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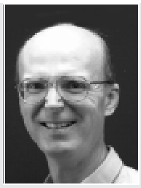

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Rail ballast: conclusions from a historical perspective

P. Claisse and C. Calla

Although it is now universally accepted that good-quality hard angular stone of nominal size 40–50 mm is the best material for ballast, historically track has been for longer on non-stone ballast than on stone ballast. Even the stone ballast specified up until the 1980s was of a smaller average size than present ballast. Research into the two-layered ballast system and a study of development of ballast specification from the early 1900s suggests that current ballast specifications should be changed to ballast of smaller size. This would: cause substantial reduction in maintenance requirements for ballasted railway track; reduce track noise levels; provide better ride quality; and increase ballast life.

1. INTRODUCTION

Ballast by weight and by volume is the largest component of the track, and the cost of buying and distributing ballast forms a significant part of the entire civil engineering budget of the railways.[1] In spite of the fact that ballast is the most important component of the permanent way, most attention has been focused on the track superstructure of rails, fasteners and sleepers, and not much consideration has been given to understanding the behaviour of ballast in detail.[2] It is now universally accepted that good-quality hard angular stone, free from dust and dirt and not prone to cementing action, is the best material for ballast. However, historically track has been for longer on non-stone ballast than on stone ballast,[3] as the first passenger train in the UK was run in 1821 and stone ballast was not adopted on all tracks until the 1930s.

This paper looks into the history of ballast specifications to understand how they have developed over the years. In light of the research into the two-layered ballast system,[4] some interesting facts have come to light with regard to specification of ballast size and material for ballast. Based on the conclusions of the research, a change in the current ballast specification may be appropriate. This paper discusses the merits of such a change, and the historical evidence to support it.

2. ORIGIN OF BALLAST

The term ‘ballast’ as a part of railway track originated on Tyneside in the UK. In the *Guinness Railway Book*[5] John Marshall mentions that ships carrying coal away from Newcastle returned ‘in ballast’ laden with gravel and other materials to maintain stability. This ‘ballast’ was dumped by the quays and was used to provide a solid bed for the tramways that carried the coal. This association of the word ‘ballast’ with the tramways was continued, and was adopted for the railways.

Early railway engineers aimed at complete rigidity of track by installing track on massive stone blocks laid on level ground. George Stephenson stuck to the system of track on rigid stone blocks for his Liverpool to Manchester railway.

Randell[6] describes the efforts of early engineers who ‘sought to form a solid bed, by pounding mother earth with the blocks of stone which were to carry the track’. He also describes an instance on a railway track between Manchester and Leeds where sleepers were fastened directly to a dressed rock cutting; this track lasted only a few weeks. Instead of laying the sleepers directly onto the ground, the engineers realised the need for a resilient base to the sleepers. More importantly, they realised the need to keep the track top ‘level’ and thus the need for material below the track, which would allow lifting and packing of the track. In many instances a sprinkling of ballast was considered sufficient bed.[6] Ballast was viewed as a medium for surfacing the track, and Ahlf[7] describes a rule of thumb in early railways that ‘ballasting and raising of the track should not exceed the amount of lift necessary to restore the surface of the track.’[7] The material had to have the right balance of rigidity and elasticity to carry the load of railway traffic without causing damage to the track superstructure components and to be able to distribute the loads to the subgrade. The material had to be free draining to prevent waterlogging of the track.

We can summarise the functions of ballast as follows.

(*a*) It provides resilience to the track and distributes stresses from the sleepers to the subgrade.
(*b*) It provides lateral and longitudinal stability to the track and maintains track gauge.
(*c*) It facilitates maintenance and provides immediate drainage of rainwater from the track.

To perform the above functions ballast depth, size and shape are specified, and the material best suited for ballast is also specified.

