The Infrastructure Heritage of Chinese Eastern Railway: Its Characteristics and Sustainable Strategies

Xu Jianzhuo¹,²,* Wang Yan¹,²,*
¹ School of Architecture, Harbin Institute of Technology, Harbin 150001, China
² Key Laboratory of Cold Region Urban and Rural Human Settlement Environment Science and Technology, Ministry of Industry and Information Technology, Harbin 150001, China
* Correspondence: tjdxjzls@126.com(X.J.); ayan97@126.com(W.Y.)

ABSTRACT
The Chinese Eastern Railway (CER) and its infrastructure are the most important railway industrial heritage in northeast China, containing a large number of buildings and such infrastructures as bridges, tunnels, culverts and railway loops, which were built to travel through mountains and cross over rivers in complex terrains. These had abundant types and were carefully designed by engineers, reflecting a high level of modern design and construction techniques of early 20th century. Meanwhile, the infrastructures had been closely connected to the natural surroundings, creating a new unique cultural landscape far more different with the traditional ones in northeast China. This paper aims to demonstrate the railway infrastructure heritage of the main line of CER from the perspective of industrial archaeology, especially focusing on its functional and technical characteristics as an industrial heritage. Moreover, based on both the field investigation and quantitative analysis, this paper will thus discuss the possible sustaining strategies for the infrastructure heritage.

Key Words
CER, Infrastructure Heritage, Heritage Characteristics, Function Transformation

Introduction
The CER main line is the part of the Trans-Siberian Railway in China, from the west point Manchuria via the hub Harbin to Suifenhe in the east. Many railway spirals, bridges and tunnels were built to help the line to travel through mountains, such as the Greater Khing’an Range (GKR), the Taiping Range and the Wanglong Mountain, and cross over rivers such as the Nenjiang River, the Songhua River and the Mudan River.

1 Types and Geographical Distribution of the Infrastructure on the Main Line
1.1 Bridges
There used to be 645 bridges along the CER main line, which contained 214 arch bridges and 431 beam bridges classified by the structure forms. According to the Album of The Chinese Eastern Railway (1905), 495 bridges whose span was less than 10.67m (5 sagenes, in Russian ‘Сажень’, 1sagine=2.134m) were constructed on the line, comparing with the 150 long-span (more than 5 sagenes) bridges which consisted of large beam bridges and arch bridges flying above the rivers and barrancas.

As for the construction material, illustrated in the Standardized Construction Drawings of The Chinese Eastern Railway (1897-1903), iron/steel was the most prominent one. There were 430 steel bridges, occupying 66.8% of all bridges on the main line, including 409 steel plate girder bridges and 21 truss bridges. Thanks to its short span and simple structure, steel plate girder bridge was widely used in the sites
with complicated topographic conditions, such as the site close to the peak of the GKR with many shallow gullies and brooks, where the bridge density reached a peak of 0.86 (one bridge per kilometer) between Wunuer and Yiliekede Station (figure 1).

Truss bridges were once the representatives of outstanding technical achievement, with unique visual effects and huge volume among all infrastructures of the CER. Steel curved chord through truss was used large bridges design to cross over great rivers, providing enough headroom for vessels passing through. Deck truss was always selected to cross the medium-sized rivers and connected the through truss and the shoreside abutment with lower cost, easy delivery and fast assembling (figure 2).

Complex materials were also applied in beam bridges, such as the Hunhe Bridge. Steel rails enclosed by concrete were used as the beams of the bridge, and superstructure was built by rough stones. The beam surface was covered by fine-polished and regular-edged stones, showing the considerations of aesthetics.
Arch bridges, both single span and multiple span, were all built by stones. The former was commonly constructed in Khing’an Range in the west and mountain area in the east, as river-crossing bridges and viaducts, while the latter was built on broader rivers without large vessels sailing. The arch bridges with straight slope and curve slope were only built to fly over deep gorges and promote line height on four loops in the east line (figure 4).

