PAPER No. 224.

CONSTRUCTION OF A CONCRETE TRACK IN MILES 306—310, GRAND TRUNK ROAD (NEAR LAHORE).

By D. P. Nayar, Assistant Engineer.

Introduction.

"Concrete for permanence" is a catechism that the highway engineers in the Punjab have been very slow to realize. Whereas in the neighbouring province of the U. P., mile after mile had been laid in concrete for the last decade or so, anything like a beginning was only made here in 1935 when about 1½ miles of a concrete track 7 feet wide were laid in miles 2 and 3 of the Lahore-Multan Road, a brief description of which has already been presented to the Congress as Paper No. 193, in 1936. Experience gained by these experiments has since been utilized in venturing on new fields of activity and the present note is meant, if anything, to be a supplement to the foregoing one; and to bring to light further details and difficulties encountered in the execution of the work.

History.

Every building engineer who has had a chance to be stationed in Lahore fully knows the usefulness of good bricks available on the Shalamar side of Lahore. It is true that there are a large number of brick kilns both on the Ferozepore and Multan Roads, but somehow due to a comparatively poor quality of clay met with on these roads, these kilns are not in such demand in these days. For good work it has been found that areas beyond Shalamar yield about the best clay available; and as such the number of kilns on this side is ever on the increase in order to cope with the general demand from the public. Besides the kilns, there are a large number of private godowns both at Moghalpura and Baghbanpura from where goods and materials are being regularly carried into Lahore every day, with the result that there is always congestion of all kinds of traffic on the road. The setting up of a large number of factories on this side has also tended to increase the volume of traffic on the road. Added to this is the daily traffic between Lahore and Amritsar, mostly vehicular, which is on the increase and there is a real demand for at least a 20-feet width of road exclusively for motor vehicles. Another factor that must be mentioned as highly instrumental in calling for a stronger type of surface than the ordinary water-bound road is the presence of the Lahore Goods Office in Mile 310. All the heavy consignments that pour into Lahore in large numbers, almost every day, are transported from here by bullock-carts and this has made

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Traffic census.

Extracts from the census reports on this road for several years are detailed in Appendix I. From a perusal of the two tables it would appear that in 1936, when this work was first conceived, there were about 1000 bullock-carts plying daily on the road. Since then the progress in the carriage of heavy materials by motor vehicles has been steadily on the increase and the most glaring increase is in the number of buses with over 25 seats which are plying on the road. All the 2-ton buses are classed in this category and their general adoption for the purpose of transport of materials around Lahore, is a really a healthy sign which might before long be emulated in other parts of the Province. It is high time that we realized the economy of employing heavy machanical units for the carriage of goods and materials and thus cut down not only the cost of carriage but also reduce the time taken in transport.

The traffic on the road in question has been about 5000 tons per day for the last three years and during the last year, as revealed by the Census taken in June, 1938, has shot up to about 7500 tons. It is a consolation however to see that the number of bullock-carts in mile 306/2 has dropped down from 1020 to about 700. Even this number surely requires some special type of road to itself. The number of bullock-carts in mile 308/2 is definitely much smaller but as the number of other vehicles in this area is very much greater, there is great congestion of traffic and there has been a constant demand for an increase in the carrying width of the road surface. Accurate figures of traffic for mile 310 are unfortunately not forthcoming but one day's count last year of vehicles passing the railway under-bridge in this mile revealed the fact that no less than about 4500 vehicles pass through that bridge. This will easily mean a load of over 7000 tons per day on this road. As some of these vehicles carry extra heavy loads on bullock-carts, the destructive effect on the road surface is very considerable.

Previous treatment.

Before describing in detail the actual construction of the cement track and the various difficulties that had to be overcome in its execution, it would perhaps be of interest to give a brief review of the various treatment given on this section of the road, with a view to making the surface really suitable for the heavy traffic uses it. The history of miles 306 to 310, during the last five or six years, is a series of unsuccessful attempts on the part of the road engineers to try to cope with the heavy strain of traffic by an extravagant use of extra heavy quantities of binders, whether tar or bitmen. The road surface continued to break up very badly and in spite of the lavish attention paid to it and the heavy patch work done thereon, the results were, it must be admitted, far from satisfactory. It is yet too early to say whether an eventual solution has actually been found and we can only hope for the best and judge by what has been definitely proved in other parts of the country.

In 1933-34, miles 306 to 310 were giving a lot of trouble and received a heavy coat of tar after excessive patching. Provision was made in the ordinary maintenance of the road for patching four times in the year.

In mile 310, just at the railway under-bridge, the surface had broken up so badly and had given such a lot of trouble that it was decided to lay a 6″ cement concrete slab in order to afford a permanent remedy. It must be stated that it has been the happy experience of engineers in charge of the road that this little bit which used always to be a source of immense trouble and disgrace to the P. W. D., has stood up very well indeed. This portion is liable to be flooded with anything like two feet of water even after the smallest shower of rain; and as there is no arrangement to pump out the water from this area, it can only be bailed out slowly by hand. So the road surface gets the ravaging effect of water for at least one or two days after each shower. It is difficult to imagine how ordinary water-bound macadum could be expected to stand such conditions.

In 1934-35 the traffic continued to increase in volume and intensity and it was thought advisable to widen the road from mile 306/3 to 309/4 by the addition of 5′ wide strips on either side. Miles 309 and 310 were however so bad that it was found necessary to reconsolidate them together with the new metalling. Mile 309 was therefore scarified after peeling off the old tar, and a $1\frac{1}{2}''$ thickness of new metal added before consolidation. Mile 310 (about $4\frac{1}{2}$ furlongs) was tried with what is known as the Cement Sandwich Grout system, which consisted of dry rolling half the quantity of metal, putting in a layer of cement and sand mortar and the addition of a fresh layer of metal and quick consolidation with the steam road roller by the addition of the necessary quantity of water, *i.e.*, just enough to make the mortar work up into the metal. The whole surface was kept wet for some days in order to allow the cement to set completely and traffic was kept off for at least 3 days. After the road had dried up, it was given the usual first and second coats of tar No. 2, in accordance with the standard Specification. Subsequent experience however showed that surface coats of tar did not stick quite satisfactorily to the stone and had a tendency to break up rather abruptly under the weight of heavy traffic. Miles 306, 307 and 308 were also showing signs of failure, as the surface of the old central width of 20 feet was breaking up much too quickly. The cause of this at that time appeared to be that the old tarred surface in these miles had become brittle and had lost its adherence to the water-bound stone wearing coat below, with the result that the tarred surface broke off, leaving a pot hole right down to the top of the stone. The condition of the stone appeared to be fairly sound, and so it was considered advisable to renew the old tarred surface and replace it by a new one which, it was hoped, would stick properly to the stone bed, and would as well be strong enough to stand up to the heavy traffic. A large number of experiments were attempted in these miles by adopting the use of ½" and 1" carpets with various materials like Tar, Bitumuls, Shellsheets and Shelmac and various combinations of some of these, but it was found that none could successfully cope with the heavy traffic. The failure was sometimes attributed to defective specification and on other occasions to defect in the subgrade, but there is no denying the fact that the road surface continued to be as patchy as ever and needed, if anything, greater attention and much more extensive patch work than had been done in the past. Ordinary maintenance estimates had to be revised almost every year because the road could not be allowed to go to ruins and the actual requirements in the nature of patch work alone were far too much in excess of what could reasonably be anticipated at the commencement of the year's programme. The cost of maintenance increased enormously and the road is this section had the privilege of being honoured by P.W.D. gang flags flying almost every day of the year, because the gangs had to be kept patrolling up and down the road permanently and patching up the surface wherever it showed signs of failure.