3. MAINTENANCE OF BALLASTED TRACK

The fundamental principle of track maintenance is as follows: to maintain a good 'top' on a line it must be lifted wherever it is low, and the ballast must be packed firmly under the sleepers at the points where they have been lifted. Thus an important requirement of ballast is to lend itself easily to maintenance of the track 'top'.[8]

Track maintenance has evolved in two basic families, as shown in Fig. 1. The methods detailed in Fig. 1 are shown schematically in Fig. 2.

In tamping, the sleepers are lifted to the required level, and the crib ballast (ballast around the sleepers) is packed into the void below the sleeper, either manually or by mechanical means. With mechanised on-track tamping machines the sleepers are lifted, and vibrating tamping tines are introduced into the ballast on both sides of the sleeper, the vibration easing the entry of the tamping tines. The vibration frequency is chosen so as to fluidise the ballast, which then is compacted inwards and upwards towards the bottom of the sleeper. Owing to the vibrating action of the tamping tines the best results for tamping are achieved on single-graded stone[9,10] and ballast size greater than 37 mm (private communication with Tim Wood of Scott Wilson Railway on ballast specification, 2002).

In measured shovel packing the sleepers are lifted above the required level and smaller-size stone chips (5–12 mm) are used to fill up the void (see Fig. 3); the sleeper is then lowered back onto the stone chippings. The height by which the sleeper is lifted above the required level depends on the size and amount of stone to be introduced below it. Stoneblowing is the mechanised version of measured shovel packing; it utilises compressed air to blow stone chips of size 14–20 mm into the void below the sleeper (see Fig. 2(b)).

The main drawback of the tamping process as compared with stoneblowing is that each tamping run damages track ballast, fouling the ballast with smaller particles, and a tamped track returns back to its pre-tamp position progressively more quickly after each tamping run. More than 50% of fouling of ballasted track in the UK has been reported as being caused by tamping of the track.[12] Thus repeated tamping of track hastens ballast renewal.

Although stoneblower trials in the UK have been successful, mechanised tamping is at present the mainstay of maintenance of ballasted track. The general opinion of authors on track maintenance is in favour of stoneblowing as compared with tamping, but the process is looked at with some scepticism by railway engineers in the UK.[13] This could be because of the poorer initial top achieved by stoneblowing as compared with tamping. One of the reasons for the poor initial top is the use of 20 mm stone for stoneblowing as compared with the 5–

