The Contribution of Latin America to the Development of Long Span Bridges

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Summary

The paper deals with innovative technologies which have been applied for the first time in the design and construction of long span Latin American bridges like

- deep water foundations with big diameter piles
- prestressed concrete bridges built by launching
- long span bridges with double steel composite section
- cable-stayed bridges for full railways
- protection of piers against ship impact.

Keywords: deep water foundations, big diameter piles, incremental launching bridges, double composite action, cable-stayed bridges for railroads, hydraulic damper, parallel wire cables, symmetrical free cantilevering erection, protection against ship impact, high strength steel composite piles

1. Introduction

In the post-Columbian times, the great Latin American rivers have eased the discovery of the subcontinent. In the times of cars and railways, instead, they formed important obstacles to a fluent traffic as they could be crossed by ferries only.

In the past 40 years, for the most important roads and railways the ferries have been replaced by bridges. Due to the size of the rivers, the ocean going ships sailing on them and the often extremely bad subsoils, their design and construction required uncommon techniques.

Some of the innovative technologies applied for the first time for Latin American bridges are

- deep water foundations with big diameter piles
- prestressed concrete bridges built by launching
- long span bridges with double steel composite section
- cable-stayed bridges for full railways
- protection of piers against ship impact.

2. Deep Water Foundations

2.1 General

The important water depth and thick layers of soft soils make a pile foundation mandatory in many South American rivers. Therefore, the construction of long piles with great diameters is closely connected to the bridges of the subcontinent, and the experiences there gathered have been applied all over the world.

2.2 Historical Examples

The historical examples, Table 1, highlight the great variety in the design of early piles.

Table 1 *Early foundations with large diameter piles*

Bridge	**Maracaibo Lake / Venezuela**	**Rio-Niteroi / Brasil**	**across the Uruguay between Fray Bentos / Argentina and Puerto Unzué / Uruguay**	**Zárate-Brazo Largo across the Paraná / Argentina**
Construction	**1959 - 1962**	**1969 – 1974**	**1972 – 1976**	**1971 – 1978**
Length:	up to 50 m	up to 70 m	up to 50 m	up to 73 m
Diameter:	1,35 m	1,8 m	1,50 m	2,0 m
Section:	Pretressed Concrete	Reinforced Concrete	Pipe from prestressed concrete t = 15 cm, filled with concrete	16 mm steel pile filled with reinforced concrete

2.3 Recent Examples

We mention two examples only out of hundreds of bridges constructed on big diameter piles.

Bridge across the Golden Horn in Istanbul / Turkey (1985 – 1993) [1]

The 477 m long, 42 m wide bridge consists of double deck approaches from prestressed concrete and a central bascule bridge with a span of 80 m. It is founded on up to 85 m long steel piles ∅ 2 m, wall thickness 20 mm, which were partly driven and partly drilled and which had to be designed for a PGA = 0,35 g earthquake and the impact of a 8000 dwt ship sailing at 2,5 m/s.

Bridge across the Orinoco at Ciudad Guayana, Venezuela (2001 – 2006) [2]

The combined highway-railway bridge has a total length of 3156 m and includes two cable-stayed bridges with main spans of 300 m.

The piles from reinforced concrete have lengths up to 83 m and diameters of 2,0 m and 2,5 m.

3. Prestressed Concrete Bridges built by Incremental Launching

3.1 Historical Survey

The first bridge from prestressed concrete built by launching was a road bridge across the Caroni River in Ciudad Guayana, Venezuela [3], Fig. 1. It has a total length of 480 m and was opened to traffic in 1961. The bridge was built completely behind the abutment and later launched. This procedure was – compared the more traditional methods – an important technical achievement, but it was still expensive and little flexible.

The logical further development has been to build the bridge in segments and then launch it incrementally. This procedure has been used for the first time in 1968 for the construction of a highway bridge across the river Inn in Austria. From then on it has been applied to hundreds of bridges worldwide.

