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Boiler & Engineering Skills Training Trust

## Steam Locomotive Repair and Overhaul

## Module LM3

# Locomotive Frames

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## Module BESTT LM3

## Locomotive Frames

## Aim

This unit will give learners and understanding of how Locomotive frames are constructed in relation to Steam locomotives and how to inspect and suggest methods of repair. Attention will also be given to the importance of alignment.

The learner will consider: -

Frame Construction

Forces acting on frames

Alignment of frames

Components located on frames

Likely regions of failure

Horn Blocks & guides and adjustment

**Learning Outcomes**

LO1 Overview of the Construction and design of Locomotive Frames

LO2 Forces acting on Frames

LO3 Horn blocks/guides

LO4 Alignment

LO5 Cracking

***Please Note: to achieve this unit LO3 – 3,4 & 5 from Wheels and Axles LM1 must be completed satisfactorily***

## INTRODUCTION

Steam Locomotive frames in the UK are generally formed from two vertical sheets of steel arranged side by side and braced across with stretchers to keep them in place. The cylinders and pistons, which drive the locomotive, are fastened to the front of the frames, and the wheels on their axles pass through the frames in vertical slots supported on springs, which allow limited vertical movement of the axleboxes to accommodate unevenness in the tracks.

The front of a steam locomotive boiler is generally anchored firmly to the front of the frames within the smokebox but the rear of the boiler is constrained to move purely lengthways as the boiler expands with heat. It is clamped in the vertical and sideways planes but free to move without hindrance longitudinally.

Early locomotives used the boiler as the frame element as in George Stephenson’s No 1 Locomotion of 1825 used to open the world’s first public Railway…. the Stockton and Darlington Railway.

