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Application and Prospect of New Steel Corrugated Plate Technology in Infrastructure Fields

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Abstract. This paper systematically analyses the application status and advantages of steel corrugated plate and its composite structure technology in domestic and foreign infrastructure construction, such as in the tunnel fields. From the aspects of Engineering characteristics, environment and energy saving, etc. We put forward the research ideas, development prospects and application ideas of steel corrugated plate technology in the field of infrastructure.

1. Introduction

In recent years, the progress of infrastructure construction such as highways, railways, bridges, culverts, tunnels, and industrial or civil buildings has developed rapidly. Taking the tunnel as an example, by the end of 2018, there were 17,738 national highway tunnels with a total length of 1,7236.1 kilometers [1]. In addition to highway tunnels, there are thousands of urban tunnels and tens of thousands of railway tunnels throughout China. The total length of all kinds of tunnels planned and under construction is about 400,000 kilometers.

As a project with huge investment, the choice of materials and technology for infrastructure construction must consider the economy, durability, safety, and other properties. Traditional reinforced concrete is the mainstream material in the field of civil engineering, but in some extremely harsh special circumstances, it's difficult to construct and the reliability will be greatly reduced. Therefore, it is necessary to develop new materials and technologies to make the construction period shorter and the cost cheaper than reinforced concrete buildings. Steel corrugated plate technology is one of the best effects in the application of new materials and new technologies at this stage.



Table 1. The Contrast between Steel Corrugated Plate and Reinforced Concrete

	Advantages	disadvantages
Reinforced Concrete	Easy to draw, high strength, good integrity and durability.	high self-weight, Poor crack resistance.
Steel Corrugated Plate	Good mechanical performance, strong adaptability, fast construction speed, good durability, low carbon environmental protection.	The construction of the joint is difficult, and the work of anti-corrosion and anti-rust is large.

With the continuous decline of domestic steel prices caused by excess production capacity and the continuous upgrading of steel anti-corrosion and anti-rust technology at home and abroad, the public acceptance of steel corrugated plate is constantly rising. Nowadays, the number of successful application cases of steel corrugated is increasing, and the remarkable advantages of steel corrugated slabs, which are different from reinforced concrete materials, have attracted more and more attention. This will greatly promote the development of steel corrugated plate material and its composite structure technology. In the near future, technology will continue to mature and shine in the field of infrastructure construction.

2. Brief introduction of steel corrugated plate structure technology

2.1. Development of steel corrugated plate structure technology at home and abroad

The steel corrugated plate refers to a steel corrugated circular tube (tube diameter is 750-2500 mm) or an arc steel corrugated plate (span greater than 1500mm) made by rolling and cold bending a certain thickness (2~12mm) of hot rolled steel plate or strip in accordance with the specified size. In order to ensure that the structure (bridge, culvert, passage or pipeline) formed by steel corrugated plate and soil can bear the common load, the steel corrugated plate structure is assembled on-site and compacted by backfilling material around the structure.

The inertia moment of the section is greatly increased after the common flat steel plate is processed into corrugated shape, so its bearing capacity is also greatly increased. In order to ensure the service life of steel corrugated board meets engineering requirements, its application must be treated with corrosion resistance in engineering, such as galvanizing, aluminizing or spraying composite coatings on the surface. When the steel corrugated plate is transported to the construction site, asphalt paint can be sprayed on the outer surface to enhance the anti-corrosion effect to improve its further service life. The Steel corrugated plate is shown in Figure 1.



Figure 1. Steel corrugated plate

The corrugated plate technology first appeared in the United Kingdom in 1784. The original purpose of using this material is to replace concrete material in the field of bridges and culverts. In 1886, American J. H. Weston successfully applied for a steel bellows patent. In 1892, W.Q.O'Neill bought out the patent for corrugated steel and established a factory to produce corrugated steel tubes. Steel corrugated board assembly technology for the first time in culverts for farmland irrigation in the suburbs of Edinburgh, the UK in 1913. Since then, steel corrugated board had been widely used. The American Railway Engineering Association has issued technical standards, design, and construction installation manual for steel corrugated boards in 1923. In the same year, Canada also applied steel corrugated board in a coal mine. In 1929, the bridge design specification for Ontario, Canada, proposed the design

requirements for steel corrugated board. Countries such as Japan and South Korea also mentioned steel corrugated plate design requirements around the 1990s [2-3].