Fig. 1 *Bridge across the Caroni River at Ciudad Guayana, Venezuela [3]*

3.2 Basic Concepts, Fig. 2, [4]

The segments have a length of 15 m to 30 m and are constructed one per week. First the bottom slab and the webs are built and later the roadway slab.

The bridge is launched by hydraulic jacks from the abutments and is supported at the piers by sliding bearings from Teflon and stainless steel.

In order to reduce the cantilever moments, a steel launching nose with a length of about 60 % of the regular span is fixed to the first section. For spans beyond 60 m auxiliary piers are recommended.

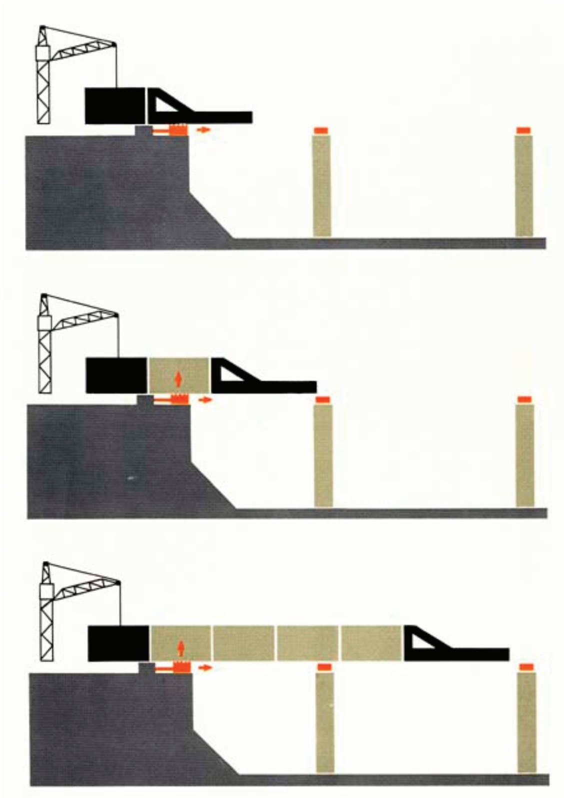


Fig. 2 *The incremental launching procedure*

3.3 Example Record

The two track railway bridge across the river Main near Würzburg, Germany, built from 1984 to 1987, has a total length of 1280 m and was registered in the "Book of Records 1986" as longest bridge ever built by incremental launching in the world. The main span of 162 m is bridged by a very slender arch [5], Fig. 3.

The arch was built by free cantilevering, supported by an auxiliary stay cable system. Later, the bridge deck was launched from one abutment to the other; the arch had to be stabilised against the important unsymmetric load inherent to this process by stay cables and a counter weight.

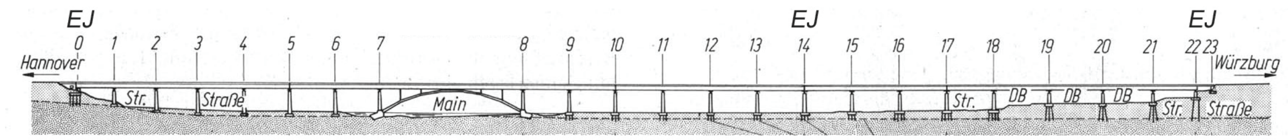


Fig. 3 *Railway bridge across the river Main near Würzburg, Germany [5]*

4. Long Span Bridges with Double Composite Action

4.1 Introduction

Long span bridges with double composite action have conquered an increasing percentage of bridges with a span range between 100 m and 200 m. This development is due to the replacement of

- the design criterion "limitation of concrete tensile stress" by "limitation of crack width"
- the steel bottom chord by a concrete bottom chord

leading both to a substantial reduction of the construction cost.

4.2 Angosturita Bridge across the Caroni in Ciudad Guyana, Venezuela [6]

This bridge, built from 1986 to 1992, carries 2 x 3 highway lanes and a centric railway designed for Cooper 72 trains. The haunched girder has a main span of 213,75 m – converting it into the longest span steel composite girder in the world – and construction depths of 5 m at the centre and 14 m at the piers, corresponding to slenderness ratios of 1:43 and 1:15 respectively, Fig. 4a. The cross section is a two cell box girder with a bottom chord from steel in the centre of the main span and from concrete over the main piers and in the long side spans, Fig. 4b. Further innovations – besides the global system – are the top slab supported by cross girders and not transversally stressed – what saved dead weight in the range of the highway live load – and the use of perfobond strips [4] instead of stud shear connectors.