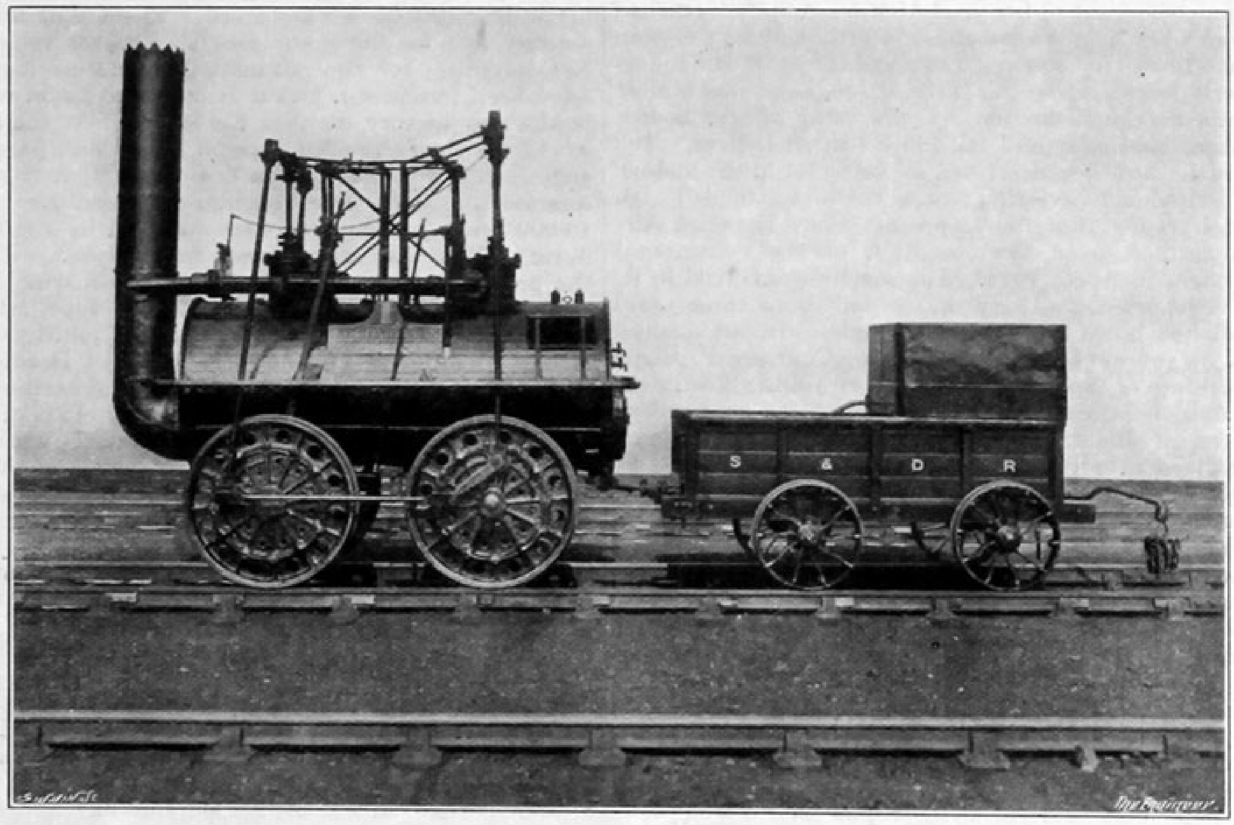


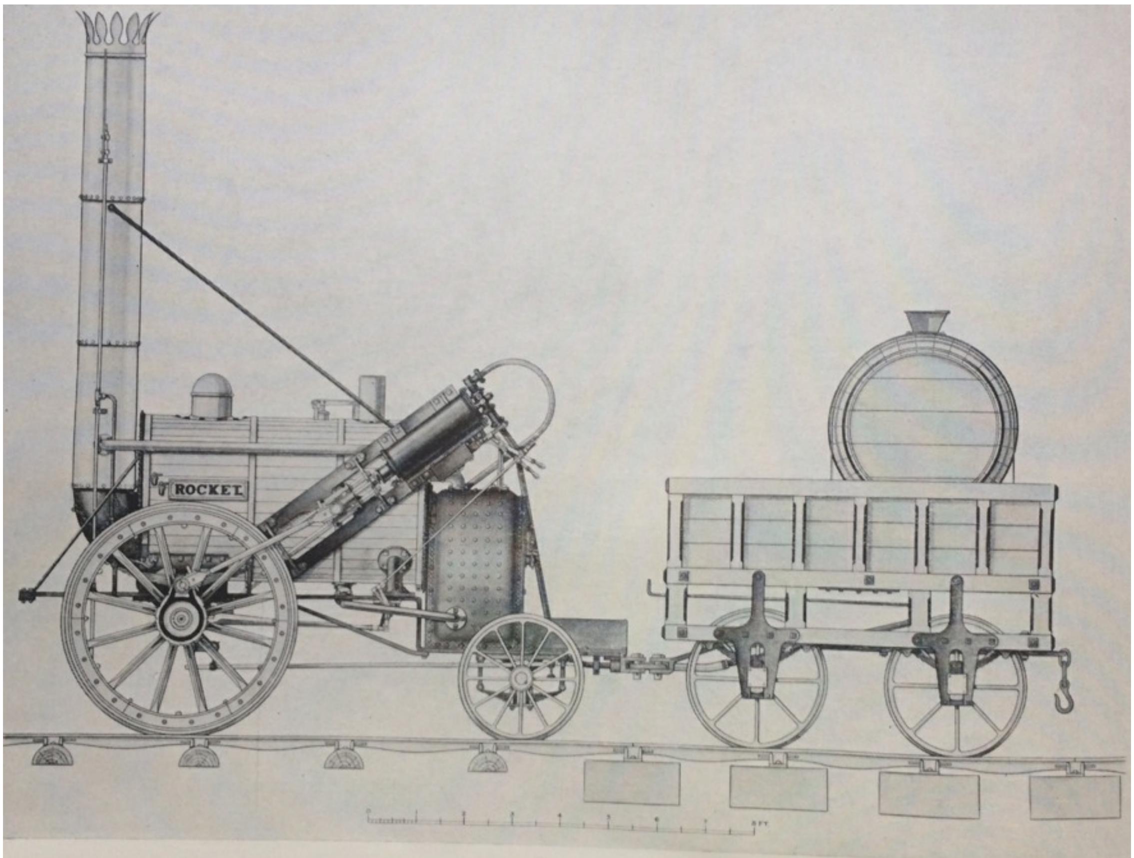

FIG. 1—“LOCOMOTION NO. 1”—STOCKTON AND DARLINGTON RAILWAY

This method created problems as the centres of the axles became variable with heat. In addition some of the mechanical stresses created by the travelling of the vehicle over uneven tracks were referred back to the boiler, which was clearly undesirable.

There is a fascinating sequel to this practice that when the London and North Western Railway at Crewe was trying to build their steam locomotives to the lowest possible price in the 1920s, they introduced a diaphragm plate into the design apparently supporting the boiler at its mid-way point. In fact what was happening was that the frames were being made so flimsy that the boiler was being used as a “strong-back” to keep the frames from bending under load. This practice was outlawed and frames had to be made stronger.

***L&NWR 0-8-0s***

As early as 1829 Stephenson and his son Robert had realised that the wheels and axles must be supported separately from the boiler. So in the “Rocket” design that was so successful at the Rainhill Trials had separate frames supporting the boiler and this set the pattern for British steam locomotives for the next 130 years!




10. Stephenson's 0–2–2 *Rocket* locomotive: Liverpool and Manchester Railway

It is interesting that the boiler of a steamroller or traction engine is similarly used as a structural member supporting the carrying wheels of the vehicle but this does not seem to create the same impediments that it does with a steam locomotive.

***Aveling Steam Roller***

Practice in the USA and often on the continent did not necessarily follow the UK pattern where bar frames were often substituted for the thin tall steel plates. These bars were wider than UK plates and were often cast in steel in one piece with the cylinder block creating a tremendously strong front end which was highly resistant to the “racking” motion which is very common with outside cylinder locomotives and caused problems for many hard working locomotives.

