PAPER No. 179.

REPLACEMENT OF GALLERY NO. 826 ON THE KALKA-SIMLA RAILWAY BY A STEEL TRESTLE BRIDGE.

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The Kalka-Simla Railway is probably one of the best known sections of the N. W. Railway, providing as it does or rather did before the days of road competition, the best means of access to the summer capital of India. To the members of this Congress, however, a further appeal lies in its engineering features which, as will be readily realized in a line of this description, are many and varied. The problems which now confront the Engineer are of course somewhat different from those which presented themselves to the original constructors and many of them are considerably more difficult. One such and its solution are described in this paper.

The Problem.

The track at many points throughout its length is carried along the hillside on galleries. Most of these galleries—the term is self-explanatory—consist of series of masonry arches often several storeys in height. The particular one—a single storey gallery—to which this paper relates, is situated some half a mile below Simla station itself. This bridge—to adopt a more general term—consists of a row of nine segmental arches of span 12 feet and rise 3 feet 9 inches. Approximately half the length of the bridge is on a curve of 150 ft. radius together with a transition length and the remainder on the tangent while there is a gradient rising from the Kalka end of 1 in 42. Plate I gives a general idea of the structure at the site of which the hillside at right angles to the bridge has a slope of about 1 in 1¼. It will be further noted from Plate I, that the foundations are shallow but as these are actually let well into the shale of which the hillside is here composed, they may be said to be adequate, particularly as the bridge takes comparatively little flood water. The presence of a retaining wall close on the uphill side of the bridge is also to be noted, this wall serving to retain a bye-road on to the adjoining Nabha State territory.

Early last August (1933) the Sub-Divisional Officer, Dharampore, in whose charge the bridge was, reported that three piers were cracked, one seriously, while the three arches at the deepest part of the bridge were also badly cracked and the spandril walls similarly affected. In the case of the piers and the arches the cracks were both transverse and parallel to the track and observations showed a deflection under trains of about $\frac{1}{8}''$ in the worst arch. The Sub-Divisional Officer considered the bridge was in a dangerous condition and, in order to carry on, he put in rail clusters immediately under the track over the affected arches and restricted the speed of trains over the bridge to five miles per hour.

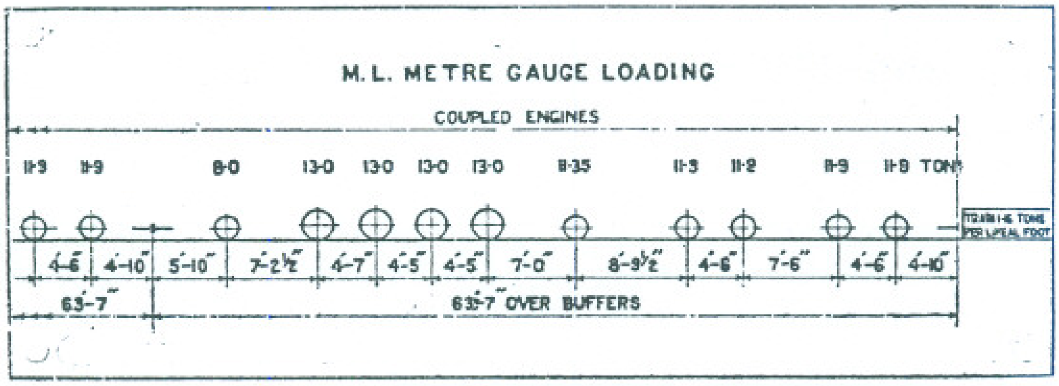
This was the state of affairs when the bridge was inspected later in the month by the Chief Engineer, N. W. Railway, who further ordered the cracked piers to be fitted with rail clamps. He also ordered a close watch to be kept on the bridge and sufficient sleepers to be collected at site immediately in order to crib up the arches should the cracks show any tendency to develop. This was fortunately not found necessary, but in October two more piers in which cracks had developed were fitted with rail clamps.

It will be realized from this description that the bridge was really in a bad way and that there was no alternative left but to rebuild it completely. It may here be stated that the masonry of the piers themselves was actually little better than random rubble, although the exposed masonry from the original ground level upwards looked much better. During dismantling, however, it was found that the insides had been very poorly built and contained numerous voids and poor mortar. The arch rings themselves were of brick, five rings, brick on edge and were of much better quality. On such poor piers, however, the arches had not very much chance and the failure of the bridge may be ascribed initially to the failure of the piers (*vide* Plate I, Fig. 4).

Complete rebuilding was therefore decided on and the Chief Engineer accordingly issued orders to prepare designs for a new bridge and plans for a diversion to enable the work to be carried out without interruption to traffic. This was proceeded with and the necessary estimate got out. However, the anticipated cost of the diversion at such a difficult site far exceeded the preliminary figures and it was at this stage that a proposal was put forward to replace the masonry arches with a steel trestle bridge erected on the sound lower portions of the existing piers. This proposal was shown to Mr. Everall, Bridge Engineer, N.W. Railway, who realized the possibilities of carrying out all the work under traffic without the need for a diversion. The cost of Mr. Everall's scheme was less than that for the complete rebuilding using a diversion. Moreover, the design and method of erection were attractive and it was considered that the work would give valuable experience in the method of dealing with a somewhat novel problem particularly as there are many similar bridges on the Kalka-Simla Railway, which may require the same treatment sooner or later. It is not suggested that this is the only method of dealing with such a problem, but the solution is considered a satisfactory one and the final structure is at least as well suited to the local conditions as the old one. A reinforced concrete bridge was mentioned as a possible alternative but it must be realized that the Railway has always on hand quantities of old steel work released from other bridges and the using up of this whenever possible is an obvious economy. In Mr. Everall's design nearly all the steel-work was second-hand and was fabricated at the Railway Bridge Workshops at Jhelum.

Design of Trestle.

The trestle was designed to carry standard M.L. (metre gauge) loading, that is, for two eight-coupled 13-ton axle locomotives followed by a train of 1·16 tons per lineal foot.



The determination of stresses in the main girders and cross girders was straightforward and presented no points of interest. The loading on the main column legs of the trestles was slightly more complex and so details showing the various forces taken into account are given below. Particulars of the stress diagram and the tabulated stresses are given on Plates Nos. VII and VIII respectively.

Forces exerted on one pair of columns of one trestle from the following causes, were allowed for :—

(*i*) Dead weight of Superstructure and Trestle itself :

Dead load on one pair of columns=10·60 *tons.*

(*ii*) Live load of train itself, *i.e.*, its weight. The equivalent uniformly distributed load on a span of 30 feet was taken and divided by two to give the total reaction on one pair of columns.

Live load on one pair of columns=39·30 *tons.*

(*iii*) Impact effect.—In accordance with the practice in vogue on the N. W. R., the impact factor was calculated from the formula : impact factor$=\frac{65}{45+L}$, where L= length of the span in feet (in this case 30 feet, for cross girders and columns) :

Impact on one pair of columns=34·10 *tons.*

(*iv*) Centrifugal Force due to the passage of the train on the curve of 150 feet radius. This horizontal force, assumed to be acting through the centre of gravity of the live load (in this case the locomotives), was calculated from the formula

$$C = \frac{W\ V^2}{15\ R}, \text{ where}$$

C=horizontal force in tons per foot run of the span.

W=equivalent uniformly distributed live load in tons per foot run (for Bending moments) W=39·3÷15 tons per foot run.

V=maximum speed of live load=15 miles per hour.

R=radius of curvature of track, in feet. (R=150 feet.)

Centrifugal Force on one pair of columns=3·93 *tons.*

(*v*) Wind load of 30 lbs. per square foot on train and trestle. This was taken to be acting in the same direction as the centrifugal force. The force of 30 lbs. per square foot was assumed to be acting all over the exposed surface of the windward columns and bracings and over 75 per cent. of those on the leeward side.

The Horizontal Force on one pair of columns due to the wind on—

(*a*) the train =1·91 tons

(*b*) the superstructure, *i.e.*, girders etc.=0·50 tons

(*c*) the trestle =0·94 tons

The distribution of wind and centrifugal forces has been shown on the diagram of forces.

(*vi*) Force due to the tractive effort and the braking effect of the live load.—

In accordance with the Rules, this force was determined by multiplying the equivalent uniformly distributed live load (used for calculating the bending moment in main girders) by the factor:

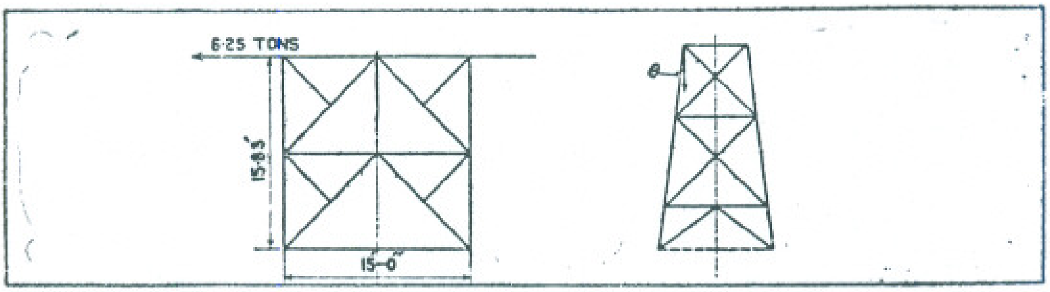
$$\frac{20}{L + 55}, \text{ where}$$

L=loaded length in feet (30 feet).

Of the total force due to tractive effort or braking effect, the rules state that six tons may be assumed to be dispersed through the running rails in the case of M.L. metre gauge.

Thus—

Tractive force on one trestle	=	18·5 tons
Dispersion through track	=	6·0 tons
Nett horizontal force on one trestle	=	12·5 tons.



Vertical Reaction due to Tractive Effort, etc., on one pair of columns

$$= \frac{12{\cdot}50 \times 15{\cdot}83}{15}$$

$$= 13{\cdot}16 \text{ tons}$$

and on each inclined column (inclined to the vertical by angle θ.), the reaction

$$= \frac{13{\cdot}16}{2} \times \sec\theta$$

$$= 6{\cdot}62 \text{ tons.}$$

Details of the Design.

Before proceeding to describe the method of carrying out the work which is the main object of this paper it is necessary to examine the design (*vide* Plate II). Points to note are the reinforced caps on the cut down piers, the provision for expansion and contraction at Pier No. 6, the girder spans at the Kalka end of the bridge, the arrangement of the cross girders on the tops of the trestles and the attached pairs of inner stringers. As will be explained later these were incorporated in the temporary staging and formed one of the main features of the whole scheme. As regards the trestles themselves, the batter of the legs was kept the same in all cases for ease in fitting the between-trestle bracings, the extra height for the higher of each pair being obtained by lengthening the legs at the top thus reducing the top transverse width between them from 5′—0″ to 4′—11″ (*vide* details Plate II).