Before long it was quite manifest that none of the binders hitherto adopted could be expected to stand up to the cutting and grinding effect of the heavy bullock-carts. Some other type of road was necessary in order to save the road from further deterioration and after a good deal of thought and discussion it was decided to have recourse to a cement concrete road. Two alternatives were possible, (*i*) either to replace the existing metalled width by a cement concrete road at least 20 feet wide, or (*ii*) to lay a track on the incoming side for the heavy bullock-carts, and thus relieve the existing metalled width of these heavy loads altogether. It does not need much explanation to see that the first proposal would have been ideal but at the same time much more expensive while the second was definitely an economical proposition and would perhaps serve the needs of traffic quite adequately for the present. The adoption of the second proposal meant an increase in the metalled width of the road surface, which automatically increased the carrying capacity of the road. It was therefore decided to lay a 10-feet wide strip on the incoming side of the road from Mile 306 to 310. The track that has been laid is by no means continuous over all this length for it has been omitted from the portion from Shalamar Garden (Miles 306/2 to 308/4), where the existing width is already 30 feet. This surface is however so rough that before long it will need some special treatment. It may be mentioned here that a 7 feet wide track of more or less a similar nature was laid in February 1935, on the Lahore-Multan Road in miles 2 and 3, and the experience gained from it was utilized on the present work.

Design.

The design of an engineering structure may be defined as the application of *theories* (based on assumptions which are rarely attained) for the purpose of estimating *loads* and *reactions* often fixed arbitrarily, and for the purpose of proportioning structural members to take *stresses* with mathematically defective *materials* employed over wide ranges of *workmanship* at a *cost* of installation and maintenance which is usually required to be a minimum. A complete design however calls for a commonsense compromise between theories, loads, stresses, materials, workmanship and costs.

In a concrete road exposed to the elements, the following loads may be expected to cause stresses :—

(*i*) Construction forces either external or inherent in the materials,

(*ii*) Type and intensity of wheel or useful loads,

(*iii*) Forces due to external temperature changes,

(*iv*) Forces due to change of moisture content,

(*v*) Resultant reactions of the ground to (*i*), (*ii*), (*iii*) and (*iv*).

The most important stress factor is the one placed last, because unfortunately the science of soil mechanics and physics cannot at present give us anything more than a general conclusion for the multitude of variables involved. So far as even other factors are concerned our present knowledge does not permit of the estimation of final stresses set up under the combination of all the above loadings and is arrived at within very wide limits. It is therefore clear that while the intensities and distribution of the vertical and horizontal forces acting at the junction plane of slab and ground have to be gussed as well as possible, practice generally continues to dictate the thickness of slab to be adopted, irrespective of soil types to be met with. In the present case the section of the road adopted was 8″—4″—6″ with a straight cross fall on the top surface of 1 in 72 (see Fig. 1). This section was one of those adopted and tried on the Multan road in 1935, and as this was probably the least and most economical in cost and was apparently giving satisfactory service, it was adopted in consultation with the Concrete Association of India, in the hope that it would be strong enough for the loads likely to come on the road for next score of years.

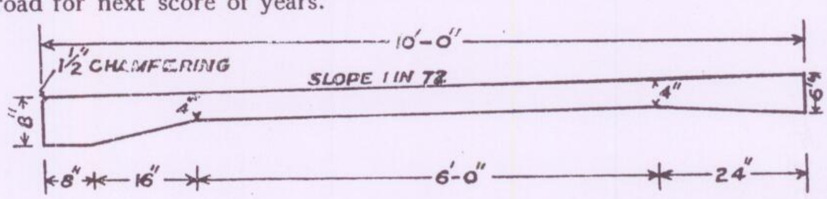

FIG. 1

Shape of the slab.

There is a great diversity of opinion among highway engineers as regards the shape of the slab to be adopted. While English engineers prefer to lay a slab of uniform thickness, the tendency in America appears to be to increase the thickness at the haunches. The necessity for this is borne out by the extensive tests carried out on road slabs in the United States of America. Indian practice seems to be in conformity with the American and most of the slabs laid in this country have been thickened at the edges. It was out of regard for current practice in this country that the slab, that was to be laid in this case, was also made with non-uniform section. The minimum thickness was kept at 4", which is quite adequate for taking the loads of ordinary bullock-carts, and the inner and outer edges were increased to 6" and 8" respectively in order to prevent the slab from failing. It cannot be denied that the edges are the weakest and most vulnerable spots in the road structure, and nothing but a very adequate thickness of concrete can be expected to last for long, especially when the slab is laid on virgin soil which is liable to get water-logged or be washed out. In this connection it would perhaps be of interest to mention that tests recently carried out by the United States Bureau of Public Roads reveal the fact that a balanced design is possible, so far as stresses from applied loads are concerned, if the section shown in Fig. 2 is adopted.

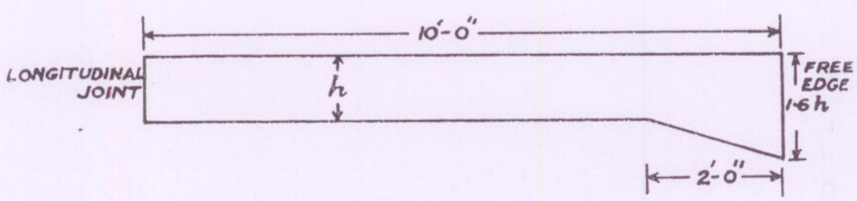

FIG. 2

Checked up on the above assumption it would be clear that the design adopted is in conformity with experimental investigations.

Materials.

