

The First French Railways of Saint-Etienne (1823 - 1833)

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Abstract

At the beginning of 1820s, Saint-Etienne collieries were very promising, but enclosed by transportation difficulties. After the Napoleonic Wars, the new situation (the first French Industrial Revolution) led to a reorganization of collieries concessions, more favorable to an industrial exploitation. Several possibilities of new transportation system were tried, such as canals, roads and railways, to the cities along the river Rhône, where there were many industrial consumers and important ports.

There are few papers and publications on the history of the first French railways, especially Saint-Etienne railways. The aim of this paper is to overview the design and construction of the first French railways by Marc Seguin. His tubular boiler of 1827 and locomotive for the heavy and hilly transportation are also discussed.

[Keywords: First French railways, Marc Seguin, Tubular boiler]

1 The Loire coal field and its transportation difficulties

Important difficulties of transportation arose in France during the 'Monarchy Restoration'¹⁾, especially in the Saint-Etienne colliery country. After the Napoleonic Wars, and a new restricted area for France, that coal field, called 'Bassin de la Loire', remained the first French site of the coal exploitation. Divided into two parts, there was a limited coal emergence in the Gier Valley, and the main resources deposited in Central and West fields, around the city of Saint-Etienne (see Fig. 1).

From the second half of the 18th century, the South-East part, near Rive-de-Gier, was on intensive exploitation. The Rhône Valley developed a local industrial take-off based on coal, with lime furnaces, copper industries (Lyon, Vienne), glass factories (Givors), coke attempts for cast iron (Vienne), and ironworks (Gier Valley)... Since 1780 the Canal of Givors gave an easy heavy carriage from Rive-de-Gier to the Rhône Valley²⁾. It completed an active local waterway network, with the rivers Rhône and Saône. In the early 1820s, according to well informed colliery specialists, first signs of a Rive-de-Gier coal field exhaustion appeared. How-

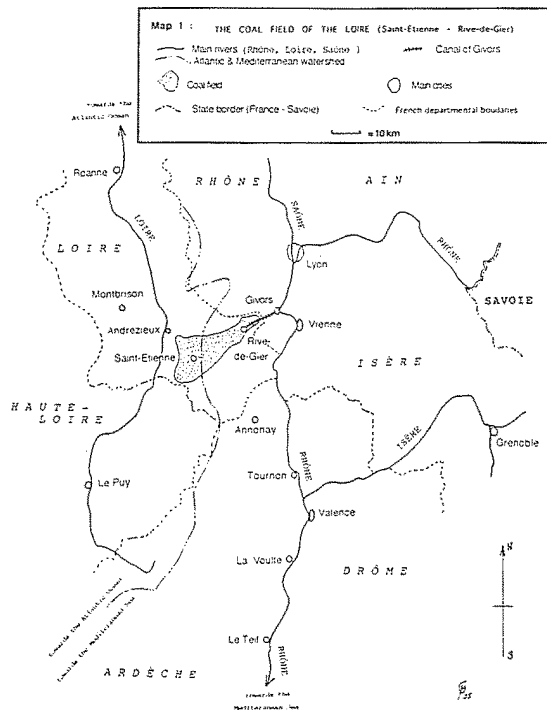


Fig. 1 : Coal field of Loire

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ever, the old transportation rate, attributed by the official canal concession, became too expensive, and equal to the road carriage rates.

Saint-Etienne main coal field had thick, numerous and good veins. An ancient superficial exploitation come from a long local proto-industrialization, producing arms and usual hardware. A traditional exportation to the Loire Valley, especially for the Nivernais iron masters, completed the coal trade of Saint-Etienne. Despite their advantages the exploitation of the main coal field was limited for two main reasons: collieries remained craft industries and coal was transported exclusively by difficult roads. Geographically, the distance was around 20 kilometers from Saint-Etienne sites to the river Loire, by the Furan valley, in the medium mountain country. Therefore difficulties to reach Rive-de-Gier through the Terrenoire pass were very significant for heavy road carriage. (see Table 1 and Fig. 2)

Proposals for the 'Canal du Forez' from Loire to Rhône were made during the 18th century. But such a canal was idealistic: differences in height were too significant for relatively short lengths.

Table 1 : Differences of level in the St.-Etienne country

	Level :	Difference of level :	Length :	Gradient ratio :
Loire Valley (Andrézieux)	378 m	142 m	18 km	8 ‰
Saint-Etienne (La Monta)	520 m	30 m	3 km	
Terrenoire pass (old royal road) by the railway tunnel	(~ 550 m) 530 m	(305 m) 285 m	21 km	13,6 ‰
Rive-de-Gier	245 m	85 m	16 km	5,5 ‰ (canal of Givors)
Rhône Valley (Givors)	160 m			

