Curioni and the experimental measurements on the strength of materials in the Scuola di applicazione per gli ingegneri of Turin

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***Abstract*—The establishment of the laboratory for the experiences on building materials at the *Scuola di applicazione per gli ingegneri* of Turin dates back to 1879. It is the result of the untiring activity carried out by professor Giovanni Curioni in the search of tools useful to combine education and scientific research and to provide concrete support to the theories given in class. The effects of this institution begun to show up from the day after its activation. As soon as the laboratory starts functioning, it becomes the fulcrum of a conspicuous activity of academic, scientific and professional experience, significantly influencing the progress of construction techniques. Since the late sixties of the XIX century, after having provided the Constructions Laboratory with equipment to support his teaching, Curioni expands the collection of tools and instruments designing a machine for testing the resistance of materials according to the most modern specifications. The operation of the machine marks the birth certificate of the experimental laboratory annexed to the Constructions Laboratory of the Politecnico di Torino.**

***Index Terms*—strength of materials, testing machines, engineering schools**

I. Introduction

The *Scuola di applicazione per gli ingegneri* was founded in 1859, at the very beginning of the process that expanded the small Piedmont into the Kingdom of Italy. Its disciplinary organization reflects a tradition inspired by the *École des Ponts et Chaussées*, which places practical and experimental exercises at the center of a technical instruction firmly based on mathematical foundations. In 1871, Johann Bauschinger (1834-1893), founded in the *Polytechnische Schule München* the first laboratory for testing materials and structures attached to a university institute, followed shortly after by other engineering schools in Europe [1, p. 279], and the idea inspired also the Italian scholars.

It is to professor Giovanni Curioni that we owe the establishment, in 1879, of the first laboratory for mechanical testing of construction materials in the Piedmontese polytechnic school, created in order to give the students all the elements useful for understanding the mechanics of solids and structures through experimental studies on the strength of materials and on the deformation of elastic systems.[1]

Since the late sixties of the nineteenth century, in fact, after having equipped the Constructions Laboratory (*Gabinetto di costruzioni*) with the basic equipment needed to support teaching, the professor grows the desire to expand the collection of tools, appliances and machines (a pile driver, two models of capstan, two models of windlass and four of lewis for raising and laying of cut stones) with a machine designed to test the strength of the materials used in constructions. The need for such equipment is by no means foreign to the School, on the contrary: at the time, in fact, in Turin's technical teaching institutions some parts of a machine created by Quintino Sella (1827-1884) and used to evaluate the strength of materials have been present for some time.

For different and adverse circumstances, first of all the fact that the available funds are just enough to complete the collection of models of construction used as teaching aids to support his Constructions course [2], Curioni has to wait almost a decade to see fulfilled his desire. At last, thanks to a considerable public funding from the Council of the Province of Turin, the project can be carried out.

Curioni personally takes care of the ideation and the design of the apparatus, endowing it with many specificities that are missing from the contemporary machines and paying the utmost attention to all the contrivances that could improve the measurements of the test variables, i. e., the applied load and the deformation of the specimen. The outcome of the project is

[1]Giovanni Curioni was born on December 8, 1831 in Invorio Inferiore, a village near the west side of Lake Maggiore, then in the Kingdom of Sardinia. He graduated in Hydraulic Engineering and Civil Architecture at the University of Turin in 1855. After he graduated, until 1866, he taught in Turin both at the Istituto Tecnico and at the Scuola di applicazione per gli ingegneri di Torino. In 1866 he became professor of Civil, Hydraulic and Road Construction. In 1882 he was appointed as vice director of the school. He kept both roles until 1887, the year of his death.

A pupil of Luigi Federico Menabrea, he is considered the founder of the discipline of Constructions Science at the Politecnico di Torino. He committed suicide on February 1, 1887. Two weeks before, in his last will, he had bequeathed all his substances to his native village "with the obligation of establishing [. . .] an Institution for a Nursery school and for a Workers' school" [6].