The earliest case of using steel corrugated plate technology in China is a culvert on the Yunnan-Burma highway in the late 1930s. In 1948, a water-crossing bridge in Pudong, Shanghai was used steel corrugated plate. The construction of bridges and culverts in the Qinghai-Tibet Expressway Freeze Spring Section officially marks the application of steel corrugated plate technology in China in the 1950s. It also lays a good foundation to popularize the steel corrugated plate [4-5]. In the 1980s, a double-hole corrugated steel plate arch passage was installed near Anjiabao Coal Mine of Pingshuo Line in Shuozhou, Shanxi Province. After the effect of steel corrugated plate passage in Shanghai Metro Line 4 and Pudong Airport is good in 1998, steel corrugated plates were widely used in Shanghai municipal and other projects. After entering the 21st century, with the great benefits of using steel corrugated plate in Qinghai and Tibet, Inner Mongolia and North China carried out a series of studies, such as anti-corrosion test, load test, construction technology, and inspection standards. on steel corrugated plate. Its related specifications including *corrugated sheet plate in highway bridges and culverts*, *corrugated steel pipe and for highway culverts*, *technical specification for arched corrugated steel roof*, etc [6-7]. In 2006, Zhulong LI published the first monograph of steel corrugated plate in China-*Design and Construction Technology of Highway Steel Corrugated Pipe Culvert*.



Figure 2. Early application cases of steel corrugated plate in China

A Steel corrugated plate has been manufactured for more than 100 years. Countries such as the United States, China, Canada, Korea, Japan, India, and Europe have done a lot of research on steel corrugated plate and have the technology to produce high quality and low price steel corrugated plate series products. Chinese enterprises can even produce steel corrugated plates anytime and anywhere with mobile large corrugated plate production units. The technology of steel corrugated plate formed by different models, different types and different structures will be widely used by its expanding application fields.

2.2. Advantages of steel corrugated plate

As a new type of flexible high-strength material, compared with the traditional rigid embedded structure (reinforced concrete circular pipe culvert, a cover culvert), steel corrugated plate unique advantages are embodied in:

- Diversified products and wide range of use. Make full use of the processability of steel, use different wall thickness and waveform (wavelength \times wave height) to produce different shapes of products to meet different functions and requirements. At the same time, bending and bifurcation structures can be made by elbows and tees to meet the linear requirements of different ditches.
- Low requirement for foundation and strong deformation capacity. Compared with masonry materials, steel has excellent tensile strength, and there is no cracking problem under load. Steel corrugated plate can give full play to the characteristics of high tensile strength and strong deformation resistance of steel, it can satisfy the influence of uneven settlement on structural deformation under unfavorable geological conditions (such as soft soil, expansive soil, collapsible loess, permafrost). Corrugated steel plate structure is suitable for cold and frozen areas in the north because it has little disturbance to the foundation and little thermal disturbance to the soil.

- Good seismic performance. Corrugated steel plate structure has light-weight, good flexibility, and can effectively reduce earthquake damage to the structure by interaction with the soil. When it is used in highway bridges and culverts, it can improve the "staggered platform" phenomenon at the junction of bridge and culvert on soft soil foundation and embankment, and improve the comfort and safety of traffic.
- Factory production, cost reduction, and quality control. Corrugated steel sheet structures are usually preformed into pipe joints or plates at the factory. Its production process is not affected by the environment, production efficiency is high, the production cycle is short, the accuracy and quality of processing is guaranteed [8].
- Easy to transport and install. Its self-weight is 50~800kg per piece or section which is 4%~20% of the reinforced concrete structure under the same conditions. It is not necessary to use large lifting equipment for lifting. The steel pipe can be transported in a nested manner, and the steel plate can be transported in bundles.
- The construction is simple and the construction period is short. Compared with reinforced concrete structures, the construction period of steel corrugated plate can be shortened by more than 70% because it is assembled on site.
- Low carbon and environmental protection. Reducing or abandoning the use of conventional building materials, such as cement, yellow sand, stone, and wood, is conducive to environmental protection.

