DEPARTMENT OF TRANSPORT

RAILWAY ACCIDENT

Report on the Collapse of Penmanshiel Tunnel that occurred on 17th March 1979

IN THE
SCOTTISH REGION
BRITISH RAILWAYS

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RAILWAY INSPECTORATE
DEPARTMENT OF TRANSPORT
2 MARSHAM STREET
LONDON SW1P 3EB
2nd August 1983

SIR,

I have the honour to report for the information of the Secretary of State, in accordance with the Direction dated 20th March 1979, the result of my Inquiry into the fall of rock that occurred at about 03.45 on 17th March 1979 in Penmanshiel Tunnel in the Scottish Region of British Railways.

At the time of the accident, work was in hand to increase the effeetive headroom by lowering the floor of the tunnel. The work on the Up (southbound) track had been completed and it had been reopened for single line traffic while a party of contractors' employees were engaged in tidying up the newly-excavated floor preparatory to the relaying of the Down line when the roof of the tunnel collapsed over a length of some 20 metres, allowing a quantity of broken rock, estimated at over 2000 tonnes, to pour into the tunnel, blocking it completely.

Of the men at work in the tunnel, 13 made good their escape but 2 were overwhelmed by the fall of rock and lost their lives, despite urgent and determined efforts at their rescue and recovery, including the attendance of a Mines Rescue team. Fortunately, no train was in or closely approaching the tunnel at the time of the collapse.

This report on my Inquiry, which was carried out under the provisions of the Regulation of Railways Act 1871 with the object of establishing, so far as it was possible, the cause of the collapse and what precautions should be taken, in the interest of public safety, to prevent any recurrence, does not describe the detailed circumstances of the two fatalities which led to the Railways Board and the Contractors concerned being indicted under the Health and Safety at Work, Etc. Act 1974. At a trial in the High Court at Edinburgh in May 1980, the Board pleaded guilty, and the Contractor not guilty, to charges of having failed to ensure that persons in the tunnel were not exposed to the risk of personal injury by the collapse of part of the structure. These pleas were accepted and the Board was fined £10,000.

In the event, it has not been possible to establish with any degree of certainty the actual cause of the collapse, despite extensive subsequent site investigations. It became apparent soon after the accident that the removal of the collapsed material would be a difficult and possibly very dangerous operation and that the reopening of the tunnel to traffic would take a long time and also be extremely expensive. It was decided, therefore, to abandon the tunnel and to divert the line on a new alignment in open cut to the west of the tunnel. The diversion scheme was commenced on 7th May and opened to normal traffic on 20th August 1979.

A length of some 1000 metres of the former route has been abandoned and the ends of the tunnel filled in to prevent further access into it. An obelisk to the memory of the two men who lost their lives has been erected on the hillside above where they lie.

DESCRIPTION

1. Penmanshiel Tunnel was located on the East Coast Main Line about 18 miles north-west of Berwick-on-Tweed, the double line of railway passing through a single bore tunnel 244 m in length on a falling grade in the Down direction of 1 in 96. The track on the approach to the tunnel from the South was on a right-hand curve of 617 m radius, straightening out towards the northern portal. A permanent speed restriction of 60 miles/h was imposed on account of curvature. The tunnel was driven in 1845/46 by Ross and Mitchell, contractors, to the design of John Miller, Engineer to the North British Railway Company and inspected on behalf of the Board of Trade on 18th May 1846 by Major-General Pasley.

2. The tunnel was driven through a formation of sedimentary rock known as greywacke in an area of steeply inclined and confused stratification with an average cover of 25 to 30 metres. It was constructed on the rock bench system with a brick arch of 4 or 5 rings of brickwork, with a span of about 7.72 metres and a rise of 3.17 metres springing from natural rock benches which were originally about 1.5 metres above the level of the ballast. The following extract from General Pasley's report describes the sequence of construction:

> "... but the tunnel itself is not yet passable as it has to be lowered 5 or 6 feet by cutting away the bottom, which is composed of whinstone rock. The upper part of it, though cut out of the same

rock has been lined with masonry or brickwork throughout, but this precaution will not be required for lower part of the sides".

