# THE NAMAL DAM.

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## Introductory.

Near the western end of the Salt Range a narrow, tortuous gorge, two miles long, with a fall of about a hundred and fifty feet, and running in a direction generally southward, has been cut by the Wahi, the name given to the stream formed by the junction, near the village of Namal, of two hill streams, the Lawa (or Tarapi) and the Golar, which have their source on the crest and northern slopes of the range, in the neighbourhood of Sakesar, a small hill station.

The site ultimately selected for the dam was, in many ways, so obviously suitable for the purpose that it long ago attracted attention. To the north, for a distance of about three quarters of a mile, lay the narrow valley of the Wahi, but beyond this, near Namal, was an open plain forming an admirable site for a reservoir basin. On the other hand, the site had some disadvantages, in that the rock was much fissured, and that numerous sulphur springs issued from the bed of the gorge. These drawbacks long deterred engineers from undertaking the work of building a dam, but early in 1910, Sir Louis Dane, then Lieutenant-Governor of the Punjab, decided that in view of the great benefit which would be derived from the work the risks pointed out by engineers might be incurred.

## Mr. Bellasis' Proposals.

In January 1910, Mr. Bellasis, then lately retired from the Punjab Irrigation Branch, had been put on special duty to investigate the site, and to make proposals for a dam to store water in connection with a small canal. Mr. Bellasis had preliminary surveys made, and suggested three sites as suitable—one at the head and two others some distance down the gorge. He also aligned a small canal as far as the village [illegible]el, about ten miles from the head of the gorge. [illegible] project was made, but Mr. Bellasis was in favour [illegible]ow dam at the head of the gorge and allowing [illegible]o spill over the crest.

With these surveys, and a recently made Survey Department map of the country, from which the catchment area could be reliably ascertained, there was not much left to be done in the way of preliminary out-door work. The catchment area was found to be 164 square miles, of which 125 miles lay on the northern slopes of the Salt Range, and the remainder in the plain near Namal ; and when orders were received to get out a detailed project for the dam and canal, a further inspection of the site showed that there was nothing to be gained by locating the dam at a distance down the gorge, as it was obvious that, owing to the steep fall in the bed, a dam built any distance down must be so much higher than one built at the head in order to impound the same quantity of water, and while it was true that there were smaller and fewer springs at the other sites selected by Mr. Bellasis, the nature of the rock did not appear to be so good down the gorge as at its head. It was also considered that there would be no great difficulty in dealing with the sulphur springs in the deep bed, by collecting them into one place, and allowing them to freely issue through a small pipe in the lower part of the dam.

**Examination of Site.**

The location of the dam having been settled, it was necessary, for the purpose of framing a reliable estimate of cost, to ascertain the depth to which the bed of the gorge had been scoured. The site selected being very narrow, with a sandy bed, it was clear that the true bed, on which the dam foundations would have to be built, must be some depth down, and in order to clear out the sand and get at the rock beneath, it was necessary to arrange to pass off the small flow in the stream, which was never less than nine or ten cusecs. This was done by building a small wall where there was a suitable gap between rock slopes, a short distance above the proposed dam site, and carrying off the water through pipes before it rose sufficiently high to flow over the wall.

It was obvious that this arrangement would only be sufficient to deal with the small constant supply in the Wahi, but it was hoped that there would be time to clear out the sand before rain brought down a flood. This, however, did not prove to be the case, and the deep bed had not been full cleared out when the estimate was submitted. The wall (P however, stood all right, and was again utilised lat same way for clearing out the bed when foundations of the dam.

## Rainfall Records.

The only rainfall records available were those made at Sakesar, just within the catchment area. These extended over a period of twenty-four years, from 1887 to 1910, and showed that the average annual rainfall at Sakesar could be taken as 21·1 inches, of which one and three quarters inches fell in June, six in July, five and a half in August and two in September ; January, February and March, had each from one to two inches ; December, April and May, each from a half to three quarters ; and October and November each less than one quarter of an inch. These were the averages for the period, but there were wide fluctuations, especially in the monsoon months of July and August. Thus in 1889 the rainfall in July was only 1·7 inches, while in 1892 it was as much as 15·2 inches.

So far as construction work was concerned, it appeared that October and November could be counted on as dry months. In nine out of the twenty-four years no rain at all was recorded in these two months, and, neglecting falls of half an inch and less, there were found to be in all thirteen similar years, consequently it was concluded that work on building the dam should commence late in September.

Cross sections were taken of the Wahi valley above the dam site, including as much as was necessary of the adjacent hills, with the ground near Namal which was to form the main storage basin, and contoured plans were prepared, from which the contents were calculated and the diagrams reproduced on Plate No. 3 prepared. This gives the cubic contents of the reservoir for each vertical foot from R. L. 1,130 to R. L. 1,180.

## Design of Dam.

In designing the dam it was considered whether it should be of the usual gravity section, or be built in the form of an arch, as had been done with success elsewhere.* It was found, however, that the area of the foundation rock would limit the arch to one of too flat a camber, and consequently it was decided to build an ordinary gravity dam, with the right flank slightly curved downstream in order to meet the hill side favourably. During construction it was also decided to curve the left flank round in a similar manner (Plate No. 4).

The next question to decide was how to dispose of the flood discharge of the streams entering the reservoir. Here, also,

* *Vide* Minutes of Proceedings of the Institution of Civil Engineers, Vol. CLXXVIII.

there were two alternatives — either the surplus water could be passed off by means of a waste weir capable of taking the whole flood discharge, or else the flood water could be temporarily absorbed into the reservoir, and then gradually drawn off by means of sluices.

It was not considered advisable to adopt the first method, as this would involve allowing a very large volume of water, estimated at 60,000 cusecs, *i.e.* the maximum calculated discharge of the streams, to pour on to the poor quality rock found below the dam site. Adopting the alternative meant building the dam to a height considerably greater than that required for the proposed storage capacity, so that it was ultimately decided that for the present the level of the ordinary storage capacity in the reservoir should be R. L. 1,160, or eighty-five feet above the silted bed of the gorge (R.L. 1,075).

A reference to the records of rainfall at Sakesar showed that during the twenty-four years period there had been one very heavy and continuous fall of rain, *viz.* in July and August 1892, when ten and a quarter inches of rain fell in twelve days ; and as the total average rainfall for a whole year amounted to only 21·1 inches, it was concluded that so heavy a fall would seldom, if ever be exceeded. Taking this as a basis of calculation, and assuming a run off on the catchment area of seventy-five per cent., it was found that, under the most unfavourable conditions, the level of water in the reservoir would not rise above R. L. 1,173·5. It was felt, however, that it would be as well to give a further margin of safety, and also add waste weirs on each flank, and it was assumed that under no possible circumstances would the impounded water rise above a level of R. L. 1,179. The crests of the waste weirs were accordingly fixed at R. L. 1,175, and the rest of the dam raised to R. L. 1,181·5, or two and a half feet above the assumed maximum high flood level in the reservoir.

As originally designed the total length of the waste weirs was 210 feet. In building, however, this had to be reduced, and the total length actually given was 171½ feet ; 65 feet on the left flank and 106½ feet on the right, as shown on Plate No. 4. Taking the high co-efficient of discharge for weirs of 0·7, and the ordinary formula in such cases, *viz.*,

$$Q = \tfrac{2}{3} \times L \times c \times \sqrt{2g} \times h^{\frac{3}{2}}.$$

where for the maximum depth of four feet occurring in this case $L$ is the length in feet of the weir, $h$ is the depth of water passing over it, and $c$ the co-efficient, taken as 0·7,

$Q$ (discharge) $= \frac{2}{3} \times 171\frac{1}{2} \times 0{\cdot}7 \times 8{\cdot}025 \times 4^{\frac{3}{2}} = 5{,}140$ cusecs.

This was a small volume of water as compared with the full flood discharge of the river—60,000 cusecs, but, since it was considered most improbable that even this small quantity would ever actually pass over the waste weirs, the latter could only be looked on as an extra precautionary measure of safety.

