

# LONDON, MIDLAND AND SCOTTISH RAILWAY.

Ministry of Transport,  
7, Whitehall Gardens,  
London, S.W.1.  
5th July, 1928.

SIR,

I have the honour to report, for the information of the Minister of Transport, in accordance with the Order of the 23rd May, the result of my Inquiry into the circumstances of the accident which occurred at about 3.28 p.m. on Friday, May 11th, at Cofton Tunnel, on the Birmingham-Gloucester section of the London, Midland and Scottish Railway.

This tunnel was in the course of being opened out to form a cutting in connection with a scheme for quadrupling the lines at this point, and a portion of it was undergoing final preparation for demolition, which was to be carried out on Sunday, the 13th May, when a length of some 60 feet of the tunnel roof collapsed without warning. I regret to state that four men, who were working on the line, were killed, and three others were injured. Two of the men killed were Railway Employés, the remainder being employed by the Contractors.

### *Description of Tunnel.*

Cofton Tunnel, which is situated about seven miles south of Birmingham on the Derby and Bristol main line, was built in 1838-1841 as part of the Birmingham and Gloucester Railway.

It was 440 yards long, and had a span of 23 feet, and a height at the centre from rail level of 17 feet 2 inches.

The tunnel, which was not inverted, was built of red brick in lime mortar. In section it consisted of a segmental arch with curved side walls, springing level being 8 feet 10 inches above rail level. The side walls were built in Old English Bond, and are 2 feet thick laid to a radius of 15 feet. The arch was built in separate  $4\frac{1}{2}$  inch rings, with no bonders between the rings, and varied from 1 foot 6 inches to 2 feet 3 inches in thickness, that is from 4 to 5 and 6 rings. The radius of the inner ring was 11 feet 6 inches.

For purposes of construction eight shafts were sunk, of which three were lined with brickwork, and kept open for ventilating purposes, the other five being sealed at the "eye" and filled in. The first six shafts from the north end of the tunnel were nine feet in diameter, the other two being seven feet in diameter. The "eye" of each shaft in the tunnel arch was formed by a cast iron flanged curb, consisting of four segments bolted together and weighing approximately 3 tons. The depth of the curbs was 1 foot 9 inches, and they were shaped so as to conform to the curvature of the arch, the outer edges of the curbs being radial to the arch at all points.

During the period that has elapsed since the time of construction practically the whole of the original inner ring has been cut out in patches, and replaced with blue brickwork either in lime or cement mortar, as a matter of ordinary maintenance. In carrying out this maintenance repair to the side walls the front half of every header brick in the original facing work was cut off, and the replacing blue brickwork laid all stretchers. No accurate records are available of the dates of such repairs, but the most recent appear to have been over 20 years ago.

Generally speaking the brickwork, both original and repaired, was in a sound condition, and the regular and detailed examinations, of which the most recent were in January, 1928, and on May 6th, indicated no serious deterioration on the visible surfaces.

The tunnel was damp in parts and after the failure some of the brickwork behind the lining was found to be in inferior condition, probably largely due to damp. It was not, however, what would be described as an exceptionally wet tunnel.

In 1922 a scheme was prepared for widening about  $2\frac{1}{2}$  miles of this line between Longbridge and Barnt Green, which included the tunnel, by the addition of two new lines on the Eastern or down side.

The tunnel was too tight in gauge to permit the use of modern wide carriage stock, and as the height of the ground above rail level was only about 70 feet it was decided to open out the tunnel and accommodate both the existing and new lines in an open cutting.

In September, 1925, a contract for the construction of this widening was let to Messrs. Logan & Hemingway, Contractors, Doncaster, and in March, 1926, excavation in the cutting was commenced near the south face of the tunnel. All work carried out by the Contractors was under the instructions of the L.M.S. Company's Engineering staff, and the work was supervised by the L.M.S. Company's Resident Engineer. The Contractors and the L.M.S. Company's Engineering Staff were in agreement as to the suitability of the methods adopted.

Careful and elaborate arrangements were made to safeguard traffic on the line, by the provision of a temporary signal box, special automatic alarm communications, flagmen, speed restrictions, etc., together with continuous patrolling and examination of the tunnel.

The material above, which consisted of sandstone and beds of hard marl, was removed in successively lower lifts, and while this excavation was in progress a slip occurred on the west side of the cutting, and to deal with this and other slips threatening on that side, it was decided to construct a heavy concrete retaining wall. This wall was commenced in January, 1927, and was constructed in trench, in alternate lengths 24 feet long by 15 feet wide, and when finished in December, 1927, was 310 yards long, commencing at approximately the north end of the tunnel, and running south alongside the tunnel. The foot of this wall was some 4 feet clear of the outer surface of the tunnel side wall.

