1944

NEW ZEALAND

FORDELL AND TURAKINA TUNNELS

(INQUIRY UNDER THE PUBLIC SERVICE AMENDMENT ACT, 1927)

Presented to both Houses of the General Assembly by leave

It was decided to hold an inquiry in terms of section 12, Public Service Amendment Act, 1927, with regard to the culpability of any officers of the Public Works Department for defects found in the Fordell and Turakina Tunnels. Under this section the Public Service Commissioner may institute inquiries without formal complaint being laid against any particular individual officer. For purposes of this inquiry there were associated with the Commissioner for professional and technical assistance and consultation Mr. H. Vickerman, M.Sc., M.Inst.C.E., as Consultant Engineer, and Mr. W. Brooke, a practical tunneller. At the inquiry Mr. H. Watkinson, Inspecting Engineer, represented the Public Works Department, Mr. D. O. Haskell, Resident Engineer, appeared for the Public Service Association on behalf of the engineers and other staff, and Mr. S. Roberts, Inspector, Public Service Commissioner's Office, conducted the examination of witnesses and acted as Secretary to the Committee.

The order of reference adopted in the inquiry was as follows:—

(1) What system obtains in the Department for the recording of discussions on projected works and of decisions taken at these discussions?

(2) In whose hands does the authority lie for making final decision for the plans and operation of approved major works? Is such authority delegated by the Engineer-in-Chief to responsible senior officers, and, if so, to what extent?

(3) In this particular case, who was the officer responsible for the adoption of the tunnel section used on this job? Was any consideration given to the fact that the class of country to be tunnelled was entirely different from that encountered where this tunnel section had previously been used, and, if so, were any factors to compensate for the different class of country considered?

(4) What measure of supervision was exercised over the job, and by whom? Assuming its inadequacy on the results shown, whose responsibility was it to see that adequate supervision was provided and exercised?

(5) Generally to assess the degree of culpability attaching to officers and employees of the Public Works Department for their acts of omission and commission in the execution of the job;

And the Committee to make any other general inquiries that were thought fit and proper.

The Committee held a preliminary meeting at Wellington on 23rd May, 1944, and proceeded to the sites of the Fordell and Turakina Tunnels on 24th idem, where a personal investigation of the faults in both tunnels was made by members of the Committee on 24th and 25th May. The taking of sworn evidence of witnesses was commenced at Wellington on 6th June and concluded on 14th June. In all, twenty-two officers were examined, including the present Engineer-in-Chief, Public Works Department, the previous Engineer-in-Chief, all Engineers, Overseers, Foremen connected with the organization, supervision, or construction of the tunnels, and the headmen of the co-operative parties engaged on the work, with the exception of the previous Assistant Engineer-in-Chief (deceased), one foreman (deceased), and one headman who through ill health was unable to attend. (See list of witnesses.)

The proposal to make a deviation in the railway between Turakina and Okoia Railway-stations was not a new one, for as long ago as 1893–94 a survey of a new route was carried out by Mr. Leslie Reynolds. His plan was largely used for the final route decided on. On 17th October, 1935, the Chief Engineer of the Railways Department asked the Public Works Department for a re-survey of the Turakina–Okoia deviation, indicating that the Employment Board was keenly interested as a means of unemployment relief. A further survey was then made by Mr. R. A. Wilson in 1936. The construction of this deviation was considered to be a sound proposition to the extent that—

(1) Length of line would be shortened by approximately 2½ miles; and
(2) Grades on new line would be much better than on existing line and curvatures very much easier, so that traffic operations on new route would have substantial advantage over those of the existing location.

On the 19th August, 1936, the District Engineer at Stratford was advised by the Assistant Engineer-in-Chief, Wellington, that Cabinet approval, for the commencement of construction work on the Turakina–Okoia railway deviation was available, and instructed him to make arrangements to commence work. Mr. Annand, Temporary Assistant Engineer, was transferred to take over local charge of the project. The necessary Railway Authorization Act for the construction of this deviation was passed by Parliament on 16th October, 1936.

The Fordell Tunnel is 72·45 chains in length. The portal was opened in August, 1937, the tunnel being pierced on 4th May, 1939, and the whole tunnel construction completed in June, 1939. The Turakina Tunnel is 104 chains in length. The portal was opened in September, 1937, the tunnel being pierced on 10th April, 1940, and the whole tunnel construction completed in June, 1940.

The first sign of defect in the Fordell Tunnel was observed on 28th November, 1938, by the Assistant Engineer in Charge, Mr. Annand, who reported to the Resident Engineer at Wanganui that "the concrete lining of the completed portion of the south end showed long cracks roughly parallel to formation level." He expresses the opinion that after thorough inquiry he had come to the conclusion that they were the result of recent earthquakes. He also says that he thoroughly inspected the other tunnel faces at Fordell, and found no signs of cracks. The District Engineer states that no action is being taken meantime, other than to closely watch developments and see if the cracks tend to open. On 6th January, 1939, a further report is forwarded, giving the result of inspection at ten test points. The statement is made that the concrete lining in all other tunnel headings had been inspected and there was no sign of any other disturbance. On 23rd January, 1939, the District Engineer at Stratford sent a further report to his Head Office, showing that the cracks were extending. This embodied two reports from the Assistant Engineer in Charge, dated 11th and 17th January. On 28th June, 1939, the District Engineer forwarded a copy of a report from Mr. Annand, showing that the cracks were getting progressively worse, and suggesting that some action was necessary. The District Engineer suggested that it would be feasible to defer any immediate repairs as the Turakina Tunnel would not be completed for another fourteen months. On 6th July, 1939, the Inspecting Engineer at Head Office, Mr. Sharp, advised the District Engineer at Stratford that it was not desired to take any immediate measures in regard to the cracks at Fordell, as he thought it would be advisable to let the matter stand at present, keeping them under regular observation and to ascertain just how they were developing. This would permit determination of remedial measures which might be required. On 24th July, 1939, the Assistant Engineer expressed the opinion that the cracks were caused by pressure from behind, though as yet bulging was not apparent. On 20th February, 1940, blue-prints and reports from the Assistant Engineer, giving details of tests, were forwarded. Further reports on the cracks and of the tests being taken were submitted to Head Office on 11th September, 1940, and 1st October, 1940, and on 2nd September, 1941, the Acting District Engineer asked whether any decision had been reached regarding remedial measures to be taken after Head Office Inspecting Engineer's recent inspection. There was also a progress report from Fordell to Wanganui on 28th July, 1941. Head Office advised on 23rd September, 1941, that the question was under discussion with the Railways Department, on the subject of minimum clearance as to whether they had any objection to the tunnel being buttressed. Further progress reports were forwarded on 23rd March, 1943, and 17th August, 1943. In the report of 23rd March, 1943, first mention was made of cracking in the Turakina Tunnel. It was stated that cracking had developed in the southern portion of the tunnel, the cracks being horizontal at a height generally of from 4 ft. to 6 ft. above the formation and with a slight projection at the lower edge which could just be felt. Further cracks in the arch of the Turakina Tunnel then developed, and a detailed examination was then made of the defects in both tunnels, which indicated the following results:—

