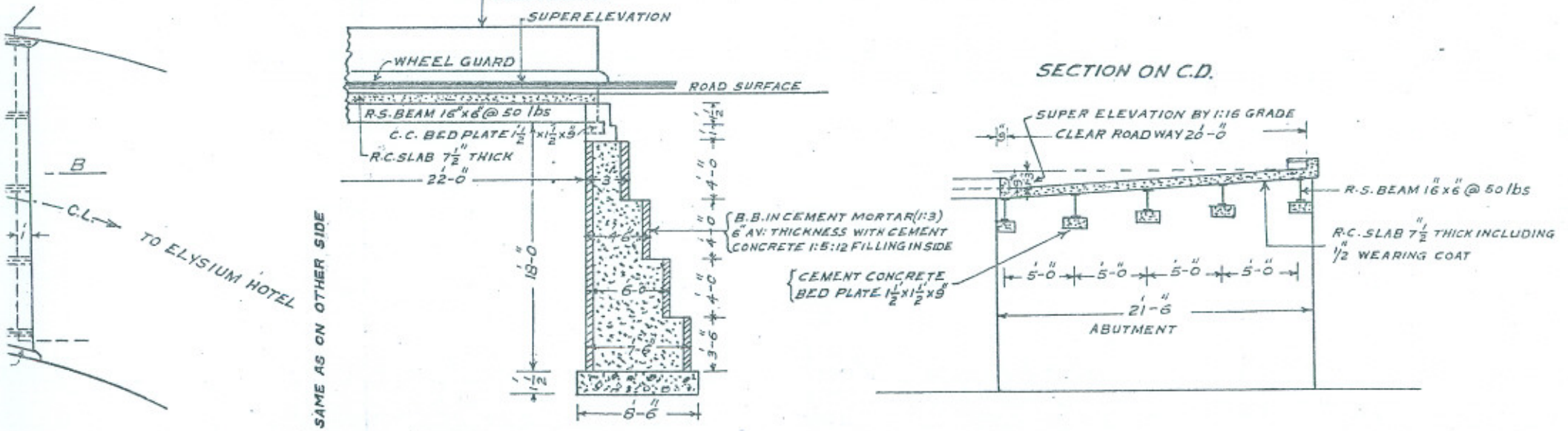
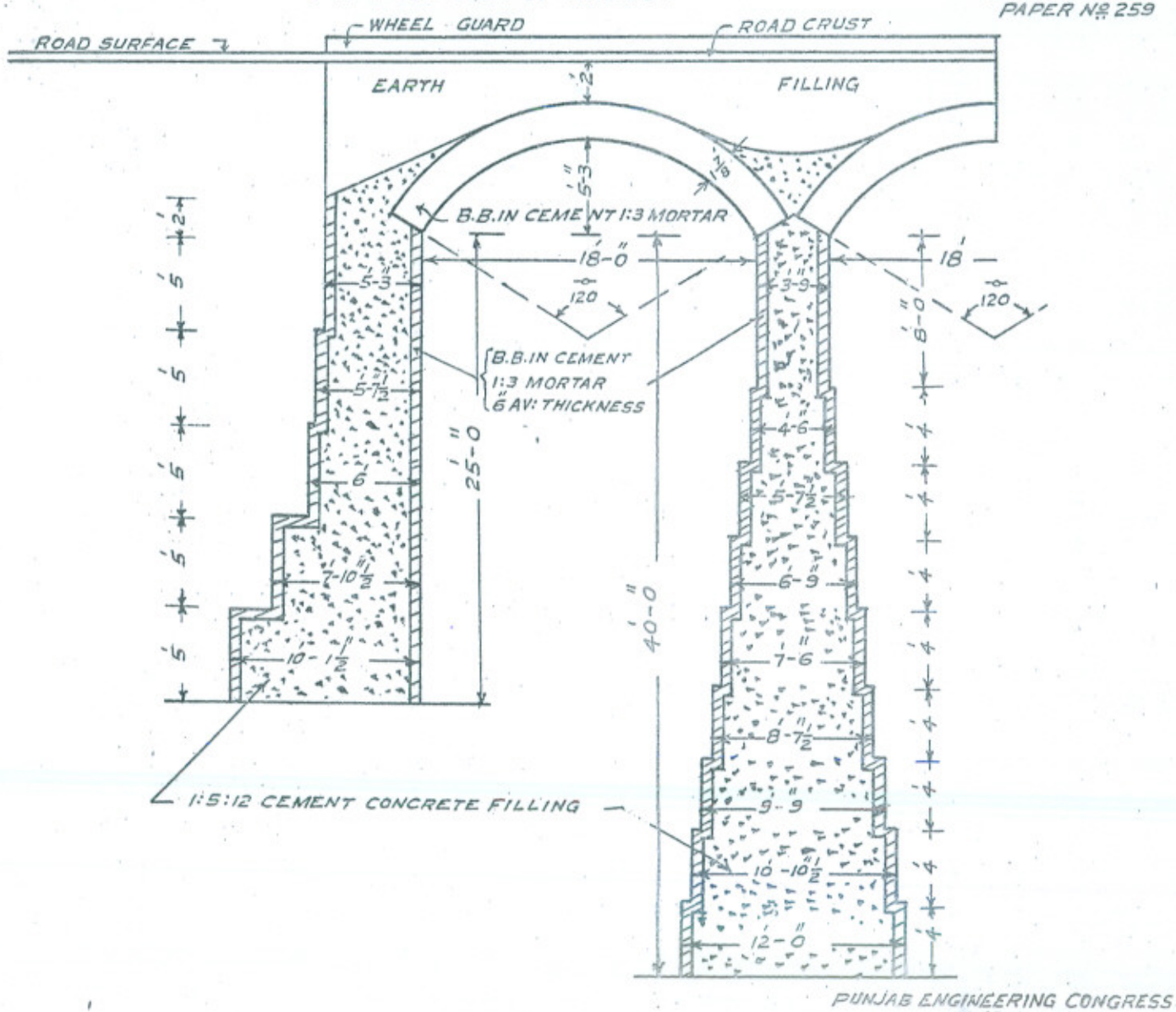
BELVEDERE BRIDGE



