

CHAPTER VII.

THE ENGINEERING CHARACTER OF THE LINE

Principles of construction - Climatic effects of frost and thaw on the works - Action on Road bed - Thorough drainage - Clearing the Line - Natural snow fences - Bridges - When bridges should be used - Precautions in building bridges and culverts - Cuttings and their width - Ballast - Iron and Steel Rails - Station buildings - Water supply - Principles of construction concurred in - The "Rail System" or Superstructure - Bessemer Steel Rails - Fish and Scabbard Joints - Cross-ties - Ballasting - The Substructure - Cuttings and Embankments - Drainage - Precautions against frost - Embankments preferable to open bridges - Measurements of streams - Standard designs - Box Culverts - Arch Culverts - Open Culverts - Pipe Culverts - Tunnels - Inclined Culverts - Bridges and Viaducts - Bridge superstructure.

A marked feature of the Report of 1865, was the opinion expressed with regard to the structures and other works throughout the line, and the general engineering features of the Railway, as a whole.

The geographical position of the Railway, and the national character of the work, equally suggested substantial masonry and iron bridges; the estimates accordingly provided for structures of this class. The exigencies of climate were also held to be paramount, calling for a perfect system of drainage, and ballasting, to assure a good and durable road-bed.

The whole character of the Railway was fully considered, and the views expressed were sustained by such argument as the necessities of the case suggested. Much which was then said may now be brought forward, as setting forth the principles, on which it was proposed that the Railway should be constructed.

The climate of Canada has a marked effect on railway works. The frost is very severe; it penetrates the ground, where denuded of snow, to a depth of from three to four feet, occasionally even to a greater depth.

On the slopes of cuttings and embankments, the snow not infrequently is drifted by the wind so as to leave such spots exposed. On the track itself the deep snow is removed to admit the passage of trains. In all such places the frost penetrates the soil to some distance, and if, owing to the presence of springs, or other causes, water be retained injurious effects will certainly be experienced from freezing, and the subsequent thaw.

Embankments, where newly formed, retain much of the rain of autumn. During the ensuing winter this moisture is converted into ice, and when the thaw of spring is felt, the material, to the extent the frost has penetrated, is frequently reduced to the consistency of paste. The material has then a tendency to slide and to produce results exacting considerable outlay to restore the work to its original form.

The first winter, with the ensuing spring thaws, is the most trying on new embankments. After the end of the third year, ordinarily the difficulty disappears. It is different with cuttings. In wet soils, time alone will not give stability. Year after year, on the breaking up of winter, certain kinds of earth, impregnated with water, become semi-fluid; in this state they slide and fill up the ditches, sometimes flowing even over the rails. In such cuttings, when proper precautions are not taken to carry off the superfluous water, such results are constantly experienced.

The road-bed itself, even when well ballasted, is not free from disturbance, when the subsoil is permitted to retain water within the frost limit. The rails, consequently, are thrown out

of level and alignment, producing an irregularity equally injurious to the rails and to the rolling stock. Wherever the track is in this condition, it is not practicable to maintain the speed of trains, with a due regard to safety.

Such effects are not always confined to cuttings. They are witnessed even on level sections of country, and, in all cases, are attributable to the presence of water and the action of frost. There is but one remedy to meet this condition - through drainage. Good ditching to some extent obviates the difficulty, but this remedy is often imperfectly applied.

Any shallow ditch, on a descending grade, will carry the surface water to the extent of its own depth. But this partial result is insufficient. The ditch must be taken below the line penetrated by the frost in the road-bed; otherwise the road-bed will continue to be saturated by moisture, and penetrated by frost, with the effect described. The subsoil, therefore, must also be kept dry by under drains, carried below frost limit. Wherever this work is effectually done, the slopes of cuttings and the road-bed, in all circumstances, will be kept dry and solid.

The clearing of the line also requires attention. In forest land the extent cleared should be of sufficient width to remove all chance of the obstruction of trains, from trees falling across the track, and to reduce the risk of injury from extensive bush fires. The latter contingency is not improbable, especially in the Maritime Provinces where resinous forests prevail. In such cases the flame becomes unmanageable from its magnitude, and, rolling across the track unchecked, it destroys everything combustible in its way, and at times impedes traffic.