Staging Design.

It is now necessary to refer to Plate III showing the complete staging arrangement for the job. It will be noted that the loads were transferred through the inner stringers and cross girders, above mentioned, by extension pieces to girders running parallel along each side of the bridge. These girders were supported on columns which were again supported on a series of parallel girders resting on cement concrete blocks carried up from the foundations at the ends of the piers. The maximum pressure on these foundations was limited to three tons per sq. foot. The foundation arrangements are shown in Plate IV.

It may here be mentioned that the staging was constructed from N. W. Railway interchangeable type steel staging units designed by Mr. Everall for general bridge work on the railway—the units being all coded so that parts can at once be recognized, thus saving much valuable time, especially in cases of emergency.

As it was imperative to guard against any local settlement or movement of the staging, all the members were securely braced together, longitudinally and transversely. As a matter of fact, during the course of the work several extra supports and ties were added in case the monsoon softened the founds. The position of these will be mentioned in this paper further on.

Emergency Staging.

Orders to start the work were actually given about the end of February, 1934, and work was commenced on the preparation of the founds for the staging immediately after. At the same time the retaining wall on the uphill side of the Bridge (Plate I) was dismantled and a new one built sufficiently far back to allow of the staging being erected on that side of the bridge, this work being carried out under the supervision of the Sub-Divisional Officer, Dharampore.

Meanwhile, however, doubts had been expressed by the Executive Engineer in charge of the Kalka-Simla Railway as to the ability of the bridge to withstand the intensive uphill traffic of April and May. It was therefore decided that, in addition to the relief afforded by the rail clusters over the tops of the arches, further relief should be provided by the shoring up of the three most defective arches in the middle of the bridge.

Mr. Everall designed a suitable arrangement which gave the required support under the arches and yet did not interfere with the scheme already got out for the erection of the trestles. (This arrangement is shown in Plate IV which should be compared with Plate III.) The design was approved and the three arches duly shored up before the end of March. No special difficulties were encountered, the materials being man-handled with the aid of the usual tackle. The existence of a short siding just on the Kalka side of the bridge greatly facilitated the transportation of materials to site, saving valuable time throughout the work, though the absence of level ground on which to stack and assemble the steelwork was a definite drawback.

During April, when the uphill traffic was at its heaviest, there was little opportunity for carrying on the erection of the rest of the staging but materials were collected and work which did not interfere with trains, was pushed on. A wooden derrick was erected and the usual offices and stores and working arrangements were generally put in order.

Checking layout.

During this time, the opportunity was taken to check up the layout of the bridge and secure accurate data for the fabrication of the steelwork in the Bridge Workshop at Jhelum. All the designs had so far been prepared from existing plans, which, good enough for the staging work, were not sufficiently accurate for the detailing of the permanent trestles. The site was accordingly accurately surveyed and the position of the centres of the piers at the levels of the base plates under trestles ascertained. A theoretically correct layout for the track using a transition curve on to the tangent at the Kalka end of the bridge was then drawn out on tracing paper and this superimposed on the plan of the pier centres, gave the positions for the centres of the trestles. A further correction of half the value of the versine for a chord of the length joining the pier centres, was then made to keep the track as near the centre of the troughing as possible. The maximum difference between the figures so obtained and the actual pier centres was only three and-a-half inches, a relatively small amount, the error being on the outer side of the curve. Levels were also taken from some distance below the bridge to some distance above and the final track levels fixed from these. Fortunately the existing levels on the bridge turned out to be nearly correct and nothing remained but to fix the level of one and adjust the remaining trestle levels from this. From the data so obtained the lengths of the top stringers were calculated and the positions of the cross girders fixed, relative to the temporary staging girders. This completed the measurements for the main items of the work and enabled the workshop to go ahead with the fabrication of the steelwork. Plate II, showing details of the cross girders, contains a note regarding the working tolerances actually allowed in the lengths of the stringers.

Erection of Staging.

By the middle of May, the Operating Branch were able to allow the line between Simla and Summer Hill to be blocked for certain periods during the day and the night. Unfortunately these periods were few and not always available daily. During day-light only one period of two and-a-half hours from 5-30 a.m. to 8 a.m. was allowed and during the night by special arrangement beforehand, one or two blocks of a little over one hour each were permitted in cases of emergency, should the work, normally carried out in the morning block, fall behind.

Stage 1. By this time, most of the staging along both sides of the bridge and underneath the arches had been erected. The heavy plate girders which were to carry the full train loads during the dismantling of the masonry were taken out on a Diplory material trolley and placed on the staging by means of the wooden derrick.

At this time, it was noticed that the two arches, one on each side of the three already supported, were showing signs of failure and so these were also shored up in the middle for a width of about 2′—6″ under the track. The staging in this case was less elaborate than that used for the first three arches but actually it proved quite as effective and was easier to erect. (This method of support is shown in Plate IV.)

Stage 2. After the heavy girders alongside the track had been got into position, the temporary rail clusters previously put in to relieve the cracked arches were removed. Then the permanent cross girders were erected and the connections to the temporary main girders completed. The four long R. S. Joists at the Kalka end of the bridge were also erected at this stage (*vide* Plate III). The former operation had to be spread out over two block periods for each cross girder, the work being divided as follows :—

First Block.—The spandril walls at the haunches were dismantled and a small-size sleeper crib was built to support the track temporarily and to retain the rest of the fill.

Second Block.—The top layers of the crib, as found necessary, were removed and the cross girder inserted and the connections to the temporary main girders bolted up, leaving the rest of the crib to retain the fill.

The erection of the four R. S. Joists at the Kalka end was accomplished in seven block periods as follows :—

First Block.—The cribs over the Kalka abutment and above Pier No. 1 were built between the haunches of arches, the masonry being dismantled as required.

Second Block.—The four temporary girders between the two cribs, erected in the first block, were put in position to carry the track, the rest of the masonry in the spandril walls being dismantled.

Third Block.—The crib between the haunches was built over Pier No. 2, in the same way as that for Pier No. 1.

Fourth Block.—Four more temporary girders were placed in position under the track between the cribs over Piers Nos. 2 and 1, the masonry being dismantled as required.

Fifth Block.—The eight short temporary girders erected during the Second and Fourth Blocks were replaced by the four long R. S. Joists (*vide* Stage 2, Plate V), and the crib over Pier No. 1 was removed.

Sixth Block.—One cross girder was erected between the columns at Pier No. 2, the crib being modified to suit.

Seventh Block.—The second cross girder at Pier No. 2 was erected and the connections completed, the crib being removed.

During these operations it was noticed that the arch at the Simla end of the bridge was also showing signs of failure and, as the adjacent pier was already badly cracked, it was decided to shore up this arch also. This was accordingly done using short columns supported upon sleeper rafts, and carrying cross girders and sleepers wedged under the masonry arches. An opening for pedestrians was maintained under this arch for the bye-road on to Nabha Estate.

These operations were completed by the middle of June and with the monsoon imminent, arrangements had to be made for carrying on the work during the rains. The foundations under the staging were all carefully examined and points noted where possible settlement might take place owing to the soaking in of rain water. As a result, extra supports were provided at "A" and "B" span No. 3 and one extra girder at "C" span No. 3 to tie the staging together more securely back to front (*vide* Plate III). Tie rods with yokes were also fitted at Piers Nos. 2 and 3, back to front, one pair being provided near the top of the concrete blocks supporting the staging and the other pair lower down in order to resist any tendency for these blocks to settle or move outwards from the piers. With the possible exception of the tie rods fitted to the concrete blocks at the end of Pier No. 2, where the reaction was greater than elsewhere, these precautions may have been superfluous but as any failure would have meant interruption to traffic, no risks, however small, could be entertained.

Stage 3. The main operations in Stage 3 were the insertion and bolting up of the inner stringers between the cross girders and the final transference of the train loads on to the staging. As a matter of fact, the operations in the two stages overlapped considerably, a number of the operations in Stage 3 being completed before all the work of Stage 2 had been finished. It is to be noted, however, that until such time as it was possible to transfer all the load to the staging, packings were kept in under the cross girders and the R. S. Joists at Pier No. 1, this being done to ensure that the reactions on the piers were as nearly vertical as possible. For the same reason no dismantling of any of the arches was done until all the load had been transferred to the staging.

The insertion of each pair of stringers between the cross girders was a comparatively easy matter and occupied one block period for each pair. The temporary bridge timbers or sleepers were all fitted to the stringers, numbered and removed before erection. This precaution saved time and trouble during the block periods and ensured a safe track. A super-elevation of half an inch was provided by notching the timbers, this being the correct amount for trains passing over the bridge at a speed of six miles per hour.

On completion of the erection of the stringers the dismantling of the arches was taken in hand, work being started from both ends of the bridge. This proved to be rather a longer process than had been anticipated and fully three weeks were occupied in dismantling the masonry and in clearing away the debris. During this period, however, "constructive" work still progressed. As each pier was dismantled the casting of the R. C. cap on top of the remaining stump was taken in hand. For the stone masonry, cement and sand mortar, in the ratio of 1 to 3 was used and for the R. C. caps and bedstones a 4 : 2 : 1 concrete was used. In the case of the masonry mortar, the sand, obtained locally from Barog, a station lower down on the Kalka-Simla Railway, proved suitable for the work ; but, it was necessary to wash it well before mixing. The stones for the masonry were obtained from the dismantled piers. For the R. C. work, better materials were necessary and hence sand from Pathankot and shingle from Chandigarh (between Kalka and Amballa) were used. As regards the cement, "Swasticrete" quick-setting cement was used for the R.C. caps and bedstones, ordinary Punjab cement being used for the stone masonry. No load was applied to any concrete work until after five days had elapsed since casting with quick-setting cement and fourteen days in the case of Punjab cement. As the weather was very damp at the time this work was being carried out, there were no difficulties about curing.

In connection with the casting of R.C. slabs on the stumps of the piers it is noteworthy that in the case of Piers Nos. 5, 6 and 7 the three bottom longitudinal staging girders, where they rested on the concrete blocks at the ends of the piers, had to be concreted in and, similarly, at Pier No. 7, the two stools resting on these girders had also to be partially embedded in concrete. This was necessary to avoid interference with the staging while it was still carrying train loads, the steelwork being cut off flush on completion of the work.