The bridge was incrementally launched, with a truss girder to scope with the haunch and an auxiliary stay cable system to reduce the cantilever moment prior to casting the concrete bottom chord.

a) b)

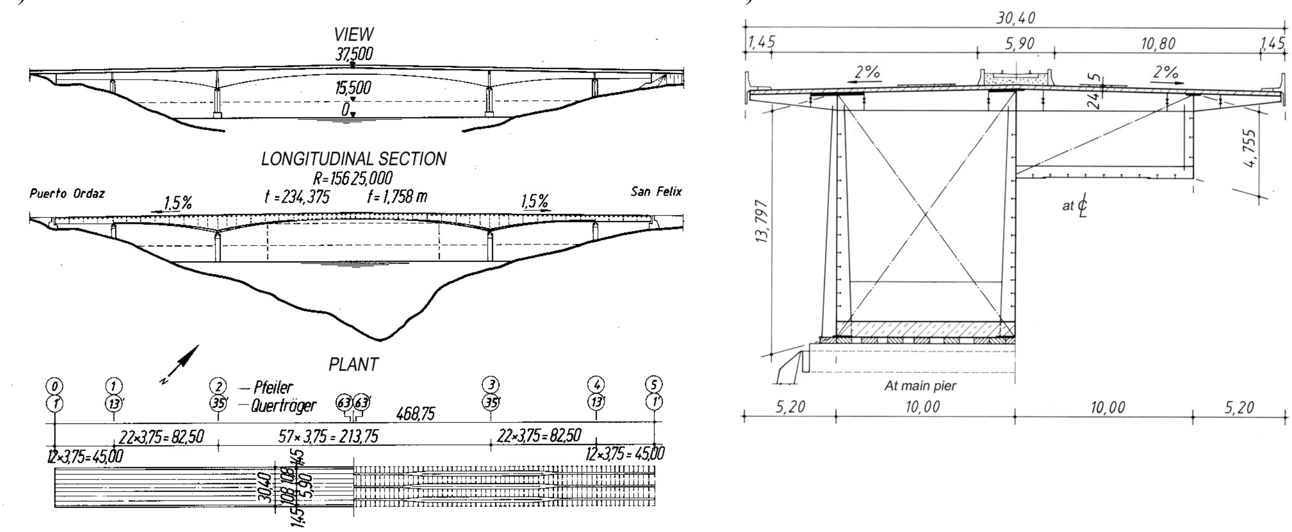


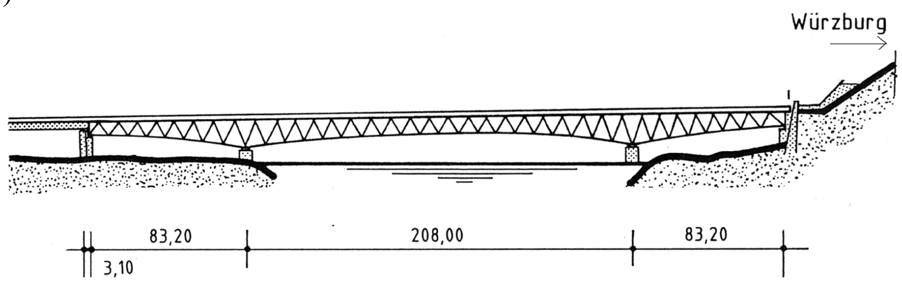
Fig. 4 *Angosturita Bridge across the Caroni at Ciudad Guayana, Venezuela [6]*
a) Layout, b) Cross-Sections

4.3 Further examples

After the successful construction of the Angosturita Bridge, long span steel composite bridges with double composite action have been built in many other places, e. g. in Germany