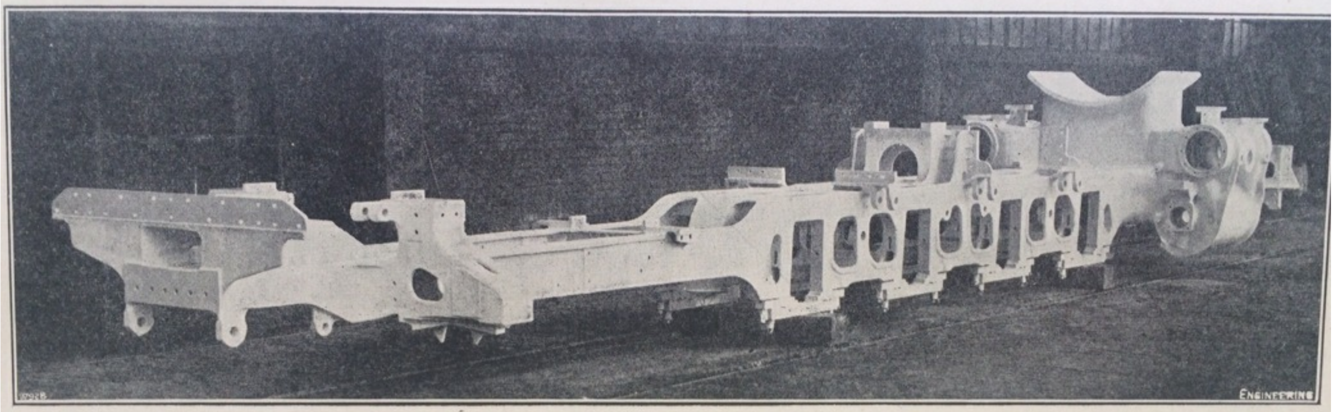
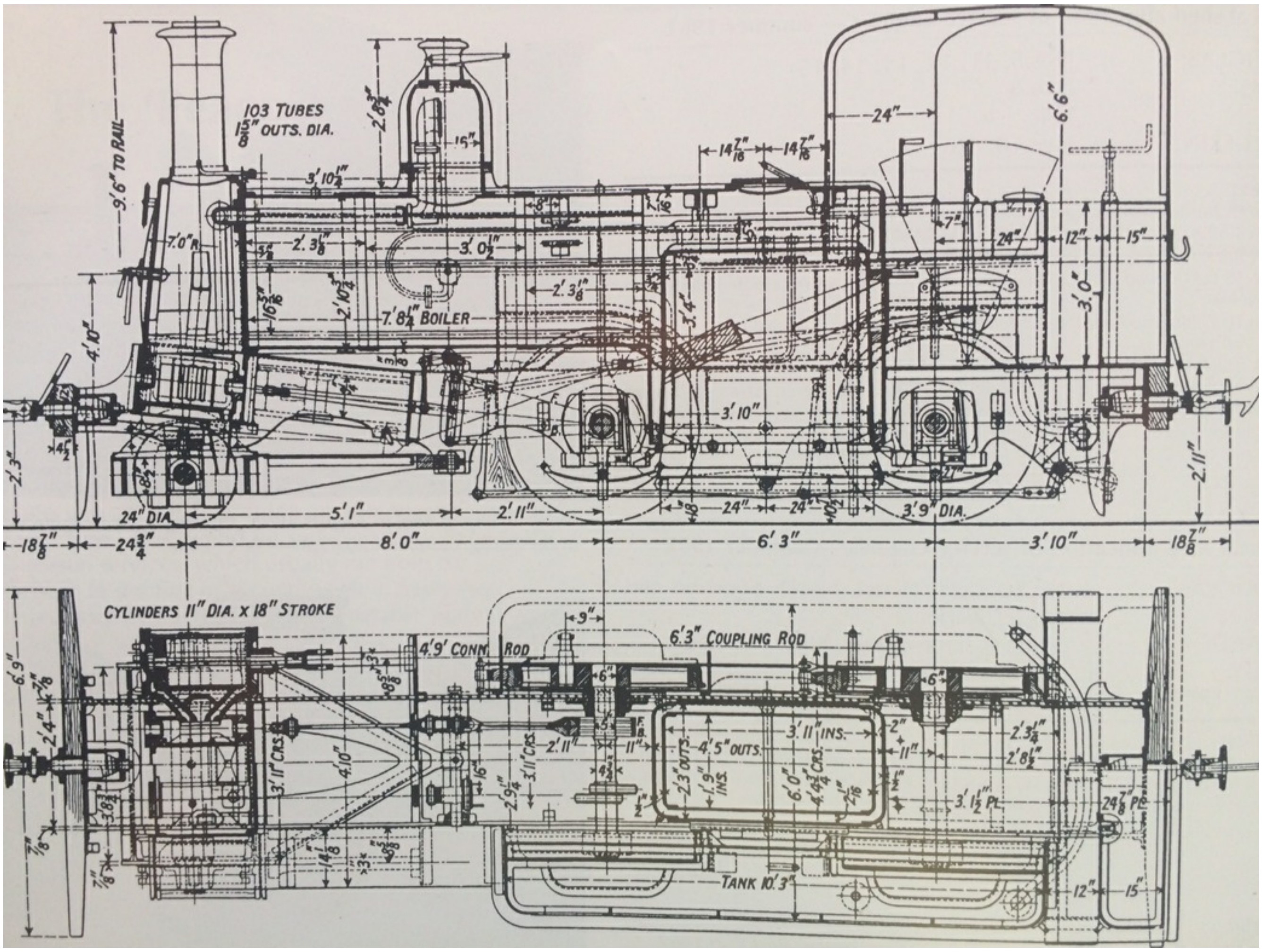


*Fig. 8.* Cast-steel Locomotive Beds.
*Above.* South African Railways 2–8–4 Locomotive.
*Left.* New York Central 4–8–4 Locomotive.

In addition to the change of design to bar frames, it was common Continental and USA practice for all the springs supporting the axleboxes to have their ends linked together in a system known as compensated springing with pivoted links between the spring ends. This meant that if one wheel sensed a high spot in the track the forces were then shared all the way down that side of the locomotive rather than being endured purely by one wheel at the expense of equal sharing with the other carrying wheels. Early examples came from Beyer Peacock with their design of Narrow Gauge Passenger Tank Engines, which are still running now in the Isle of Man




Frames of locomotives can be- prone to cracking owing to the cyclic repeating of the bending from the reciprocating piston forces, as well as the dead weight of the locomotive and bending forces from the track.

## OVERVIEW OF LOCOMOTIVE FRAMES

For an overview we can do no better than quote from Simpson and Roberts

" Locomotives and their Working" Chapter 9 Published by Virtue & Co 1952.

*The main frame of a locomotive supports the boiler and cylinders, as well as many other parts and is itself carried on the wheels through the medium of axles axleboxes and springs etc. It is subjected to a complex system of forces, which are due primarily to the dead weight of the engine, the piston thrusts, the buffing load and the drawbar pull. British locomotives are almost always provided with plate frames, but bar frames and cast steel beds are used extensively abroad.*

*The plate frame is built up from two deep steel plates, about 1 in. to 11/4" thick, arranged vertically and parallel to each other either inside or outside the coupled wheels, and cross braced by stretchers, cross stays, a saddle, drag box, buffer beams etc. In the case of a locomotive with a firebox between the frame plates no cross bracing can be provided in the extensive zone occupied by the firebox. There is therefore considerable flexibility in the frame. Indeed, any design of frame plate, for engines with and without trailing wheels, inevitably allows some horizontal flexibility-certainly more than that obtaining in bar frames or cast steel beds. In some designs the frame is cross-braced to the maximum possible extent, so as to achieve rigidity; in others the designer has deliberately aimed at flexibility. It is not necessary here to deal with this problem more fully; it is sufficient to appreciate the general situation. Provision must be made for the locomotive to negotiate curves by allowing sufficient side clearances between the wheel flanges and the rails, the wheels and the axleboxes, and the axleboxes and the hornblocks, in addition to the inherent flexibility of the frame. Sometimes the tyres of one or more pairs of coupled wheels are made flangeless, or the flanges are made thinner for the same purpose. The functions of bogies and trucks in this connection are dealt with later in this chapter. Each frame plate is generally in one piece extending the full length and each plate has a number of horn gaps, one to each coupled axle, and is otherwise shaped to suit the bogie, saddle, cylinders etc. Some parts e.g. the cylinders are bolted to it; others such as the horn-blocks or guides are usually riveted to it* usually riveted to it.