Owing to the inclement weather, all the concrete work had to be done under cover, both for the sake of the labour and in order to protect the work from damage from the heavy rains. Wagon paulins, easily slung, were used for this purpose. Stage 3 (*vide* Plate V) was finally completed early in July. Another "view" of this stage (*vide* Plate V) shows the intermediate supports put in beneath the inner stringers at the centre of each span. These supports were lightly wedged against the bottoms of the stringers, the object being for them to take a portion of the load when the stringers deflected and to serve as "emergency" supports when inserting the tops of trestle legs between the cross girders, a certain amount of interference with the diaphragm joints in the cross girders being unavoidable.

Stage 4. As in the case of Stages 2 and 3 so with Stages 3 and 4, there was a good deal of overlapping. The erection of the trestles came in Stage 4 but a number of them were installed and connected up before Stage 3 had been completed. No special difficulty was encountered in these operations and the work proceeded quite quickly, full advantage being taken of the block periods so that the men did not have to waste time every twenty minutes or so when a train passed.

The holes in the connections between the cross girders and the tops of the trestles were drilled in position, between trains, the rivetting being done later on. The other holes in the trestles for bracing connections, etc., were all drilled in Jhelum Workshop, the complete trestles having been erected, marked and dismantled before despatch to Simla. In the case of the bracings between trestles, the holes were all drilled at site.

During the erection of the trestles, opportunity was also taken to grout up the old masonry remaining in the stumps of the piers, particularly as at this time they carried little or no load, order for this grouting work to be done being issued when, on dismantling the piers, the quality of the masonry work in the interior was found to be very poor. Holes spaced about 2′—6″ and 3′ apart were drilled to a depth of about half the thickness of the masonry of the piers and pieces of one inch diameter iron piping nine inches long were forced into these holes and cemented in position with quick-setting cement, the end protruding being screwed to make connection with a flexible hose from the grouting machine. This machine was the same one as was used for grouting the piers of the Bishendore Bridge and was described in Paper No. 175 presented before Congress by Mr. J. D. Watson last year.

On this bridge at Simla a grouting pressure of about 20 lbs. per sq. inch was maintained, the air being supplied from the same Diesel driven compressor as was used for operating the Pneumatic tools. The average quantity of cement pumped into the piers was about 1·75 bags per hole. The result of this grouting appeared to be satisfactory so far as could be ascertained.

Apart from the erection and bracing up of the trestles and the above mentioned grouting the only other work to be done, shown in Stage 4 was the rebuilding of Pier No. 2 and both the abutments, pier No. 1 having already been finished in Stage 3.

Work on Pier No. 2 and the Kalka abutment was divided into the following operations, each being carried out in one block period (*vide* Plate V).—

First Block.—Timber cribs were built behind the Kalka abutment, spaced so that the one farthest back from the bridge would form a support for the four R. S. Joists, pulled back from Pier No. 2 to Pier No. 1 in the next block ; these joists having previously been used in Stage 3 for the rebuilding of Pier No. 1.

Second Block.—The four R. S. Joists were pulled back so as to span from Pier No. 1 to the crib behind the Kalka abutment. The two inner permanent girders were placed in position between Piers Nos. 1 and 2, the track being laid on temporary bridge timbers fastened direct on the upper flanges of these girders.

Third Block.—The cross girders and packings at Pier No. 2 were removed and new packings were inserted in the centre to enable the outside masonry to be built up to the level of the bottom of the bedstones. The Kalka abutment was then completed and the bedstones cast thereon—this work being done irrespective of block periods.

Fourth Block.—The centre packings at Pier No. 2 were removed and rail clusters were put in to support the ends of the girders. The central portion of the masonry was then built up to the level of the bottom of the pier cap—this work being carried out irrespective of block periods.

Fifth Block.—The rail clusters on Pier No. 2 were removed and special built-up stools were placed in position to support the ends of the girders.

Later, the whole of the central part of the top of this pier including the pier cap was completed in concrete, the stools being left in permanently.

Sixth Block.—The four R. S. Joists spanning between Pier No. 1 and the aforementioned cribs were removed and the two permanent inner girders together with the track supported on temporary bridge timbers, were placed in position between that pier and the Kalka abutment.

Later the ballast wall was completed at that abutment.

The abutment at the Simla end was dealt with in a manner similar to that of the Kalka abutment. So much for Stage 4.

All the trestles had been erected and the bracings completed ; the permanent inner girders were in position from end to end of the bridge and the track, supported on double timbers, was being carried on these girders: Photographs taken after the completion of Stage 4 are shown on Plate VI. Although the temporary connections between the ends of the cross girders and the staging girders had been severed and the whole of the loading was being carried on the trestles, the staging,

Tests etc.

The completed structure was tested under two of the heaviest engines running on the Kalka-Simla Railway, the deflections and stresses in various parts of the structure being measured and compared with the calculated stresses.

The results of these tests were sent to the Senior Government Inspector (Railways) who duly approved of them on 19th September, sanctioning the opening of the bridge to the maximum permissible speed of the section, *i.e.*, 15 miles per hour.

The work was executed under the immediate supervision of Mr. A. S. Faruqui, Assistant Bridge Engineer, to whom the author is also indebted for the collection of much of the data. It is also desired to record an appreciation of the help rendered by Mr. J. D. Watson, Executive Engineer, Bridges, and Mr. P. S. A. Berridge, Assistant Bridge Engineer, Technical.

The paper is presented with the kind permission of Mr. W. T. Everall, Bridge Engineer, and the Administration of the N. W. Railway.

excepting where it interfered with trestle bracings etc., was left in position. This was done to avoid handling the staging until there was a clear space to stack it.

Stage 5. In this stage, the outer pairs of permanent girders were erected and the troughing laid in position. This latter work was done during block periods, temporary timbers being recessed in the troughs to carry the track pending the spreading of the ballast at a later date. Opportunity was taken to complete the painting, the top of the troughing being coated with a bitumastic solution and the rest of the steelwork receiving coats of red oxide in accordance with standard N. W. Railway practice.

Finally after the alignment of the trestles had been checked up, and all bracings rivetted, the holding down bolts were grouted in position.

As in all bridges on the N. W. Railway, lead sheet packings $\frac{1}{8}$ inch thick were inserted under all bed plates and under the column bases of the trestles. This material squeezes into any irregularities in the surface of the concrete and makes for even distribution of the load.

As the situation of the bridge is such that it is approached from either side by blind corners, two small refuges for the use of platelayers etc., were erected, one at span No. 3 and one at span No. 7.

On completion of the work, the temporary staging was dismantled and loaded into trucks, the derrick and Diplory trollies being used. Although a ten-ton travelling hand crane is available on the Kalka-Simla Railway, the cost of using it and the difficulties attendant with its operation on the steep grades etc., made it quite unsuitable for use at this bridge.

Plate IX shows the completed structure.

Time taken.

Although work was started at Gallery 826 at the end of February, 1934 and completed at the end of the following August, it must be remembered that the line between Summer Hill and Simla could not be blocked during the month of April and the first half of May when the uphill rush was taking place.

Quantitative Data and Cost.

The total weight of steelwork in the finished structure	= 70 tons.
The weight of steelwork employed in the temporary staging	= 150 tons.
The approximate cost of the permanent structure, *i.e.*, including all masonry work, grouting, etc.	=Rs. 25,000.
The approximate cost of the temporary staging, its erection and dismantling, the dismantling of the arches, etc,	= Rs. 9,000.

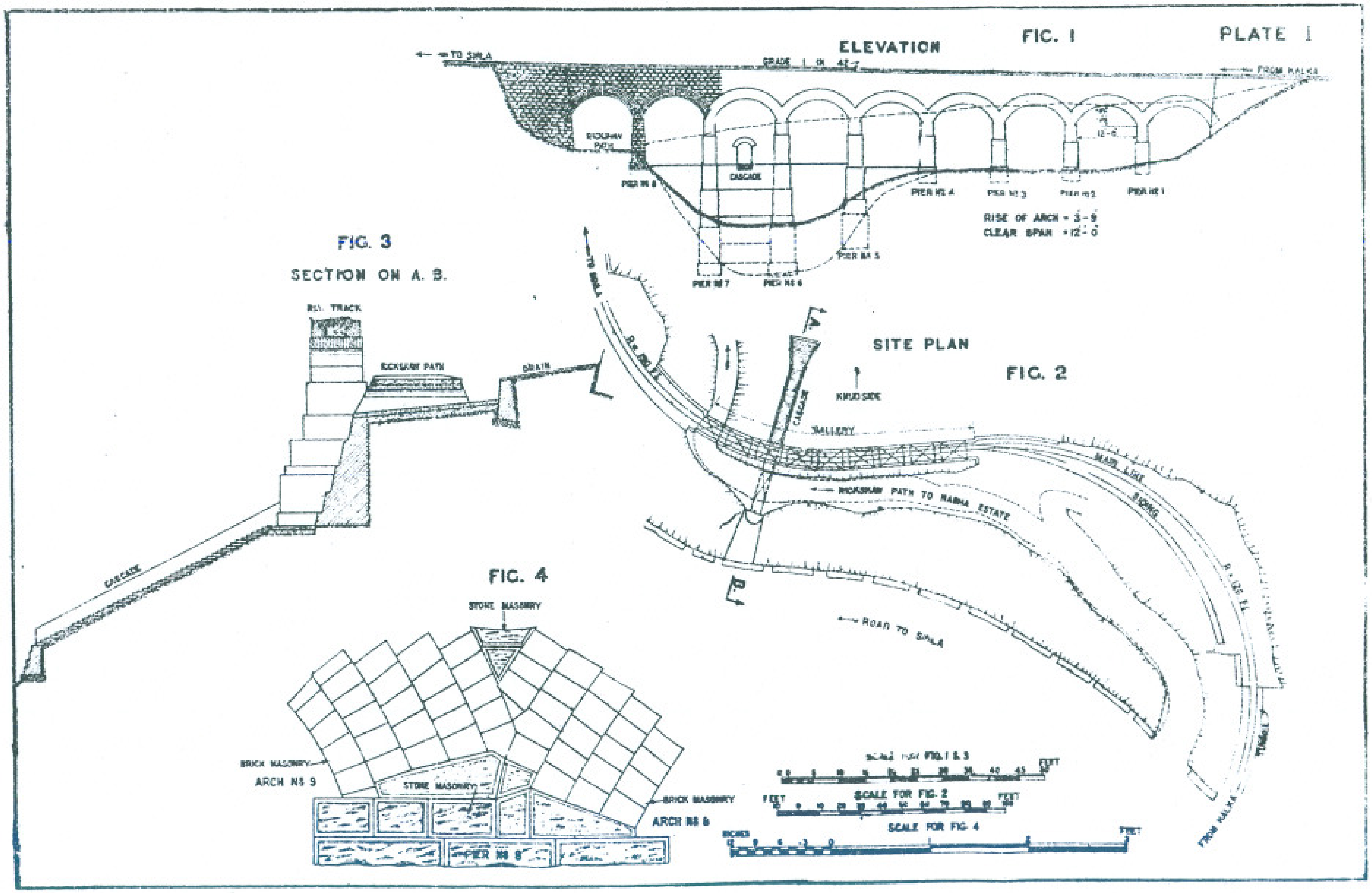


PLATE I
FIG. 1
ELEVATION
TO SIMLA
GRADE 1 IN 42
FROM KALKA
RICKSHAW PATH
CASCADE
PIER NO 8
PIER NO 7
PIER NO 6
PIER NO 5
PIER NO 4
PIER NO 3
PIER NO 2
PIER NO 1
12'-0"
RISE OF ARCH = 3'-9"
CLEAR SPAN = 12'-0"
FIG. 2
SITE PLAN
TO SIMLA
KHUD SIDE
CASCADE
GALLERY
MAIN LINE
SIDING
RICKSHAW PATH TO NABHA ESTATE
ROAD TO SIMLA
FROM KALKA
TUNNEL
A
B
FIG. 3
SECTION ON A. B.
RL. TRACK
RICKSHAW PATH
DRAIN
CASCADE
FIG. 4
STONE MASONRY
BRICK MASONRY
ARCH NO 9
ARCH NO 8
PIER NO 8
SCALE FOR FIG. 2
SCALE FOR FIG. 4
FEET
INCHES