During this period the cutting over the tunnel was excavated to a general level of 12 feet above the tunnel arch, and on the east side of the tunnel to a level approximately the same as the springing level of the arch, leaving a minimum thickness at the side of the tunnel arch of 12 feet.

#### *Arrangements for Demolition.*

In November, 1927, the method of excavating the remaining material round the tunnel and removing the tunnel itself was discussed and a scheme in six stages was adopted.

The first three of these stages included the removal of the material above and at the sides of the arch down to approximately springing level, and the fourth stage was the actual dropping and removal of the arch masonry itself. It was decided that this work should be carried out by dividing the tunnel into lengths of about 50 feet by cutting chases through the brickwork across the arch from springing to springing, and that windows should be cut through the haunches at springing level on both sides during the week days prior to the Sundays fixed for demolition, the final dropping being effected by small charges of ammonal in the pillars remaining between the windows.

During all the later stages suitable precautions were taken to ensure that steam navvies and cranes should only work at a safe distance from the tunnel and similarly that no blasting should be allowed within 12 feet of the tunnel.

At the end of April, 1928, it was decided that a length of 400 feet at the northern end of the tunnel should be dropped on Sunday, May 13th, and it was arranged in conference with the traffic officers concerned that on that date the Engineers should have complete occupation of both lines for three periods of about four hours each, and occupation of the down line only throughout the day. On Monday, May 7th, the cutting of the chases and windows was started on this length. When the chases were marked out it was found that the southernmost one would come very close to one of the 9 feet diameter cast iron curbs of the old shafts, and the southernmost length (No. 8) was therefore extended to 60 feet in order that the chase should be well clear of this. The windows at springing level in the haunches were each about 4 feet long by 2 feet 6 inches high, and spaced so as to leave pillars about 3 feet wide between the windows. A light timber strutting was placed in each window in order to prevent the brickwork in the top of the window from falling, but this strutting was not intended to, and in fact could not, give any appreciable assistance to the pillars in supporting the main body of brickwork of the tunnel arch.

The procedure adopted was that the red brick main outer thickness of each window was cut away by men working pneumatic hammers; the light timber strutting was then put in place, and finally the blue brick inner skin of the tunnel was cut through by pneumatic hammers. During the latter work, men were employed in the tunnel below to remove any broken brickwork which fell inside.

Throughout the cutting of chases and windows the brickwork revealed by the cuts was found to be sound and in good condition, the latest inspection being made on the Friday morning by the L.M.S. Resident Engineer who examined chases and windows from outside and inside, and was satisfied as to the condition of the brickwork therein.

#### *Conditions Immediately prior to Collapse.*

By the afternoon of Friday, May 11th, all the chases had been cut and all the windows had been cut and timbered in the northernmost seven sections, i.e., 350 feet out of the 410 feet length which was to be dropped on Sunday 13th. In the eighth section the outer red brickwork had been removed from all the seven windows on the west side and from two windows at each end on the east side and work was in hand on the third window from each end on the east side. The timbering had been inserted in all the windows on the west side, and the carpenters were preparing their timber for the four windows just cut on the east. Most of the inner skin of the windows on the west side had been cut away and the men were just completing the cut in two of these windows near the Barnt Green end.

Thus in the immediate vicinity of the east iron curb there were three pneumatic hammers working, two on the west side and one on the east, and on the west the blue brick inner skin was being cut away in two windows, the red brick having been removed therefrom already.

A heavy mineral train had passed through the tunnel some seven minutes before the collapse. There is no evidence to indicate that the vibration caused by this was abnormal or that its speed was in excess of the 15 m.p.h. restriction. Blasting operations were in progress some 180 yards away, and 4 or 5 small charges of 4 ounces of ammonal were fired about a minute before the collapse. No vibration on the tunnel was noticed from these or similar charges fired earlier.

#### *Collapse of No. 8 Section.*

A number of men were working in the tunnel under No. 8 section, placing sleepers to protect the permanent way in readiness for the Sunday, and clearing away the brickwork knocked in by the workmen outside who were finishing the windows, when the whole of No. 8 section of the tunnel suddenly collapsed on the top of them. One of the men, who was standing at the north end of No. 8 section, suddenly saw light shine through a crack which appeared to open at the Barnt Green (South) end, lying towards the west side of the arch, and which extended to the north end of the section. He had the impression that the crack was near the west side of the curb, and that the west side of the roof fell first. Another man standing below saw dust coming from one of the pillars at the north end on the east side. He shouted a warning and jumped back in time to get clear. Various other men who were working above agreed that the arch collapsed suddenly without any warning. The general impression of those working on the east side was that the arch fell away from them, whereas two men working on the west side had the impression that the arch came towards them like a wave, and they were both knocked over by a quantity of brickwork. Portions of the windows and pillars on the east side were left standing after the collapse.