Figure 1 shows the principal forces acting on a plate frame. The static

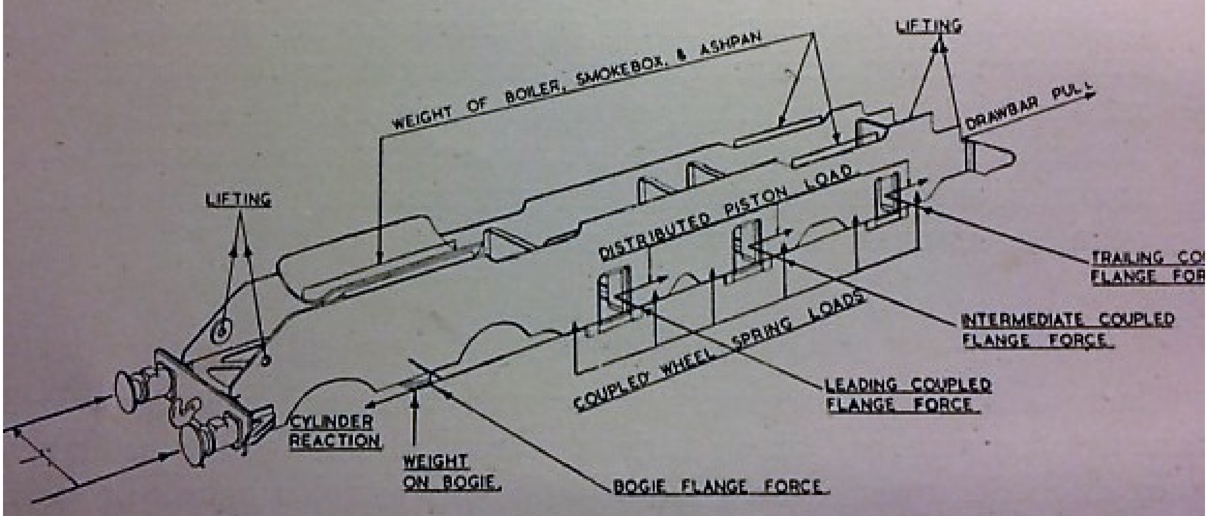



*Fig. 1.* The Forces to which a Locomotive Frame is subjected.

*The static loads (i.e. those which exist when the locomotive is stationary) include those due to the weight of the boiler, smokebox, ash pan etc. which of course act downwards, and those which are transmitted to the springs, and which acting upwards are the "reactions" due to the downward static loads. The weight on the bogie and trailing truck (if fitted) acts similarly. The loads due to the piston thrust and the force between the tyre and the rail were considered in Chapter 1. In brief they resolve into a forward pull on the frame where the cylinder is mounted, and a rearward thrust on the hind horn faces, when the engine is travelling in fore gear with the piston moving backwards; and into a backward thrust on the frame and a forward thrust on the front horn face when the piston is moving forwards. Other forces, which may be transmitted to the frame, include those due to side thrust on the flanges of the wheels, to buffing load and drawbar pull, and to lifting by cranes when the locomotive is in the shops.*

*Of these forces those, which occur when the locomotive is running, are complex especially as the two three or four pistons of the engine do not act in unison. It is not surprising therefore that the frame plates develop cracks in service. Such cracks usually develop around the horn gaps- regions where the frame has no great depth and stresses are high. The tendency to develop cracks varies considerably with different class of locomotive; in some cases cracks never develop n, in others the incidence of cracks is high especially after several years of locomotive life. The cracks develop slowly, not suddenly and can be repaired by direct welding or by welding in a new piece of frame plate when the locomotive is in the shops.*

*The frame plates are braced together at several points: at the front by the buffer beam, to which they are fixed by riveted gussets; at the back by the drag box; and intermediately by stretchers and cross stays, as well as by a smokebox saddle in the case of outside cylindered locomotives or by inside cylinders and a spectacle plate. Various disposition of bracing members are shown for 3 different classes of 4-6-0 locomotive shown in Fig 2.*