To pass off the flood discharge of the river, temporarily absorbed into the reservoir, six sluice gates, each four and a half feet wide, with a clear height of six feet, giving a total waterway of 162 square feet, were provided. The number of gates was governed by the space available, after allowing for a suitable interval between them, and they were kept as low down as convenient, in order to get the benefit of the maximum possible head of water. The sills were fixed at R. L. 1,120, but even then a considerable quantity of rock had to be removed, by blasting down stream, in order to give a free passage to the issuing water.

**Pressure on Foundation.**

When designing a dam it is necessary to decide the maximum pressure per square foot that may be allowed on the foundation. This was fixed at nine tons, which it was considered might be accepted with safety. The weight of masonry per cubic foot also came into the calculations, and it was necessary to assume a probable value for this. The ordinary weight of stone masonry in lime lies between 140 and 150 lbs. per cubic foot, and calculations having been made with each of these values it was found that the lesser weight gave, with the dimensions proposed, 9·39 and the greater weight 9·03 tons maximum pressure on the base of the dam. These results may, perhaps, at first sight, appear to be somewhat curious, but it will be found that with the lower figure for the weight of the masonry, the resultant pressure, with the reservoir full, falls at a point further from the centre of the base than is the case when the higher value is taken. Consequently the maximum pressure, which depends on, and increases rapidly with this distance, is greater when a low value is taken for the weight of the masonry used than it is when a high value is taken.

It is not necessary to go into the details of the method of designing a gravity dam, as all necessary information on the subject will be found in standard works of reference. The main condition that must be satisfied is that the resultant pressure on

any horizontal sectional plane shall never fall outside the centre third of the plane, whether the reservoir be empty or full.

Although for the purposes of arriving at a suitable section for the Namal dam, the weight of stone masonry (uncoursed rubble in lime) was taken at 150 lbs. per cubic foot; it was ultimately found, by experiment, that this weight might have been more accurately taken as 143 lbs. For the sake of economy, it was decided to substitute stone concrete in lime for uncoursed rubble in lime in the upper part of the dam. It is generally assumed that the maximum pressure which may be allowed on lime concrete is 60 lbs. per square inch equivalent to 3·86 tons per square foot. As designed and built the portion of the dam above R. L. 1,130 was of stone concrete in lime, and the calculated maximum pressure at this level was found to be 4·23 tons per square foot (65·5 lbs. per square inch), which was somewhat in excess of that usually allowed, but in view of the fact that the dam would probably never be tested to its fullest extent, this was neglected.

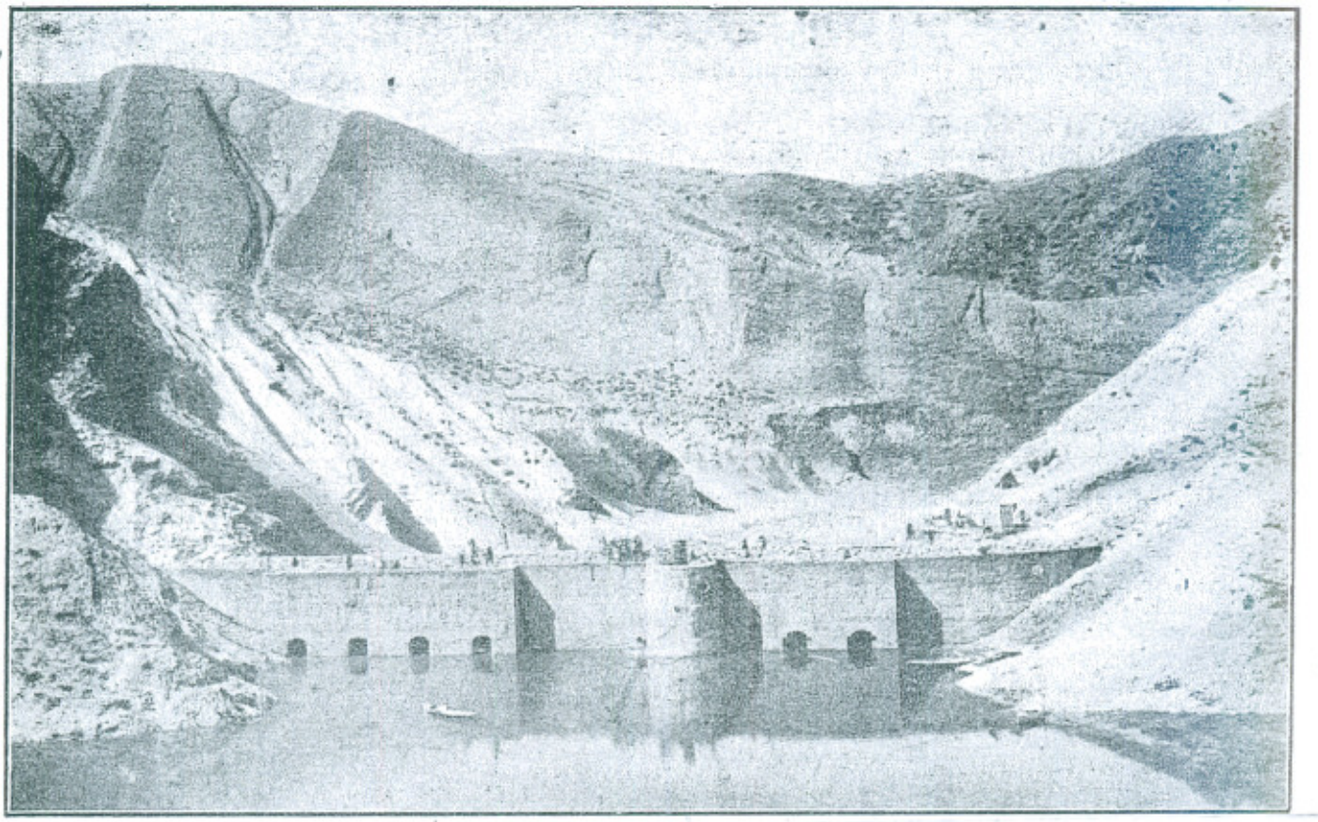
## Valve Tower.

In order to allow for sending down the small quantity of water required for the canal built in connection with the dam, a valve tower was necessary. The maximum supply required was only sixty cusecs during the kharif, while the rabi rarely exceeded forty, and might often be as low as twenty cusecs, and these small discharges could not be controlled by means of the sluice gates. The valve tower consisted of a chamber, semi-circular in plan, built on to the inner face of the dam and containing a central steel pipe of thirty inches diameter, with three inlets through the masonry walls of the valve tower, governed by means of valves operated by separate lifting gear placed on the top of the tower. The inlets (Plate No. 4) were at different levels to suit the level of the water in the reservoir, so that the head over the inlet in use should not be excessive. The lower end of the steel pipe was carried about eleven feet outwards, through the body of the dam, till it discharged into a strongly constructed masonry channel built in the dam and continued for some distance along the face of the rock. The water was then allowed to fall into the gorge below and find its way to the head of the canal, about two miles distant.