3. As was the normal practice when the tunnel was built, there was a considerable degree of overbreak and the arch ring was not in direct contact with the overlying rock. During the construction of the arch ring, timber props, known as Memel logs, were used to hold up any parts of the exposed rock that appeared insecure until they could be supported by brickwork from the arch ring. After the arch ring was complete, the timber props were cut off flush with the inner face of the brickwork. Towards the northern end of the tunnel, an aperture in the brickwork in the crown of the arch allowed access to a large void above the arch ring. This cavity was approximately 9 metres in length and 6 metres wide and its sides tapered towards an apex some 9 metres above the arch ring. At this point, the ring was of 6-brick thickness and it supported crossing brick walls to hold up the sides of the cavity. Apertures had been left in these walls allowing access to all parts of the cavity for inspection. There was another aperture in the arch ring near the southern portal that had been bricked up at sometime in the past. The tunnel was generally dry except near the portals, above which the rocky hillside rose steeply.

4. During the life of the tunnel, the faces of the rock benching below the springing of the arch ring had been faced in patches with brickwork, making it difficult to determine the exact level at which the true arch was founded. All the exposed brickwork showed some degree of weathering but nothing inconsistent with exposure to steam locomotive exhaust over so long a period.

The Work in Hand

5. The work being carried out in Penmanshiel Tunnel was part of a major scheme to permit the carriage of 8 ft 6in high international containers on freightliner wagons over the East Coast Main Line. Similar improvements had already been completed in Stoke and Peascliffe Tunnels near Grantham. The work involved the removal of the track and ballast, the lowering of the rock floor by amounts varying between 300 and 800 mm, and the installation of paved concrete track through the tunnel and on its approaches, a total distance of some 840 metres. In order to minimise interference with traffic, one track was being dealt with at a time. Work on the Up line had been completed by 10th March 1979 and over the weekend 10th/11th March traffic was transferred to the newly laid track and the Down line lifted and removed from the tunnel. By the date of the accident, the lowering of rock floor of the tunnel had been completed and final tidying up was in progress ready for the laying of the concrete base slab on the Down side.

The Course of the Account

6. Early on the morning of Saturday 17th March there were 5 items of plant at work in the tunnel, 3 JCB excavators trimming the rock floor to profile with hydraulic picks, and a further JCB, fitted with a bucket, loading loose rock into a dumper. The latter was located about 90 metres from the South portal of the tunnel, with a JCB immediately to the North of it. In the same area, in addition to the plant operators, there were two contractor's employees acting as banksmen and the Railway Works Inspector on duty at the time. The latter, from where he was standing on the edge of the concrete slab of the Up track, shone his torch across in front of the dumper towards the tunnel wall and saw small pieces of rock apparently bursting off the vertical face about 200 m below the springing level of the brickwork. He decided that it would be advisable to shore up the wall as a precaution and started to walk southwards out of the tunnel on his way to the site office to make the necessary arrangements. He had walked only some 20 m when he heard a loud noise and turned round to see that the tunnel behind him had collapsed and was filled with rock. He noted that the time was 03.45 and took immediate steps to ensure that the line was blocked to traffic.

7. The rock fall filled some 30 m of the tunnel and engulfed both the dumper and the adjacent JCB, the operators of which could not subsequently be accounted for. Both the banksmen escaped without injury, as did the rest of the men working in the tunnel at the time. Although it was estimated that about 20 m of the arch ring had collapsed, none of the fallen brickwork was visible in the tunnel. Each face of fall was in the form of a scree of broken pieces of rock, filling the tunnel from crown to floor, the individual pieces being angular and ranging in size from 150 mm downwards. Most of the faces of the pieces of broken rock were thinly covered with mud which was reported as damp at the time of the fall.

8. The available evidence which might be expected to throw some light on causes of the collapse comes from three distinct sources; firstly, the previous history of the tunnel, as revealed by inspection reports and maintenance records; secondly, from the way in which the work of enlargement was planned and executed; and, lastly, from the investigations and observations made subsequent to the collapse. Since much of the available evidence is negative in character, little would be achieved by quoting it in full, and I have summarised it for the purposes of this report.