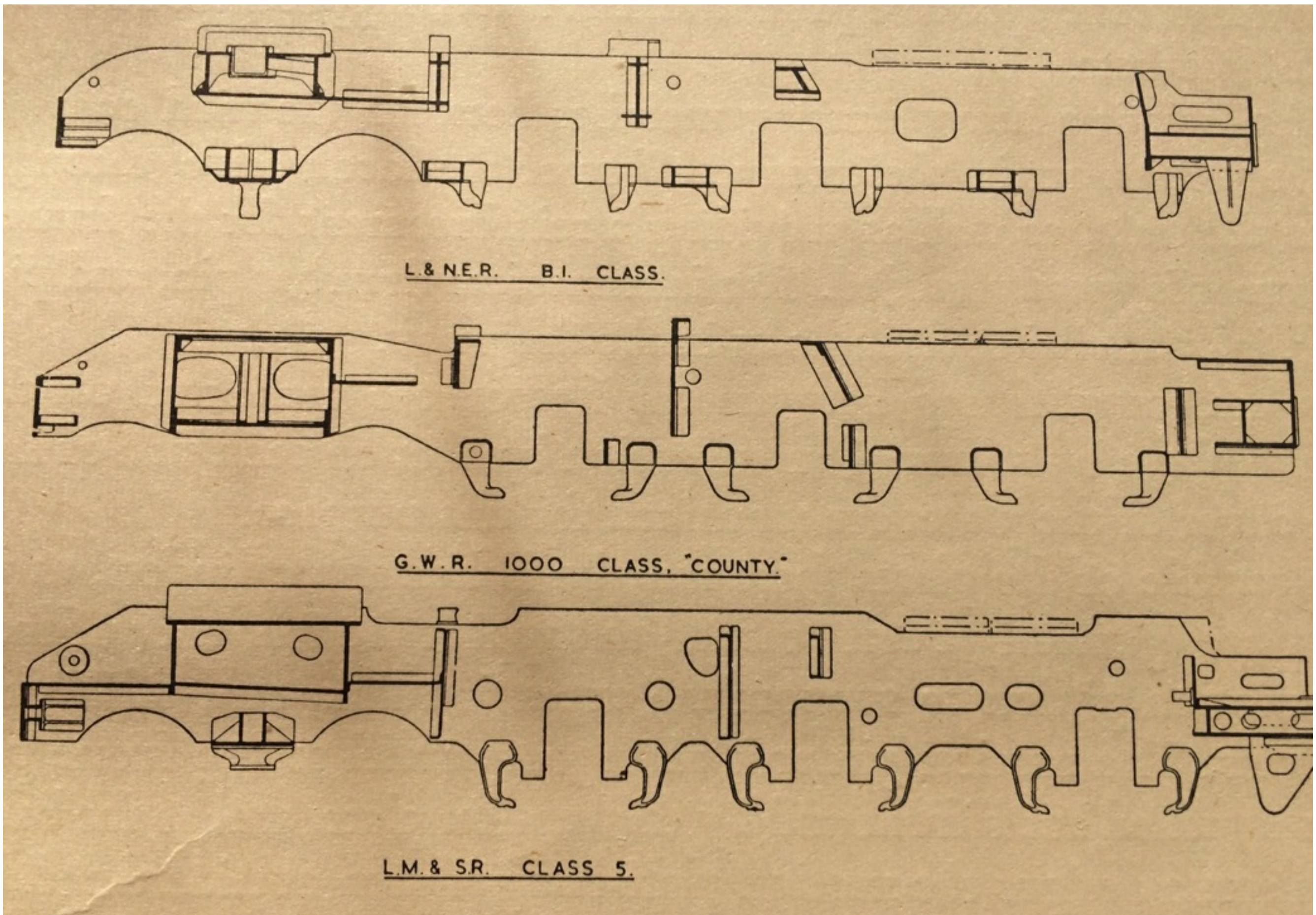



*Fig. 2.* Frames of representative British 4–6–0 Mixed Traffic Locomotiv

*These frame-bracing members may be cast or fabricated, i.e. made of a number of steel plates of suitable shapes and sizes welded together. Each is machined on the side faces so as to fit snugly between the frames, which are thus spaced accurately at the correct distance apart. The bracing members are held to the frames by large bolts, which are a driving fit in the holes, or by rivets.*

*The saddle in addition to supporting the smokebox (and possibly the front end of the boiler, may incorporate exhaust passages leading from the outside cylinders to a flanged aperture on the top of the saddle, to which the blast pipe is fixed. The pivot for the bogie may be attached to the underside of the saddle or to a separate stretcher.*

*In the case of inside cylindered locomotives the cylinder casting usually takes the place of the saddle, and is shaped to carry the smokebox. The boiler of a 4-6-2 locomotive has a long barrel and is generally supported near the front end on a cross stretcher which may take the form of a motion spectacle plate. A large pad fixed to the underside of the barrel rests on the upper surface of the stretcher. The spectacle plate if one is fitted, supports the rear ends of the inside slide bars.*

*The drag box is a heavy bracing member between the hind ends of the frame plates. It transmits the tractive effort of the locomotive through the tender to the train, as well as providing reinforcement for the frames at a point where it is greatly needed. The intermediate drawbar pin, and pins for the safety links or chains, fit in holes in the drag box.*

*Narrow fireboxes fitting in between the frames are supported on the top edges of the plates by means of an expansion bracket on each side of the firebox. The edges of the plates are machined for this purpose.*

*On the outside of the plates there may be bolted the cylinders, as well as a motion plate (generally a cast bracket) to support each end of the rear end of the slide bars and motion girders to support the expansion link etc. of Walschaerts or Baker gear. The motion girder is arranged parallel to the frame plate, to which it is attached at its front end by the motion plate and at the back by a bracket. In some designs the motion plate hangs down outside the slide bars, in others it is wholly between the bars and the frame.*

***Horwich Crab motion plate***

*In wide firebox locomotives having trailing truck wheels, the frame plates are not usually continued back in the same straight line beyond the rear coupled wheels.*


*The distance between the frame plates may be increased or decreased; or separate plates may be fixed to the main plates directly or through an intermediate member, or the frame may be doubled on each side; or a cast steel cradle, forming an extension of the main frame may be fitted. In any case there is a hind truck pivot cross stretcher which in addition to carrying the truck pivot on its underside is fitted with a firebox support bracket on its upper surface. There are also bearing pad brackets for transmitting the weight of the rear end of the locomotive on to the truck or other means for filling the same function according to the design off the truck.*