3. The Application Status of steel corrugated plate structural technology

3.1. Bridge and culvert engineering

3.1.1. Construction of New Bridges and Culverts

In special areas such as soft soil, high cold, and high environmental protection requirements, materials for making concrete are difficult to obtain and its transportation costs are high. The use of concrete will also cause some damage to the local ecological environment. As shown in Figure 3 (a) and (b), we can use steel corrugated board materials and composite structural technology to replace traditional concrete technology to build bridges and culverts. In this way, the construction period of the bridge and culvert is short, the environmental affinity is high, and the average cost is reduced by 10% to 40%. When building high fill, high embankment and long-span bridges and culverts, using special steel corrugated plates such as local double-layer corrugated plates of pipe body will save more cost.

Figure 3 (c) shows the world's largest steel corrugated plate structure with a span of 24 meters, located in the Baima River, Canada. The construction time of the bridge is only 6 weeks. During the construction period, the river course and the interruption are not changed. Significantly reduce environmental impact by backfilling and compacting with granular materials. Figure 3 (d) shows a horseshoe-shaped corrugated steel plate bridge in Sanjiangyuan Nature Reserve in Qumalai County, Yushu Prefecture, Qinghai Province. The bridge is located at an altitude of 4,600 meters and has a single span of 7.5 meters in which the sidewall is made of steel corrugated plate reinforced earth retaining wall and which the arched structure is made of steel corrugated plate with large wave distance. The construction cost of the bridge is low, which meets the requirements of the state to promote green development, strengthen the energy-saving and environmental protection industry.

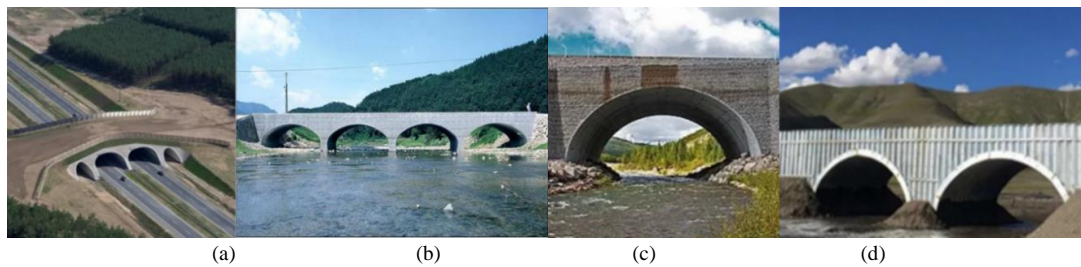


Figure 3. Example of new steel corrugated plate bridge and culvert

3.1.2. Reinforcement and enclosure of existing bridges and culverts

With the continuous improvement of China's vehicle load standards, especially the load standard for small and medium-sized bridges has increased the most. At the same time, the bridge management department has an insufficient investment in the maintenance of existing bridges that a large number of bridges and culverts have not reached the design standards led to small and medium-sized bridges entered the stage of large-scale maintenance and reinforcement. The method of demolition and reconstruction bridges is expensive and will interrupt traffic for a long time, which has a serious impact on society and does not meet actual needs. Using steel corrugated plate for reinforcement and maintenance not only improves the stress state of existing bridges, minimizes the traffic impact on bridges and culverts, but also saves huge engineering costs. When the bearing capacity of the steel corrugated plate does not meet the design index, it can also be strengthened to deal with. For example, forming steel corrugated sheet stiffeners, CBS, etc [9-10]. Figure 4 (a) shows reinforce stone arch culvert. Figure 4 (a) shows reinforce and wide simply supported beam bridges.