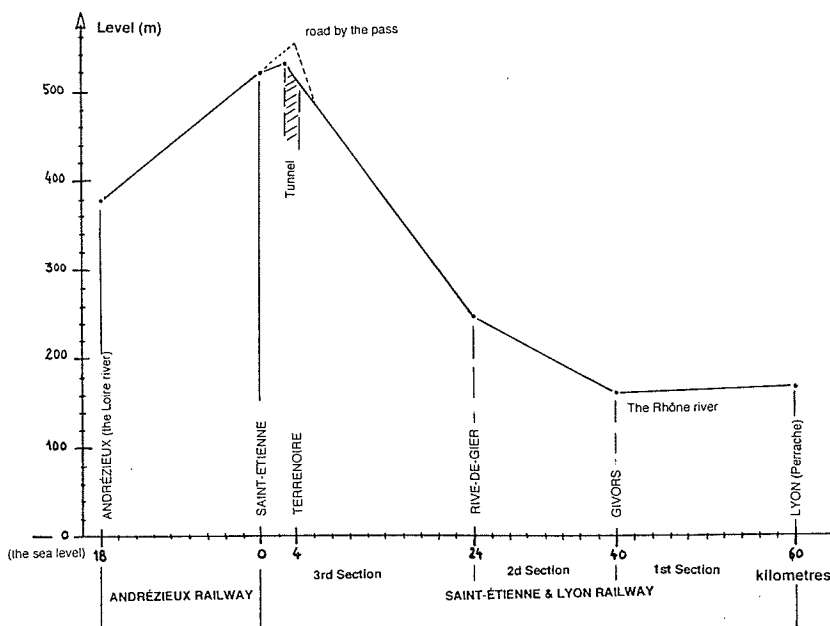


Fig. 2 : Differences of level in two railways

2 The first French railway from Saint-Etienne to the Loire river, by Louis Beaunier³⁾

At the beginning of 1820s, Saint-Etienne collieries were promising, but enclosed within transportation difficulties. At the end of Napoleonic Empire, the new situation led to a reorganization of collieries concessions, more favorable for the industrial exploitation. Creation of the mining school: 'l'Ecole des mines de Saint-Etienne' (1816), began the education of engineers and miner chiefs. Professors and State mining engineers, such as de Gallois⁴⁾ and Beaunier⁵⁾, realized a scientific geological study of the coal field. Those technicians had a global conception of the industrial development of the country, coming from the English model of heavy industries.

De Gallois made the first important study for an application of railways in France, after an English fact-finding trip, probably made together with his colleague, Beaunier (1818). His report has shown clearly a great similitude between the Saint-Etienne situation and the English sites of heavy industrialization based on coal, such as the Newcastle country. That coal field had an important local network of railways for carriage, from collieries to industrial consumers and to exportation ports⁶⁾. De Gallois made a technical and an economical general study, adapted to the French situation. Beaunier tried to design the first railway line for the coal transportation toward Andrézieux, the main Loire river port for the Saint-Etienne exportations at that time. In 1821, he deposited an official proposal for the French government⁷⁾. He obtained the official concession in 1823, for an 18 kilometer railway line along the Furan Valley, from Saint-Etienne to Andrézieux⁸⁾ (see Fig. 3). The debate on the carriage railway issued in a low rate, but only for coal!

The company foundation followed the authorization, gathering one million francs for the line construction⁹⁾. That one started really in 1825 and was finished during the summer 1827.

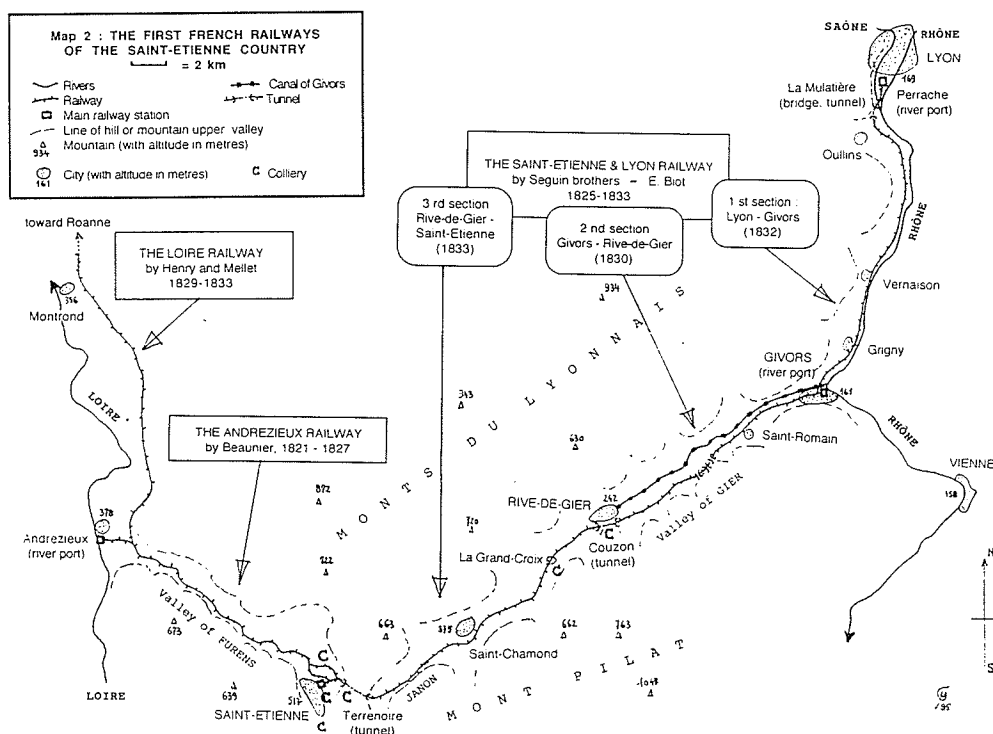


Fig. 3 : First French railways of the St.-Etienne country

The Beaunier's railway followed the geographic curves of the valley, with some short radius imposed by local difficulties (up to 100 meters). The line went down globally with regularity, which tried to reach powering by the gravity of loaded wagons. But the gradient ratio was not constant, and followed the main natural inclines and curves. The Beaunier's conception for railway line resulted from the usual road design in medium mountain, in which French engineers had a great experience.