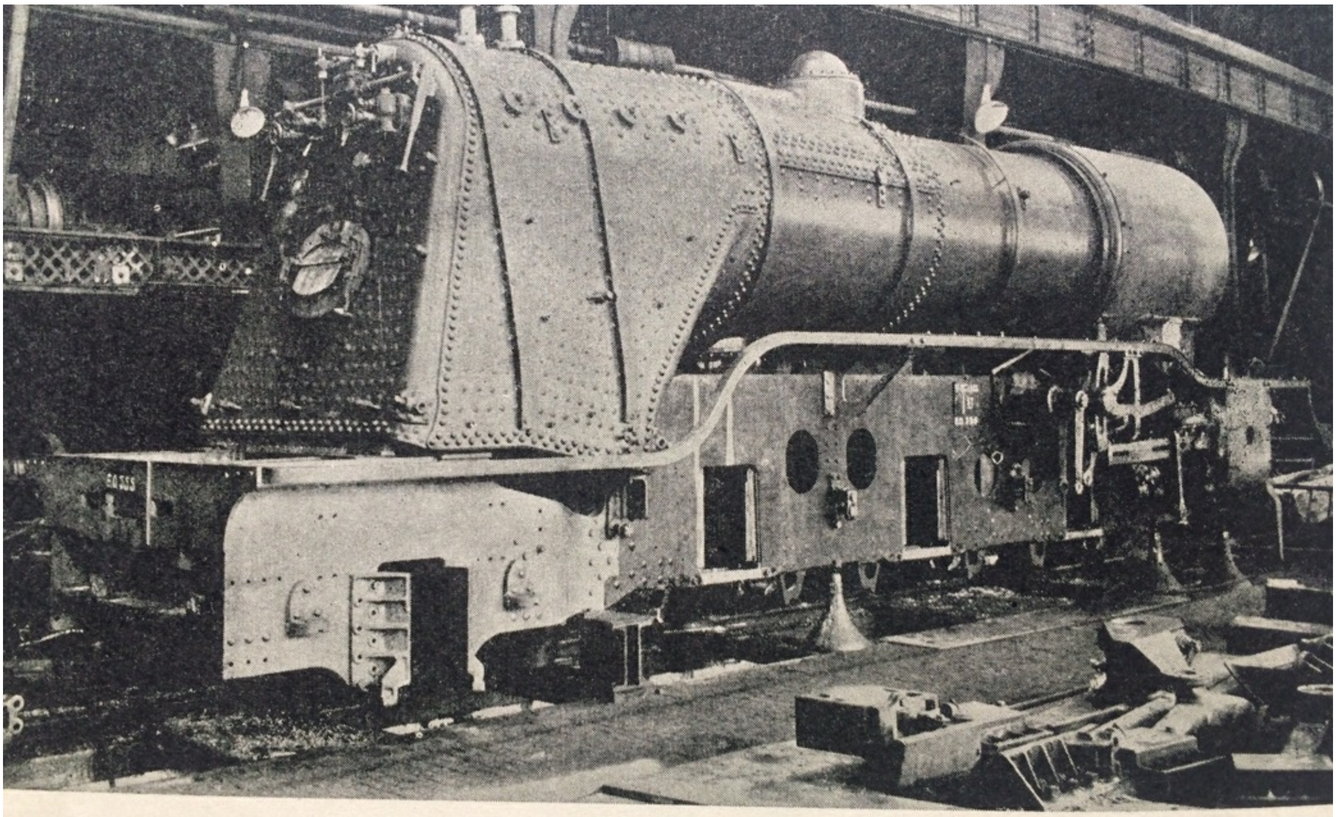


*Fig. 4.* 2–6–2 Locomotive under construction at Doncaster. Note Rear Frame for Cartazzi Truck

*The horn gaps are reinforced by horn-blocks or horn-guides, which hold the axle boxes whist allowing them to move up and down when the springs flex. A hornblock is a single horseshoe shaped steel casting conforming to the sides and top of the gap in the frame plate, to which it is riveted or attached with driven bolts. It has two broad faces accurately finished in which the axle-box slides. As these faces are subjected to heavy pounding and wear, some railways fit manganese steel liners, or composite liners consisting of a manganese steel flanged plate riveted and welded to a mild steel backing plate. The special property of manganese steel is that it "work-hardens", i.e. its working surface becomes harder in use. The axle-box may also be fitted with manganese steel liners. Fig 5 shows a horn-block with spigoted cheeks held in place by bolts.*

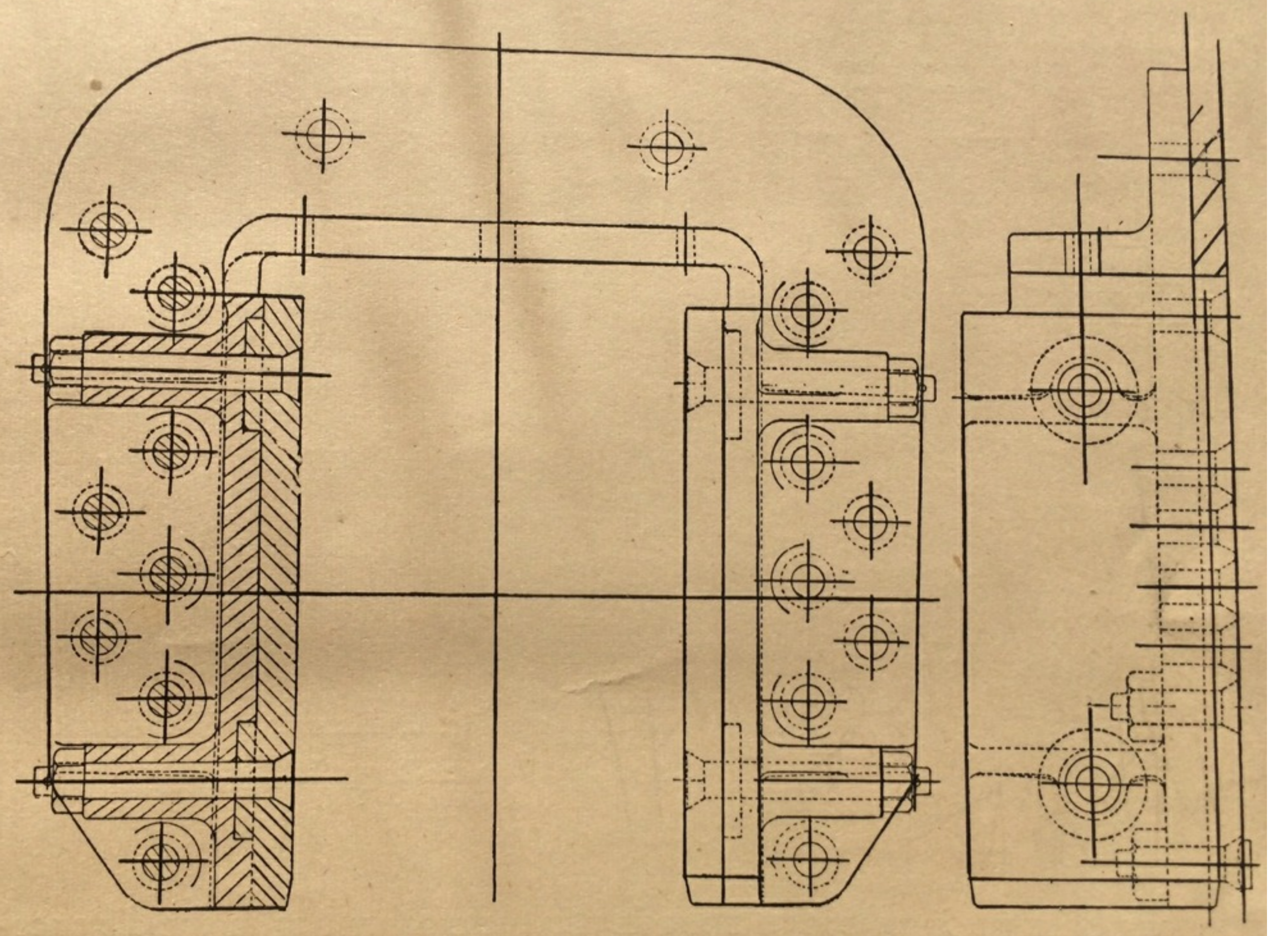


*Fig. 5.* Horseshoe Horn-block with renewable parallel cheeks.