Fordell Tunnel.—From 3 miles 68 chains to 4 miles 7 chains—almost completely free from visible cracking. From 4/7 to 4/24—almost continuous cracking in both walls, at approximately the middle of the vertical wall. From 4/24 to 4/39—no visible cracking. From 4/39 to 4/53—generally cracking in both walls at half-wall height. From 4/54 to 4/57—slight cracks in one wall only. From 4/57 to the portal is free from cracks.

Turakina Tunnel.—From the north portal, 8 miles 43·20 chains to 8 miles 44·90 chains—free from cracks. From 44·90 to 46·00—a fine crown crack. From 46·00 to 46·45—free from

cracks. From 46·45 to 47·25—a fine crown crack. From 47·25 to 54·70—free from cracks. From 54·70 to 55·75—fine crown crack. From 55·75 to 56·50—free from cracks. From 56·50 to 58·10—fine crown cracks. From 58·10 to 60·00—free from cracks.

8 m. 60·00 to 61·50—fine crown cracks.
61·50 to 62·50—free from cracks.
62·50 to 63·56—fine crown crack.
63·56 to 64·25—free from cracks.
64·25 to 65·00—fine crown crack.
65·00 to 66·50—free from cracks.
66·50 to 79·00—fine crown crack.
79·00 to 9 m. 1·80 free from cracks.
9 m. 1·80 to 2·50—fine springing crack on left side.
2·50 to 3·00 fine springing crack on left side, plus fine crown crack.
3·00 to 5·80—very fine springing crack left wall.
5·80 to 6·50—free from cracks.
6·50 to 8·00—very fine springing crack right side.
8·00 to 8·25 free from cracks.
8·25 to 10·00—fine crown crack and very fine springing crack left and right walls.
10·00 to 10·10—springing crack, very fine, left and right walls.
10·10 to 11·00—free from cracks.
11·00 to 13·75—springing crack, fine, right wall.
13·75 to 26·25 free from cracks.
26·25 to 27·75—very fine springing crack right wall.
27·75 to 28·25—free from cracks.
28·25 to 29·50 fine springing crack right wall.
29·50 to 39·00—free from cracks.
39·00 to 40·50—springing crack right wall.
40·50 to 45·25—free from cracks.
45·25 to 46·00—crown crack $\frac{3}{8}$ in.
46·00 to 46·50—free from cracks.
46·50 to 53·00—crown crack, gradually increasing in width from fine to $\frac{1}{4}$ in.
53·00 to 54·50 —$\frac{1}{4}$ in. crown crack, plus $\frac{3}{8}$ in. to $\frac{1}{4}$ in. crack, right wall at half wall height.
54·50 to 59·50—crown crack decreasing from $\frac{1}{2}$ in. to $\frac{1}{16}$ in., and wall crack, left wall, only $\frac{1}{32}$ in. to $\frac{1}{16}$ in.
59·50 to 60·50—fine wall crack left wall.
60·50 to portal, 66·86—free from cracks.

A very fine crack has developed in the crown at the portal.

Borings in the walls and arches of both tunnels were carried out at regular spacings, and from the data thus obtained, and evidence submitted at the inquiry, the Committee has obtained the following picture of the work carried out in the tunnels and the defects shown therein:—

FORDELL TUNNEL (3 m. 68 ch. to 4 m. 60·45 ch. = 72·45 ch.)

1. *North End* (S. Mitchell and Party), (3 m. 68 ch. to 4 m. 29 ch. = 41 ch.)—

(1) Country generally sandy throughout.

(2) Concrete all hand-placed.

(3) No cracks for first 18 ch.—then cracked for 19 ch. along right wall and 17 ch. along left wall—last 4 ch. free from cracks. The uncracked portion at the commencement is through fairly good standing country, but, where the cracks follow, the sand is much looser, and where they cease the arch runs through papa. Length cracked about 47 per cent.

(4) Average concrete thickness (inches)—

	Over Full Length.	Over Cracked Portion.
Left wall	12·65	12·15
Right wall	12·75	13·10
Left shoulder	10·70	10·40
Right shoulder	11·30	11·00
Crown	8·50	9·00

(5) The walls are almost entirely of the full 12 in. thickness demanded and generally a good job. The main defect lies in the existence of substantial cavities over the arch, these extending generally over its whole width and not merely over the crown. Work shows fairly good effort, but evidently influenced by an effort to keep wall thickness at the minimum required.

2. *South End* (R. Day and Party), (4 m. 29 ch. to 4 m. 60·45 ch. = 31·45 ch.)—

(1) Country half sand and half papa for first 7 ch., followed by soft papa for 21 ch., with 3½ ch. of slip near the portal. The last 11 ch. of the papa is either damp or wet.

(2) Concrete all hand-placed.