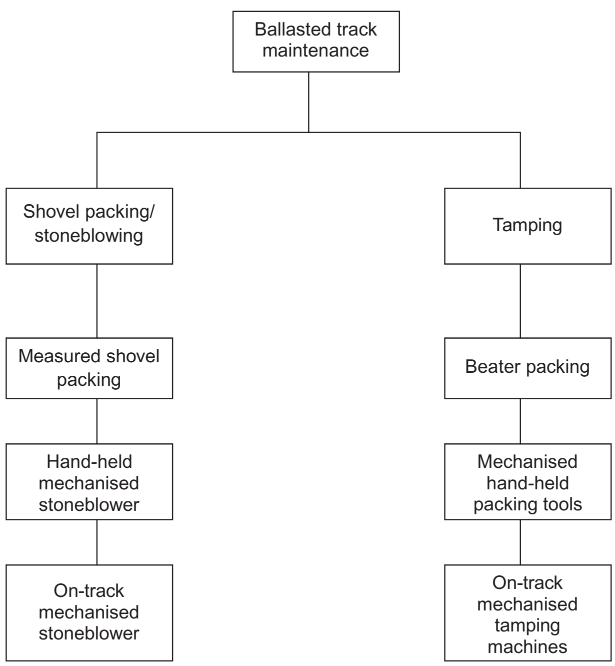

Fig. 1. Ballasted track maintenance methods

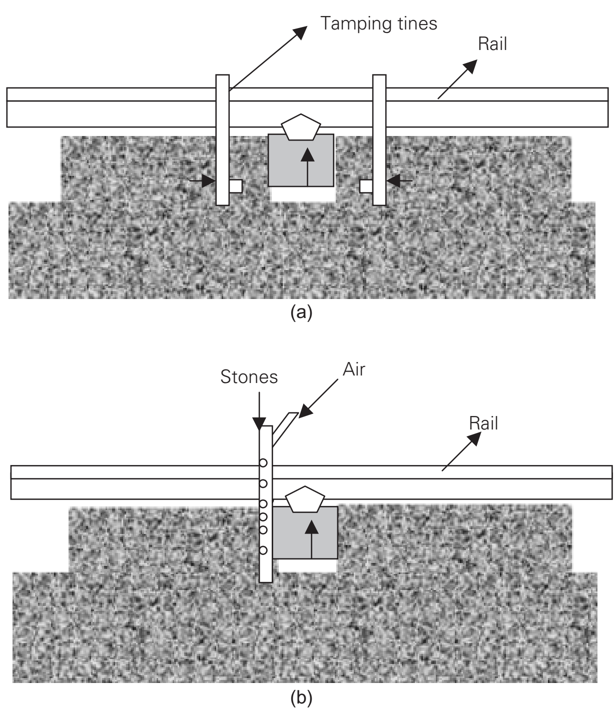

Fig. 2. (a) Tamping operation; (b) operation of pneumatic ballast injection machines (stoneblowers)

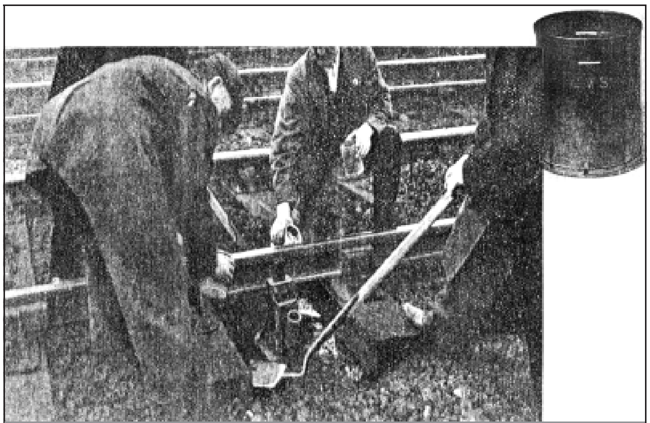

Fig. 3. Measured shovel packing in progress: note the can used to measure the quantity of chips required for packing[11]

10 mm stone used for measured shovel packing. The use of larger stone for stoneblowing does not allow for finer corrections to the track top.

The stoneblowing stone is placed in the position of maximum ballast stress, but it has been observed that it does not break under traffic.[14] As the stoneblowing stone is smaller than the standard ballast more contact points are developed under the sleeper to allow better load distribution: thus ballast breakage is reduced. Esveld[14] has noted that, contrary to the view that stoneblowing stone impedes track drainage, it actually helps to improve drainage because it reduces or eliminates the vertical pumping action of the sleeper.

4. MATERIAL FOR BALLAST

Ballast, being the largest component of the permanent way in terms of volume and cost, should ideally be a cheap material capable of being packed.[1] A variety of materials have been used as ballast along with stone ballast up until the 1970s: these are discussed in this section.

In the early railways easy availability and cost were the two most important factors considered for selection of ballast materials. Any locally available and cheap material was used. By the early 1900s permanent way engineers understood the importance of ballast and its functions with regards to stress distribution to subgrade and drainage. Tratman[15] has stated that 'ballast is a most important item in securing good track, with economy in maintenance and operation.' He recommends the use of hard and tough rock for ballast. In literature from the UK from the early 1900s it is accepted that hard angular stone is the best ballasting material, but various other materials were accepted for use as ballast. The reason for this could be the great difficulty encountered in trying to transport large quantities of stone to all the various locations where track was being constructed. In Britain, with no stone quarries in the south-east, it would have been virtually impossible to transport huge amounts of stone from the north without the railway being in existence.