PLATE II

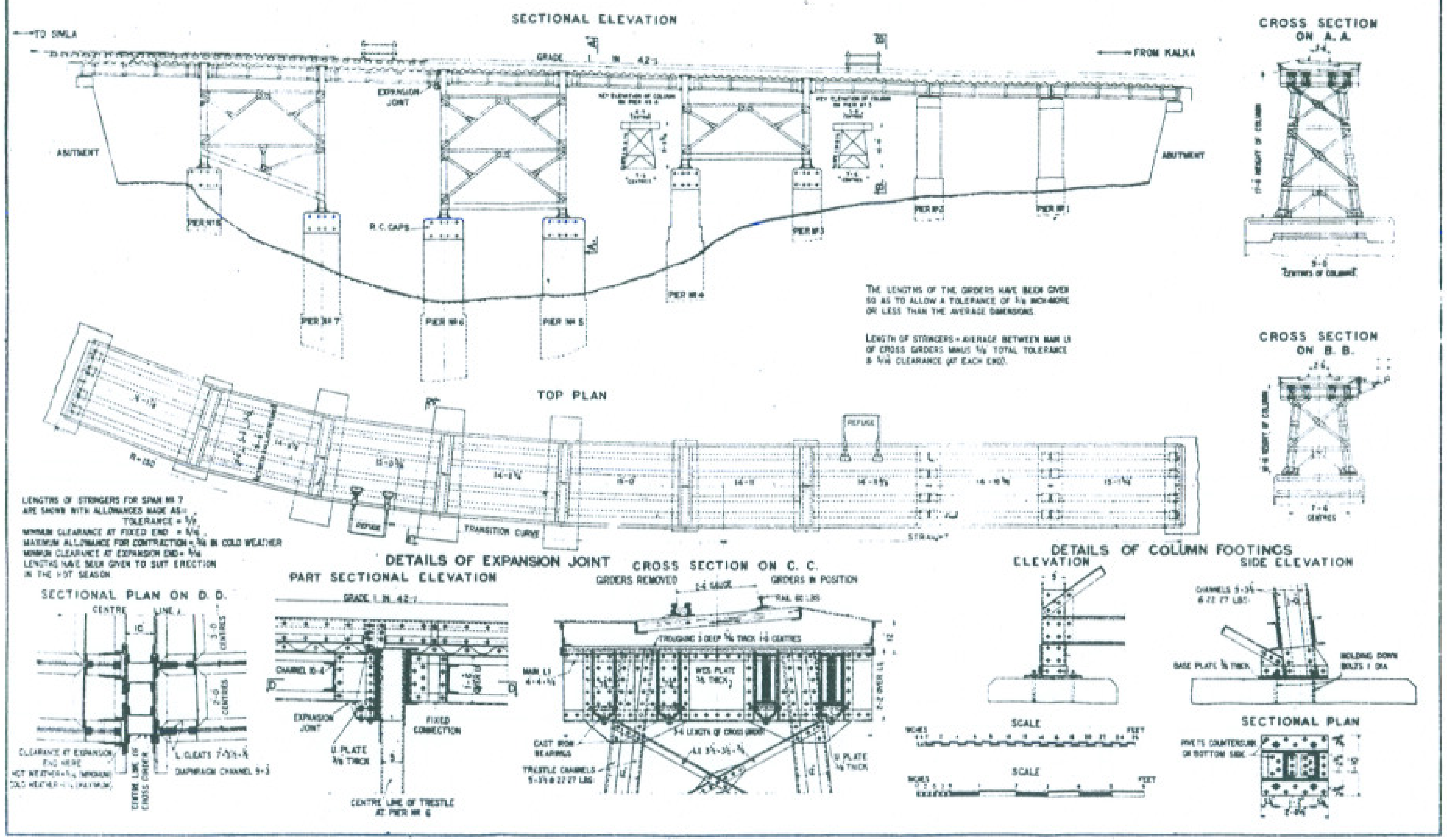

SECTIONAL ELEVATION
TO SIMLA
FROM KALKA
GRADE 1 IN 42·3
ABUTMENT
EXPANSION JOINT
R.C. CAPS
PIER No 7
PIER No 6
PIER No 5
PIER No 4
PIER No 3
PIER No 2
PIER No 1
CROSS SECTION ON A.A.
CROSS SECTION ON B.B.
THE LENGTHS OF THE GIRDERS HAVE BEEN GIVEN SO AS TO ALLOW A TOLERANCE OF 1/8 INCH MORE OR LESS THAN THE AVERAGE DIMENSIONS.
LENGTH OF STRINGERS = AVERAGE BETWEEN MAIN LI OF CROSS GIRDERS MINUS 1/8 TOTAL TOLERANCE & 1/16 CLEARANCE (AT EACH END).
TOP PLAN
REFUGE
TRANSITION CURVE
STRAIGHT
LENGTHS OF STRINGERS FOR SPAN No 7 ARE SHOWN WITH ALLOWANCES MADE AS:-
TOLERANCE = 1/8
MINIMUM CLEARANCE AT FIXED END = 1/16
MAXIMUM ALLOWANCE FOR CONTRACTION = 1/4 IN COLD WEATHER
MINIMUM CLEARANCE AT EXPANSION END = 1/16
LENGTHS HAVE BEEN GIVEN TO SUIT ERECTION IN THE HOT SEASON
DETAILS OF EXPANSION JOINT
SECTIONAL PLAN ON D.D.
PART SECTIONAL ELEVATION
CROSS SECTION ON C.C.
GIRDERS REMOVED
GIRDERS IN POSITION
FIXED CONNECTION
CENTRE LINE OF TRESTLE AT PIER No 6
CAST IRON BEARINGS
DETAILS OF COLUMN FOOTINGS
ELEVATION
SIDE ELEVATION
SECTIONAL PLAN
SCALE