"the first modern Italian machine" [3, p. 38] [4, p. 30-31], i. e., an innovative apparatus for empirical research on construction materials, corresponding to the complex objective "for which it was intended" [5]:

> The purpose for which the School needed a good machine for strength of materials was [...] to be able to answer all the questions that would be asked by practical engineers and builders, eager to know the degree of strength of the new materials that they intend to employ; on the other hand, it was desired that the machine could tackle, thanks to its power and measuring devices, no less than to its disposition, any research of a scientific nature.

Curioni's original design, aimed at fulfilling all these goals, is finally carried out and in 1879 the machine is built by the workshops of the Colla Brothers of Turin.

II. Curioni's universal testing machine

The description of the specifications, the operating procedures, and the construction details are drawn primarily from a memoir read on January 11, 1880 by Curioni at the Academy of Science of Turin, the prestigious scholarly institution founded by J.-L. Lagrange, whose he was a fellow since 1873 [7]. A résumé of the most important aspects of the apparatus was also published in 1881 in a technically-oriented journal, published under the auspices of the Association of Industrial Engineers, founded in Turin, among others, by Curioni himself in 1866 [5].

The machine can be described as a hydraulic press that produces a horizontal force (Fig. 1). It is 4.60 m long, 1.44 m wide and 1.90 m high. The force is generated by the pressure of a liquid, acting on a moving piston.

Usage of a hydraulic press to deliver the force needed to break a specimen in a testing apparatus is not new, in Curioni's days. The earliest record of a hydraulically actuated testing machine goes back at least to the apparatus designed by Thomas Brunton in 1813 to test the strength of the anchor chains for the British Royal Navy [8]. In 1863 David Kirkaldy patented his Universal Testing Machine, still working today in his laboratory, now the Kirkaldy Testing Museum in London.

In the next section, Curioni's testing machine is presented through the description of its principal functional components, i. e., following the outline given in [7]. Greek letters refer to the notation of Fig. 1a. Fig. 1b represents a section of the apparatus along a vertical plane passing through the center axis of the loading piston.

press (α): is the part devoted to control the loading of the specimen during the test;

carriage (β): is the mobile part of the machine, which imposes a displacement to one end of the tested specimen, in order to change its length or shape;

lever support (γ): constitutes a fixed structure to support a L-shaped lever, designed to define exactly the direction and the position of all the relevant forces;

lever (δ): is a device designed to reduce the force applied to the specimen so that it can be measured by means of the steelyard;

steelyard support (ϵ): is a fixed part to which the moving load measuring steelyard is attached;

steelyard (ζ): is the load measuring device that gives the applied force at any time during the test;

foundation (η): is the base of the machine, to which the other parts are connected.

After the description of the structure and the purpose of each component in the next section, to better illustrate the apparatus the operation of the machine is briefly described in the following one.

A. Main parts of the apparatus

1) Press: This part of the machine (α, in Fig. 1a) has its origin in the *presse sterhidraulique* conceived by Desgoffe and Ollivier, engineers in Paris [9], [10]. The functioning of the machine is, as in all hydraulic devices, based on Pascal's principle, i. e., given a vessel filled with a liquid, connected to two pistons with different size, being the pressure in the fluid the same on each part of the vessel walls, a small force acting on the surface of the smaller piston induces a large force on the surface of a larger one. In this particular press, instead of the usual small piston, a catgut cord with a small section is introduced in the closed chamber, filled with oil or glycerin, by means of a gradual coiling around a pulley: the liquid volume must remain constant, so that the large piston is moved outwards, multiplying the applied force by a factor corresponding to the ratio between the cross-area sections of the piston and the cord. This arrangement permits to obtain a smooth, gradual and precise movement of the loading piston, defining a *displacement-controlled* test, during which the load could decrease even with increasing piston stroke, e. g., because of damage or rupture of the specimen. The maximum force by design is 120 000 kg [2], corresponding to a pressure in the chamber of about 336 bar.