(3) No cracks for the first 10 ch., then cracked along both walls for the next 14 ch., followed by 1 ch. free from cracks and then by 3 ch. cracked along one wall, the last 3½ ch. to the portal being uncracked. Weepholes were provided for 5 ch. from the south portal, but not elsewhere, as the country was dry when excavated, though some 9½ ch. have since become wet. Length cracked, 53 per cent.

(4) Average concrete thickness (inches)—

	Over Full Length.	Over Cracked Portion.
Left wall	13·40	12·30
Right wall	13·20	12·60
Left shoulder	12·80	11·17
Right shoulder	12·70	12·20
Crown	9·35	9·45

(5) The walls are more than the full 12 in. demanded, and the arch is generally reasonably well filled, except for the cavity left over the crown. The archwork on the whole is better than at the north end. Cracks occur largely in papa country, where the thickness of lining demanded has proved to be inadequate. Appears to have attempted to do a good job.

TURAKINA TUNNEL (8 m. 43. ch. to 9 m. 67 ch. = 104 ch.)

1. *North End* (Hansen and Party), (8 m. 43 ch. to 9 m. 15 ch. = 52 ch.)—

(1) For the first 36 ch. the country is heavy packed sand, and for the balance coarse gritty sand over the arch, with clay pug below.

(2) The concrete was hand-placed for the first 17 ch. and for the balance gun-placed.

(3) The first 12 ch. is free from cracks, except for 2 ch. of fine crack along the crown. In the next 12 ch. half the length is similarly cracked. This is followed by some 12 ch. cracked throughout along the arch. The remaining 16 ch. has about 9½ ch. showing fine cracks along the springing. No cracks appear in the side walls.

(4) Average thickness of concrete (inches)—

	Hand-placed.	Gun-placed.
Left wall	12·0	16·0
Right wall	12·8	15·7
Left shoulder	18·2	16·7
Right shoulder	18·7	17·6
Crown	6·9	11·9

(5) The hand-placed work is well done and up to demands along the walls and shoulders, but the crown is badly filled for a considerable length.

The gun-placed concrete is thicker because the effort to save concrete by restricting the thickness to 12 in. was abandoned. The work is generally well done except for cavities immediately over the crown and due mainly to the type of timbering used. Shows an honest attempt to do a good job, except that hand-placing on crown is deficient.

2. *South End* (Murch and Party), (8 m. 15 ch. to 9 m. 30 ch. = 15 ch.)—

(1) The country was shingly sand over the arch and half-way down the walls with clay pug below.

(2) All concrete was gun-placed.

(3) The work is free from cracks except for about 2½ ch. of fine crack along the spring near the end.

(4) The average concrete thickness was (inches)—

Left wall	14·8
Right wall	15·7
Left shoulder	14·8
Right shoulder	16·2
Crown	11·4

(5) The work is generally satisfactory except for cavities over the crown. Shows evidence of an attempt to do a good job.

3. *South End* (Sullivan and Party), (9 m. 30 ch. to 9 m. 36 ch. = 6 ch.)—

(1) The country consisted of clay pug along the floor and for about 2 ft. 6 in. up the walls, with shingle and course gritty sand above.

(2) All concrete was gun-placed.

(3) The work is free from cracks.

(4) The average concrete thickness is (inches)—

Left wall	15·6
Right wall	16·0
Left shoulder	14·5
Right shoulder	16·0
Crown	11·8

(5) Except for cavities along the crown, the work is well done. Shows evidence of an attempt to do a good job.

4. *South End* (Wood and Party), (9 m. 36 ch. to 9 m. 62 ch. = 26 ch.)—
   (1) For the first 10 ch. the country is the same as along Sullivan's length, followed by 2 ch. all coarse gritty sand. From this point to the end, some 14 ch., it consisted of shingly sand traversed by three horizontal beds of clay pug.
   (2) The first 8 ch. of concrete were gun-placed and the balance hand-placed.
   (3) In the gun-placed work the only cracking is a length of 1½ ch. along the right side spring. In the hand-packed the first chain has no cracks, but this is followed by some 15 ch. of rather badly cracked arch with some 7 ch. of side wall cracks mostly along the left side.
   (4) The average thickness of concrete is (inches)—

	Hand-placed.	Gun-placed.
Left wall	13·0	17·1
Right wall	12·7	17·0
Left shoulder	8·7	15·6
Right shoulder	9·5	16·7
Crown	7·8	15·0

   (5) In the gun-placed length the walls are good, but there are cavities over the arch for approximately half of each length concreted. The hand-placed work is poorly done, the wall thickness being under requirements in places with large cavities over the arch and inadequate thickness. Gun-work must be regarded as reasonably satisfactory. Hand-work poor and shows no great effort to fill shoulders and crown.

5. *South End* (Eade and Party), (9 m. 62 ch. to 9 m. 67 ch. = 5 ch.)
   (1) Except for 1½ ch. of slip at the end the country, was packed sand with some pug seams.
   (2) All concrete was hand-placed.
   (3) The work is free from cracks.
   (4) The average concrete thickness is (inches)—

Left wall	13·8
Right wall	14·4
Left shoulder	13·2
Right shoulder	15·0
Crown	10·8

   (5) The walls and shoulders comply very reasonably with the requirements, but there are cavities over parts of the crown. On the whole the work shows attempt to do a good job.

Causes of Failure

The causes of failure are really twofold - firstly, in that the strength provided by the design, as interpreted from the drawings, was inadequate; and, secondly, in that the workmanship was in some major respects faulty and very greatly reduced the strength which would otherwise have been available.

As a result, costly repairs are now required, but the extent of these has been greatly increased by failure properly to investigate the cracks when these were first reported, and to take measures then so to amend the design as to prevent their occurrence along the length still unstarted.

Design

The design adopted was new to this country and followed American practice by having vertical side walls instead of these being arched in accordance with the standard hitherto followed for New Zealand railway tunnels.

There is nothing inherently unsafe in this design of structure, as wide experience elsewhere in all classes of country has amply demonstrated, provided the wall thickness is made adequate. Where this becomes relatively great there is some waste of concrete, but a section of this type has the advantage, during construction, of being easier to timber and of offering better facilities for the mechanization of the work. It was for these reasons that it was adopted.