The cast iron rails were one yard long, as the British model. Horses accompanied coal wagons while going down as the complementary engine or the brake. To climb empty wagons back, horses drove them along the line.

3 Competition for the Saint-Etienne & Lyon railway concession

Despite French engineers, except Beaunier, had little knowledge of railways, three companies competed from October 1825 to March 1826, to obtain the governmental concession of the Saint-Etienne & Lyon railway. The Givors Canal Company argued at the Chamber of Deputies an illegal competition, but without success¹⁰. Local institutions, such as Town Councils, Chambers of Commerce, etc. asked for a very low rate for the new railway. The debate showed high level of transportation rate in France, and its action against the economical take-off, especially for the Saint-Etienne coal field and the industrialization of Rhône Valley. Table 2 indicates a brutal decreasing of the transportation rate, in debates of the Saint-Etienne & Lyon projects. For the government, the private companies' transportation rate proposals became the only decisive criterion of the official competition to give the railway concession.

The Seguin's brothers Company¹¹ archives indicate hard competition from the autumn 1825 to the spring 1826, with local lobbies, political influences, and financial brainwashing...¹². Adjudication was impressive: coal transportation rate was drastically reduced to more than one-third in a couple of months! It was a kind of technical idealization of railway possibilities, issued from the first English experiment, but without serious technical considerations toward the characteristic of the Saint-Etienne hilly country. A probably indicative occurrence: Beaunier retired his project from the competition before the end (see Table 2).

Table 2 : Transportation rate in the Rhône Valley and St.-Etienne

1823-1825	transportation rate (c/t.km)	proposals for St-Etienne & Lyon Railway	
<u>Waterways :</u>		<u>1st studies (1823-1824) :</u>	
Rhône (come back up)	17 to 27	Beaunier	29
Givors Canal : coal	20	Chamber of Art..	
other goods	30	of St-Chamond : coal	18
		other goods	25
<u>roads :</u>		<u>debates of 1825 :</u>	
Rhône Valley	30 to 35	local administrations	19 to 22,5
St-Etienne country for coal	31 to 34	Seguin 1	21,5
		Seguin 2	23
		Seguin 3	
		(going down)	10
		(come back up)	15
<u>Railway</u>		<u>final competition (1826)</u>	
St-Etienne & Andrézieux		State maximal rate	15
coal (going down)	23	for concession	(unique rate)
other goods	37,5	Bérard Co.	14,7
		Lapanouse Co.	13,5
		Seguin and Biot Co.	9,8

As for the first Seguin brothers' studies, technical elements were superficial but the economic analysis of the coal supply market was accurate. They understood immediately the tremendous possibilities of Lyon and the Rhône Valley, and they made a good economic project based on the link between a low rate and a considerable increasing of the heavy transportation by railway. Their incredible proposition, less than 10 centimes for one metric tone and one kilometer, was both an excellent economic study and an enthusiastic technical bet¹³⁾. The Seguin's fact-finding trip to England and Scotland, from December 1825 to January 1826, gave the latest information about locomotives, rails, line design and fixed steam engine plans¹⁴⁾.

Marc Seguin became a famous civil engineer after the achievement of the first great suspension bridge in France, over the Rhône at Tournon-Tain, by the new technology of the iron wire cable¹⁵⁾. Thus, he could gather a group of capitalists for the foundation of the Saint-Etienne & Lyon railway Company. They would mainly come from the intermediate Parisian bank and business. It was a 10 million franc capital, one of the most important French firm at that time. Some 'ultra royalist' aristocrats, close to the Monarchy, completed that first capitalist group. Count Alexis de Noailles became the first president of Board of the Company, and also his main political protector. Some important French scientists were founder members too, such as the physicist Biot and the chemist Thenard. The first was associated with the Seguin's brothers firm for the construction. The second would become the President of the Board of the Company in 1838¹⁶⁾.

In March 1826, the official concession from the government to the private association 'Seguin's brothers and Edouard Biot' awarded an independent proposal, from the 'Ponts et Chaussées' Administration and from the State engineers. The French railways opened under the liberal rule, same as the English railways. Nevertheless, the number 2 of the P.C. Administration, Barnabé Brisson, had a personal participation to the proposal and his nephew, Edouard Biot, was one of the five founder contractors!

4 An ambitious railway proposal to reach the Rhône Valley, by Marc Seguin¹⁷⁾

We have seen that the section from Saint-Etienne to Rive-de-Gier (no.3 in Seguin's project) was height difference level zone (Table 1). In his first proposal, Seguin studied the possibility of a long sloping tunnel through the Terrenoire hill (1 500 meters). The next section (no.2 in Seguin's project) was only possible by the right side of the Gier river, reaching the Rhône Valley at Givors. It is a narrow and hilly passage, with a lot of rocky spurs. The canal of Givors occupied the other side of the river¹⁸⁾. That section imposed a range of short tunnels and a lot of important banking up. The project was completed by a nearly horizontal section (no.1) from Givors to the big city of Lyon, 20 kilometers upstream in the Rhône Valley, at the Saône river confluence (see Figs. 1 and 3).