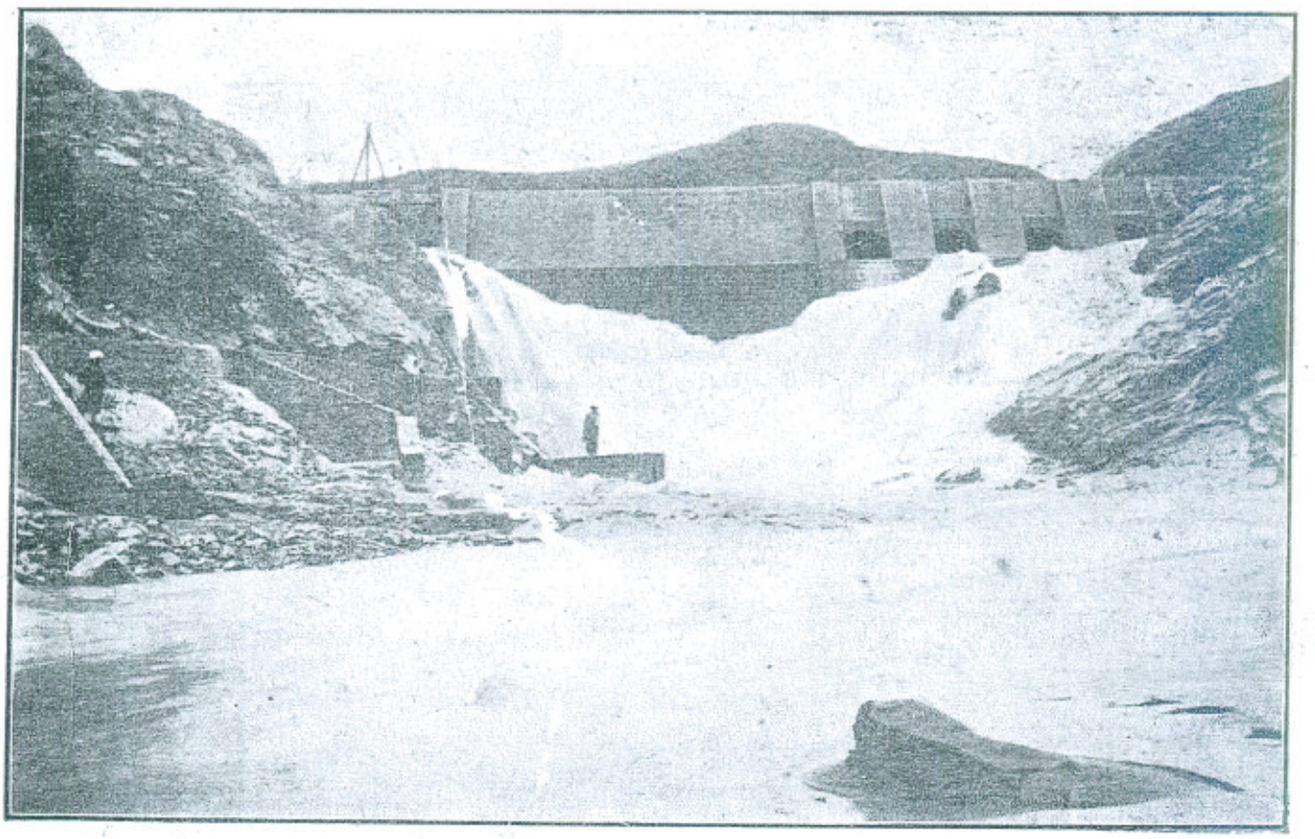
## Sulphur Springs in Foundations.

In building the dam it was first of all necessary to remove all silt and thoroughly clean the deep river bed down to the

# NAMAL DAM.



Upstream view on 14th April 1913.



Downstream view on 4th March 1913.

rock foundations, which was troublesome work, owing to the restricted space and interruptions caused by small floods. When the silt had been removed, boulders and rock debris were encountered, and the sulphur springs, (of which there were fifteen altogether) were definitely located. Though each of these springs was of small size, they collectively produced a considerable flow of water, which had to be kept under control, during the clearing operations, by means of two pulsometer pumps. It was necessary to collect the discharges from these springs into one place, and lead the water, impregnated with sulphuretted hydrogen, through a three inch pipe, which ultimately discharged through the lower part of the dam.

The general procedure was to sink a series of small pits over the springs (six such pits were made in all) and introduce the suction pipes of the two pumps, which were kept going night and day as long as was necessary to complete the work. Each pit was carefully closed in rotation with stone masonry in cement, so as to force the water issuing from the spring through a small channel cut for the purpose into the next pit in the series. At the sixth pit the three inch pipe was inserted.

The deep bed in the gorge was filled in with uncoursed rubble masonry in cement mortar consisting of one part of cement to three parts of cleaned sand, up to R. L. 1,075, the original silted bed level of the river, thus forming a solid base for the dam. With this exception practically all the masonry work in the dam was in lime mortar. Great care was taken everywhere in building to remove all disintegrated surface rock, and to thoroughly clean the exposed face with water and wire brushes before adding any masonry. To facilitate this work, a small masonry tank was built at about R. L. 1,200, which was kept filled with water by means of a hydraulic ram placed near the bed of the gorge downstream of the dam. The water in this tank was also utilised for keeping the masonry wet during construction.

**Masonry in Superstructure.**

Care was taken to break joint in the heart of the dam as frequently as possible, and concrete made of small stone ballast and *bajri*, with lime mortar, was worked by means of iron bars into the space between the larger stones. Local lime stone was used everywhere, except for facing the inner portions of all outlets through the dam where stone from Hassan Abdal, near Rawalpindi, was used. The lime mortar was composed of one part kankar lime, one part white stone lime and two parts of surkhi, and this was found to give good results.

Surkhi and lime were prepared at Musakhel and Mianwali, respectively about six miles and twenty miles distant, and brought to the site on camels. Owing to the bad roads, the use of wheeled transport was limited to cases where it was unavoidably necessary to carry heavy loads, and camel transport had to be chiefly used to bring up all material.

**History of the Work.**

'Work on the dam was commenced in September 1911. In May and June of that year a series of thirty-four bore holes had been drilled in the rock by means of an Ingersoll Sergeant type of rock drill. The maximum depth to which it was found possible to use this drill was twenty feet, but many of the holes did not go down more than six feet owing to the hard rock encountered, and in some cases the drill came against large flints bedded in the rock, when work on that bore hole had to be stopped. The holes were drilled all over the area to be covered by the dam, except in the deep bed, which up to that time had not been cleared. About one-third of the holes drilled lay outside the area of the dam, and here, in one or two cases, local sand pockets were encountered a few feet down. So far as the work went it proved that the rock was sound enough where it was intended to build. It was unfortunate that owing to the impossibility of getting a suitable rock drill in India this work could not be done in the cold weather of 1910-11, since started, as it was, late in the season, the work had to be carried out under great difficulties, and in the intense heat so particularly trying in the Namal gorge.

'In the cold weather of 1910-11 attempts were made to clear out the deep bed, in order to ascertain to what depth it would be necessary to carry the foundation of the dam, but as already mentioned these attempts were not successful.'

Although, the work of excavating the foundation was commenced in September 1911, contrary to expectations a flood came at the end of October, and the work had to be practically restarted in November, when it was continued day and night, though the weather was generally disturbed. The masonry work was started in December and built up to R. L. 1,090, when at the end of May work was stopped to give the completed masonry time to set before the commencement of the monsoon floods. Rock cutting down to R. L. 1,120, where the six flood gates were to be built, which could not be done at the same time as the masonry, was finished by the third

week of September 1912, when the masonry above R. L. 1,090 was restarted and pushed through vigorously, so that the main work of the dam was completed by the following September, and the railing, &c., by the end of October 1913.

The total cost of the work was Rs. 3,65,241. This included Rs. 30,777 as compensation for submerged houses and fields, Rs. 13,077 for rebuilding the District Board Rest House at Namal, Rs. 4,083 for temporary buildings and roads, and Rs. 4,882 for special plant.

The inaugural ceremony was performed by the Lieutenant-Governor, Sir Michael O'Dwyer, on the 2nd December 1913, the dam being named the Dane Dam in recognition of Sir Louis Dane's great interest in the scheme.)

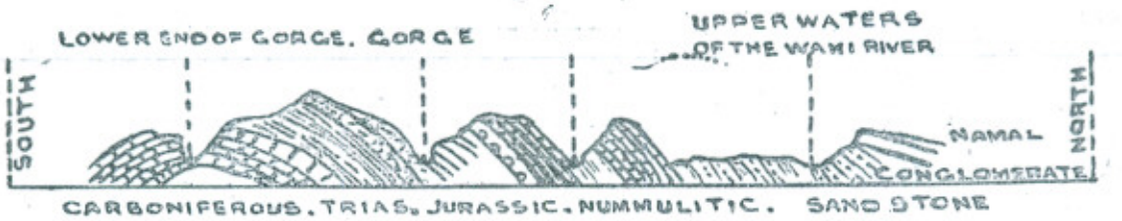
# APPENDIX I.