*Horn guides consist of two separate cast steel guides to each horn gap; they are in effect a horn block without the cross part at the top. Although they are used on many locomotives some designers prefer horn-blocks as they provide greater reinforcement for the frame. Horn-guides are finished in exactly the same way as horn-blocks, and may also be fitted with manganese steel liners.*

*The latest practice on British Railways, for engines that had wide fireboxes, is to arrange the frame plates on the longitudinal centreline of the horns and weld the horns directly to the frames.*

*To allow the slack in the axlebox due to wear, to be taken up, one face of the horn may take the form of an adjusting wedge. The bolt or bolts, which hold this wedge firmly to the horns, is slackened whenever it is necessary to adjust the wedge by means of an adjusting screw and nuts. The adjusting screw is fixed to the wedge and passes through a hole in the hornstay. In some designs the adjustment is automatically effected by means of a spring.*

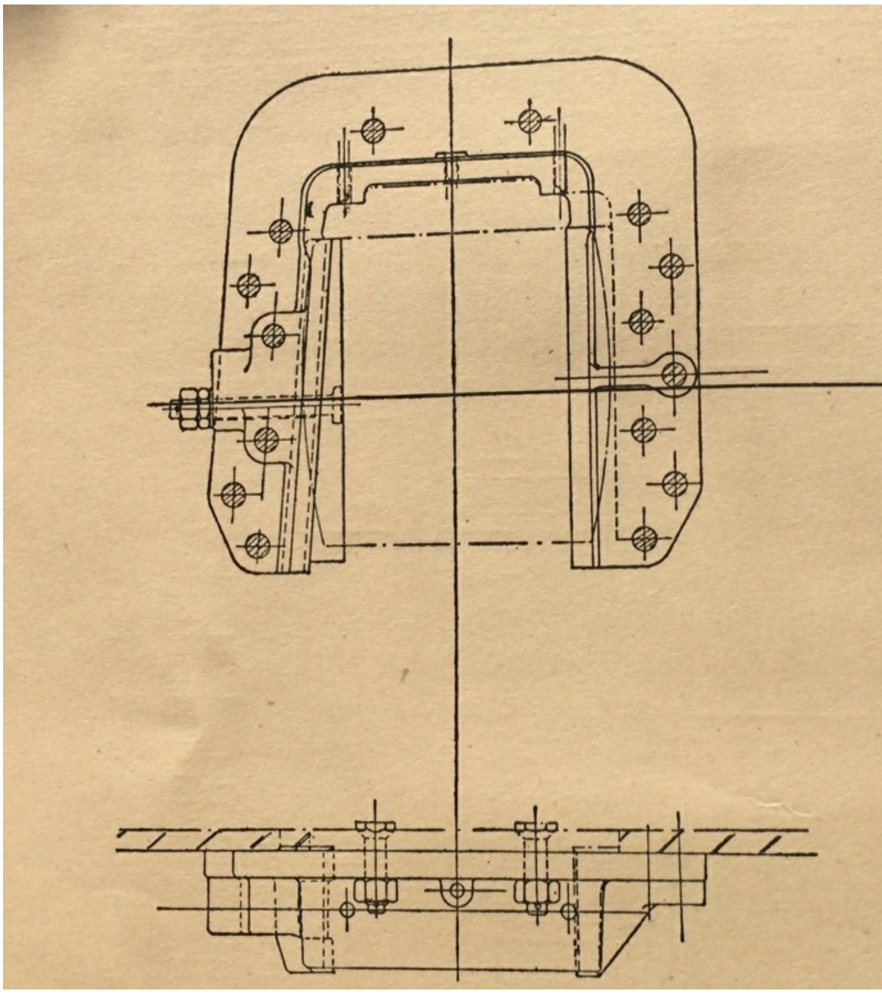


*Fig. 6.* Horseshoe Horn-block with Taper Wedge at one side.

*The horn-stay or horn-tie as it is sometimes called, is fixed across the bottom of the horn gap. Without it the frame plate would tend to be distorted and the horn gap would widen. Three types of horn stays may be mentioned. Studs and nuts to the bottom faces of the horn block or guides hold the clip up type. Four lips on the stay mate with the edges of the horn; a slight wedge effect is provided so that the stay can be drawn up tightly. The second type is a bar, spanning the horn gap, and held to downward extensions of the frame (not the horn) on each side of the gap by studs and nuts. A wedge effect is also provided in this design. In the third type, a substantial distance piece is fitted in the bottom of the horn gap, and is held by two long bolts passing through holes in the horns as well as in the distance pieces.*

*It is sometimes necessary to brace the frame crosswise from the bottom of one horn to the other so as to resist lateral or flange thrust transmitted from the tyres. The cross stays provided for this purpose take a variety of forms. They are usually attached to the horns by rivets studs bolts or pins. Cross stays cannot of course be fitted across crank-axles.*

*In addition to the principal bracing members, which have been described, the frames also carry numerous brackets, etc. for brake gear, sanding gear, foot framing and the cab. It is not necessary to enlarge on the construction of the cab, except to note that provision is made for the expansion of the boiler where the cab fits round the firebox.*

*Plate frames are relatively weak in the transverse plane. I.e. their flexibility comes into play when the locomotive is rounding a curve. They are extensively used in Great Britain, however, because with adequate bracing they are strong enough even for the most powerful British locomotives, and because they allow the maximum possible width between the frames for inside cylinders, valve gear and motion and for a narrow type firebox. Locomotives for* *overseas many of which are built by British firms are often larger and more powerful; and the narrow gauge of some railways such as the 3ft. 6" of the South African Railways leads to the use of wide fireboxes and outside cylinders. These and other considerations have favoured the adoption of bar frames, and more recently cast steel beds.*

*Whilst bar frames have great lateral stability – usually regarded as a disadvantage-they are very weak vertically and unless proper precautions are taken when lifting they may easily be seriously damaged. Any slackness in the horn stay will result in excessive strain upon the top rail above the horns.*

*Due to the increased thickness of bar frames the distance between the side members compared with plate frames is considerably reduced. For this reason bar framed engines never have more than one cylinder inside. There would be insufficient space for an adequate crank axle.*