It has been used previously in New Zealand only in some of the Waikokopu to Gisborne railway tunnels undertaken shortly before, but the design as adopted there was for use in hard rock having horizontal beds with no side pressure, and the side walls were lined with pumped concrete generally 19 in. thick placed against the solid ground. Under these conditions it proved entirely successful.

There are no records of the preliminary investigations made to establish the class of country likely to be encountered at Fordell and Turakina. No boring was done (this was not exceptional) and no geological report was obtained. It was, however, apparently considered that hard rock would be met, as amongst the first plant to be supplied was a full equipment of rock drills. It is difficult, however, to determine how such an assumption was justified and why no real preliminary investigation was carried out.

There are also no records of the preliminary discussions regarding the design, but the matter was certainly not referred to the Designing Engineer, and he did not take part in discussions. This also is not exceptional, as he is usually not consulted unless extraordinary difficulties are anticipated and these were reasonably not to be expected. It would appear that it was decided that the ground would prove similar to that met with on the Gisborne railway and that the same design could be used, as no special plan or specification was prepared.

The initial instructions from Head Office to the district officers were largely verbal and given during visits of the Inspecting Engineer. For this reason, apparently, there is no record on the files of the official number of the plan to be used, nor of any specification having been sent, and, except that the only plan available was that prepared for the Gisborne tunnels, it is really largely surmise that this was the one adopted. However, from the absence of any copies of it, and of any specifications in the District, Resident, or Works Engineers' offices, it seems very doubtful whether any were ever supplied. Plans were, however, provided giving full particulars of the type of timbering and of the steel profiling for the concrete work. These showed the tunnel dimensions and, *inter alia*, some measurements of the required concrete thickness. It was apparently from them that the tunnels were built, but without any directing or explanatory specification. Whilst the details of the timber and of the profiling they afforded were complete, those of the concrete were ambiguous and the interpretation unfortunately adopted, possibly justifiably, was that a wall thickness of 12 in. and a crown thickness of 9 in. was all that was required. This should be compared with the general thickness of 19 in. placed at Gisborne. Neither plan gave details of weepholes nor of the footings, and the latter as actually constructed are only 1 ft. deep and 1 ft. 9 in. wide, which in country of the class encountered is quite inadequate.

The Fordell Tunnel was started before Turakina and, though hard rock was not encountered, the ground stood well, that at the north end being a firm sandy clay and at the south end a soft papa. Neither showed any immediate signs of side pressure, and for this reason, presumably, no attention was paid to the adequacy of the wall thickness. As the work proceeded, and when Turakina was opened up, the country changed to a fairly compacted sand, but on exposure becoming loose sand requiring close lathing to prevent it rilling down. Moreover, considerable pressure was evident, necessitating the use of intermediate timber sets in parts of the Fordell and almost entirely throughout the Turakina Tunnel. This should at once have made it quite plain that the intended wall thickness was insufficient, especially realizing the vibration inevitable during the passage of a heavy locomotive followed by a long train. This was even more serious because of the restriction to the minimum of 12 in. in the thickness of concrete due to the boarding-up of the legs (in some places into the arch). It must have been obvious to any one with knowledge of tunnelling that the ground was very heavy and the timbers were taking considerable weight. As the timber gave way or rotted the entire weight would be supported by the concrete alone. No change was made in the wall thickness except instead of increasing it virtually to reduce it to the minimum of 12 in., or in places even 11 in. The question of its adequacy or otherwise does not appear to have been raised, and no reports referring to the matter appear on the files.

Another factor which should have drawn attention to this matter is that shortly after the commencement of tunnelling the ground was found to be so loose that anchors could not be provided for the mechanical scrapers intended to be used. They were therefore abandoned, and all spoil was hand-shovelled throughout.

In this respect, therefore, though an American type of tunnel was adopted, American practice requiring the proportioning of the concrete thickness to the class of country was neglected; and again, instead of placing the concrete by using a concrete gun, or pump, and finally grouting up any cavities in the arch, which are more difficult to avoid with its timbering than with the old type, all the Fordell and much of the Turakina concrete was hand-placed, and no grouting whatever was done.

Thus, whilst the change was made to provide for mechanization of the work, this was abandoned, and with it the use of the well-proved safe standard type of tunnel in the construction of which all concerned were fully experienced.

Workmanship

The work was done by co-operative contractors, there being four parties always at work, one at each end of both tunnels, each having a head man who was a member of the party, in charge of operations. These head men, and a sufficient number of each party, were tunnellers with considerable experience in the construction of railway tunnels as built to the old standard design. A number of the other men were new to tunnel work, but there was admittedly a sufficient leavening of experienced men to permit the satisfactory carrying-out of the job. None of them, however, had been engaged on tunnels built to the design adopted.

The Public Works overseers and supervising foremen were experienced miners and, except for one foreman, had had considerable experience in constructing railway tunnels, but again to the old standard and not to the new design. Their records in the Department are good.

Neither workmen nor supervisors were therefore by experience familiar with any pitfalls attaching to the new type of work. At the same time their experience was quite adequate to teach them what had to be done to ensure a good, sound job. For example, they would be expected to know that all concrete must be of the full thickness; that it must bear up against the solid country, except where otherwise specially approved; and that then solid packing must be inserted between this and the concrete. Nothing more than this is called for by the design adopted.

The working parties each signed a contract which embodied a schedule of the rates payable for the different classes of work involved, but not a specification relating to the requirements of the tunnel work and the methods to be followed in executing it. They either received, or had access to, the plan previously referred to, giving details of the timbering but which was ambiguous regarding the concrete thickness, and deficient as to the placing of weepholes and the dimensions of the footings.