#### *Measures taken after Collapse of No. 8 Section.*

After the collapse of No. 8 section, traffic was stopped immediately by the cutting of the alarm wire, and steps were taken to extricate those injured and the bodies of the four men who had been killed. Thereafter the fallen brickwork and debris were cleared away as quickly as possible, and by about 8 p.m. the lines were clear for traffic. In the meantime a careful examination of the tunnel had been made, and as no signs of weakness were seen, except on the surface of the

walls of the fallen section, it was decided to allow trains to pass through under a speed restriction of 5 miles an hour, only one train being permitted in the tunnel at a time. Arrangements were also made for a continual examination of the tunnel. Some six passenger trains and eight other trains passed through the tunnel in each direction up till midnight. It was decided that after midnight no more loaded passenger trains should proceed through the tunnel, arrangements being made for passenger transport by bus over the section in question.

#### *Signs of failure of No. 5 Section and Further Demolition.*

On the Saturday morning it was proposed to make another detailed inspection. Shortly before 11 a.m., however, a workman, who was making holes in pillars for the ammonal charges, started work on one of the pillars of No. 5 section by a blow with a pick to form a centre for his drill. No other work had been done on No. 5 section since the previous day. He thought he noticed a small movement of the brickwork and therefore did not start drilling, but sent for the foreman. The latter on arrival observed that two or three courses of bricks of two or three adjoining pillars seemed to have moved outwards and to be standing a little proud of the pillar surface. These pillars were close to the curb on the east side. He did not delay to examine the matter in much detail, but immediately gave the alarm signal to stop traffic, and referred the matter to the engineer in charge, who, observing that on one side some of the brickwork joints of the pillars were opening, and on the other side the mortar was crnshing, decided to demolish No. 5 section forthwith. In the few minutes that elapsed while the charges were being connected up, further signs of weakness appeared and dust started dropping from the roof of the tunnel, and those present considered it probable that unless the charges had been placed and fired promptly the arch would have fallen without them.

By the time the debris of this second fall had been cleared it had been decided that all the remaining portion of the tunnel, as far as the arch had been uncovered, should be dropped forthwith, and the six fifty-foot sections in which windows had been cut, and a further length of some 160 yards in which windows had not yet been cut, were demolished during the week end, the line being reopened for traffic on the following Tuesday. Out of this 160 yards the southernmost ten yards was felled by hand, after chases had been cut, to avoid risk of weakening the remaining portion not yet uncovered. The other 150 yards was felled by explosions as noted below. There remains a length of some 140 yards still standing over which the material has not yet been removed.

The strength of the arch in its uncovered condition is illustrated by the steps which had to be taken for the demolition of the length of some 150 yards which had been uncovered by Saturday, May 12th, but in which windows had not then been cut. When it was decided to drop this as rapidly as possible, charges of  $1\frac{1}{4}$  lbs. of ammonal were fixed at 7 feet intervals in the outside of the springing of the arch on one side, and these were fired simultaneously, with the result that a number of windows were blown through the arch on that side. Similar charges at the same intervals were then applied and fired on the opposite side with a similar result, and only some 20 feet of the tunnel at one end came down.

Thus the majority of the arch still remained standing, though probably in a precarious condition, even after windows of appreciable size were made at the same intervals as in the original eight lengths, and in spite of the fact that these latter windows had been made, not one by one like the others, but by simultaneous explosion all along each side in turn, which would presumably have been a more severe strain on the structure than individual cutting by pneumatic tools.

Ultimately it was necessary to put in a number of additional charges in the legs to bring this length down, and even after this a number of portions of brickwork up to 4 or 5 feet high were left standing and some had to be brought down by still further small charges.

#### *Method Adopted and Possible Alternatives.*

The method adopted for the demolition of this tunnel was a well-known one and had been employed successfully in a similar work on the L.M. & S. Rly. a few years before. It is common knowledge that it is often surprisingly difficult

to weaken a well-constructed arch sufficiently to make it fail, and cases have been known where the brickwork on one side has been cut away until a solitary brick remained which gradually crushed until the arch fell.