Constant and limited gradients for the line design constituted the first ambitious option of the 1826 Seguin's proposal. After his 1825 fact-finding trip to England, to Newcastle and Darlington railways, the French civil engineer did not agree with the dominant British conception of that time: a succession of horizontal sections powered by horses or locomotives and inclined plans powered by a fixed steam engines. 'Seguin's brothers' and their partners, the Biot family¹⁹⁾, made the line plotting from Lyon to Saint-Etienne during the summer 1826. We should observe the outstanding knowledge in plotting of the Saint-Etienne & Lyon railway staff. Jean-Baptiste Biot²⁰⁾ had been a member of the French expedition to Spain, to measure the meridian length by the triangulation method during the French Revolution²¹⁾. Brisson²²⁾ was one of the most famous engineers for the summit level canal, in which French State engineers had got an outstanding know-how at that time²³⁾. The measurement equipment was very fine, for example with a Gambey's theodolite²⁴⁾.

In winter of 1826-27, Marc and Charles Seguin made a new travel to England, meeting George Stephenson on the new building site of the Liverpool - Manchester railway line. Discussions with British engineers led French contractors toward a new design for the line. Completing the initial option of constant gradients, Marc Seguin chose great radius curves, more than or equal to 500 meters, as another fundamental principle

for the new railway line. Immediately, he drew a new proposal for the railway line, including a heavy increasing for the civil works: great new banking up, ten new tunnels, especially at Rive-de-Gier (Couzon tunnel, 960 meters) and at the entry of Lyon (La Mulatière). The total tunnel length reached four kilometers, on sixty kilometers for the full line. Constant gradients were near 6 per 1000 on the second section. Despite the 1500 meters inclined tunnel of Terrenoire, it remained at 13.6 per 1000 on 22 kilometers, the major part of the third section.

5 The construction of the line and the beginning of exploitation

Seguin's organization of the railway line construction was a division of each section into numerous little building sites. Each one was directed by a foreman, leading a team of workers. Each group was under contract with the 'Seguin's brothers and E. Biot Co', for a global amount of work and payment. For example, a long tunnel such as Terrenoire was divided in a succession of 9 or 10 vertical shafts, three of them were more than 50 meters deep²⁵). A miners group signed a contract with Seguin for a shaft and a correspondent part of tunnelling. From 1828, first rails and wagons allowed to a new banking up method, faster and more economic. Tunnelling was a hard work: movements of soils, collapses, opposed difficulties to the line construction, followed by accidents, construction lateness and increasing prices. Saint-Etienne & Lyon railway was a two-way line, but difficulties of tunnelling limited the three main tunnels at one way, during the years 1830s. Difficulties arose in great banking up, for stabilization and by the succession of frost and thaw in soils.

At the beginning of 1827, Seguin chose the long iron rail with a constant section for his railway line (5 meters), and made it by the rolling mill method. That was done against the main British engineers suggestion for the undulating iron rails. The Saint-Etienne and Lyon Co. signed an exclusive rail contract with the famous firm of Le Creusot, in Burgundy (170 km north from Lyon). It was an important step in the development of the industrial iron works in France at that time.

During 1828 and 1829, years of a fully construction along the three sections, there were more than 2000 manual workers on the line. But the 'Seguin's brothers and E. Biot' staff consisted of only 60 employees²⁶). There were engineers and assistants for technical direction, financial estimation of works, material supply and control of building sites. However, there were also accountants and clerks for each section.

During the second half of 1829, financial difficulties in the Company led to a partial but fast achievement of the railway line, to get the first receipts. The second section was the most advanced in construction then, and competition with the Givors canal Company stimulated Seguin's brothers and the railway Company Board. The 2nd section seemed the most profitable, with the coal of Rive-de-Gier for the Rhône Valley. Furthermore, it was a good commercial training on a medium gradient for the first Seguin's locomotives. Despite of the strong Seguin's desire to open the line on the 1st January of 1830, a symbolic date, the traffic started at the end of June only²⁷).

Important social troubles accompanied the first experiment of the line exploitation, during 1830 summer. They were local events of the French 'July Revolution', followed by a Monarchy change, with the constitutional king Louis-Philippe. For the railway Company, it was a violent debate and a strike against the mechanical emptying of coal wagons arriving at the Givors port. By the cantilever rails, or a movable weighing machine, wagons came directly under the boats. With just one or two manual workers, a trap door emptied them it very quickly. Other devices made an automatic filling at the Grand-Croix collieries.

In October 1830, first attempts of the locomotive traction, to make empty wagons come back to Rive-de-Gier and Grand-Croix collieries, gave good results. There were some important breaks down in four locomotives, but a regular use of two machines was possible. That was enough for a limited traffic, such as during the first months which were a social and economic troubled period. In summer 1831, possibilities of locomotives became not sufficient, and the Board Company was divided as for the choice of engine. With a perspective of a general line opening, the construction of an important number of locomotives asked a

difficult capitalist question and a fast increase of the Perrache workshops. However, performances of the steam locomotive engine on a 20 kilometer high gradient of 13.6 per 1000 were not proved. Horses were a compromise supported by the first receipts of exploitation. In spring 1831, Board Company preferred horses to increase of the traction power. They were not so fast, but that seemed enough at that time for coal and goods. Horses used on high gradients were expensive and slow, but sure²⁸⁾.

The Company surmounted its difficulties with a strong increase of capital. At the end of the construction, in February 1833, it reached 15 million francs²⁹⁾. The general opening of the exploitation line was an optimistic time, with a strong start in traffic. It reached immediately the initial annual purpose of 300000 metric tones, as soon as the 1883 Company account³⁰⁾.