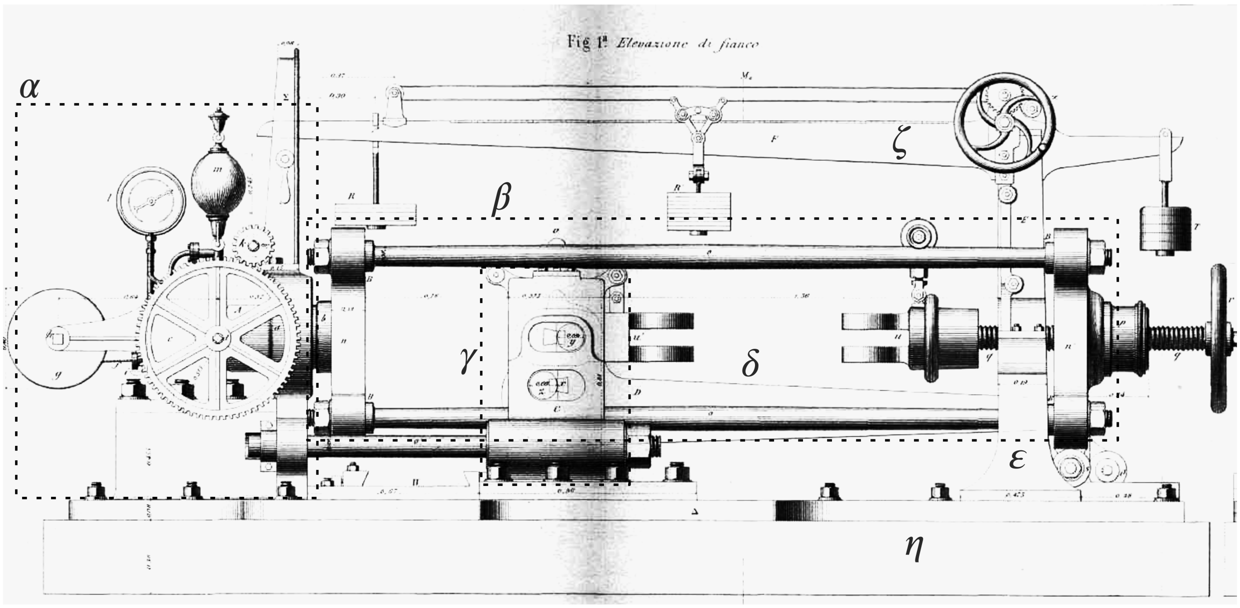
2) Carriage: The carriage (β, in Fig. 1a) consists of two strong cast-iron plates connected by four iron rods. One of the plates is joined to the head of the piston and the other shows two cast iron wheels sliding over suitable guides, so that the cart can move forward or backward according to the movement of the piston. Through a hole in the middle of this plate, an iron screw with a steering wheel of cast iron at its end holds an iron bracket to which one end of the tested specimen can be fixed.

3) Lever support: This support (γ, in Fig. 1a) is made of cast iron and has been designed to give free passage to the two lower tie rods of the carriage, to support the lever so that its fulcrum is reduced to a single knife edge, and finally to give free passage to the organs devoted to transmit to the lever the efforts exerted to produce a certain resistance. The support is fixed to the foundation by means of bolts and also connected horizontally to the press body with two iron tie rods.