The Previous History of the Tunnel

9. In accordance with British Railways normal practice, Penmanshiel Tunnel had been regularly and comprehensively examined annually, by the Divisional Civil Engineer and his Assistant alternately. The records of these examinations show it to have been in reasonably good condition. The relatively minor defects found from year to year received attention as required, a total of some £45,000 having been spent on the tunnel from 1966 to 1978. The latest examination, carried out on 20th August 1978, revealed no serious defects in the brick lining, although there was some loss of mortar in the joints of the innermost ring and some surface spalling. The general impression was that the brickwork, whilst perfectly sound, was somewhat scabby in appearance and that remedial work should be programmed, to consist of repointing and renewal of spalled areas as necessary: (this work had not in fact been carried out when the collapse occurred).

10. There had been no indication of any serious deterioration in the rock side walls and no apparent serious distortion in the arch ring, although some slight sags had been recorded; there had been no signs of any movement in the arch ring. The void above the arch, described in paragraph 3 above, had been regularly inspected; the rock appeared sound and there was no indication of recent spalling. Because of the existence of this chamber and knowledge of the nature of the rock over the tunnel, British Railways had, in 1971, opposed a scheme to re-route the A1 London-Edinburgh Trunk Road through the hillside over the tunnel.

11. The history of the tunnel revealed only one small untoward incident. Some 25 years ago, whilst repairs were being carried out to a section of brick facing of the tunnel sidewall below the arch, a quantity of broken rock had spilled out into the cess. No detailed record of the incident existed and estimates of the quantity of rock involved, based on verbal accounts, varied from 2 to 5 tons.

The Enlargement of the Tunnel

12. The scheme for enlarging the tunnel to permit the transit of 8 ft 6 in containers had originally been prepared in 1974 and because of the nature of the rock and the undesirability of any interference with the brick lining, it had been agreed that the only possible way of achieving the desired result would be to lower the floor of the tunnel. In order to reduce to a minimum the amount of lowering it was decided to replace the ballasted track through the tunnel with paved concrete track. Based on the assumption that the arch ring was not supporting the overlying rock, the load on the rock side walls was estimated at between 2 and 3 tons/square foot, allowing for a small amount of loose rock lying on the back of the arch. On this basis it was considered safe to increase the height of the rock side walls by the amount required to obtain the additional headroom needed, which was calculated at that time to be up to 500 mm.

13. In the event, the scheme was deferred for 3 years and planning was restarted in 1977, to allow for the possible future electrification of the East Coast Main Line and to take account of clearances needed for the Advanced Passenger Train running at speeds greater than the 70 mile/h planned for conventional trains. This further study showed that the amount of rock to be removed would be an average of 550 mm and a maximum of 770 mm. It was decided that it would be safe to go ahead on this basis, provided that the lowering was done by machine and that great care was taken to ensure that the side walls were not undercut in the process. The use of explosives would not be allowed.

14. Preliminary rock ripping tests and trial borings were made to confirm the feasibility of the proposed method of working and contracts were let early in 1979, work commencing on the site on Sunday, 21st January. As work proceeded it was found that the cross-sectional profile of the tunnel varied in places from the typical cross-section shown in the contract drawings, with the rock side walls curving inwards. Where this occurred, it was necessary to take the excavation closer to the side walls than indicated on the drawings, which showed a scarcement some 600 mm wide at the level of the base slab. In some places, this resulted in the edge of the excavation being flush with the pre-existing face of the side walls. Although great care was taken not to undercut the walls there were some locations where loose pieces of rock became detached. In several where this happened, the engineer in charge instructed that rock bolts be installed to improve the stability of the wall.

15. As the work proceeded, it became possible to make a closer study of the stratification of the exposed rock in the floor of the tunnel and a member of the BR staff with a degree in engineering geology reported that the strata dipped roughly from south-east to north-west, which indicated that, of the two side walls, that on the Up side might be expected to be the more likely to cause trouble. Since, when he received this report, the work on the Up side had already been completed, the engineer in charge was satisfied that the work could be completed without trouble.