The object of the windows is to weaken the structure along the intended line of failure to such an extent that it is possible to do the final demolition by small charges, and thus ensure that no material damage will be caused to the side walls and also that no large portions at the side of the arch will remain standing to form a source of danger and delay in demolition after the main explosion.

The obvious alternative was to erect a shield inside the tunnel, but owing to the small dimensions of the tunnel it was not possible to erect a shield which would enable trains to continue to run on both tracks while the demolition of the tunnel was in hand by gradual process, probably over a period of five weeks or so. It would have been possible to erect a shield if the tracks had been interlaced or converted to single line, but it was considered by the Company's officers that single line working on this section for such a comparatively lengthy period was not practicable. The line in question carries about 170 trains a day in both directions, about half of which are passenger trains including a number of through expresses, and the best alternative route would involve a considerable detour over a foreign line, which would cause inconvenience and delay.

Another scheme considered was to divert the traffic of the down line over a temporary track to be laid in the cutting on the east side, the tunnel then being used single line for up traffic only, thus giving space for a shield in it. The main objections to this were the risks of slips in the cutting and various practical difficulties about the clearance of material and demolition if half of the cutting were occupied, while under construction, by a running line.

Assuming that these two schemes were ruled out for the reasons stated, there remains the plan which was actually adopted for the demolition of the 150 yards in which windows had not been cut prior to the Saturday, i.e., the use of explosives alone. This would no doubt necessitate longer periods of complete occupation of the lines than the four-hour periods originally arranged, but there appears no reason why each such occupation should extend beyond the daylight hours of a Sunday, and it is understood that this method is under consideration for the final demolition of the length still standing.

A careful check of the theoretical curve of equilibrium of the arch after it had been uncovered down to springing level indicates no adequate reason to doubt its stability in this condition, the curve lying almost within the centre third throughout; the difference between the portions containing the curbs and those of plain brickwork is in this respect negligible, the total extra weight caused by a curb being less than 2 tons, which might safely be assumed to be distributed over at least 12 feet run of the tunnel.

Having due regard to the information available and all the circumstances it was decided that the arrangements proposed for the demolition of the tunnel were suitable, and that there were no reasonable grounds for anticipating risk of accident.

Notwithstanding these considerations one section of the tunnel did actually collapse, and another section was in a very precarious condition; it would appear probable from the latter that the margin of safety throughout the sections in which windows were cut was unduly low.

#### *Probable Causes of Failure.*

Analysis of the origin of such an accident must be to a large extent a matter of speculation. There are, however, certain indications of probable causes of failure as follows:—

From markings on the curbs of No. 8 and No. 5 sections, it appeared that the brickwork of the arch had not been bearing on a considerable portion of the perimeter of the curb on both sides, though it was impossible to detect this on the surface of the brickwork, either inside or outside. The surface (blue) brickwork round the curbs inside the tunnel had been examined by the Resident Engineer in person and no defects were visible, but owing to the presence of the flanges it would in any case have been impossible to detect faulty brickwork between the inner and outer rings.

Assuming that the brickwork of the arch was not bearing on a considerable portion of the perimeter of the curbs, it is reasonable to suppose that the curb itself was not acting properly as a keystone, but was largely a dead weight on the adjoining brickwork, and possibly such arch action as did exist was mostly taken up by the inner ring of blue brickwork which was not bonded to the adjoining brickwork either in the arch or in the side walls.

Immediately opposite the curb in No. 8 section a comparatively large patch of blue brick lining had been laid in lime mortar, and after the collapse it was found that this patch had stripped bodily off the side wall. Assuming that most of the load was being taken by this blue brick inner lining there would have been on it at the springing a thrust of some 5 to 6 tons per square foot in a direction within 20 degrees of the vertical, prior to the cutting of windows. The latter operation would have more than doubled the thrust on the portions left standing, which in addition to violent vibration of the pneumatic hammers operating from the outside, might well have been the final factor in weakening the structure to the point of collapse.

Apart from the stripping of inner blue brickwork referred to above there were no signs of bulging or cracking in the side walls either before or after the demolition, and there appears to be no suspicion that these were affected in any way by slips, explosions or other excavation work.

The cast iron curb in No. 8 section was found to be broken at the two opposite bolted joints, on the diameter at right angles to the length of the tunnel. The breaks were apparently many years old, and may well have dated from the original construction of the tunnel. Two of the coupling bolts were missing from the lower edge of the joints. The circumstances were such as to indicate that the lower edges of the curb had been forced apart, presumably by a heavy pressure from above on the centre of the curb. The breakages were not visible from the surface and were not discovered until after the collapse. The position and extent of the breakages were such as to make it unlikely that they had any connection with the portions of brickwork which were not bearing on the exterior perimeter of the curb. After the collapse of No. 8 section the whole of the curb was found to have fallen solid with the brickwork inside it. In view of this fact I think it is unlikely that the breakages of the curb joints had any direct effect in weakening the arch structure.