*Extracts from a report on the proposed dam site at Namal by Mr. H. C. Jones, Assistant Superintendent, Geological Survey of India.*

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**Geological details.**

The accompanying geological section taken from Mr. A. B. Wynne's account of the Salt Range,* gives a good idea of the rocks which occur in the gorge.




GEOLOGICAL SECTION

The Tertiary sandstones, clays, and the Nummulitic limestone are the only beds which have to be considered in detail as affecting the building of the dam. The Tertiary series consist of alternations of soft grey and greenish grey sandstones, and red and brown clays, overlying the Nummulitic limestone. This limestone, on which it is proposed to build the dam, is six to seven hundred feet thick, but varies greatly in character in different bands. At the site, the limestone dips at 65° to the north-east; the dip, however, decreases in height; in fact, the beds are the eastern arm of an anticline, the top of the arch occurring near the western end of the gorge.

At the actual site the beds have been slightly bent, that towards the south striking N. 33° W., and that towards the north striking N. 45° W. This bending, no doubt, weakened the rock, and thus decided the point at which the river should cut through the range. Close to the limestone ridge the Tertiary sandstones and clays have been denuded away, thus forming longitudinal valleys parallel to the ridge, so that the limestone would be exposed to the waters held up by the dam.

**Nature of the rock.**

The limestone on which it is proposed to build the dam is a white, cherty, nodular variety about fifty feet thick, and is composed of thin

* See Memoirs, Geological Survey of India, Volume XIV.

nodular bands about six to eight inches in thickness. It is overlain by a cavernous white and pink compact limestone, which would offer little resistance to percolation of water; while it is underlain by a thin band of softer clayey limestone followed by further bands of thin bedded cherty limestone and more solid limestone. The bedding planes in the limestone are well marked although appearing somewhat irregular, owing to the nodular character of the rock. These bedding planes in places are fairly open, but as they run parallel to the proposed dam, little percolation of water would take place through them. In the bedding planes and between the nodules, or lumps, of hard compact limestone, occur thin bands of soft shaly, or clayey, limestone. At the actual site this has been largely washed away, making the rock look much more open than it really is.

**Joints.**

The limestone bands below the actual site are traversed by two well marked series of joints dipping at 30° to N. 50° W., and 60° to S. 30° E. At the actual site only one well marked series of joints are seen dipping at 60° to N. 50° W. Owing to the nodular character of the rock, the joints are often somewhat obscure. These joints are continuous, and run right through the band, and although at present they are only open a short distance from the surface, I am inclined to think that when exposed to water under pressure, percolation along them will take place.

**Cracks.**

At the proposed site, several bad irregular cracks occur, which will necessitate the removal of a considerable quantity of limestone, in order to get a good foundation. Two of these cracks can be seen on the south side of the gorge, one on the north side of the gorge about fifteen feet above the water, and another much higher up on the same side.

**Sulphur Springs.**

Hot water and sulphurous springs emerge at numerous points in the gorge, and are not confined to any one particular formation. Just below the proposed site there are a number of these springs. Hot water and sulphuretted hydrogen gas issue from numerous cracks in the rocks. In some cases hot water rushes out in considerable quantity, with a large escape of gas, others issue quietly. The water is covered with a thin film of gypsum, and at the bottom of the pools is a deposit of thick black mud. In most cases where these springs occur, a considerable amount of erosion has taken place. Some of these springs occur just at the base of the east and west sides of the band on which it is proposed to build. Bubbles of gas are also seen escaping from the sand at the bottom of the pool which covers the proposed foundations.

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# APPENDIX II.

## *Note by Colonel Morton, R. E., on the time taken to fill and empty a reservoir of known capacity with special reference to the Namal work.*

*First Case.* The first case which arises is when a given number of cusecs enter a reservoir and part of this volume of water is let off by means of sluice openings only.

Under these conditions the *time in hours* can be calculated from the formula given by Mr. Farrant*—

$$t = \frac{2\,A\,H}{Q \times 3{,}600}\left[\log_e \frac{1-\sqrt{\frac{h}{H}}}{1-\sqrt{\frac{k}{H}}} - \left(\sqrt{\frac{k}{H}} - \sqrt{\frac{h}{H}}\right)\right],$$

where $A$ is the mean surface area in square feet of the reservoir between the level of the water in it at the moment the given supply commences to enter and the level of the water when this supply ceases to flow. $H$ is the head of water in feet required to pass the given supply through the sluice openings—measured over their centres, $Q$ is the given supply in cusecs, $h$ is the head in feet of water in the reservoir over the centres of the sluice openings at the moment of commencement of flow, and $k$ the head at the moment the flow ceases.

In the case of the Namal dam, supposing the level of water in the reservoir to be R. L. 1,160 when a maximum flood of 60,000 cusecs commences to enter, then, the R. L of the centres of the sluice openings being 1,123, $h = 1{,}160 - 1{,}123 = 37$ feet.

To find in how many hours this flood continuously flowing would fill up the reservoir to R. L. 1,175, $k = 1{,}175 - 1{,}123 = 52$ feet. It is first necessary to calculate $H$, which is given by the ordinary formula $Q = a\,c\,\sqrt{2\,g\,H}$, where $a$ is the area of the sluice openings = 162 square feet, $c$ is the co-efficient of discharge, which may usually be taken as $\frac{2}{3}$, $Q$ is the given supply (flood) in cusecs, and $\sqrt{2\,g} = 8{\cdot}025$.

Then $60{,}000 = 162 \times \frac{2}{3} \times 8{\cdot}025 \times \sqrt{H}$

$$\therefore \sqrt{H} = \frac{60{,}000}{866{\cdot}7} = 69{\cdot}228 \text{ feet.}$$

The surface area of the reservoir was found to be, at R. L. 1,160, 60,443,000 square feet, and at R. L. 1,175, 164,541,000 square feet.

So that according to the usual formula in such cases, the mean surface area $A = \frac{B + \sqrt{B\,C} + C}{3}$ (formula for volume of a frustum of a cone where $B$ is one surface area and $C$ is the other.)

*Punjab Public Works Department Paper No. 64.

This gives a mean value for $A$ between R. L. 1,160 and 1,175 = $\frac{60{,}443 + \sqrt{60{,}443 \times 164{,}541} + 164{,}541}{3}$ in thousands of square feet = 108,237,000 square feet.

$$t = \frac{2 \times 108{,}237{,}000 \times H}{60{,}000 \times 3{,}600} \left[ \log_e \left( \frac{1 - \sqrt{\frac{37}{H}}}{1 - \sqrt{\frac{52}{H}}} \right) - \left( \sqrt{\frac{52}{H}} - \sqrt{\frac{37}{H}} \right) \right]$$

$$= \frac{216{,}474 \times H}{216{,}000} \left[ \log_e \left( \frac{1 - \sqrt{\frac{37}{H}}}{1 - \sqrt{\frac{52}{H}}} \right) - \left( \sqrt{\frac{52}{H}} - \sqrt{\frac{37}{H}} \right) \right]$$

= 8·31 hours.

So that the time taken for a flood of 60,000 cusecs to raise the water level in the reservoir from R. L. 1,160 to R. L. 1,175 is 8·31 hours.

The above is given merely as an example of working with the formula. In practice the height for which the value of $t$ is to be calculated should be divided up and calculations made by stages, in this case say,

R. L. 1,160 to 1,165
R. L. 1,165 to 1,170
R. L. 1,170 to 1,175

If this is done, not only will the results be somewhat more accurate than when the calculations are for the whole depth from R. L. 1,160 to R. L. 1,175. but, what is more important, a curve can be plotted, from which, with sufficient accuracy, the time $t$ for any intermediate level can be found, and, conversely, the level for any time $t$. The level of the water cannot be found for a given value of $t$ from the formula direct.