The space thus cleared will, in a few years, admit of the growth of a belt of evergreens, to act in winter as a natural snow fence. Should the adjoining lands be cleared of their timber, a snow fence becomes a necessity, and a thick belt of brush would prove extremely effective for that purpose.

No portion of railway work is more important than its bridges. When a line is carried out by private effort, a circumscribed capital may compel the adoption of cheap structures. In such cases it is not the character of the structure, or its economy, which commends itself; but it is the necessity of the case, which limits its cost.

A railway constructed to meet a national requirement, and situated like the Intercolonial, is controlled by no such limitation. It requires no argument to establish that in such circumstances all structures should be of the best form suggested by experience, and that the most durable material should be used. They are then permanently built, and require no subsequent renewal. The first expense is the one cost and in the end, the durable structure is by far the least costly.

These principles clearly establish what bridges on the Intercolonial line should be, structures marked by no unnecessary expense, substantial, massive and permanent.

Some general rules were laid down to determine the mode in which the large streams and the minor rivers should be crossed. Wherever practicable, an arch culvert for the waterway was introduced with superincumbent embankment. Only in cases where the height of the roadway, above the stream, would not admit an arch, was it considered expedient to employ an open structure, and in all openings, except when capable of being spanned by beams of timber, it was designed that wrought iron girders should be used.

The sizes of the bridges and culverts were not reduced to the narrowest limits. It was held of importance, not only to make full provision for the passage of flood-water, but to keep in

view the increased freshet discharge, to be looked for at a future period when the cultivation of the land and the removal of the forest would cause more rapid surface drainage.

Mainly to facilitate the removal of snow from the track, it was designed that the rails should be raised more than ordinarily above the level of the adjoining surface, and that the cuttings should have sufficient width to admit of the snow being cast aside by snow-ploughs. The quantities of excavation submitted were computed on the basis that the cuttings should have generally a width of 30 feet at formation level with side slopes of one and one-half to one. That average width to be varied in different localities in proportion to the record of snow-fall.

Ballast is an important element in a railway. Much of the durability of the rails, and, indeed, of the rolling stock, depends upon it. The railways which do the most business with the least outlay are, as a rule, found to be the best ballasted; and the employment of the best ballast obtainable, even at somewhat high cost, was recommended as true economy.

At the time when the report of 1865 was made, steel rails were but little known, and it was then contemplated to use iron rails, weighing, with the joint fastenings, 70 lbs. per lineal yard. It was pointed out that the iron should be the best manufactured. There is no economy in purchasing low-priced, inferior iron. The charges of shipping, transporting, handling, laying track, and other expenditure, are the same, whatever be the quality of the iron. This point was satisfactorily met, as steel rails were substituted for iron throughout the whole line.

With the exception of the few localities where towns called for extended accommodation, it was held that there was no necessity for much expenditure on station buildings: and it was held to be wholly unnecessary to spend money through the wilderness portions of the line on costly buildings.

The water supply for the engines always exacts consideration, and attention must be directed to provide a frost-proof water service; without it a railway cannot be satisfactorily worked.

A sufficient number of permanent establishments, consisting of engine stables and workshops, with suitable machinery, for the accommodation and repair of rolling stock, were recommended to be placed at central and convenient points, judiciously selected.

The principles laid down received general assent, and it was recognized that a work of such national importance should be of a high standard.

The report and the estimates were submitted to the Imperial and Provincial Governments, and in the negotiations which followed, these documents, with others of the same import, prepared in London by the Chief Engineer in 1868, formed, in part, the basis of the arrangements by which the Imperial guarantee was given.

On the consolidation of the Dominion in 1867, the location was proceeded with, and it became the duty of the Chief Engineer to prepare designs for the work, and to determine how the accepted principles of construction could be best applied.

It is not necessary to enter into the details of the explorations and surveys, and of the preparation of the working plans, and of the conduct of the work for the years it has been in progress; but a description of the railway as it has been carried out, is indispensable to show what its engineering character really is.

It is claimed that unfavourable climatic influences have been guarded against; that the structures are thorough and permanent; and that with regard to the permanent way, when

drainage and ballasting are completed as designed, the railway may be classed as second to no work of its kind either on this Continent or in Europe.