Thanks to the activities of the various organizations formed in this country to propagate the use of cement, elements of concrete making are now generally more widely known and better realized than they were perhaps a few years ago. Concrete, as ordinarily understood, is regarded as a mixture of cement, sand and coarse aggregate, with the requisite quantity of water added to make the mixture easily workable, which is dumped in some sort of forms of the required shape or dimensions. The success obtained or, to be more exact, the absence of failure in very many cases, is due not to the amount of care exercised in the selection of aggregate or a proper proportioning of the various constituents, or a careful check on the cement water ratio which is theoretically the only scientific basis of concrete design, but in my opinion, (which I hope will be borne out by other members) is to be attributed to the high factor of safety allowed, and the great improvement in the quality of cement marketed now-a-days by the cement companies. It has been my experience that on ordinary works where the use of cement concrete as a structural material is ever on the increase, little care is bestowed, even though it is possible, on a proper proportioning of the aggregates. Very few workmen bother about the void contents of the aggregate ; and the general belief seems to be that the smaller the gauge of coarse aggregate used, the denser and perhaps stronger is the mix. The contractors usually try to use small size *bajri* on a large scale, because it is their experience that this gives them greater workability and also, perhaps due to a comparatively smaller proportion of voids, requires less cement and sand mortar for a given quantity of the finished concrete. They however lose sight of the fact that within certain reasonable limits the greater the maximum size of the coarse aggregate used, the greater is the ultimate strength of the concrete produced. Tests carried out on different occasions clearly prove the truth of this statement. The strength of the concrete is not for them to bother about. All that they are concerned with is the mixture of material by volume. The engineer's job is to get the maximum strength of concrete with the minimum cost of materials, and this can only be done if adequate attention is paid in the first instance to a regular design of the mix. The old practice of specifying mix as 1 :2 : 4 by volume of materials is likely to give misleading results because the volume of aggregates, especially of sand, is really a variable figure depending on the moisture content of the aggregates. Perhaps a scientific designer would choose to specify the proportions by weight of dry materials, worked out from their specific gravity, and not by volume. Even with all the huge advance in the use of concrete the fact remains that theory in its design is ahead of practice. The use of Fuller's curves and all the rest of the elaborate diagrams that play such an important part in designs of academical or laboratory interest do not find much room in the scope of the average practical builder. The reason for this deplorable state of affairs is not far to seek. The aggregates usually obtained on the works are so diverse in their sieve analyses, that any attempt at basing a rigorous design on one consignment is bound to create trouble with the next one. These aggregates are either hand broken from big boulders or picked up from the river bed as water worn pebbles ; and in general practice no two batches are alike in grading. The mere fact that they are screened through definite limiting sizes of screen does not carry us very far because it is the actual grading between the maximum and minimum limits that really guides the design. What then is the remedy to be adopted in actual practice ? I am of opinion that if conclusions arrived at in the laboratory after considerable experimentation are to be given a fair trial in practice, mixing on all big works should be controlled at some central place, where some responsible and sensible official could be entrusted to the supervision and direction of the mixing operations. So long as the mixing is left to the will and pleasure of the conservative type of foreman or mistri, it is doubtful whether really successful results can be guaranteed. Great care is required in the use of regularly graded aggregates both coarse and fine and the control of the water-cement ratio must be worked out with due consideration of the moisture content of the component aggregates especially of the sand. The use of the proper quantity of water is also essential to ensure proper strength, durability and density of concrete, and even very slight variations in this quantity, which in actual practice are generally negligible from the average mistry's point of view, are likely to have a very adverse effect on the ultimate strength of the concrete. It has been found by experience that in a concrete of otherwise constant specification the increase of the water-cement ratio by 0·1 (a difference of a little more than 1 gallon of water to a bag of cement) results in a loss in weight of the concrete by 3 lb. per cu. foot and a reduction in the compressive strength after 28 days of as much as 1200 lb. per square inch. From this illustration it will at once be clear what a great part the proper control of water plays in the eventual success of concrete as a structural material.

Cement.

The cement used on the work was either Portland cement or Rapid Hardening cement, both supplied from Wah. In order to encourage the use of cement for road construction the Associated Cement Companies, Ltd. had given a special concession rate of Rs. 25 per ton f.o.r. Wah for the ordinary cement as against Rs. 32 which is charged on consignments for ordinary general use on Government works.

Sand.

The sand for the work was specified as coarse sand from the bed of the Chakki river near Pathankot and was obtained from there. As it was not found to be clean enough, all sand was washed so as to remove any traces of silt before it was used on the work. The only difficulty experienced was that the wet sand could not be accurately gauged in volume on account of bulking and the water content of the different batches was found to vary so much that the quantity of water added for the concrete had to be regulated very carefully to ensure the best results.

An average sample gave the following sieve analysis :—

Retained on sieve	No. 8	6 per cent.
Do.	No. 16	30 ,,
Do.	No. 30	63 ,,
Do.	No. 50	90 ,,
Do.	No. 100	98 ,,
Fineness Modulus of sand		=2·87

Actually it was found to vary from 2·75 to 3·0.

Coarse Aggregate.

The coarse aggregate required was obtained by breaking the quartzite boulders available near Pathankot into metal graded from 2″ gauge to ¼″. The metal was divided in two sizes—one from 2″ to 1″ and the other from 1″ to ¼″.

An average grading analysis of the two types of metal is given below :

(A) 2″ metal.

Retained on 2″× 2″ screen	*Nil.*	
,, 1½″×1½″ do.	.. 28	per cent.
,, 1″× 1″ do.	.. 52	,,
Passed through 1″× 1″ screen	.. 20	,,
Total	.. 100	,,

(B) 1″ metal.

Retained on 1″×1″ screen	.. *Nil.*	
,, ½″×½″ do.	.. 44	per cent.
,, ⅜″×⅜″ do.	.. 24	,,
,, ¼″×¼″ do.	.. 26	,,
Passed through ¼″×¼″ screen	.. 6	,,
Total	.. 100	,,

It was found by experience that 3 parts of (A) mixed with 1 part of (B) gave a void content of about 43 per cent. On mixing the two batches the shrinkage in volume was found to be about 4 per cent. The above proportions were adopted for the major portion of the work but on some occasions they had to be slightly modified to suit the actual requirements and gradings of the various consignments. The metal was all obtained from Pathankot and was all hand broken. In the intitial stages of the work an attempt was made by the contractor to bring crushed stone from a crusher, especially for the small gauge type, but it was found that this stuff contained too many of flat, elongated pieces which were considered to be not very desirable, and so this type of metal was rejected. The contractor was ordered to bring all the stuff after hand breaking. This latter is definitely more expensive and more troublesome to arrange, but it could not be helped.

Another item which was a source of great trouble in the aggregate and which must be specially mentioned as likely to cause premature failure of the road, is the presence of round stuff in the aggregate. The stone at Pathankot is not quarried from rocks, but is broken from small boulders collected in the bed of the river Chakki. In spite of all the care taken in the selection of the source of supply, it was found that the admixture of small pieces of round or half round metal could not be helped. All these pieces were carefully sorted at considerable expense when the concrete was actually being mixed. This was the best that could be done but it must be admitted that it was by no means satisfactory.

Water.

