A SHORT HISTORY OF A

STEAM LOCOMOTIVE

UPALI JAYARATNE

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Conference a ready man; and
writing an exact man'**

Francis Bacon

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Upali Jayaratne
(BA Hons, MBA (Sri J))

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PREFACE

How and why the Railways came?

I think you will like to see the day when railways will supersede almost all other methods of conveyance in this country (England) - when rail coaches will go by railway and railroads will become the great highway for the Kings and all his subjects.

George Stephenson - 1825

It was the writer's long standing ambition to write a small book on the history of steam locomotives, explain how it works including the technical details and then include some drawings of the writer on Sri Lankan steam locomotives for the interested railway lovers, general public and students.

The writer is a keen enthusiast of steam engines since his childhood and Galle railway station was the place where he watched the operation of steam engines as a student. He could remember staying close to an engine just to smell the exhausting fumes. The smell was quite different from the steam airing out of a home kettle.

Truly speaking, the writer is a layman on the subject, but he has read exclusively to develop a comprehensive databank about the subject. The illustrations given in this booklet had been obtained from such references and material collected by the author over a long period of time.

A separate chapter is kept apart to embody some of the pictures of locomotives the writer had drawn. Any person wishing for a picture of an engine drawn (in water color or pencil), is welcome to contact the writer at the address given.

The writer acknowledges the great assistance given to him by the officials of Dematagoda Running Shed, Ratmalana Workshop of Sri Lanka, and the drivers of the "Viceroy" steam engine to take close-up photographs of the surviving locomotives. Special mention needs to be made about Mr. Sirisena Rajapaksa, a well known author of many Sinhala books on railways of Sri Lanka, who was eager to lend whatever literature available on steam locomotives.

The writer is a former Assistant General Manager in Bank of Ceylon and once served the Institute of Bankers of Sri Lanka as a consultant.

U. O. Jayaratne
BA (Hons), MBA (Sri J)
12/15, Dharmaratne Avenue,
Rawathawatte, Moratuwa,
Sri Lanka.

Tele : 0112- 647757.

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Chapter 1

History of Railroads

A railroad is a guided track and no one exactly knows when the first railway was built. Like the rotating wheel, its origin is not clear. However, it could be assumed that there were railways long before there were the railway engines or locomotives. Perhaps, the parallel lines of stone blocks laid by Greeks to move ships across Isthmus of Corinth was the first indication of a railway to be established 2600 years back. According to history, it was a special form of a road, quite permanent, which guided ships with people and goods.

Then around 400 years back, during the days of Queen Elizabeth I, carriages running on tracks made out of rails were used to move coal from the mines of Leberthal, in Alsaco, England. A notable feature was the development of rail tracks for mines and coalfields in 1676 as expressed by Roger North. Four carriages with four wheels each ran on straight and parallel tracks of timber, and one horse was able to draw four or five of the carriages laden with coal. Later in 1767, in Coalbrookdale in Shropshire (England), horse drawn carts were pulled along angled iron plates laid parallel on the ground.

Loded Coal Wagon Coasting downhill. The horse will haul it back

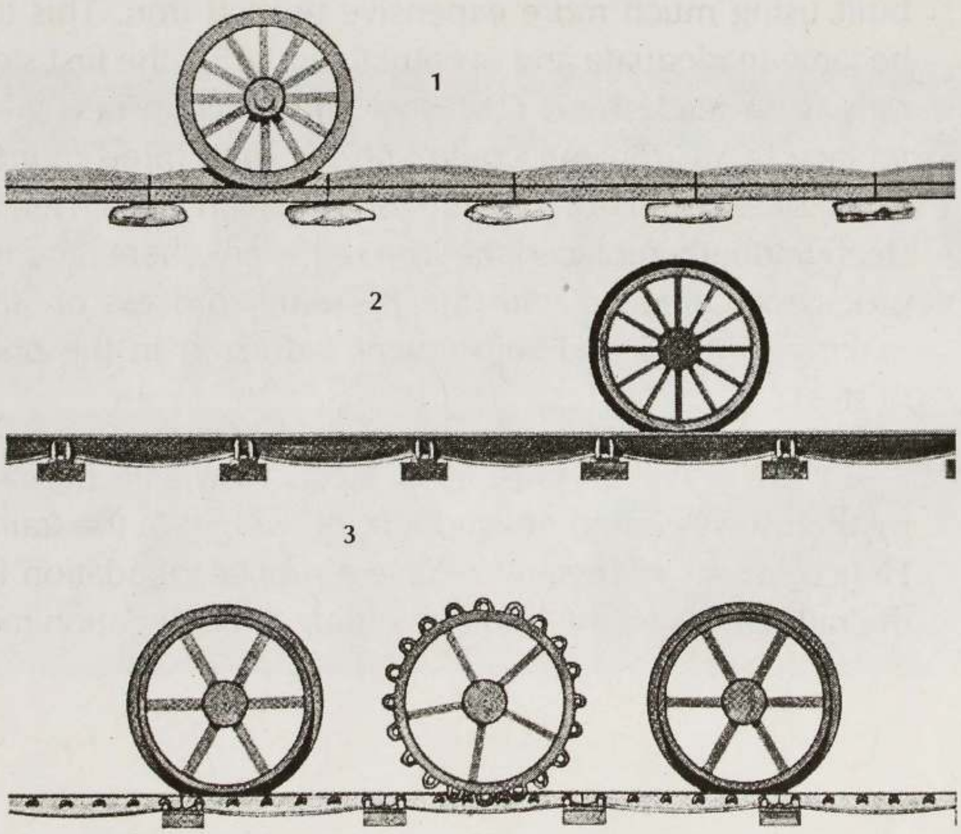
It was the birth of rail tracks, the principle still holds good, that with a given tractive force, an engine could move a series of wagons of much bigger load than which is possible with same effort and same weight on a non-specialized road system.

The first iron rails were flat and had an angle so that wheels could run within the boundary of the rails. The angle plates were laid in Sheffield in 1776 with the wheels running on the flat part and the raised angle prevented the wheels leaving the track.

An ordinary cart with suitable wheel spacing could use these tracks, but speed of movement had to be controlled to avoid wheels leaving the track. Later, there was an interesting developments with the introduction of a standard gauge, a spacing of little less than five feet. In this manner, it grew up to the currently used standard gauge of 4 feet and 8 ½ inches of the British Railways and which was adopted by many others internationally excluding Sri Lanka and India, where they have opted for a gauge of 5 feet and 6 inches.

Another development was the construction of rails with a flange so that flangeless wheels could run on the rails. The rails were L-shaped. These 'plate ways' and 'tramways' were also used in South Wales and it was here in 1804 that a Cornish mine owner Richard Trevithick tried working on a steam locomotive which was able to haul a load of 20 tons.

The next man in the field of new ideas was John Blackinsop of Leeds, who believed that smooth tyres and smooth rails would not give strong enough grip for hauling heavy loads. So in 1811, he invented a teethed driving wheel which engaged in cogs fixed to the sides of the rails. It prevented the wheels from slipping. This idea is still being applied on mountainous railways in some countries, where the train will secure a hold on steep slopes.



1. Flangeless wheels steered by flanged rails.

2. Wheels running on top of rail steered by wheel flanges.

3. Blenkinsop's system; toothed wheels, racks on outside rails.

Development on another front led to the use of water-ways to transport of heavy loads. By about the mid 18th century, artificial canals came into being as arteries for goods making their way to the larger rivers and the sea.

However, the railroad era saw the demise of waterways, for public mail and family coaches.

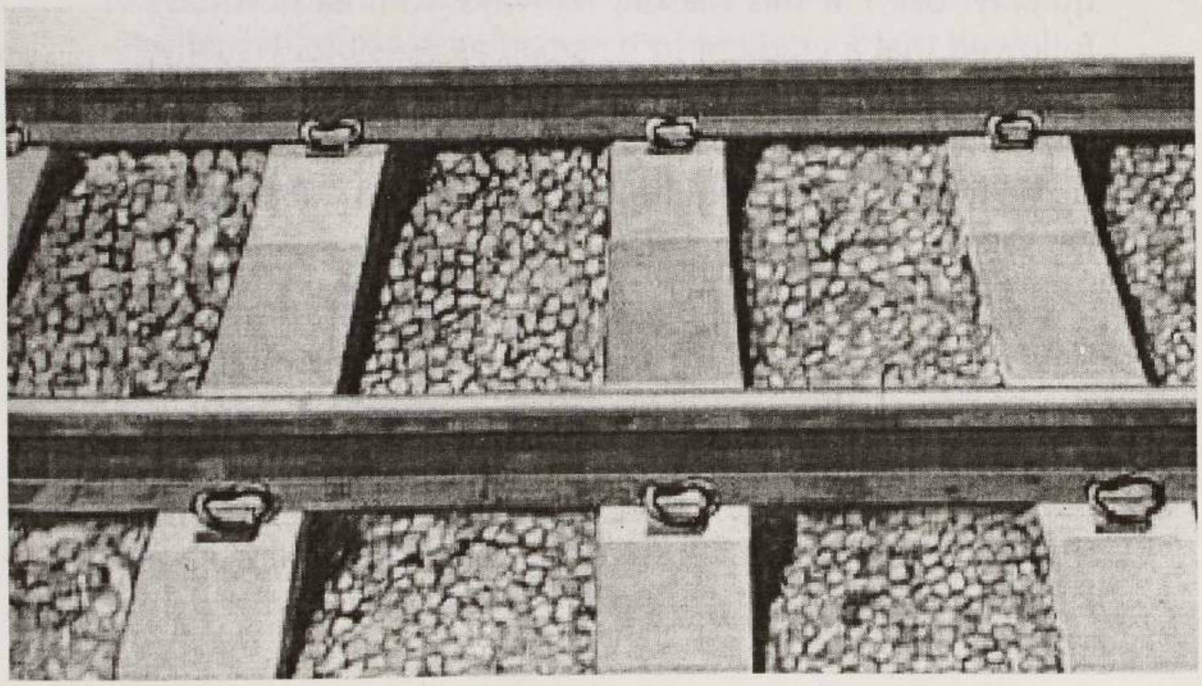
The next generation of railroads started with the development of the steam locomotives. The engines happened to be heavy and therefore strongly anchored tracks had become a necessity. Hence the plates and L-shaped rails were replaced by upright rails that are as used today, with the flange on the wheel guiding the movement on the rail. The early rails were around one meter long and were supported by joints.

The first effective rails were made of cast iron, but as soon as traffic on these rails became heavier, it was found that cast iron was liable to break. So, the rails were built using much more expensive twisted iron. This too became inadequate and eventually in 1857, the first steel rails were made by R F Mushet and the iron rails were replaced. An iron rail could survive only three months while steel could last long for about sixteen years. Hence, steel gradually replaced the iron rail everywhere, and the process accelerated with the Bessemer process of steel making in 1855 and subsequent reduction in the price of steel.

Nowadays, all rails are of steel. However, the rails by themselves could not support the weight of the trains. Hence, it was necessary to have a proper foundation for the rail. The exact method of building the foundation may differ from country to country. Yet the track foundation not only has to spread the load, but had to be loose enough for the water to drain through it, to hold sleepers in place and level, and to give springiness to the track.

The foundation materials or 'ballast' as is usually known are typically a broken stone such as granite or limestone. There is usually a lower layer of large pieces of material, around nine inches across, and an upper layer of small material around two inches. On this the sleepers are laid and loose ballast of smaller size is spread in between them. The sleepers may be of wood, steel, or pre-stressed concrete. Thereafter, the rails are fixed on to the sleepers with bolts or spikes keeping a distance between the two rails.

The numbers and spacing of sleepers depend largely on the weight of the train, but in Britain, there are some 2,100 sleepers per mile, in France 2,800; U.S.A. 3,000 to 3,500 so on.



Modern high-speed track with concrete sleepers and long welded rails

In most, usually a baseplate is inserted between rail and the sleeper. It can be of metal, rubber or plastic. The rails themselves have grown longer and with rails-joints more far apart and it can be of hundred feet long especially on main lines. The end of rails is joined by 'fishplates' (short metal bar placed on both side of the rail) with bolts passing through them. But the modern practice is to weld each rail end, preferably at intervals of 600 feet. To take care of expansion or contraction depending upon the temperature, the rail joints between of long-welded rail are feathered i.e. each rail is cut to a fine taper so that the ends can slide alongside each other without disrupting the running surface on which the train wheels run. Long welded track gives very smooth running without the constant bumping over rail-joints which is so noticeable on other types of track.

A locomotive gives its best performance on a level track and loses effort rapidly when it has to climb a gradient. The advantage of the steel wheel on steel rail is quickly lost. For this reason, railways from earliest days followed that a gradient to be small as possible. Usually, a rise of one foot for 100 feet is acceptable. On the other hand one steep gradient will limit the size and the extent of the train and may require more power to haul a line of carriages.

Chapter 2

History of a Steam Locomotive

The steam locomotive is one of man's greatest inventions and without it; we would not had the industrial revolution to happen in 17th and 18th centuries. This was because something more powerful and faster than the horse was needed to speed up the journeys and carry heavier loads.

For thousand of years until the early 1800s, movement in Britain and in other countries was limited to the speed of the horse; about 30 km/h for a horse rider, and less half of that for the average speed of a horse drawn coach or wagon. When canals were used for transporting loads, although movements did make heavier loads and volumes were feasible, the speed had been not more than 5 km/h.

Starting with the era of steam locomotion, the first steam engines were the scientific novelties of Hero of Alexandria in the 1st century AD, such as the aeolipipe, but not until the 17th century attempts were made to use steam for practical purposes. The first practical steam engine was a form of a pump, used to move water from mines. It was invented by Thomas Savery in 1698. In his

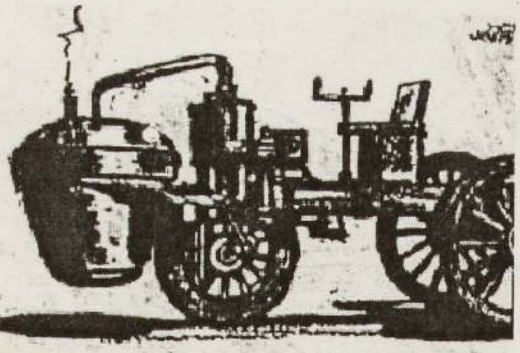


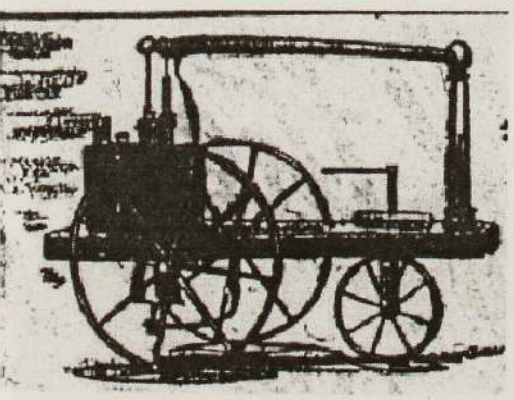
Fig. 1 - *Cugnot's Steam Carriage*

simple machine, steam was condensed to form a very small volume of water, thus providing a partial vacuum. This was used to suck water up a mine shaft.

In 1712, another Englishman, Thomas Newcomen invented a steam operated pump with a piston. The piston was used to separate the steam from the water. In 1765, James Watt improved on Newcomen's ideas and produced a more efficient steam engine. A separate condenser was added to avoid heating and cooling the cylinder with each stroke. Watt then developed a new engine that rotated a shaft providing the simple up-and-down motion of the pump. This rotary motion concept paved way for the development of the steam locomotive.

The next develop- ment was the use of steam for transport of goods and people. In 1769 a Frenchman; Nichlas Joseph Cugnot invented a steam carriage for the roads (Fig 1). A prophecy was made during the time, that there would be traffic jams in Regents Park by these steam carriages. (Look at illustration 1 on page 10). Unfortunately, at the trial run of Cugnot's steam carriage, the machine got out of control and overturned, injuring several spectators. Consequently, Cugnot was sent to prison.

Fig. 2 - *Murdock's Steam Loco the first in England 1786*



It was William Murdock, a poor Scotsman, who lived at Redruth in Cornwall, England, who built the first steam locomotive (Fig. 2). It was a small locomotive to move on the road. He used his spare time to build it. It had only three wheels; a small one for steering and two larger ones as driving wheels and for the furnace, it had a spirit lamp. Although, it was a toy like carriage, he succeeded making it run along a roadway under its own power in 1764. The development was the beginning for the steam locomotive in its prime way.

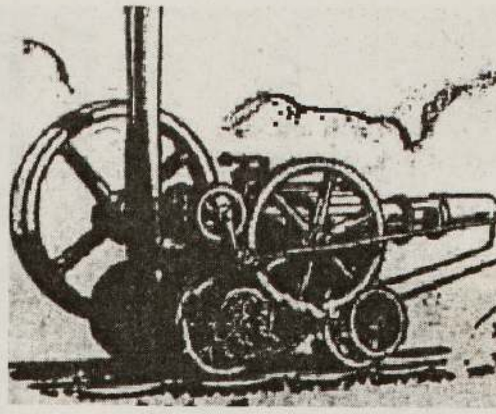


Fig. 3 - *The First Steam Loco to run on Rails 1802*

Thereafter, little was heard of what everyone thought was just a madman's craze until 1797. During this year, a Cornishman, Richard Trevithick, produced a full sized steam carriage. A successful trial of this machine was carried out on the Christmas Eve of 1801 at Camborne in Cornwall, and Trevithick was so pleased that he made the first steam locomotive which pulled on a level road, a load of wagons with rails (Fig. 3). This was the start of obtaining forced flow of air (draught) for the furnace, a trick which is still in use today.

Trevithick continued his experiments and in 1808, he erected a circular track in Euston Square, London on which he ran his latest production "Catch Me Who Can." The public was invited to pay a shilling (a day's wages) to take on a ride. However, the venture failed and in a few weeks he had to close it down.

Richard Trevithick

History now considers Trevithick as the true father of the steam locomotive, pioneering on features such as the use of high pressure steam and tuning of the exhaust steam into the chimney to improve the intake of air in to the fire box. He had built several locomotives. The last one was more advanced and it was considered as the world's first passenger locomotive which ran around a circular track.

Illustration 1
AN ARTIST'S IMPRESSION ON HOW TRAFFIC CONGESTION WOULD BE OF STEAM CARRIAGES IN REGENT'S PARK, PARIS IN 1831

Several locomotives were continued to be built in early 19th century. They were experimental engines adopting various types of drive gearing, different cylinders and boiler designs. One of the experimenters was William Hedley's "Puffing Billy," and his engine worked many years at Wylam Colliery in Northumberland, England hauling coal wagons (Fig. 4). It was the first locomotive to have a wrought-iron boiler and two outside cylinders. In addition, it used the exhaust steam to increase the draught through the firebox, thereby increasing the engine's efficiency. Constructed on a solid wooden frame, the boiler and probably the cylinders were lagged with wooden strips, while remainder appeared as black metal.

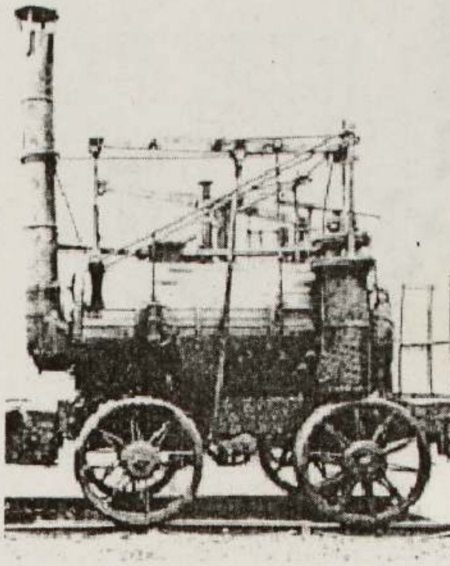


Fig. 4 - *William Hedley's Puffing Billy*

William Hedley was followed by George Stephenson, the most famous pioneer on steam locomotives. He was a Nortumbrian engineer and between 1814-21 he built 17 experimental locomotives. Although, he was not the first to produce a steam locomotive, he was the prime mover in introducing the engine on a grand scale.

He brought up the railway system by planning, organizing, building, and equipping it. His turning point came in 1821 when he was appointed engineer-in-charge of what became the 42kms long Stockon & Darlington railway within an industrial zone. It was opened in September 1825, Stephenson's Locomotion No. 1 drew the first train (Fig. 5). This historic event saw the world's first public railway to use steam locomotives to haul wagons of goods (the main traffic was coal) and carriages of passengers. He drove the engine at the opening of the railway. The engine weighed 6½ tons, succeeded in hauling a train of 28 carriages at a speed of 12 miles per hour on its first run.

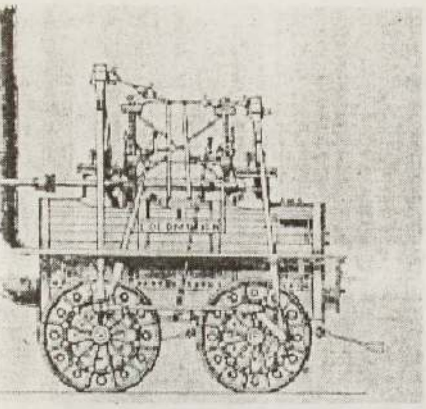


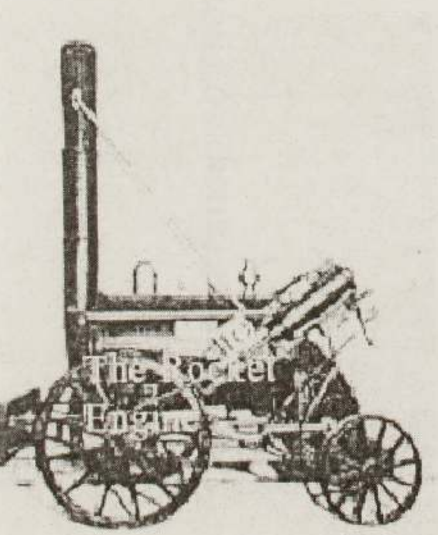
Fig. 5 - *The drawing of Stephenson's "Locomotion"*

A newspaper of the day described the event in these words, "The engine started off, drawing six loaded wagons, a passenger carriage and twenty-one trucks fitted with seats. Such was its velocity that in some parts the speed was 12 mph. The number of passengers counted to be 450, which, together with coal and other things, would amount to nearly 30 tons. The engine with its load did its first journey of eight and three-quarter miles in five minutes over an hour."