A railway of a high standard is in fact a simple problem. It does not exact magnificence of design, or works which astonish by their display or cost. Architectural monuments have no place on public works like the one in question, and many well known structures can be regarded only as mementos of useless expenditure.

As a theory, the perfect railway consists of two parallel lines of continuous rails, uniformly sustained by a firm and slightly elastic support. Bridges and culverts are incidents naturally to be looked for, but never to be introduced, except where absolutely exacted. It is the duty of the Engineer to design and establish them as cheaply as he can, having regard to permanency, and not to convert them into opportunities for display. Taste may even be consulted without any expenditure beyond that required to secure solidity, and the skill of the designer should aim at the attainment of effect with the least extent of adorned material, and strive after the grace of outline to be found extreme simplicity.

In the Intercolonial Railway it was held better to aim at the realization of this principle, than to advocate the introduction of structures remarkable for their magnitude and ornament, however gratifying to the personal pride of the designer.

The Railway proper may indeed be narrowed to two essential parts.

1. The "rail-system," which may be called "the superstructure," including rails, cross-ties or sleepers, ballast, and everything placed above the permanent firm surface, known as formation level.

2. The "sub-structure," which includes all works required to bring the road-bed up to "formation level," on which the rail system is superimposed.

THE SUPERSTRUCTURE.

The Intercolonial Railway has been laid throughout its length with Bessemer steel rails, weighing 57¼ lbs. to the yard. This weight is nearly 20 per cent lighter than the iron rails originally proposed, but owing to the character of the material, the steel rails are in reality stronger and much more durable.

It has been said that to be perfect, a rail track should be continuous, but such a result is not practicable. Rails are manufactured in bars, generally not exceeding 30 feet in length, laid end to end and the continuity is broken where the joints occur.

Figure VII-1

These frequent joints constitute one of the defects to be guarded against. On the Intercolonial Railway, two expedients have been adopted, to overcome it; one the ordinary fish-joint, Figures 1 and 2; the other what is known as, the scabbard joint. The former is a well-known contrivance for keeping the ends uniform in line and level. The fish-plates lie between the flange and head of the rail, and are only 2½ inches deep. As they have to endure the strain of passing trains, the rigidity of the joint is inferior to that of the rail, the latter having a larger sectional area and a depth of 4¼ inches. The ordinary fish-plates do not, therefore, give perfectly unyielding joints.

Figure VII-2

Figure VII-3
Figure VII-4

The scabbard-joint, Figures 3 and 4, is more rigid, inasmuch as it makes a steel beam, 3½ inches deep, instead of 2½, has a greater mass of metal, better distributed; and is more simple, having fewer parts. The scabbard when properly made of good steel; is undoubtedly the best splice known for rails; and severe tests go to prove that, of all fastenings, it makes a joint approaching the most nearly in strength that of the mid-section of rail. In effect, it renders the rails composing the track, approximately continuous.

The rails are spiked to cross-ties or sleepers; 6 inches thick by 8 inches on the face, laid on an average 2 feet 6 inches from centre to centre. They are invariably of the best description of timber procurable in the districts traversed, and generally consist of Black Spruce, Prince's pine, Tamarack and Cedar.

A substance, not too rigid, is needed to furnish a bed for the cross ties: this is designated ballast. It lies as a cushion on the road-bed, and gives to the rail system a slight and uniform elasticity. The quality of the material for ballast is important. Gravel, the material generally employed, if mixed with clay or light, loamy sand that will hold water, is unsuitable and should not be used. A coating of such unsuitable material is even injurious, as it simply elevates the road-bed, and has the effect of narrowing the space for proper ballast. The embankments are 18 feet wide at formation level. If a coating 12 inches thick be added, the side slopes being 1½ to 1, the width of the ballast bed is reduced to 15 feet, and it thus becomes necessary to widen the embankment when proper ballast is laid down. The use of improper ballast, results in the premature destruction of rails and rolling stock, while the longer life attainable by both on a well ballasted line, establishes the necessity for the use of material of the best quality.

THE SUB-STRUCTURE.