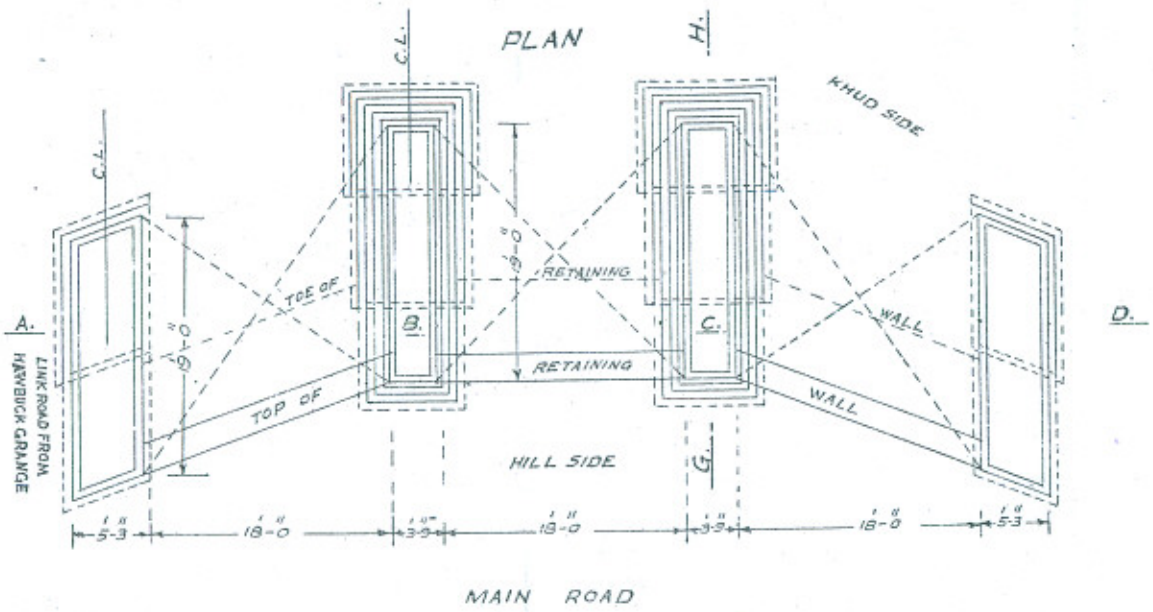
TYPE SECTION OF VIADUCT

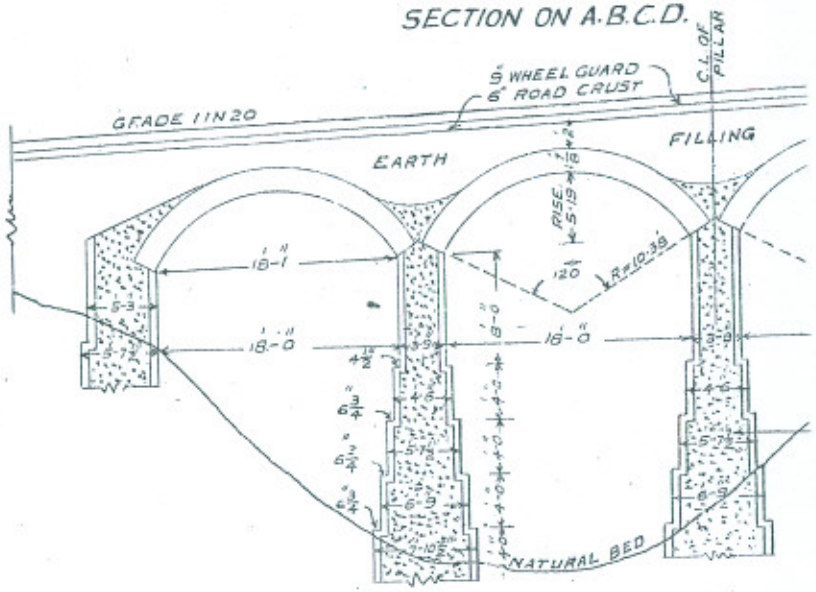
PLATE 6
PAPER No. 259



PUNJAB ENGINEERING CONGRESS
1943

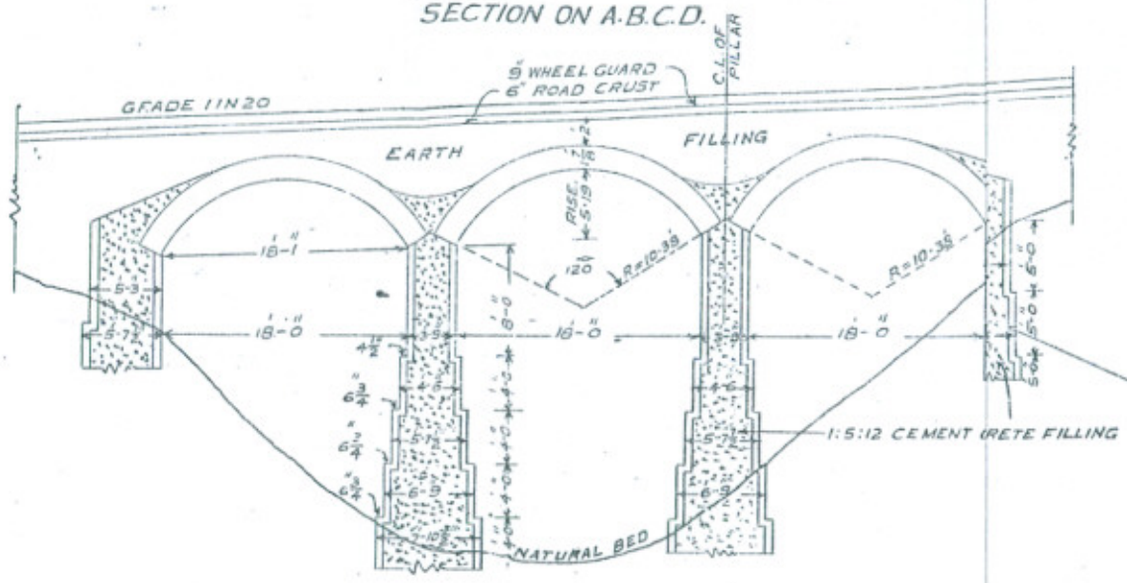
CHHOTA SIMLA VIADUCT



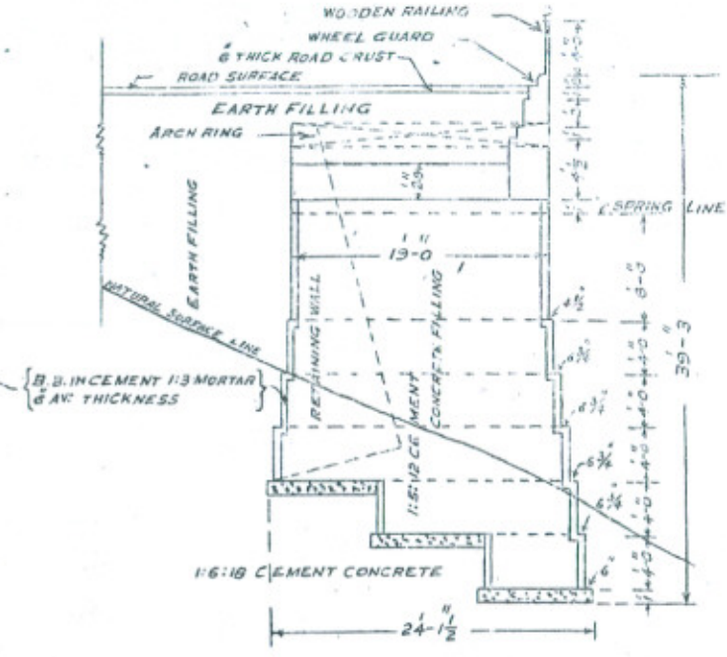


CHHOTA SIMLA VIADUCT.

SECTION ON A.B.C.D.