In 1829, the owners of the Liverpool and Manchester Railway offered a prize for the best engine. The competition was won by George Stephenson's "Rocket" which drew a train 56 kms in little under two hours. This success made Stephenson and his son Robert, famous with the "Rocket" and it set the design for locomotives years to come (Fig. 6).

The important thing the Rocket had the blast pipe, once more something that was fundamental to the success of almost all locomotives ever built. By arranging exhaust steam discharged through a jet, up the chimney, a partial vacuum was set up at the chimney. Air would rush into fill this vacuum and the only way it could do so was through the fire gate at the other end of the boiler. Hence, it was a situation where the amount of air being drawn through the fire and thus the amount of heat produced would depend upon the amount of steam being used. More than anything else, this automatic connection between the amount of heat needed and the amount supplied was what gave the Stephensons, father and son, their triumphs.

Fig. 6 - *The Rocket Engine*



After the success of "Rocket", the steam locomotive was established. Like most of the early steam engines, the

"Rocket" had only one pair of driving wheels and two cylinders. Its boiler had multiple fire-tubes rather than single flues previously used, and the steam pressure in the boiler was almost 3.5 bars (50 pounds per square inch). Usually, 1 bar means 14 lbs per sq. inch. The tender of the engine was a large water barrel fixed to a wooden frame carried by four cast iron wheels. The cylinders instead of being vertical, first time set at an angle. Hence, the rocking vibration that was present in early engines was greatly reduced. Together with the tender, it weighed about 7.5 tons.

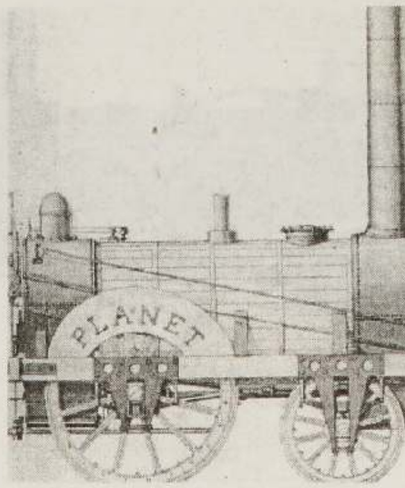


Fig. 7 - *The Planet*

In 1830, George Stephenson built the "Planet". It was a radical step taken forward from the "Rocket" and its derivatives established the general form of the future locomotives. Planet combined the multi-tubular-boiler with a fully water jacketed firebox and a smoke box. The cylinders were inside and horizontally mounted (Fig. 7).

The first Planet was a passenger engine with 5 ft. driving wheels and 3 ft. carrying wheels. The construction of the Liverpool & Manchester Railway as a medium-distance passenger line created a further incentive to improve locomotive design.

By 1830's, the essentials of a steam locomotive design had been laid down. The design of the boiler, firebox, exhaust parts, construction and positioning of cylinders, type of wheels, general layout of an engine and the tender were established. When the need rose for more powerful engines, it was admitted that Planets were unsteady at any speed and their firebox capacity was limited.

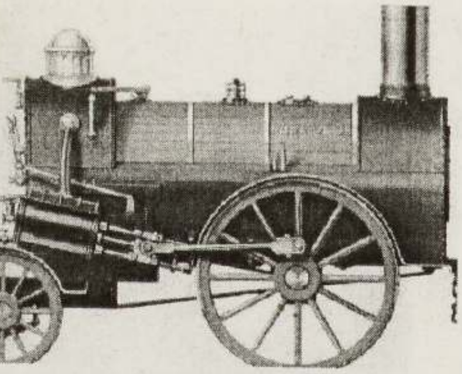


Fig. 8 - The Nothumbrian

Thereafter, there were further developments made regarding locomotive design. One example had been the "Nothumbrian" introduced in 1830 (Fig. 8). It had several important things which the Rocket did not have. Firstly, she had a smoke box in which ashes drawn through the boiler tubes could accumulate. Secondly, the boiler was integrated with the water jacket round the firebox. These two things meant that the locomotive-type, fitted to almost all the locomotives that were built later. The third was that the cylinders had now come to the horizontal position quite different from Rocket. This development stopped the rocking effect on the rails. Moreover, the Nothumbrian's cylinders were fitted in an accessible position and fitted outside the wheels, but however, it was at the wrong end. Another improvement was the use of vertical frames as the border-frames of the tender.

The features that made Rocket a success continued in Nothumbrian too. One was the availability of multi-tubular boiler (a boiler which has numerous tubes instead of one big flue for the hot gases to pass through) which was larger and stronger. Numerous small tubes had a much grater surface area than one big flue so that heat was passed across the water at a higher rate; hence such a boiler had high steam raising capacity in relation to its size.

Another feature was that the boiler fitted to the Nothumbrian came to be a characteristic for the future locomotives. Many attempts were made to make different boilers later, but they were not enough to produce something better than the Nothumbrian. So, Stephenson boiler stayed around. Credit for suggesting multi-tubular is attributed to Henry Booth of L & M Company and Robert Stephenson.

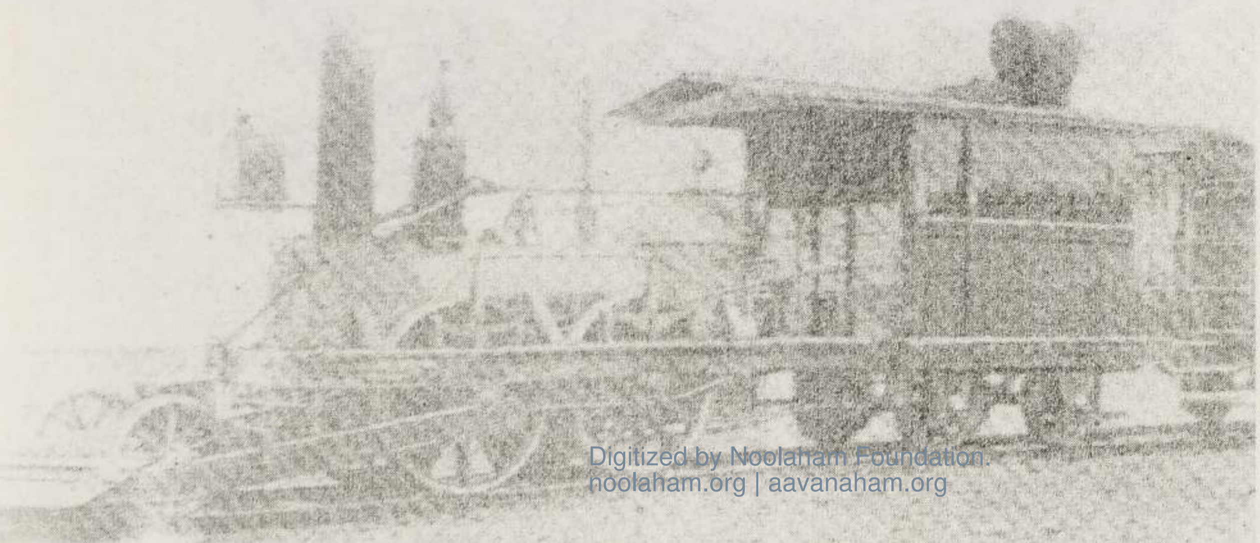
Mechanically, because of Nothumbrian, the principle of having two cylinders outside the frames and directly connected to the driving wheels became more and more the world standard as years went by. Towards the end of the steam, this principle became virtually universal.

However, the actual layout of the Nothumbrian's machinery had some drawbacks as the driving wheels were at the front and the heavy firebox and the heavy cylinders at the end on the carrying wheels. There was only a box full of smoke at the other end and yet the driving wheels needed all the weight to provide tractive power and keep them from slipping. Moreover, when engine started puffing, the engine tended to lift at the front and thereby further reducing the weight for gripping of the rails.

Also, the combination of outside cylinders with a short wheelbase created a problem where alternate piston thrusts resulted into boxing motion rather than a smooth continuous motion. It was not until the Nothumbrian layout was considerably altered by having an extended wheelbase and moving the cylinders to the front that some of these problems were solved.

Contemporarily, in the United States (1831), a steam locomotive named "John Bull" was introduced to Pensylvania Railroad by the works of George and Robert Stephensons of England (Fig. 9). Issac Drops, a mechanic introduced a bell, a head light and a cow catcher to this engine. The bell which was put on the John Bull is still carried by all North American locomotives today.

Fig. 9 - *John Bull built by Stephensons*

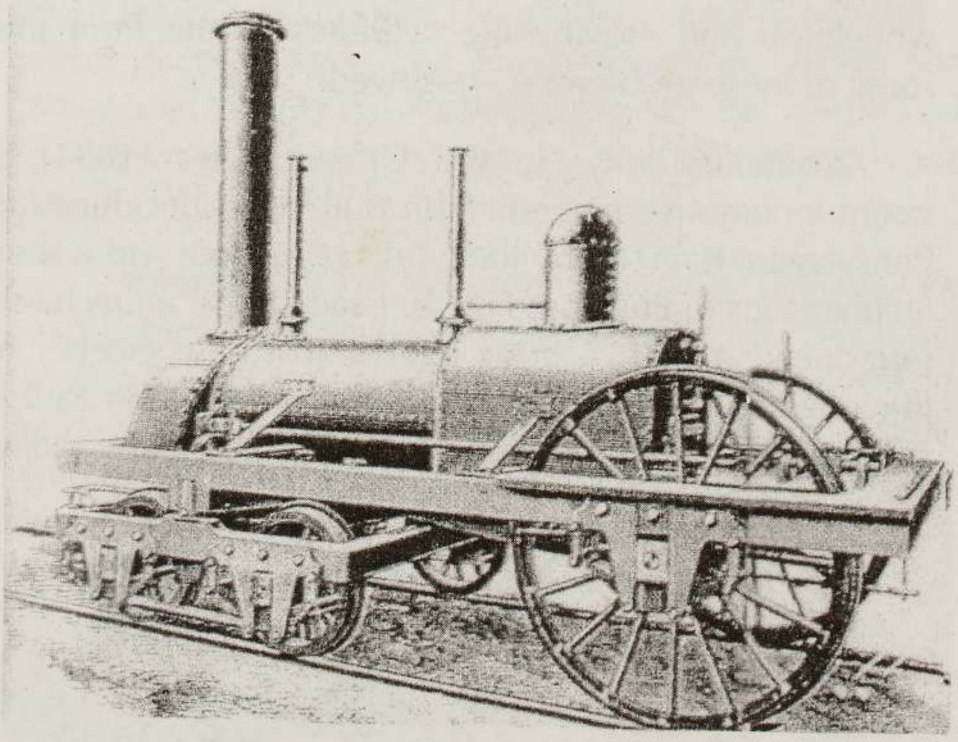


However, the cow catcher was quite different from today's being carried on a pair of wheels. It was a primitive kind of a leading truck.

In the same year, John B Lewis, an American built the locomotive named "De Witt Clinton" in the United States (fig 10 on page 16). It was the first engine to have a dome on the boiler. When there was no dome with the locomotives earlier, there was a tendency for the boiled hot water entering the cylinders. Within the dome, a gap was created between heated vapor and boiled water, avoiding boiled water leading to the cylinders and thus the dome became a feature for latter engines.

In 1831, another locomotive named Brother "Jonathan" was built by John B Lewis of United States (Fig. 10). A special feature of this engine was the introduction of a bogie or a truck for the first time. This feature became a standard for some locomotives at a latter stage in the United States. This locomotive became a successful engine because of its wheel arrangement of 4-4-0.

Fig. 10 - *Brother Jonathan built by John B. Lewis in 1831.*



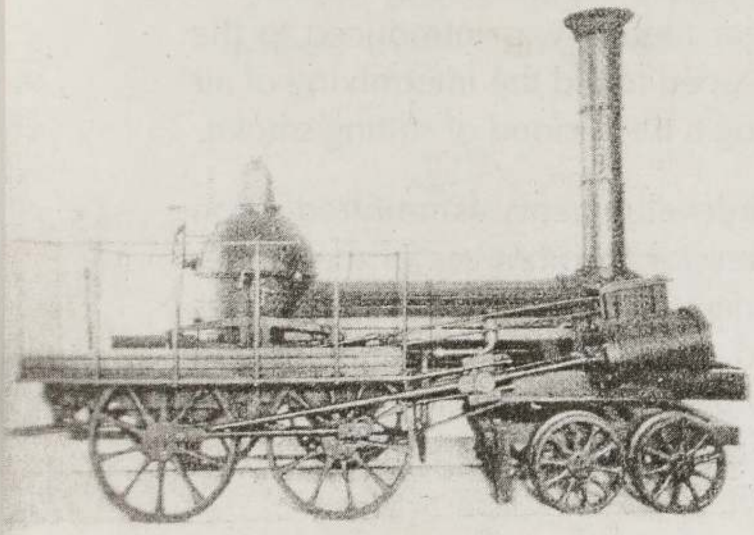
Under the name of "Vauxhall", a locomotive was introduced to Ireland in 1832. An interesting feature of this engine was the horizontal positioning of the cylinders fitted on the outside frame. This placement became the final position of cylinders for the locomotives built for subsequent 170 years.

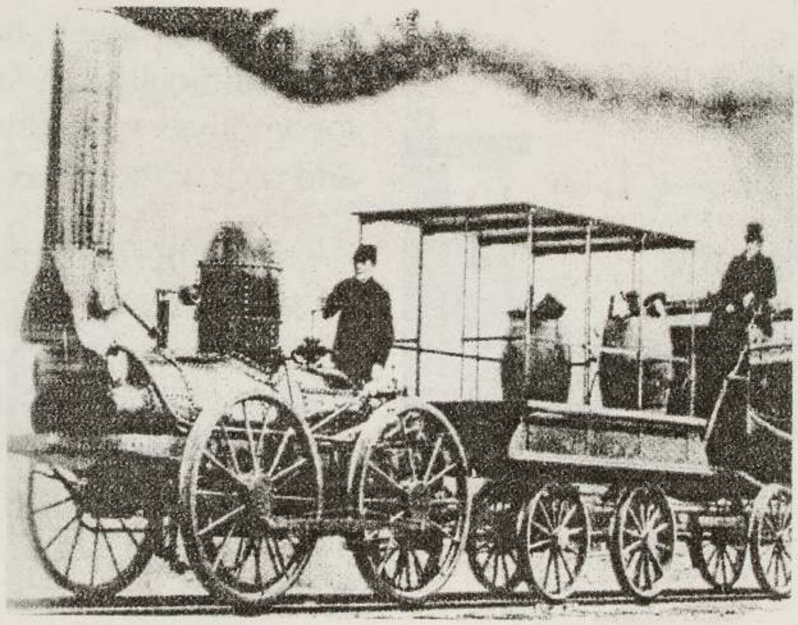
Then in 1834, Joseph Harrison built the "Hercules". The engine had a wheel arrangement of 4-4-0 (Fig. 12). All these eight wheels were made to support the body of the locomotive at three points. It was a brilliant notion which solved the problem of running on rough tracks and was the basis of the three-point compensated springing which was applied to most of the world's locomotives from simple ones to 4-12-2s.

After the Rocket, another major development was to place the driving wheels at the back and put the cylinders at the front under the firebox. Outside frames were employed for the first time. The original design for

Fig. 11 - *A replica of De Witt Clinton re-enacting. Its inaugural trip from Albany to Schenectady on that memorable day in 1831.*

;. 12 - *Hercules ilt by Joseph arrsion in 1836.*





this came from the Planet, built by Robert Stephenson. Thereafter, many variations were constructed around this theme. For example, it became the practice to replace the front set of carrying wheels by a second pair of drivers linked by a connecting rod.

The adoption of an outside frame to support the boiler, firebox and wheels, encouraged the transfer of cylinders from under the smoke box to outside frames. Forester of Liverpool was the first to build 2-2-2 engines to this design. However, these engines had a tendency to shake and were nick named as "boxers." The fault was corrected in 1839 with the adoption of counter-balancing, which involved placing a metal weight inside the rim of the driving wheel to counteract the thrust of the piston.

By the late 1830s, the 2-2-2 wheel arrangement had been established as the standard for the next 30 years. In 1860s and 1870s, there were a number of important technical breakthroughs. Many experiments were carried out to find a satisfactory method of burning coal rather than coke, which had been expensive. To overcome these difficulties, a larger firebox was introduced to the locomotives specially sloped to aid the intermixing of air and coal without creating a thick cloud of stiffing smoke.

Anotherinterestingdevelopmentwastheintroduction of a spectacular chimney for locomotives in the Unites States. The engine under the name "Mud-digger" was built by Gillinham and Winans for the Baltimore and Ohio Railroad in 1844 (Fig. 13). Another feature of the engine was the horizontal position of its cylinders.

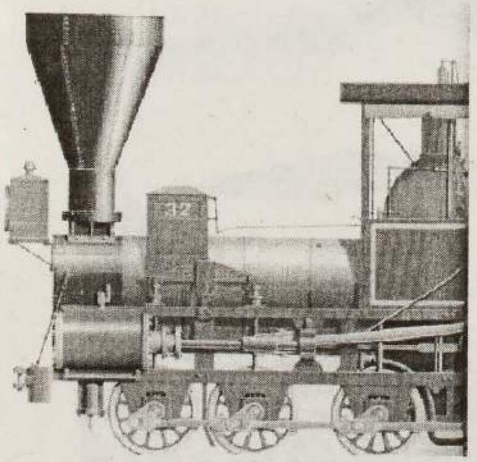


Fig. 13 - *The Mud-Digger built in 1844*

In Britain, with the cheaper and more effective production of steel, engineers were able to replace many of the weaker iron parts with steel. Steel wheels began to be fitted in the late 1850s, becoming a general application in the following decade. Steel also made use of to produce axles, reversing shafts and cylinders. The manufacture of rolled steel plates meant that boilers could be produced to withstand higher pressures and hence generate greater power.

The introduction of the bogie also permitted faster speeds, could cope up the curves and indirectly encouraged production of more powerful locomotives (fig. 14). With the introduction of the bogie, longer engines could be built and provided greater stability at speed on the straight. Therefore, it was highly used in United States for several years. However, the development was considered as serious as a single overloaded front axle resulted in breaks and had been the cause for many accidents.

As bogies more generally adopted, the driving wheels were often doubled. Another development was

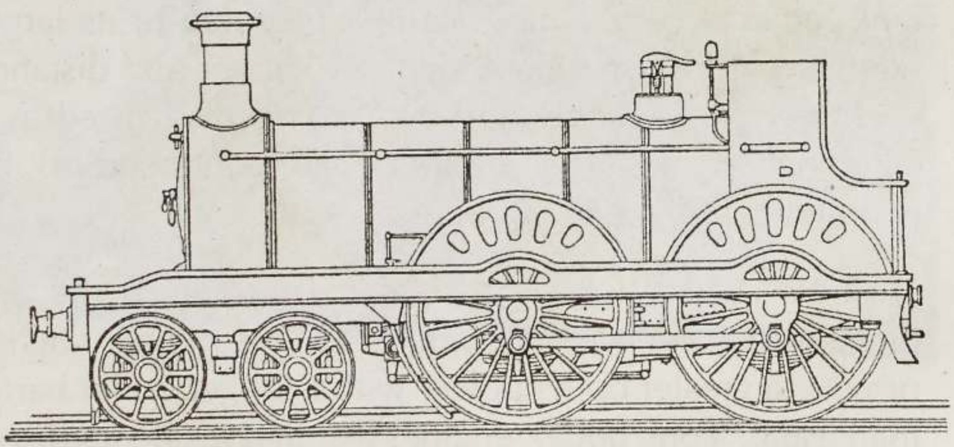


Fig. 14 - *James Stirling's first bogie locomotive, completed for the Glasgow & South Western Railway in 1873.*

the introduction of larger tanks for the goods locomotives. A goods locomotive was firstly built with a 0-6-0 wheel arrangement. The advantage of this design was that it afforded maximum grip on all the six driving wheels without putting much weight on any single axle. Among the best known 0-6-0s were those designed by Mathew Kirley for the Midland Railways in 1869 (Fig. 15).

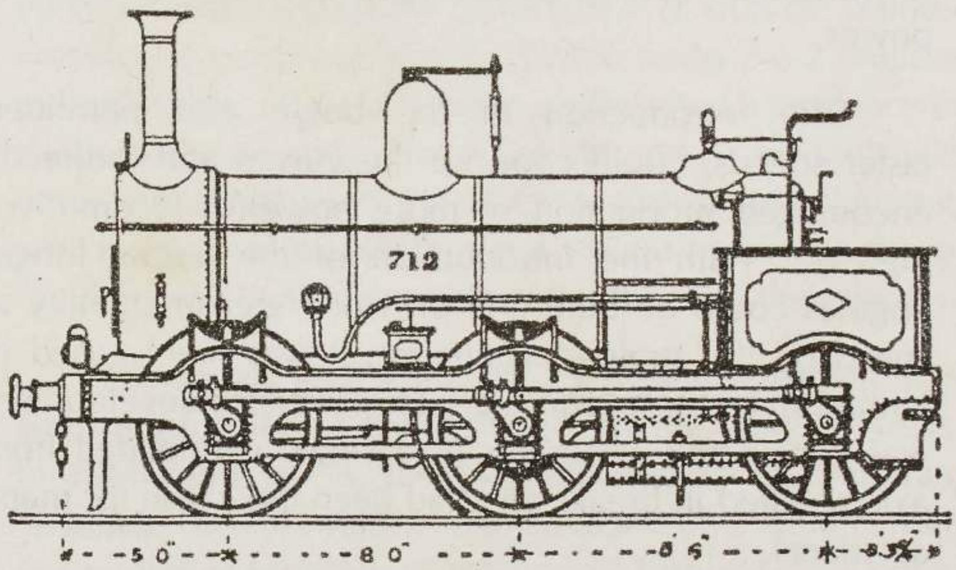


Fig. 15 - *Matthew Kirtley's goods 0-6-0 locomotive, designed for the Midland Railway in 1869.*

Another advance had been that the wheel arrangement of 4-4-0 was selected for the tank engine design, when smaller goods trains were needed. The tank locomotive is a more compact version of its larger counterpart for use where loads are lighter and distance is shorter. Accordingly, the 0-6-0T was often used as a shunting engine. This basic design continued to be adopted until the end of steam.