- double track railway bridge across the river Main near Würzburg with a main span of 208 m and a truss girder [5], Fig. 5
- highway bridge across the river Elbe at Torgau, main span 106 m [7].

a) b)



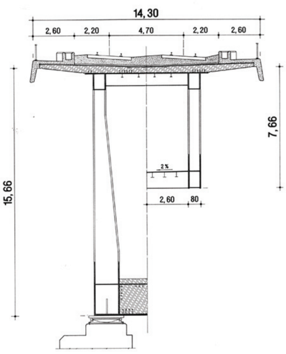


Fig. 5 *Railway bridge across river Main, Germany*
a) Layout, b) Cross-Sections

5. Cable-stayed bridges for railways

5.1 Introduction

The two bridges across the Paraná de las Palmas y Paraná Guazú, Argentina, built from 1971 to 1978, were worldwide the first cable-stayed bridges designed for a full railway and a highway.

The railway is placed at the northern border, causing a pronounced non-symmetry of the entire system [8], Fig. 6.

a)

b)

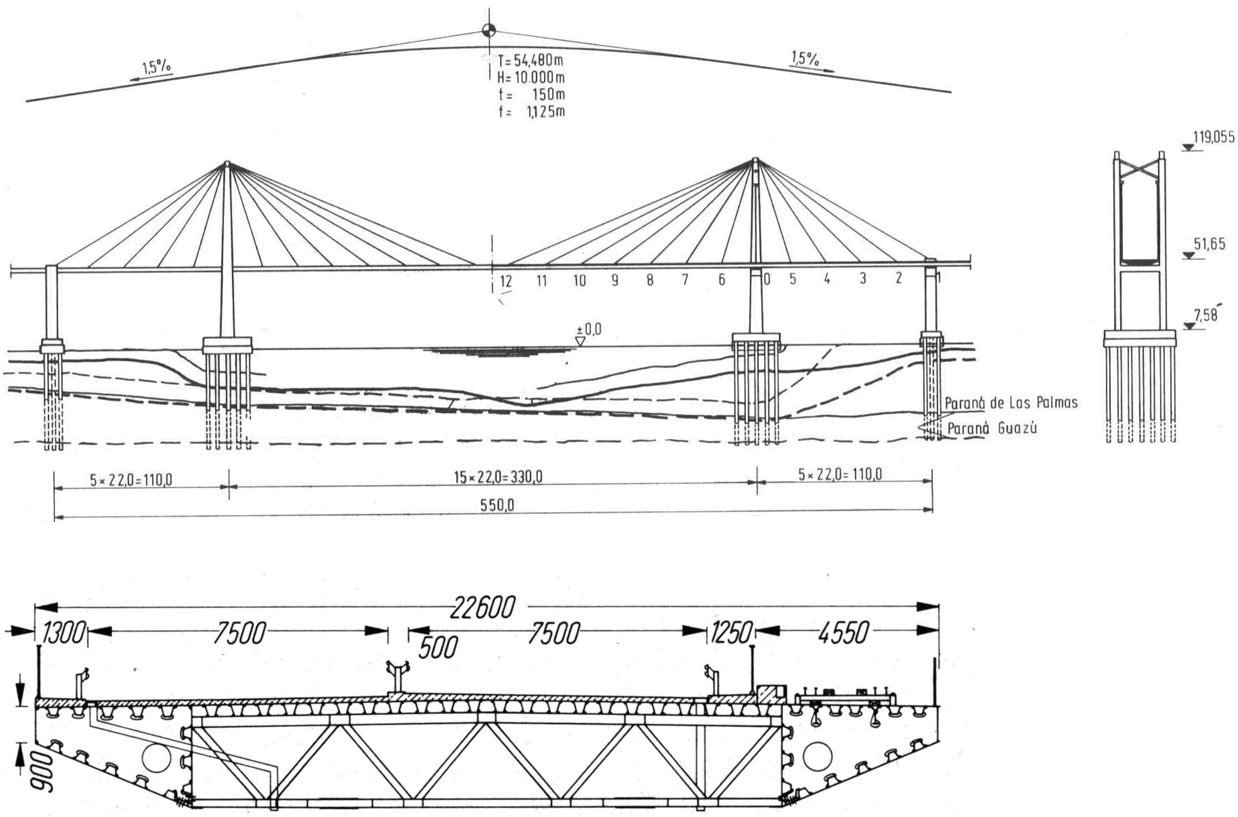


Fig. 6 *Zárate-Brazo Largo Bridges across the Paraná, Argentina*
a) Layout, b) Cross-section