PLATE III

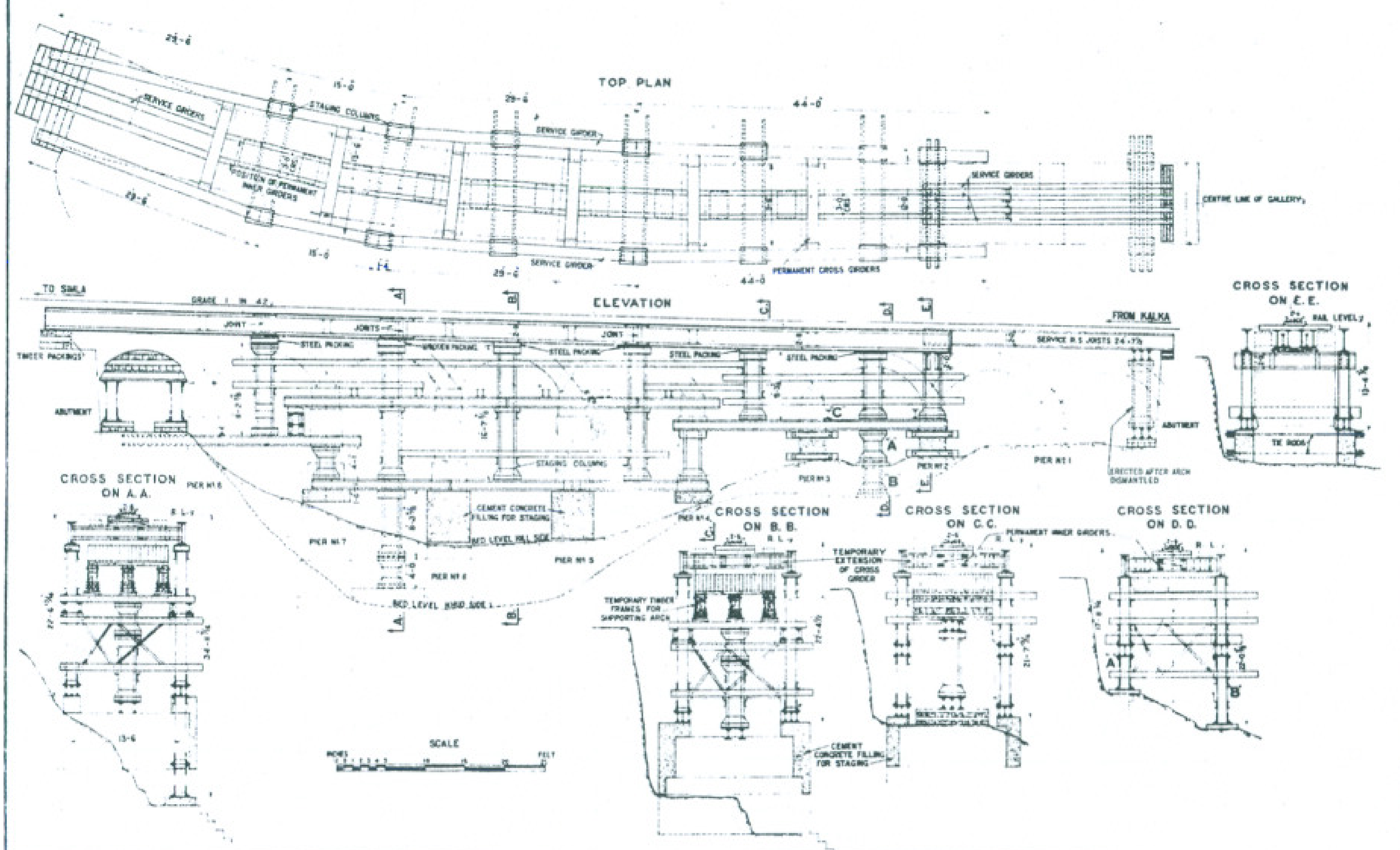
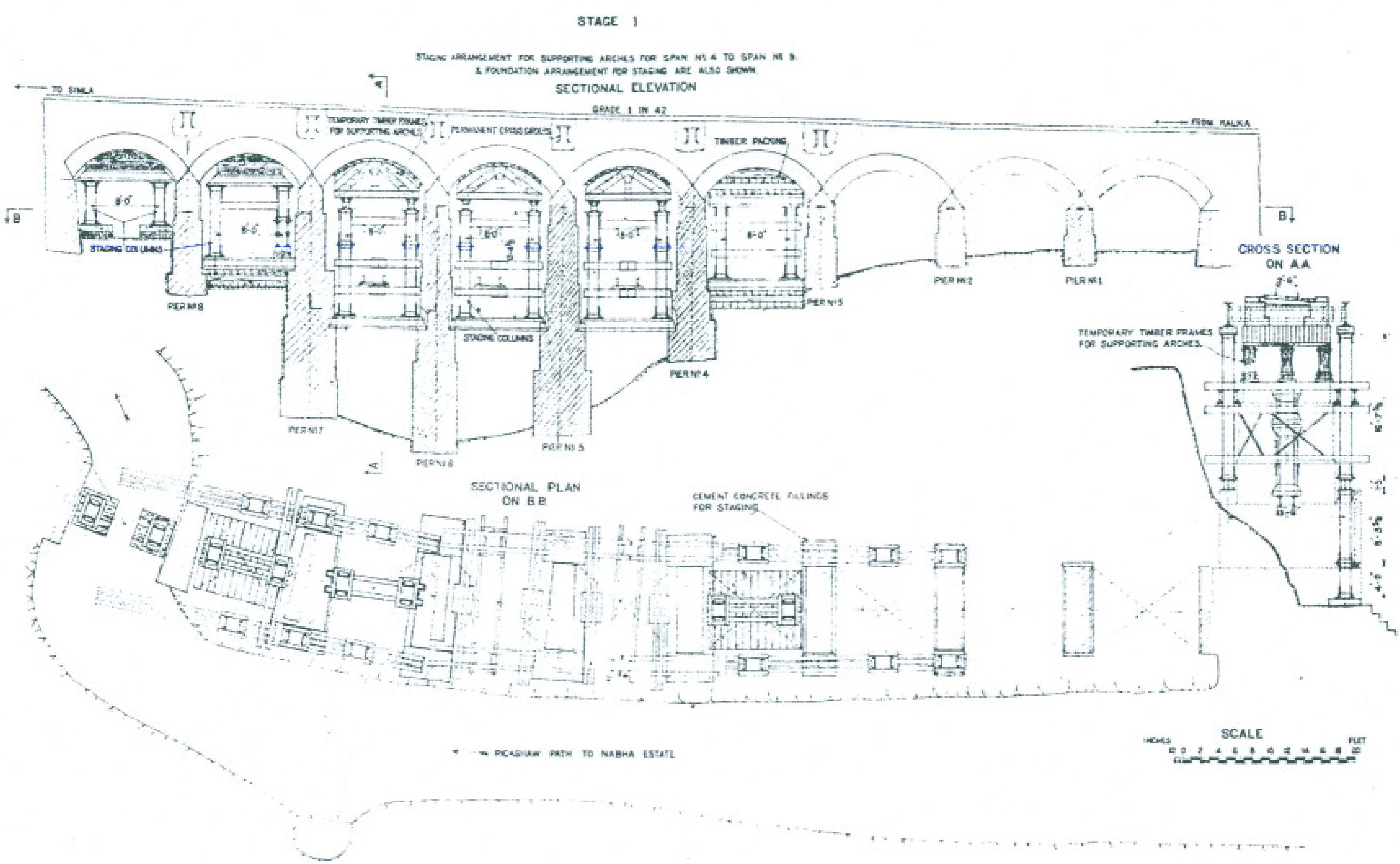

TOP PLAN
SERVICE GIRDERS
STAGING COLUMNS
SERVICE GIRDER
PERMANENT CROSS GIRDERS
CENTRE LINE OF GALLERY
ELEVATION
TO SIMLA
FROM KALKA
GRADE 1 IN 42
JOINT
JOINTS
STEEL PACKING
WOODEN PACKING
TIMBER PACKINGS
ABUTMENT
STAGING COLUMNS
CEMENT CONCRETE FILLING FOR STAGING
BED LEVEL HILL SIDE
BED LEVEL KHUD SIDE
PIER No 1
PIER No 2
PIER No 3
PIER No 4
PIER No 5
PIER No 6
PIER No 7
PIER No 8
ERECTED AFTER ARCH DISMANTLED
CROSS SECTION ON A.A.
CROSS SECTION ON B.B.
CROSS SECTION ON C.C.
CROSS SECTION ON D.D.
CROSS SECTION ON E.E.
RAIL LEVEL
TIE RODS
TEMPORARY TIMBER FRAMES FOR SUPPORTING ARCH
TEMPORARY EXTENSION OF CROSS GIRDER
PERMANENT INNER GIRDERS
CEMENT CONCRETE FILLING FOR STAGING
SCALE
INCHES
FEET

PLATE IV


STAGE 1
STAGING ARRANGEMENT FOR SUPPORTING ARCHES FOR SPAN Nº 4 TO SPAN Nº 9.
& FOUNDATION ARRANGEMENT FOR STAGING ARE ALSO SHOWN.
SECTIONAL ELEVATION
GRADE 1 IN 42
TO SIMLA
FROM KALKA
TEMPORARY TIMBER FRAMES FOR SUPPORTING ARCHES
PERMANENT CROSS GIRDERS
TIMBER PACKING
STAGING COLUMNS
PIER Nº 8
PIER Nº 7
PIER Nº 6
PIER Nº 5
PIER Nº 4
PIER Nº 3
PIER Nº 2
PIER Nº 1
CROSS SECTION ON A.A.
TEMPORARY TIMBER FRAMES FOR SUPPORTING ARCHES.
SECTIONAL PLAN ON B.B.
CEMENT CONCRETE FILLINGS FOR STAGING
RICKSHAW PATH TO NABHA ESTATE
SCALE
INCHES
FEET

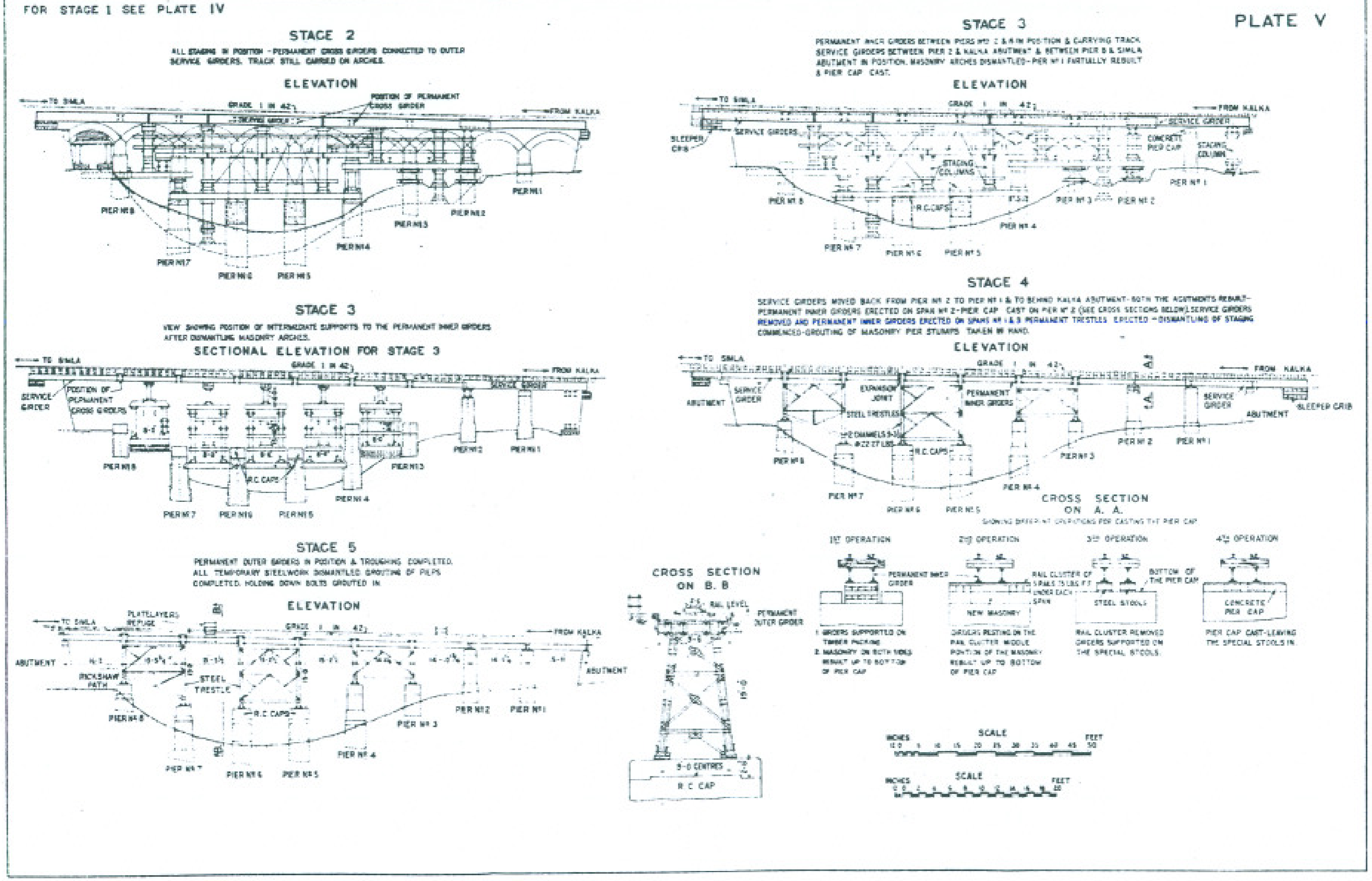
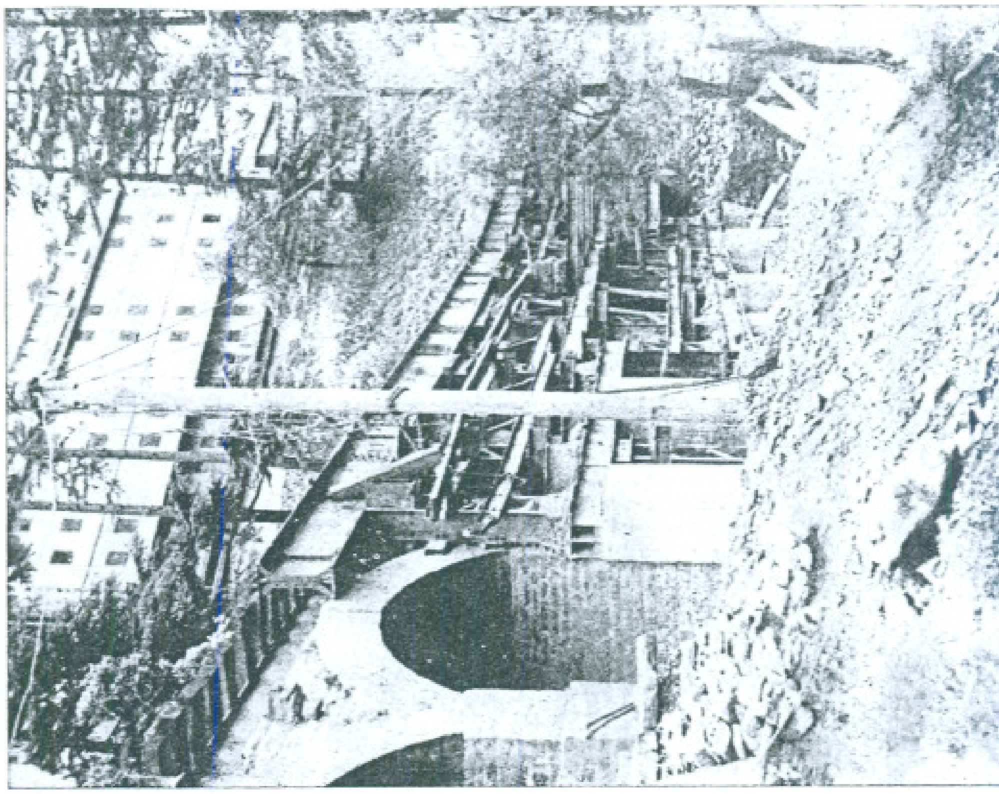