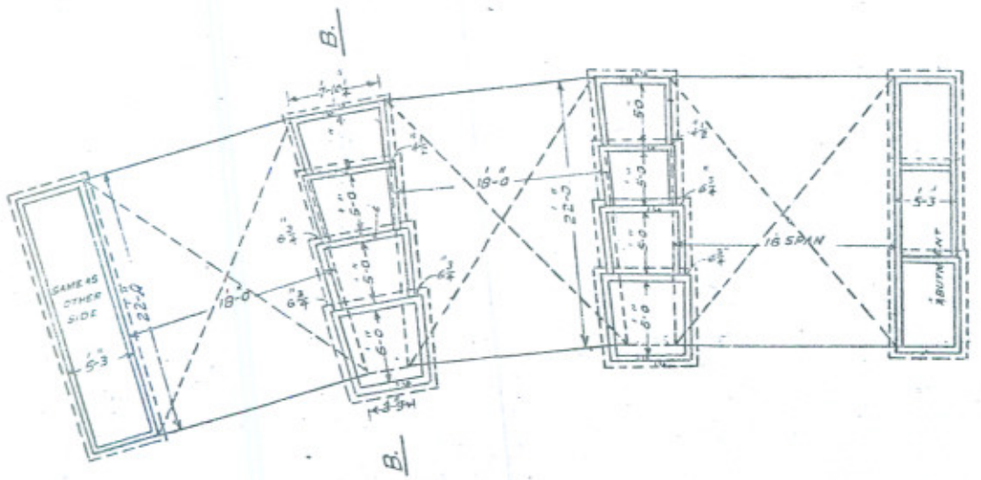
SECTION ON G.H

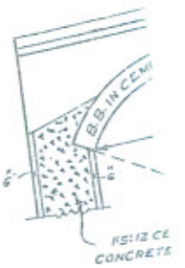


PUNJAB ENGINEERING CONGRESS
1943

LINK ROAD V

PLAN

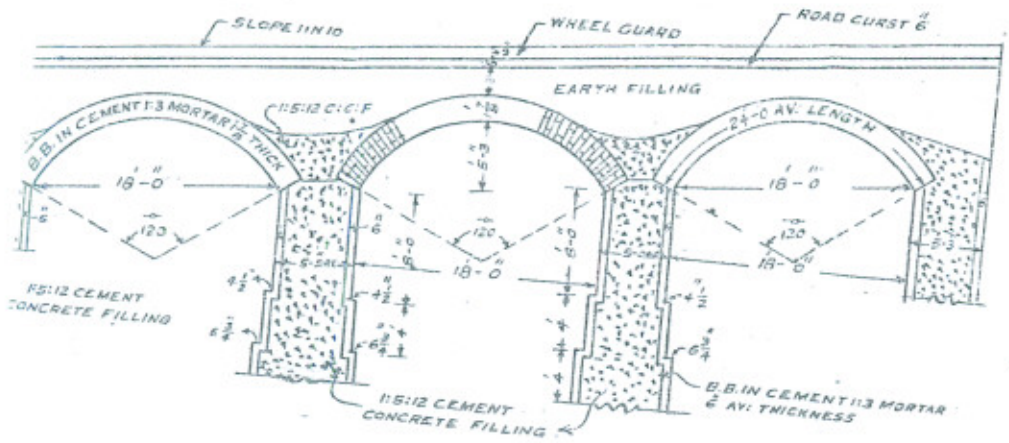




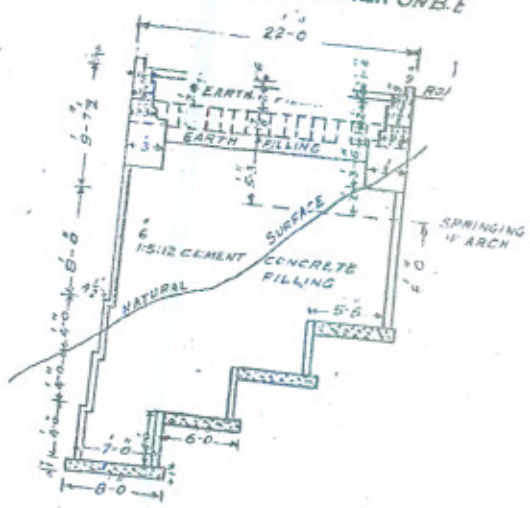
)AD VIADUCT

PLATE 8
PAPER NR 259

LONGITUDINAL SECTION



ROUGH PIER ON B.E



DISCUSSION

Mr. **Baker** in introducing the Paper, pointed out certain omissions and errors in printing. The Paper having been written in September 1942, certain portions of this were not quite up-to-date and Mr. Baker then commented on these.

On page 45 reference was made to the driving of a pilot tunnel having then been started. This had long since been driven right through the ridge, and had proved the authors' expectations regarding the contents of the hill to have been false. Actually almost entirely quartz schists had been encountered and schistose quartzites, which were heavily intersected by various kinds of planes. Though thus disintegrated they were hard and compact in the mass, and this enabled the authors to consider the degree of passive resistance to arch thrusts which could be tolerated. The authors also considered that the figure of one ton quoted in the Paper could safely be increased to $2\frac{1}{2}$ tons per square foot, and suggested consideration of a tunnel section with arched sides. The design for this had not been approved, but, as a matter of interest, Mr. Baker showed a drawing of what was then envisaged. Mr. Baker said that it would be agreed that the waste space at the sides, where headroom for unrestricted traffic was not attained, was conveniently utilised by footpaths, and by the semi-covered drain. By providing footpaths the width of the roadway could safely be reduced to 18 feet. In the Paper the authors referred to the original section, as printed, having been finally adopted. This was ill-expressed as it was obvious that, pending knowledge of the contents of the hill, no decision was possible. The section described represented what was adopted for estimating purposes in considering the advantages or otherwise of the various alignments. The section shown was based on existing examples such as that at Ludgate, while the new proposal resembled in general outline the famous Mont Cenis tunnel. Incidentally the specification mentioned at the bottom of page 45, that the tunnel lining should be strong enough to withstand the dead weight of 12 feet of spoil had then been considered unnecessary, and for the final design only Fruhling's formula was being considered.

Mr. Baker observed an error near the bottom of page 45, and was not sure whether he could blame the printers or not. With $H = 16{\cdot}5$ feet Q_2, becomes, obviously, a minimum with value zero, and not a maximum as stated. Further, Mr. Baker said that mathematicians point out that the value of Q_1 reaches its point of inflection when $H = 16\frac{2}{3}$, and not at $16\frac{1}{2}$. He believed that they were right, but the formula had been quoted literally.

Mr. Baker then referred to Belvedere Bridge. It had been finally decided, while retaining the super-elevated decking, to make the bridge straight-sided in plan for the sake of simplicity in construction. "The difference in cost in widening the bridge so as fully to accommodate the "Effective" roadway shown was negligible, and, moreover it was felt that to disguise the fact of the existence of a bridge might induce careless driving.

On page 48 reference had been made to four viaducts: two already constructed and two contemplated. It had since been found possible to eliminate the two new ones, without impairing the qualities of the road, by modifications to the layout of the road in plan. This would, of course, effect considerable financial saving.

Regarding the 1 : 5 : 12 concrete, the Paper did not make clear that its cost was only just over half that of brickwork in 1: 6 cement mortar.

The authors had referred briefly to stone-masonry-faced-concrete walls. This method had been tried out, and had proved successful. A notable example of its use was the rebuilding of the wall near Bemloe, to the earlier collapse of which reference was made on page 53.

Progress had continued disappointing, entirely due to the absence of transport facilities. Every effort had been and was being made to use local stone, but everything had to be carted from a greater or less distance. In view of what appeared to be a constant increase in transport difficulties it was unlikely that the road would be complete in all respects before the summer of 1944, even if the Governments did not, as the Papers said was being done generally, curtail present outlay on works.

Mr. Baker as the Executive Engineer since the early days of the project, and throughout construction, felt that he could not end the introduction without mentioning the name of Mr. G. D. Habib, the Sub-Divisional Officer, along with that of his co-author, and of paying them the apparently rather grudging compliment of saying that, without their untiring efforts, progress would have been still slower. Their help had always been immense and unstinted. Finally he drew attention to his remarks on page 51. These remarks indicated the very free hand always given to him by his Superintending Engineer, Mr. Freak. Mr. Freak, who had throughout taken the closest and keenest interest in all stages of the project, had always been willing to spare the time to discuss at length problems, both theoretical and practical, as they arose. The way in which this had assisted his task could well be imagined.

Mr. **Balwant Singh** said that Mr. Baker, in introducing the Paper, had covered most of the ground. He had, however, a few observations to make regarding the type-design of retaining walls adopted and the design of viaducts.

In the type-design for retaining walls, offsets in the vertical face at height of 8′, 14′ and 18′ had been introduced in order to improve frictional stability. The base had been stepped to safeguard against any possible sliding occurring and also to avoid deep excavations at the back. Moreover pucca-masonry bonds 2′ thick, had been put in to ensure equal distribution of pressure for walls exceeding 20′ depth.

A comparison of the rates showed that dry-stone masonry was easily the cheapest of the various materials at the disposal of builders in Simla for obtaining the width required in these walls and since the intensity of pressure at base did not exceed 3 tons per sq. ft., it was at the same time the most suitable for the purpose. Wherever intensity of pressure increased beyond 3 tons per sq. ft., cement masonry was substituted for dry-stone masonry in the face. A further development in construction was the use of fine cement concrete as filler in coarsed-rubble masonry instead of stone-masonry in cement.

Viaducts :

Here again a type-design had been adopted, keeping a uniform span of 18′ for all the arches. This span was found to be the most economical for the average of 20′ height of piers and for the rates obtaining in Simla. For this span the cost of one pier per foot-width almost equalled the cost of one span of superstructure which satisfied the well-recognised rule. 18′ span arch also lent itself to easy construction and centring of a portable type was devised.

The arch-ring was tested for Indian Roads Congress Loading for the following cases :—

(*a*) Distributed live load on the whole of span and knife-edge load at one third of the span.

(*b*) Distributed live load covering $\frac{1}{4}$th span and knife-edge load at the same $\frac{1}{4}$th point

(*c*) Distributed live load over whole span and knife-edge load at centre.

The first two were a symmetrical loadings and with the ends of the arch fixed, a mathematical treatment of the subject was complicated. Therefore the test was made by Fuller's graphical method.