Following this example, cable-stayed bridges for railway traffic have been built all around the world, e.g. the Oeresundbridge between Denmark and Sweden, the Iwakurojima Bridge in Japan, the Posadas-Encarnación bridge between Argentina and Paraquay [9] and the bridge across the Orinoco in Ciudad Guayana, Venezuela [2].

The design and construction of the Zárate-Brazo Largo Bridges comprise many innovations, e.g.

- towers from concrete
- prefabricated parallel wire cables
- use of hydraulic dampers to transmit the railway braking forces to both towers

symmetrical free cantilevering erection from the towers

5.2 Concrete towers

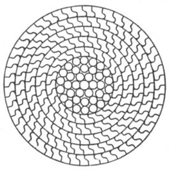
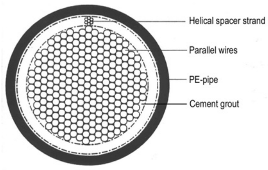
The vast majority of the early cable-stayed bridges – e.g. across the Rhine in Germany – had steel towers.

But towers, exposed to compression and bending, are cheaper in concrete than in steel and were therefore in the last three decades used for many cable-stayed and suspension bridges – even in places with poor subsoil conditions.

5.3 Parallel wire cables, Fig. 7

In Germany – the country of the origin of the cable-stayed bridges – due to tradition and due to strong rope fabricators locked coil ropes from St1500 have been used for virtually all cable-stayed bridges. These cables have a rather poor fatigue and a notable creep.

Starting with the Zárate-Brazo Largo Bridges, outside of Germany shop fabricated cables from parallel wires have been used, which have a relatively high fatigue and no creep. Nowadays, site fabricated cables from strands 0,6” St1570/1770 are the state of the art and have recently been applied also in Germany [10].

<table>
<tr><th colspan="2">Characteristics</th><th>Modern locked coil rope
</th><th>Parallel wire cable

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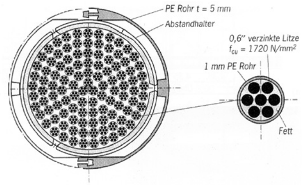
</th></tr>
<tr><td>E ·10⁵</td><td>[N/mm²]</td><td>0,170</td><td>0,205</td><td>0,195</td></tr>
<tr><td>fu</td><td>[N/mm²]</td><td>1470</td><td>1670</td><td>1870</td></tr>
<tr><td>Δσ</td><td>[N/mm²]</td><td>150</td><td>200</td><td>200</td></tr>
<tr><td rowspan="4">biggest cables fabricated so far</td><td>∅ [mm]</td><td>180</td><td>499 ∅ 7</td><td>100 ∅ 0,6“</td></tr>
<tr><td>Pu [MN]</td><td>31,0</td><td>32,1</td><td>24,5</td></tr>
<tr><td>L [m]</td><td>> 1000</td><td>250</td><td>≈ 200</td></tr>
<tr><td>max G [t]</td><td>> 80</td><td>23</td><td>≈ 20</td></tr>
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Fig. 7 *Cables for cable-stayed bridges*

5.4 Hydraulic dampers

A great problem in the design of railway bridges is the absorption of the braking forces of about 10 MN, especially in areas of deep water and poor soil.

In the Zárate-Brazo Largo Bridges, all longitudinal forces are transmitted by 4 hydraulic cylinders to both towers. They have valves which guarantee that

- for high temperature, the braking force causes a displacement minor than 0,67 mm/s
- for low temperature, the thermal expansion causes a reaction force of no more than 0,5 MN.