It is now generally admitted that the quantity of water used in mixing has a very great direct effect on the ultimate strength of the concrete. In actual practice however this factor is what is most difficult to control. Generally, slump is reckoned to indicate excess or otherwise of the quantity of water used, and in the case of road work when concrete is meant to be tamped hard with a special tamper, only a maximum of ½″ slump was found to be safely permissible. This slump appears to be rather low, especially as all text books on concrete permit as much as 1″ to 1½″ of slump, but actual experience showed that any thing in excess of this figure yielded rather a wet concrete which could not be properly tamped. It may be mentioned that the ½″ figure was also the upper limit, arrived at only in a few cases. Generally the slump was ¼″ to 3/8″, and in very many cases there was no slump at all. After some days' experience, concrete of the required consistency could be judged by its appearance, and, the quantity of water used for the job had to be regulated to suit the various batches of materials.

It is difficult to give an exact account of how many gallons of water were used per bag of cement. This quantity had to be varied from morning to afternoon and again in the evening as was required by the time in which drying of the concrete surface could take place. The aggregates, both coarse and fine, were regularly washed before being used on the work, and the presence of moisture in them (especially in the sand) was a great factor in controlling the water required. It is unfortunate that the exact water content of a batch of sand could not be taken from time to time because it was such a difficult and a laborious matter. However from a note published in the September, 1938 issue of "Concrete and Constructural Engineering," it appears that an apparatus for estimating the water content of sand, aggregate and unset concrete has recently been marketed by the Concrete Tool Supply Co., 7C, Lower Belgrave Street, Westminster, London, S.W. 1. It comprises a glass tube with bung, a glass float, a brass measure and a bottle of liquid and a printed table mounted on a strong card. To make the test, the tube is filled with the liquid to a mark near the enlarged top, the hydrometer is placed in the liquid and the level of the liquid is read off on the scale above the float. The brass measure is then tightly filled with the material to be tested,

(I) Old Cement-Sandwich Grout Being Dismantled for Laying Cement Concrete,
(Concrete Track, G. T. Road.)

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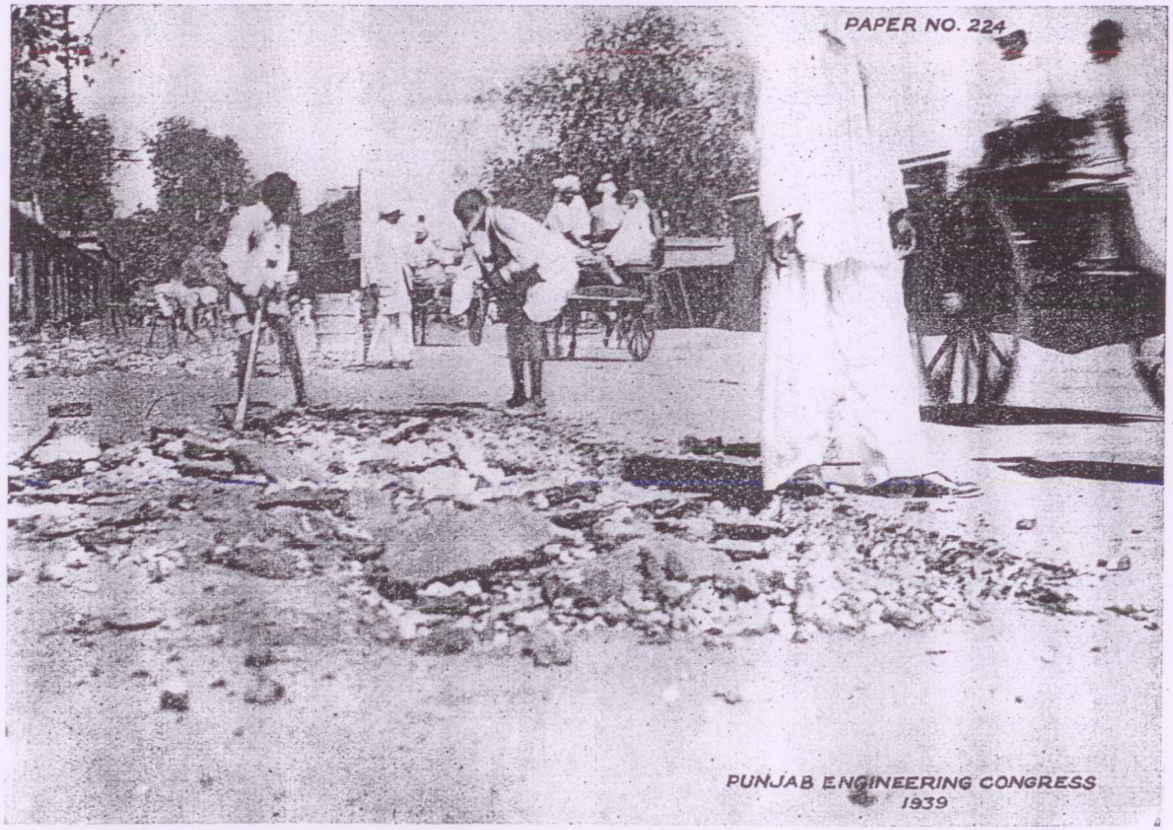

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placed upside down on the top of the tube, the bung is inserted and the tube is shaken till all the material has been washed out of the measure. The bung and measure are removed, the material is allowed to settle to the bottom of the tube and hydrometer is again inserted. Due to the moisture content of the material mixing with the liquid, the liquid now has a different specific gravity and the reading on the scale is again taken at the top of the solution. The two readings are found on the top horizontal line and the left hand vertical lines of the table and traced down and across until the intersection is found. The figure found at the intersection gives the water content of the material in pints per cubic feet. A test can be made in a few minutes. It will be seen that the extensive use of this apparatus is bound to solve a very difficult and intricate problem in the mixing of concrete. Sand is the component most difficult to handle and the quantity of water on the surface of the coarse aggregate is not of very great consequence. If the exact moisture content of the sand can be gauged, the exact amount of bulking can be easily worked out and a proper mix obtained.

Forms.

The specifications for the work held laid down that the forms should be of steel. To begin with, the contractor was ordered to purchase 10 sets of forms consisting of steel channels 6″ & 8″ deep by 3″ wide, each set 34 feet long. The length of each bay was to be 33 feet and a 6″ overlap on either side was considered desirable.

As these forms were not removed till the third day and could not be used again till the fourth day, it was found that this number was inadequate. The contractor was therefore ordered to arrange for another set of forms. To keep down the cost these extra sets were made in wood which was protected on the top by a piece of angle iron $2'' \times 2'' \times \frac{1}{4}''$ screwed into the wood. Experience however showed that the wooden forms were a source of great trouble, due to warping and swelling of wood, and had to be kept constantly planed in order to present a uniform and straight surface. If the extra labour involved in the use of wooden forms is also taken into account it would appear that steel forms are perhaps cheaper in the long run.