Stability of piers and abutments was also tested by graphical method. The piers were designed to take out-of-balance

thrust due to loadings as mentioned in the case of testing of the arch-ring for one span and dead load only for adjacent span.

The abutments were tested to sustain the thrust of end-arches unbalanced by the counter-thrust of any adjoining ones and also to act as retaining walls for the filling behind the abutment.

Construction work on this road was kept going in winter as well, which is very severe in Simla. Concrete work was naturally difficult and a problem to be faced was that the concrete should not catch cold. It was likely to, if it were deposited at temperature below 35° F, when in its freshly laid condition it needed protection from extremes of weather. This was afforded either by heating the concrete materials before mixing or by having braizers burning near the site of works.

Mr. **Trevor Jones** remarked that the Paper was of great interest and that the authors were to be congratulated. The Buildings and Roads Branch were and had been building a number of hill roads in recent years but the Simla motor road was a peculiarity in itself, in that there was very little field for easy alignment and the route which had to be adopted was dictated by a number of obligatory points in the existing properties and houses which covered the hill sides. It had, therefore, to be a compromise between improving the existing mule road and providing diversions and by-passes wherever possible and feasible. In the Paper it was stated that only 2 or 3 houses had been interfered with, which was a remarkable feat. The road was nothing more than a Municipal one and it was stated in the Paper that its main object was, *inter-alia*, to relieve congestion by indirect means. Mr. Trevor Jones thought that many of the questions that he was going to put to the authors, he could probably answer best himself, but the Paper did give one opportunity to expose some of the faults and misconceptions which exist about road alignments.

He quite understood that a large percentage of the public were puzzled at the introduction of this motorable road and felt that in many ways it was a case of putting the cart before the horse. If this road was to be considered as a link in a motorable arterial from Tibet to India then Mr. Trevor Jones considered that it was put in the wrong spot. There had been too much custom in the past that arterial roads should run through the towns they served rather than by-passing them. They were finding some truth in this remark in the case of so many important arterial roads in the Punjab at the present moment, *e.g.*, Amritsar and Lahore on the Grand Trunk Road. However its value as a Municipal road as a means of allowing easy access to the suburbs was an obvious benefit to the over-congested and over-crowded city of Simla.

The super-elevation question was, indeed, a highly controversial matter and he thought it very wise that a cross grade of 1/12 was considered the maximum permissible. This was the maximum grade allowed in the Road Curve Graph Table XII in the P. W. D. Specification. If their building a road was a racing-track for cars, it was obviously insufficient but if as roads are at the present time to be designed to take all sorts of vehicles the super-elevation was again a compromise to meet all conditions. He was particularly interested to see that so much of the work was carried out by petty contractors on Work Order as well as by departmental labour. It was a method which was then not very popular in the Buildings and Roads Branch and the tendency was to place all the eggs in one basket and give work to one firm of contractors throughout.

A point of interest was the design of retaining walls. In a technical road-paper he read the other day, it was stated "Road Engineers, if the truth be told, are quite unprincipled." They work by guess-work and precedent ; what was good enough for great-great grandfather Telford, was good enough for them.

It was certainly the precedent and the established custom in hill roads to construct walls in dry stone masonry and had proved such excellent guess-work construction that they appeared to be the most economical and efficient means of retaining earth. But it would be interesting to know how much was spent annually in repairing dry-stone retaining walls on many miles of hill roads. It was also interesting to read the end of the Paper that in half a dozen places walls showed signs of their front faces blistering. Mr. Trevor Jones said that he must confess that his experience of anything of this nature had always seemed to him to be a warning of collapse and he had been told that many of their petty contractors not only accepted that warning but helped the collapse to occur in order to provide themselves with the accustomed work in the rains. It was true that in the dry-stone retaining wall tension could not be contemplated but it was for consideration whether it would not be in many cases more economical to design and build walls which would stand up to any such stress. They had in many hill roads conditions where retaining walls must behave very much as a dam. As an example Mr. Trevor Jones said that he would quote the Dalhousie road where the "keroo" earth in monsoon conditions specially as occurred last year, became little less than liquid mud. He was not advocating anything so ambitious as to build batteries of multiple arch walls or reinforced concrete rataining walls throughout their works, but there were places where collapse had occurred so frequently that something more resilient and stable than dry stone retaining walls was required.

Mr. **Freak** drew attention to the failure of dry-stone walls by the front face blistering off as mentioned in the Paper. In some cases the blistered portion came away entirely and collapsed leaving the wall of less section than before, but sometimes the wall then continued to stand showing that the reduced section was actually strong enough or in other words that the original section was greater than necessary. Mr. Freak enquired if any member of the Congress could advise to what extent our design could be reduced in thickness. The only theory for the blistering which he had been able to form was that given in the Paper, namely greater settlement of the back stones of the wall than of the face stones. In actual practice complete dismantlement of the whole wall was not found necessary and replacement of the blistered-off face by masonry in cement proved to be an effective repair and in some cases slight bulging was corrected by similar treatment which is rather similar to a dentist stopping a tooth. Mr. Freak also mentioned the saving achieved by the stepped foundations to the retaining walls. Reference was also made to the brick-faced concrete masonry which was found easy to construct course by course and proved definitely economical.

Mr. A. R. Thomas after remarking on the difficulties of construction suggested that the culverts presented an excellent opportunity of collecting data on rainfall-runoff from steep wooded catchments.

Mr. Murari Lal wished to congratulate the authors for bringing out a Paper which dealt with a problem of far-reaching importance and a subject which embraced various aspects of road constructions.

For the purpose of discussion he took the first and the last part of the Paper together. The first part dealt with the causes and the origin of the scheme and the last with their difficulties encountered in execution. The remedy suggested for the removal of congestion in the Simla bazar area was the opening of a motor road round Simla. It was, however, doubtful if this remedy would be effective because the average shopkeeper preferred to hug close to his business premises.

It was not considered by him as likely that the shopkeeper would leave his place of residence on the upper flat over the shops for a more open area residence offered by the new road and therefore congestion would remain as ever before. The sites offered by the new road would most probably be seized upon by speculative builder who would build for profiteering. It was also hard to think how the number of coolies would be reduced when mule traffic from the suburbs would continue to pour in.

It was not really clear why such a stupendous scheme should have been started at a time when the more pressing needs of war required the much coveted money in different fields of war. If the scheme would have been in execution in normal times or after war many of the difficulties complained of by the authors should have, of themselves, disappeared or at least should have not caused such trouble. Even the design of structures would have been more modern and pleasing in appearance. What now one found in the Paper running throughout its pages was the old brick-arch which knows no variety while if the same were designed in concrete it should have lent itself to a variety of treatment to harmonise with the surroundings. In the actual construction, however, brick had been used. The tiny blood-red brick hardly blended with the bold grey landscape of the hills and was a misfit from an aesthetic point of view. The structures should have been either stone or concrete.

He then came to the technical side of the Paper. He was glad to find that in the matter of super-elevation the authors had adopted a formula which was worked out by him ten years ago in the Punjab Congress Paper No. 180. On page 31 of the Paper in the very first line the slope of banking was given as 10/r which was identical with the formula adopted by the authors. As they had not indicated the steps by which they had arrived at this formula, it was presumed that they had drawn from his Paper and if so, it should have been acknowledged. This formula was based on an average speed of 17·5 miles per hour which it is not desirable to exceed on a hill road which abounds in curves and blind corners. This formula gives curves which have the equation $XY = Alfa$, and is very much similar to the curve given in the revised P. W. D. Specifications. These are, however, based on a speed of 30 miles an hour and are rather excessive for hill road though admirably suited to the roads in plains.

Mr. **D. A. Howell** remarked that the only matter in the Paper in which he had taken direct interest was the proposed tunnel under the hill near the Legislative Assembly Chamber. He had perused the geological Report and also inspected the proposed tunnel alignment, which was more direct and shorter than the other alternatives mentioned in the Report. At both ends of the tunnel, there were a certain amount of loose broken material, while at the northern end there was an existing roadway carried by a retaining wall, which was at a level of only a few feet above the tunnel and the speaker had suggested that instead of driving in under this roadway for the pilot tunnel, a shaft should be sunk in more solid ground on the hill-side of the roadway, from the bottom of which

the pilot tunnel could be driven in both directions, without disturbing the roadway.