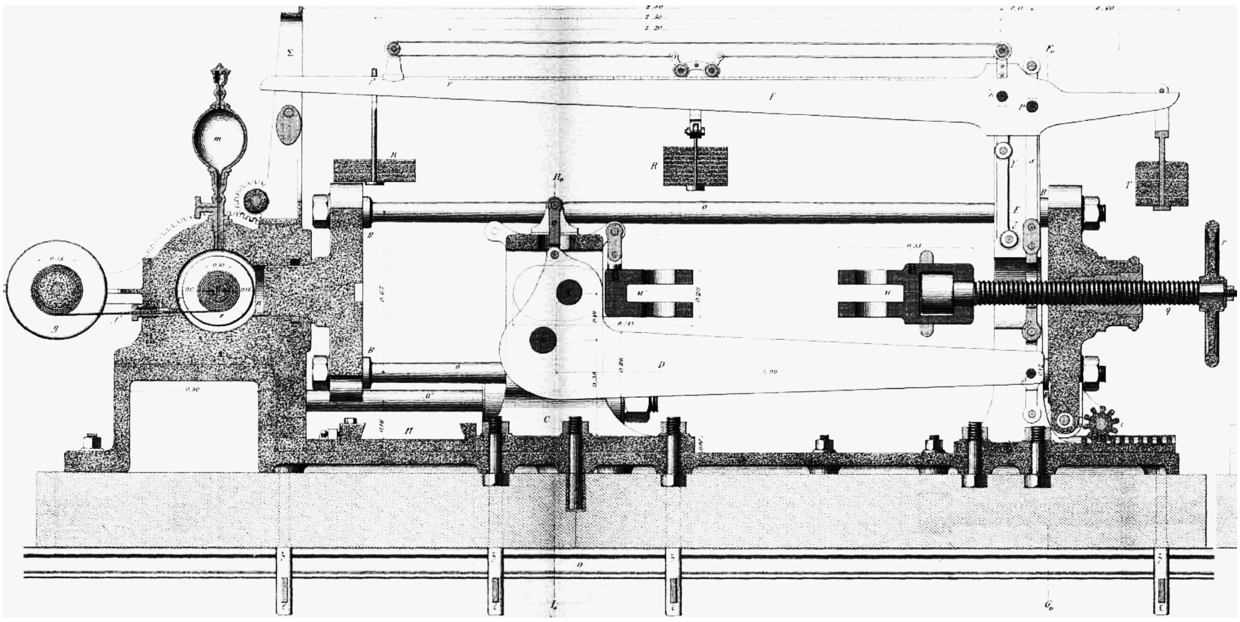
[2] The values of loads and weights are expressed, as in Curioni's times, in the customary unit of kilogram force: 1 kg $\approx$ 9.81 N.

4) Lever: This piece of the machine (δ, in Fig. 1a) is made of steel. It has two trunnions to receive the force coming from the specimen under test, and two other trunnions to receive the horizontal reaction force from the support γ. Fulcrum of the lever is the vertical knife edge described above. In the equilibrium position of the lever, the contact points of the trunnions are on the same vertical and their distance is 0.19 m. At the end of the longest arm, the lever is attached to a vertical tie rod at a point whose horizontal distance from the above mentioned vertical is 1.90 m, so that the ratio between the length of longest and the shorter arms of the lever is 10. For equilibrium reasons, the ratio between the horizontal force exerted by the loaded specimen and the vertical force to be applied to the long arm of the lever is the same, i. e., one tenth of the testing load is required to ensure the equilibrium of the lever.

5) Steelyard support: This part of the machine (ϵ, in Fig. 1a) is made of cast iron, and has a rather complicated shape due to the many pieces, which must be supported without any obstacle to their motion. These pieces are the two lower tie rods of the carriage, the horizontal end of the lever, the screw of the specimen holder and the vertical tie rod to the lever,



(a) Longitudinal view. Greek letters denote the parts of the apparatus described in the text.



(b) Vertical longitudinal section through the center axis.

Figure 1: Drawings of the universal testing machine. Adapted from [7], plates I and II.

which transmits the equilibrating load to be measured by the steelyard. This support is fixed with bolts to the foundation, and at the top presents the appropriate bearings to receive the fulcrum of the steelyard and a wheel to move a counterweight on the steelyard itself.

6) Steelyard: This part of the machine (ζ, in Fig. 1a) is made of steel. It may rotate with respect to its support around a hinge that corresponds to its fulcrum[3]. The lever δ transmits to the steelyard a tenth part of the force applied to the specimen and this transmission takes place through a vertical tie rod, made in such a way as to give free passage to the horizontal screw of the specimen holder. The horizontal distance between this rod and the steelyard fulcrum is 0.11 m when the steelyard is balanced, i. e., when its upper edge is horizontal. The other arm of the steelyard is 2.20 m long, and this length is graduated with 200 divisions. On the press body there is a cast iron piece, which is designed to support the end of the longest arm of the resting steelyard, and to prevent it from rising beyond a certain limit when it is about to balance it.

At a point located near the end of the steelyard and distant 2.50 m from the fulcrum, there is a fixed counterweight, which is intended for the measuring machine forces with steps of 10 000 kg, corresponding to cast-iron weights of 44 kg each. The steelyard extends on the side opposite to the measuring scale and carries a fixed counterweight which perfectly balances the system of the lever and the steelyard in unloaded conditions to ensure that the indications given by the steelyard correspond only to the force applied to the specimen.