Figure 4. Example of reinforce steel corrugated plate bridge and culvert

3.2. Tunnel engineering

Steel corrugated plate structure has been widely used in urban, highway and railway tunnels in developed countries abroad. Compared with the original scheme, the application of steel corrugated plate in tunnel support has fewer construction steps and shorter construction periods. When it is used in the area where the tunnel is stressed and easily deformed, there will be no cracking and falling of concrete support structure. In addition, the waveform design can absorb noise and exhaust gas which can reduce the impact of urban tunnels on the surrounding residents.

Fig. 5 (a) shows the reinforcement construction of a tunnel support structure. It pours self-compacting concrete between the steel corrugated plate and the tunnel wall. This method has fast construction speed, good reinforcement effect and can be strengthened at night without interruption of traffic. Fig. 5 (b) shows the scene of Huaishuguan Tunnel in Hanzhong after being strengthened by corrugated plates. After transformation, the tunnel is more beautiful and the strength of the tunnel is greatly enhanced. Fig. 5 (c) shows the application of a steel corrugated plate in an open cut tunnel in China. The shock wave generated by falling stone which often occurs in these areas replace steel corrugated plate is shared by the buffer layer and the structure itself. Even if the corrugated plate is deformed greatly, the structure will not be broken down by falling stone.

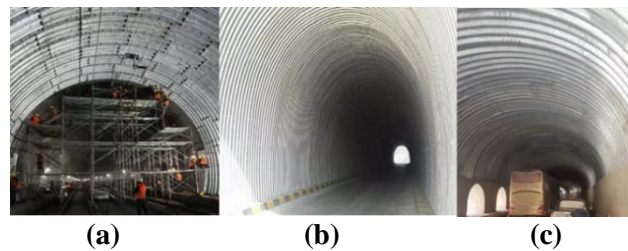


Figure 5. Example of steel corrugated plate tunnel

3.3. Housing construction engineering

The steel corrugated plate has a typical wavy and smooth line appearance that installation with horizontal, vertical or different angles for civil buildings can create a vivid and shocking visual experience for people in a large area. With the continuous optimization of steel corrugated plate structure and construction period, a luxury house can be built in only 300,000 yuan and one month. Figure 6 shows the steel corrugated plate houses with horizontal and vertical lines.



Figure 6. Example of civil steel corrugated plate house

Steel corrugated plate can be made into various types of houses as the characteristics of its flexibility and high Strength. It is often used in commercial buildings under the dual conditions of strength and aesthetics. As shown in Figure 7 is a foreign coffee shop which consists of an arc steel corrugated plate dome and a brickwork end wall. It has a unique shape and is popular among young people.



Figure 7. Example of steel corrugated plate cafe

4. The Prospect of steel corrugated plate technology

The Ninth National Congress of the Communist Party of China put forward the strategy of building a safe, energy-saving, environmentally-friendly and efficient modern transportation power. The owner units and the construction units not only need to strengthen the awareness of energy conservation and environmental protection, but also need to overcome the problems of high cost and long construction period. Steel corrugated plate technology in energy-saving, safety, fast and other fields are becoming more and more obvious that can be applied not only to the fields mentioned in the previous chapter and to its derivatives, but also to other fields. We will look into the future application of steel corrugated plate technology next.

4.1. Large span steel corrugated plate tunnel shade

According to the structural materials, the tunnel shade can be mainly divided into steel structure tunnel shade, reinforced concrete tunnel shade, steel-reinforced concrete composite structure tunnel shade and so on [10]. The steel structure tunnel shade is easy to rust and has poor fire resistance. It needs regular

rust prevention and maintenance when it is in a harsh outdoor natural environment for a long time, which leads to high construction costs and operation costs. The reinforced concrete tunnel shade has a long construction period, the structure is self-contained which has low tensile strength and easy to crack, it is also difficult to repair and reinforce. The steel-reinforced concrete composite structure tunnel shade is now widely used that combines the advantages and disadvantages of the steel and reinforced concrete.

The steel corrugated plate with strong plasticity, many waveforms, high strength, and strong adaptability forms large-span tunnel shade has the same advantages with steel-reinforced concrete composite tunnel shade. When the steel corrugated tunnel shade is designed as a semi-open structure, it can be integrated with the surrounding landscape and is conducive to tunnel ventilation, which can play a triple role in energy saving, safety, and landscape application. The effect and model of the large span steel corrugated plate tunnel shade are shown in the figure below.