By 1840s, Robert Stephenson introduced the first of his 'long boilered' locomotives. The motive was to provide a greater boiler power with a longer boiler barrel than usual. 'Long boiler' engines featured inside frames of iron-plate and inside-cylinders which shared a common steam-chest placed between them. In Fig. 16, it is shown a long boilered engine "Derwent" built by W A Kiching in 1841.

Through, these developments, the essentials of a steam locomotive design had been laid down. Yet these engines could not be considered as powerful engines from today's standard. The Rocket for example could only develop a tractive effort of 825 lb. Collett's "Castle Class", introduced in 1923, produced a tractive effort of 31,625 lb. The history of locomotive design from 1830 to 1950s was one of continual modification to increase power and raise the running speed.

For example "Jenny Lind", a 2-2-2 constructed for Midland Railway in 1847, had a tractive effort of 4,900 lb, and could run at 50mph (Fig. 17). Unlike the Rocket, she could pull around three times her weight.

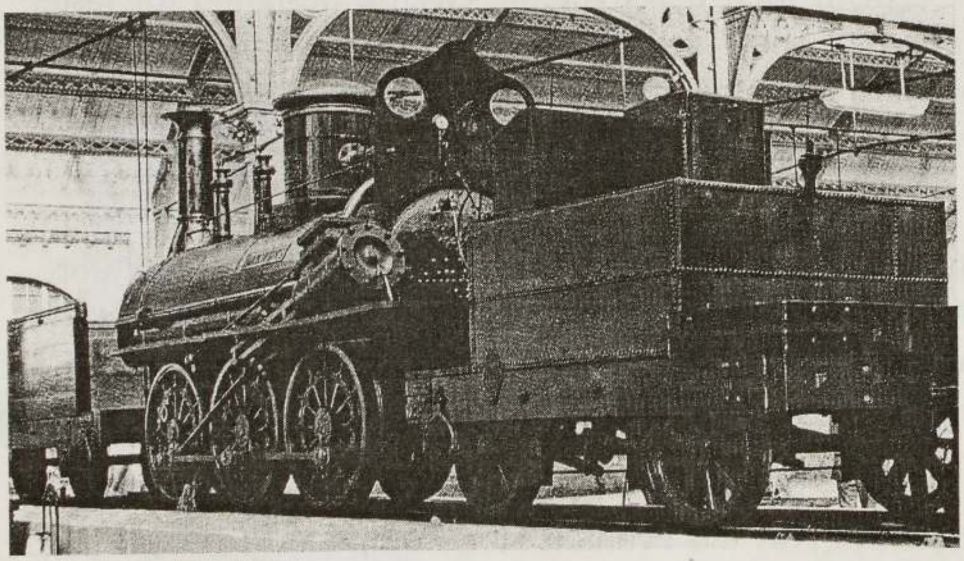


Fig. 16 - *Derwent built by W. A. Kiching in 1841*

g. 17 - *David y's Jenny Lind comotive, uilt for Midland ailway in 1847.*

The next major breakthrough came in the first decade of the 20th century. With the continued growth of passenger traffic and demand for faster and more luxurious trains, pressure was placed on engineers to produce more and more powerful locomotives. George Churchward, a great engineer created a well advanced locomotive with four cylinders (two internal and two external), a superheater, and a tapered boiler to provide maximum heating at the firebox end.

The ultimate development of the steam engine came with the Pacific Class, the 4-6-2s. The first Pacific to run on British Railways, the "Great Bear", was an engine distinguished with an enormous smoke box. It was designed by Churchward in 1908. Nigel Gresley, another engineer, produced one of the world's finest express engines. With high boiler pressures and a revised valve gearing, he produced the Flying Scotsman Class in 1923, and in 1935 the more powerful and streamlined A-4s with their aerodynamic casting designed for faster running. They developed a tractive effort 35,455 lb. Mallard was the most famous of these and holds the world's steam speed record, at 126mph (Fig. 18).

It was considered as a most advanced steam locomotive but it could not be developed completely. With development of this powerful engine, the decision was made to shift to diesel and electric traction, and no further steam locomotives were manufactured.

The last steam engine manufactured by British Railways was the Evening Star, completed in 1960 (Fig. 20).

To mark the occasion, this powerful 2-10-0 was painted in lines green livery rather the usual plain black. The Evening Star successfully worked on passenger services but steam running ended in 1968. Although, further developments were possible, the steam locomotive reached the end of its history and electric locomotives took over the tasks of providing passenger and goods services all over the country (U. K.) thereafter.

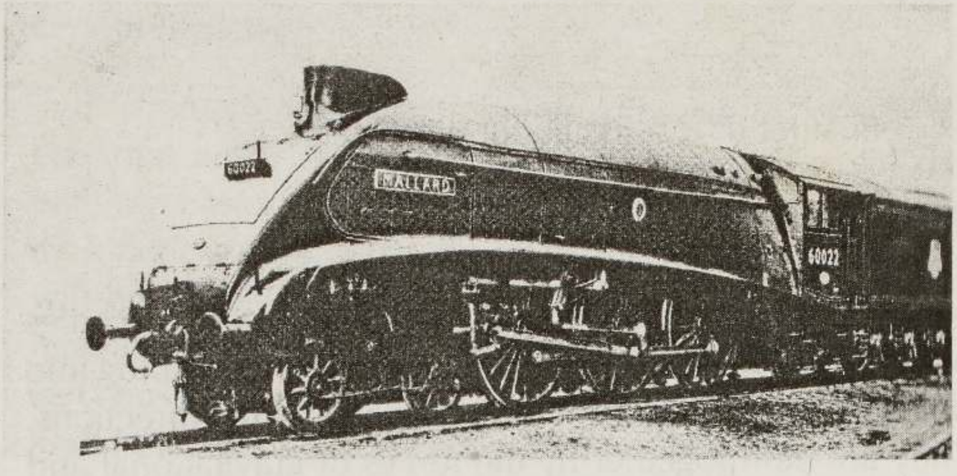


Fig. 18 - *No. 60022, Mallard, now preserved at York and still holder of the fastest steam train record 126 mph*

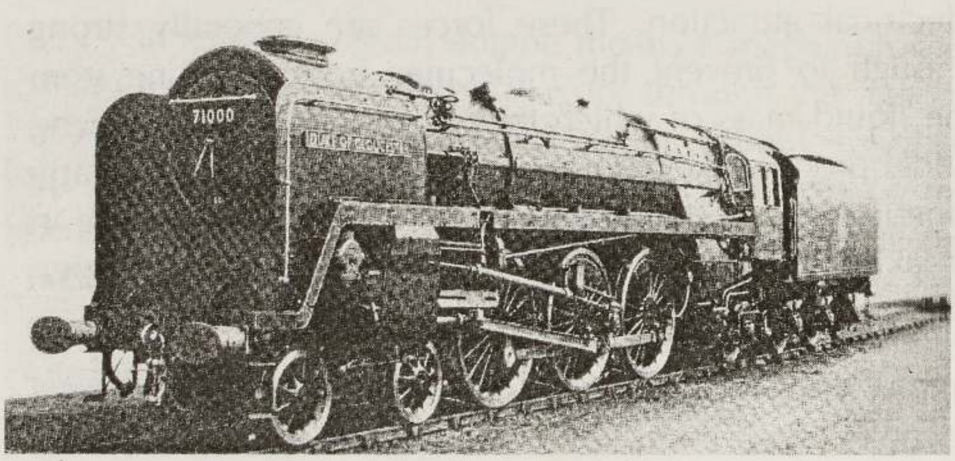


Fig. 19 - *No. 71000 Duke of Gluesctor,Britain's most advanced steam locomotive, built by B. R. at Crewe in 1954. But never fully developed. Note the innovative and complex valve gearing*

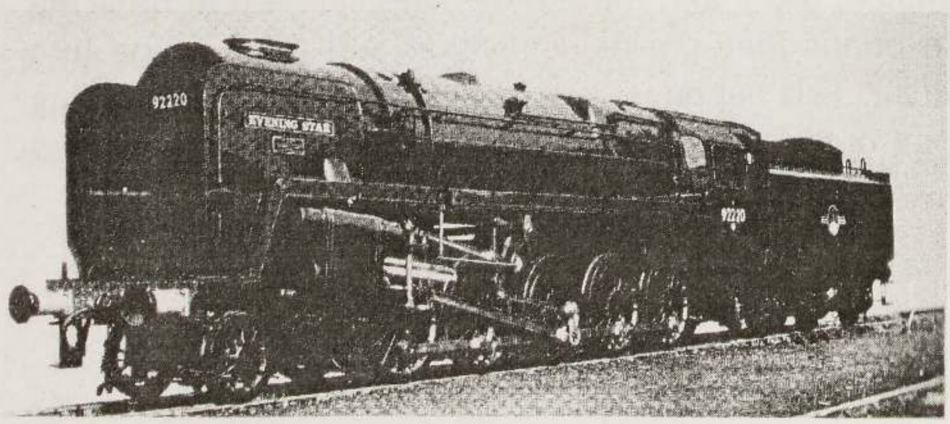


Fig. 20 - *No. 9220, Evening Star, a Standard 9 class locomotive and the last steam engine built by British Railways, being turned out from Swindon in March 1960*

Chapter 3

How a Modern Steam Locomotive Works?

First let us discuss about what steam is?

What is steam?

Steam is made up of vast number of molecules which are in constant motion, bumping into one another, rebound and set off again in other directions. They are held together by the forces of gravitational and electrical attraction. These forces are generally strong enough to prevent the molecules from escaping from the liquid mass of which they form a part of. However, under process of evaporation, molecules with particularly kinetic energy - that is the energy in motion - succeed in breaking away from the liquid and escaping into open air.

If heat is applied to plain water, the kinetic energy of its molecules is increased and their motion becomes more agitated. More and more molecules succeed in breaking the bonds they are held together and thus escape into the air. This happens when the water reaches the boiling point of the temperature. The vapor or gas that is formed as a consequence is called steam.

When it is in a pure state, steam is a dry and invisible gas. Often, however, once some of the water vapor particles of which it consists are condensed into liquid form as they come in contact with air, so that the steam forms a mixture of gas and liquid particles. This mixture appears as a visible cloud. They are free to fly apart, that means the gas of they form expands. As gas expands, it releases energy, which can perform work; as a physicist would put it, gas can exert a force through a certain distance.

If steam instead of being allowed to escape, is confined within a limited space, its molecules will dart with increased vigor. The steam will exert great pressure; its kinetic energy - its capacity for performing work - will be greatly increased. Also, there is a corresponding increase in temperature of steam as pressure increases. It can cause pistons to move to and fro within the cylinders and draw a train with compartments along a track.

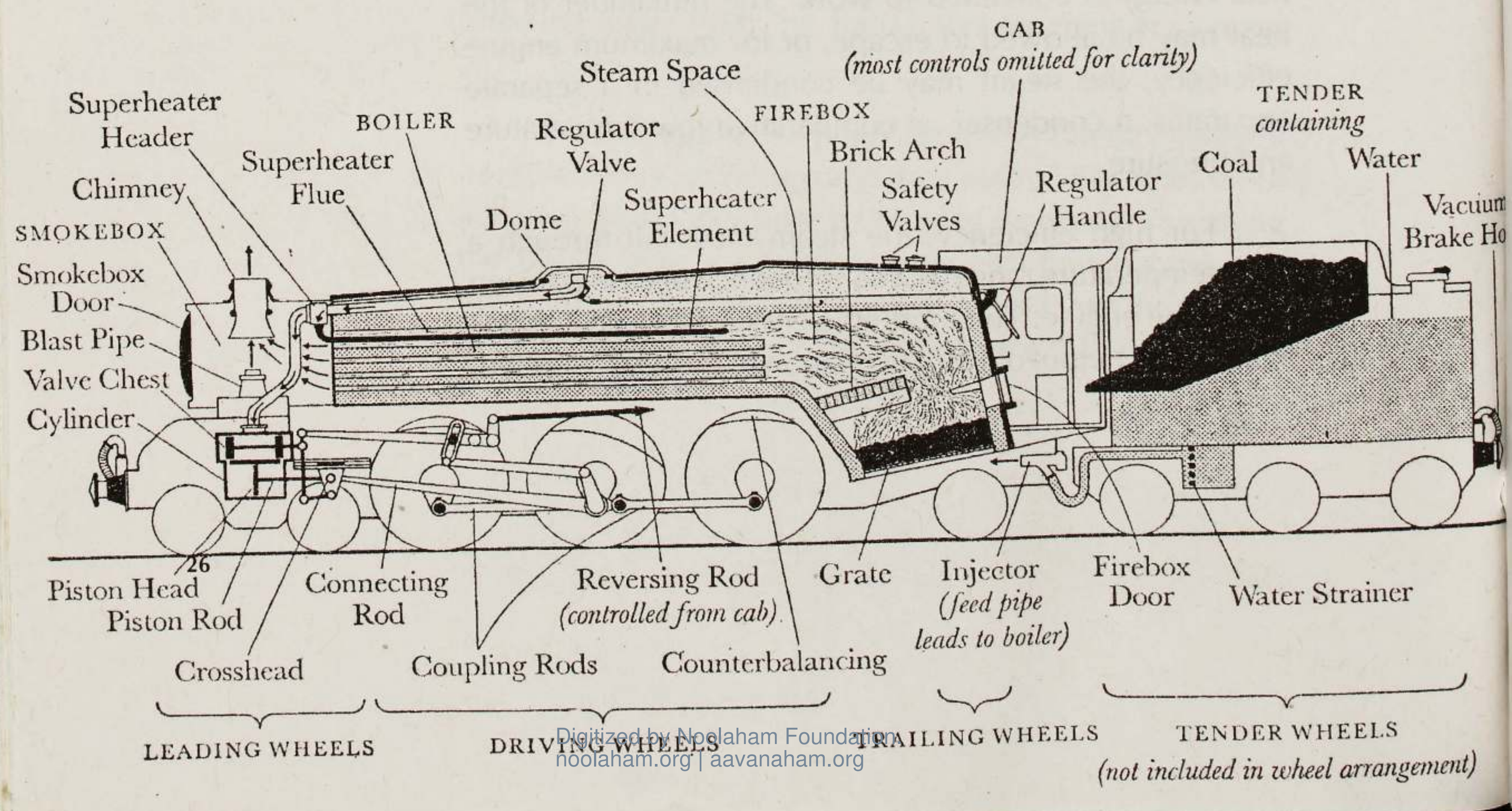
Generally, a steam engine means a machine using steam to perform mechanical work through the agency of heat. In a steam engine, hot steam, usually supplied by a boiler expands under pressure, and part of the heat energy is converted to work. The remainder of the heat may be allowed to escape, or for maximum engine efficiency, the steam may be condensed in a separate apparatus, a condenser, at comparative low temperature and pressure.

For high efficiency, the steam must fall through a wide temperature range as a consequence of its expansion within the engine. The most efficient performance- that is the greatest output of work in relation to the heat supplied-is secured by using a low condenser temperature and a high boiler pressure. The steam may be further heated by passing through a superheater on its way from the boiler to the engine. A common superheater is a group of parallel pipes with their surfaces exposed to the hot gases in the boiler furnace. By means of superheaters, the steam may be heated beyond the temperature at which it is produced by boiling water.

The energy released by steam is great; so is the velocity of a jet of steam. If steam is drawn from a boiler at high pressure and directed through a nozzle, it will develop a velocity of 3,000 to 4,000 feet per second, or a speed of 35 to 40 miles per minute.

There is a practice to superheat the steam, which really means 'drying' the steam. This makes it twice as hot and twice as powerful. Drying is done by passing the steam through the boiler twice by means of a special superheating device consisting of a number of small steam tubes inside the bigger ones, where it is dried up by direct heat from the furnace. Thus, when it arrives at the cylinders, the steam is very powerful and "eager to work."

Fig. 21 - *A Cross-Sectioon of a typical 4-6-2 express steam locomotive*



The application of further heat to the steam during superheating causes it to expand, so that less weight of superheated steam is required to fill the cylinders at each stroke than would be the case if saturated steam at equal pressure was used. Since it takes a kilo of water to produce a kilo of steam, it follows that if superheating enables the cylinders to do their work on a lower weight of steam, a saving of water and coal. A further advantage is that sufficient heat can be retained in the steam after expansion behind the piston to prevent condensation takes place within the cylinders.

How a firebox operates?

Firebox is a place where heat is created by burning the fuel. The fuel can be of coal, oil or wood. Inside the firebox is the grate for the fire which is fed by the fireman through an opening in the cab, called the fire-hole. The grate is connected up to the tubes, and from the grate the flames and smoke pass through the boiler tubes so that water is heated.

How should the fire prepared?

The coal in the firebox (see illustration 2 below) need to be spread evenly over the entire grate and few shovels of small coal sprinkled around the sides of the box to start the fire burning vigorously.

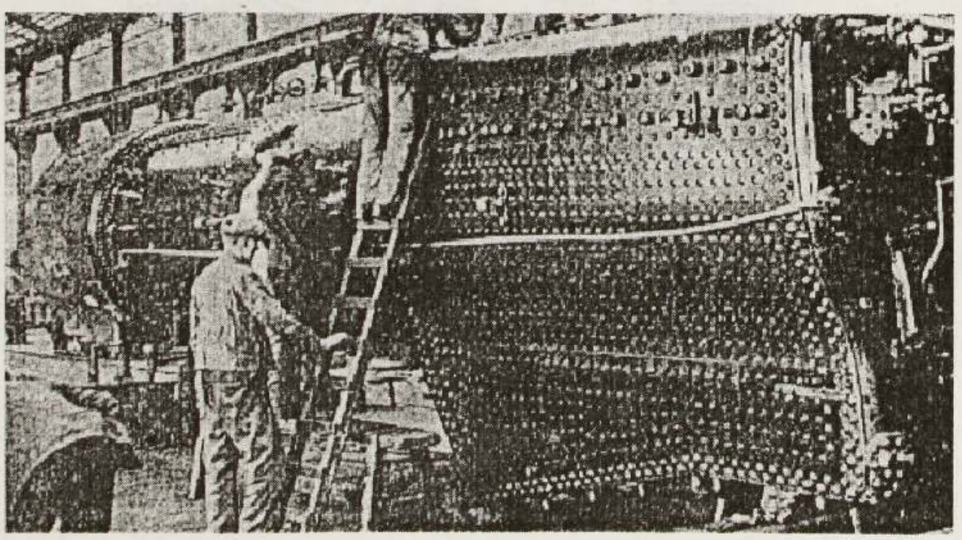
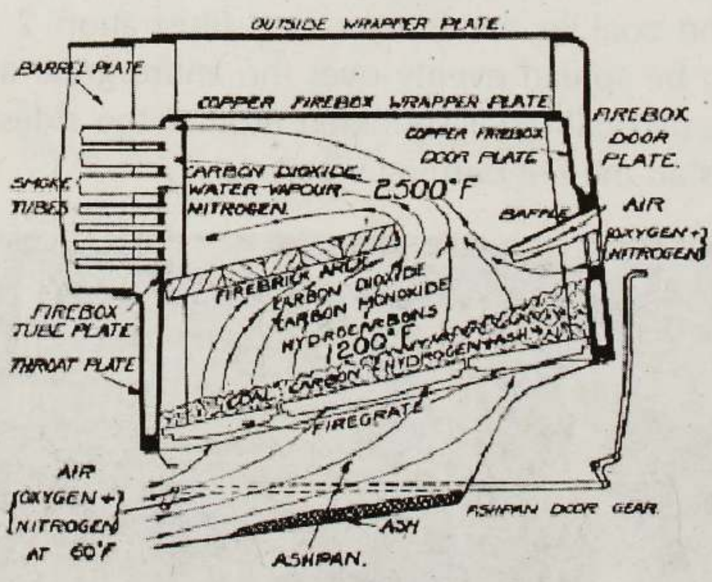


Illustration 2 - *Fire box, Smoke box and Barnel assembled*

The dampers will be opened slightly and the blower applied sufficiently to promote proper combustion of the fuel. When fuel (coal) burns or the combustion is complete, a colorless gas called carbon dioxide is formed. Each pound of carbon burned will produce around 14,000 British Thermal (B.T) units of heat. If the combustion is not satisfactory, the carbon in the coal will not be consumed and a colorless and highly poisonous carbon monoxide may form up. The heat generation will be less and carbon so burns imperfectly will produce just 4,500 B.T. units of heat.

However, if further supply of oxygen is introduced, the carbon monoxide would ignite and burn with a pale blue flame, giving out a further considerable quantity of heat to form carbon dioxide gas. In the absence of supply of oxygen, the carbon monoxide gas will escape up the chimney unburned and in the form of smoke, and the available heat in it would be lost. This may represent a loss of 69 % of the available heat.

Fig. 22 - *A Firebox*



While coal burns up, clinker will be left behind. The clinker formation has to be controlled, since over-collection of clinker may block the air supply through the dampers. This may hinder the burning of coal properly and thus would be another reason for the loss of heat. Incorrect firing and mismanagement of dampers tends to accelerate formation of clinker. The best method is to spread broken clean firebrick or limestone over the grate before the fire is built up. These materials tend to collect round them as it forms and by doing so prevent getting adhering to the firebars.

Usually, a large quantity of air will be required for proper combustion to take place in the firebox. Normally, air is drawn in by the blast and enters the firebox through the dampers and the fire-hole door. However, air surplus means the air gets heated absorbing some useful heat which otherwise could be used to produce heat. Hence, excess air is a wasteful method affecting the level of heat.

The level of heat in the firebox can be gauged by its appearance and colour. Red, orange, and yellow flames indicate temperatures of 1,000 to 1,200 Fahrenheit. If the fire glows a brilliant red, it is an indication of a temperature around 1,800 Fahr. The fierce white fire means a good working condition of heat, a temperature between 2,000 to 2,500 Fahr.

Also, since the opposite sides of the firebox plates contain water and it absorbs radiation from heat, the firebox plates do not get damaged.

What is the brick arch for?