Everything which goes to form the foundation for the rail-system may be called the substructure.

When a level tract of country is not intercepted by streams, no necessity presents itself for openings through or across the railway. We then have the most favourable conditions for construction, and it is necessary only to form a light embankment, two or three feet in height, brought up a trifle above the ordinary level of the snow, the material being taken from two parallel side ditches. *Figure VII-5*

It is rarely that conditions so favourable are met. On the Intercolonial Railway they are the exception. Although in limited localities the line traverses ground approximately flat, the natural drainage of the country and provision for freshet discharge, generally rendered openings through the railway indispensable, even in these localities.

The railway passes over several ranges of elevated water-sheds and numerous subsidiary ridges, separating the river systems which it crosses. In traversing a long extent of country with a surface so diversified, cuttings and embankments of all depths and heights are unavoidable; and nearly every variety of soil and rock is to be met. Where embankments are necessary, they have generally been formed of a uniform width of 18 feet at formation level, with slopes generally of 1½ to 1. In some cases the natural slope which the material has taken is not in accordance with

this proportion. The maximum height of embankment on the whole line is 110 feet.

Figure VII-6

The original intention was to form cuttings of more than the usual width, for the purpose of securing ample drainage, and to afford facility for keeping the track clear of snow. With a view to avoid expense, this proposition was not entertained; and generally the width is but 22 feet at formation level. There are exceptions, however, where the width is greater. The side slopes in rock are 0.25 horizontal to 1 perpendicular, as in Figure 6; in ordinary earth 1½ horizontal to 1 perpendicular; but in some wet clay cuttings, slopes of 2 to 1 were found necessary.

It has been stated that the frost penetrates the ground to a great depth, and as a consequence wherever the soil is at all wet, the thaw disturbs the road-bed and injuriously affects the earthworks. Special care was consequently directed to drainage. Figure 7, illustrates the plan adopted in the formation of underdrains: they are placed, as a rule; immediately at the foot of slopes; formed with drain pipes and the trenches filled with ballast to within a foot of the surface. In rock cuttings, provision was made for carrying off the water by shallow trenches on both sides, as shown in figure 6, so as to keep the track perfectly dry.

Figure VII-7

Figure VII-8

Figure 8 is a cross section of the ordinary cutting, 22 feet wide at formation level. It shows the underdrains below the frost limit, so that water to a depth of at least four feet will be carried off, and the road-bed kept dry and free from the effects of frost. When such cuttings are subjected to the effects of the maximum snow fall, as is indicated on the diagram, the operation of the railway becomes difficult. A large expenditure, either in removing the snow, or in roofing the cuttings, may be looked for.

Figure VII-9

It is to be regretted that the cutting were not formed on the principle shown by Figure 9. The deep side ditches would have fulfilled the duty of underdrains in keeping the road-bed dry and free from disturbance by frost, and at the same time would have afforded space to receive the snow thrown off by the snow plough. The increased width would have enhanced the cost to a less extent than was assumed by the opponents of the principle, as the extra width in many cases would have provided material for embankments, where, the narrower cuttings being insufficient, borrowing pits had to be resorted to. It is also estimated that cuttings of the larger form referred to, would have entailed less additional cost than the erection of snow sheds. Besides, wide cuttings are preferable; as in themselves the snow sheds being perishable, and from time to time requiring renewal, are always exposed to destruction by fire.

Structures for the passage of water, whether of rivers or less important streams, should never be lightly considered. One of the leading principles observed, was to create as few bridge openings as, possible. Whenever practicable to pass a stream through a covered passage in the continuous embankment that system was followed. The same principle governed in carrying the line across valleys. It was held that no viaducts should be introduced; that as an engineering question, an earthen embankment is preferable. A calculation of the comparative cost, proved

that of the two, under ordinary circumstances, where the height does not exceed 80 feet, the embankment is the cheaper, and that in some exceptional cases, embankments of a greater height may be with economy employed.

Open bridges were, therefore, strictly confined, with a single exception,* to the large river crossings.

So little was known, at this period, of the country through which the Intercolonial Railway now runs, that it was difficult to establish in each case the requirements of waterway and the other conditions to be observed. In settlements, information of some kind may be obtained, but the country to be traversed was for a great extent a wilderness, and few data of any kind were known concerning it.