Some ingenuity was used in trying to adapt any locally available material as ballast. Tratman[15] mentions the use of oyster shells as ballast on some lines along the coast in America. Otherwise materials such as ashes, sand, slag, broken bricks and clay were all used.[6,15] Fig. 4 shows track ballasted with 37·5 mm (1·5 in.) slag ballast.[6]

Ashes were considered good material for ballast as they were free draining and provided for good packing under the sleepers, although they would disintegrate quickly under heavy loads.[16] They also provided a very silent track.[6] Even as late as 1922, 90% of the mileage of the former North Eastern Railway was ballasted with ash.[1] Ash was accepted as an alternative to stone ballast in *British Railway Track*, published by the Permanent Way Institution, until the 1971 edition,[17] but it disappeared from the list of acceptable materials for railway ballast in the 1979 edition.[18] The current authors suggest that the main cause for this may simply have been the end of the supply of ash from steam locomotives, as these were phased out of use. Also, mechanised tamping machines were introduced on the UK railways in 1970s, and these are ineffective in maintaining track with ash ballast. Ash ballast was maintained by measured shovel packing, and thus with the increasing use of mechanised tamping machines ash ballast was phased out of the railways. Railwaymen working with ash used to consider it a good material for ballast, as it was easy to handle and could be readily packed under the sleeper, allowing for fine adjustments to track vertical alignment (private communication with Tim Wood of Scott Wilson Railway on ballast specification, 2002). One problem with ash ballast was that it was chemically harmful to wooden sleepers and track fittings.[6]

Another material used as ballast worthy of note is sand.[6,15,19] Coarse sand was considered as good ballast for light traffic.[15,19] The drawback of sand was that it was washed away by rain or drifted away by the wind. Sand was used on tracks in France and India covered with a layer of broken brick or stone to prevent it from washing or blowing away,[15] and is still used on some tracks in India, as reported by Arora and Saxena.[19] Another means used in America for preventing sand from blowing away was to apply a layer of crude oil on the sand, called oiling of ballast. One notable advantage of sand ballasted track is that it is noiseless, an attribute that would be very popular in many modern railways. It has been the experience of one of the authors while travelling on a train in the desert regions of India that sand blows off from the desert and enters the stone ballast in many locations. These tracks give a virtually noiseless ride to the trains. Contrary to what one would expect, Tratman[15] mentions that track drainage is not a problem with sand if it is clean. The British experience with sand was not successful, and Randell[6] mentions the problems with sand ballast in wet weather with it becoming spongy and in dry weather with it flying in all directions. Again, it is difficult to maintain sand-ballasted track by beater packing or tamping; the only possible means of maintenance is measured shovel packing.

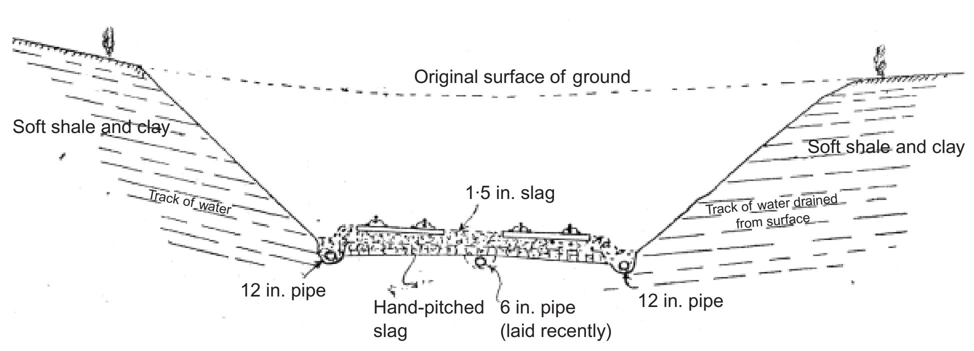

Fig. 4. Track ballasted with 37·5 mm (1·5 in.) slag ballast[6]

5. BALLAST SIZE

The most important parameter of ballast is its size and gradation. Ballast size should be chosen such that it supports the track superstructure, allows for drainage of water, and also lends itself to maintenance for correcting track geometry faults. The choice for ballast gradation is generally similar in all countries, with some local variations.[1]

The importance of having good-quality hard stone with sharp edges as ballast was understood by permanent way engineers by the 1900s, although the specification for the stone was not very clear about size and quality. F. R. Conder, in his book *The Men Who Built the Railways*[20] (first published in 1868) mentions an instance of a specification for ballast that stated 'no bit of broken stone be used as ballast larger than a man could put in his mouth'. Conder then describes how a contractor used a labourer with the largest mouth as a ballast gauge in anticipation of questions regarding ballast size by the engineer on a site visit.