He was glad to hear that this had been done with satisfactory results. The geological Report on the proposed tunnel alignment did not hold out high hopes that the strata was suitable. Engineering experience, however, seemed to indicate that it was not sound to place reliance fully on a geological Report in a case of this kind. Even bore-holes which had actually been made into strata, had, he believed, given incorrect indications, sometimes, of the nature of the ground to be proved.

The Engineer, when making a decision on an engineering work for which he is responsible, had to arrive at a definite conclusion which in a case like this could only be safely reached after making an exploratory heading.

Mr. Champa Lal had the following questions to ask from the authors of the Papers :—

Firstly—It was stated on page 43, that transition curves had nowhere been used on account of slow moving traffic. He thought that the Theory of road curvature recently advanced in a comprehensive manner by Prof. Royal Darson and Mr. Criswell should influence modern practice, in case of new roads with several sharp curves, when it may mean no extra cost. Mr. Champa Lal pointed out that an interesting article on the subject was read before this Congress by Mr. W. R. Fleming, I.S.E., in the year 1941.

Secondly—The ruling gradient adopted was 1 in 10. What was the maximum length in which this was given ? Had any compensation for grade in curves been allowed ? What was the fully compensated ruling gradient ?

Thirdly—Had the slips been heavy during summer and winter monsoons, and had any special difficulties been experienced on this account ?

Fourthly—What had been the average premium paid so far over the schedule rates, for items like soling and wearing coats, retaining and breast walls, and parapets ? What type of parapets were used ?

Mr. **Karnail Singh** said that construction of a road in hilly areas and the considerations for safety of structures thereon were in many aspects similar to those which apply to a railway in the hills, and based on his knowledge of conditions on Kalka-Simla section of the North-Western Railway, he felt he could usefully offer the following remarks :—

1. **Design of Retaining Walls.**

He did not agree with the observation of the authors in regard to design of retaining walls given in paragraph 3 at page 41 of the Paper. They had taken no account of the surcharge and had considered that the design, which was suitable for level filling at the back, should also do for a wall with surcharge at the back. If the authors considered that soil in that particular area was hard enough to stand at slopes steeper than 45° even during rains, he wondered why revetments of facing of masonry on such slopes were treated at all, or even classified as retaining walls. Correctly speaking, these should be treated as slopes which are to be faced with masonry or concrete purely to afford protection against weather-action. If, however, these are to be designed as retaining walls, these hold back the earth and it is presumed that the effect of earth pressure at the back has to be taken into consideration. It is quite possible that earth when cut can stand to a steep slope, but the conditions are materially altered when the earth in hills is wet and sloppy due to continuous rains. On Kalka-Simla section there are many places where earth actually forms into a mass of thick fluid with an angle of repose between 15° to 35°. In the circumstances, the only correct way of designing the retaining walls was to allow for surcharge. On the North-Western Railway the method for determining equivalent level surcharge, was given on pages 222 and 223 of "Masonry Structures and Foundations" by Williams, and was followed. It was a good practice which led to an economical design if the back of the retaining wall were placed at an incline of 1 in 6 towards the filling.

2. **Water way for Culverts.**

At page 42 the authors' formula $A = Ca^{\frac{3}{4}}$ was to Mr. Karnail Singh apparently a modification of the Dickens formula with an assumed velocity of 10 feet per second through the bridge. This generalisation, in the absence of detailed observations, was considered by him too drastic, as it might not always be possible to obtain the 10 feet per second velocity. This subject was dealt with in Paper No. 254 last year at this Congress and advantage should have been taken of the observations made therein. Since Mr. Karnail Singh was a joint author of the Paper referred to and the Paper was readily available, he thought it needless for him to go into any details for offering suggestions in this particular case.

3. **Vertical Curves.**

On page 44 the authors had given a formula for length of vertical curves as 5 (N − M). If in practice such short

lengths of vertical curves, as given by this formula, were found adequate, it was hardly necessary to bring in the technical term of " vertical curves " for such a provision and in the opinion of Mr. Karnail Singh these had better be termed as " rounding off of the corners in the road." It would be seen that the authors' formula conformed to that given in the proceedings of the Institution of Civil Engineers, February 1941, *viz.*, $L = 08.6V^2 (N - M)/100$ with V at $3\frac{1}{2}$ miles per hour. It would be a miracle if it would be possible to run motor vehicles at a speed of $3\frac{1}{2}$ miles per hour on a hilly road.

4. **Viaducts.**

The authors, on their own admission, had not designed these with due considerations which should be given to all designs of structures, but on a cursory examination even, the tall slender piers could hardly be expected to afford any reasonable constraint to arches at the springing. Mr. Karnail Singh said that there were three fundamental assumptions of arch analysis, *viz.*, (*i*) the angular change between skew backs is nil, (*ii*) the change in span length is nil, and (*iii*) the change in levels is nil. In the case of arches supported on tall slender piers on Kalka-Simla section of the North-Western Railway analyses had shown that when these arches were considered monolithic with the piers, the piers were stable but not otherwise. This was self-evident since the yielding of tall slender piers would result in a considerable reduction in the unbalanced horizontal thurst due to live load. The arches, therefore, had to be made correspondingly stronger, especially near the haunches. Such a structure scientifically designed would be both economical and pleasing. He felt that the viaduct shown in Plate VI could be improved in appearance by giving the pier a gentle batter and making it much thinner at the base. The thickness of arch at the haunches could be increased to keep the line of pressure within the middle third considering the arch and pier as a unit.

5. **Blistering of retaining walls.**

As mentioned on page 53 of the Paper, S. Karnail Singh presumed that the word " blistering " had the same meaning as ordinarily expressed by " bulging out " of retaining walls. The explanation of " bulging out " of retaining walls horizontally, as given was not considered by him as satisfactory, because the authors of the Paper had considered only the primary stresses acting in the wall and had neglected principal stresses resulting from a combination of direct and shearing stresses. Such stresses were taken care of in steel girders by stiffeners which prevented diagonal buckling of web, and

in reinforced beams by stirrups which withstood diagonal tension. But in the case of a dry-stone retaining wall there was nothing to withstand diagonal tension except friction between stones, which may disappear due to lubricating action of water during rains. The result would be the pushing out of stones at the face. This may be aggravated by a local increase in horizontal pressure, which would tend to get distributed along the length of the wall by making a part of it to act as a horizontal beam. Mr. Karnail Singh said that bulging troubles had been frequently experienced on the Kalka-Simla section of the North-Western Railway. The remedy applied in some cases had been to put in courses of pucca masonry at intervals along the height. These courses localised the bulging and made any repairs necessary very easy, since the top portion remained practically unaffected due to beam action of pucca masonry courses.

Mr. **G. R. Nangea** offered a few results of his observations.

Retaining Walls.

In 1937 when the Kulu Valley experienced extraordinary rains and floods, hundreds of walls which had been built at different times fell down. While inspecting these walls Mr. Nangea had noted the following facts :—

(*i*) Most of the high retaining walls fell by soakage of water in the road.

This percolation of water lowered the angle of repose and reduced the cohesion in the fill.

Mr. Nangea put up a proposal of stopping this percolation by metalling and sealing the lengths of roads which had high and expensive retaining walls.

Turning to Plate I, Mr. Nangea suggested sealing the whole width of the road right up to the outer edge of the retaining wall.

(*ii*) Examining many of the fallen retaining walls Mr. Nangea had noticed that the failure was seldom as a whole. Usually a vertical crack developed which divided the retaining walls into two. The front half of the wall fell first and mostly the remaining half followed. It was observed that the crack usually had a slope of 1 in 6.

The stress in retaining walls, Mr. Nangea, observed is not wholly vertical and central but is inclined and eccentric and has a horizontal component. It results in extraordinary difference in pressures at the toe and the innermost point which helps division in the front and the back portions of the walls. The slightest yield develops a crack which enormously

increases the pressure on the outer half of the structure and can never be repaired. Wire mattresses did help in counteracting this tendency but the netting usually yields and the deformation in walls becomes visible. The older system of building in wooden frames made out of battens was found really effective and successful.