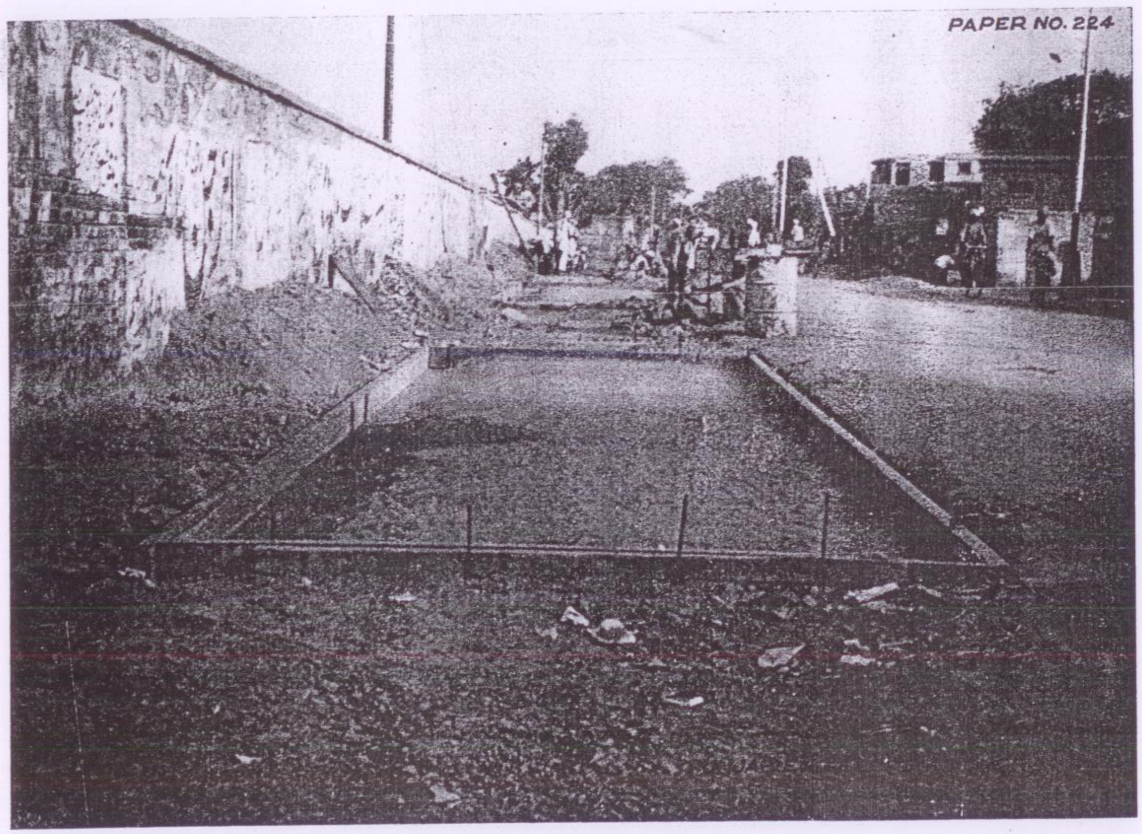
The cross forms were made of wood which, to begin with, were protected from water by covering them with a thin sheet of iron screwed right round the top and sides. After a few days' work, the sheet seemed to develop kinks under the blows of the tamper, and as the forms started warping it was a serious matter to have to plane them after removing the sheets. The sheet was therefore discarded in favour of a $2'' \times \frac{1}{4}''$ flat iron screwed on top of the forms. This was found to be a better arrangement, because whenever the wooden cross forms needed replacement due to warping or otherwise, it was a comparatively easy matter to unscrew the flat iron, and use another piece for the forms. Great attention is required in the laying of the forms. They have to rest on fairly solid ground, because otherwise they are liable to settle under the heavy blows of the tamper. In spite of all possible care being exercised to provide adequate foundation, it was found that the side forms did give a settlement of 1/8″ to 1/4″ depending on the soil met with. These forms were supported on full bricks placed on end and spaced about 3 feet apart. The idea was to give adequate supports to the forms from *pacca* ground.

Subgrade.

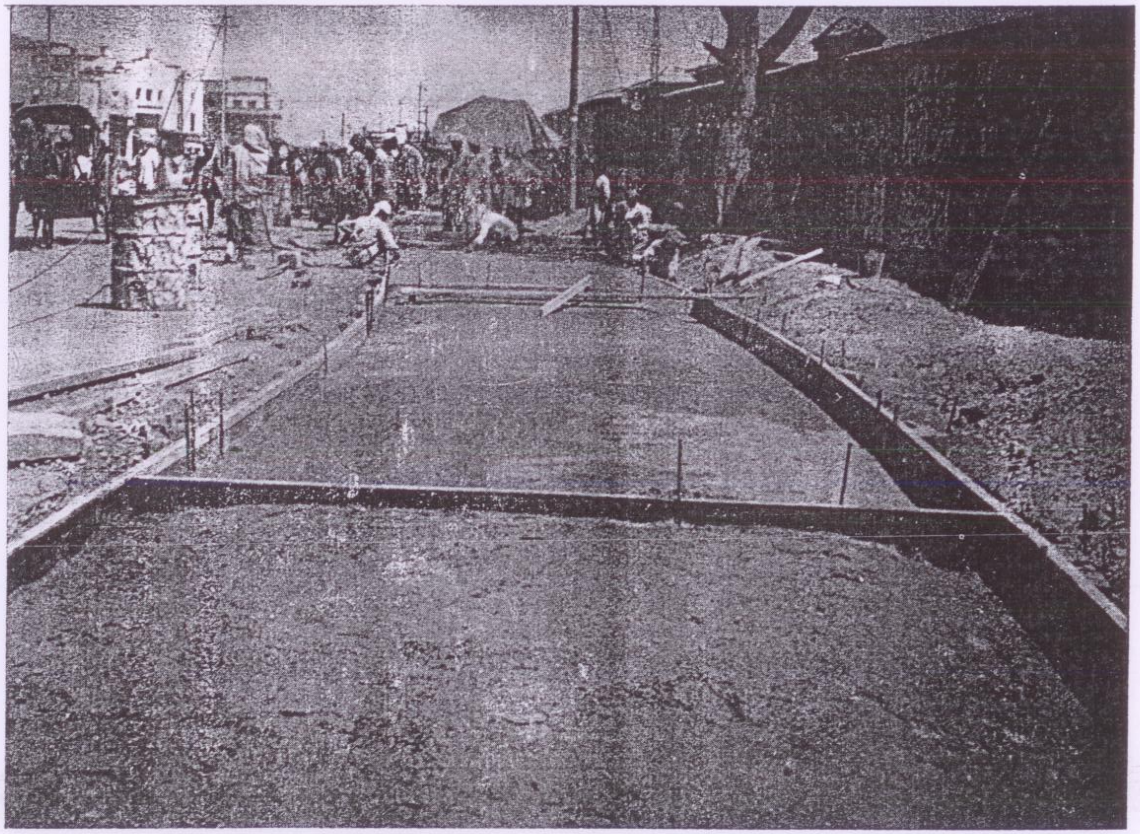
Having placed the forms at the correct levels the next operation was to prepare the subgrade. As already remarked the concrete track was laid on berms alongside the existing metalled surface, and was to be founded on ordinary soil. As it happened the road metalling had been renewed from time to time and each time fresh consolidation was done, a fresh layer of earth had been dumped on to the berms. It was therefore found that the earth had consolidated into layers 2″ to 3″ thick which had evidently been made compact in varying degrees by the weight of traffic above. For the concrete track only definite depths of excavation were required to be done, but in many cases due to this particular type of soil it was found that these levels could not be rigidly adhered to. The earth would come off in layers, and either one had to be content with a surface about 1″ or so higher than the required level or had to take it down by 1½″ to 2″ in many cases. All such cases had to be specially dealt with by filling the low spots with brick aggregate mixed in mud. This arrangement tended to put up the cost but it could not be helped. All hollow or soft spots met with had also to be similarly filled up with mud concrete. Depressions less than 1″ in depth were filled with a mixture of cinder and sand in the ratio of 3 : 1, and those above 1″ deep were made level with mud concrete. Cinder was used on the advice of the Concrete Association representative who stated that in Bombay, concrete roads had been laid on a 3″ or 4″ bed of cinder or coal ash, rolled to compaction with a roller. There is no doubt that cinder prevents the moisture in the soil from rising up and is the only cheap material available for levelling up small inequalities in the surface.