The brick arch (Fig. 22) serves some useful purposes. It protects the tube plate and tube ends from the direct flame from the fire. During the intervals of rest and firebox temperature falls, it radiates heat which tends to prevent rapid lowering of tube plate temperature. It promotes through the combustion of the gaseous products of the coal by lengthening their path from the fire gate to the tube plate and further it causes intimate mixing of these burning gases even when the air admission is stopped by the closure fire-hole door.

How a boiler works in a steam engine?

The boiler is the largest part of a steam locomotive. Its principal parts are the steel shell, which includes the boiler barrel and the firebox wrapper plates which is generally made of copper and the fire tubes leading from the inner firebox to the smokebox tube plate within the barrel. The inner firebox is secured to the wrapper plates by over thousand stays passing through the water spaces which surround the inner firebox on all sides except the bottom.

When a superheater is fitted, that consists of a number of large flue tubes within the boiler barrel; (Fig. 23) these flues house the superheater element tubes through which the steam has to pass on its way from the regulator valve to the steam chest. This means steam from the regulator valve is fed via the internal steam pipe to the saturated steam chamber of the super heater header. From this chamber the steam is fed to the superheater elements of which there may be from 7 to 40. Each element is enclosed within a large flue tube and extends back to within about 2 feet of the firebox tube plate, where a return bend is fitted which brings the steam backwards the smoke box.

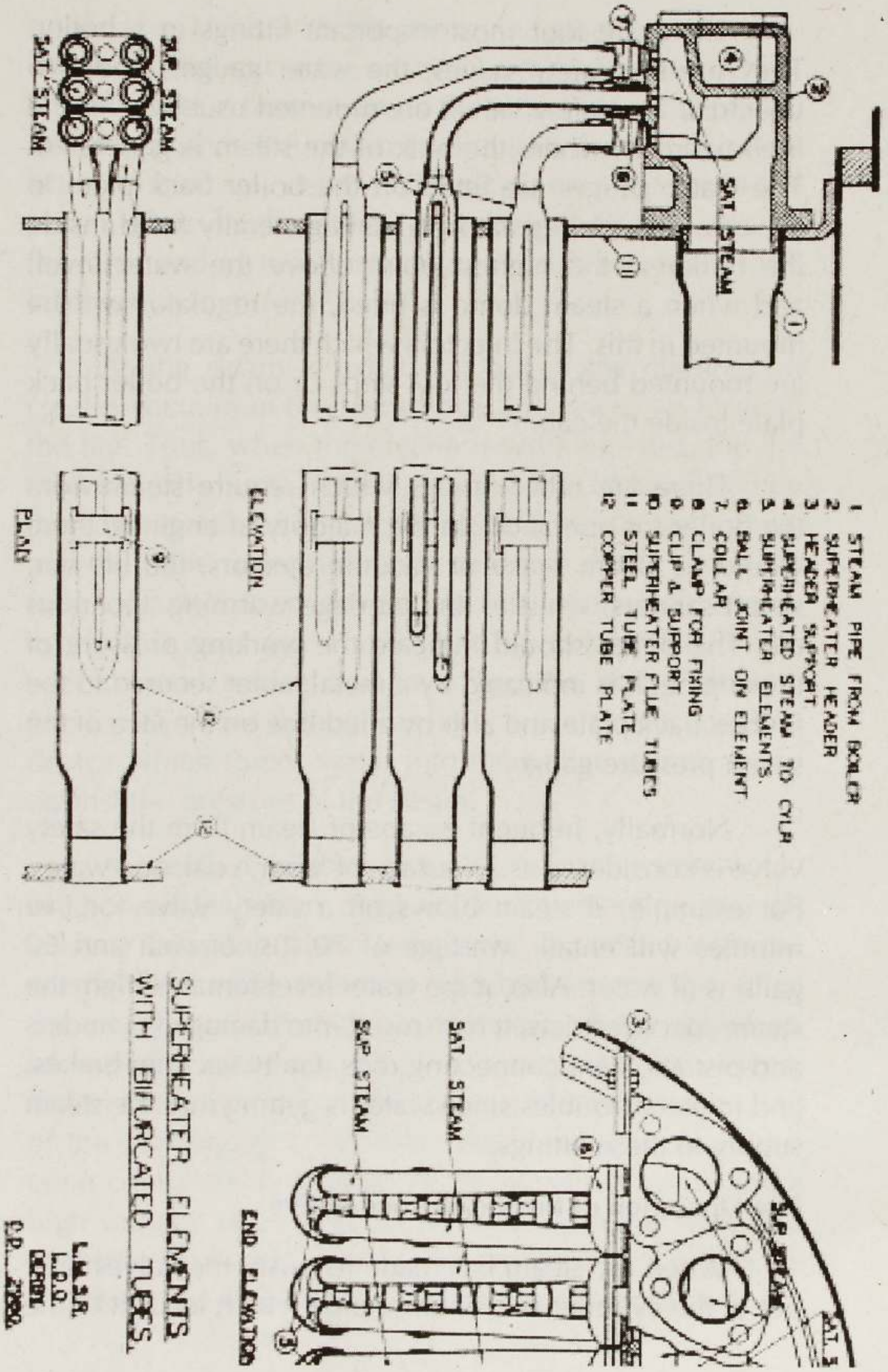


Fig. 23 - *The Superheater arrangement of a Locomotive*

There are four most important fittings in a boiler. They are the safety valves, the water gauges, and two injectors. The safety valves are mounted usually over the firebox crown where the bulk of the steam is generated. The water gauges are fitted on the boiler back plate in the cab, and the regulator valve is generally fitted inside the boiler at the highest point above the water level, and when a steam dome is fitted, the regulator will be mounted in this. The injectors which there are two usually are mounted behind the foot-steps or on the boiler back plate inside the cab.

There are other fittings which require steam from the boiler for operation. In the majority of engines, there would be steam brake or vacuum ejectors, the blower, steam sanders, whistle, and carriage warming apparatus etc. The boiler should indicate the working pressure of the engine. It is indicated by a metal tablet secured to the firebox back plate and also by a red line on the face of the steam pressure gauge.

Normally, frequent escape of steam from the safety valve is considered as a wastage of labor, coal, and water. For example, if steam blows off a safety valve for five minutes will entail wastage of 70 lbs. of coal and 60 gallons of water. Also, if the water level remains high, the steam space restricts, it may result into damaged cylinders and pistons, bent connecting rods, faulty vacuum brakes, and injector troubles since water is getting into the steam supply to these fittings.

The Operation of the Steam Locomotive

When the steam has made its push, the valves let it out of the cylinder into another pipe which leads it to the smoke box. Here, with the smoke and gases from the fire, it is exhausted out of the chimney as a 'puff.' Meanwhile, the valves let in more steam to the other side of the piston, and this pushes the piston back again. So a continuous action is built up, steam pushing first on one side of the piston, then on the other, propelling it backwards and forwards and in turn the driving wheels to revolve and locomotive to move (Fig. 24).

As the steam is exhausted out of the chimney, it creates vacuum in the smoke box and draws air through the fire. Thus, when the engine is working hard, the fire automatically burns fiercely, making a lot of steam. When the engine is eased and steam shut-off, the fire dies down and the boiler does not make so much steam - an early form of automation developed by Robert Stephenson, nearly 150 years ago. The fireman has to keep the firebox well covered with a coal layer and the boiler properly filled with water through an injector, a steam operated device which forces water into the boiler at high speed against the pressure of the steam.

A standard injector (Fig. 25), which is commonly used, operates when a jet of steam emerging at high velocity from the steam is brought in contact with the normal feed water which is admitted around the tip of the steam cone. Partial condensation of the steam jet takes place, a partial vacuum is formed, and the water is drawn forward at a considerable speed into the wide end of the converging combining one. Passage through this cone completes condensation of the steam producing a high vacuum and the water emerges from the small end at greatly increased velocity. The water jet then jumps the overflow gap and enters a diverging cone known as the delivery cone. The shape of the cone causes the speed of flow to be quickly and considerably reduced, which process coverts the energy of motion in the water jet into pressure energy at the outlet end of the delivery cone. The pressure developed in this way at the delivery end of the injector exceeds the boiler pressure sufficiently to enable the feed water to lift the clack against the steam pressure and enter the boiler.

Types of Valve Gear Systems

Another important difference lies between the gears used to operate the valves. The valves are driven by the valve gear which also incorporates an arrangement for regulating the valve travel and for reversing the engine by changing the valve's position on the port face in relation to the piston.

1 PISTON
2 EXHAUST PIPES
3 INLET PIPE
4 VALVES
5 STEAM PORTS
⟸ NEW STEAM
⟵ EXHAUSTED STEAM

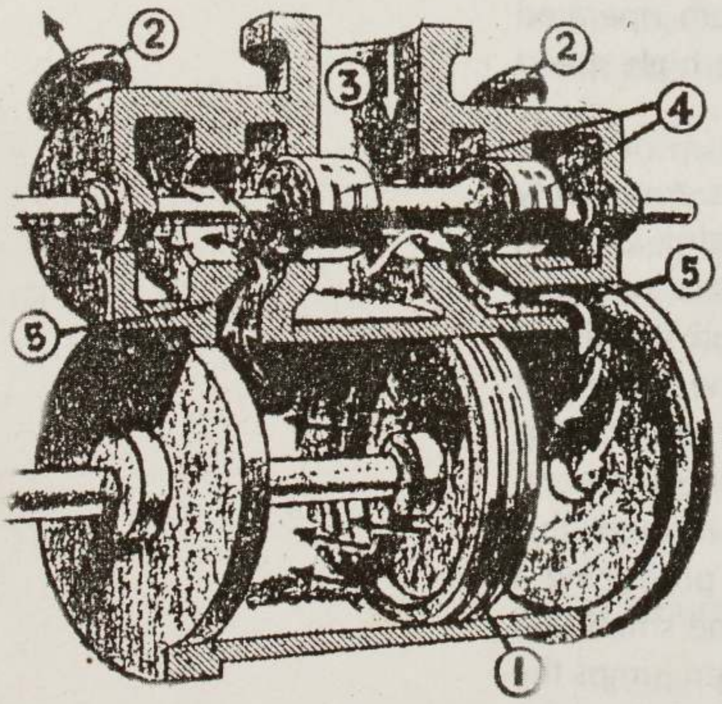


Fig. 24 - *A Standard Piston*

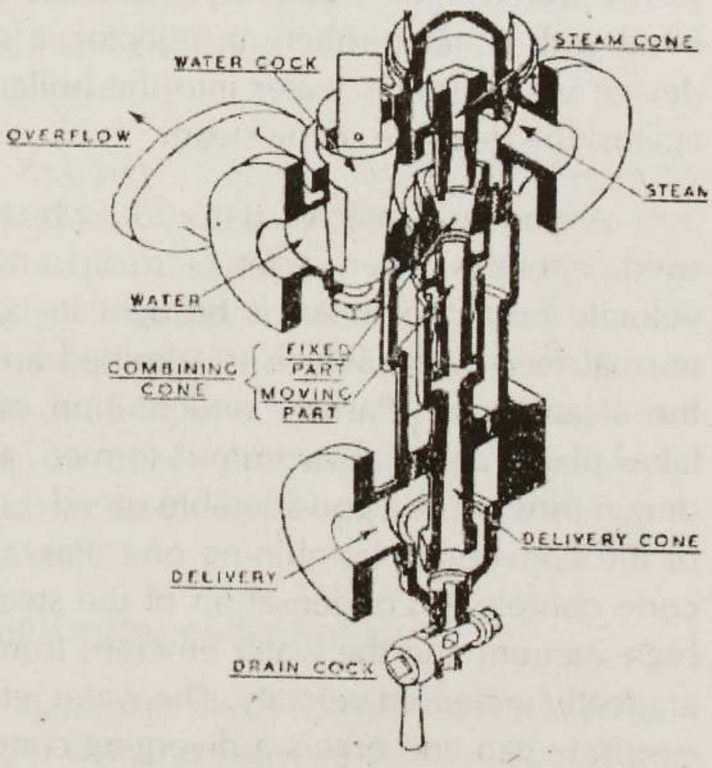


Fig. 25 - *Standard injector*

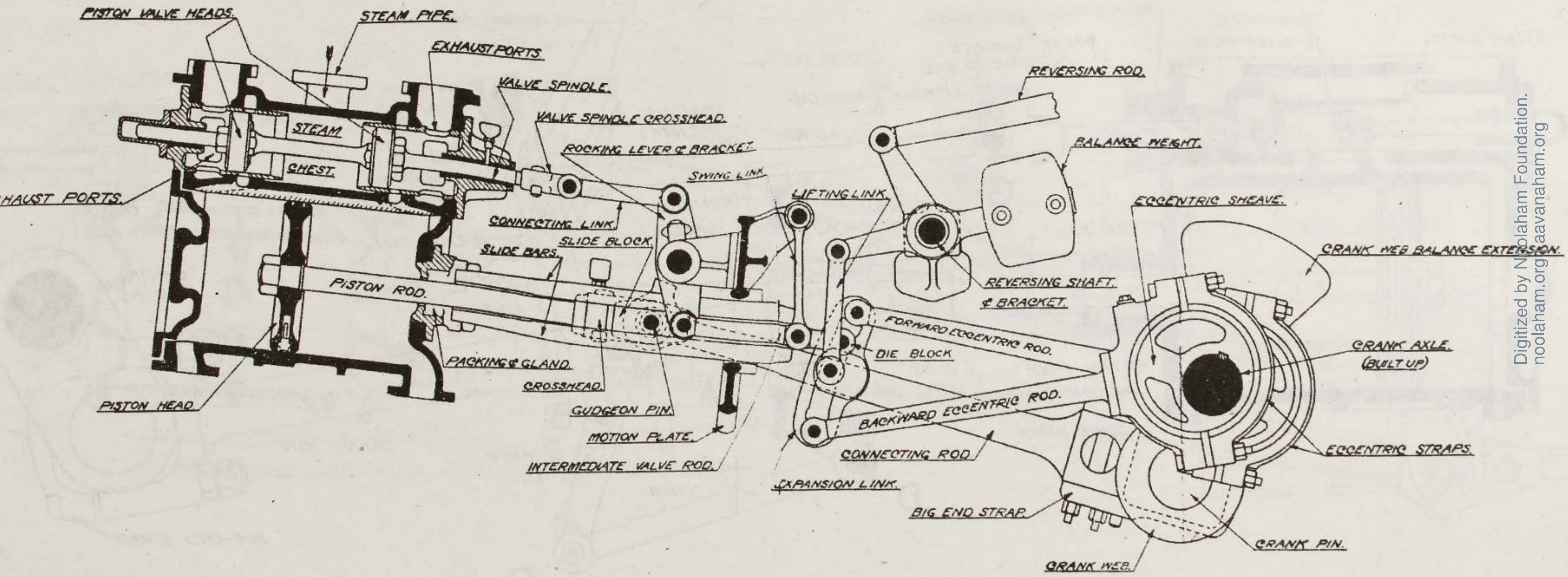


Fig. 26 - *Stephenson's Valve gear*

With rocking lever and inside admission pistion valves

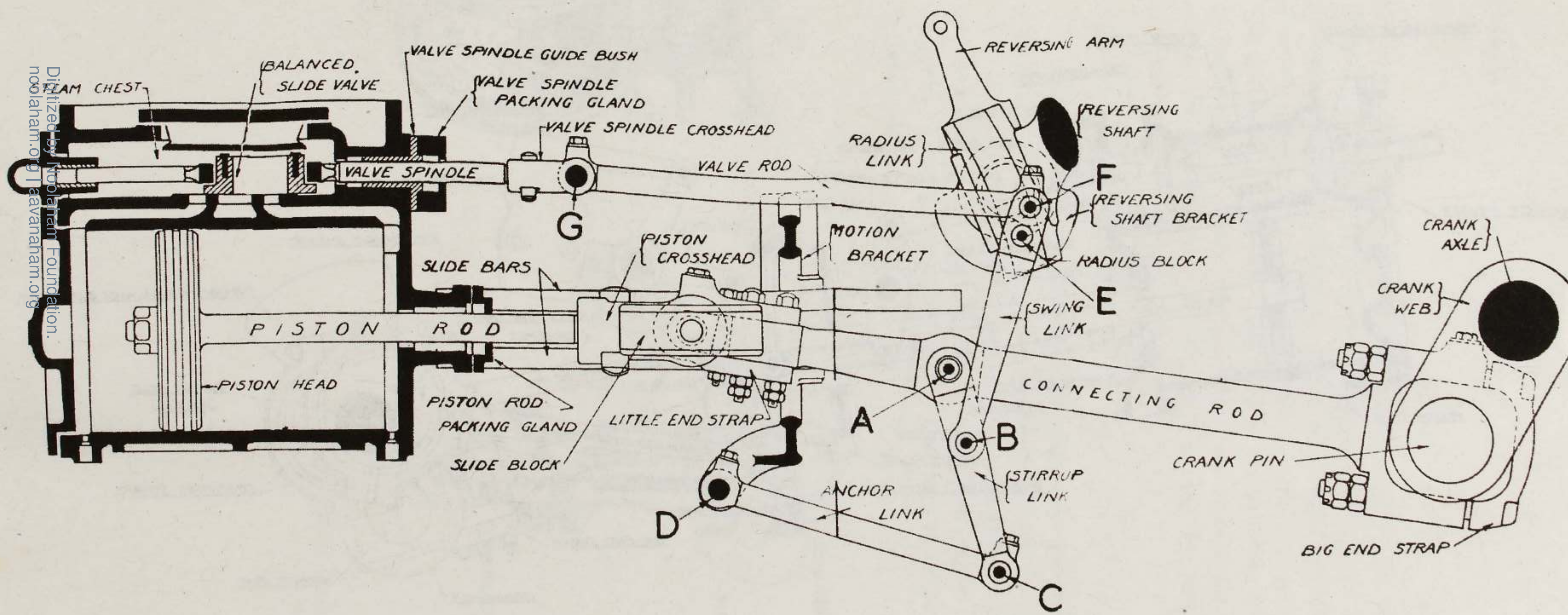


Fig. 27 - *Joy's Valve Gear*

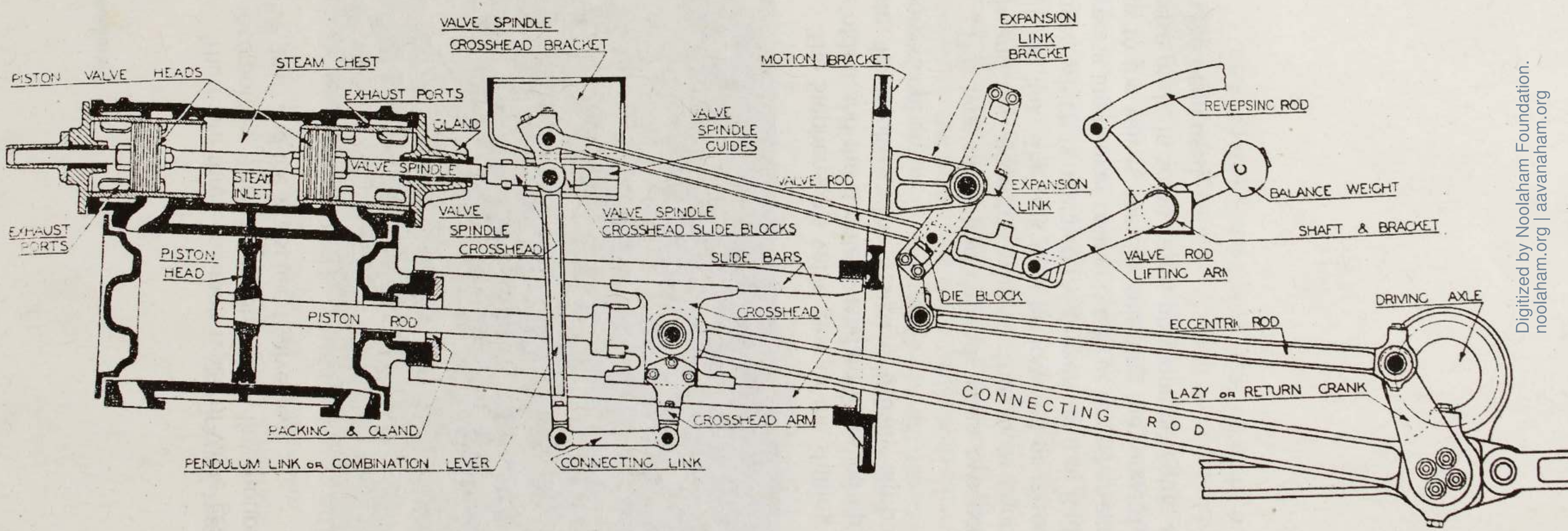


Fig. *28 - Walschart's Valve Gear*

There are three common types of valve gear used in locomotives. They are Stephenson's link motion, Joy's valve gear, and the Walschaert valve gear.

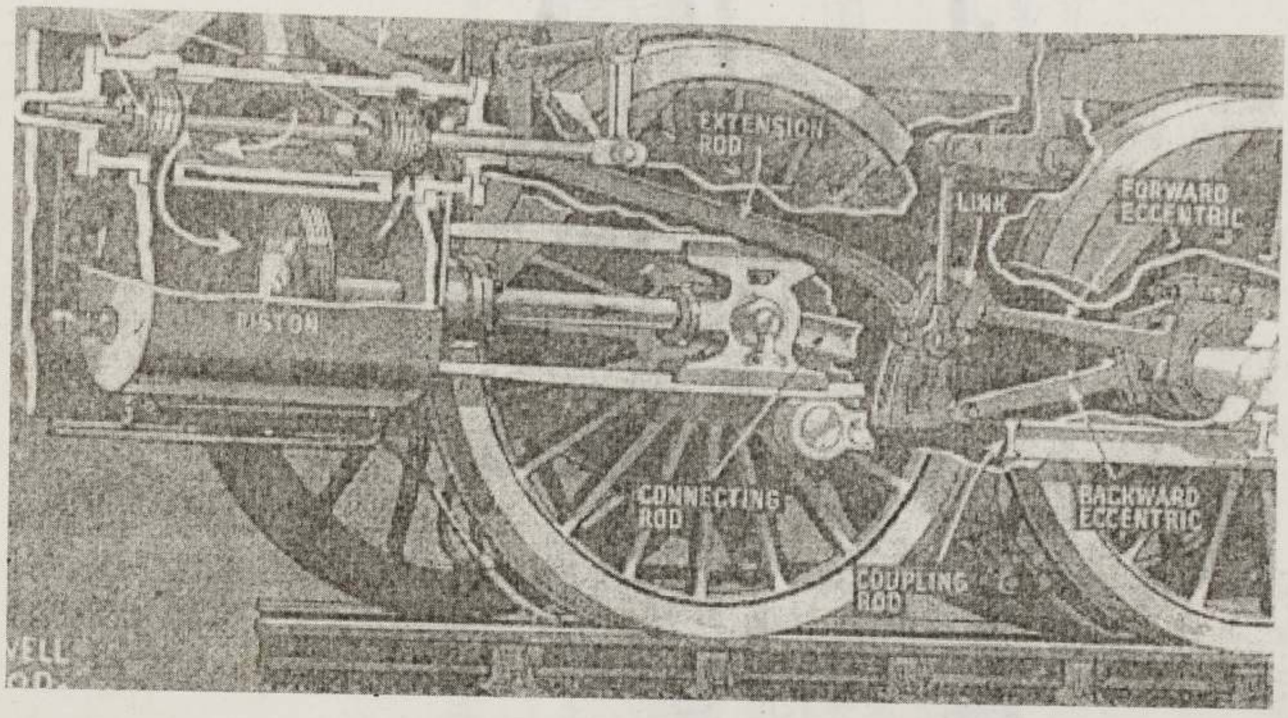


Fig. 29 - *Stephenson's Valve Gear*

The Stephenson's valve gear or the shifting link is the oldest and the simplest standard followed up in old steam locomotives. The design is usually attributed to George Stephenson.