Continuing, Mr. Nangea said that even where a wall is subjected to vertical pressure alone, it always develops horizontal tension which may be demonstrated by building a vertical wall in dry bricks. With the most balanced placing of bricks and standard bond, the slightest horizontal pressure and lubricant like water at once swells it, divides it into two and fells it all. A wall in mud mortar, due to better bearing, distributes point-loads on a wider area and behaves far better. Cement mortar when used counter-balances all horizontal tension and gives bigger safe stress.

In retaining walls, Mr. Nangea remarked that probably the compressive stress required of the masonry was not much and could be provided by mud or other lean mortars. Mud had one draw-back that it could be washed out but if the top and face of retaining-walls were sealed or made weather-proof its use could improve the life of such walls. The economic possibilities of using mud and very lean cement or lime mortars would, of course, require detailed examination before general adoption.

Bridges.

The authors had mentioned a settlement of 0·6 inches in an arch built in cement mortar. Mr. Nangea had an occasion to build a number of arches in cement mortar and had to leave the centrings for 27 days as otherwise he thought the mortar in the joints would get squeezed out and become useless. In the case of lime mortar it was correct to strike centring immediately after filling the haunches but he doubted if the same could be followed for cement mortars.

Lean Cement Concrete mixes.

In the opinion of Mr. Nangea the factor governing the proportion of cement concrete was the quality and grading of aggregates used, the idea being to obtain the densest mix and least number of individual units which the cement was to hold in position.

The authors had not mentioned if they had used broken stone or shingle in the lean concrete used by them. Mr. Nangea remarked that broken stone when used gets interlocked and gives greater safe stress.

From examination of old spandral fillings over the fallen arches of Chakki bridge and the fallen towers of the old Chhoi bridge Mr. Nangea was convinced that the internal corners of the face blocks could seldom get wholly filled. However, that did not mean that the concrete cannot develop proper strength but one will have to be cautious to rely on the uniformity of bearing power of the face-work with the internal filling and more so for arches where the skew-backs are subjected to heavy pressure.

Mr. G. C. Khanna said that he would like to deal only with one point in this interesting paper. The authors on page 48 of the Paper had stated that the work-charged Establishment had great difficulty in building skew arch bridges. Building a skew arch was, not doubt, a problem not only for the Mistries and overseers but also for the qualified Engineers, as the most experienced were likely to stumble on the layout of joints, which is both difficult and intricate.

Continuing Mr. Khanna said that a skew arch differs from an ordinary symmetrical arch in that the bed joints are not paralleled to the abutments, but are placed as nearly as possible at right angles to the face of the arch, because the best position for the joints is perpendicular to the thrust of the arch. If the joints are parallel to the abutments there is a tendency of courses to slide against each other.

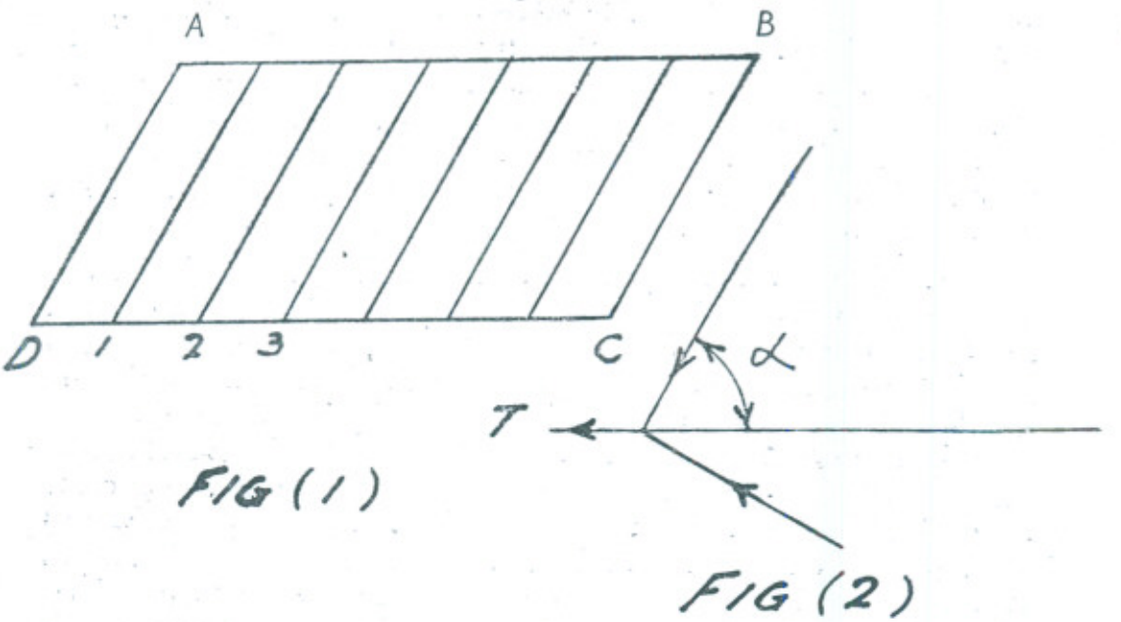


FIG (1)

FIG (2)

Figure (1) shows a skew arch with joints parallel to the abutments. The thrust of the arch is actually parallel to faces A B and C D.

The thrust T can be resolved into two components, T Cos α and T Sin α, which are parallel to the bed joints and

at right angles to the bed joints. When α is 90°, T Cos α is zero, and therefore there is no force acting along the bed joints. This is true in a right angled arch. In case of a skew arch, this component produces shear along the line of the joint which is undesirable, therefore the bed joints are made at right angles to the face of the arch. This is very necessary when the arches are built in lime mortar or weak cement mortar. The cement now manufactured in India, Mr. Khanna, remarked is capable of standing very high stresses when properly used. The strength of joints laid in cement mortar, one part cement and 3 parts sand was stated by him to be stronger than the brick itself. Therefore if a skew arch were built in cement mortar 1 : 3, it would be as strong as a right angle arch whatever the shape of the joints.

Mr. Khanna said that the arch masonry is then practically one solid mass of bricks and cement mortar, in which the joints are not any weaker than the adjacent bricks. If the arch is likely to shear through the joints which are parallel to the bed joints, it is as likely to shear through the bricks. The safe compressive stress for brick masonry was taken as 8 tons per square foot which was equivalent to 125 lbs per square inch. The safe shear strength of brick-work was 40 lbs per square inch, and this was equivalent to the shear strength of the brick itself. The adhesive strength of mortar on bricks was, according to Mr. Khanna definitely more than 40 lbs per square inch. Buckley's Pocket Book gave the adhesive strength of one cement, one sand mortar on brick-work as 300-400 lbs per square inch. For comparison the adhesive or bond strength of concrete on steel was taken as 200 lbs per square inch. Thus it was obvious that the joint of the arch was not less strong than the brick itself, and therefore the joints could have any shape.

Mr. Khanna therefore, drew the conclusion that it was not necessary to have the joints at right angles to the face, and therefore, the layout was simple. The joints could be laid parallel to the abutments and masonry arch built up in the usual manner. Bricks would, however require dressing.

For a place like Simla, where bricks are imported, Mr. Khanna thought that arches made of plain cement concrete would have been much more economical. The arch ring would be lighter in section and equally graceful as a brick arch. When the authors had made use of cement concrete in piers, etc., Mr. Khanna questioned as to why they had not used this material for arches. A skew arch laid in concrete would have offered no more difficulty than a right angled arch.

For those interested in building a skew arch in the old orthodox style, Mr. Khanna then gave an easy method of lay-out of joints which could be adopted in the field. In this

method there was no necessity to make out a development of the soffit of the arch in the drawing office and draw on this helical joints. He had come to know of this method through the courtesy of R. B. Mr. Madan Gopal Sardana, Principal of Thomson College, Roorkee.

After preparing the centring to the true shape of the arch, spread a large sheet of paper on the centring and cut it to its exact size. The paper should then be spread over a flat piece of ground which will develop the shape shown in the figure 2. Small sheets of paper can be pasted and joined together to cover the whole arch.

