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Toward Structural Mechanics Through Wooden Bridges in France (1716–1841)

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To Luca, Pietro, Benedetta and Matteo

Preface

La filosofia è scritta in questo grandissimo libro
che continuamente
ci sta aperto innanzi gli occhi (io dico l'universo),
ma non si può intendere se prima non s'impara
intender la lingua,
e conoscer i caratteri, ne' quali è scritto. Egli
è scritto in lingua matematica
e i caratteri son triangoli, cerchi ed altre figure
geometriche,
senza i quali mezi è impossibile a intenderne
umanamente parola;
senza questi è un aggirarsi vanamente per un oscuro
laberinto.

G. Galilei, *Il Saggiatore*, 1623

Understanding the structural design of construction works built between the eighteenth and the nineteenth centuries is a particularly delicate issue; in fact in this period, due to the advancing and progressive diffusion of the scientific method by Galilei, heuristic criteria based on tradition and experience were gradually converted into scientific ones, based on mathematical analysis.

This work aims at examining the effects that the rationalization of empirical knowledge had in building practice, analyzing in particular the evolution in the design of wooden bridges between the second half of the eighteenth century and the first half of the nineteenth century. A new design mentality, very different from the previous one, arises.

Furthermore, this work observes the effects that structural mechanics theory had on building practice, focusing in particular on the bending problem.

In a context strongly influenced by the Aristotelian tradition, Galilei introduced a new kind of knowledge based on experimentation.

In this innovation, based on the works by Galileo, mathematics is adopted to describe physical phenomena, great importance is given to the relationship between theory and experimental tests, and a slow outmoding of the supposedly "correct" structural forms in favor of element dimensioning based on the strength of materials, initially proposed by Galilei himself, is underway.

The progress in wooden bridge design which occurred between mid eighteenth and mid nineteenth centuries is extremely significant, both in terms of structural typology and for the material, wood.

A bridge is, in fact, a particularly challenging structural typology, and wood has a good behavior both in bending and in tension; the same cannot be said of stone, which has only a good compressive performance.

The *Grand Tour*, the traditional journey throughout Europe undertaken by upper class European young men, and the *Encyclopédie* played an important role in disseminating knowledge: the *Grand Tour* contributed significantly to increase wooden bridges documentation: precious information about bridge elements dimensions can be found in drawings and sketches, while the *Encyclopédie* by Diderot and D'Alembert contributed to disseminate knowledge to a wide audience and in creating a common technical language.

A primary role in civil engineering is played by the *École des Ponts et Chaussées*, the most famous School of Engineering of the time. The *Académie d'Architecture*, the *Académie des Sciences* and, later, the *École Polytechnique* had preeminent importance in students' training and were characterized by a lively scientific and cultural debate. Based on the model of these Schools, similar academies were founded throughout Europe: in 1751 the *Wiener Neustadt Academie* in Wien, in 1787 the *Reale Accademia Militaredi Napoli* and in 1824 the *Cadetti Matematici Pionieri di Modena*.

Architecture and engineering treatises were mainly conceived and developed within these cultural institutions that played a key role in understanding the mentality change and in disseminating the new concepts in building design.

Due to their strong rational mentality, French scholars were able to recognize the innovative nature of challenging solutions. A network of cultural exchanges and interactions extended as far as the United States of America through the nineteenth century.

With reference to such cultural network, this research tries to outline and discuss the emerging of the scientific approach to the design of wooden bridges between 1716 and 1841. In 1716, the *Traité des ponts* by Henri Gautier was published; it is the first French treatise devoted only to bridges. This text is among the first books where the need for rules based on scientific criteria is expressed. In the 1841 issue of the *Annales des Ponts et Chaussées* is documented the first application of the bending theory by Navier to a specific bridge. It concerns a test related to the bending strength of a wooden bridge truss built in France according to the structural layout patented in the United States by Ithiel Town. In the United States indeed, in 1829 a table based on the Navier's bending theory was published by Stephan Harriman Long in order to make the application of this theory, easier.

This work is developed into three steps. The state of heuristic knowledge inherited from the past and based on handed down experience is documented in the first step through the analysis of wooden bridges built in the Alps and in France in the period that preceded the knowledge transformation process.

In general, the first half of the eighteenth century is characterized by a strong need for renewal in the scientific field and the desire to adopt rational criteria. In the *Fonds Ancienof theÉcole des Ponts et Chaussées* a few isolated attempts to dimension wooden bridge elements are reported; the most significant ones were selected and have been discussed in this work.

In the second phase, the early decades of the nineteenth century, structural mechanics theory developed considerably; design criteria of structural elements began to be rationally based. The study of this period makes reference to the architecture and engineering treatises, that are the main means in disseminating the theory of structures. In these treatises both mathematical studies and results of experimental tests are reported, both of them are equally important to prove the new theory.

The first effects of the theory of structural mechanics on building practice are documented in the third phase. The new capabilities offered by the computational approach are applied to test construction works built according to heuristic criteria. It is the beginning of a new way to building, which rationalizes and thus revitalizes the old traditional practice.

Milan, May 2013 Chiara Tardini

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Contents

Unit of Measure

Unit of length	mm	cm	m
Line	2.2558	0.2256	
French inch	27.07	2.707	
Tesa		194.9	1.949
French foot		32.48	0.3248
Vicenza foot		35.7	
Bavarian foot		29.859	
English foot		30.48	
American foot		30.48	

Unit of surface	mm^2
Square line	5.08876

Unit of weight	g
French Lbs	489.5
French Ounce	30.59