6 The Seguin's tubular boiler of 1827

Seguin's family Company began its first steam works in early 1820s, with a participation of the paper mill mechanization. They had lived in Annonay, a famous paper mill city in France since the 18th century, especially the Montgolfier brothers, ballooning inventors and famous paper makers³¹⁾. In the early 19th century, paper makers of Annonay (Montgolfier family, Canson, Johannot) were dynamic manufacturers interested in the mechanization³²⁾. They made a lot of improvements, and the Seguin's family Co. was involved in that business as subcontracting for specialized products or engineering. For example, they became the most important French producers of the paper mill felts. They made some mechanical devices for factories, such as waterwheels or industrial uses for steam³³⁾. However, Marc Seguin reached an original scientific thinking on the equivalence of heat and mechanical work, leading to the first principle of thermodynamics³⁴⁾.

In 1825, the Seguin's brothers took the direction of an ambitious project for a steam navigation Company on the Rhône river, by a tow device. On their design, a London mechanist, Martineau, constructed two steamboat engines, with a three horizontal cylinders acting directly on the driving shaft. The 'Voltigeur', the first boat of the 'Seguin, Montgolfier, d'Ayme Co.' sailed in 1826. The 'Remorqueur' sailed in 1827. Company made some navigation trials on the difficult river Rhône, with important streams all along its way³⁵⁾. A lot of technical problems arose during that experimental period, and Seguin tried to improve his steam engine and mechanical devices, especially to increase the steam production and to get a more light machine.

Those studies led Marc Seguin and his young son, Paul, in two directions : first towards the tubular boiler; second, to force and control the fire by a pushed air ventilator. After a vain research of an iron master for a possibility of an iron tubular boiler, Seguin had the excellent idea to use the high skillful copper workers from Lyon to do that. Construction of the first tubular boiler, by the craftsmen Butillon and Forest, was made in less than four months and was finished in December 1827. First experiments in Seguin's Perrache workshop was a complete success, against the opinion of French and British specialists³⁶⁾.

Seguin's family Co. asked immediately for a French patent for the tubular boiler, and it was delivered in February 1828 (see Fig. 4).

Explication du dessin

- a, Fourneau alimenté par un ventilateur ou autrement.*
- b, Chambres d'air.*
- c, Tuyau amenant l'air au foyer.*
- d, Porte pour alimenter le fourneau.*
- e, Tuyaux calorifères.*
- o, foyer,*

Chaudière à vapeur par Mr. Seguin

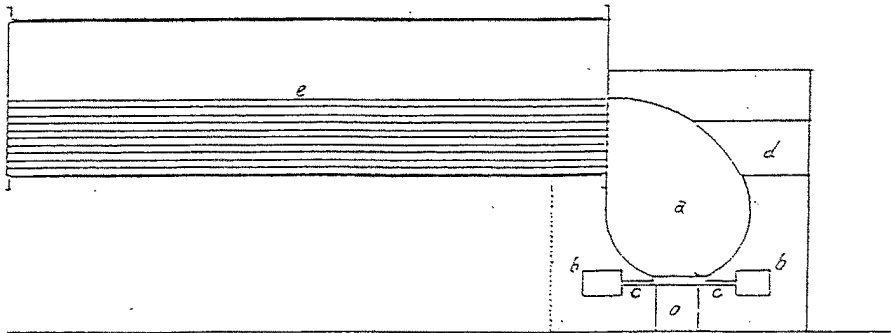


Fig. 4 : First Seguin's French patent on the tubular boiler (February 22, 1828)
(From : I.N.P.I., Description des brevets, Paris, vol.37, p.422)

7 The Seguin's locomotive for the heavy and hilly transportation

After an experimental period, during the first half of 1828, for the tubular boiler use, Marc Seguin decided to modify the Stephenson locomotive, he just received from England in summer 1828. In December 1828 and January 1829 he made a positive attempt of his tubular boiler on the Stephenson mechanism. That one was a two low vertical cylinders, fitting between the two wheels of each side. Two lateral, parallelepiped devices powered a 4-wheels drive locomotive.

Consequences of that mix-prototype were important for the Saint-Etienne & Lyon railway Co.. Seguin decided to extend the Perrache workshop to a locomotive factory, the first outside England. In the following months, he designed a homogeneous locomotive engine, involving an integrate tubular boiler, a copy of the former mechanical device, and a tender supporting the fire ventilator (see Fig. 4). The first run for the Seguin's tubular boiler locomotive was in October 1829. At the same time, Robert Stephenson experimented with a similar tubular on the famous Rocket, during the Rainhill meeting. It was a locomotive engine competition for traction of Liverpool & Manchester railway Co..

Seguin designed his locomotive with two main options: First it had to permit to empty or light loaded wagons to come back up on the second section (gradient: 6 per 1000). Second, it had to be operational on the third section (gradient: 13.6 per 1000). The line use was quickly intensive. The heavy coal carriage ran down mainly by gravity. That posed important braking problems. The second Seguin's purpose was to powering by steam the full traffic all along the first section, in the Rhône Valley. For Seguin, speed was not important for an intensive goods transportation. He thought that an excessive speed became an expensive game, dangerous for the integrity of locomotives! Quickly, he recommended a 16 kilometer limit by hour to the engine drivers. Traveler transport was a later option of the Company(1833), and the Seguin's locomotive was not designed for it at first³⁷).