They were thus mainly dependent for details on verbal instructions given as and when necessary by the supervising staff, or otherwise on their assumed knowledge and experience of what is essential in good tunnel-construction practice. The absence of any specification, and of any written instructions, unfortunately makes it impossible to know whether they did all that

was asked, and, indeed, whether the supervisors themselves knew definitely what to demand. In this respect there appears to be a wide difference of opinion as to who gave certain orders, and what they meant, and as to when they were given and/or cancelled; again there was a considerable divergence in the practices followed in their application. One case in point is the boarding up in front of the legs of the timber sets said by some to be universally applicable, by others to extend also up into the arch, but by others to be restricted to holding up short lengths of ground. An approximate date is available for the issue of this order, and it is stated it was subsequently cancelled, though when, and if, this was done, or if the cancellation was observed, is not definitely ascertainable.

In spite, however, of these facts and happenings, it is held that the presumable general expert knowledge of essential requirements on the part of engineering and supervisory staff should have prevented some of the disgraceful conditions found, though even amongst those assumed to know there appears to have been much difference of opinion as to correct practice, and the absence of a specification is therefore all the more regrettable.

The main difference so far as workmanship is concerned between the new and the old type lies in the method of timbering and the effect this has on the placing of the arch concrete. In the new it is held to be much more difficult to know whether the concrete is bearing up against the roof laths, and, moreover, there is not the same incentive in ensuring this that there was with the old bar method, where the bars had to be removed, and where this could not be done unless the concrete or packing held the laths. Again, in the new, the arch bars, which are transverse, and which are left in place, make it impossible to push the concrete forward so as to get it tightly packed over the crown. This applies also when it is placed by the gun, though with it the arch is automatically better filled. Actually with the type of timbering authorized it would be practically impossible, except perhaps with pumps, completely to fill the crown, and either the timbering should have been redesigned or grouting should have followed as is the practice in America. The difficulty appears to have been realized, but no remedial measures were taken, and this may have led to a belief that complete filling was not necessary provided the required minimum thickness of concrete was placed.

No test holes were made by borings in crown of the arch to see that sufficient concrete was going in to give the required thickness. Had this been done, and the fact revealed that the crown concrete was far too thin, it could easily have been rectified by bridging back the laths over the centre of the cap to allow sufficient room for the concrete to be pushed over the top of the cap to fill the cavity behind, as it is practically impossible to fill back to the laths by pushing it underneath the segments; or grouting could have been employed to fill the voids.

The results show that the work done with the concrete-gun is, at least along the arch, much superior to that where hand-work was adopted, and it is unfortunate that, for no apparently good reason, this method was not followed throughout.

The main defects in workmanship lie in the failure fully to fill the arch so as to catch the country. This, as already indicated, applied more particularly where the concrete was hand-placed, and where a considerable variation of practice is evident. Some contractors took every care to fill the shoulders right up to the lathing, whilst others were content merely to place enough to comply with the minimum requirements, and this in some instances without packing the resulting cavity between it and the arch lathing. This is a practice which they should have known was bad and which the supervisors should have observed and checked, but which it would appear some must have condoned. It is, however, along the crown that the poorest results are evident, but the fact that in places the filling is reasonably good shows that a more satisfactory job could have been done if a more adequate effort had been insisted upon. Much has been said about the slumping that would occur along the crown following the vibrating of the profiling immediately after the concrete had been placed in order to ensure a good face on the exterior of the work. Some slumping would necessarily follow, but this could hardly have occurred to anything like the extent evidenced had the lower portions of the arch been properly filled as the crown was approached and the concrete not made too sloppy.

Had the arch work been properly executed the structure must have stood much better, and some of the cracking might not have resulted, or would not have become evident so soon. At the same time the failure of considerable portions must eventually have followed, especially where the 12 in. thickness of wall and 9 in. of arch standard was adopted. This is evident from the cracking now observable in the gun-placed length of the Turakina Tunnel. Here the wall thickness averaged about 16 in. and the arch work was fairly good. No cracks were noticed for about three years, but they have since occurred and appear to be extending. Some of these may be ascribed to cavities over the crown; others are more difficult to explain; but the fact remains that 16 in. thickness is, under the circumstances, not up to proper safety requirements in the class of country involved.

There seems to be no doubt that the engineering staff, because of the ease of tunnelling and absence of the usually occurring difficulties, became imbued with the idea that the ground was safe and that only a relatively thin lining was required. This may have affected considerably the observance of the usual rigid precautions and also resulted in the question of the adequacy of the lining not being considered.

All those directly concerned with the construction of the tunnels appear, from the evidence obtained, and from the frankness with which this was given, to have been keen both to push the work along and also to ensure its being a good job within the limits of their instructions

and knowledge, though in some respects results have shown they failed to do some of the things which were essential. At the same time it cannot be properly said that any evidence has been shown of deliberate neglect on the part of the Public Works construction staff, most of whom were grossly overworked; nor of any deliberate slumming on the part of the contractors. As a matter of fact, the conclusion of the work is said to have been followed by mutual congratulations between all concerned on the satisfactory results of their efforts, thus indicating their general opinion that all was well.

Cracks

On page 2 of the report will be found an account of the discovery of cracks in Fordell Tunnel and the action taken to acquaint Head Office and the District Engineer with the position.

The following observations are made:—

(1) The Assistant Engineer in charge was at first of the opinion that the cracks were due to earthquake action, but, notwithstanding this, he did make regular reports from November, 1938, until June, 1939, when he suggested that remedial action should be undertaken:

(2) The Resident Engineer forwarded reports of the Assistant Engineer in charge regularly, and, in the case of the June, 1939, report, accompanied it with a sketch of two alternative proposals for strengthening the tunnel:

(3) The District Engineer, Stratford, also forwarded to Head Office the Reports he received, but he does not appear to have become unduly alarmed, and in forwarding the June, 1939, report he even suggested that remedial action could await completion of the Turakina Tunnel some fourteen months later:

(4) In spite of reports showing progressive deterioration, Head Office mind is indicated by its reply in July, 1939, which really said, "Wait and see":

(5) It was not until July, 1939, that the opinion was expressed that the cracks were due to lateral pressure:

(6) During the course of construction, bulging in the side legs occurred, and this should have made it evident that lateral pressure existed:

(7) It was not until 23rd March, 1943, that mention was made of cracking in the Turakina Tunnel.