Diagram Plate No. 1 shows the results obtained in the case of the Namal dam, from R. L. 1,160 to 1,175, the calculated times being—

| | | | |
|---|---|---|---|
| | R. L. 1,160 to 1,165 | 1·872 | hours |
| | R. L. 1,165 to 1,170 | 2·724 | ,, |
| | R. L. 1,170 to 1,175 | 3·738 | ,, |
| Total | R. L. 1,160 to 1,175 | 8·33 | ,, |

as compared with 8·31 hours found in the example given above.

*Second Case.* The second case which arises is in finding the time of emptying a reservoir by means of sluice openings only, *i. e.*, calculating the discharges through such openings with varying heads.

The formula in this case is —

$$\left( \text{hours} \right) = \frac{2\,A\,k}{q \times 3{,}600} \left( 1 - \left( \frac{h}{k} \right)^{\frac{1}{2}} \right)$$

Where $A$ is the mean surface area in square feet, $k$ is the head in feet over the centres of the sluice openings at the commencement and $h$ is the similar head at the end of the given time $t$, and $q$ is the discharge in cusecs due to the head $k$.

In the present case, when it is required to find in how many hours the level of the water in the reservoir would be lowered from R. L. 1,175 to R. L. 1,160 by means of the six sluice openings provided, each

being fully opened. $A$ has the same mean value as in the first example, *viz.*, 108,237,000 square feet and taking the same value as before for the co efficient of discharge $c$.

$$k = 1{,}175 - 1{,}123 = 52 \text{ feet}$$

$$q = 162 \times \tfrac{2}{3} \times 8{\cdot}025 \times \sqrt{52}$$

$$\log q = 3{\cdot}7958704 \ (q = 6{,}249{\cdot}86 \text{ cusecs})$$

$$h = 1{,}160 - 1{,}123 = 37 \text{ feet}$$

$$t \text{ (hours)} = \frac{216{,}474{,}000}{Q \times 3{,}600} \times 52 \left( 1 - \left( \frac{37}{52} \right)^{\frac{1}{2}} \right)$$

$$t \text{ (hours)} = 78{\cdot}30$$

Here, also, if the time of lowering be calculated by short stages, a curve can be plotted. This was done in the case of the Namal dam with the results shown on Diagram Plate No. 1.

The times found were—

R. L. 1,175 to 1,170 32·968 hours
R. L. 1,170 to 1,165 25·400 ,,
R. L. 1,165 to 1,160 18·683 ,,

Or 77·05 hours, as compared with 78·30 found before.

*Third and Fourth Cases.* When a waste weir is available for letting off the water in addition to the sluice openings, though it might be too much to say that no formula similar to those given above could be devised to suit these two cases, it is certain that such a formula would be a very complicated one and troublesome to handle.

The only practical method of finding the time in these two cases is to add together calculated discharges through the sluice openings and over the waste weir. Thus, in filling the reservoir, if $Q$ be the entering supply, $q_1$ the discharge over the weir and $q$ that through the sluice openings, $Q - (q_1 + q)$. will be the nett amount of water entering, and, if $A_1$ be the cubic contents of the reservoir between two levels above the crest of the weir, the time required to fill up the reservoir from the lower of these two levels to the higher is given by the formula.

$$t \text{ (hours)} = \frac{A_1}{(Q - (q + q_1)) \times 3{,}600}$$

And in *Case* 4—emptying the reservoir

$$t \text{ (hours)} = \frac{A_1}{(q + q_1) \times 3{,}600}$$

The discharges $q$ and $q_1$ should, for accuracy, be calculated for small depths of water over the weir and to obtain a curve as before mentioned, a mean value being taken for $h$ in the formulæ.

Merely as an example of working, to find the time required to raise the level in the Namal dam reservoir from R. L. 1,175 (waste weir crest) to R. L. 1,179 (maximum high flood level in the reservoir at the dam) when a 60,000 cusecs flood discharge enters. The cubic contents of the reservoir between these two levels is 3,009 − 2,300 million cubic feet = 709,000,000 cubic feet. The mean value for $h$ over the centres of the outlets will be 1,177—1,123 = 54 feet. Hence using the same value for $c$ as before.

$$q = 162 \times \tfrac{2}{3} \times 8{\cdot}025 \times \sqrt{54} = 6{,}368{\cdot}9 \text{ cusecs.}$$

Similarly for the waste weir, the mean head over its crest is two feet and using the formula given elsewhere –

$q_1 = \frac{2}{3} \times L \times c \times \sqrt{2g}\ h^{\frac{3}{2}}$

$L = 171\frac{1}{2}$ feet, $c$ may be taken here also as 0·7, $\sqrt{2g} = 8{\cdot}025$ and $h = 2$.

$q_1 = 642{\cdot}27\ (h)^{\frac{3}{2}}$ generally, and here $q_1 = 642{\cdot}27\ (2)^{\frac{3}{2}} = 1{,}816{\cdot}6$ cusecs.

Hence 60,000 — ( 6,368·9 + 1,816·6 ) = 51,814·5 cusecs and represents the nett volume of water filling up the reservoir, while

$$t = \frac{709{,}000{,}000}{51{,}814{\cdot}5 \times 3{,}600} = 3{\cdot}80 \text{ hours.}$$

Taking successive depths over the crest of the waste weir of one f ot, the times were calculated in the case of the Namal dam in the same way, and found to be —

| | | |
|---|---|---|
| R. L. 1,175 to 1,176, | 0·880 | hours |
| R. L. 1,176 to 1,177, | 0·932 | ,, |
| R. L. 1,177 to 1,178, | 0·968 | ,, |
| R. L. 1,178 to 1,179, | 1·013 | ,, |
| Total R. L. 1,175 to 1,179, | 3·790 | ,, |

These results are shown on the diagram (Plate No. 1) and the total time which a 60,000 cusecs flood (supposing that it continued so long) would take to raise the reservoir level from R. L. 1,160 to R. L. 1,179, against the draw off by outlets and waste weirs would be 3·79 + 8·33* = 12·12 hours. It is, perhaps, unnecessary to remark that the diagram here given would be useless for practical purposes, being on far too small a scale. In the original project for the Namal dam a diagram on a very much larger scale was prepared, and, in addition, calculations were made for other volumes of water entering, such as 50.000, 40,000, etc., cusecs.

As an illustration of working the fourth case, to find the time of emptying the reservoir from R. L. 1,179 to R. L. 1,175. Here $A_1$ is, as before, 709,000,000 cubic feet.

$q + q_1$ (as before) = 8,185·5 cusecs, and $t = \frac{709{,}000{,}000}{8{,}185{\cdot}5} = 23{\cdot}51$ hours.

Taken as before by short stages, the times found and plotted on the diagram (upper curve) are- -

| | | |
|---|---|---|
| R. L. 1,179 to R. L. 1,178, | 4·689 | hours |
| R. L. 1,178 to R. L. 1,177, | 5·533 | ,, |
| R. L. 1,177 to R. L. 1,176, | 6·487 | ,, |
| R. L. 1,176 to R. L. 1,175, | 10·175 | ,, |

Total R. L. 1,179 to R. L. 1,175, 26·88 hours as compared with 23·51 hours found by direct calculation.

Fo plotting the rest of the upper curve on the diagram these times are added to those found in *Case 2* above, and the total time for emptying the reservoir from R. L. 1,179 to R. L. 1,160 is found to be 26·88 + 77·05 = (say) 104 hours. To save space the upper emptying curve is only shown as far as R. L. 1,165, the time to this level being 26 88 + 32·97 + 25·40 = 85·25 hours.

* See page 65.