For the Perrache locomotive workshops, we should observe three main periods. The first period (1828-31) was an experimental time. The first set of four locomotives followed the construction of the mix-prototype with the tubular boiler. They were for the first exploitation of the second section of the line railway. The

Koechlin and Schlumberger report remains the best document on that technical period, with completed plates on the Seguin's locomotive³⁸⁾ (see Figs. 5 and 6). The second period (1831-32) followed the credit crisis of 1830-31, associated with the exhausting of the initial 10 millions francs capital. These difficulties led to a break in the locomotive construction, and to a temporary choice of horses, especially to come back up on the sloping sections. Impulse by Marc Seguin, the third period (1833-35) was a new take-off of the Perrache workshops, and the construction of a height locomotive set, with improvements such as new fire boxes (iron and copper furnace of the engine) or a fire control by a steam exhaust pipe at the bottom of the chimney³⁹⁾.

Nevertheless, the Board Company rejected the 1834 Seguin's proposal for a fast completion of the rolling stock with 30 locomotives, to reach a full steam traction. In February 1835, he tender his resignation, ending to a lot of discords. The new director of the Company, Léon Coste pursued a more careful policy for the locomotive construction, and a mix-powering line: horses and Seguin's locomotives.

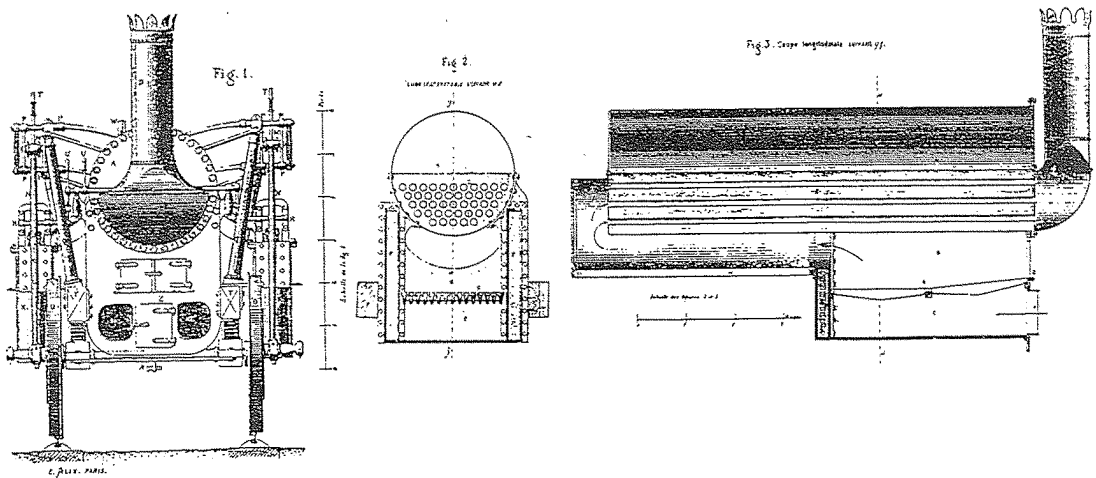


Fig. 5 : Seguin's locomotive with tubular boiler (type 1829)
(From note 38.)

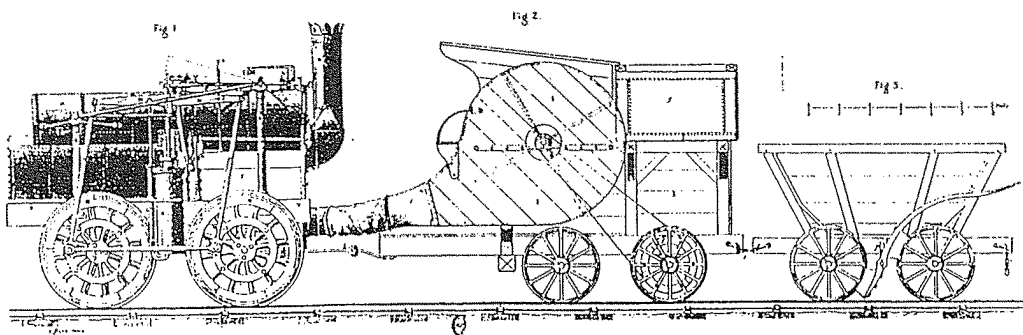


Fig. 6 : Initial rolling stock
(type 1829: locomotive, tender two lateral ventilators, coal wagon)
(From note 38.)

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Table 3 : Simplified chronology for the St.-Etienne and Lyon railway Co.