16. From the time the work was started, all the staff concerned paid particular attention to the condition of the side walls but at no time were any cracks or fractures of any kind observed. Check tie points were established at 10 metre intervals, where Hilti nails were driven into the side walls. Check measurements were taken across the tunnel every two or three days between these nails but at no time was any movement at all discerned. Nevertheless, as a precaution, the contractor had been instructed to keep a supply of 12 in by 12 in timbers on site so that any part of the tunnel could be shored up without delay should any movement occur. It was thus without any sense of expectation that a major collapse was on the point of taking place that the BR inspector on duty, when he saw small pieces of rock bursting out of the side wall, set off to arrange to have the area shored up.

17. All the staff principally involved in the planning and execution of the project were very experienced in the type of work concerned. The engineer in charge had undertaken similar operations in a total of 17 tunnels, some of them involving work of an identical nature in every respect except in relation to the nature of the rock encountered. The contractor had also carried out similar work for BR in tunnels in the Glasgow area. The work on site would appear to have been carried out with proper care and foresight and to have been properly supervised. There was no evidence that the side walls were subjected to any worse vibration than they had experienced from 133 years of railway traffic nor of their having been heavily struck by the plant at work in the tunnel.

Subsequent Site Investigations

18. In the immediate aftermath of the collapse, it was assumed that it would be possible to clear the tunnel and re-open the line on its original route and that, in the process, it would be possible to gain access to the collapsed zone and so determine the actual mechanism of failure. In the event, this was not to be. For reasons explained above, the collapsed material in the tunnel was not removed and thus direct evidence from the affected area never became available. However, before the decision to re-route the line was taken, in order to make if safe for men to approach the collapsed zone, the adjacent portion of the tunnel roof was supported by a number of steel arch rings. These made it possible to cut a number of "windows" in the brickwork in the area of the springing of the arch, allowing closer examination to be made of the quality of the brickwork and of the way in which the arch ring was founded on the rock benches. A number of holes was also drilled both through the arch near its crown and through the haunches to determine the thickness of the brickwork, the nature of the rock behind it, and the existence of voids or cavities.

19. The results of these investigations were generally inconclusive, but they revealed a number of inconsistencies in the construction of the tunnel. The "windows" cut through the haunches revealed that the brickwork in the arch ring tapered down towards the side walls in most places and to as little as 6 inches in one instance. At another location, within about 60 feet of the collapse, there was a large cavity behind the haunch and in others there were smaller voids, some filled with loose rock. The holes through the crown of the arch revealed varying thicknesses of brickwork but the arch ring was generally at least 5 rings thick. Some showed voids up to a maximum height of about 5 feet, others revealed broken rock overlying the brickwork to a maximum thickness of about 8 feet. The holes through the haunches revealed brickwork varying in thickness from 34 inches down to as little as 6 inches, with voids in 2 cases.

20. Tests were carried out at Paisley College of Technology into the strength of a sample of the collapsed brickwork. They indicated a high compressive strength, although tests on 3 typical half-bricks showed them to be of poor quality individually. The analysis of the mortar showed it to be lime/sand based, but of reasonable strength and possibly harder than the bricks. These results confirm reports of the high strength of the brickwork encountered whenever repairs had been carried out in the past and of the observations made during the cutting of the "windows" in the haunches, which showed good brickwork behind the spalled inner ring, with the internal joints consistently filled with good mortar.

21. A series of resistivity traverses on the hillside above the line of the tunnel, carried out by a firm of Consulting Geotechnical Engineers showed anomalies which suggested the presence of open or debris-filled fissures, with a high proportion of voids in the area over the collapsed portion of the tunnel.