This type of motion depends upon two eccentric rods and two eccentric wheels. They both connect to a sliding link. The link may be lowered or raised by a hanger, which is operated by a reversing rod. Raising or lowering the hanger connects one or the other eccentric arms to the valves, thereby selecting the forward or the reverse push. In some cases, only one eccentric and an arm has been used.

Walschaert Valve Gear

Walschaerts valve gear was invented by Belgium railway mechanical engineer Egide Walschaerts in 1844. The gear is thereafter patented by his name. It is extensively used for steam locomotives since 1844 until end of the steam era. Most of the Sri Lankan locomotives had the Walschaert valve system.

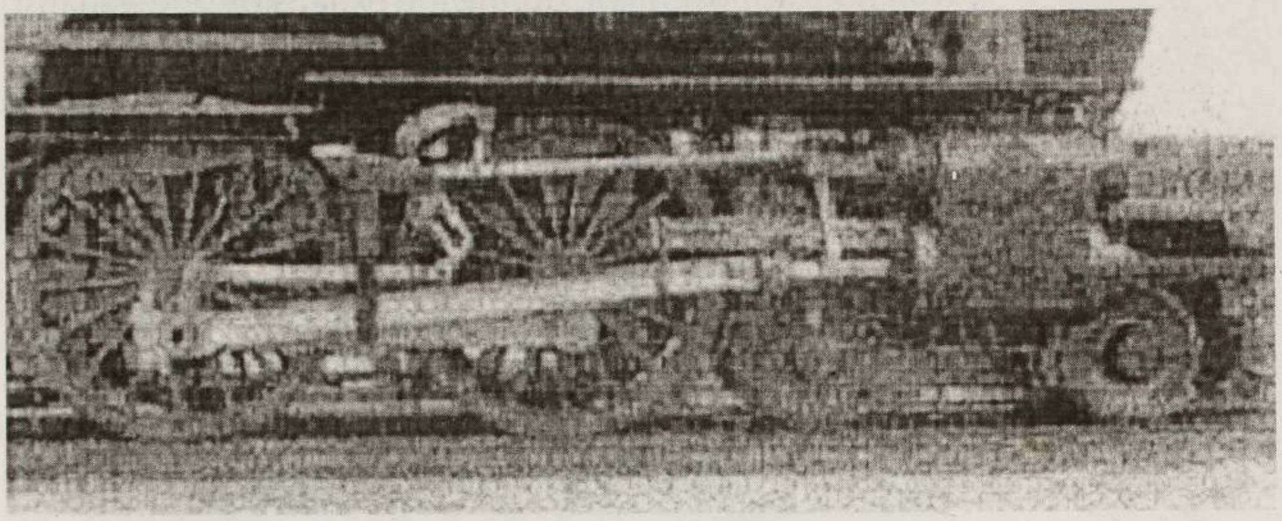


Fig. 30 - *Walschaert Valve Gear*

The gear had the advantage that it could be mounted entirely on the outside of the locomotive. Thus it gave space between the wheels and the frames. In this motion, valve travel is derived from two separate points. Movement amounting to twice the lap and twice the lead is obtained from the piston cross head, giving a constant lead for all positions of the gear, and the remainder of the valve travel, amounting to twice the port opening, is obtained from the eccentric or return crank by the way of the eccentric rod, expansion link, die block, and valve rod. These two movements are added together, at the valve spindle pin in the combining lever, thereby producing the total travel of the valve when the lever is in the full gear position.

Joy Valve Gear

Joy valve gear is patented in 1870 and was designed by David Joy, a locomotive and a marine engineer. This type of valve gear employs no eccentrics. This gear provides a constant lead in all positions of the lever, and it has also a good feature where the valve is given a rapid movement when opening and closing the ports, coupled with a slow movement, during the expansion and exhaust periods.

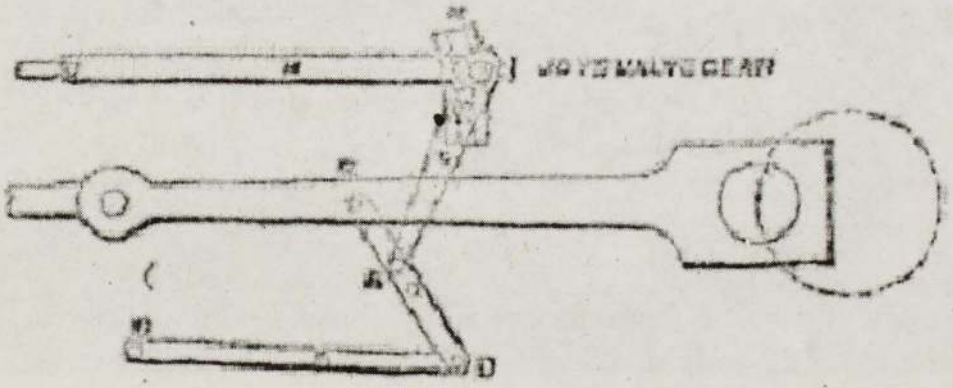


Fig. 31 - *Joy Valve Gear*

What is an eccentric?

An eccentric is form of an auxiliary crank frequently used in valve gears to obtain reciprocating or to or fro movement for the valves from the crank axle or other rotating part. It consists of a circular disc called 'sheave' which is securely fixed to the axle so that it will rotate with it.

The center of the sheave does not coincide with the centre of the axle, and the distance separating the sheave center from the axle center called the 'throw' of the eccentric, in exactly the same way as the distance between the crank pin center and the axle center is the 'throw' of an ordinary crank. The 'throw' of the sheave causes it to describe a circular path about the axle center, and consequently the eccentric strap, which encircles the sheave and works upon its outer surface, as also forced to follow the same circular path, producing the back and forward movement at the front of the eccentric rod which is bolted to the strap.

Valve types; From the valves used in the locomotives, there are again three types. They the 'Slide' valve system, 'Piston' valve, and the 'Poppet' valve system. Each type has its particular advantages. First in the field is the slide valve which is used widely. It is a system, where the valve shuts and opens by sliding.

Under the piston valve system, being used for high pressures is considered as somewhat a superior valve. It has less friction than the slide valve.

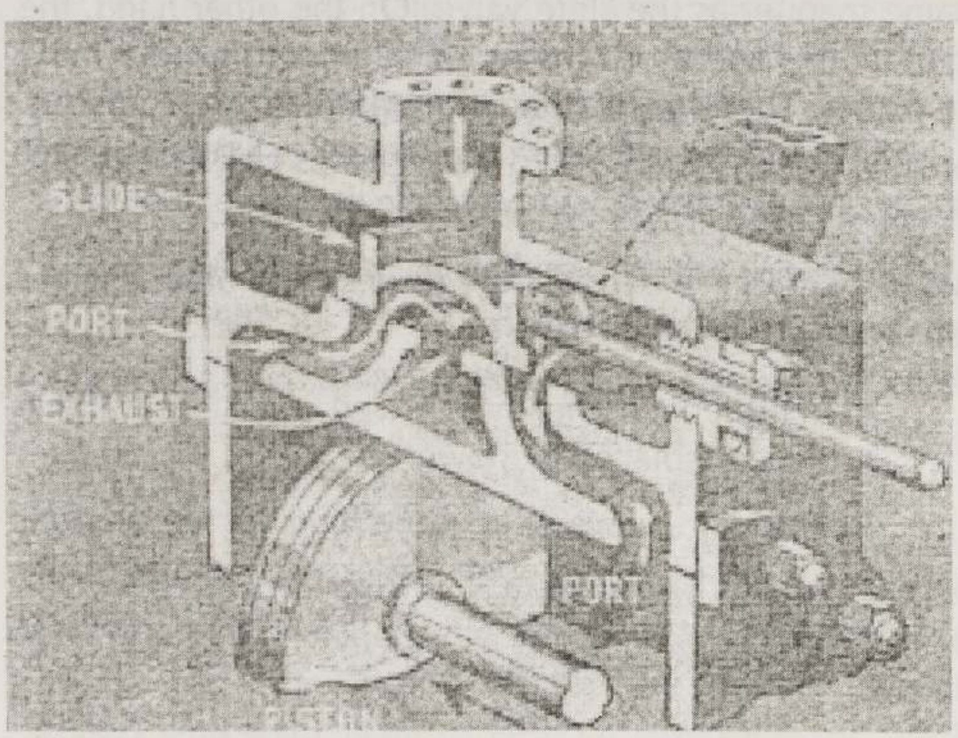
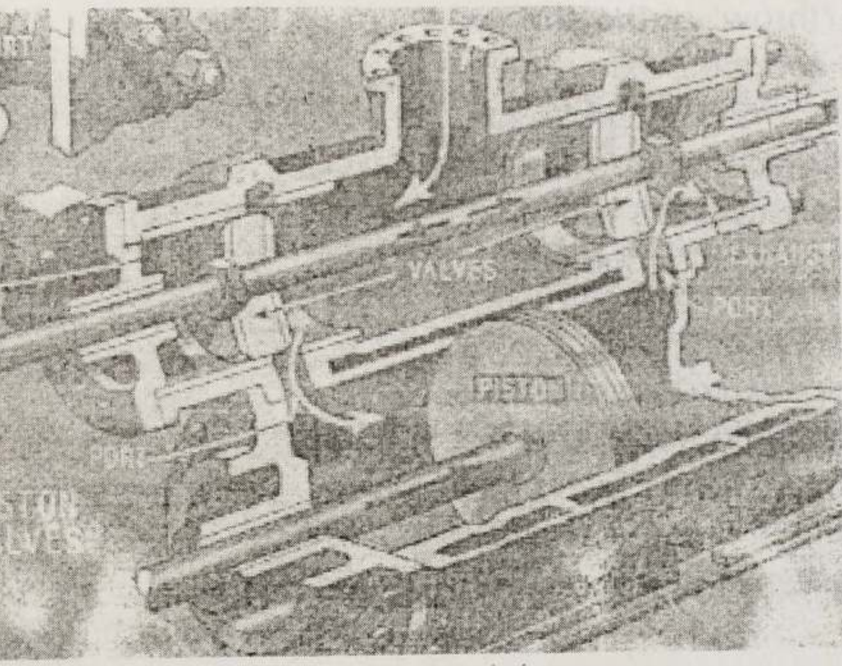


Fig. 32 - *The Slide Valve System*



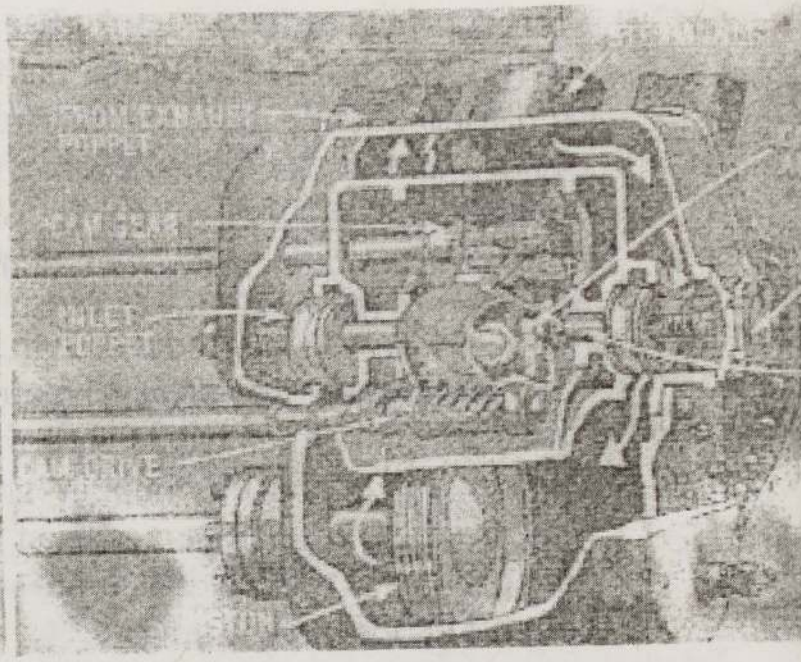


Fig. 33 - *Piston Valve System*

Fig. 34 - *Poppet Valve System*

The piston valve as the name suggests, is a form of piston working in a smaller cylinder alongside the driving cylinder, uncovering the inlet and outlet ports in much the same manner as the slide valve. On the other hand, the poppet lifts and drops instead of sliding. It is more rapid in action. The usual method of working is by a camshaft. Usually the valve is fitted in shunt engines than passenger trains. It is claimed by many to take the pride of place.

What's difference between the modern and older engines the latter produced in 1830s?

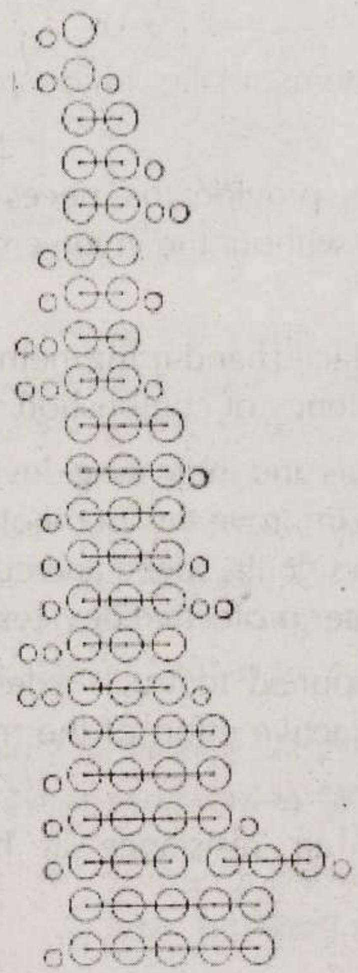
- Formerly, manually operated reverse gears have been replaced by power gears.
- Modern valve gear limits cut off the amount of steam to cylinders to take advantage of the expensive properties of the steam, resulting operating economies.

- Roller bearings on the journals and the moving parts decrease frictional drag and resistance.
- Cross counter balancing of the driving wheels allow higher operating speeds.
- Integrally cast steel engine beds, including main cylinders, main frames, crossties, and bumpers in one piece, replaced the old-style bolted bar frames.
- Efficient air-brake systems make high speed operations safer.
- Mechanical lubricators provide the necessary continuous lubrication without the involvement of hands.
- Mechanical stokers replaced hand-firing methods and improved the efficiency of combustion.
- Many automatic controls and indicating devices have been perfected to improve the locomotive, such as continuous cab signals, speed and cutoff indicators, and low water protective devices.
- Booster engines are applied to truck axles to augment the starting tractive effort of the main engine.
- Streamlining reduced air resistance at high speeds.

The Wheel Arrangement

The arrangement and size of the wheels govern the work of any particular type of engine is expected to do. For high speeds on fast passenger services, driving wheels with a diameter as great as seven feet are used, whereas on the hard pulling freight engines the wheels may be well under five feet. Between the two, are the mixed freight or passenger types, with a fair speed yet good tractive power.

STEAM



Front *Rear*	*Notation*	*Name of type*
	2–2–0	Planet
	2–2–2	Jenny Lind
	0–4–0	
	0–4–2	
	0–4–4	
	2–4–0	
	2–4–2	Columbia
	4–4–0	American
	4–4–2	Atlantic
	0–6–0	
	0–6–2	
	2–6–0	Mogul
	2–6–2	Prairie
	2–6–4	Adriatic
	4–6–0	
	4–6–2	Pacific
	0–8–0	
	2–8–0	Consolidation
	2–8–2	Mikado
	2–6–6–2	Garratt
	0–10–0	Decapod
	2–10–0	

The wheels are coupled together to increase the grip of the engine on the rails. The simplest arrangement is the 0-4-0, which represents no carrying wheels front or behind but the presence of two pairs of driving wheels. Under 0-6-

6-2 wheel arrangement, it has one pair of carrying wheels in front, six driving wheel pairs and no carrying wheel pair behind. So distinct from driving wheels, carrying wheels are used to spread the weight of the locomotives over the track. A higher arrangement helps to have a good weight distribution, a higher grip on the rails (because of driving wheels), and perfect movement on the curves without the risk of a derailment.

Duties Performed by the Engine Driver and the Assistant (Fireman)

Generally, a steam locomotive is operated by two personnel namely the loco driver and his assistant apart from the personnel employed in the shed.

The Driver; After reaching the engine, the driver will see the gauge frames tested, and satisfy himself that the head plugs and tubes are tight. At the same time, he looks at the condition of the fire and the steam pressure. He then tests the injectors, vacuum brakes, and sanding gear. If any defects are disclosed then, he can have them attended to and avoid a late start.

Before leaving the shed, he needs to check the water scoop and oiled, and take care to see that the scoop is on the 'Up' position to avoid any damage being done when the engine is moved, and he must satisfy himself that the coal and fire-irons are properly and safely stored on the tender.

The Assistant or Fireman; Towards the end of a run, the fire must be leveled in the fire-box, and worked down as low as possible to avoid coming to the shed with a large amount of unburned coal on the grate. Experience will say about the best time to commence working down the fire, but the aim should be to run on to the shed with the fire as low as possible.

Arriving at the shed, first duties will be to obtain coal and water before proceeding on to the ashpit. At the ashpit, he will empty the smoke box and clean or lift out the fire according to the instructions received. While he is performing these duties, the driver will be examining the engine. The fireman must see quick clearing of ashes and after which all dampers and the firehole doors are tightly closed. Then, before leaving the engine inside the shed, he must see that the boiler be filled to a height of three-quarters of gauge glass.

The end of steam era

During the Second World War and the years immediately after, it was felt to replace the steam with diesel powered or directly electrified locomotives. There are many reasons for this change to happen in Britain.

- The firemen became in short supply and it became difficult to train the youngsters for this back breaking job which also dirty the clothes.
- Coal of suitable quality became difficult to obtain and was expensive.
- The water intake methods were too cumbersome and required building up a huge pump with a rubber hose and a high rising overhead water tank nearby or a long trench between the rails containing water, so that when the engine

is on the run it could lower down a pipe to suck water into the tender tank. Both methods were costly and needs to be available at fair distances. Hence, the capital cost in running steam locomotives was very high compared with diesel and hydraulic engines.

- In terms of energy power, the diesel and electrified engines could generate a higher level of energy power in proportion to the fuel content consumed and expenditure involved.

- A steam engine required two people on the engine and support services for daily maintenance and overhauling. The daily cleaning process and firing were cumbersome.

- The steam engine lacked personal comforts for the crew relative to the diesel and electrified engines. Most usually, they had to operate in a warm environment and exposed to weather elements.

- If the engine is on the reverse run, the crew has to suffer from ill effects of the weather elements as the cab is not being covered.

- The control systems of the newer diesel engines were not manual and they became easy to operate as they worked on electricity.

- The steam engine was not environmentally friendly as like electrified and diesel engines.

- The passengers too have to suffer from the effects of exhausting smoke levels from the chimney of a steam locomotive which billows out soot and ash particles that makes it so difficult to breathe and mostly gets into their eyes and also dirties their clothes.

So, 1950s was the starting era to the end of steam in all the countries, yet people respect the steam engine as the man's greatest invention. Hence, many countries still use the steam passenger train in a limited way to attract enthusiasts and tourists.

Chapter 4

Terminologies on Steam Locomotive Components

The components that are numbered in the figures 35 and 36 in page 50 are explained below;

1. **Boiler-**It is a water container which is heated by hot gases passed through long tubes, thereby producing steam. These tubes have to be cleaned from time to time to get rid of the accumulated soot. The smokebox door at the front of the locomotive allows the fireman to have access for cleaning the tubes since more steam is demanded by the locomotive for its operation; a boiler typically has a very high heating surface owing to the length of the tubes.