**FIGURE 4.** The examples and numbers of the straight zero slope, straight slope and curve slope arch bridges (1 verst = 1.0668 km)(Source: The author)

<table>
<thead>
<tr>
<th>Types</th>
<th>Examples</th>
<th>Numbers</th>
<th>Types</th>
<th>Examples</th>
<th>Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elevation</td>
<td>Picture</td>
<td></td>
<td>Elevation</td>
<td>Picture</td>
</tr>
<tr>
<td>Straight Zero Slope</td>
<td>![Image]</td>
<td>![Image]</td>
<td></td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Stair Style</td>
<td>![Image]</td>
<td>![Image]</td>
<td>the 409 verst Bridge</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Straight Slope</td>
<td>![Image]</td>
<td>![Image]</td>
<td>the Hui River Bridge 1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Slash Style</td>
<td>![Image]</td>
<td>![Image]</td>
<td>the Shana River Bridge</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Curve Slope</td>
<td>![Image]</td>
<td>![Image]</td>
<td>the Shitouhezi Bridge</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
1.2 Tunnels
There were 9 tunnels constructed on the CER main line. 8 tunnels were on the east running through mountains like Laoye, Zhangguangcai, and Wanglong, with the length of each tunnel no more than 500m. The only tunnel on the west line, Xing’an Tunnel, constructed under the main peak of the GKR from 1901 to 1903, became the longest tunnel (1442.85 sagemes =3079m) on the main line, meanwhile the longest both in China and in Asia before 1940s, showing a high level of modern design and construction techniques. Tunnels were often built at the turning point when the slope changed, so their plans were often in straight lines, curves and straight-curve mixture. In the longitudinal section tunnels were designed as a ramp to connect with the railway line and match with the terrain. Semi-circle or three-centered arch could always be seen at the transverse section containing vaults and sidewalls (figure 5).

FIGURE 5. Types of the transverse section of the tunnel on the main line(Source: The author)

<table>
<thead>
<tr>
<th>Types</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Straight</td>
</tr>
<tr>
<td>PPPlans</td>
<td><img src="image1.jpg" alt="image" /></td>
</tr>
<tr>
<td></td>
<td>the 1263 vers tunnel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lining</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed Lining</td>
<td>Partial Lining</td>
</tr>
<tr>
<td><img src="image4.jpg" alt="image" /></td>
<td><img src="image5.jpg" alt="image" /></td>
</tr>
<tr>
<td><img src="image6.jpg" alt="image" /></td>
<td><img src="image7.jpg" alt="image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transverse Sections</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image8.jpg" alt="image" /></td>
<td><img src="image9.jpg" alt="image" /></td>
</tr>
<tr>
<td><img src="image10.jpg" alt="image" /></td>
<td><img src="image11.jpg" alt="image" /></td>
</tr>
</tbody>
</table>

1.3 Culverts / Pipes
Culverts/ pipes were built for the railway line to cross over streams and to drain off the surface pond, and large culverts were also used to transport human and goods from one side of the line to another. The length of culverts depended on the width of the roadbed. 154 culverts were constructed on the main line, and the one with a length of 36.55 sagemes, which located on the GKR loop crossing over the Yalu River, was the longest culvert, contrasting with the shortest one (10 sagemes) near Aihe station. Widths of the culverts varied from 0.5 to 4.4 sagemes on the main line.

The transverse section of culverts was always in five-hearted ellipse, and the vault and bottom were constructed with concrete. Where water flow was huge and dispersion was significant in mountains, the bottom would be constructed with stone instead. The distribution density reached a peak of 1.19 (one culvert per kilometer) in the section between Yuquan to Xiaoaling where ridges densely covered and the slope became sharply steep (figure 6). All pipes were made by iron with the same width of 1.07m.
1.4 Railway Loop
The railway loop, which are composed by the rails, bridges, tunnels and culverts, is a large infrastructure group to cross over mountains. There used to be 6 loops in the CER main line in U-shape, S-shape, 8-shape and spirals shape. The GKR Spiral, consisting of a short tunnel, 9 bridges (4 steel plate girder bridges, 2 truss bridges and 3 stone arch bridges) and 4 culverts, was the only loop on the west line, with a length of 6km, raising a height of 51m (24 sagenes) and a slope of 12‰. The S-shape, U-shape and some Z-shape loops were built from Yiliekede to Boketu as a temporary line to deliver workers and materials in the early period of the construction, but were finally replaced by the GKR tunnel and the spiral in 1904, because the Z-shape loop reversed too many times for the low-powered locomotive to travel through (figure 7).