For weighs or fractions of weighs corresponding to forces under 20 000 kg there is a sliding counterweight, which can be loaded with five different weights of 20 kg each. This weight is moved by rotating a wheel that actuates an endless rope joined to the slider and passes on another pulley at the opposite end of the steelyard (Fig. 2). From the number of weights on the fixed and on the moving counterweights, and on the position of the latter, the load applied to the specimen can easily be determined by ensuring that the steelyard remains perfectly horizontal.

7) Foundation: For the foundation of the machine (η, in Fig. 1a), four sturdy iron crosspieces are used, each of which crosses the lower ends of two vertical rods having threaded upper ends; three long iron rails are placed on said crosspieces. All the space between the horizontal plane determined by the lower faces of the crosspieces and of the rails is filled with masonry, on which two parallelepiped stones, 0.30 m thick and altogether longer and wider than the base of the machine are laid. On the stones, the general cast-iron platform of the machine is fixed by means of bolts cemented to the stones and, through eight vertical rods, to the underlying crosspieces so that the crosspieces, the rails, the masonry, the stones and the platform form a rigid base that does not deform even under the action of the maximum load that can be produced on the pieces submitted to experiment.

[3]The steelyard and its supports are the only surviving parts of the testing machine. They are on permanent display at the Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, which is the heir of Curioni's scientific legacy.

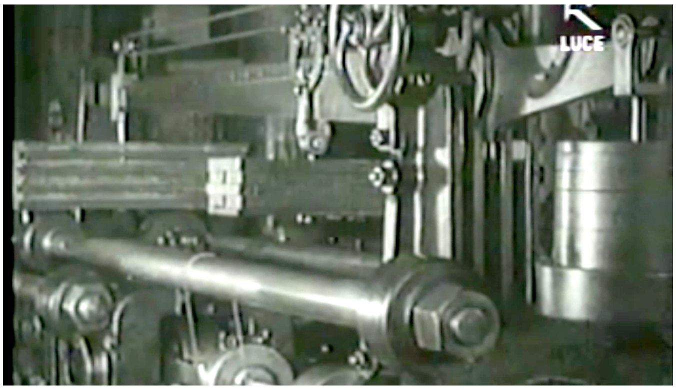


Figure 2: A view of the machine: the steelyard for measuring the applied force, with the moving load device, is clearly visible in the upper part of the image (Istituto Luce).

B. *Operation of the apparatus*

The machine designed by Curioni can be used to test specimens of different materials in a number of loading conditions. By using specially designed accessories (Fig. 3) to be mounted into the apparatus, the samples of materials can be subjected to strength tests in: longitudinal tension or compression, transverse shear, longitudinal or lateral shear, internal tension, perforation, pressure.

Generally speaking, a first alternative in testing conditions is to apply to the specimen tensile or compressive forces. Considering that the loading piston acts only outward from the press, the former condition is realized by placing the specimen in the space between the lever support and the vertical plate of the carriage far from the press; the latter is produced when the specimen is positioned between the other plate and the support. In order to describe the operation of the machine, the case of tensile test is considered. The other cases differ mainly in the disposition of the specimen by means of the different grip tools shown in Fig. 3.

In case of a tensile test the specimen is placed horizontally between the fixed lever support and the outmost plate of the carriage (top-left drawings in Fig. 3). The specimen is linked to the brackets with pins or vises, according to its shape, using the axial wheel to put the specimen holders at the right distance.

Once the specimen is held between the holders, by acting the wheel of the press the cord is pulled into the press chamber; at the same time the piston moves outward together with the carriage to which one end of the specimen is firmly connected.

The specimen length gradually increases and, by regulating the weights and the position of the counterweights, the tensile force acting on it can be determined at any instant of the test run.