In each case reliable information had to be gathered in order that the size and character of structure might be determined. A structure conceived on a scale unnecessarily large calls for a useless expenditure of money. If too cramped in size, annually during floods it will be exposed to the risk of being carried away. Ultimate destruction is generally its fate, and when this contingency arises, even if no loss of life results, the money expended in reconstruction may be held as so much dead loss. Any miscalculation with regard to the size or character of a structure generally results in uncalled-for expense, and it is therefore necessary clearly to determine what the true requirements in each case are. *Folly River Viaduct.

Assistants were accordingly detailed to measure the streams during the periods of maximum discharge; to ascertain the section area, velocity and volume, when the freshets from the melted snows were at their height. This information was tested by repeated observations; and the number and sectional area of all opening for the passage of water was determined in accordance with it. To the sectional area thus ascertained was added a marginal allowance for floods of more than ordinary occurrence.

The precise character of each individual work next became the subject of consideration.

It was deemed advisable to reduce the plans to a limited number of classes; to adopt designs of the simplest type; and to prepare standard working drawings, which would suit ordinary cases, and which could readily be adapted to any peculiar necessity. They were as follows:-

1. Box culverts.
2. Arch culverts.
3. Open culverts.
4. Pipe culverts.
5. Tunnels.
6. Inclined culverts.
7. Bridges and viaducts.

Many of the structures embraced in this classification are remarkable only for their number. Nevertheless the description of the railway would be incomplete, without mention of them.

1. BOX CULVERTS.

These culverts were designed to carry off runs of water, or for places where an outlet for surface drainage across the line was necessary.

They ranged from two feet to six feet in width, and from two feet to nine feet in height, but the prevailing size was two feet or two feet six inches in width by four feet high. Figure 10 is a cross section of the commonly occurring size. It was deemed advisable to adopt four feet as the standard height for the smaller culverts, so that a man could pass through to repair or clean them out.

Figure VII-10

Few culverts have been constructed of less height than four feet, although occasionally where the road-bed was low, culverts two feet six inches square have been introduced.

As some quarries furnished large flat stones, adapted for this character of work, and other quarries supplied material better fitted for the arch, it was an object to accommodate the designs to such circumstances.

Figure VII-11

Figure VII-12

Figure VII-13

Figure VII-14

Box Culverts, of various sizes ranging up to six feet in width by nine feet in height, were used when it was advantageous to do so. Figures 11 and 12 are cross sections of medium sized box culverts, the waterway of the one three feet wide, by four feet six inches high, that of the other four feet wide by six feet high. Figures 13 and 14 indicate the proportions of the largest sizes built, the water-way of the one being five feet by seven feet six inches, and the clear opening of the other being six feet wide by nine feet high. These sections show the manner in which structures of this class, over three feet in width, had their walls corbelled, in order to carry the massive covering stones required.

These large box culverts were introduced only when the material available was unusually strong and massive. The ends of all culverts of this class were of a simple design, as in Figure 15; they were usually placed square to the body of the work, with deep apron walls to prevent any undermining by the stream or upheaval by frost.

Figure VII-15

2. ARCH CULVERTS.

Figure VII-16

The arch culvert was designed for streams requiring a clear width of water-way from 4 feet to 20 feet and upwards; and when the embankment through which they passed was of sufficient height to admit the turning of the arch.

With some modifications to suit local circumstances, they were all made after one type. The lower, or downstream end, is shown by Figures 16 and 17; the former being an elevation and the latter a longitudinal section. The upstream end is formed with cross wall to obviate the possibility of the current finding a passage behind the masonry.

Figure VII-17

Figure VII-18

Figure 18 represents an elevation of the up-stream end of this culvert, and Figure 19 is a longitudinal section. The parapet walls, indeed exposed walls in all structures, were directed to be backed with a quantity of small rip-rap or broken stone, as indicated in Figures 17 and 19, to prevent injury from frost. Particular attention was paid to the foundations; in all cases where the natural sub-stratum seemed at all doubtful, artificial foundations were obtained by piles, concrete and other means.