22. The most revealing of the evidence that became available subsequent to the collapse arose from the decision to re-route the line in open cut parallel to and only about 40 metres from the line of the tunnel. This exposed a full-length section of the rock along the line of the tunnel, allowing a detailed

study to be made of the geology of the hill through which the tunnel was constructed. It thus became possible to identify positively a complex anticlinal structure considered by geologists to be most significant to the collapse, the existence of which could never otherwise have been confirmed. The axis of this anticline (inverted "U" structure), where the beds are sharply folded, is characterized by a central core of shattered and sheared rock. This feature appears to intersect the line of the tunnel in close proximity to the collapsed portion of the tunnel. Consequently, in the area of collapse, the direction of the bedding dip is likely to be vertical, with intense jointing and well developed shear zones. Conditions were thus favourable towards the formation of an unstable wedge of broken rock "hanging" over the arch ring of the tunnel. These particularly adverse geological conditions have not been observed elsewhere in the locality.

23. A final piece of evidence in respect of the stability of the remainder of the tunnel structure arose from the use of explosives during the excavation of the new cutting. For this purpose, charges of 500 kg of gelignite were detonated, at distances rarely greater than 40 metres from the tunnel, on each of 18 days. No discernable damage or deterioration was caused to the tunnel as a result.

Discussion

24. The collapse of the tunnel was essentially a localised event and the dangerously unstable condition of the area involved could only have been discovered by means of a very detailed geological exploration of the whole tunnel, for there were no indications of any kind to lead the investigation towards the area where the collapse actually occurred; rather the reverse, because the annual inspection reports contained a minimum of adverse comment in respect of this area. After the complexity of the rock formation became apparent as a result of the excavation of the new cutting, the Board's principal tunnelling consultants expressed the view that it was most unlikely that the extreme complexity of the geology could ever have been deduced from rock exposed in the tunnel or by any reasonable programme of exploratory drilling or other investigation techniques. A similar view was expressed by the geotechnical consultants who carried out the resistivity traverses mentioned in paragraph 21 above.

25. I think it is extremely unlikely, therefore, that, even if a full geological survey had been carried out prior to the work of enlargement being put in hand, it would have produced a sufficient weight of evidence to lead the engineers responsible to reconsider their plans or even to close the tunnel to all traffic until the area had been made safe. At the trial in Edinburgh, the Board was criticised for its failure to carry out such a survey, and to that extent had failed to do all that was reasonably practical to ensure that persons in the tunnel were not exposed to the risk of personal injury by the collapse of part of the structure. If such a survey had been carried out, though it might have provided a good legal defence, it would not, in my opinion, have prevented the collapse of the tunnel.

26. Because the collapse occurred whilst engineering work was in progress in the tunnel, it was natural to reach an early assumption that the way in which the work was being carried out had, in some way, been the cause of the collapse. It is my view that the tunnel had been in a dangerously unstable condition for some time, perhaps for many years, prior to the collapse and that it would have happened in due course, whether or not the work of enlargement had been done. It is likely, however, that the collapse occurred when it did because the additional excavation in the tunnel increased by a small amount the stress in the already over-stressed rock in the side walls. This, however, is not a criticism of the way in which the work was planned or carried out.

Conclusions

27. Without access to the collapsed zone, it is not possible to be certain of the actual cause of the collapse. On the evidence available, it seems likely that it was initiated by the degeneration of the rock within the anticlinal structure over the line of the tunnel, which progressively built up heavy (and probably eccentric) loading on the arch ring beneath it. This excessive loading was probably not well distributed into the rock in the side walls because of deficiencies in the way in which the arch was backed up at its haunches, resulting in stress concentrations in the rock in the side walls in an area where, due to the very steep angle of the bedding dip, it was least able to cope with them.

28. I am satisfied that there are no grounds on which any individual can be held in any way responsible for the collapse.

29. Though there is no possibility of any recurrence as far as this particular tunnel is concerned, British Railways is still responsible for over 900 tunnels, aggregating in length to almost 300 miles,

many of which are well over 100 years old. Their safety record is a good one and there are no grounds for any changes of substance in their procedures for the annual inspection of tunnels by qualified senior engineers, though I am sure that the lessons of Penmanshiel Tunnel will not be lost on those responsible for other tunnels.

I have the honour to be,

Sir,

Your obedient Servant,

I. K. A. McNAUGHTON

Lieutenant Colonel

The Permanent Secretary,
Department of Transport.

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