<p>1823 1824-1825 October 1825 November 1825 Dec.1825 - Jan.1826 March 1826</p> <p>May 1826</p>	<p><u>To the concession :</u> Beaunier proposal of a continuation of his Andrézieux railway toward the Rhône Valley. Public enquiries on the railway opportunity. Two new projects submitted to the government, one of which was from Seguin bro. & Biot. Seguin's economic studies on the coal transportation market from St-Etienne to Lyon. Seguin's England and Scotland trip. State concession to 'Seguin bro. and E. Biot'. Constitution of the St-Etienne & Lyon railway Co, a 10 millions F capital.. Seguin brothers and E. Biot contractors for the Company. Contract between Seguin bro. and the City Council of Lyon, for a large industrial project at Perrache, the end of the line.</p>
<p>Summer 1826 Autumn 1826 January 1827 February 1827 March 1827 April 1827 Summer 1827 December 1827 Summer 1828 Autumn 1828 Winter 1828-1829 Summer 1829 Sept. - October 1829 Winter 1830</p>	<p><u>First step of the construction :</u> Railway line plotting by Seguin, Biot and Brisson. Beginning of land buying. First official design of the line, with constant gradients New studying trip for English railways, contract with Stephenson for models (rails, wagons). Second design of the line : constant gradients and great radius curves, opening of the first building sites, towards a general activity along the line. Official acceptance of the Railways Company by the government, order for two locomotives to the Stephenson Co., Newcastle. Contract for long iron rails (5 meters) by rolling mills of the 'Charenton & Le Creusot Co.'. Large activity along the 3 sections of the line. First attempt, and success, for the Seguin's tubular boiler. Large activity along the 3 sections of the line. Tunnelling at Terrenoire. Opening the building site of the Perrache port. First training with the Stephenson's locomotive, deception for steam. Experimental construction of a mixed locomotive with Stephenson's device and Seguin's tubular boiler. Seguin's decision for construction of locomotives at Perrache. First financial difficulties, 2d section favoured to a near exploitation opening. Achievement of the first Seguin's locomotive, training at Perrache. Very cold winter, all the building sites were stopped.</p>
<p>June 1830 July 1830 October 1830 Autumn 1830 & Winter 1830 - 31 1831 - 1832 Summer 1832 October 1832 February 1833 October 1834 February 1835</p>	<p><u>End of the construction and beginning of exploitation :</u> Opening of the 2d section, from La Grand-Croix colliery to Givors (20 km). Social troubles against the mechanisation of the wagon emptying, linked with the French. 'July revolution' of 1830 (Louis-Philippe, new constitutional king). First try for a complete locomotive traction, success for a limited going down transportation. Important financial difficulties for the railways Co, major credit crisis in France, Line construction for the 1st and 3rd section stopped, tunnelling and ports digging too. Company crisis solved by an important capital increasing and a new property policy, building sites reopened. First organisation for passenger transportation. General opening for passenger transportation. General transportation all over the line, mixed powering by locomotives and horses. Marc Seguin first director of the Co.. Marc Seguin's proposal for a full steam traction, the board Co. refusesal. Seguin tender his resignation.</p>

8 Conclusion

The Beaunier's railway from Saint-Etienne to Andrézieux started the History of railways construction in France (1823-27). It was a line for opened the mining site of Saint-Etienne to the market of the Loire Valley, and furthermore towards Paris. Technically there were not any innovations but an efficient adaptation of the British colliery lines, with short radius curves along the geographical context, the use of short cast iron rails and animal traction.

The second French railway line, made by the Seguin's brother Company was more ambitious (1825-33). At first, it was the corresponding project of the Beaunier's railway on the East side of the coal field of Saint-Etienne. Thus geographical difficulties were impressive, with the pass of Terrenoire (550 meters in height), a height difference of level to reach Rive-de-Gier (245 meters in height), and the Rhône Valley at Givors (160 meters in height). After two study trips to England, and a critical study of the British proposals at the Stockton-Darlington and the Liverpool-Manchester railways, Marc Seguin's choices were even more ambitious for the heavy and hilly transportation by locomotive engines. He gave the standard of the hilly line (1826-27): 1) long and constant slopes, 2) large radius curves (more than 500 meters). Consequences were important in associated civil engineering works, with great banking up, numerous and long tunnels (4 kilometers in a 60 km line), the skew bridge over the river Saône...

Seguin chose the five meter long iron rail with constant section, manufactured by rolling mill process by the 'Le Creusot' company. That was an important step in the development of iron works in France. He also imported two Stephenson's locomotives (1827-28) for the traction, and improved it immediately with his famous innovation of the tubular boiler (French patent of February 1828). The first continental workshop of locomotive engines started at Perrache, in Lyon (1828).

Economic aspects showed a brutal decrease of the transportation rate in France: it was divided into two! An immediate intensive require of coal transportation followed the final opening of the line (1833). All that was connected with the strong possibilities of an industrial take-off of the city of Lyon and the Rhône Valley. Railway Company had a lot of technical difficulties to answer that heavy carriage need. Locomotives did not have a sufficient power to climb up trains on the impressive gradient (13.6 per 1000) along the twenty kilometers final section toward the Terrenoire tunnel. Horses were of a great support on that part until the beginning of the 1840s !

Consequences on the financial side were important: achievement of the line needed an exceptional increase of capital. Internal conflicts for the Board of the Company followed, together with a financial crisis (1830-31). The low rate, and the difficulties of an immediate heavy and intensive transportation limited the Company benefits, despite its amount of goods carriages (more cargo tons than on Liverpool-Manchester railway line) and an unexpected success of the civil transport (1833-34).

Notes

1. Cotte, M., Kobayashi, I. : Innovations of Marc Seguin between 1815-1835, Historical Studies in Civil Engineering, No.15, pp.363-374, 1995 (In Japanese); French Monarchy Restoration started in 1815 after the Napoleon's abdication.
2. Cayez, P.: Méziers Jacquard et hauts fourneaux, aux origines de l'industrie lyonnaise, P.U. Lyon 1978.
3. Merley, J., Luirard, M., Zellmeyer, M.: Bulletin du Centre d'Histoire régionale de l'Université de Saint-Etienne, 1978, vol. 1, an issue on Louis A. Beaunier.
4. Louis Georges de Gallois, born in 1775, dead in 1825. A French State chief engineer of Mines for the Loire department(1814), the founder of the coke blast furnaces of 'Janon', near Saint-Etienne(1818).
5. Antoine Beaunier, born in 1779, dead in 1835. A French State chief engineer of Mines, director of French mining schools (Geislautern 1813, Saint-Etienne 1815), iron-master of the La Béraudière's steel factory (1817), founder of the Saint-Etienne-Andrézieux railway line(1823-1827), Inspector of Mines and member of the National Mining Council(1824), member of the 'Conseil d'Etat'(1830).
6. De Gallois: Des chemins de fer en Angleterre, notamment à Newcastle, Annales des Mines, 1818, p. 129.
7. National French Archives, Paris (Archives nationales), F14 9030, file on the Loire railways.
8. It was to known under the name: "Andrézieux Railway"
9. Railway achievement needed a complement of 725 000 francs in 1826.