*Fifth Case.* One more case might arise, though it did not do so in the Namal dam. This is when only a waste weir is provided to dispose of volumes of water entering the reservoir when the crest of the weir is reached, and this case has been fully gone into by Mr. Farrant in Punjab Public Works Department Paper No. 64 "Flood Absorption in Tanks." The formula for finding the time $t$ required to fill up a reservoir to any height over the crest of the waste weir, when a volume of water of known capacity enters the reservoir, is given on the second page of the paper, and the method of arriving at the formula is detailed on the first page. Applying this formula to the case of the Namal dam, in order to find in how many hours a flood of 60,000 cusecs entering would raise the level of the water in the reservoir from R. L. 1,175 (crest of waste weir) to R. L. 1,179 (maximum high flood level at the dam) when the weirs only are used to pass off as much as possible of the flood, $A$ (the mean surface area between the given levels) is found to be 177,530,000 square feet and $H$ (the head due to the given flood discharge) is found from the formula already given.

$$Q = \tfrac{2}{3} \times L \times 0{\cdot}7 \times \sqrt{2g}\, H^{\frac{3}{2}}$$

and, as $Q = 60{,}000$, $\log \sqrt{H} = 0{\cdot}6568118$, $\sqrt{H} = 4{\cdot}5374$ feet

$H = 20{\cdot}5884$ feet, and $h = 1{,}179 - 1{,}175 = 4$ feet

The value of $\tan^{-1} \dfrac{\sqrt{H} + 2\sqrt{h}}{\sqrt{H}\ \sqrt{3}}$ is found to be $\tan^{-1} 1{\cdot}08631$,

and consequently the angle is 47° 22′ 8″, which expressed in circular measure (for which see *e. g.* Chambers Mathematical Tables, or multiply the above reduced to degrees and decimals of a degree, by 0·0174533 (the value of one degree in circular measure)) $\tan^{-1} \dfrac{1}{\sqrt{3}} = \tan 30$ and in circular measure $= \dfrac{\pi}{6} = 0{\cdot}5235988$.

Finally calculation shows that $t = 3{\cdot}4065$ hours, which is the time required to fill up the reservoir from R. L. 1,175 to R. L. 1,179 under the given conditions.

Practically the same result can be found by using the method given before for *Cases 3 and 4*, taking separately depths of one foot and the mean depth in each case over the waste weir crest to find the discharge.

Thus filling from R L. 1,175 to R. L. 1,176, the capacity of the reservoir is 175,000,000 cubic feet, and the mean depth is 1,175·5 — 1,175 = 0·5 foot, which gives, by the formula already used, a value for $q_1$ of 227·1 cusecs.

$$t = \frac{175{,}000{,}000}{(60{,}000 - 227{\cdot}1) \times 3{,}600} = 0{\cdot}81326 \text{ hours.}$$

The times thus found are—

R. L. 1,175 to R. L. 1,176, 0·813 hours
R. L. 1,176 to R. L. 1,177, 0·831 ,,
R. L. 1,177 to R. L. 1,178, 0·860 ,,
R. L. 1,178 to R. L. 1,179, 0·896 ,,

Total R. L. 1,175 to R. L. 1,179, 3·40 hours, as compared with 3·4065 found above.

Mr. Farrant's paper also gives, on page 4, the time for emptying a reservoir and shows how the formula is arrived at.

In this case,

$$t \text{ (hours)} = \frac{2Ak}{Q \times 3{,}600}\left(\sqrt{\frac{k}{h}} - 1\right)$$

Here $k$ is the depth over the crest of the weir at the commencement, and $h$ at the end, of the time $t$, and $Q$ is the discharge corresponding to $k$.

This formula is an unsatisfactory one, as when $h=0$, *i.e.* in the case of emptying to the waste weir level, $t$ would be infinite, but though $t$ might be considerable it could not in practice have an infinite value.

As an example take the figures for the Namal dam.

$k = 4$ feet, $Q = \frac{2}{3} \times 171\frac{1}{2} \times 0{\cdot}7 \times \sqrt{2g}\,4^{\frac{3}{2}} = 5{,}138$ cusecs * while $A$ is 177,530,000 square feet.

Then the time taken to empty from R. L. 1,179 to R. L. 1,175·5

$$= \frac{2 \times 177{,}530{,}000 \times 4}{5{,}138 \times 3{,}600}\left(\sqrt{\frac{4}{0{\cdot}5}} - 1\right) = 140{\cdot}39 \text{ hours.}$$

So that the time to empty by the waste weir only from R. L. 1,179 to R. L. 1,175·5 is 140·39 hours from the given formula.

As an alternative the method employed before in *Cases 3 and 4* can be used to find the times; and the total time fro n R. L. 1,179 to R. L. 1,175·5 is found to be 131·23 hours or about nine hours less than by the formula in the Punjab Public Works Department Paper given above.

In this way it may be shown that the total time to empty from R. L. 1,179 to R. L. 1,175 is 286·85 hours.

The values of $A$ and of the mean head used together with the calculated values of $q_1$ are given in the following table—

| R. L. | Value of $A$. | Mean head. | $q_1$ in cusecs. |
|---|---|---|---|
| 1,179 to 1,178 ... | 180,000,000 c.ft. ... | $3\frac{1}{2}$ feet ... | 4,205·5 |
| 1,178 to 1,177 ... | 178,000,000 ,, ... | $2\frac{1}{2}$ ,, ... | 2,538·8 |
| 1,177 to 1,176 ... | 176,000,000 ,, ... | $1\frac{1}{2}$ ,, ... | 1,179·9 |
| 1,176 to 1,175·5 ... | 87,500,000 ,, ... | $\frac{3}{4}$ ,, ... | 416·2 |
| 1,175·5 to 1,175 ... | 87,500,000 ,, ... | $\frac{1}{4}$ ,, ... | 227·5 |

*See formula on page 66.

the discussion on each group of papers ; and a bound copy sent each member of the Congress who has paid his year's subscription.

**Discussion.**

7. The time for which a member may address the Congress shall be limited at the discretion of the Chairman, and members must accept without question the ruling of the Chairman on all points as final. Ordinarily a speaker shall not address the meeting for more than ten minutes. A member introducing a paper shall be allowed five minutes for the purpose, and at the end of the discussion will be given an opportunity of replying to any criticisms which may have been made.

The whole discussion will be recorded in shorthand and subsequently typed out at length (in duplicate). The author and each member who has spoken will then receive one copy of his remarks for necessary correction, but to this he must not add any new matter which he did not bring forward at the meeting.