2. **Firebox**- A box like furnace chamber that is built into the boiler and usually surrounded by water to contain the fire that is used to heat the boiler. While early locomotives used firewood as fuel, later engines used coal or oil as the fuel. With each change in fuel, different types of fireboxes have been built including the Wootten, which is very wide and shallow to

Fig. 35

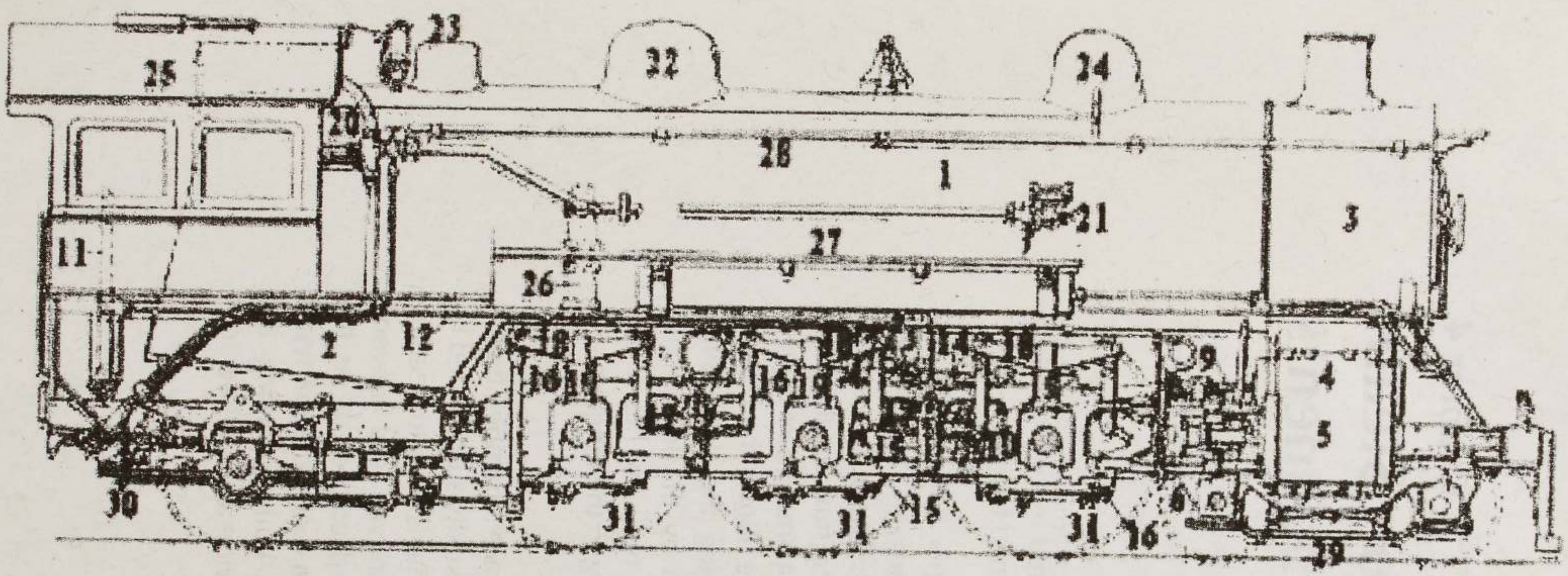

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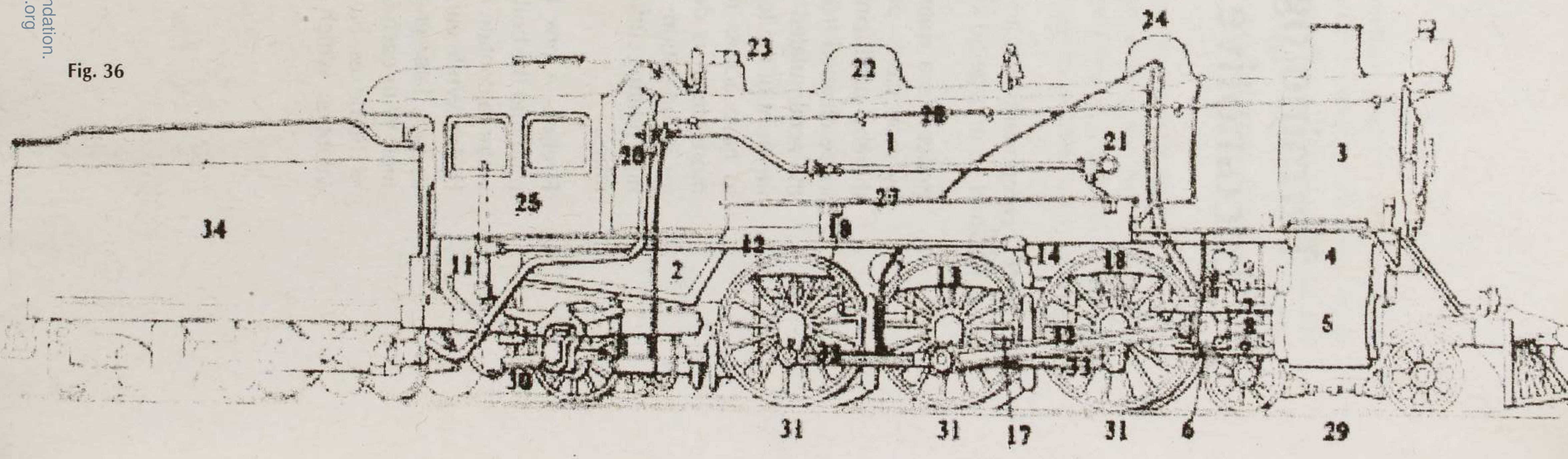
Fig. 36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burn poor grade of coal, the Belpaire, and has a flat crown sheet and deep legs surrounded by water jackets. The Belpaire type was used exclusively in British locomotives (Sri Lankan too) and in machines built by the Pennsylvanian Rialways.

3. **Smokebox-** It is the drum in front of the boiler. Within it the exhaust nozzle or blast pipe creates a partial vacuum effect, to draw the exhaust gases through the boiler tubes. When the locomotive is not working, steam can be fed to a ring of steam jets (the blower) around the exhaust nozzle (blast pipe) which produces an inflow of air to the firebox.

4. **Valve chest**- A small chamber (sometimes cylindrical) above or to the side of the main cylinder containing passage ways used by the valves to distribute live steam to the cylinders.

5. **Cylinder**- A hollow device that converts steam energy into mechanical energy through the operation of pistons.

6. **Cross head** - A sliding bearing which guides and supports the end of the piston rod and provides a connection of the rod to the main rod. (small end) (Fig. 37)

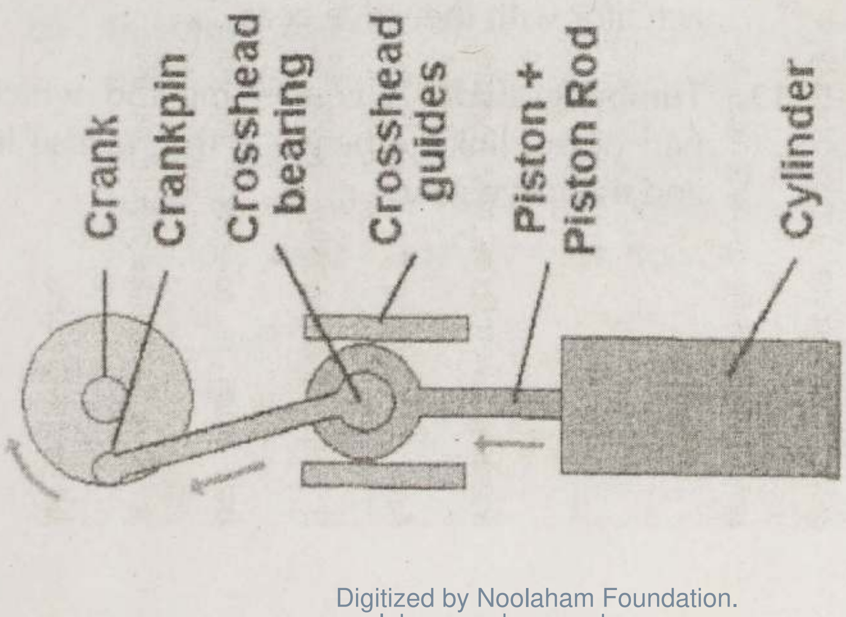


Fig. 37 - *What is corss head about*

It is the one where the piston rod links, so that piston rod movement is guided in a crosshead guide. This allows the link or the crosshead bearing to move in the crosshead guide in the same direction as the piston travels. A crosshead is essential to a steam engine since much force generated by steam would cause an intolerable degree of wear on the piston and the cylinder, as well as increasing overall friction in the engine. The crosshead is also connected to the rotating crank *via* the connecting rod. In this way, the transverse forces are applied only to the crosshead and its bearings, not to the piston itself.

7. **Cross head guides**- These guide the cross head and take the thrust produced from the reciprocating piston to rotary motion. Also known as slide bars.

8. **Piston rod**- A rod that connects the piston in the cylinder to the cross head axle.

9. **Valve stem**- A rod attached to the valve for moving during the engine operation.

10. **Link**- It is the linking rod between two driving wheels.

11. **Reverse lever** - A lever within the cab that controls the direction of travel and the timing of the valve.

12. **Reach rod**- It is the rod that links the reversing actuator with the valve gear.

13. **Tumbling shaft**- A connecting rod which is part of the linkage between the reverse lever and the valve gear.

14. **Rocker arm**- A link which connects the tumbling shaft to the reach rod.

15. **Eccentric rod**- Part of the valve gear.

16. **Frame** - The steel beams around which the locomotive is built. The wheels run in slots within the frames and the cab, firebox, boiler, and smokebox are mounted on top of them. Frame can be plate frames (cut from steel plate) or bar frames (fabricated from steel bars or one piece of steel casting including the cylinders).

17, **Equalizing levers or bars** - This is a lever free to pivot about its center which is firmly affixed to the locomotive frame. The free ends of the lever are connected to the leaf springs associated with each wheel.

18. **Springs**- A built up leaf spring is located typically above, and sometimes below each drive wheel. These are connected at their middle to the journal box of the axle they are centered with. The ends of these springs connect to the locomotive frames either through a hanger, or through an equalizing lever or bar.

19. **Pedestal**- Also referred to as a saddle. It is a link which connects the clamp at the center of the springs to the bearing journal.

20. **Injector**- Steam driven vacuum pumps used to inject water into boiler under pressure.

21. **Boiler check valve**- A check valve at the point where water enters the boiler from the injectors; used to prevent back flow.

22. **Steam dome**- An expansion at top of the boiler to show space for the heated steam to collect. The throttle valve for the locomotive is located here.

23. **Auxiliary steam dome**- A collection point for steam used to power the locomotive appliances such as the generator turbine, air compressor pumps, and steam lubricators. On many locomotives, a steam manifold serves the same purpose and is mounted within the cab.

24. **Sand box**- A container for holding sand used to improve traction especially on wet or icy rails.

25. **Cab**- A compartment from which the driver and the fireman can look after the controls of the engine.

26. **Air pump**- A pump to provide air pressure for operating the breaks.

27. **Foot board**- A walkway along the locomotive to facilitate inspection and maintenance.

28. **Hand rail**- A railing above the foot board used for support walking along the foot board.

29. **Pilot track***- Wheels at the front that help to guide the locomotive. Some do not have it.

30. **Trailing truck***- Wheels at the rear of the locomotive to help support the weight of the cab and the firebox.

31. **Drivers***- The wheels that deliver locomotive power to the rails. The drivers are weighed so that the center of gravity of the drivers and rods coincide with the center of rotation.

32. **Main rod**- A steel arm that converts the horizontal motion of the piston into a rotation motion of a driver. Also referred to as the connecting rod.

33. **Site rods**- Also referred to as coupling rods.

34. **Tender**- A carrier that holds water and fuel for the locomotive.

* Locomotives are classified by the number of wheels on the pilot truck, number of driving wheels, followed by the number of wheels on the trailing truck. Thus the locomotive illustrated in figure 36 in page 50 would be classified as a 4-6-2 locomotive. This system is known as the Whyte notation.

Additional Components of a Locomotive;

1. **Air hose**- A hose for supplying air pressure to release the brakes on the rail cars. A hose is located next to the front and rear couplers.

2. **Backhead**- The firebox wall in the cab used for mounting the locomotive controls.

3. **Bell**- A bell may be located on top of the boiler for signaling.

4. **Coupler**- A device at the front and back for connecting with the rail cars or locomotives.

5. **Pilot**- Also known as the cow catcher. A protective guard at the front and sometimes at the rear to push aside obstructions.

6. **Feedwater heater**- An optional routing of the feedwater piping below the smoke box to heat the water before it enters the boiler.

7. **Firebox door**- The door to the firebox in the cab to allow access for shoveling coal and lighting the fire.

8. **Gauges**- Air pressure gauge and a water level gauge located in the cab.

9. **Headlight**- A lamp fixed on the smoke box to provide visibility.

10. **Smoke stack**- A short chimney on the smoke box to carry away the smoke. Usually extended down inside the smoke box.

11. **Whistle**- A steam whistle located on top of the boiler as signaling and warning device.

12. **Valve gear**- A system of rods and other linkages that synchronize the valves with the pistons and controls the direction and power output of the locomotive. The illustrated engines in figures 35 and 36 have inside connected Stephenson valve gear, although most parts are not visible in the illustrations.

13. **Ejector**- A device working on the venturi principle to create vacuum on vacuum braked trains.

14. **Vacuum pump**- A pump, often worked via a connection to a cross head, to maintain vacuum.

15. **Vacuum hose**- A hose for supplying vacuum to release the brakes on the carriages. A vacuum hose is located adjacent to the front and rear couplers.

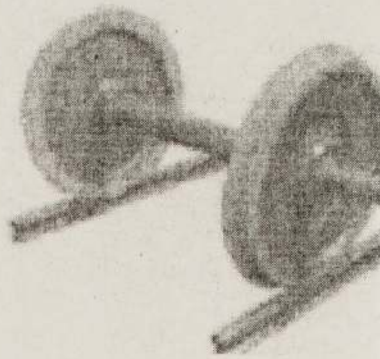


Fig. 36 - *An axle*

Other words but not illustrated

1. **Axle**- An axle is a central shaft for a rotating wheel or a gear. The axle maintains the position of the wheels relative to each other and to the vehicle body.

2. **Ballast**- It is the gravel or broken stone laid down as a railroad bed.

3. **Bogie**- It is a structure underneath a train to which wheel axles are attached through bearings. Most bogies have two axles (Fig. 39).

4. **Blast pipe**; The blastpipe is a part of the steam engine that discharges exhaust steam from the cylinders to the smokebox beneath the chimney in order to increase the draught of the fire.

Fig. 39 - *A bogie*

5. **Combustion (chamber)**; This chamber is a part of the engine in which fuel is burnt. The leftover

hot gases produced by this combustion tend to occupy a far greater volume than the original fuel, thus creating an increase in pressure within the limited volume of the chamber. This pressure can be used to do work, for example, to move a piston or a crankshaft.

6. **Crank**; It is a device, as a handle attached at right angles to a shaft, for transmitting motion into rotary motion, or *vice versa*.

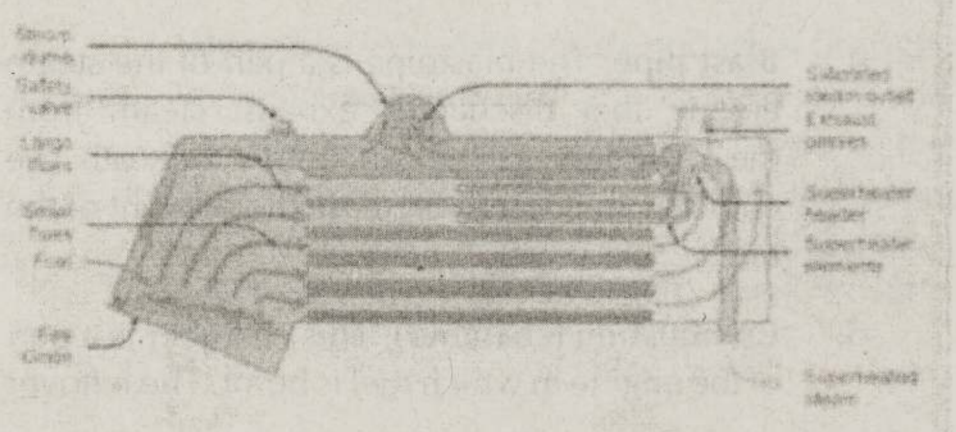
7. **Clinker**; It is the stone like residue left by coal burning.

8. **Dome**; Dome is the site of the regulator that controls the exit of steam from the boiler. It is where steam rises to the highest point separating boiled water and steam.

9. **Fire-tube boiler**

   It is a boiler type in which hot gases from the fire pass through one or more tubes within the boiler. It can be horizontal or vertical. It is sometimes called a smoke tube boiler.

Fig. 40 - *Fire-tube boiler*



10. **Safety valve**- It is a valve which release steam before a dangerous pressure can be built up.

11. **Stays**; Stays or ties, physically link the firebox and boiler casing, preventing them warp.

12. **Super heater**; A superheater is a device in a steam engine that heats the steam generated by the boiler again, increasing its thermal energy and decreasing the likelihood that it will condense inside the engine. Steam that has been superheated is known as superheated steam; non-superheated steam is called saturated steam or wet steam.

    Locomotives fitted with a super heater will usually have a super heater header in the smoke box. Steam enters the header as "wet" (saturated) steam, and then passes through a superheater element. This takes the form of a pipe which runs twice through enlarged smoke tube in the boiler. The steam enters a special chamber in the header, this time as superheated or dry steam. The advantage of superheating is that the steam has greater expensive properties when entering the cylinders, so more power can be gained from a small amount of water.

Chapter 5

Illustrations

The Inner Structure of a Steam Locomotive

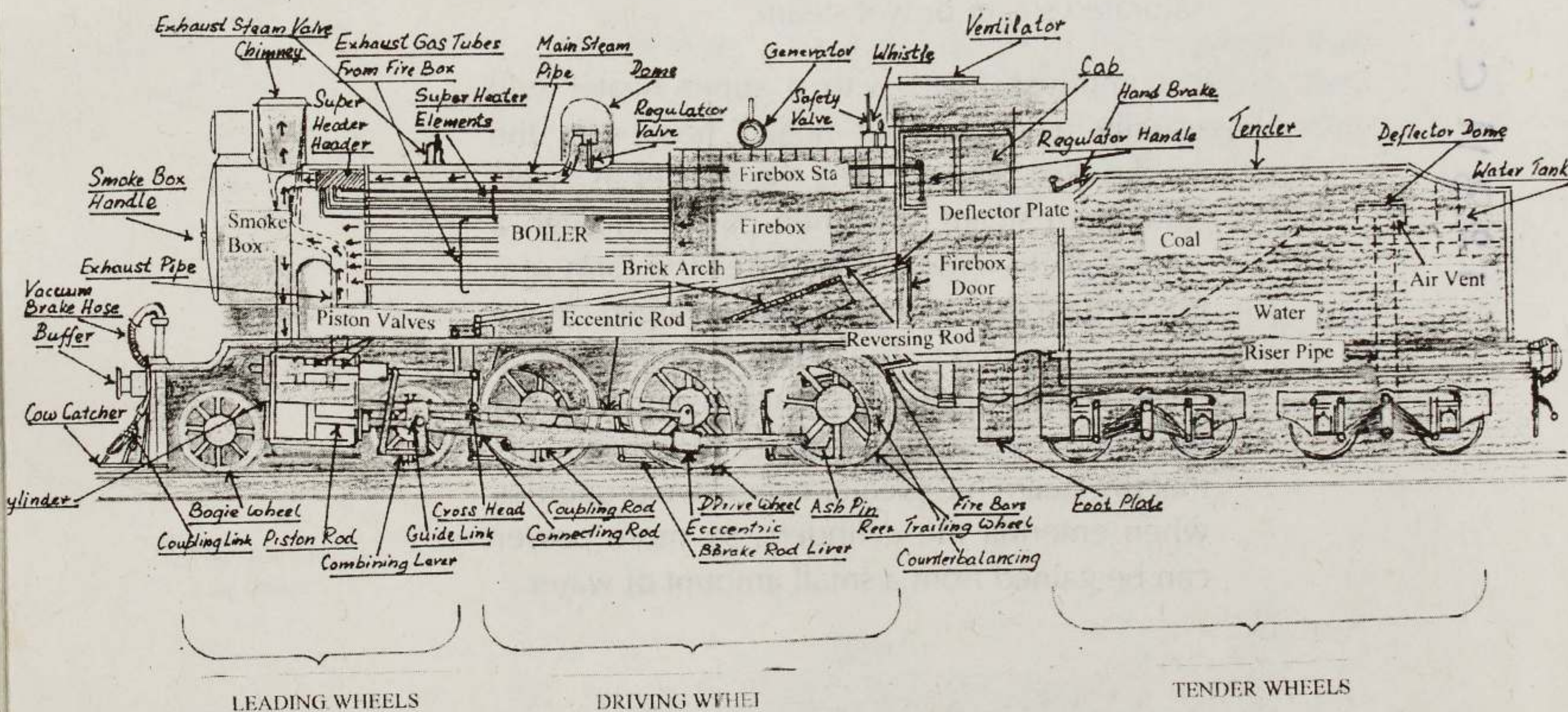


Illustration 3

Drawn by the writer

This is a pencil drawing of the steam locomotive No.262 Class B1, 4-6-0. Introduced in 1928 and after the coronation in 1937, it was named as 'King George VI.' The builder was Beyer Peacock Ltd. G.B. It could hold 8 tons of coal and 3300 gallons of water. Total length is 59' approximately. The engine was used mainly for upcountry running. The shape of engine is highly unique to Sri Lanka. It was ultimately scrapped in 1963.