The size of ballast was selected based on trial and error with different sizes over the years, and it seems that selection was based on the size that would allow easy and efficient maintenance of the track with mechanised tamping machines. In the days when track was maintained by manual means ballast consisted of smaller stones, but with the introduction of mechanised on-track tamping ballast size has been increased to suit the tamping machines (private communication with Tim Wood of Scott Wilson Railway on ballast specification, 2002). The main concern in the days of manual track maintenance was to achieve fine adjustments to the track vertical alignment, for which ballast consisted of smaller stones.[7] Ballast in the USA in the 1900s used to be smaller stones of size around 20 mm and less, but this was soon changed to 50 mm. Tratman[15] mentions that stone broken to a 0·75 in. (20 mm) size is less noisy, wears the ties less, can be tamped more easily, and gives a better surface with less labour. The earliest reference the authors could obtain, from the UK in 1913, shows in figure 2·44 a track section ballasted with 37·5 mm slag ballast.[6] Another reference, from 1928, mentions that 'stone ballast should be of size passing a ring of 50 mm (2 in.) diameter however presented'.[21] Tazwell[21] mentions that it was very expensive and difficult to obtain stone of such specification, and he gives an example of a permanent way ballasted with 25 mm slag ballast, and also an example of the difficulty of maintaining a track with ballast larger than 75 mm (3 in.). Another factor before railway nationalisation was that the various companies used different specifications for the ballast, and also different methods for maintenance. It is more likely that, with a broad specification of stone passing a 50 mm diameter ring with no limit on the minimum size, except 'not to contain smaller material than is made in the process of crushing',[21] the ballast used in the early railways was stone of size 10–25 mm. In the book *British Railway Track* (1943 edition), Hamnett[8] mentions that good qualities of ballast are

(*a*) good bearing capacity
(*b*) good drainage capacity
(*c*) high frictional resistance to movement of sleepers
(*d*) suitability for packing.

He then mentions that the first three qualities would be fulfilled by a hard angular material, which will lock together and will not crush into dust. To satisfy the fourth requirement, the material should pass a 50 mm (2 in.) mesh sieve. Note that no minimum size for the stones has been specified, and even the 1979 edition[18] of the book specifies ballast as stone passing a 40 mm sieve and states that a proportion of smaller material is desirable. Thus again it seems likely that ballast consisted of small stones of average size 20 mm to allow for effective maintenance of the track. In the book *Track Laying for Underground Haulage* published by the British Coal Board,[22] ballast for a new track is specified as follows.

> The material should pass through 1·5 inches (37·5 mm) square or 2 inches (50 mm) round mesh and stand on $\frac{3}{8}$ inches (9·5 mm) square or $\frac{1}{2}$ inch (12·5 mm) round mesh. The coarser material is used for the initial layer of ballast and the finer for the final packing and lifting to grade.

The authors are of the opinion that the same philosophy was applied when ballasting railway track. Wood (personal communication) is of the opinion that ballast on British Rail, even in the late 1960s, was of smaller average size, with more particles in the size range 15–20 mm. This was before the widespread introduction of the on-track tamping machines and when measured shovel packing was still the preferred method of maintaining the track. As measured shovel packing was carried out using 5–12mm stone chips, with larger bottom ballast the stone chips would be lost in the voids of the bottom ballast.