Attempts were made to water the earth base in order to make it soft and easy for scraping but it was found that the wet clay on drying up cracked rather badly and the position at the end of the experiment was no better. Therefore it was decided to resume the scraping of dry soil as originally contemplated and deal with rebellious spots as indicated above. The surface was rolled with a 5-ton Diesal Roller in order to compact the soil before concrete was laid.

This method of risking the concrete slab straight on virgin soil is perhaps open to considerable arguments and discussion. It should be stated that the earth is likely to get washed away or become waterlogged and thus be incapable of bearing heavy loads. The result would be that the concrete slab would be left to bear the weight of the superimposed



(II) Forms in Position.
(Concrete Track, G. T. Road.)



(III) Concrete Track G. T. Road
Another view of Forms in position.

(IV) Concrete Track G. T. Road
Brick side forms used at curve.

load by itself and is therefore bound to develop trouble. Some failures have recently occurred in Assam where small concrete track-ways failed due to the subgrade soil getting bogged; but it is highly unlikely that such conditions are ever likely to be met with on the road in question. The embankment on the Grand Trunk Road has the reputation of having stood for years and can be counted on as fairly compact. If adequate protection is afforded against large quantities of water creeping into the subgrade and flooding the base, it can be hoped that nothing serious would happen, and the slab would bear the loads adequately. It would of course be ideal if a firm and solid base of brick concrete or water-bound stone metal were provided for the concrete slab to rest on; but this would only put up the cost. It must not be forgotten that this work is really an experimental one and if it fails, the experience gained in this would be utilized on other works of this nature. If it does succeed (and there is little so far to fear it will be otherwise) a good and trouble-free riding surface will have been achieved at low cost.

Insulation Layer.

When the subgrade had been prepared true to level and had been checked by a template specially designed for the purpose, an insulation layer of Ravi river sand was spread on the surface. This layer of sand was specified to be not more than half an inch in thickness, but on account of the peculiar nature of the soil as explained in the foregoing paragraph it had to be slightly exceeded in some cases. Opinions differ as regards the usefulness of this insulation layer. Whereas some people are of opinion that the slab must be given perfect freedom to expand and contract and must have a smooth bed to slide on, others are inclined to the view that it is perhaps better to lay the concrete straight on an uneven surface, and thus provide some embedment for the slab. From a theoretical point of view the former practice appears to be the more reasoned one, but the experience gained on some of the roads in the U.P. seems to show that an insulation layer is not at all neessary.

The practice in road construction in the West seems to be to use a thin stout paper as a base for the concrete road. The object of this is to ensure that there is no point of contact between the slab and the base, so that the slab is perfectly free to slide when expanding and contracting. Another reason for its use is that all water that is used in the mix is conserved in the concrete and is not allowed to soak into the subgrade, which is bound to happen if the slab is laid on sand. This latter method of construction is likely to give a honey-combing of the bottom portion of the concrete slab due to the absorption of a certain amount of water from it and thus produce a definitely weaker structure.

Only a few sections of the road were tried, as an experiment, with Road paper.

The following kinds of papers were used:—

(*i*) Road Lining paper. Marketed by Garlick & Co., Haines Road, Bombay.

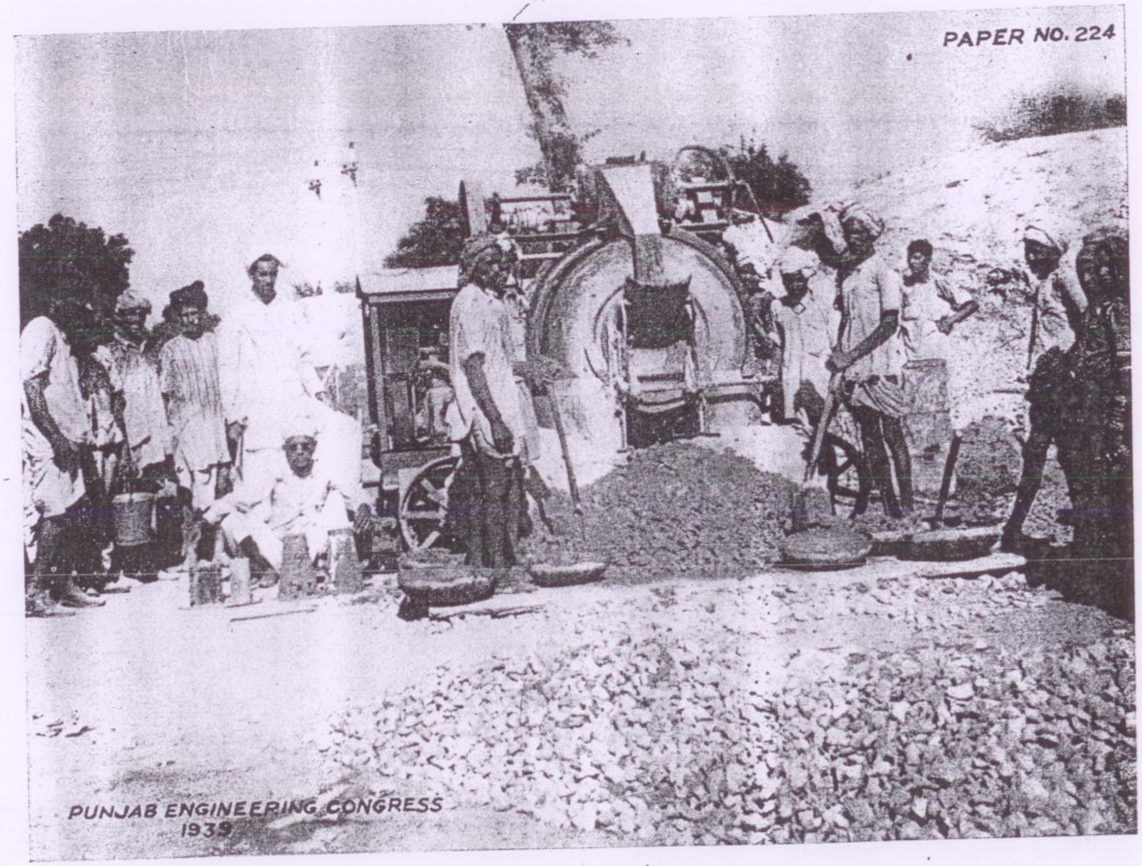
(*ii*) Tar paper. Supplied by Messrs. Killick Nixon & Co., Bombay.