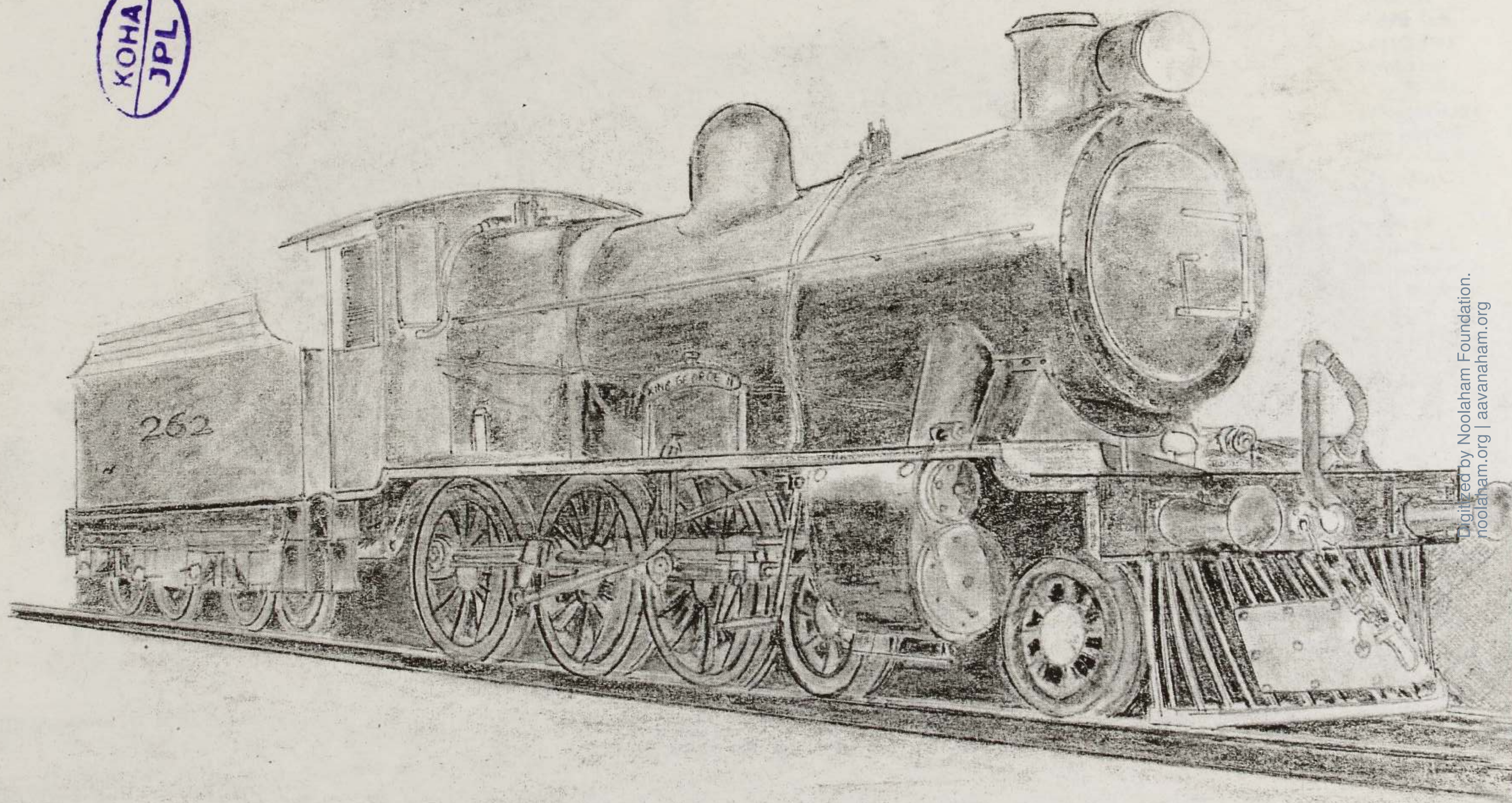
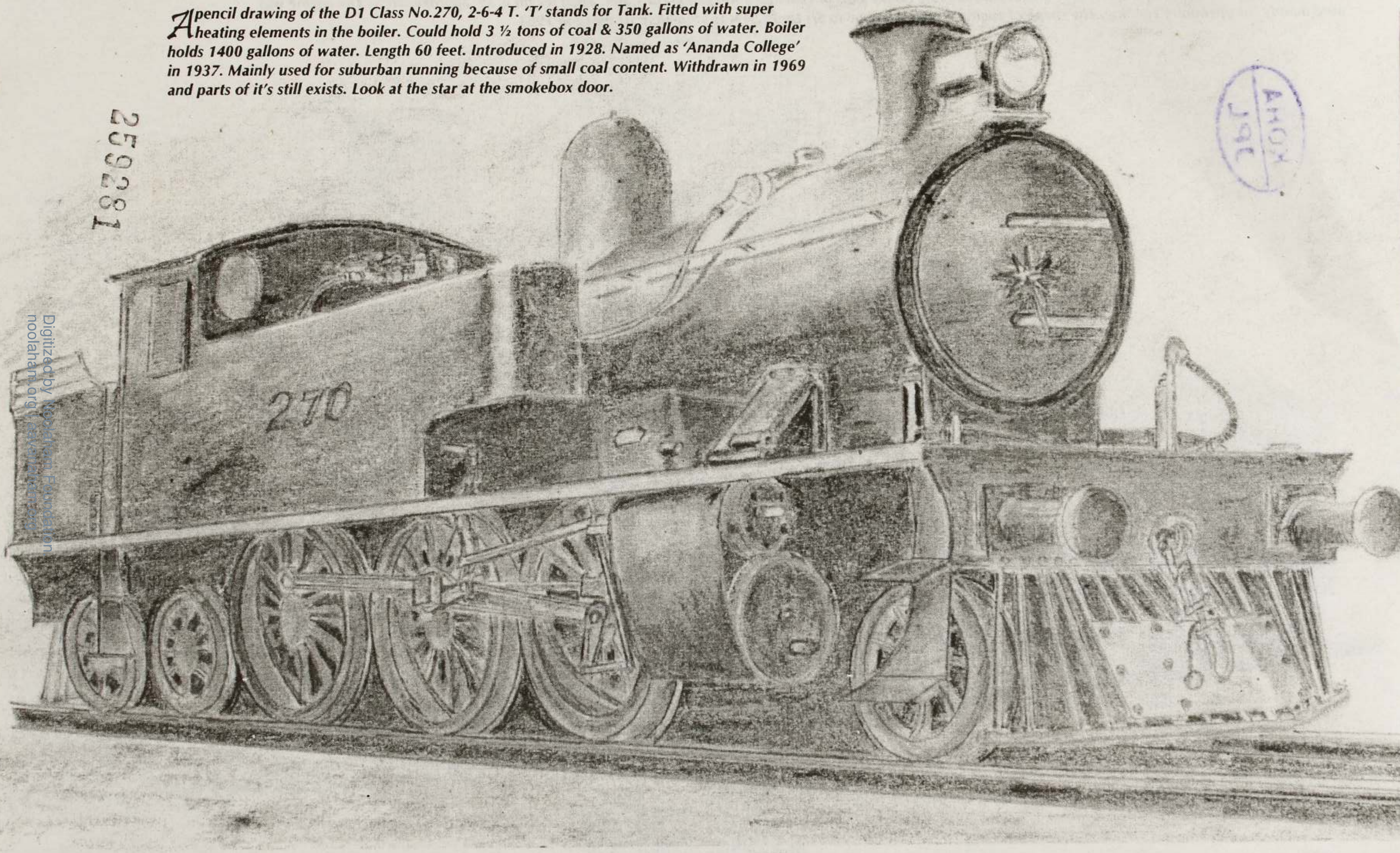


Illustration 5

***A** pencil drawing of the D1 Class No.270, 2-6-4 T. 'T' stands for Tank. Fitted with super heating elements in the boiler. Could hold 3 ½ tons of coal & 350 gallons of water. Boiler holds 1400 gallons of water. Length 60 feet. Introduced in 1928. Named as 'Ananda College' in 1937. Mainly used for suburban running because of small coal content. Withdrawn in 1969 and parts of it's still exists. Look at the star at the smokebox door.*



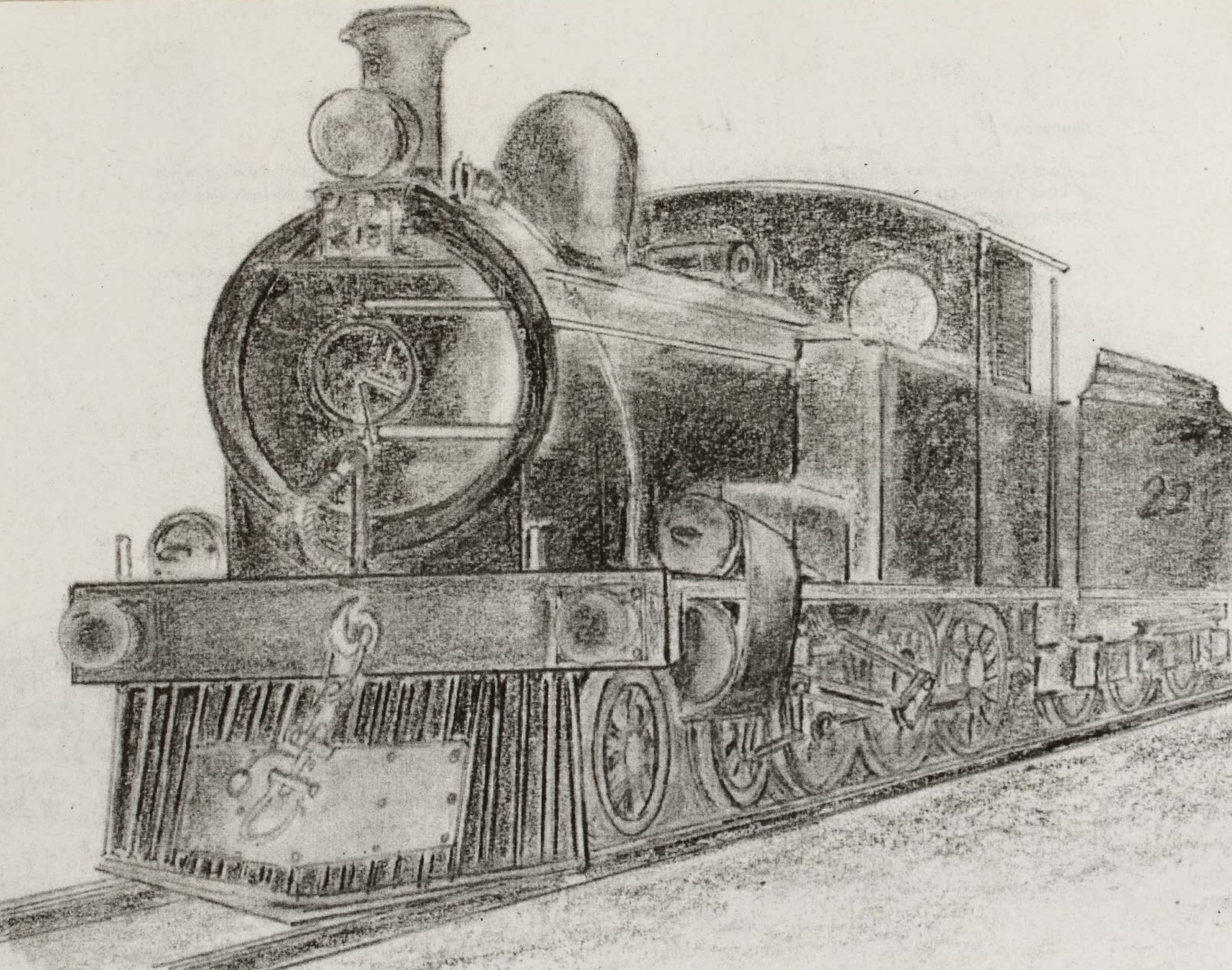


Illustration 6

A pencil drawing of the B3 Class No.22, 4-6-0 TT. 'TT' stands for Tender Tank. Could hold 5 tons of coal & 1800+400 gallons of water with side tank. Boiler holds 470 gallons of water. Length 54 feet (approx). Introduced in 1913. Builder was Kitson Ltd. GB. Mainly used for Kandy Matale running.

Illustration 7

A pencil + water colour drawing of the B2 Class No.213, 4-6-0 TT. Could hold 5 tons of coal & 2400 + 400 gallons of water with side tank. Length 53 ft (approx). Introduced in 1922. Builder was Vulcan Ltd. GB. A very successful engine and with side tanks. There was good for weight distribution. Mostly used for upcountry running. Now used for special trains.

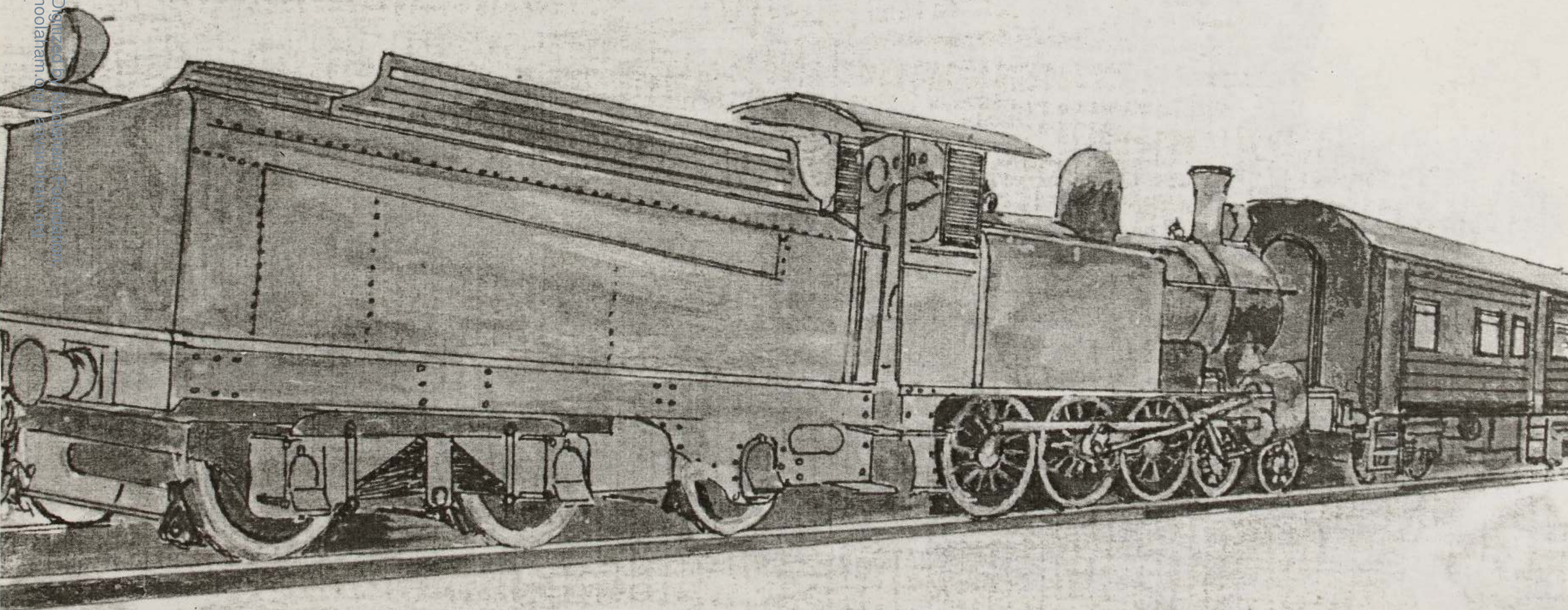


Illustration 8

***A** water colour drawing of the A3 Class No.297, 4-8-0 Could hold 4 tons of coal & 2700 gallons of water. Length 57 ft (approx). Introduced in 1930. Builder was Hunslet Ltd. GB. Mostly used for load hauling on the Batticoloa line.*

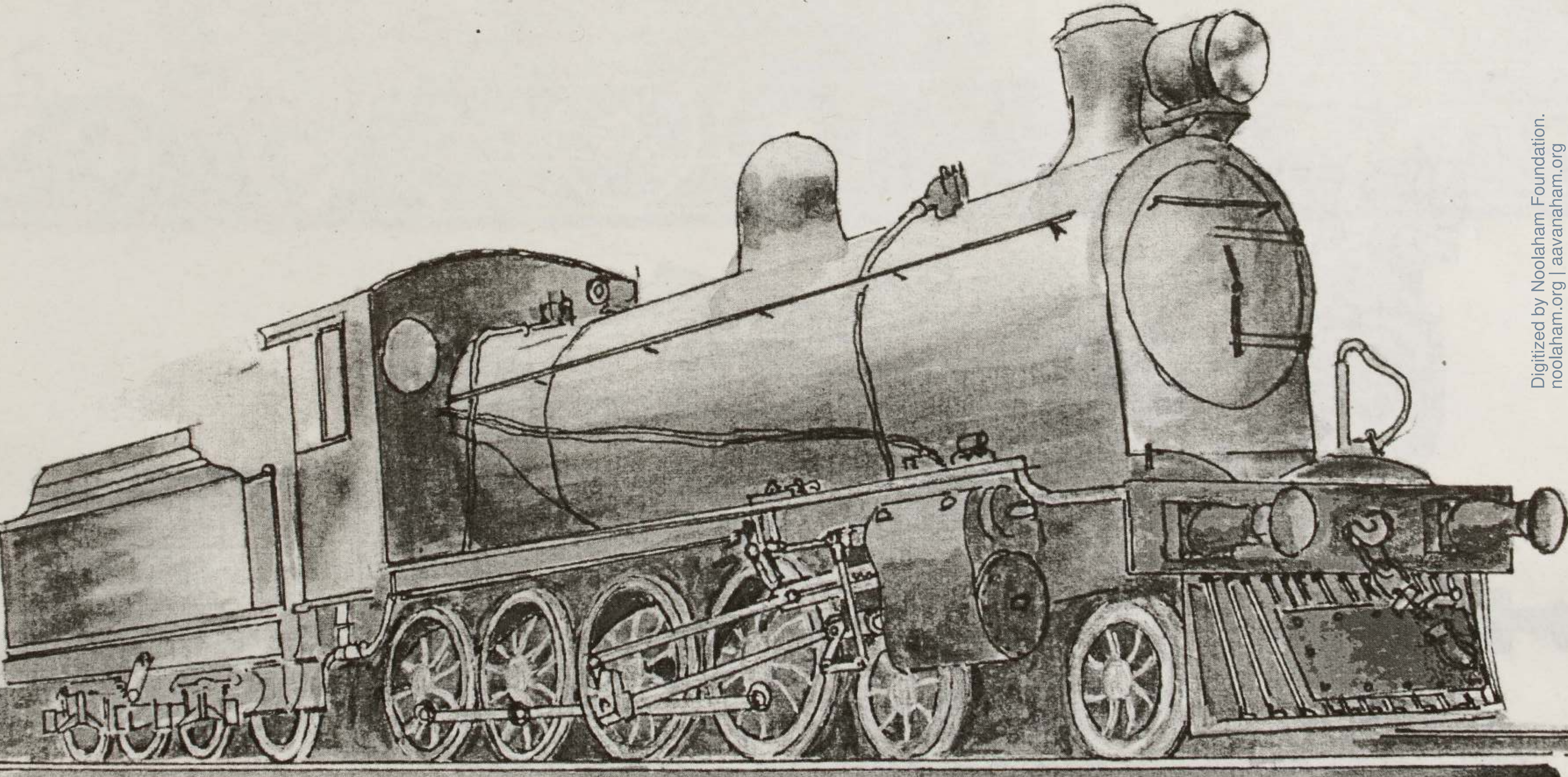
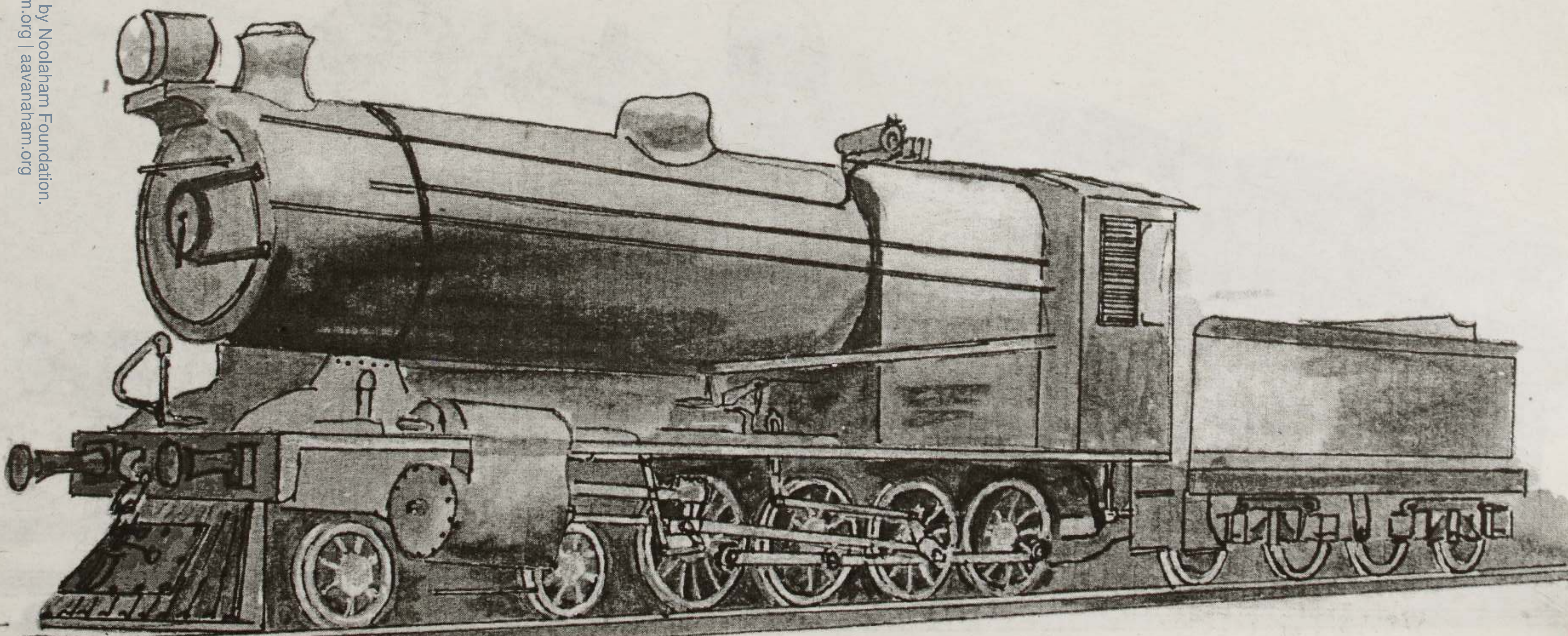


Illustration 9

A water colour drawing of the A1 Class No.19 4-8-0. Called as Big Bank Class. Could hold 5 tons of coal & 3000 gallons of water. Length 59 ft (approx). Introduced in 1913. Builder was Kitson Ltd. GB. Very powerful. Used to push trains Kadugannawa climb.