Figure VII-19

Drawings were prepared for ten different sizes, with arches from 4 to 20 feet diameter, cross-sections of which are shown by Figure 20. Every horizontal and vertical dimension was proportioned to the size of the arch. The length only varied according to the height of the superincumbent embankment. And to prevent mistakes in setting out the work in the field, tables of lengths above and below the centre line were prepared, by which culverts of any size, in any embankment on the line, could be laid off with accuracy.

Figure VII-20

Only at one point has an arch of more than 20 feet been introduced; and special drawings were then prepared. In Figure 20 are represented cross sections, of the various arch culverts up to 20 feet span, which have been built on the line.

3. OPEN CULVERTS.

As already mentioned, a decided preference was given to covered structures for the passage of streams; and they were adopted whenever practicable. There were cases, however, when, owing to the width of streams, or insufficient height of embankment, a covered passage could not be obtained. In all such cases the streams had to be spanned by open structures, which were formed of beams or girders placed on walls of masonry. Open structures above 20 feet span were termed bridges; when of less than 30 feet spans, they were accounted open or beam culverts. Figure 21 is a type of the open culvert. It consists essentially of two masonry abutments, proportioned to the height of the embankment, sufficiently far apart to allow a passage for the stream, and on which rests the rail system, supported on beams stretching from abutment to abutment. In open culverts of small span the beams are single under each rail; in the larger spans they are double and set side by side. The great majority of structures of this class do not exceed 10 feet span and are invariably in shallow embankments. For reasons given, the introduction of the large size was studiously avoided; the number on the line is consequently limited. The figure shows an open culvert of 20 feet span, in an embankment 20 feet high; this is the largest size. In cases where the embankment exceeded 20 feet in height, and the stream required the width, arches of 20 feet span were substituted.

Figure VII-21

4. PIPE CULVERTS.

In localities where building material could not be obtained without difficulty, it was found advantageous to employ cast iron pipes or cylinders. These pipes were of cast iron three

feet in diameter, with spigot and faucet joints. Culverts of this class were advantageously introduced on sections of the line near tide-water, where the iron cylinders could be brought by sea-going vessels. They were quickly and economically made, the two ends were encased in masonry; the body of the culvert consisted of a sufficient number of iron pipes to reach across the embankment, the castings being of different lengths. The pipes were bedded and completely encased, to a minimum thickness of nine inches, in hydraulic cement concrete.

There can be no question with regard to the durability of this class of structure. The chemical affinity between cement and iron is such, that the concrete becomes as hard as stone and will alone be sufficient to resist the pressure of the embankment and all wear and tear, even should the iron lining be removed by oxidation: a contingency not to be looked for, except after a long interval of time. Pipe culverts were introduced in all situations, but they were found more especially useful in side-hill ground, where structures of the 6th class were called for. Figure 22 illustrates the lower portion of a pipe culvert on side-hill.

Figure VII-22

5. TUNNELS.

Where streams crossed the railway in deep rocky ravines, it was frequently found preferable, as a matter of convenience and economy instead of spanning the ravine by a bridge or constructing a culvert, to pierce one side of the ravine by a tunnel, through which the stream could be diverted, and to form a solid embankment across the channel of the stream itself. This expedient was adopted, not only in deep ravines, but in other localities. Figures 23 and 24 show a section and plan of a tunnel, which was formed at one point on the line under an embankment exceeding 100 feet in height. The whole work, including the embankment, was completed at less cost than a bridge, or even a culvert with the superincumbent embankment. The one condition necessary, was the presence of rock of sufficient solidity and durability. They have been used in cases where the rock was of a nature requiring to be lined with masonry; as in the perishable Sandstones, along some parts of the Bay of Fundy. In all cases they brought into play a cheap description of labour in their construction, and allowed the formation of the roadway to be proceeded with, much sooner than would have been possible, had structures of masonry been carried out.

Figure VII-23

Figure VII-24

On side-hill ground, such as occurred in passing over the Cobequid mountains in Nova Scotia, small tunnels were frequently introduced, they are shown in Figure 25.

Figure VII-25

6. INCLINED CULVERTS.

The designs for structures of the 1st and 2nd class were applicable where streams flowed in channels with little fall; but on side hills, where the streams often become swollen torrents, it was necessary to adopt means to prevent the possibility of destruction of the structure.