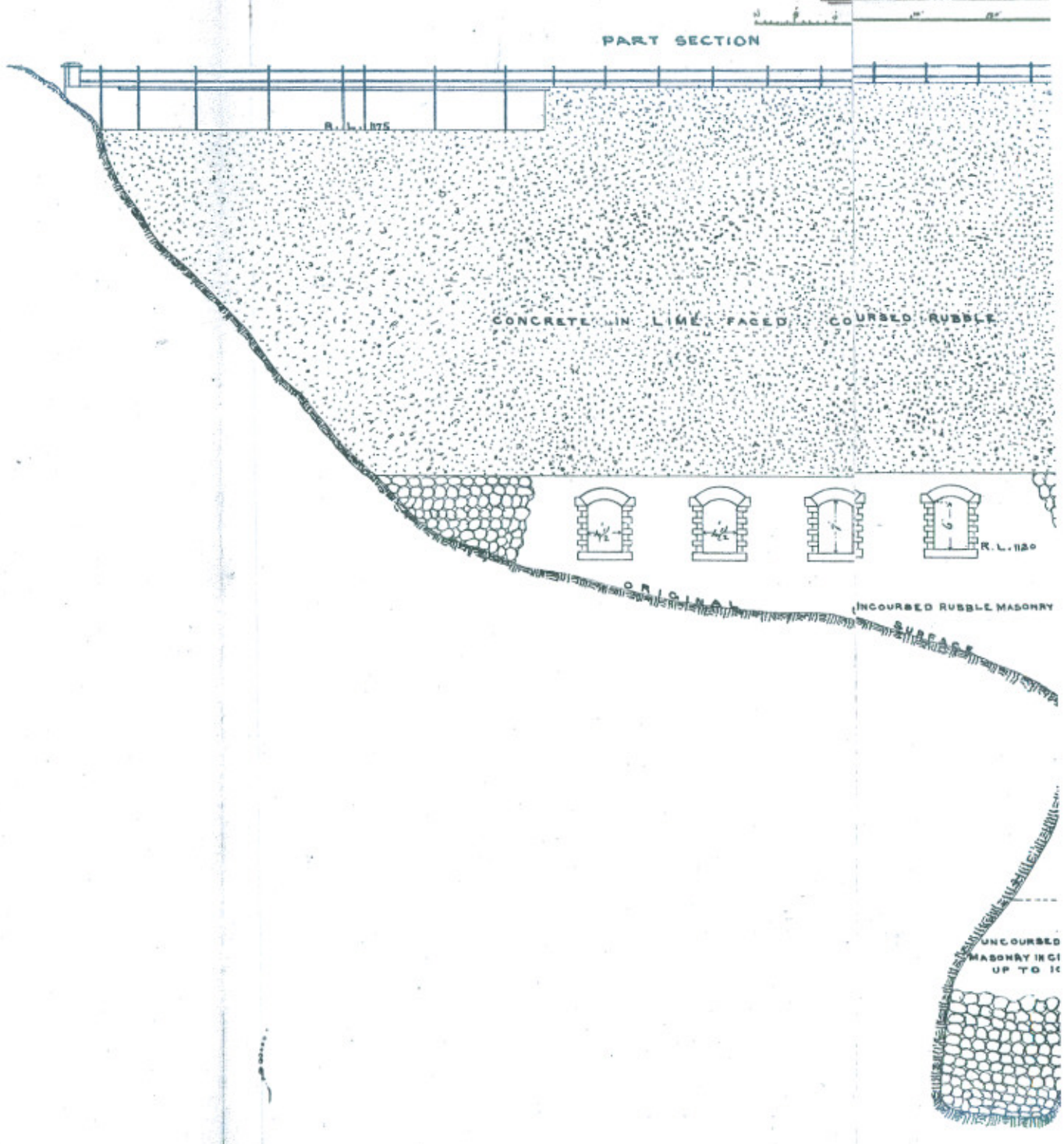
Members may send the author a written communication within a fortnight after the Congress and the author will send all such communications with his further collective reply to the Honorary Secretary in continuation of the original discussion.

**Visitors.**

8. Members of other Provincial Engineering Congresses will be welcomed as visitors to any ordinary session of the Punjab Engineering Congress on submitting their names to the Honorary Secretary through their own Provincial Secretaries.

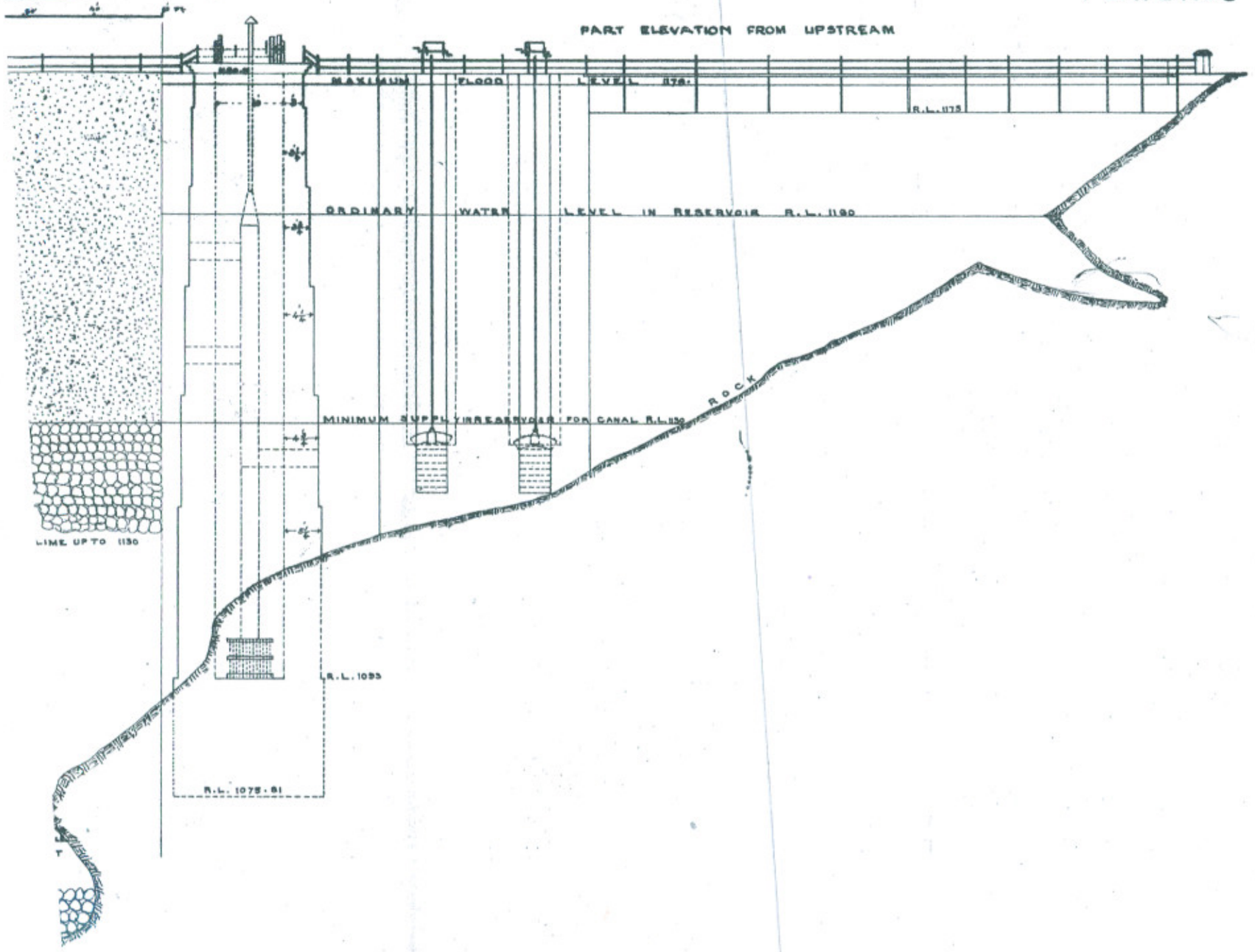
The Executive Committee shall also have power to issue complimentary tickets in special cases.

# NAMAL


PART SECTION
R. L. 1175
CONCRETE IN LIME FACED COURSED RUBBLE
R. L. 1120
ORIGINAL
INCOURSED RUBBLE MASONRY
SURFACE
UNCOURSED
MASONRY IN CI
UP TO I

# DAM

PLATE No. 3



## DISCUSSION.

MR. CARNE in opening the discussion asked whether the author could give any information as to whether the loss by evaporation from the water surface of the reservoir had been taken into account in the calculations, and if so, what values had been adopted for the annual, monthly or daily loss in depth. Taking values, based on the figures given in Mr. Schönemann's paper on the absorption losses of canals,* the annual evaporation loss worked out to about $9\frac{3}{4}$ feet thus :—

| | |
|---|---|
| January ... ... ... | 6″ |
| February ... ... ... | 7″ |
| March ... ... ... | $8\frac{1}{2}$″ |
| April ... ... ... | $10\frac{1}{4}$″ |
| May ... .. ... | 15″ |
| June ... ... ... | 15″ |
| July ... ... ... | $12\frac{1}{2}$″ |
| August ... ... ... | $10\frac{3}{4}$″ |
| September ... ... ... | 9″ |
| October ... ... ... | $8\frac{3}{4}$″ |
| November ... ... ... | 7″ |
| December ... ... ... | 6″ |

$115\frac{3}{4} \div 12 = 9{\cdot}65$ ft.