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10. National French Archives, Paris (Archives nationales), F14 9030 and 9031.
11. There were two Seguin's companies: first one was 'Seguin and Co', the historical family holding gathering all the industrial and commercial activities and shares of the father and his children; the second was 'Seguin's brothers', made especially for the Saint-Etienne & Lyon railway, only with Marc, Camille, Paul and Charles, but without the father (retired), the daughter Helen (dead in 1823), and Jules (independent for industry).
12. Departemental Archives service of Ardèche, Privas, France, 41J/ 34, 35 and 270.
13. Seguin frères et Edouard Biot: *Compte rendu aux actionnaires du chemin de fer de Saint-Etienne à Lyon*, Paris 1826.
14. Departemental Archives service of Ardèche, Privas, France, 41J/99.
15. Kobayashi, I., Cotte, M.: On the foundation works of the Tain-Tournon bridge designed by Marc Seguin, *Historical Studies in Civil Engineering*, No.15, pp.175-186, 1995 (In Japanese).
16. Cotte, M.: *Innovation et transfert de technologies: le cas des entreprises de Marc Seguin*, thèse (Doctoral thesis) EHESS Paris, 1995, chapitre 18.
17. Marc Seguin, born in 1786, dead in 1875. It was one of the most famous French civil engineers of the Industrial Revolution: suspensions bridges supported by wire cables, innovation of the tubular boiler for H.P.engines, builder of the Saint-Etienne & Lyon Railway, 1st French constructor of locomotives. He was a scientist in Thermodynamic too, precursor of the '1st principle'.
18. Seguin frères et Edouard Biot: *Mémoire sur le chemin de fer de Saint-Etienne à Lyon*, Paris 1826.
19. The physician Biot, his son Edouard, his brother in law Barnabé Brisson, the no.2 of the direction of 'Ponts et Chaussées', the French administration for roads, bridges, waterways and other transportation means.
20. Jean-Baptiste Biot, born in 1774, dead in 1862. He was one the most important French physicians in the early 19th century, famous by his accurate measurements (Astronomy, density of gas, cristallin polarization in Optic, the 'Law of Biot and Savart' in Electricity...).
21. The purpose of the two French expeditions for meridian measuring was an accurate definition of the unit of length: one meter as 1/10 000 of the meridian length. Arago and Biot led the Mediterranean expedition, Delambre and Mechain led the North expedition.
22. Barnabé Brisson, born in 1777, dead in 1828. It was chief engineer and inspector of the French State corp of the 'Ponts et Chaussées', professor at the P.C.school.
23. Brisson: *Essai sur le système intérieur de navigation*, Paris 1829.
24. Seguin Aîné[Marc]: *De l'influence des chemin de fer et de l'art de les tracer et de les construire*, Paris 1839, 2nd edition, 1887, p. 58.
25. *ibid.*, p. 187.
26. Dept. Archive Service of Ardèche, 41J/files 271, 267, 194, Seguin's brothers correspondence for 1828, 1829, 1830.
27. *ibid.*, file 194, Seguin's correspondence of 1830.
28. *ibid.*, file 55 and 307, reports of share holders meeting, 1831, 1832.
29. One million of capital increasing and around 4 millions bonds.
30. National Archives of France, F14 9030.
31. Charles C. Gillispie: *The Montgolfier Brothers and the Invention of the Aviation*, Princeton U. 1983; this book contains an interesting analysis of Seguin's scientific and industrial activities, because Seguin brothers was the grand nephew of Joseph and Etienne Montgolfier.
32. Louis André: *La papeterie en France, 1799 - 1860, aspects d'une mécanization*, Paris EHESS 1995.
33. Dept. Archives of Ardèche, 41J/166, correspondence of the Seguin's family firm.
34. Seguin Aîné[Marc], "Letter to sir J.F.W.Herschel: observations on the effects of heat and motion", *Edinburgh Philosophical Journal*, X, n° 20, April 1824, p.280-283; he wrote the letter in 1822.
35. Cotte, M.: thesis named (note 16), chapter 12 to 15, p. 407-536; a technical and economical History of the Seguin's navigation Co..
36. *ibid.*, chapter 16, p. 537-588; a History of the Seguin's tubular boiler.
37. *ibid.*, chapters 24 and 25, p. 849-912. Some French authors make a mistake since 19th C. about that : Seguin's locomotive was not a speed locomotive such as the Stephenson Rocket at the same time! Economic purposes were not the same, technical system of construction was not equal too.
38. Koechlin, M. and Schlumberger, A.: *Extrait du rapport lu à la séance du 26 octobre 1831 sur [...] le nouveau système de chaudière à vapeur de MM. Seguin et Cie à Saint-Etienne*, *Bulletin de la Société-industrielle de Mulhouse*, 5, 1832, p.169-230.
39. Seguin Aîné: *De l'influence des chemin de fer...*, 2nd ed. 1887, chapter 8, p. 310-342.