This ingenious solution has later been adopted for many railway bridges, e. g. bridges of Germany’s high speed railway lines [11].

5.5 Symmetrical free cantilevering erection

The cable-stayed bridge across the Rhine were at a few meters only above the ground. Consequently, first the side spans have been erected on auxiliary piers and later the main span by free cantilevering.

If, instead, the brick deck is high above the water and auxiliary piers need to be protected against ship impact, it is more convenient to erect the bridge by symmetrical free cantilevering from the towers to the side span pier and the centre of main span.

This erection method has been used for the first time for the Zárate-Brazo Largo Bridges and later for many bridges around the world, e. g. the Columbia River Bridge [12] and the Houston Ship Channel [13] in the USA.

6. Protection of bridge piers against ship impact

6.1 Introduction

With the collapse of the Sunshine-Skyway Bridge in the USA and the Askeröfjord Bridge in Sweden – both in 1980 and causing 33 and 8 fatalities respectively – it became obvious that the ship impact is one of the biggest dangers for bridges.

The problem is increased if

- the bridge has to be built on piles in deep water and on poor soil
- besides the ship impact, earthquake has to be considered, too
- there is a big difference between lowest and highest navigable water.

6.2 Protection of the Zárate-Brazo Largo Bridges

This protection for ships up to 15.000 dwt was tendered on a design and build basis in 1979, that means after the habilitation of the bridge. 13 offers, ranging between 10 and 50 million € were received [14] [15] – what shows that the tender procedure was not adequate for this type of structure.

The cheapest solution – floating platforms, kept in place by anchored chains – was selected for construction, a solution which has afterwards been realised in many other bridges.

6.3 Protection of the Rosario-Victoria Bridge

About 30 years after Zárate-Brazo, the Rosario-Victoria Bridge, also crossing the Paraná River in Argentina, had to be protected against 50.000 dwt as the river had been deepened by dredging.

In the meanwhile, the problem of ship impact had been, treated scientifically in many conferences - organized by IABSE and others – and books, and new, high performance materials had been developed.

The above protection has been designed for a probability of collapse of the bridge of 10^{-2} in 100 years. It consists of concrete platforms supported by ∅ 2 m steel-composite piles from StE690 and concrete C45. These piles have been designed not for strength, but for absorption of the ship's energy by plastic deformation [16], Fig. 8.

A similar protection has been adopted in 2004 for the pedestrian bridge across the Rhine between Kehl/Germany and Strasbourg/France.

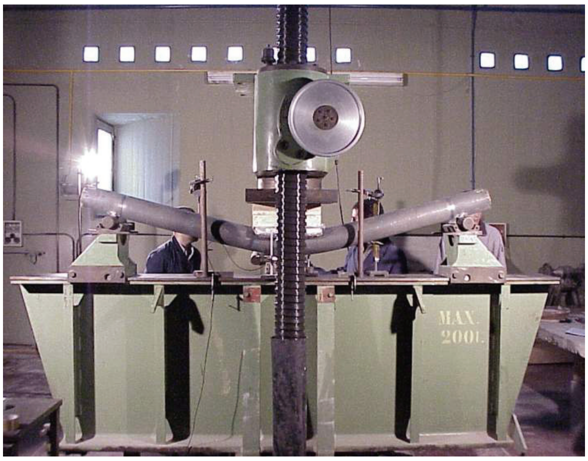

Fig. 8 *Model test on a steel composite pile*

7. Final Remark

Developments in the design and construction of long span bridges have been described, which were originated in Latin America and which have rapidly conquered the world-wide construction of bridges. Although we have limited our report to two countries – Argentina and Venezuela – the important contribution of the subcontinent to the development of long-span bridge became evident.

Leonhardt, Andrä und Partner from Stuttgart, Germany, has participated in the realization of nearly all bridges presented. To the authors it is a debt and a great pleasure to thank to the owners of these bridges and to all others involved for their courage and for their support of innovations – what unfortunately not is the case in many countries.

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