![FIGURE 6 Distribution of the culverts and pipes on the main line(Source: The author)](image)

2 Functional and Technical Characteristics of Infrastructure Heritage
2.1 Standardized designs
Such designs exists in the bridge length, arch bridge patterns and the tunnel elevation. This standardizing method not only provides a series of flexible design approaches, but also can reduce the material preparing time and construction period. All bridges of different spans and different width units were able to meet the construction requirements under different conditions. The longest unit of 74.7m was mostly used in steel truss bridges, such as the Nenjiang River bridge and the Songhuajiang River Bridge. As shown in figure 8, we can observe that arch bridges and steel plate girder bridges also used the same design method.

![FIGURE 7 The loops (1901-1903), tunnel and spiral (after 1904) traveling through the GKR(Source: The author)](image)
Among those small-scale arch bridges, the bridges with the same appearance have the standardized designs in the plan, such as the basement of abutment and pier, the appearance and cross section of abutment and other components. But the design of single span length and pier height depends on the surrounding (figure 9). The stones with regular edge and rugged surface were inset on the tunnel arch outside on the elevation, and other parts were covered by stone block wall, with the capstone at the top of it (figure 10).
2.2 Advanced technology
The length of the Songhuajiang River Bridge (1901) is nearly one thousand meters (949.6m), containing eight 74.7m steel curved chord through truss and eleven 32m steel deck truss. Meanwhile, Pratt truss and Warren truss were widely used along the lines, the hinged movable supports and hold-down supports were also applied in the truss bridges (figure 11).

Comparing with the railway bridges constructed at the same time period in China, the technology applied in the CER was more advanced than the Yunnan-Vietnam Railway (1910). For example, the Grid truss, which was abandoned by the CER designers, was still used in bridges like the longest Grid truss bridge called Xiaolongtan bridge but was only 50m long. Even its longest bridge, the Baizhai bridge (134.7m) was only one seventh the length of the longest one in the CER, so we can find the bridge length, the single span length and the truss types were worse than the CER. Although deck truss and through truss were applied in the Jingzhang Railway (1909), the longest span was only 33.3m long (the South Sha river bridge) and the longest bridge called the Huailai river bridge is only 213.5m were all less advanced than the CER too (figure 12).
<table>
<thead>
<tr>
<th>Truss Types</th>
<th>Schematic Diagram</th>
<th>Example</th>
<th>The number of Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Truss</td>
<td><img src="image1" alt="Deck Truss" /></td>
<td><img src="image2" alt="Deck Truss Example" /></td>
<td>15</td>
</tr>
<tr>
<td>Through Truss</td>
<td><img src="image3" alt="Through Truss" /></td>
<td><img src="image4" alt="Through Truss Example" /></td>
<td>4</td>
</tr>
<tr>
<td>Composite Truss</td>
<td><img src="image5" alt="Composite Truss" /></td>
<td><img src="image6" alt="Composite Truss Example" /></td>
<td>2</td>
</tr>
<tr>
<td>Pratt Truss</td>
<td><img src="image7" alt="Pratt Truss" /></td>
<td><img src="image8" alt="Pratt Truss Example" /></td>
<td>6</td>
</tr>
<tr>
<td>Warren Truss</td>
<td><img src="image9" alt="Warren Truss" /></td>
<td><img src="image10" alt="Warren Truss Example" /></td>
<td>8</td>
</tr>
</tbody>
</table>

(a) the Xiaolongtan Bridge and the Baizhai Bridge

(b) the South Sha River Bridge and the Huailai River Bridge

FIGURE 11. The truss types using in the bridges (Source: The author)

FIGURE 12. The steel truss bridges in the Yunnan-Vietnam Railway and the Jingzhang Railway (Source: figure from the Standardized Construction Drawings of The Yunnan-Vietnam Railway (1910) and...
2.3 Rich texture and visual effect
Rich texture and visual effect can be found in many aspects of the design of arch bridges, tunnels and culverts, especially the decorative details of arch bridges and tunnel facade. Various stones like granite, basalt and limestone and their different processing depth provided abundant color and texture appearances. Both the three types of walling which contains the block stone regularly shaped, irregularly shaped and rubble random shaped were applied, and the corner of the large arch bridge abutments inset convex block stones and the elegant key-stone were inset on the abutment arches and the main arches are the best demonstration of walling multiple forms (figure 13).