(*iii*) Sisalkraft paper which is obtainable from Messrs. William Jacks & Co., Karachi.

Of the above grades, the last is perhaps the best and the most expensive, but the second one is the cheapest. The experiment in using them, was made in the beginning of April, when the temperature in the sun was fairly high and due to a belief that the water content had to be reduced to the absolute minimum when paper was to be used, very little water was allowed in the mix. The concrete was poured and finished as usual but about an hour after the surface was finished some of the slabs developed a considerable number of cracks on the surface. The slabs laid on the tar paper cracked the most and though most of the cracks were of the nature of fine hair cracks there were a few which were then considered to be definitely of an alarming nature. In spite of this experience a further trial was made with all three kinds of paper and the concrete used was slightly wetter than that adopted in the first instance, This concrete corresponded in consistency to the one ordinarily adopted, These slabs took very much longer to finish on account of a slight excess of water on the top of the surface but the cracks were considerately reduced, if not absolutely eliminated. It is argued by the manufacturers of such papers that their use ensures absolute freedom from cracks and is essential for a properly laid concrete road. The practice in England and Germany seems to be in favour of their general use but it is doubtful if cracks can be eliminated altogether even when they are laid as an insulation layer. No final conclusions in the matter have yet been drawn and there is much to be said on both sides. As however their cost is not very considerable it would appear that some advantage might be gained by using them.

Mixing.

When the subgrade has been prepared and the insulation layer laid, the surface was checked by a template running on the side forms of channel iron. This was done to ensure that a uniform thickness of concrete was available all over the surface. To begin with, the mixing of concrete was done by hand in wooden troughs but as this arrangement needed a colossal amount of supervision and did not give a uniformly mixed concrete, the Department decided to purchase a concrete mixer for the job. The mixer used was a 10—7 cubic feet capacity, non-tilting type, and was supplied by Millars. The machine worked admirably and much greater control both over the mix and the water-ratio was possible.



(V) Mixer at Work.
(Concrete Track, G. T. Road.)

It was a definite gain to the contractor as well, because the cost of mixing by machine was very much less than that by hand mixing. The mixed concrete was brought by baskets and spread by rakes wherever it was required. The top of the concrete was kept about $\frac{1}{2}$ inch proud of the forms, in order to make it possible for proper tamping. The edges were rammed with big wooden rammers in order to ensure a thorough compaction and the rest of the concrete was tamped by a special tamper 11 feet long, held on both sides of the road by two men on either side and dropped on the concrete. Due to the weight of the tamper and the impact of the blow good compaction could easily be obtained and a few strokes of the tamper were found to be adequate for finishing the concrete. In the beginning a tamper was made of rolled steel beam $5'' \times 3''$ in section but later on one was made in wood strengthened at the bottom with a $\frac{1}{4}''$ iron plate. This was found to be more convenient by workmen, because the handle of the former type gave a lot of trouble. The bolts fastening the handles to the beam got broken every now and then and work was hampered when they were being replaced. The wooden tamper is by no means a costly affair, and can work quite satisfactorily if a properly heavy section is adopted.

Finishing.

After the concrete had been made more or less level with the tamper it was finally smoothened with a teak wood strip carried across the slab on the side forms. This arrangement was found to succeed better than belting with a canvas belt as originally specified by the Concrete Association. The final finishing was however done with wooden floats and was carried out just after the water liberated on the hydration of cement had dried up. This item was perhaps the most difficult and the most important part of the whole job. Great care is necessary to ensure that true levels are maintained and undue undulations avoided. The cross fall had to be checked fairly often and so had the longitudinal grading. The former was checked with a proper template fitted with a spirit level, while the latter was attended to by an extensive use of a piano wire about 18 feet long, stretched tightly on the road by means of a stout bamboo bow. The maximum undulation permitted by the specifications was $\frac{1}{4}$ inch in a 10 feet length. Attempts were made to regard this as the maximum and not the usual deviation. On some of the German roads where a much higher standard of workmanship is possible the maximum variation permissible is 1/6 inch in a length of 13 feet. Incidentally this fact explains why concrete roads provide a more comfortable driving surface than is possible on any type of road. As the life of a road is considerably reduced by the impact caused to the structure from traffic through corrugations and inequalities, it is obvious that other facts being equal, a concrete road constructed with a standard of perfection as indicated above is bound to last very much longer than the ordinary type of macadam road consolidated with the usual type of two-wheel roller. It has been observed after careful experimentation that with the design of rollers in use at present that it is not possible to obtain a truly finished surface to the road which will be immune from the dynamic effects of the fast moving and heavy traffic. As much greater perfection of the surface is possible with a concrete road, due to the fact that each square foot of this road is floated down carefully with hand floats, it is evident that this is the best type of road so far as the convenience to traffic and eventual economy in maintenance are concerned.

During finishing operations it was experienced that any excess use of water in the concrete mix made the surface extremely difficult to render properly. The water on top of the surface had to be dried up with gunny bags because the surface had to be finished before the initial set had really set in. Any attempt to delay the final finishing longer meant a disturbance to the concrete in its setting, and as this was not considered desirable extra labour had to be put on, in several cases, to keep the finishing close behind the laying operations.

Curing.