FOR STAGE I SEE PLATE IV
PLATE V
STAGE 2
ALL STAGING IN POSITION - PERMANENT CROSS GIRDERS CONNECTED TO OUTER SERVICE GIRDERS. TRACK STILL CARRIED ON ARCHES.
ELEVATION
POSITION OF PERMANENT CROSS GIRDER
TO SIMLA
FROM KALKA
STAGE 3
VIEW SHOWING POSITION OF INTERMEDIATE SUPPORTS TO THE PERMANENT INNER GIRDERS AFTER DISMANTLING MASONRY ARCHES.
SECTIONAL ELEVATION FOR STAGE 3
SERVICE GIRDER
POSITION OF PERMANENT CROSS GIRDERS
R.C. CAPS
STAGE 5
PERMANENT OUTER GIRDERS IN POSITION & TROUGHING COMPLETED. ALL TEMPORARY STEELWORK DISMANTLED GROUTING OF PILPS COMPLETED. HOLDING DOWN BOLTS GROUTED IN.
ELEVATION
PLATELAYERS REFUGE
ABUTMENT
RICKSHAW PATH
STEEL TRESTLE
R.C CAPS
STAGE 3
PERMANENT INNER GIRDERS BETWEEN PIERS Nº 2 & 8 IN POSITION & CARRYING TRACK. SERVICE GIRDERS BETWEEN PIER 2 & KALKA ABUTMENT & BETWEEN PIER 8 & SIMLA ABUTMENT IN POSITION. MASONRY ARCHES DISMANTLED - PIER Nº 1 PARTIALLY REBUILT & PIER CAP CAST.
ELEVATION
SLEEPER CRIB
SERVICE GIRDERS
STAGING COLUMNS
CONCRETE PIER CAP
STAGING COLUMN
R.C.CAPS
STAGE 4
SERVICE GIRDERS MOVED BACK FROM PIER Nº 2 TO PIER Nº 1 & TO BEHIND KALKA ABUTMENT - BOTH THE ABUTMENTS REBUILT - PERMANENT INNER GIRDERS ERECTED ON SPAN Nº 2 - PIER CAP CAST ON PIER Nº 2 (SEE CROSS SECTIONS BELOW) SERVICE GIRDERS REMOVED AND PERMANENT INNER GIRDERS ERECTED ON SPANS Nº 1 & 8 PERMANENT TRESTLES ERECTED - DISMANTLING OF STAGING COMMENCED - GROUTING OF MASONRY PIER STUMPS TAKEN IN HAND.
ELEVATION
EXPANSION JOINT
STEEL TRESTLES
PERMANENT INNER GIRDERS
SLEEPER CRIB
CROSS SECTION ON B. B
RAIL LEVEL
PERMANENT OUTER GIRDER
R C CAP
CROSS SECTION ON A. A.
SHOWING DIFFERENT OPERATIONS FOR CASTING THE PIER CAP
1ST OPERATION
2ND OPERATION
3RD OPERATION
4TH OPERATION
PERMANENT INNER GIRDER
NEW MASONRY
STEEL STOOLS
BOTTOM OF THE PIER CAP
CONCRETE PIER CAP
1. GIRDERS SUPPORTED ON TIMBER PACKING
2. MASONRY ON BOTH SIDES REBUILT UP TO BOTTOM OF PIER CAP
GIRDERS RESTING ON THE RAIL CLUSTER MIDDLE PORTION OF THE MASONRY REBUILT UP TO BOTTOM OF PIER CAP
RAIL CLUSTER REMOVED GIRDERS SUPPORTED ON THE SPECIAL STOOLS.
PIER CAP CAST-LEAVING THE SPECIAL STOOLS IN.
SCALE
INCHES
FEET

PLATE VI.



