Denmark; Polysus, IBAU - Germany) in Vietnam. The construction location of these roofs is usually from 40 to 80m high, and the span is greater than 20m; so, the composite solution seems to be the only feasible solution.

## 4. Conclusion

The composite structure has a long history of formation and development and is widely applied. With the advantages of optimal working with fast construction time and a variety of structures, composite structures need to be applied more. Especially using composite structures in multi-storey buildings, where reinforced concrete structures are still being used the most in our country.

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