RAI SAHIB MAKKHAN LAL wished to know whether the mortar used had ever been tested, and if so, with what result. He would also like to know what was the maximum intensity of pressure on the base, and how the face masonry had been joined with the heart masonry.

BAWA BUDH SINGH pointed out that although the Namal Dam scheme had been a success, the sluice gates had never worked satisfactorily. The original set of gates designed and supplied by a Calcutta firm could not be raised and the shutters were jammed up to the present day.

One of the gates had, however, subsequently been provided with a new worm screw lifting gear which worked satisfactorily for some time, but had lately broken down. The dam and canal were now in the charge of the Irrigation Department, and while the speaker could not assign responsibility for its failure, the facts were as stated.

* *Vide* page 17.

MR. ASHFORD said that a short time ago he had seen the sluice gates, and it would be interesting to know how the designers had come to make such a mistake. The gates were apparently designed on the Stoney principle, with ropes attached in the centre for raising them. They were to have closed under their own weight, but they would neither close nor open. Another design had also been tried and proved a failure. The first defect was the arrangement of the rollers, where, though the water was strongly corrosive, there was no satisfactory provision to prevent corrosion, and he had been able to remove flakes of oxide an eighth of an inch thick. All the rollers, as well as the roller pathway, appeared to be corroded. The method of suspending the gates to give them the necessary traverse was also faulty. The ropes were too thin, and were not well placed, with the result that they stretched. Where the gates shut down there should have been a cavity to allow for possible stretching. There were also lengths of roller girders which ran from the top of the gearing down to the gates. These were insufficiently supported, so that there was lateral deflection, and with a stretch of nineteen feet, the long strut had buckled out of shape.

MR. DORMAN asked whether he was right in thinking that the sluice gates had jammed so that they could not be raised, and that consequently the country side was patiently waiting till the gates had corroded sufficiently to let loose a stream of water over the thirsty land? With a full reservoir the velocity of the escaping water through the sluice openings would be about forty feet a second, and he wished to know whether any special precautions had been taken to resist the effect of this heavy scour on the masonry.

MR. MORRIS remarked that dams were often built in the form of a flat arch, though designed purely as gravity dams. The arching effect was not considered in the calculations, but was an extra factor of safety. The Namal Dam could apparently have been built on this principle, and he would like to know if the point had been considered. He also wished to know how the maximum discharge of 60,000 cusecs had been obtained. The detailed drawings of the gates would have been a valuable addition to the paper, because one often learnt more from mistakes than from successes. As regards the sulphur springs, had these been grouted up finally or left to flow freely through the pipes embedded in the dam? From the

report of the geological expert and the records of the borings over the base of the dam, it appeared that the foundation was not as good and as tight as one might wish, and he would like to know whether any attempt had been made to force grout into the bore holes to rectify this, and if not, had the possibility of water pressure under the base of the dam been considered ? Were there any signs down-stream of water passing under the dam through cracks or fissure. The range of temperature in the Namal gorge was apparently very great, necessitating contraction joints. How had these been provided, and had any cracks appeared in the masonry. The dam had now been completed four years, and it would be interesting to know whether it was quite water-tight.

He would be glad if the author would give particulars of any temporary works and machinery used on construction. How was material delivered to the site of the dam, and was a ropeway used ? If so, details would be of interest.

MR. NICHOLSON asked, with reference to the author's statement that great care had been taken to remove all disintegrated surface rock, that he would please state to what depth this had to be removed in order to get to good sound unweathered rock, also that he would explain what the small tongue on the right of Plate No. 3 indicated ; if it was a layer of inferior material, what fixed the limits to which it had been removed, and how was the masonry built in to make a sure joint with the overhanging sound rock above ?

SARDAR BAHADUR LAHNA SINGH, in replying said that the loss by evaporation had not been taken into account in the calculations, nor had the perennial flow in the Vehi, which in the winter was from ten to twelve cusecs, and from four to five cusecs even in the hottest month of the year. In spite of a discharge of about ten cusecs passing away through the dam, the water in the reservoir rose during November and December in 1913. The loss by evaporation could, however, be worked out from the daily gauge readings of the reservoir, for which a register had been opened.

The mortar used was tested from time to time, and the results recorded. The maximum intensity of pressure on the toe of the dam was 9·3 tons. The face masonry was built along with the heart masonry, both with the uncoursed rubble masonry up to R. L. 1,130 and higher up with

the concrete. The uncoursed rubble masonry consisted of large stones laid in mortar, with the spaces between the joints filled up with fine bajri concrete. Joint was broken both horizontally and vertically. The concrete above R. L. 1,130 was rammed with iron rammers, but large stones were put in to form a key between the various layers, and the dam had proved quite water-tight.

A leading Calcutta firm had been entrusted with the design for the sluice gates, and it was only after much delay that intimation was received of the work having been put in hand, though the designs had never been approved. Eventually, when a copy of the drawings was received, it was too late to stop the work, and it was finally decided to utilise the gates in order to avoid delaying the work on the dam. The gates had jammed, and could neither be raised nor lowered. In trying to raise one, the rope, which was fastened in the middle of the gate, but at one end of the crab winch drum, caused the gate to tilt and jam against the sides, while owing to the water pressure it would not drop of its own weight when the rope was slackened, and there was no means of forcing it down. The design was altogether defective and though the firm's representative twice visited Namal and examined the gates, he was unable to rectify matters, and the worm screw lifting gear, which was tried on one of the gates, also proved a failure.

Hasan Abdal stone had been used for lining the flood gate openings, as well as the channel for passing the canal supply through the dam. This was a good hard stone well able to stand the high velocity.

The maximum discharge of 60,000 cusecs had been calculated in 1909 by Mr. E. A. Bellasis by noting the high flood marks of 1908, and plotting the sections of the two nullahs which feed the Vehi stream, as well as of the Vehi stream itself. The discharges of the nullahs and Vehi were worked out separately by Mr. E. A. Bellasis and Colonel Morton, R. E., to check the results calculated from the flow of water from the catchment areas.

There were a number of fissures left by old sulphur springs, but the rock on which the dam was built was solid lime-stone, and the excavation for the foundations showed that the rock below, as seen in the deep pot holes, was solid and quite compact, with only occasional fine fissures through which the

sulphur water and gasses found a way out. There was no danger of water pressure under the foundations, and the necessity for grouting the bore holes had not arisen.

When the reservoir first rose to about R. L. 1,140, water issued under the left arched wing and waste weir at R. L. 1,136. This fissure was a fairly big one and was eventually plugged when the reservoir was emptied.

No contraction joints had been provided, and consequently a fine crack had made its appearance above R. L. 1,130. The masonry was itself quite water-tight, though some water still found a way through the fissure already mentioned, and also through some fissures on the right side, under the arched wing, when the reservoir rose above R. L. 1,164. This year, owing to the gates not working, the reservoir rose to R. L. 1,165, though normally the level would not exceed R. L. 1,161 except when heavy floods were temporarily being absorbed.

The only temporary works carried out in connection with the dam was the wall A, shown in cross-section in Plate No. 4, for diverting the perennial flow through a temporary channel. No machinery except a boiler, some pulsometers, a centrifugal pump, an oil engine, and a hydraulic ram, had been used on the work. No ropeway was used for carrying material. Pathways were cut on the hillside, and all materials were carried by men. Mixing the mortar and concrete was done just below the dam site.

Where the flood gates were located, the rock had to be blasted down to R. L. 1,120, and at this level the rock was quite solid, but on the wings the surface was covered with debris, which was removed by pick-axes and some loose lime-stone by jumpers.

The small tongue on the right of Plate No. 3 was a cavity left by an old sulphur spring. All loose material was removed as far as possible, and the surface of the rock scoured by water under pressure. After cleaning, it was grouted with fine cement mortar and concrete, which was at first consolidated with iron bars, and then, when the space became wide enough, with iron rammers concurrently with the rest of the dam. The rock face was cut or roughened everywhere to make a sure joint, and the part of the masonry adjoining it was built in cement mortar.