The strain of the specimen can be evaluated through the measurement of the specimen length by means of a vernier scale, whose readings at predetermined load values permit to

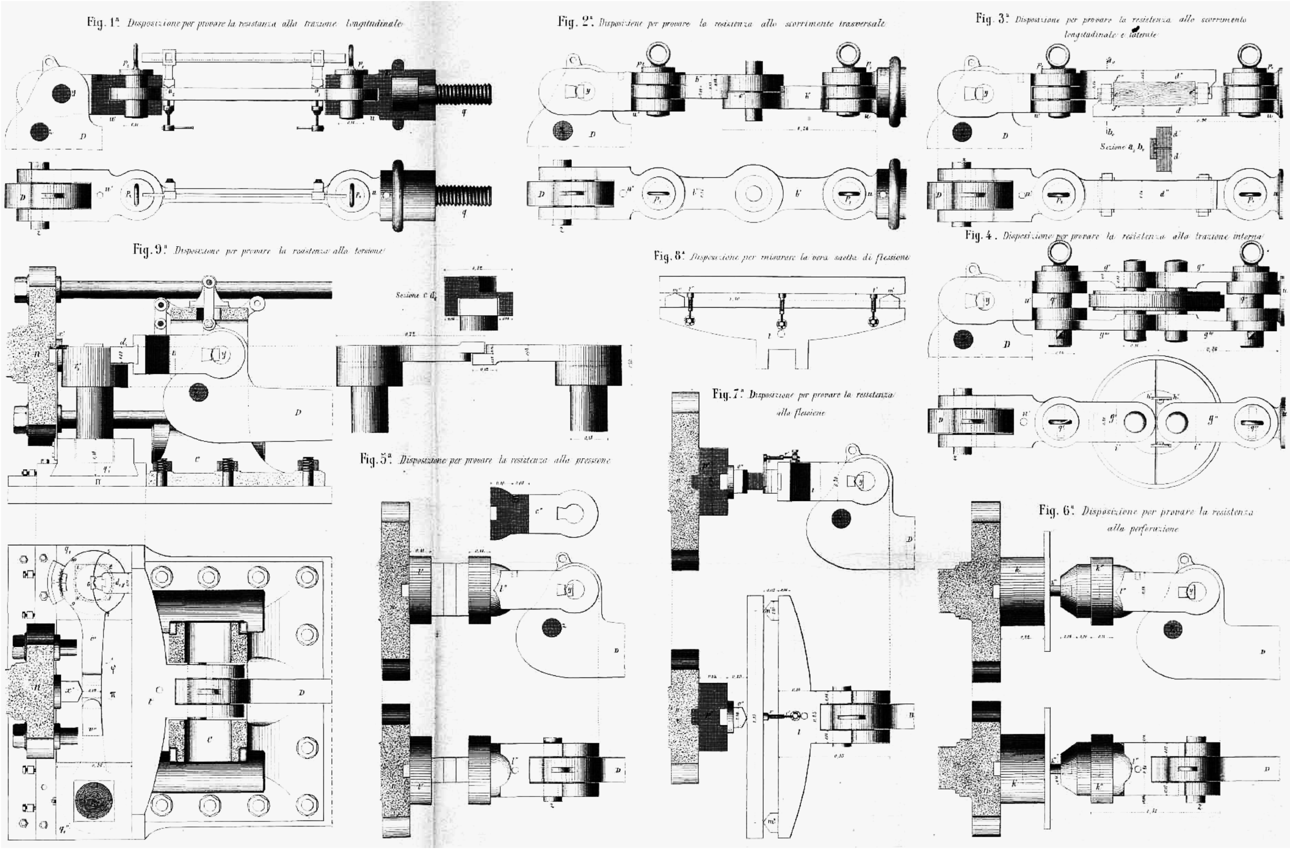


Figure 3: Accessories designed to hold specimens subjected to the different possible testing conditions (from [7], plate III).

obtain the force-elongation law and, accordingly, the value of the elastic modulus of the tested material.

III. Conclusion

The location of the new testing machine in the central room of the ground floor of the Valentino Castle (today called "Sala delle colonne", Fig. 4) marks the birth certificate of the experimental laboratory of the Turin School. This facility produces immediate positive effects, becoming the trigger of a conspicuous activity of academic, scientific and professional experiments carried out in the laboratory that will greatly influence the progress of building techniques and the introduction and development of new construction materials.