![FIGURE 13 The multiple forms of the arch bridges](source: picture a)~c) taken by author and d)~f) from the Standardized Construction Drawings of The Chinese Eastern Railway (1897-1903)

2.4 Special Landscape
The steel bridge is a symbol of the early-20s’ latest material characteristics and latest aesthetics on modality. Its strength and forms allow it to acquire technical characteristics naturally through its gigantic scale. As a new manufacturing accomplishment of the new era, the steel bridges stayed in the natural environment and constitute a magnificent and elegant picture with the sky, the sun and moon, and the rivers, plains, and mountains together. Moreover, the running river below the bridge, the hurtling train on the bridge, and the reflection on the river that changes with time and seasons make the scenery varying more dynamically (figure 14).

![FIGURE 14 The scenery of the Songhua River bridge in different seasons](source: picture from Baidu Album)

The tunnel portal which was regard as the unreal space in the design of the GKR tunnel constitute a strong comparation with the real wall. The entrance elevation were designed with the art nouveau, which most straight line were replaced by the curve. And this constituted a special picture which straight outside and curve inside and straight mixed curve. Moreover, there are three interesting, abundant and solid comparation couples. The first one is the straight mixed curve are used in the same elevation, and the flexible curve and monotonous straight constitute a statical comparation. The second one is the hurtling train and its floating smog compare with
the statical entrance. When the train is coming, a vivid painting is completed with the help of the entrance wall and the portal regarding as a drawing board and a viewing frame. The last one is the tunnel as a manufacture compared with the natural environment and scenery changed by the seasons constitute a picture under the time attributes (figure 15).

![Figure 15: The entrances design drawings of the GKR tunnel and the west entrance picture. Source: the first and second picture from the Standardized Construction Drawings of The Chinese Eastern Railway (1897-1903) and the third picture taken by author.]

### 3 Sustainable Strategies

As time went by, many infrastructure heritages were abandoned and destroyed by the natural and human forces like wars, floods and development, and got even further worse with the original lines replaced by the high-speed railway in recent years. The sustainable strategies for the cherish heritages should be discussed. Some bridges, culverts and tunnels with their original functions still play an important role on the railway line, such as the Mayan River Bridge, the Wanglong Mountain Tunnel II and the GKR Tunnel (figure 16). The key tasks to protect them are daily inspection and necessary renovation to keep them in good conditions.

![Figure 16: The infrastructures maintaining original function. Source: The author.](a) the Mayan River Bridge *(b) the Wanglong Mountain Tunnel II *(c) the GKR Tunnel)

Meanwhile, the original function of some infrastructures has been transformed completely. For example, the GKR Spiral was announced the cultural heritage by the provincial government in August 2018, but afterwards buildings, railways and infrastructures here were almost worn-out without protection and restoration (figure 17(a)~(e)). The abandoned loops containing different types of infrastructures present not only a unique regional scenery for tourists and railfans, but also adequate length for sightseeing trains to run. In this case, it’s better to transform it into an experiencing museum containing static and dynamic display. Some other bridges and culverts in rural area have been used as daily paths for shopping, working and farming, especially in remote valleys (figure 17(f)~(g)). There should be considerations of sustainable and adaptive use for the infrastructures, as the practice of Songhuajiang River Bridge being transformed into a municipal park, displaying the history of the CER and let people enjoy the scenery above the river, and provide a slow-traffic lane for cyclist and pedestrian (figure 17(h)~(i)).
Conclusion
Although researches on the CER cultural heritage have apparently increased, few focuses on the infrastructure heritage which contains bridges, tunnels and loops. These infrastructures which were carefully designed by engineers, occupying various types and large quantities, are unique carriers of the design and construction techniques in early 20th century. It is very important for us to focus on the infrastructure heritage of the CER and take effective measures to protect them.
References
The CER Authority, 1903, *The Standardized Construction Drawings of The Chinese Eastern Railway (1897-1903)*.

Biographical notes
Author 1: XU Jianzhuo

XU Jianzhuo is a postgraduate of architectural history and theory in School of Architecture, Harbin Institute of Technology, major research on The Infrastructure Heritage of Chinese Eastern Railway.

Author 2: WANG Yan

WANG Yan, female, PhD, is an associate professor in School of Architecture, Harbin Institute of Technology. Her research field is Architectural History and Theory, and is specialized in modern architecture in China and architectural heritage.