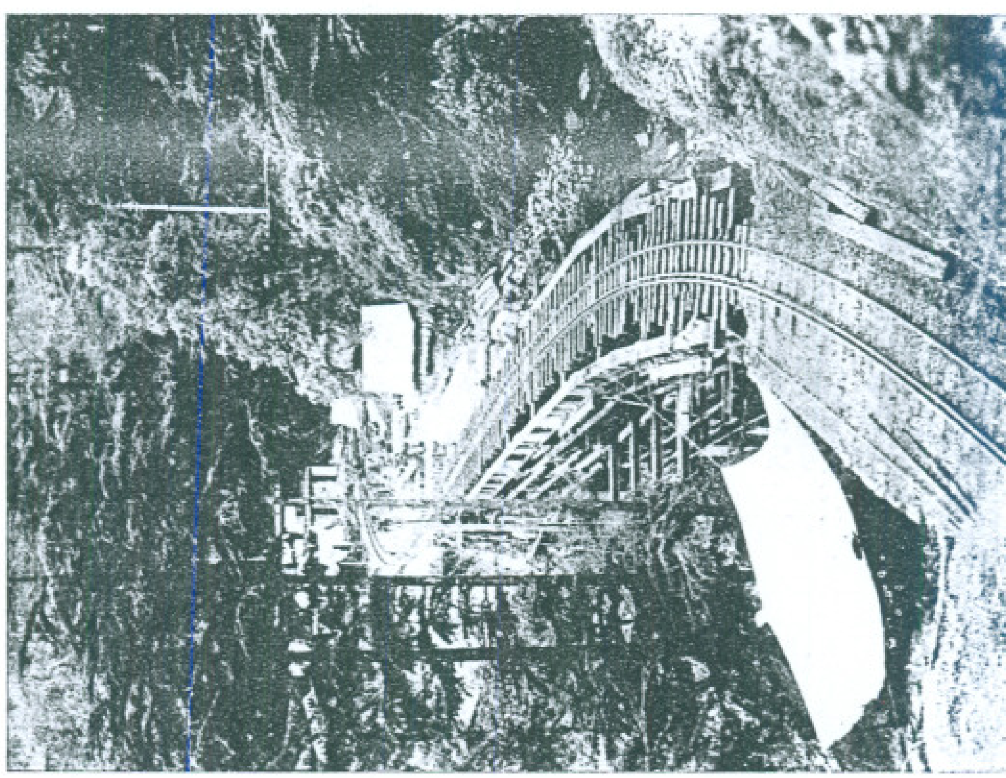


PLATE VII

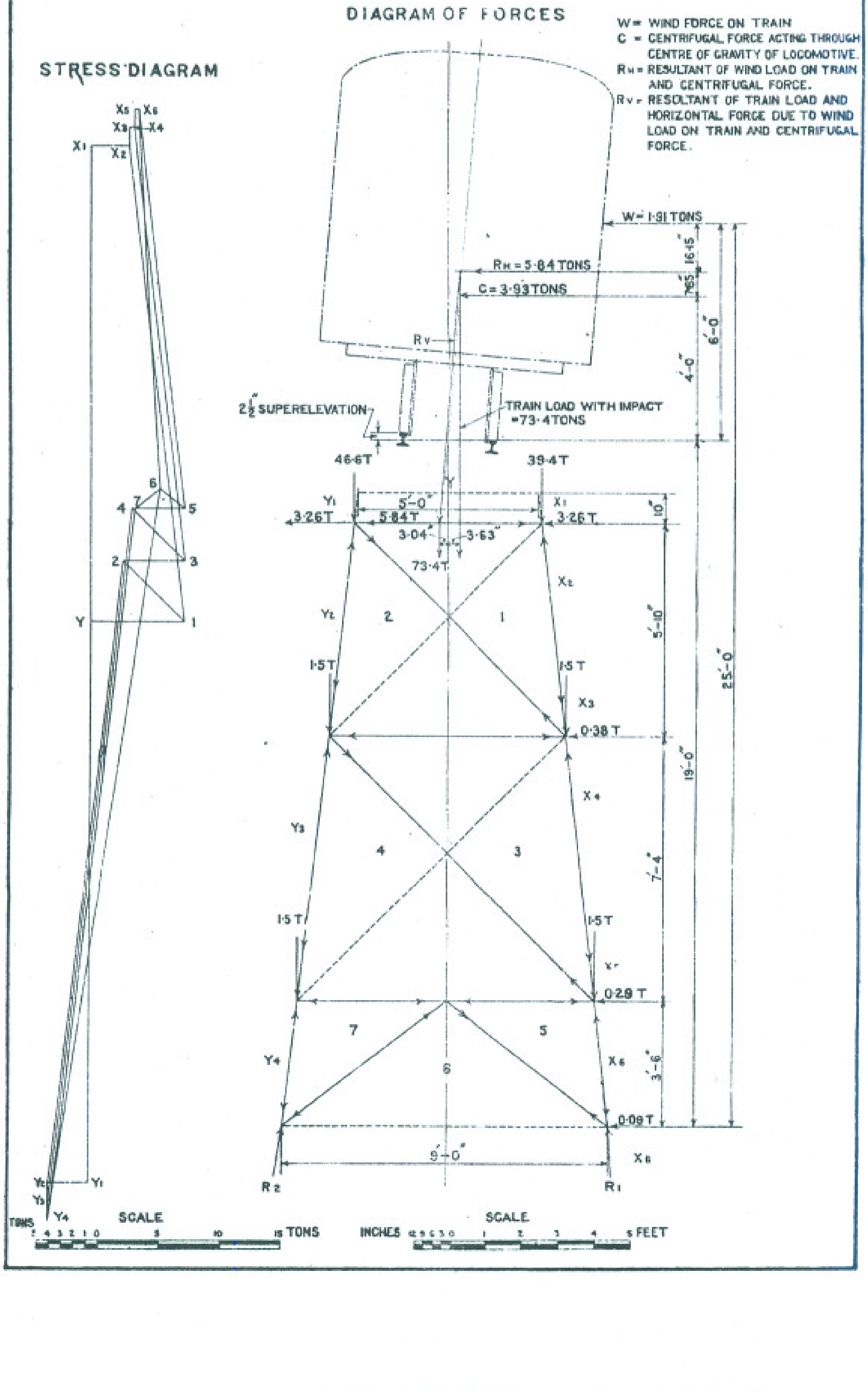


DIAGRAM OF FORCES
STRESS DIAGRAM
W = WIND FORCE ON TRAIN
C = CENTRIFUGAL FORCE ACTING THROUGH CENTRE OF GRAVITY OF LOCOMOTIVE.
RH = RESULTANT OF WIND LOAD ON TRAIN AND CENTRIFUGAL FORCE.
RV = RESULTANT OF TRAIN LOAD AND HORIZONTAL FORCE DUE TO WIND LOAD ON TRAIN AND CENTRIFUGAL FORCE.
W = 1·91 TONS
RH = 5·84 TONS
C = 3·93 TONS
2½" SUPERELEVATION
TRAIN LOAD WITH IMPACT =73·4 TONS
46·6T
39·4T
3·26T
5·84T
3·04"
3·63"
73·4T
1·5T
0·38 T
0·29 T
0·09 T
5'-0"
9'-0"
10"
5'-10"
19'-0"
7'-4"
3'-6"
25'-0"
6'-0"
4'-0"
R2
R1
SCALE
TONS
INCHES
FEET

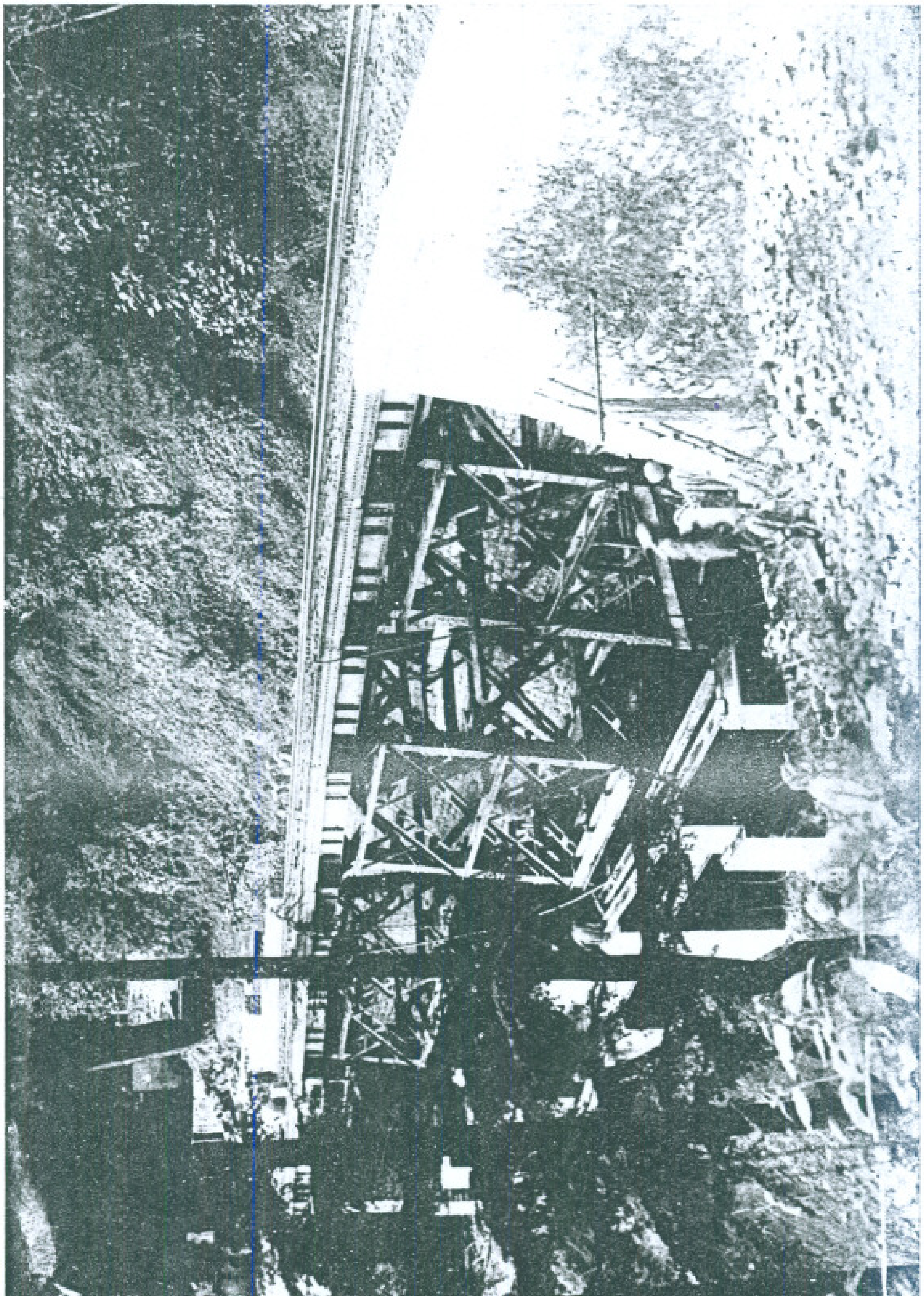
TABLE OF STRESSES

	MEMBERS	SECTION USED	STRESS DUE TO LIVE LOAD, DEAD LOAD WIND & CENTRIFUGAL FORCES IN TONS	STRESS DUE TO TRACTIVE FORCE IN TONS	MAXIMUM STRESS IN TONS	AREA OF CROSS SECT. IN INCHES	STRESS IN TONS PER SQUARE INCH	VALUE OF L ÷ R *	MATERIAL	PERMISSIBLE STRESS IN TONS PER SQUARE INCH	REMARKS
MAIN COLUMNS	X_5 – 1	2 CHANNELS 9" × 3½" @ 22 27 LBS/' 2 STIFFENING PLATES 6¾ × 7/16	+39·7	+ 6·62	46·32	17·32	2·67	24·1	STEEL	7·51	
	X_4 – 3	"	+36·1	"	42·72	"	2·47	24·7	"	7·50	
	X_6 – 5	"	+33·4	"	40·02	"	2·32	"	"	"	
		"									
MAIN COLUMNS	Y_2 – 2	"	+52·0	+6·62	58·62	17·32	3·33	24·1	STEEL	7·51	
	Y_3 – 4	"	+57·8	"	64·42	"	3·72	24·7	"	7·50	
	Y_4 – 7	"	+59·3	"	65·92	"	3·80	"	"	"	
CROSS GIRDER	Y – 1	4 Ls 4 × 4 × 3/8 2 PLATES 20 × 3/8 13/16 DIA: HOLES	+ 7·5	–		GROSS AREA 33·44	1·26 (–) 1·54 (+)	–	W. I.	6·0 (–) 6·8 (+)	INCLUDING BENDING STRESSES.
HORIZ: ANGLES	2 – 3	2 Ls 5 × 5 × 3/8	+5·0	–	+5·0	5·72	0·87.	73	"	5·17	
	4 – 5	"	+4·3	–	+4·3	"	0·75	46	"	5·76	
	4 – 7	"	+0·2	–	+0·2	"	0·03	46	"	5·76	
DIAGONALS	1 – 2	2 Ls 3½ × 3 × 3/8 13/16 DIA: HOLES	–7·1	–	–7·1	4·0	1·78	–	W. I.	6·0	
	3 – 4	"	–6·0	–	–6·0	"	1·50	–	"	"	
	5 – 6	"	–2·6	–	–2·6	"	0·65	–	"	"	
	6 – 7	"	+2·6	–	+2·6	GROSS AREA 4·60	·57	53	"	5·6	

MINUS SIGN (–) INDICATES TENSION
PLUS SIGN (+) " COMPRESSION

* L = GREATEST UNSUPPORTED LENGTH
R = MINIMUM RADIUS OF GYRATION

PLATE IX.



DISCUSSION.

In introducing his paper, the **Author** observed that there was not very much to be said by way of introduction to his paper. His subject was perhaps of most interest to Railway members, but he ventured to think there were points which might appeal to others also.

The author said that the paper dealt primarily with the actual carrying out of the work, but it was possible that in following the many detail operations described, the broader aspects of the problem might be lost sight of. He therefore drew attention to the following three points :—

(1) The increasing demand on engineers for the carrying out of works with " Business as usual."

(2) The design under discussion as enabling this Principle to be followed.

(3) The " Ford " method of execution of the work.

The author said that he need not enlarge on the first point, as one had only to pick up an Engineering magazine to see some example described. The demand was no doubt legitimate though possibly in some cases the financial implications might be more carefully studied.

As regards the design, he would also say little. He saw, he went on to say, Messrs. Everall and Berridge of the N. W. Railway Bridge Branch, who were responsible for it, were present and he understood they would be allotted the regulation five minutes each and would enter into the discussion.

Lastly there was what he had termed the " Ford " method of execution. The name, the author pointed out, might be somewhat misleading but he used it in the sense that all the stages of the work had to be divided up into very simple operations capable of easily being carried out in the short block times allowed. That was not always an easy matter but its success might be gauged from the fact that during the whole course of the work they had not a single complaint of delay to trains—a serious matter, had one occurred—and there had been no accidents.