Accepting the combination of the three reasons suggested above as explaining the collapse of No. 8 section, viz., (a) indifferent brickwork not bearing properly on curb and consequent lack of proper arch action, (b) patch of inferior brickwork in lime mortar in side walls and springing opposite the curb and (c) vibration and loosening of brickwork in pillars caused by three pneumatic hammers operating in vicinity of curb, we have in the case of No. 5 section the same reason (a) brickwork not bearing on curb, and the possible after effects of (c) loosening of brickwork in pillars by pneumatic hammers, but there is no evidence to indicate any defective brickwork at the springing, nor were the pneumatic hammers in operation on No. 5 section for many hours prior to the collapse.

The curb in No. 5 contained an open shaft, and the brickwork of this shaft had been left in position for a height of some 3 feet, but the weight of this was only approximately equal to the weight of the brickwork used in bricking up solid the closed shaft at the curb of No. 8 section.

I do not consider that reason (a) indifferent brickwork not bearing properly on the curb, is in itself sufficient to explain the failure of No. 5 section, though the fact that both the sections which failed contained such curbs indicates the probability of this being a contributory factor of importance. I consider that the only reasonable explanation is that the cutting away of such large windows combined with the shattering effect of the pneumatic hammers, had reduced the margin of safety of the whole structure to such a low limit that the hidden defects in the brickwork and possibly also the vibration of passing trains were sufficient to cause collapse, the final cause in No. 5 section being no greater than a blow from a pick. The windows were nominally 4 feet wide, leaving pillars of nominally 3 feet so that, even taking exact dimensions, four-sevenths of the springing was cut away. But it is evidently impossible to cut such brickwork to exact dimensions without at least loosening and weakening the edges of the

brickwork left standing in the pillars, and allowing for the use of pneumatic hammers I think it is not unreasonable to assume that the springing of the arch was weakened to about a quarter of its original strength.

*Conditions after Collapse of No. 8 Section.*

When the debris of No. 8 section had been cleared away on Friday evening, traffic was resumed subject to the additional restrictions already detailed and a continuous patrol and inspection of the tunnel all night by an assistant engineer and others. This decision was made after a careful inspection of the sections still standing.

It is difficult to appreciate fairly after the event the considerations and the information available at the time on which such a decision had to be made, and made without delay. I cannot but think, however, that this decision was a mistake, fortunately unattended with serious results. It was not possible at the time to allocate definitely the cause of the collapse of No. 8 section nor to be certain that the same undefined cause might not apply to another section. The only additional margin of safety through the night would be due to the facts that pneumatic hammers would not be working, that train vibration would be reduced, and that the examination of the structure would be more detailed and more continuous than in the past. As events proved, the first two of these had no effect in preventing the final failure of No. 5 section; it is uncertain whether at night the actual warnings of failure of No. 5 section would have been observed by those inspecting in time to stop traffic by the special arrangements provided.

The decision to allow traffic was stated to be the unanimous opinion of the engineers concerned, but the fact that it was decided to discontinue the working of loaded passenger trains through the tunnel after midnight can only be interpreted as indicating doubts about the prudence of this decision.

*Conclusion.*

With the information now available it seems clear that the structure of the tunnel was in places less sound than was expected, and further was unduly weakened by the cutting of such large windows by means of pneumatic hammers. The reason underlying this was the desire to facilitate the final dropping of the arch without damage to side walls, and to expedite clearance of the debris and thus to minimise delay to traffic on the line.

The method adopted for weakening the arch prior to demolition was based on actual experience of those concerned and all available information pointed to the soundness and strength of the brickwork concerned.

It is impossible to say whether, if the brickwork had been as sound throughout as appeared on the surface, there would have been an adequate margin of safety in the structure in its final condition, but I am of opinion that it was an error of judgment to carry the deliberate weakening of this old structure to such an extent.

It must be recognised that, in dealing with old work of this nature on a running line, a very generous margin of safety must be allowed to cover possible weakness due to hidden defects and factors which are not calculable, even though such allowance may involve serious interference with traffic.

I have the honour to be, Sir,

Your obedient servant,

A. C. TRENCH,

*Colonel.*

The Secretary,  
Ministry of Transport.