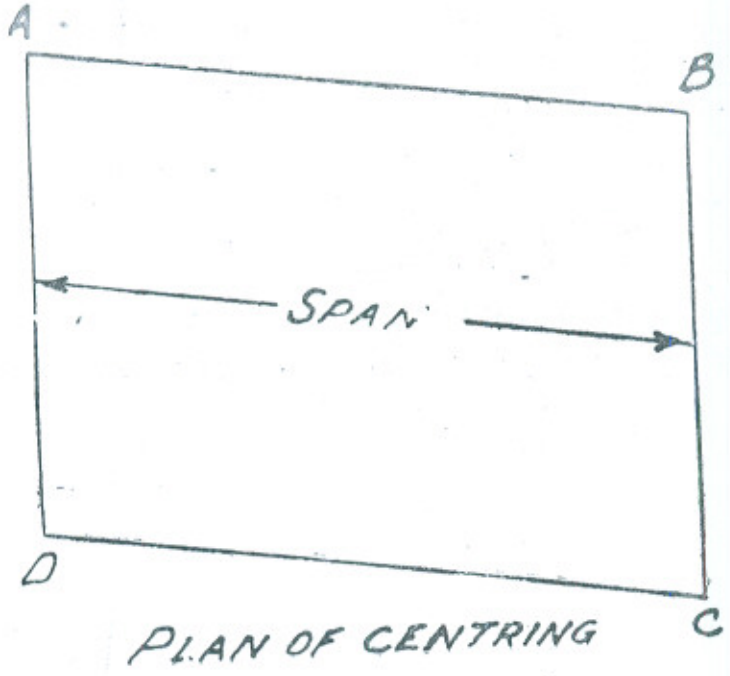
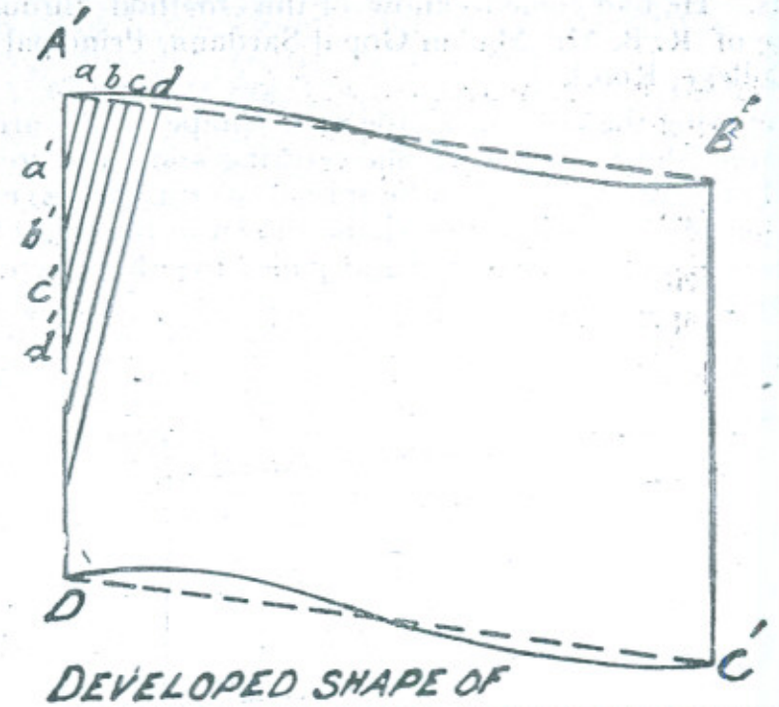


FIG (3)

On the developed figure A′, B′, C′, D′, join A′ B′ and D′. C. These lines will be parallel and mark out points on these lines 3″ apart to indicate the thickness of the brick and the joint. Then draw lines at right angles to A′, B′, and C′ D′ from the points marked on these lines as shown above. The paper should then be placed on the centring and the lines aa′, bb′, cc′, etc. will represent the line of mortar joints in the arch. The brick-work can then be started with these lines as the guides.

The end brick as shown at R in figure 5 will be drooping downwards and the abutment should have proper nitch to receive this brick. The joint of this brick with the abutment

should be made in 1 : 3 cement mortar. The above method will give an exact spiral arch.



DEVELOPED SHAPE OF PAPER CUT TO THE SIZE OF CENTRING.

FIG (4)

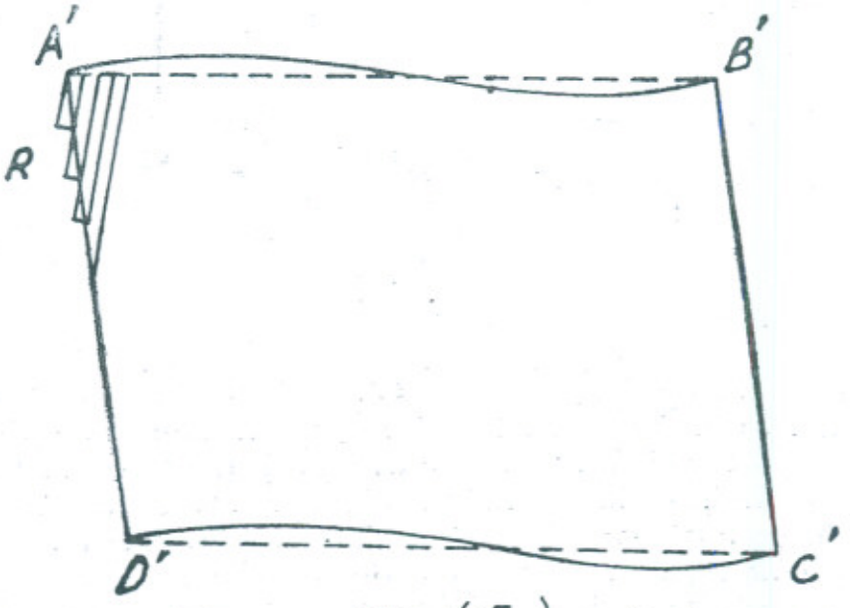


FIG (5)

Mr. **Baker** in reply to the discussion thanked Mr. Trevor Jones for his appreciation. He was not in a position to enlarge on his remarks as to the purpose of the road and agreed that

Mr. Trevor Jones, his Chief Engineer, probably knew far more about that than the authors. Mr. Trevor Jones had referred to petty contractors acquiring the habit of deliberately creating work. The authors, in their executive capacity, had tried to make it clear to all the contractors that only such of them as turned out reliable construction would be given further work. Mr. Baker agreed with Mr. Trevor Jones that there were many cases where more careful design and possibly more substantial forms of construction were necessary than the standard dry-stone walling described in the paper. It was expected that a few such cases would probably come to light among the many walls constructed above and below this road. These would, in due course, be considered on their merits but it was of course not desirable to abandon a generally reliable and cheap form of construction on account of the small percentage of failures likely to arise. He felt that this was Mr. Trevor Jones' view. Regarding the cost of rebuilding retaining walls, this was likely to be high in the initial stages and to reduce as the road settled down, to a figure in the neighbourhood of Rs.50 to 100 per mile per annum.

Mr. **Freak's** observations required no answer from the authors but in support of his remarks regarding the replacement of the collapsed faces of retaining walls Mr. Baker mentioned that one wall 35 feet high had been rendered completely sound by this method after having apparently been on the verge of complete collapse.

Referring to Mr. Thomas' remarks Mr. Baker promised to explore possibilities of giving figures concerning rainfall run-off from the wooded catchment areas. He was glad to see Mr. Thomas among the speakers as this gave him an opportunity of expressing publicly to Mr. Thomas his thanks for the help he had always given the authors by way of access to his excellent engineering library.

Mr. **Murari Lal** had doubted the efficacy of the road as a means of reducing congestion. Mr. Baker admitted that he had heard similar criticism before but pointed out that there was a reasonable probability of the road serving this purpose in this respect, aided by judicious town-planning and it was impossible to foresee to what extent hopes would be realised. Mr. Murari Lal had suggested that the commencement of construction in war time was injudicious. Mr. Baker regretted his inability to comment on this. Mr. Murari Lal had expressed keen disfavour with the appearance of the engineering structures involved stating that they would be out of keeping with Simla but Mr. Baker was not prepared to agree to this at all. The important engineering structures were, as is mentioned in the Paper, brick-faced and there were many such buildings in Simla.