Ordinary culverts were employed in all cases where the fall of the stream did not exceed, on an average, one foot in twenty. With streams of a greater fall, the structures employed, came

under the designation "Inclined Culverts," and in all such cases special designs were prepared. Inclined culverts were built of both Box and Arch work: Figure 26 shows the mode adopted for arches.

In both cases the walls were regularly stepped, to insure stability: and precautions were taken to prevent the water of the stream from finding a way underneath the paving below the walls.

Figure VII-26

The line of paving was placed considerably lower than the natural bed of the stream; the whole masonry was laid in cement; and the walls at the upper end were built in such a way as to be impervious to water.

To increase the security of the work, a concrete wall was formed underneath and around the body of the culvert, midway between the two ends; and this wall was made perfectly water-tight, across the ravine in which the culvert was built. The footings of walls were full bedded in cement, and the spaces underneath the paving and around the walls were filled with concrete. The paving was all laid in cement.

Other precautions were taken to render the work secure. In cases where the walls could not be founded on rock, the lower ends had a deep set apron wall, with wing walls and a secondly front wall also deep set. Above and around the whole, loose stone filling, "rip-rap," was placed, to deaden the effects of the stream rushing rapidly down the smooth surface of the culvert. These and other precautions were adopted as the circumstances of each individual case seemed to dictate, in order to secure permanence in the work. Figure 26, represents a longitudinal section of the up-stream portion of a culvert of this class. Here the wing walls are square to the body of the structure: but at the down-stream end, the arrangement shown on Figure 22 was generally carried out, with such modifications as each case necessitated.

It has already been stated that iron pipes were used for inclined culverts, but they were only introduced to carry off streams requiring less than three feet water-way. The pipes were cast in short lengths, those for the lower part of the culvert having radiant ends, so that, when set in place, they would lie in a curve as in Figure 22. By this means the water descending through the culvert with great velocity, would be changed in its direction and discharged horizontally, thus reducing the tendency to undermine the lower end of the structure.

7. BRIDGES AND VIADUCTS.

This class includes all structures with clear openings exceeding 20 feet. On the Intercolonial Railway, the spans range from 24 feet, the *minimum*, to 200 feet, the *maximum*.

It has already been stated that a viaduct is not, under ordinary circumstances, an economical or desirable structure; and that it should only be introduced where a river of considerable width has to be crossed. Accordingly Bridges have been avoided in all cases, where a solid earthen embankment could be formed. The one exception, at the River Folly in Nova Scotia, has already been mentioned.

The number and length of spans, and, to some extent, the form of the superstructure of a bridge, depend on the width of the river at flood, the character of the river bed, the formation and movement of ice, and the quantity of drift timber which may be looked for. It was not found

necessary in any case to have wider openings between the piers than 200 feet, and although in many instances several openings occur in the same structure, it was only considered expedient to adopt spans so great in three bridges. Wherever the cost of founding piers was not excessive, spans not exceeding 100 feet were used; and in every instance where the character of the river would admit with safety the employment of spans shorter than 100 feet, they were adopted.

In laying down general principles by which the construction of the whole of the structures on the line was to be governed, engineering requirements were primarily regarded; but economy in expenditure was by no means lost sight of. It was felt that while the abutments and piers should be designed to efficiently resist the peculiar climatic forces to which they would be exposed, it was equally important to accomplish the desired object at a minimum cost. A saving of expenditure at one point, or on a single structure, might be a matter of no great consequence, but when multiplied by the number of cases which occur on such a length of line, the importance of a well-considered system becomes apparent.

The question is governed by several considerations, the most important of which is the difference between skilled and unskilled labour. The Engineer determined that iron should be used instead of wood in the spans of bridges, on account of its durability, but he also considered that there should be as few bridges as possible, for reasons already submitted; and from the consideration that the iron work had to be imported; and, being the product of skilled labour, more costly than ordinary earth or stone work executed in the locality. Again, as masonry, is likewise the product of skilled labour and costs for a given quantity, fifty times as much as earthwork, it should in consequence be used sparingly, in fact never introduced where the latter can be substituted: moreover, it was held that none but the best masonry should be admitted and that a limited quantity of good masonry could in most cases be employed more advantageously than a larger quantity of inferior masonry; that the difference in cost between equal quantities of both kinds was limited, and no way in comparison to the greater degree of stability and permanency attained by the use of masonry of the first quality.