Figure 8. Example of steel corrugated plate tunnel shade

4.2. Steel corrugated plate tunnel safety house

The lives of drivers and passengers will be seriously threatened when they drive in long tunnels in emergency situations such as fires and earthquakes. It is impractical to escape from the tunnel. The best way of that time is to transfer to the tunnel safety house to ensure their own safety and wait for rescue. Long tunnel requires a large number of safe houses, but the traditional safe house has long construction time and high cost. These problems can be effectively solved by using the steel corrugated plate as shown in the following figure to make tunnel safety houses.



Figure 9. Example of steel corrugated plate tunnel safety house

4.3. Steel corrugated plate underground integrated pipe gallery

In an underground integrated pipe gallery that is dark and humid with high carbon dioxide concentration, reinforced concrete is not only chemically corroded by this external environment, but also corroded by carbonation of concrete itself. According to the mandatory provisions of *Technical code for urban utility tunnel engineering*: The service life of the pipe gallery structure should be 100 years [11-12]. Therefore, the thickness of the concrete protective layer of the reinforced concrete underground pipe gallery is 1.4 times than of the thickness of the ordinary concrete protective layer. However, the thicker concrete cover thickness is easy to cause concrete cracking, so it is necessary to control the durability quality of reinforced concrete [12]. The steel corrugated plate treated with anti-rust treatment in which the condition of durability quality control is low can meet the service life of the underground pipe gallery requirement.



Figure 10. Example of steel corrugated plate underground integrated pipe gallery

Waterproofing and drainage are a very important part of the construction of an underground pipe gallery. The waterproof level of the underground pipe gallery is level II which means the surface of the structure may be slightly wetted but not allowed to leak. The main structure of the pipe gallery is made of waterproof concrete, waterproof coating and waterproofing membrane. The steel corrugated plate used in bridge and culvert engineering is used in the underground pipeline gallery, water seepage will not occur, the corrugated structure can also play the role of guiding water flow to ensure the durability of a structure. Take the first steel corrugated plate underground integrated pipe gallery was built in Jena, Germany, in 1945 as an example, the project is in good condition that the pipes are working normally and there are no obvious corrosion marks inside.

The price of 4x3.5m reinforced concrete is about 80 million yuan per kilometer, the price of diameter of 4.5m circular steel corrugated plate is about 60-70 million yuan per kilometer Compared with the reinforced concrete, steel corrugated plate can save 15%~25% of the cost which fully meets the needs of engineering needs and has obvious advantages.

The steel corrugated plate pipe gallery can effectively improve the phenomenon of "road zipper". Integrate the technology into urban construction and combine it with a smart city pipe network is a new idea for urban underground construction. It is conducive to the construction of liveable cities with green, modern, intelligent and sustainable development.

4.4. Steel corrugated plate highway service area

In recent years, the rapid development of highways has led to the rapid development of service facilities and housing construction projects along the highways. As one of the assembled buildings, steel corrugated plate building is supported by the government due to its fast construction speed and low engineering cost. The application of steel corrugated plate in the construction of expressway service area can not only alleviate the scarcity and difficult acquisition of building resources in the expressway service area but also reflect the green, energy-saving, and environmentally-friendly highway design ideas.



Figure 11. Example of steel corrugated plate highway service area

4.5. Temporary passage for emergency and disaster relief

In the mountainous area of western China, the mountain is steep, the geology is loose, and the road network is single. Once natural disasters such as earthquakes and flash floods occur, they often accompany landslides and destroy the roads. The rescue personnel can use the landslide debris or gravel near the mountain to backfill the temporary passage while splicing the steel corrugated plate at the same time. This scheme can be used as a special structure for earthquake and flood relief. The whole construction process only uses excavators or bulldozers without other mechanics, in addition, to avoid mixing concrete or mortar on-site to gain valuable rescue time. The most important point of the whole scheme is that it has a certain back pressure on the slope of the landslide body, which greatly improves the stability and safety of the landslide body.