Modern reinforced concrete structures as envisaged by Mr. Murari Lal would be unique in Simla and would harmonise with nothing. Mr. Baker regretted that the authors had apparently adopted Mr. Murari Lal's formula for super-elevation without acknowledging its source. He was unaware that Mr. Murari Lal had originated this formula but the technicalities put forward in support (during this discussion) were not, in Mr. Baker's opinion, sound. The formula, however, had worked very well in practice and Mr. Baker was sure that Mr. Murari Lal was glad to know this and would accept his apologies for any inadvertent omission to mention his name. Regarding Mr. Murari Lal's opinion that the retaining walls were of excessive section, Mr. Baker considered that such remarks were not based on calculations, which would readily disprove them.

Mr. **Howell** raised no questions requiring answer but it was confirmed that Mr. Howell's advice concerning the tunnel problem had been accepted in all respects and had been found to work excellently in practice. The Geologist's Report, to which Mr. Howell referred, had caused a lively argument which was cut short by a crisp order from Mr. Trevor Jones to drive a pilot tunnel and find out who was right. This had been done without untoward happening, and had been performed entirely with local labour, completely new to tunnelling, at a cost approximately half that of the lowest quotation received from contractors.

Mr. **Champa Lal** had inferred that transition curves had been omitted without due consideration. This was not the case but if anybody had inspected the plan of the road he would have realised that there was literally no room for effective transition curves which would make the road one long series of bends. The maximum length of 1 in 10 gradient was about 1/4 mile. Compensation of curves by way of reduced gradient was not practicable on account of the winding nature of this road; such an attempt would have made the profile of the road almost unintelligible. There had been no serious slips on the road except that described below Ravenswood. No special difficulties were experienced anywhere. The annual rainfall in Simla was about 60 inches. As explained in the Paper it was impossible to generalise on the nature of the excavation as it varied from yard to yard. Everything from uncompacted debris to the hardest of sand-stones had been encountered. Mr. Baker regretted that he could not compare the rates paid for stone-walling with the schedule of rates as much of the construction was through new areas, but for the more orthodox items such as brick-work no premium in excess of 15 per cent above the schedule rates had been allowed. The more orthodox items were, however, a very small part of the

work. Parapets had nowhere been used; timber railing was the standard form of protection.

Replying to Mr. Karnail Singh Mr. Baker thanked him for his offer to advise on past railway experience. Mr. Karnail Singh's criticism of the design of the retaining walls was all very well but the authors had attempted to explain that there was no constancy of conditions in Simla warranting, or leaving possible, individual consideration of each case. The conditions would not be known until the excavation had been done and there would then be no time to await designs. Mr. Baker did not agree that a sloping hillside necessarily constituted a surcharge; many old contractors in the hills argued "The steeper the hill the sounder the soil" and Mr. Baker considered this a very sound dictum in general. A sloping surface of newly deposited material indeed constituted a surcharge but Mr. Baker contended that this was an entirely different state of affairs; he agreed that the methods employed made likely a few failures and these would be dealt with on their merits in due course, but to design all walls on this expectation would be equivalent to paying 99 per cent insurance premium. Mr. Baker would be pleased to show anybody disagreeing with his views examples of "angles of repose" varying from 0° to more than 90°. Concerning the waterway of culverts Mr. Baker did not agree that an assumed velocity of 10 feet per second was excessive in the steeply sloping "hill nallas" which the majority of these culverts were intended to serve. In other cases culverts had been introduced to carry small quantities of house sullage, etc., but as no culvert was made less than $2' \times 2'$ (in order to afford access for inspection and maintenance) these few culverts did not warrant careful technical examination being *prima facie* 100 per cent too big. Concerning Mr. Karnail Singh's criticism of the vertical curves Mr. Baker joined issues as to the inferences. The curves, as designed, would affect a vehicle travelling at 60 miles per hour to an extent of not more than about one per cent of its stationary weight from the point of view of pressure on the road. This could easily be checked mathematically; the formula had first been tried out on the Khaur Dhulian Road and had been found very satisfactory for fast moving vehicles over pronounced changes of gradients. Mr. Baker was at a loss to understand Mr. Karnail Singh's remarks that the authors had admitted not having designed the viaducts with due consideration. He thought it had been made clear that they had been designed with every consideration of possible combination of the Indian Road Congress standard loading. Mr. Balwant Singh in his introductory remarks had explained this still further. Mr. Karnail Singh's further criticism of the design was a little difficult to assimilate as he started by saying that the "tall slender piers" were defective and went on to say

that the appearance could be improved by making it thinner at the base. Whatever the criticism intended the fact remained that the viaducts, as designed, were safe for combination of all Indian Road Engineering Congress loading even with the very safe precaution mentioned in the Paper of allowing no tension anywhere. Mr. Baker regretted that the paper had evidently not been clear in explaining that the " blistering " of the faces of retaining walls was not the same as " bulging ". A wall which had bulged was clearly unstable but in the blistering the remainder of the wall was in many cases often undisturbed and the authors were condemning the usual practice of blindly dismantling and rebuilding a wall showing apparent " bulging " which was really " blistering ". The question of the principal stresses in retaining walls had been very fully examined by Mr. Halcro Johnston in a Paper presented to this Congress and Mr. Johnson had derived his own conclusions. Mr. Baker did not agree that Mr. Johnson's conclusions were sound in practice. It was not wise to compare steel structures under determined loads with dry-stone masonry structures under loads which, as the authors had been at pains to explain, were in Simla completely indeterminate. Concrete bonds as shown in the Paper had been introduced for these retaining walls in place of the pacca masonry courses mentioned by Mr. Karnail Singh; their purpose was identical. Mr. Baker again stressed that a percentage of failures would be tolerated in view of the enormous financial saving effected by taking this risk. Mr. Baker pointed out that the collapse of a road retaining wall merely impeded; as distinct from interrupting traffic, while in the case of a railway the road was either open to traffic or closed thereto. Railways cannot, therefore, afford these risks.

Mr. **Baker** agreed with Mr. Nangea's suggestion to water-proof the whole road surface where retaining walls had given trouble. Mr. Nangea's observation that walls had failed in two parts was similar in effect to the authors' observation regarding blistering of the face work. It would be interesting to know if Mr. Nangea had been able to save such walls by rebuilding a front wall portion only. Mr. Nangea's other observations were interesting and would be borne in mind in case they were found applicable. Mr. Baker would not say that he was right in striking the centring under arches of brick-work in cement mortar or admit that Mr. Nangea was correct in expressing his dislike for the practice. Exponents of both these views could be found among the ablest bridge engineers in the world. Mr. Nangea's remarks that the proportion in cement concrete should be controlled according to the quality and grading of the available aggregates were obviously correct in theory but it was impracticable in a very large scheme scattered over many miles under such circumstances. Mr. Baker felt that Mr.

Nangea would agree that it would be safer to give specific orders. Generally broken stone aggregate had been used in the lean concrete. Mr. Baker agreed that this gave better interlocking but he personally preferred rounded ballast for good concrete as this permitted a practical degree of workability with a better water cement ratio.

Mr. G. C. Khanna had drawn attention to the necessity of engineering supervision in laying out skew arches. This had been fully appreciated by the authors who spent hours trying to explain methods to the artisans, but in the end the authors failed as the artisans remained quite unconvinced that the engineers were anything but mad! Mr. Khanna's points had received timely consideration by the authors in designing and constructing the arches in question. It was possible that plain cement concrete arches might have been more economical than the brick work arches as constructed, but the centring would have been much more expensive and the large and necessarily long concrete job might have been damaged by the weather. Mr. Khanna's suggestion that the courses should be laid out full-size on a large sheet of paper would not be practicable in a climate such as that of Simla with its winds and rains. The authors had actually laid out the courses on a thin plaster on the centring and this method was the same in effect as that suggested by Mr. Khanna. Mr. Khanna's method would be ideal, Mr. Baker considered, for repetition work on small culverts but with 18 feet span bridges Mr. Baker felt that the method as adopted was better.