Thus it seems that the present ballast specifications were developed between the 1980s and 1990s. The requirements of the ballast specifications became more stringent, requiring a larger percentage of particles in the ballast matrix of a size between 37 mm and 50 mm. The present ballast specifications have evolved from ballast with a smaller average size—that is, a maximum size of 50 mm with a large proportion of particles of size 10–30 mm—in the 1970s to ballast with larger average size, with the majority of particles of size between 37 and 50 mm. Mechanised tamping machines vibrate the ballast to fluidise it before compacting it in the void below the sleeper. Small stones would flow around the tamping tines, and effective compaction of the ballast would not be achieved. Modern research confirms that effective packing of ballast by tamping requires that it consist of single-size particles,[9,10] as tamping of well-graded ballast will cause it to segregate, with the smaller particles moving down towards the subgrade when vibrated.

It is interesting to compare the British Rail specification for ballast in 1988,[1] the Railtrack specification for ballast in 1995, and the draft European specification for ballast released in 1997:[23] see Table 1.

As can be seen in the table, in 1988 ballast was a broad collection of particles, with sizes ranging from 28 mm to 50 mm, and up to 20% of the particles of size between 14 mm and 28 mm. In the 1995 specification most of the ballast is stones of size between 37·5 mm and 50 mm with a small percentage (up to 20%) of stones with sizes between 14 mm and 28 mm. In the draft European specification particles of size between 63 mm and 80 mm have also been introduced into the ballast, and the minimum size possible is between 32 mm and 22 mm.

It is also noted that the main concern of modern railway

Size: mm	% passing sieve						
	British Rail specification 1988	Railtrack specification 1995	European specification 1997 for different track categories (taken from draft prEN 933–1)[23]				
80	–	–	100	100	100	100	100
63	–	100	100	97–100	95–100	97–100	95–100
50	97–100	97–100	70–100	70–100	70–100	65–95	55–100
40	–	–	30–65	30–70	25–75	30–60	25–75
37·5	–	65–35	–	–	–	–	–
31·5	–	–	0–25	0–25	0–25	0–25	0–25
28	0–20	0–20	–	–	–	–	–
22·4	–	–	0–3	0–3	0–3	0–3	0–3
14	0–2	0–2	–	–	–	–	–
1·18	0–0·8	0–0·8	–	–	–	–	–

Table 1. Development of British Rail ballast specification

Size: mm	Network Rail specification: % passing	Proposed specification			
		Option 1: % passing	Option 2: % passing	Option 3	
				Bottom ballast (below sleepers)	Crib ballast (around sleepers)
63	100		Stoneblowing stone specification	Current for Network Rail specification for 50 mm ballast	Stoneblowing stone specification
50	97–100	100			
37·5	65–35	77			
28	0–20	67			
20	–		100		100
14	0–2	12	17		17
10		0	0		0
1·18	0–0·8				

Table 2. Current and proposed ballast specification

engineers as regards the use of stoneblowing for track maintenance and smaller stone for ballast is that the smaller particles in the ballast matrix (size 14–20 mm) will hamper drainage. To date, none of the literature on track drainage has suggested that an increase in smaller particles in the ballast matrix will hamper drainage. Instead Selig and Waters[2] have suggested that even track fouled with sand particles and gravel (< 6 mm in size) will provide adequate drainage. Even clean sand ballast provides good track drainage.

6. PROPOSED TWO-LAYERED BALLAST SYSTEM

The authors have been involved in research and testing on an innovative method of ballasting railway track by replacing crib ballast around the sleepers with stones of size smaller than standard railway ballast. Model-scale and full-scale laboratory tests carried out on the proposed system have shown that, if a void is formed below the sleeper larger than the particle size of the crib ballast, the crib ballast moves in under the sleeper and fills up the void.[4] The proposed system does not work with steel sleepers. The working of the system is not affected by the depth of ballast below the sleepers. The proposed system has good potential as it maintains the track level with minimum human intervention. If implemented it would reduce the maintenance requirements of ballasted railway track, as with the use of smaller ballast voids below sleepers will be virtually eliminated, depending on the size of ballast used.