In designing the Piers, their exposure to ice and drift-wood rendered it necessary to make them massive and of a form which would enable them to resist any shock. It would be no economy to make them otherwise. But in the form of the abutments, it was found that strength, durability, and the principles of economy referred to, could be consulted at one and the same time.

Figure VII-27

Figure VII-28

The plan of abutment adopted, consisted simply of a hollow tower of no greater width than was required for the support of the superstructure, and built perpendicularly on the four sides. The sections Figures 27 and 28 give the form of tower as it has been built; in some cases with two rectangular cells as in Figures 27 and 29; in others, the void was made circular as in Figures 28 and 30; and in both cases the voids were corbelled or arched at the top to support the ballast and rail system.

Figure VII-29

Figure VII-30

A comparison between the cost of this form of abutment and the plan commonly carried into execution on Railways previously constructed, may be advantageously made.

Abutments have usually been built with wings, necessarily heavy, in order to resist the pressure of the embankments.

Taking four different designs carried into execution on the Grand Trunk Railway, with the formation level 60 feet high, the quantity of masonry in each abutment is as follows:-

Design No. 1 3230, Cubic Yards.

Design No. 2 2060, Cubic Yards.

Design No. 3 2260, Cubic Yards.

Design No. 4 2310, Cubic Yards.

Giving an average of 2465 cubic yards for each abutment.

As the difference is almost wholly in the form of abutment, it is not necessary to take into the calculation the intermediate piers, when a comparison of cost is made.

The two estimates of cost stand thus:-

(1) In the Intercolonial Railway system:-

2180 cubic yards of masonry in the pair of land piers and towers	at \$13	\$28,340
2 sixty feet iron girders erected		\$3,834
Less 12,000 cubic yards of embankment, saved	at 30 cents	<u>3,600</u> <u>234</u>
		\$28,514

(2) In the Winged Abutment system:-

4930 cubic yards of masonry	at \$13	<u>64,090</u>
Difference in favour of the new system		\$35,516

It will thus be apparent that the saving effected is large; it amounts indeed to fully fifty per cent. of the cost of both abutments constructed on the old plan. The estimate indicates the saving in one bridge only.

But economy in first cost is not the only or main advantage. It is well known that winged abutments, even if built sufficiently massive to resist the thrust of embankment, are frequently injured and ultimately destroyed through another agency. If the embankment be formed of any material that will hold moisture, the low temperature of winter is certain to act injuriously upon it. The moist clay or earth behind the masonry becomes frozen solid, and in obedience to the expansive powers of frost, produces all irresistible thrust on the masonry, which, whatever its strength, will eventually become fractured and displaced.

This destructive agent, acting year after year, will sooner or later render reconstruction a necessity.

This effect can never take place with the bridge abutments of the Intercolonial Railway. It is impossible for the hollow towers, placed in the hearts of the embankments to be rent asunder, or in any way injured, either by the thrust of the earth or by frost. The pressure is at all times external, and being nearly uniform from all sides, no destructive effects can result.

It is not claimed that there is anything remarkable or novel in the peculiar kind of abutment described; but it is held that the principles of construction observed show a due regard to economy as well as to engineering requirements and climatic conditions.

Figure VII-31

Figure 31 represents an abutment of moderate height before its connection with the embankment. It also shows a common form of pier adopted in cases where the structure is opposed to running ice.

The superstructure of three of the bridges viz. :- at River du Loup, Isle Verte and Missiguash are of wood. These were erected, under the protest of the chief engineer, by direction of the Commissioners before their policy on this question was reversed. All the other bridges on the line have iron superstructures; three of the latter viz:- the Restigouche and the two Miramichi bridges, are "pin connection" trusses, constructed by a Philadelphia firm, Messrs. Clarke, Reeves & Company. All the others are "plate" or "lattice" girders erected in place by an English firm, The Fairbairn Engineering Company.

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