Despite several defects that the machine will demonstrate over time, thanks to the possibility of experimenting "all types of strength and not just tension, compression and bending", allowing also tests on specimens subjected to shear or torsion by means of a number of different cleverly designed grips, it represents a cutting-edge research tool for the time.

The universal testing machine gained also the praise of Curioni's most famous pupil, namely, Alberto Castigliano, who in an unpublished letter dated December 29, 1880 [12] in which he thanks his mentor for sending him the memoir on the apparatus, wrote:

> I greatly appreciated [the memoir] as it seemed to me to find two novel ideas in such a kind of machines, i. e., the way of producing the pressure by means of a liquid avoiding the usual disposition of the hydraulic presses, which leads to an intermittent action, and the way to measure at each instant the force produced.

From a purely didactic point of view, the foundation of the laboratory gives to Curioni the opportunity to provide a new contribution to the subjects of his teaching. In fact, since the academic year 1879-1880, he systematically remolds the discipline enhancing practical exercises by means of specific reference to tests on materials, aimed at the quantitative verification of the predictions given by the theory presented in the lectures. This change is fundamental. It allows the student to take a first-hand view of the mechanical properties of various materials, through a series of experiences aimed at placing each tested element in conditions close to the real ones. Through critical examination of the materials' properties, Curioni contributes, on the one hand, to introduce to students the study of the matter as it is in reality, on the other hand, to gradually develop their insight in statics problems and their understanding of the construction techniques, and to place them, in a concrete manner, in the face of all the issues and problems related to the future profession.

The goal of Curioni's course of Constructions is to provide the students, already equipped with good mathematical tools, with both theoretical and applicative knowledge: it is therefore necessary to adopt the most effective approaches to make dogmas understandable by everybody [13]:

> [teaching at the School] was theoretical-practical in all the extension of the phrase; it had therefore to be completely detached from those empirical and traditional rules. [...] At the same time the teaching had to be pushed forward so that the students did not insist only in the field of abstractions, but descended down to the last numerical applications and these learned both as consequences of theories, and seeing them already in action practiced by the best engineers in the country.

To achieve this goal, since the beginning of his teaching, the attention of Curioni is aimed at feeding the students' curiosity through the strengthening of the conjuncture between theory and practice, in the care given to imparting them the notions of science and technology through theoretical and laboratory lessons and field experiences.

Under his guidance, the *Scuola di applicazione* of Turin is perfectly adapting to the change taking place during this period, through the adoption of the most suitable means to provide certain answers to the requests raised by the new emerging technical and scientific culture.

If Curioni is credited with having first promoted the need for alternation between theory and experimental observation and the value of laboratory experience as an essential control tool in refining research, with its successor, professor Camillo Guidi[4], this branch of the discipline begins to play a decisive role in promoting scientific empiricism and in improving national building practices.

[4]Camillo Guidi (1853-1941), professor of Graphic Statics, Constructions Science and Theory of Bridges at the Politecnico di Torino for forty-six years and the first to promote the theory of reinforced concrete construction at a national level.

Figure 4: The laboratory for testing materials in the *Sala delle colonne* of the Valentino Castle during Guidi's period (Archives of the Politecnico di Torino).

The machine, under the direction of Guidi, is subjected to several modifications, especially as a result of scientific issues and the need to comply with the standards proposed in international conferences for the unification of test methods. Guidi, in fact, while on the one hand is aware that the revision and refinement of machinery are necessary in achieving reliable results, at the same time shows a particular caution in their implementation. This is demonstrated by the fact that, before making significant changes, each plausible solution is carefully studied and evaluated in order not to alter the primitive design, respecting the memory of the predecessor. He introduces some improvements to produce higher loads, to reduce execution times (for example through the automation of operations) and to ensure greater effectiveness of the experiments, and adds special pieces in order to perform better tests in particular loading conditions.

Updated by Guidi's interventions, Curioni's universal testing machine was still operative in the thirties of XX century. Unfortunately, when it was decommissioned it was not considered as a historical asset worthy of conservation and was dismantled. Only the finely crafted steelyard remains as a silent witness of a heroic era.

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