It does therefore appear that there was an entire lack of appreciation of the seriousness of the cracks, both in Stratford and Wellington, and everywhere a failure to attempt a diagnosis of the case to the extent really warranted. Had this been undertaken, as should certainly have been done, when the reports of January, 1939, showed the cracks extending, remedial measures could have been undertaken in both Tunnels in time to have made a substantial saving in money.

At the time (1939) the opinion was expressed that the cracks at Fordell were due to lateral pressure, there was still eleven months of construction to complete Turakina, and though it is considered that a proper investigation should have disclosed the position much earlier, a change, if made even at that late hour, could have still made a very large saving in public moneys.

The conclusions reached may be best indicated in relation to the headings of the order of reference:—

(1) *What system obtains in the Department for the recording of discussions on projected works and of decisions taken at these discussions.*

The normal procedure leading up to projected works like the Turakina deviation were stated by the present Permanent Head of the Public Works Department in his evidence. After the passing of the Authorization Bill an instruction would be received from the Minister to proceed with surveys. In the case of railway deviations these would be carried out in conjunction with the Railways Department. First comes the reconnaissance survey indicating the best route to adopt. A report is made to the Minister, the Engineer-in-Chief discusses the project with the Minister, and a decision is made to carry out a trial survey. Alternative routes may loom largely, but if the issue is clear the matter would usually be submitted to the Minister for decision by Cabinet, and the Department would then receive authority to proceed with the permanent survey, which would be carried out at the same time as estimates are compiled for inclusion in parliamentary estimates. A decision is then given to proceed with the work.

The practice in Head Office is for verbal discussions to take place between the Engineer-in-Chief, the Assistant Engineer-in-Chief, and the Inspecting Engineer at several points in the foregoing procedure. It is customary for any decision of importance to be recorded by a minute on the file or by inclusion in a memorandum to the Minister or to the District Engineer. This was accepted as proper practice by the Permanent Head, the previous Permanent Head, and the previous Inspecting Engineer. It was carried out in connection with the South Island Main Trunk.

The lack of record of the discussions and decision to use the amended tunnel section in this case is definitely admitted by the present Permanent Head in a minute of 22nd September, 1943 addressed to the Designing Engineer in the following terms—

> "This is the only correspondence which can be found regarding the amended tunnel section. It does not throw any light on how it came to be used at Turakina."

The Permanent Head is obviously as surprised as were the members of the Inquiry at the absence of any record of the decision and discussion concerning the tunnel.

(2) *In whose hands does the authority lie for making final decision for the plans and operation of approved major works? Is such authority delegated by the Engineer-in-Chief to responsible senior officers, and, if so, to what extent?*

There is no doubt but that the responsibility for making final decisions for the plans and operations of approved major works lies in the hands of the Engineer-in-Chief. The practice is for the Engineer-in-Chief, the Assistant Engineer-in-Chief, and the Inspecting Engineer concerned to work as a "team." Considerable authority is delegated to the Assistant Engineer-in-Chief and to the Inspecting Engineer, but even if the Engineer-in-Chief is absent from Headquarters with the Minister or otherwise it is expected he shall be kept apprised of decisions of importance and of any other matters deemed of sufficient weight.

In the case under consideration there was a conflict of evidence between the then Permanent Head and the then Inspecting Engineer. The Permanent Head has no recollection of any discussion concerning the adoption of the particular tunnel section, but will not swear that no discussion took place. The Inspecting Engineer insists the matter was discussed. Unfortunately, the Assistant Engineer-in-Chief is now deceased. The circumstances therefore emphasize the necessity for a proper record of all important decisions, and the officer who needed the protection of a record—the Inspecting Engineer, who would issue the district instructions and supervise the work—is, to say the least, very unwise in that he did not acquire the protection of committing the decision to writing.

The members of the Inquiry find it hard to believe that no discussion took place involving all three administrative officers.

(3) This question should be dealt with in two separate sections: –

A. *In this particular case who was the officer responsible for the adoption of the tunnel section used on this job?*

The answer to this question is seriously complicated because of the three who would normally share the responsibility, one (the Engineer-in-Chief) does not remember being consulted, the second (the Assistant Engineer-in-Chief) is dead, so that the inquiry had to rely mainly on the evidence of the third—the Inspecting Engineer—with the limited information available on the files.

The conclusion reached was that Mr. Sharp, the Inspecting Engineer, carried a substantial share of the responsibility. It was he from whom the District Engineer received his tunnel instructions, and it was he who supervised the work for Head Office. On various occasions when questions were raised by the District Engineer he was advised, "Mr. Sharp would discuss the question on the spot." It is also clear that the decision was entirely a Head Office one.

In his favour should be said that the new section had been accepted as a standard one, notwithstanding that it had been used in New Zealand only once previously, on the Gisborne line, and that in a special class of country. Further, the instruction to the District Engineer to commence work on the deviation was dictated and signed by the Assistant Engineer-in-Chief, the late Mr. Baker.

If, therefore, there is any unfairness to Mr. Sharp in assessing his responsibility so highly, it is a decision to which he has left himself open by his failure to maintain adequate records of discussions and instructions, but on the evidence given, and from examination of the files, no other conclusion could be reached.

B. *Was any consideration given to the fact that the class of country to be tunnelled was entirely different from that encountered where this tunnel section had previously been used, and, if so, were any factors to compensate for the different class of country considered?*

On the evidence available the conclusion is forced that no serious consideration was given to the class of country likely to be encountered. There was an assumption that sandstone and papa would be met, but the Inquiry was certainly not satisfied that the assumption was one the Department was entitled to make. The Departmental Geologist was not consulted; no adequate field investigation was made on the point, whereas there are indications in the surrounding country that the probability of striking sandstone and firm papa was quite unlikely.