Mr. W. T. Everall remarked that the paper which Mr. Anderson had put up on the subject of the Replacement of a Masonry Gallery Bridge on the Kalka Simla Railway, was one in which he had been interested. He said the work illustrated an interesting example of the reconstruction under traffic of a defective bridge, and one which presented considerable practical difficulties in its execution in the field.

As Mr. Anderson had stated in his paper, the bridge was sited in a rather difficult position, the track being built on a severe gradient as well as on a sharp curve, and the nature of the adjacent hillside was such that the provision of a diversion for the track during the reconstruction of the bridge would not have been possible except at an enormous cost.

When the proposal to rebuild this bridge was put up to him for consideration, Mr. Everall stated, he investigated the possibilities of using their standard type of service staging to form a temporary structure, outside the masonry, on which traffic could be carried during the dismantling and rebuilding of the bridge.

As the foundations were not particularly good, being founded on very badly weathered and fissured rock, he considered that it would be an advantage if the loads on the existing foundations could be reduced. That had been done by employing a steel trestle bridge, the details of which were well described and illustrated in the paper before Congress.

An alternative to this steel trestle would have been a structure built of reinforced concrete; which, however, would have been more difficult to place in position and would have resulted in the addition of more weight on the foundations.

Another reason why a steel trestle bridge was an advantage in this area, was that it offered considerable resistance to earthquake effects and although no very severe earthquakes had been felt in the Simla area for some considerable time, it definitely fell within the earthquake zone which, running parallel at the foot of the Himalayas, extended right across India from Assam to the North West Frontier Province. He, the speaker, considered that more attention should be given in the design of structures of this nature, to their resistance to earthquake effects.

Another interesting feature of the work was that Mr. Anderson had been very successful in reinforcing the old masonry and foundations of the bridge by means of cement grouting; and trial holes, drilled after the cement grout had been forced into the masonry, showed that considerable absorption had taken place where required.

Mr. Everall further stated that on completion of the work the bridge was tested under maximum loads running on the section and the structure proved satisfactory in all respects, being very stiff and free from excessive oscillations.

Although the work was not one of great magnitude, he said, considerable care and skill had had to be exercised by Mr. Anderson and his Assistant Mr. Faruqi, in carrying out the work under unusual conditions. The details of the various operations could be clearly followed from Mr. Anderson's paper.

Mr. Berridge stated that having been associated in some small way with the design and later with the testing of the first steel trestle bridge put up on the North Western Railway, he felt that he had a special debt of gratitude to Mr. Anderson for his paper.

He said that they might have noticed that the bridge was designed for M. L. Metre Gauge Standard of Loading and possibly some of them might have anticipated a repetition of Mr. Brunel's historic battle of the gauges ; but, he could assure them that there was no intention of widening the 2 feet 6 inches Kalka-Simla Railway. The fact was that all 2 feet 6 inches gauge lines on the North Western Railway were designed to carry Metre Gauge Standard of loading and a comparison between the actual loads now running into Simla and the theoretical Metre Gauge locomotive for which the trestle had been built revealed a close relationship—the existing 4-K class engines representing 87 per cent of the equivalent M. L. Metre Gauge loading on a 15 ft. span.

He further stated that he had had the accompanying table of the results obtained from the tests drawn out—Plate X. By the use of Fereday Palmer Stress Recorders attached to the steelwork, the stresses, produced under a load of two coupled engines, had been obtained in a number of important positions. As they would see, he remarked, there was a reasonable agreement between the calculated and the measured stresses taken at dead slow speed and noticeable dissimilarity between the same figures under full impact and under the maximum speed obtained during the tests, namely 15 miles per hour. The Impact Factor of $\frac{65}{45+L}$ used in the design of all new bridges on the Broad and Metre Gauge lines of Indian State Railways gave 100 per cent increment on these 15 ft. spans and 86 per cent. on 30 ft. spans, the length governing for the design of the trestle legs.

According to the rules in force to-day for *existing* Metre Gauge bridges, the Impact Factor might be multiplied by $V/45$ where $V=$ Maximum speed in miles per hour. It was noteworthy that this rule applied only to existing bridges and not to new bridges. In the case of this trestle bridge at Simla, a saving of weight might easily have resulted had such a speed factor been applied to the Impact allowance, for the site of the bridge rendered a speed in excess of 15 miles per hour almost an impossibility. It would seem a revison of this rule was overdue. He said that apart from this difference between actual and theoretical stresses due to the seemingly excessive impact factor, their attention would probably have been drawn to the stresses in the bottom flanges of the stringer girders. There, the recorded stresses at slow speed exceeded the calculated stresses. The reason was that in the case of calculated stresses, the assumption had been made that all four girders would be carrying equal shares of the load. This would have been true had the trough decking been stiffer but as results went to prove the inner pair of stringers directly under the track carried most of the live load.

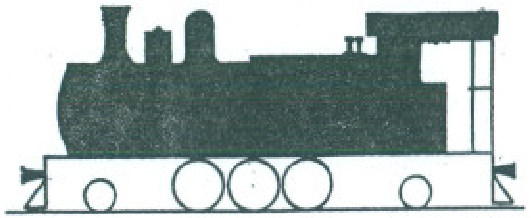
Actually one pair of stringers were designed as sufficient to carry the full load, the outer ones being added to suit the curvature etc. This had been mentioned in the description of the erection where the track had been carried on the inner pair alone previous to the completion of the outer pair and fitting the troughing.

An alternative reinforced concrete structure might have been put up, but not without the necessity of providing a diversion, the cost of which would have been prohibitive.

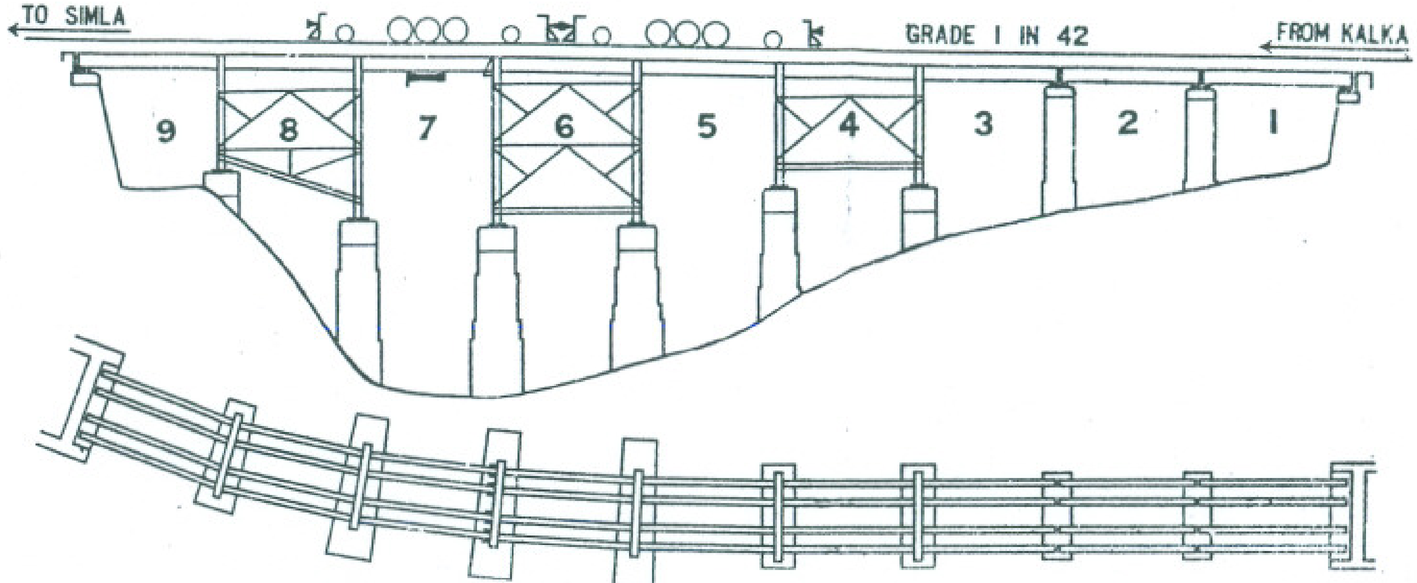
Mr. Berridge remarked that Mr. Everall's scheme for replacing this gallery without the need of a diversion looked attractive from the beginning; and, as subsequent events showed, it was probably the only way of tackling the problem economically.

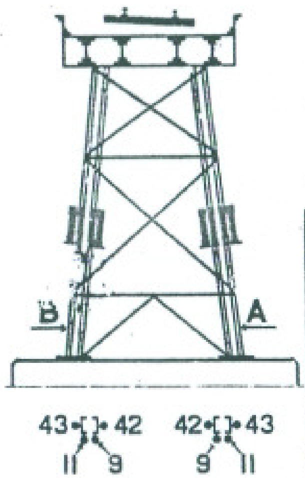
He said that it had been argued that a cheaper way of dealing with the situation would have been the bricking up of the arches and the grouting of the masonry; but, that was not the problem presented to the Bridge Department. Their's was to replace the old gallery as economically as possible and this they had done most successfully.

CLASS 4 K ENGINE-38·53 TONS



WEIGHT 5·11 9·14 9·35 9·5 5·43 TONS





TEST Nº	SPEED M.P.H.	STRESS RECORDER Nºs 43	11	9	42	CALCULATED STRESSES: DEAD LOAD ONLY	LIVE LOAD ONLY: TEST ENGINES WITH IMPACT	TEST ENGINES WITHOUT IMPACT	M.L. OF 1929 METRE GAUGE WITH IMPACT
MAXIMUM STRESSES IN TRESTLE LEG A						TONS PER SQ: INCH			
26	CRAWL	0·7	0·7	0·7	0·7				
27	10	0·8	0·8	0·8	0·8	0·45	1·43	0·97	2·02
32	15	0·8	0·8	0·8	0·8				
MAXIMUM STRESSES IN TRESTLE LEG B						TONS PER SQ: INCH			
34	CRAWL	0·7	0·7	0·7	0·7				
35	10	0·8	0·8	0·8	0·8	0·45	1·87	0·78	3·27
36	15	0·8	0·8	0·8	0·8				

TEST Nº	SPEED M.P.H.	STRESS RECORDER Nºs A 43	B 42	C 11	D 9	CALCULATED STRESSES: DEAD LOAD ONLY	LIVE LOAD ONLY: TEST ENGINES WITH IMPACT	TEST ENGINES WITHOUT IMPACT	M.L. OF 1929 METRE GAUGE WITH IMPACT
MAXIMUM STRESSES IN SPAN Nº 7						— TONS PER SQ: INCH			
13	CRAWL	1·3	2·4	2·4	1·2				
14	9	1·5	2·8	2·8	1·4	0·53	4·07	2·07	4·67
15	15	1·7	3·0	3·0	1·5				