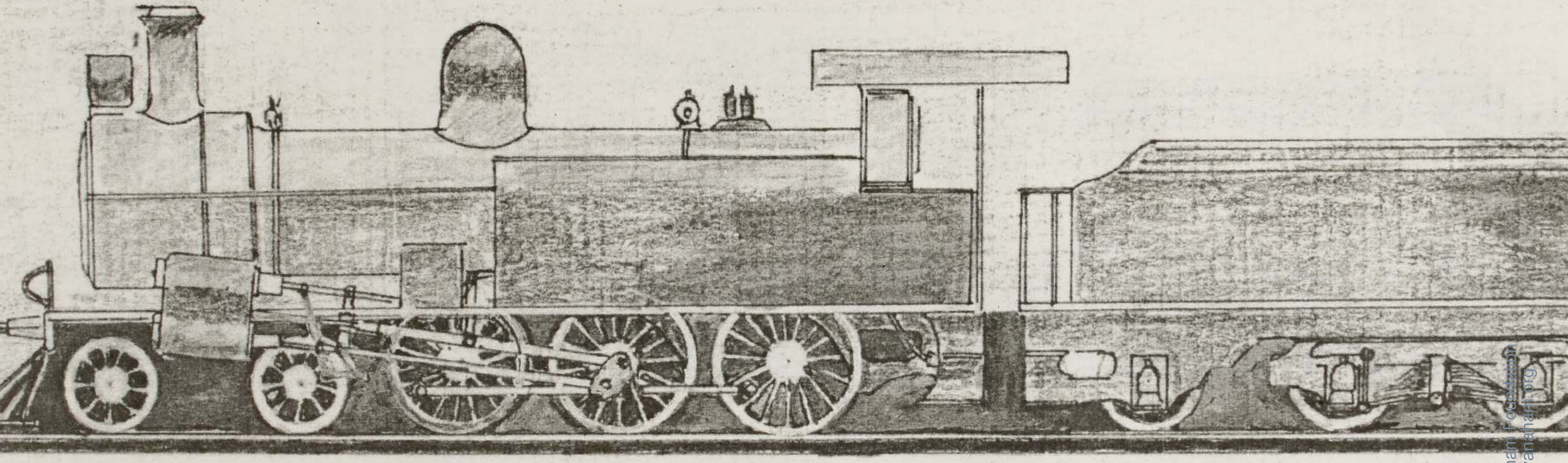


Illustration 10

***A** pencil drawing of the B7 Class No.340 4-6-0. Could hold 5 tons of coal & 2350 gallons of water. Length 49 ft (approx). Introduced in 1875. Builder was Hawthorn Leslie, GB. Used for Kadugannawa climb.*

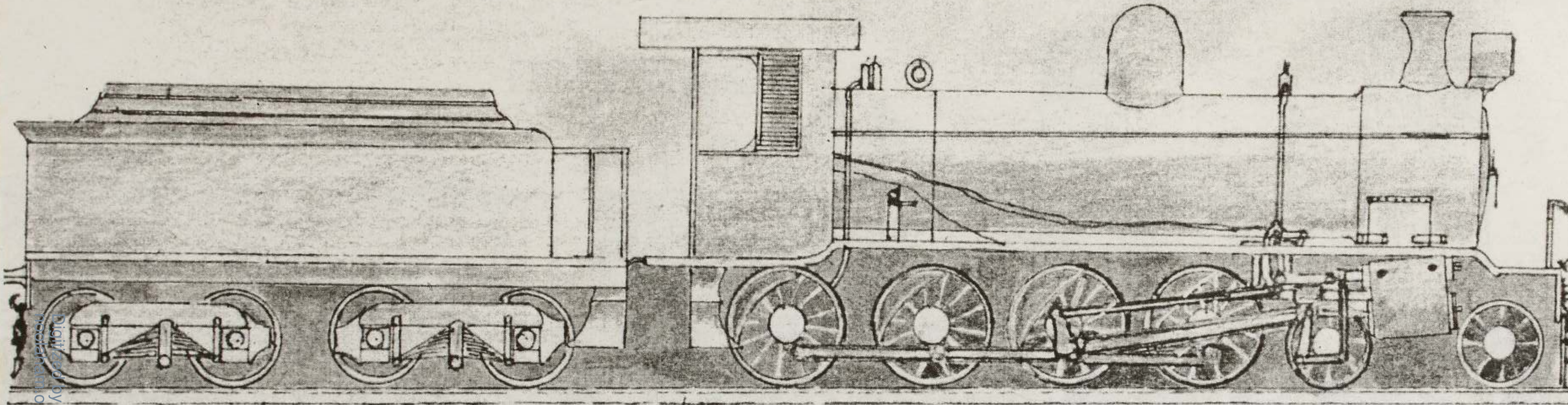


Illustration 11

A pencil drawing of the A3 Class No.340 4-8-0. Could hold 4 tons of coal & 2700 gallons of water. A light engine. Length 49 ft (approx). Introduced in 1875. Builder was Hunslet, GB. Successfully used for Batticoloa line.

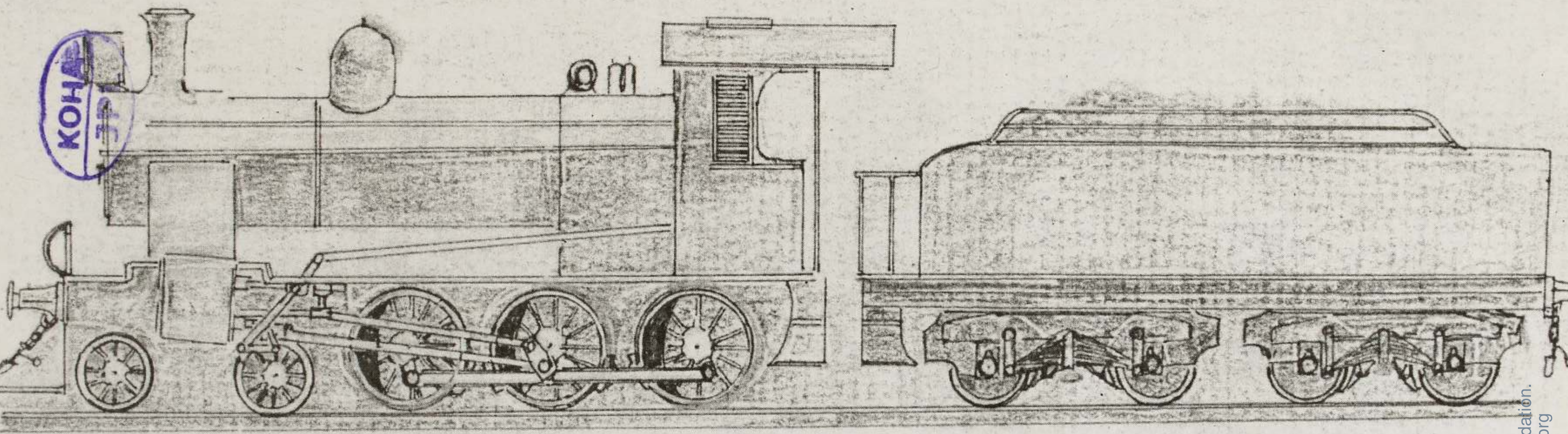


Illustration 12

A pencil drawing of the B3 Class 4-6-0.TT. Could hold 5 tons of coal & 1800 + 400 gallons of water with side tank. A light engine. Length 54 ft (approx). Builder was Kitson, GB.

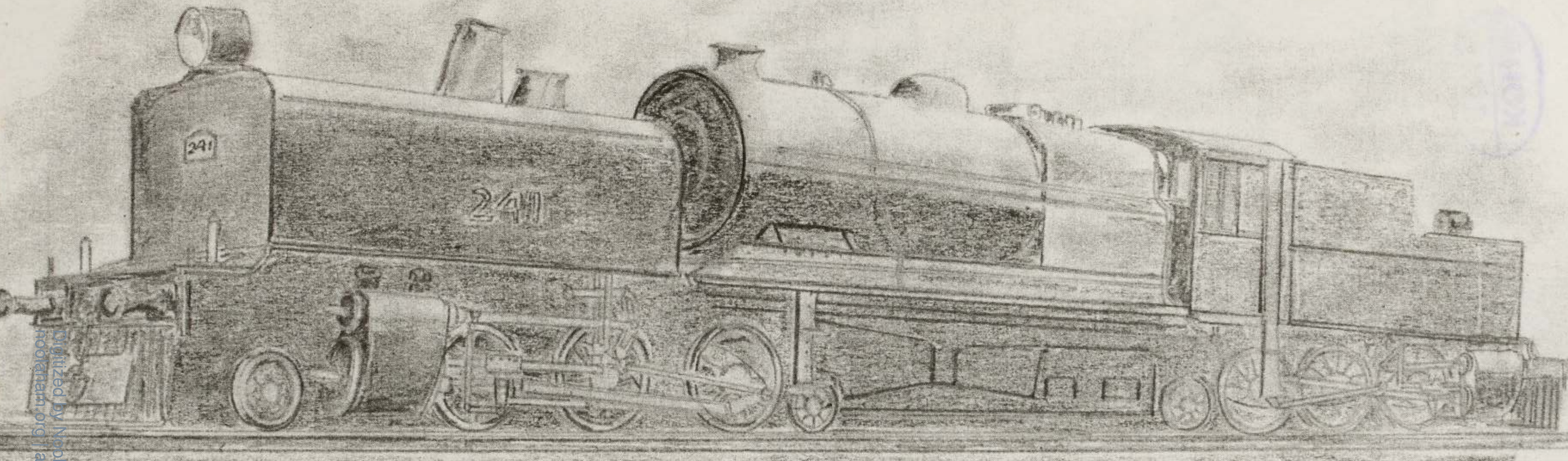


Illustration 13

A pencil drawing of the Class C1A Beyer-Garrat. Locomotive No. 344. Built by Beyer Peacock, GB. Introduced to Sri Lanka in 1946 mainly for the purpose of taking up the loads from Nawalapitiya onwards. It had a wheel arrangement 2-6-2 + 2-6-2 with four cylinders. Could hold 3500 + 1900 gallons of fuel. Earlier, it was powered by coal but later converted to using fuel. Due to conversion, the engine was not successful with dark smoke and one engine was damaged by fire. It could be seen at Dematagoda running yard. Withdrawn in 1973.

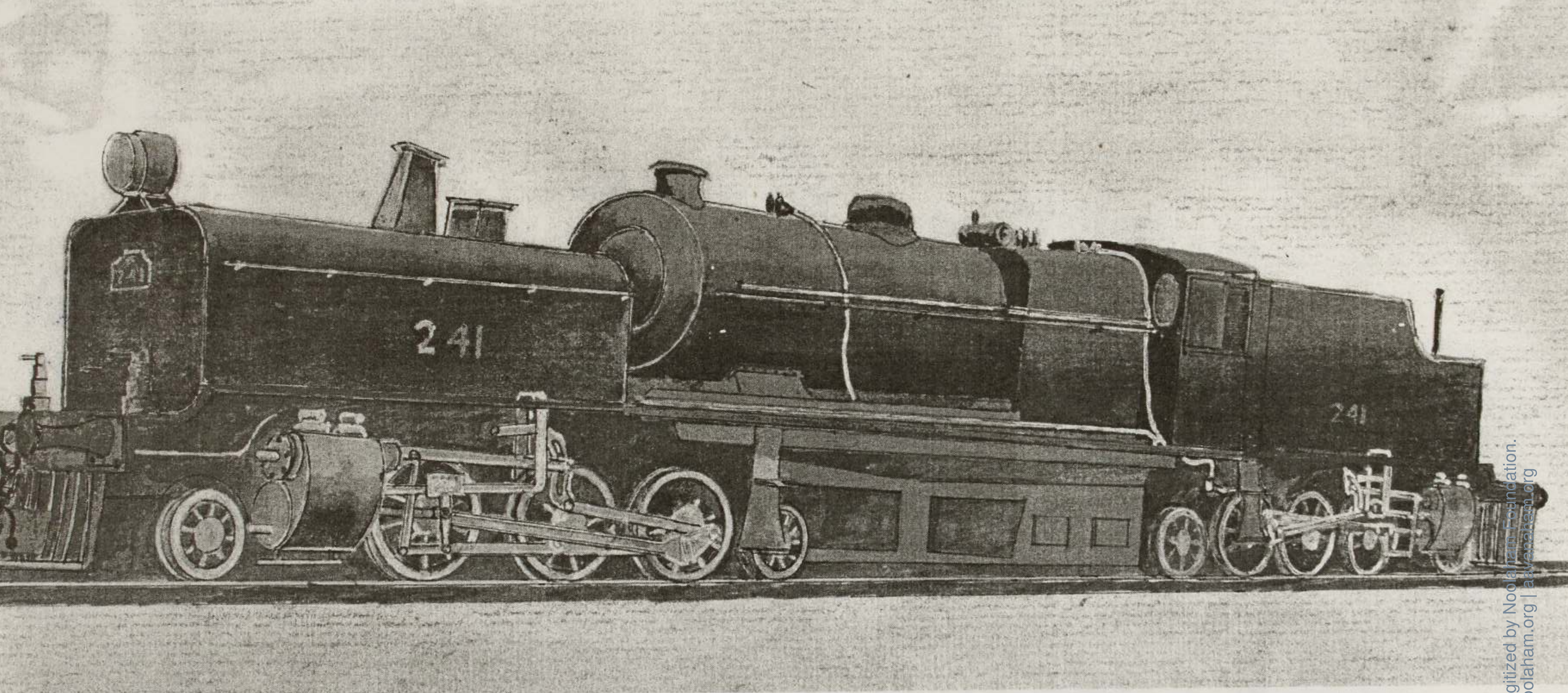


Illustration 14

An Art Impression of the Beyer-Garrat Steam Locomotive

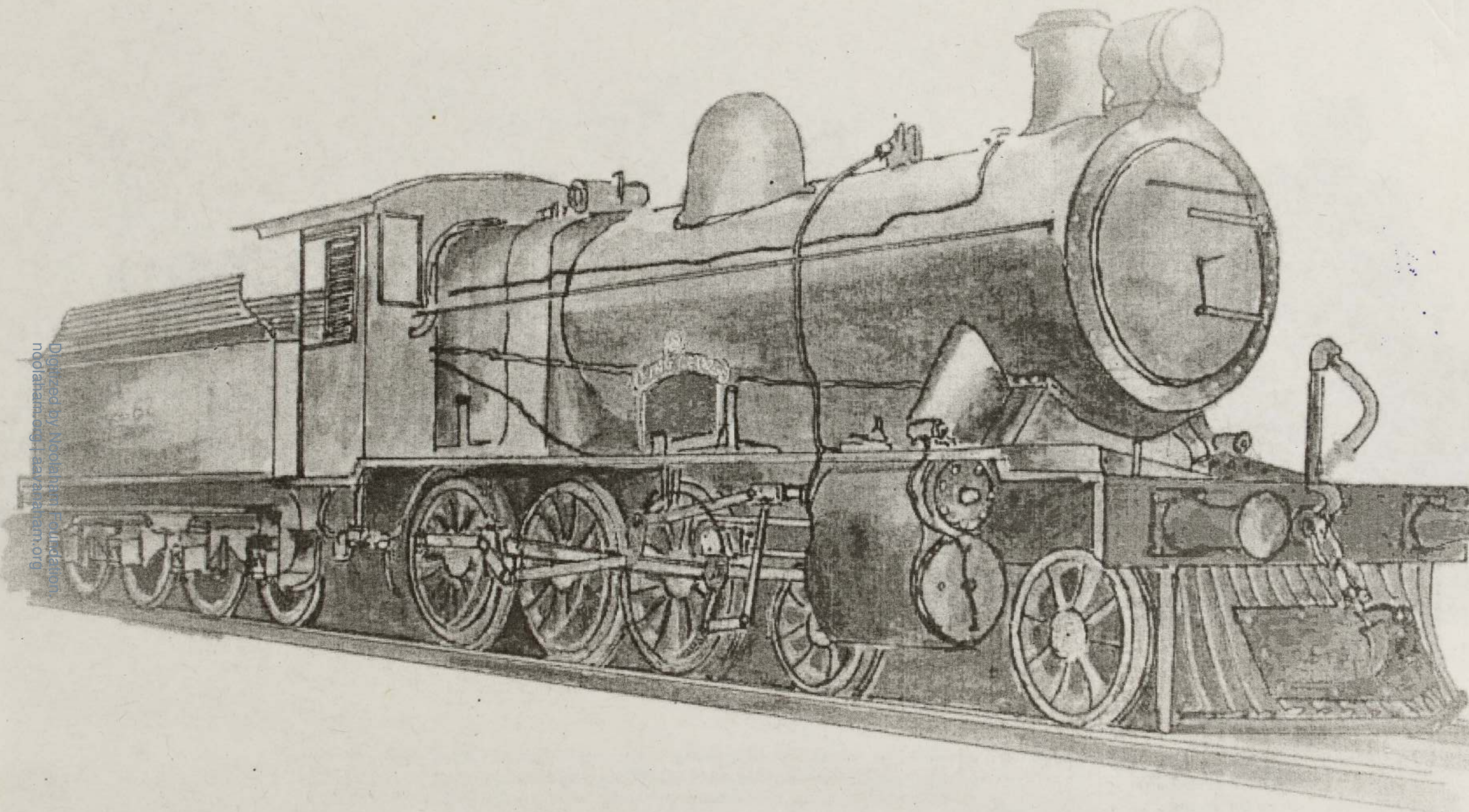
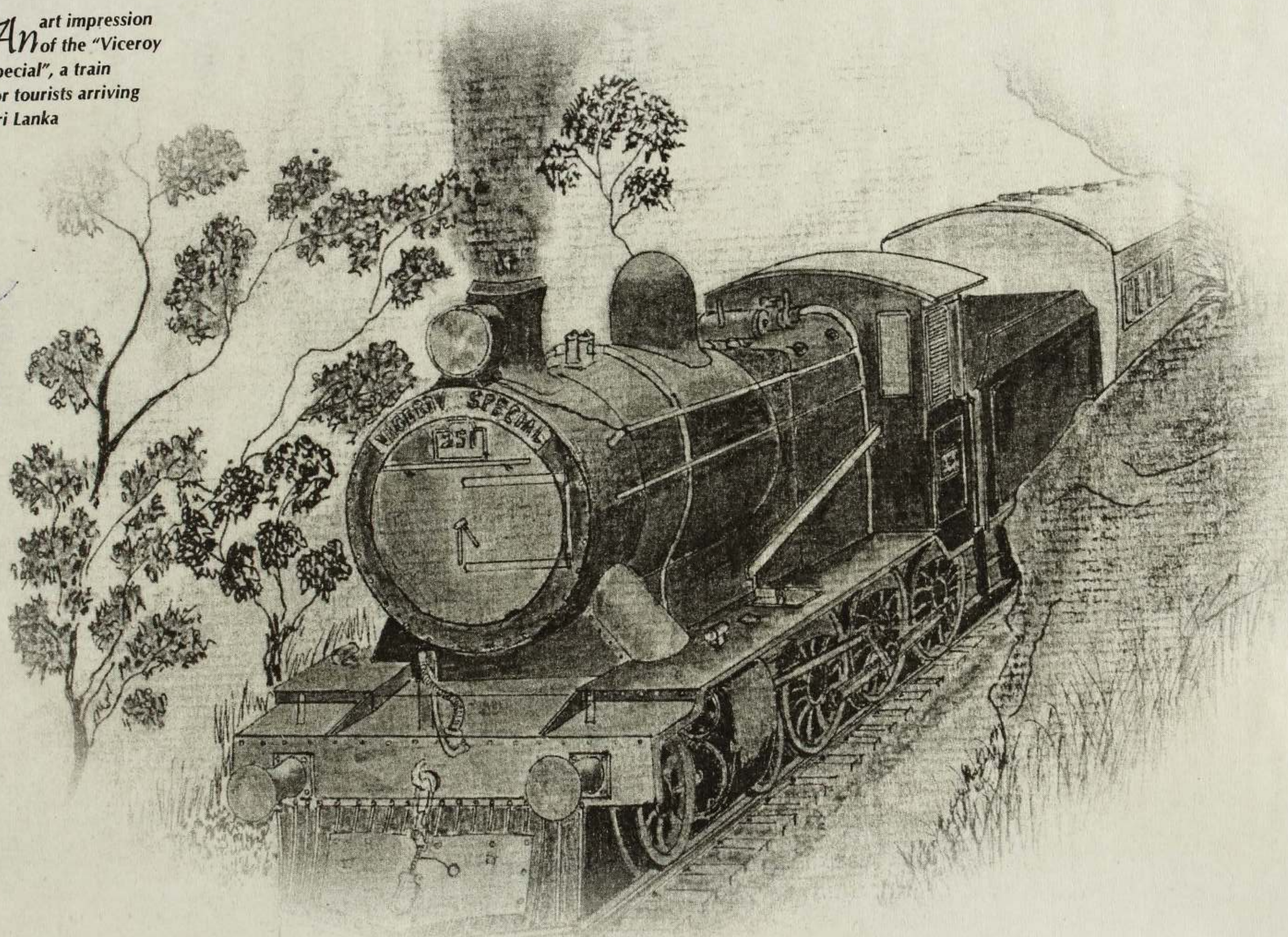


Illustration 15

An art impression of the Class B1 4-6-0

Illustration 16

An art impression of the "Viceroy Special", a train for tourists arriving Sri Lanka



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A Handbook for Steam Railway Locomotive Enginemen, London Midland and Scottish Railway Company, 1st Ed., C. Tinling & Co. Ltd. Printers, Liverpool, Great Britain, 1941.

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You have now holding a small, comprehensive, and informative book detailing about steam locomotives, their origin and development up to the end of the steam era especially relating to UK. It describes the origin of the railroad system, historical aspects of a steam locomotive. properties of steam, inner structure of a steam engine, how it operates, explanation of major components, various wheel arrangements, tasks assigned to the Loco driver and the fireman, steam loco terminology and a dictionary, and illustrations on Sri Lankan steam engines with some drawings of the writer. No doubt, this guide will prove its worth over the years to the thousands of old timers, enthusiasts, and students in transport by providing a fair know-how about steam locos. Readers will find some useful and interesting facts about steam locos without the need to go through a long set of heavier books on the subject.

The author, Upali Jayaratne is a great enthusiast on steam engines since his childhood in Galle, Sri Lanka. As a school boy, he used stay closer to a stationary steam engine to smell its vapor and watch the operations of a fireman. He is a born artist like his family sisters who all received a great teaching from his deceased mother. She taught them the art of drawing, water color painting and music throughly. The writer started drawing pictures of steam engines no sooner he retired from banking service as a senior Assistant General Manager in Bank of Ceylon.

It may be interesting to note that as a layman, he initiated himself writing a small book on steam engines. He received great assistance from present and retired railway officials and especially from a well known author Mr. Sirisena Rajapaksha who wrote on railways in Sinhala language. The writer too referred many references on the subject visiting various libraries. His other major endeavors will be to write similar books on M1, M2 and M4 diesel electric engines and the Garrat steam locomotive in time to come.

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