The surprising factor is that, although quite early in construction it was obvious to all concerned that the country was quite different from that stated to be expected, no one considered it necessary to make any modification to provide adequate strength. On the contrary, approval was given to the boarding-up of the "C" legs, which had the effect of restricting the thickness of concrete, thus providing less than was used on the Gisborne line, where the country encountered was hard rock. Moreover, no special precautions were taken to get commensurate thickness in the arch and to ensure this being solidly filled to the full extent of the excavation.

(4) *What measure of supervision was exercised over the job, and by whom? Assuming its inadequacy on the results shown, whose responsibility was it to see that adequate supervision was provided and exercised?*

The Head Office supervision of the work was carried out by the Inspecting Engineer, who visited the job about once in three months. The main engineering supervision was left to the District Engineer, whose headquarters were at Stratford. He visited the tunnel frequently in the early stages, as often as once in two or three weeks, less frequently later. In this district there was for most of the period of construction a Resident Engineer at Wanganui. It would be

usual for the Resident Engineer to be located at the job. At the tunnel the supervisory staff consisted of the Assistant Engineer in Charge, one overseer for each tunnel (who also had construction work to supervise), and one foreman for each face, although three shifts were engaged on each face. The supervision of the Resident Engineer at Wanganui was not of great value, owing to his lack of tunnelling experience. This was known to the District Engineer and to Head Office, as in the early stages he had asked in writing for a competent engineer in charge, citing his lack of experience in support of his request. One of the overseers was only in an acting capacity, being a foreman acting as sub-overseer. For a period of six months there was no overseer on Turakina Tunnel; part of his duties in theory being carried out by an Engineer's Assistant who, however, had had no tunnelling experience at all.

In the opinion of the Inquiry, there should have been an Assistant Engineer or an Engineer's Assistant on the tunnel construction, the overseers should have been free from all duties other than tunnel supervision, and there should have been two foremen for each face.

The responsibility for ensuring adequate supervisory staff must rest largely with the District Engineer. He himself had many other duties over a wide district, and therefore his only means of protecting himself and of ensuring a completely satisfactory result was by personally making sure of the adequacy of supervision.

In this case, too, some responsibility should fall on the Resident Engineer, but his lack of experience, known to the District Engineer, would limit the value of his opinion.

The District Engineer should to some extent be able to rely on the Assistant Engineer in charge asking for further supervisory staff if he considered it necessary, but in this instance an Assistant Engineer was appointed who, while able to carry out efficiently instructions received, was nevertheless not strong on the technical side, and this would be known to the District Engineer.

The effect of the lack of engineering assistance was that the Assistant Engineer in charge had too much detail to do, with the result that he was unable to give the detailed supervision to the actual tunnel work. Things happened in the tunnel of which he was not aware.

It should be stated that the lack of specifications and the absence of proper instruction had a serious effect on the supervision in that there was considerable variation and substantive lack of understanding of what was expected of overseers and foremen.

Although the main responsibility under this heading must thus be allocated to the District Engineer, in the opinion of the Committee, Head Office cannot escape its share for seeing that the supervisory staff was adequate to ensure performance up to requirements demanded. The Head Office representative challenged in this respect was the Inspecting Engineer. Obviously if supervisory staff is insufficient, then adequate supervision cannot be maintained.

The Committee cannot understand how any members of the supervisory staff could fail to observe or be aware of the following matters:—

(*a*) The change in the class of country from what was stated to be expected:
(*b*) The boarding-up in front of the "C" legs and at one part into the arch also:
(*c*) Failure to get concrete behind the caps and completely fill the arch:
(*d*) Carrying on with the placing of concrete in the afternoon shift without a foreman present.

(5) *Generally to assess the degree of culpability attaching to officers and employees of the Public Works Department for their acts of omission and commission in the execution of the job.*

After fullest consideration the Inquiry has reached the conclusion that a substantial degree of culpability must rest on Head Office, this attaching particularly to the Inspecting Engineer, Mr. Sharp. The main headings under which he was at fault may be summarized as follows:—

(*a*) Approval of type of tunnel without proper preliminary investigation as to whether mechanization could be carried out on the lines intended.
NOTE.—This was claimed to be the primary reason for adoption of the particular section.

(*b*) Failure to maintain a proper record of important decisions made and of instructions given.
(*c*) Failure to send proper plans and specifications to ensure that proper strength of concrete was provided, and failure to give specific instructions concerning the thickening of wall if country was not so suitable as was anticipated.
(*d*) When the country was subsequently found by Inspecting Engineer to be different from anticipations, in not seeing that strength was increased proportionately.
NOTE.—As the result of one of his instructions a reduction of strength resulted instead of an increase.

(*e*) Issuing instructions for the adoption of the type of timbering shown on timbering plan, which in terms of the plan itself did not permit of filling the crown with the plant made available.
(*f*) Failure to be fully apprised of what was being experienced in the tunnel and of adjusting matters accordingly.
(*g*) Failure to take adequate steps to ascertain causes of the cracks at an early stage and to apply remedial measures.

Next in order of culpability is the District Engineer, Mr. Lindup. Due to the fact that he was working under the general direction of the Inspecting Engineer, and that certain vital decisions had been made in Head Office without apparently consulting the District Engineer, his share of blame is considerably less than Mr. Sharp's.

He failed—

(*a*) By failing to record important decisions and in accepting verbal instructions of major importance without noting same on file.

(*b*) By failing to take action when the class of country encountered was found different from expectations.

NOTE.—Under this heading the District Engineer must share with the Inspecting Engineer the responsibility in the points quoted below. Had the District Engineer taken proper action as he should have done, the lack on the part of the Inspecting Engineer in these particular matters could have been corrected.

(i) Failure to insist that proper plans and specifications were provided giving clear details which would ensure the proper strength of the lining, and containing specific instructions concerning the thickening of the wall if the country was not such as was anticipated, and at a later date these were promulgated to the supervisory staff.

(ii) When the country was subsequently found to be different from anticipations, in not seeing that the strength was increased proportionately, and in not stressing this point when reporting to Head Office.