7. CONCLUSION

On the basis of the historical evidence given in this paper and the results of tests on the proposed two-layered ballast system[4] the authors propose that a change in the UK ballast specification be considered. Table 2 gives the current and proposed specifications for ballast. The proposed specification has been subject to full-scale laboratory tests as part of the research for the two-layered ballast system.

Initially the proposed system can be implemented by removing existing size crib ballast and replacing with smaller stone, leaving ballast below the sleepers as existing (Option 3). When implemented with complete ballast renewal, existing ballast should be replaced with nominally single-sized smaller ballast (Option 2) or graded ballast (Option 1).

The advantages of the proposed specification would be

(*a*) reduced maintenance of ballasted railway track
(*b*) increased life of ballast
(*c*) better ride quality of track
(*d*) low rail fatigue
(*e*) less noise from tracks.

The change should take place at the same time as a move from tamping to stoneblowing for ballasted track maintenance.

REFERENCES

1. COPE G. H. *British Railway Track: Design, Construction and Maintenance*. The Permanent Way Institution, Stoke on Trent, 1993.
2. SELIG E. T. and WATERS J. M. *Track Geotechnology and Substructure Management*. Thomas Telford, London, 1994.
3. BALL M. *Railway Ballast Maintenance*. Final year project, School of Science and the Environment, Coventry University, 2003.
4. CLAISSE P. A., KEEDWELL M. and CALLA C. Tests on a two-layered ballast system. *Proceedings of the Institution of Civil Engineers: Transport*, 2003, **156**, No. 2, 93–101.
5. MARSHALL J. *The Guinness Railway Book*. Guinness, Enfield, 1989.
6. RANDELL W. Track beds and ballast. *Journal and Proceedings of The Permanent Way Institution*, 1913, **31**, No. 1, 82–87.
7. AHLF R. E. Ballast basics: Part I. *Railway Track and Structures*, 1995, April, 14–15.
8. HAMNETT R. A. *British Railway Track: Design, Construction and Maintenance*. The Permanent Way Institution, Nottingham, 1943.
9. SELIG E. T. Ballast's part: its key roles and qualities. *Railway Track and Structures*, 1998, March, 21–35.
10. SELIG E. T. Ballast performance: considering more key factors. *Railway Track and Structures*, 1998, July, 17–20.
11. FRAZER I. R. Measured shovel packing. *Journal of The Permanent Way Institution*, 1935, **53**, No. 3, 79–95.
12. MCMICHAEL P. L. and STRANGE P. R. BR adopts new maintenance process. *International Railway Journal*, 1992.
13. CALLA C. *Two-layered Ballast System for Improved Performance of Railway Track*. PhD thesis, Coventry University, 2004.
14. ESVELD C. *Modern Railway Track*. MRT Productions, Zaltbommel, The Netherlands, 2001.
15. TRATMAN R. E. E. *Railway Track and Track Work*, 3rd ed. McGraw-Hill, New York, 1909.
16. HAMNETT R. A. *British Railway Track: Design, Construction and Maintenance*, 2nd ed. Permanent Way Institution, Nottingham, 1956.
17. COOMBS D. H. *British Railway Track: Design, Construction and Maintenance*, 3rd ed. Permanent Way Institution, Nottingham, 1971.
18. HEELER C. L. *British Railway Track: Design, Construction and Maintenance*, 4th ed. Permanent Way Institution, Nottingham, 1979.
19. ARORA S. P. and SAXENA S. C. *A Text Book of Railway Engineering*. Dhanpat Rai and Sons, New Delhi, 1988.
20. CONDER F. R. *The Men Who Built the Railways* (SIMMONS J. (ed.)). Thomas Telford, London, 1983.
21. TAZWELL B. Lifting and packing. *Journal and Proceedings of The Permanent Way Institution*, 1928, **46**, No. 3, 179–184.
22. ANON. *Track Laying For Underground Haulage*. British Coal Board, 1973.
23. BRITISH STANDARDS INSTITUTION. *Tests for Geometrical Properties of Aggregates*. BSI, London, 1997, BS EN 933-1: 1997.

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