Figure 12. Example of steel corrugated plate temporary passage



Figure 13. Permanent or temporary bridge with porous steel corrugated plate

4.6. Rainwater reservoir

The reservoir is built underground and made of galvanized curved steel corrugated plate with a plastic inner membrane on the inside to meet the waterproof requirements. Quickly construct the steel corrugated plate with bolts. Compared with the above-ground reservoir, the scheme has lower land cost and comprehensive utilization of land resources that we can build parking lots, squares, etc. above the underground reservoir.



Figure 14. Example of a steel corrugated plate reservoir

5. Application research on ventilation flat guide wall in Zhegushan Tunnel

Zhegushan Tunnel Project of Wenma Highway starts from Shan Jiao ba village, Lixian. It goes up the Laisu River and enters Wangjiazhai through the Zhegushan Tunnel. The total length of the project route is 11.5 km, the main part of the project is Zhegushan Tunnel. The right line of the Lushan Tunnel is 8766m and the left line is 8790m. Chengdu Huachuan Highway Construction Group Co., Ltd. Yuangu

Company built the ventilation guide (single hole) which is 3732m and a maximum depth of about 1406m on the left side of the tunnel exit part.



Figure 15. Zhegushan Tunnel Project of Wenma Highway

The original design of the flat guide wall is cast-in-place C30 waterproof reinforced concrete with a thickness of 30cm. When the second lining is applied, the steel bars are reserved for the middle wall reinforcement. The lining is constructed by molding concrete with a section length of 12m, and the formwork is reinforced by a monolithic sliding steel formwork. It is very difficult to remove the formwork of a special-shaped flat guide wall, which is time-consuming and labor-consuming. A little carelessness will damage the appearance and quality of concrete.

The construction of flat guide wall lining was originally planned to start on October 1, 2019, and completed in February 2020. The total construction period is 5 months. Due to operational management needs, it must be completed in advance by January 2020. In order to achieve this goal, assistant president Yu HAN actively solicited the design optimization plan of the design institute. Technical director of design institute, Xingping WANG organized project management department, design institute, Southwest Jiaotong University and Xi'an Century Metal Structure Co., Ltd. to carry out research work together. They formed a feasibility study report and put forward five alternative schemes, and finally decided to adopt a new type of fully assembled steel corrugated plate structure. It is found that the weakest parts were the joints because of great stress concentration. In the process of construction, high-strength bolts should be used for lapping and anti-rust measures should be taken.

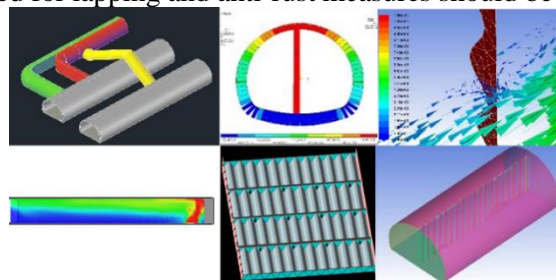


Figure 16. Technical scheme and research process of new type flat guide wall

The construction period of the fully assembled scheme is only two months. It can be completed and opened to traffic three months ahead of schedule, equivalent to half of the construction period in advance. It is an important practice for the new flat guide wall technology if this design optimization change can be carried out successfully.

The research results of this project have applied for 1 invention patent, have published 1 provincial ministerial engineering method and 4 papers.

6. Conclusion

Steel corrugated plate technology has been widely used abroad and its application prospect is broad. The technology has been used in many high-quality projects in bridge, tunnel, culvert and other fields to improve the quality of the project, speed up the progress of the project and save a lot of money.

However, in order to make its application and promotion have good technical standards and market environment for design, processing, installation, and acceptance, it is necessary to improve industry design specifications, product specifications and construction specifications. In addition, the applicability of steel corrugated plate is mainly affected by temperature change and load conditions. Large load will lead to great deformation and even instability, in which the steel corrugated plate is not recommended. In high temperature environment such as fire, the high temperature resistance of corrugated steel plate should be rechecked.

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