(iii) Issuing instructions for the adoption of the type of timbering shown on the timbering plan which in its terms did not reasonably permit of filling the crown especially with the plant made available; and in taking no steps to remedy the position.

(*c*) By failing to exercise closer and more effective personal supervision. Had this been given he must have been aware of the weight on the timber; and also that the arch was not being constructed satisfactorily.

(*d*) In failing to ensure that adequate supervisory staff was allotted.

(*e*) In failing to make sufficient effort to diagnose the causes of the cracks at an early stage and to recommend remedial action soon enough.

It is considered that the Resident Engineer, Mr. Sampson, is blameworthy to a limited extent under the same headings as the District Engineer. But the fact that he lacked tunnelling experience and that he placed this on record in the early stages does substantially reduce his share of responsibility, though thereby there was left an undue burden of responsibility on the shoulders of the Assistant Engineer in Charge. It should be noted that Head Office acquiesced in this.

The Assistant Engineer in Charge, Mr. Annand: Ordinarily the Engineer in charge would carry a very large share of the responsibility for the trouble, as both the District Engineer and the Inspecting Engineer should have been able to rely on him to call their attention to most of the matters wherein they are deemed to have failed. The circumstances, however, are not ordinary. Mr. Annand is not highly qualified academically, and this was known to all concerned. The Committee formed the opinion that he is a man who could manage a job but would need instructions in substantial details on the design to be used. The decision as to type of tunnel section was made in Head Office, and he received only verbal instructions on the method to be used, and neither proper plans nor specifications. In addition, he was not the Resident Engineer, but had one located at Wanganui.

His main protection, however, lies in the lack that existed of sufficient supervisory staff. He was required to undertake other duties which made it impossible for him to give adequate attention to what was taking place in the tunnel, and things happened of which he should have been aware, but was not, and in the opinion of the Committee, could not.

He should be blamed—

(*a*) For failing to see that proper specifications in writing were supplied to the parties:

(*b*) For failing to ask for further supervisory staff and for seeing that the overseers and foremen understood what was expected of them:

(*c*) For failing to ensure that instructions issued by his superior officers were clearly transmitted to supervisory staff.

Overseer Ryan, Turakina Tunnel, and Sub-Overseer Thompson, Fordell Tunnel: They are both to be criticized for relying too much on the foreman without seeing that they were adequately instructed, and without ensuring that they fulfilled the duties expected of them.

Against this, however, their time on tunnel supervision was limited by having to travel on foot from one face to the other, and in having duties other than the construction of the tunnel.

In Mr. Ryan's case he was absent on sick-leave for some six months during the construction of Turakina Tunnel.

Foremen: There was considerable variation in the responsibility as understood and carried out by the four foremen.

In general terms their main fault was a lack of uniformity in understanding the requirements of the tunnel construction.

The personal performance of the foremen may be summarized:—

Mr. Storey, South End, Fordell: Since deceased.

Mr. McDonald, North End, Fordell: Unsuitable for position of foreman. Did not understand requirements and was not aware of happenings of which he should have known.

Mr. Howard, South End, Turakina: Experienced tunneller, but lacked keenness and did not understand the full requirements of the position.

Mr. Knight, North End, Turakina: A keen foreman with good experience. Was considered the best of the foremen.

Tunnellers: The placing of the concrete in the crown of the arch in portions of the tunnel indicates bad workmanship on the part of the workers, as considerable variation in the thickness of the lining is revealed by the borings. In some places the concrete has been put in to the required thickness, while in others, it is less than half this amount, indicating either that insufficient care was taken to see that the concrete was properly placed or mixed, or that the arch timbers were standing too low to allow this to be done. In the latter case it would be the party's obligation to pole back the timbers to give sufficient clearance. In this connection, however, the difficulties attaching to the class of timbering ordered to be adopted should not be overlooked.

There is also evidence of insufficient concrete filling or, in its absence, of adequate packing of the arch shoulders along some portions of the tunnels, but this must be deemed to have been condoned by the supervisors, as they raised no objection to the practice and the tunnellers must thereby escape serious blame, even though it is contrary to good tunnelling practice. There is, however, no evidence of deliberate slumming in the execution of the work; but the evidence indicates that the tunnellers merely carried out what was required of them, although in some instances this was against their experienced judgment. In the opinion of the Committee, this course was not justifiable.

(Sgd.) J. H. Boyes.
(Sgd.) H. Vickerman.
(Sgd.) W. Brooke.

Wellington, 17th July, 1944.

LIST OF WITNESSES

W. L. Newnham	Present Engineer-in-Chief and Permanent Head, Public Works Department.
C. O. Turner	Designing Engineer, Head Office, Public Works Department.
J. Wood	Retired Engineer-in-Chief, Public Works Department.
H. H. Sharp	Retired Inspecting Engineer, Public Works Department.
E. D. Kalaugher	Engineer, Public Works Department, Fordell.
F. W. Lindup	District Engineer, Public Works Department, Nelson, previously at Stratford.
G. W. Sampson	Acting District Engineer, Public Works Department, Wanganui.
B. C. Annand	Engineer, Public Works Department, Trentham, previously at Fordell.
A. P. L. Thompson	Senior Foreman, Fordell Tunnel, acting as Overseer.
A. McDonald	Foreman, Fordell Tunnel, now retired.
S. A. Mitchell	Headman, Fordell Tunnel.
R. W. J. Day	Headman, Fordell Tunnel.
J. H. Ryan	Overseer, Turakina Tunnel.
R. L. Knight	Foreman, Turakina Tunnel.
H. N. Hansen	Headman, Turakina Tunnel.
W. Howard	Foreman, Turakina Tunnel.
J. Eade	Headman, Turakina Tunnel.
F. T. Wood	Headman, Turakina Tunnel.
E. Murch	Headman, Turakina Tunnel.
J. R. Ensoll	Engineer, Public Works Department, Wanganui.
A. J. Allison	Engineer's Assistant, Public Works Department, New Plymouth, previously Fordell.
J. H. Christie	Assistant Designing Engineer, Head Office, Public Works Department.

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