*It is not unusual to use combination frames. These consist of a plate member joined to one of a bar type. This arrangement was used extensively on the Former Great Western Railway for locomotives with two outside cylinders The bar section at the front enables a half saddle to be incorporated with each cylinder casting and the cylinders may be housed in recesses in the bar frame thus relieving the cylinder holding bolts of direct shearing stresses. Combination frames may also take the form of a bar from the front to a point behind the trailing coupled wheel the trailing coupled wheel where a plate extension is fitted joined through the medium of a substantial steel casting. This form of construction used especially in narrow gauge locomotives, enables a wider deeper firebox to be fitted…"*

**LO1: Overview of the Construction and design of Locomotive Frames**

1. The design of frames
2. The boiler as a structural component
3. Boiler expansion
4. Cast Bar Frames
5. Cracking of frames
6. Components attached to the frames
7. Fastenings

| LO | Objectives | Assessment Criteria | Delivery | Date achieved and Supervisors signature |
|---|---|---|---|---|
| LO1 1 | Frame Construction | Draw 2 examples of locomotive frames | Classroom | |
| LO1 2 | Boiler as a structural component | Explain why this is not desirable. Give an example where a boiler is used as a structural element. | Classroom | |
| LO1 3 | Allowing boiler expansion | Draw a diagram to show how the expansion of the loco boiler is accommodated within the frames | Classroom | |
| LO1 4 | Cast bar frames | Draw a diagram of a cast bar frame | Classroom | |
| LO1 5 | Cracking of frames | Why does cracking of frames occur? | Classroom | |
| LO1 6 | Components secured to frames | List 5 items that are the major components attached to the frames and indicate the attachment method. | Classroom | |
| LO1 7 | Types of fastening | Discuss the merits and drawbacks of Rivets, bolts and fitted bolts. Use annotated diagrams | Classroom | |

**LO2**: **Forces acting on Frames**

1. Static Loads
2. Dynamic loads
3. Horn gaps
4. Reinforcement of horn gaps

| LO | Objectives | Assessment Criteria | Delivery | Date achieved and Supervisors signature |
|---|---|---|---|---|
| LO2 1 | Static loads on frames | Draw a diagram showing the principle static loads experienced by the frames | Classroom | |
| LO2 2 | Dynamic loads | What dynamic loads will the frame experience? | Classroom | |
| LO2 3 | Horn guides and their influence on the frame | What influence does the horn gaps have on a frame? | Classroom | |
| LO2 4 | Horn Gap reinforcement | How are the gaps reinforced? | Classroom | |

**LO3: Horn Blocks/guides**

1. Horn block/guides
2. Horn block material
3. Securing of horn block
4. Horn stays
5. Adjusting Horn blocks

| LO | Objectives | Assessment Criteria | Delivery | Date achieved and Supervisors signature |
|---|---|---|---|---|
| LO3 1 | Hornblock/guides | Draw a diagram of a hornblock and guides detailing their difference | Classroom | |
| LO3 2 | Material for hornblock | Suggest a material to be used in the manufacture of a horn block and why that material is suitable | Classroom | |
| LO3 3 | Methods of fastening horn blocks | What methods could be used to secure a hornblock to a frame | Classroom | |
| LO3 4 | Horn stays | Draw diagrams of the 3 differing type of horn stays. Why are horn stays necessary? | Classroom | |
| LO3 5 | Adjusting of hornblocks | Why is it necessary to arrange for horn blocks to be adjustable? | Classroom | |

**LO4**: **Alignment of Loco Frames**

1. Incorrect alignment of frames
2. Methods for checking alignment
3. Carl Zeiss method
4. Straight edge method
5. Carry out an alignment check

| LO | Objectives | Assessment Criteria | Delivery | Date achieved and Supervisors signature |
|---|---|---|---|---|
| LO4 1 | Incorrect Alignment | What are the possible consequences of misaligned frames? | Classroom | |
| LO4 2 | Alignment methods | Name the two main systems for checking alignment | Classroom | |
| LO4 3 | Carl Zeiss Optical alignment | Describe the principles of the Carl Zeiss method of alignment | Classroom | |
| LO4 4 | Mechanical method | Describe how you would check alignment using straight edges and taught piano wire. | Classroom | |
| LO4 5 | Check frame alignment using one of the methods above | Carry out an alignment check and report your findings | Workshop | |

## LO5: Frame Cracking & Management

1. Where cracks appear
2. Testing for cracks
3. Crack propagation

| LO | Objectives | Assessment Criteria | Delivery | Date achieved and Supervisors signature |
|---|---|---|---|---|
| LO5 1 | Where cracking is likely to occur | Draw a diagram of a typical loco frame and annotate the areas where cracking is likely to occur | Classroom | |
| LO5 2 | Checking for cracking | Describe how you would check a frame for cracks | Classroom | |
| LO5 3 | Crack propagation | How do you prevent a crack from propagating? | Classroom | |
| LO5 4 | Managing cracking | William Stanier introduced a design into his frames to manage cracking. Draw an annotated diagram to explain his design. | Classroom | |
| LO5 5 | Examination for cracking | Inspect a loco frame for evidence of cracking and report your findings | Workshop | |

### From Module LM1 – Wheels and Axles

| | | | | |
|---|---|---|---|---|
| LO3 2 | Pressing of wheels onto crankshaft axles | Describe the issues involved around wheel pressing with crankshaft axles | Classroom | |
| LO3 3 | Weighing of locomotive wheel sets | Describe why a locomotive should be weighed | Classroom | |
| LO3 4 | Adjustment of weight | Describe how to correctly adjust weight | Classroom | |
| LO3 5 | Checking | How would you check the process has been carried out correctly? | Classroom | |

On completion of the module the trainee should be able to use correctly and safely the following equipment:

- Measuring instruments
- Hand Tools
- Alignment equipment

**Assessment**

Learners could demonstrate competence in this unit by:

- Documental evidence
- Photographic evidence
- Witness statements e.g. written or verbal statement from a competent person stating that they have completed tasks satisfactorily.
- Underpinning knowledge questions e.g. written questions, multi choice answer sheets, on-line tests, and assignments.
- Practical training tasks