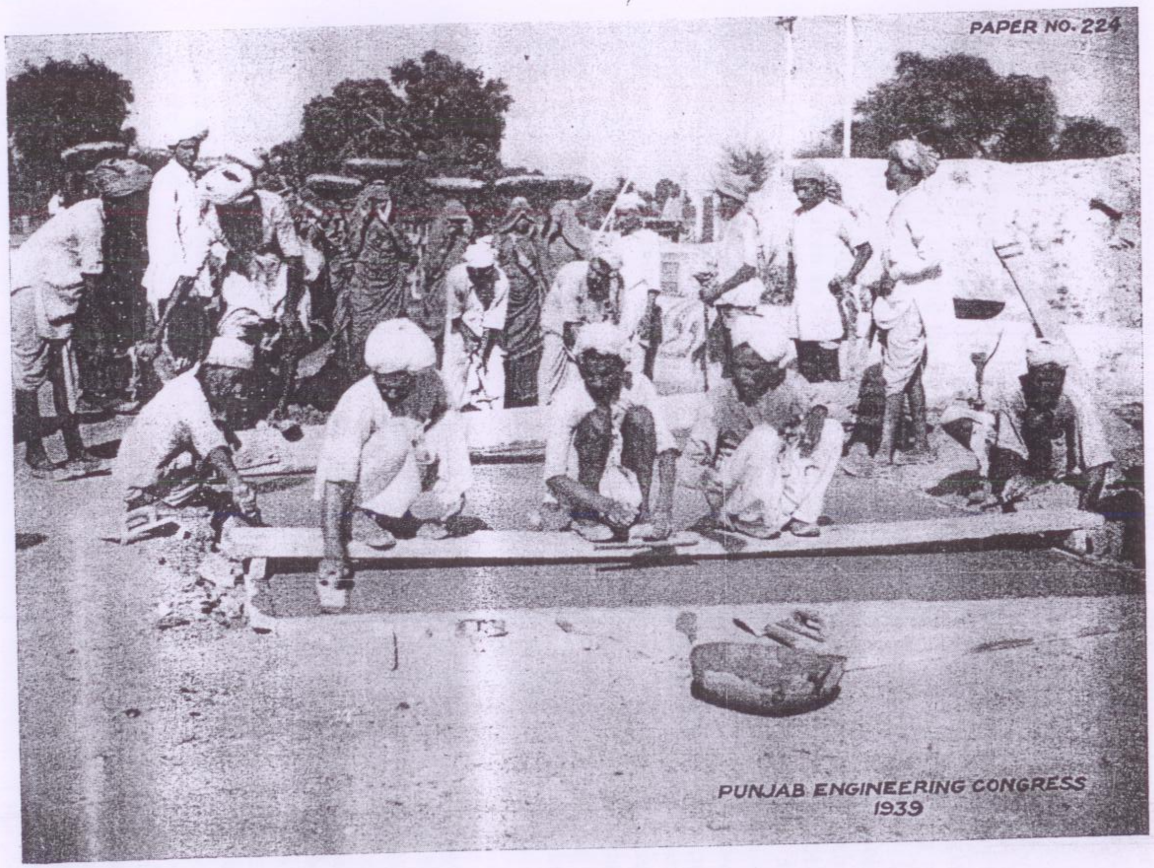
After the surface had been finished, it was kept wet with gunny bags or sprinkled over constantly with water till the surface had become sufficiently hard to receive the layer of mud for curing. It was considered that the most economical way of curing the concrete was by putting in 4″ to 6″ layer of earth obtained from excavation of the subgrade. This layer of earth could very easily be kept wet more satisfactorily than if ponding of the concrete had been resorted to. The mud layer was kept wet for a period of 10 days, when watering was stopped and the wet earth allowed to remain on the concrete for another period of 10 days or so. Thus with only 10 days of proper watering a curing extended over a period of three weeks could be obtained. When the mud was removed after this latter period, the bottom layer of earth just adjacent to the concrete was generally found to be wet, thus showing that the desired amount of curing had been effected.

In some of the western countries use is made of Sisalkraft or some other such paper for curing purposes but this method of curing is considered far too extravagant for this country. When rapid hardening cement was used the road was opened to traffic after a week.

Soda silicate.

Before the road was opened to traffic it was specified that it should be hardened with three coats of P 84 silicate of soda, applied in accordance with the specifications of the manufacturers. The actual amount of extra hardness obtained by the use of this stuff is really a matter of considerable doubt, and therefore only about half the length of the road was treated with the material while the rest was opened to traffic without using it. So far, there appears to be no difference at all in the behaviour of the two types of surfaces under traffic. It may be

(VI) Concrete Being Tamped and Finished.
(Concrete Track, G. T. Road.)



(VII) Another View Showing Finishing of Surface.
(Concrete Track, G. T. Road.)

argued that it is is perhaps too early to form any conclusion, but whatever thin film the soda silicate may have formed it has surely been knocked down by the heavy traffic. How far the soda silicate had actually penetrated into the pores of the concrete and sealed them is a question that only a microscope could tell. This has not been attempted so far in the field, but it could perhaps be observed with interest in a laboratory.

Joints.

The greatest problem in the construction of a concrete road is the treatment of joints. Experiments have been made both in England and Germany during the last few years with various types of joints and results obtained so far are by no means absolutely conclusive. The general practice in this country appears to be in favour of butt joints which were adopted in the case under review. The average length of the bay was taken as 33 feet which was arrived at from experience in other parts of the country. After every three bays, an expansion joint 3/8″ thick of Garlex patented sheet was inserted to take up the expansion of concrete. The maximum temperature variation on the road between different periods of the year may be as much as 140° F. and if the expansion in each bay, on this basis, is calculated, it would appear that at least ¼″ expansion should be allowed for every 25 feet or so. Experience has however shown that the joints are the weakest links in the chain. As it has not yet been possible to eliminate excess wear and breaking up at the planes of the joints it is obvious that their number should be kept as low as possible, consistent with actual requirements.

It was originally intended to put in butt transverse joints with straight arrises, but when the work was started it was argued that if this practice were adopted, any increase in the length of the slab would cause the edges to rise up in a sort of hump and thus provide an undue inconvenience to traffic. This hump was expected to result in an undue amount of impact stress in the adjoining sections which might possibly cause their failure. To tide over this difficulty it was thought that if the arrises of the joints were rounded off to a 3/8″ radius, a small cavity 3/4″ diameter would be formed at the joints that could ordinarily be filled with some sort of bitumastic material and would take up the expansion of the concrete road quite conveniently. Subsequent experience has however shown that this arrangement is by no means a very satisfactory solution of the problem. The tar filler used for these joints does not seem to have any affinity for the concrete and gets knocked out in no time. An examination of these joints after very severe cold weather has revealed the fact that the bitumastic material used in filling them has cracked very badly, and the voids left in the two planes due to contraction of the slabs have caused the edges of the slabs to be broken under the weight of traffic. The curvature at the edges is therefore likely to go on increasing and after some time big potholes may be formed.

Another trouble with this type of joints is that it is not absolutely water-proof. When the slabs contract as they must in the cold weather, there is a small gap left in the joints which might allow the penetration of water underneath the slab and thus produce an unnecessarily weak foundation for the concrete under the joint, by increasing the moisture content of the subgrade soil.

The difficulty with most of the patent stuff for expansion joints is that they are only compressible, but not elastic. While the slabs expand they exude above the surface, but they do not expand when the slab contracts. Therefore contraction of the slab after expansion is bound to result in undesirable gaps being left in the planes of the joints. In order to overcome this drawback, it would perhaps be better if the material to be used for expansion joints be of the nature of cork, and be specified as below.

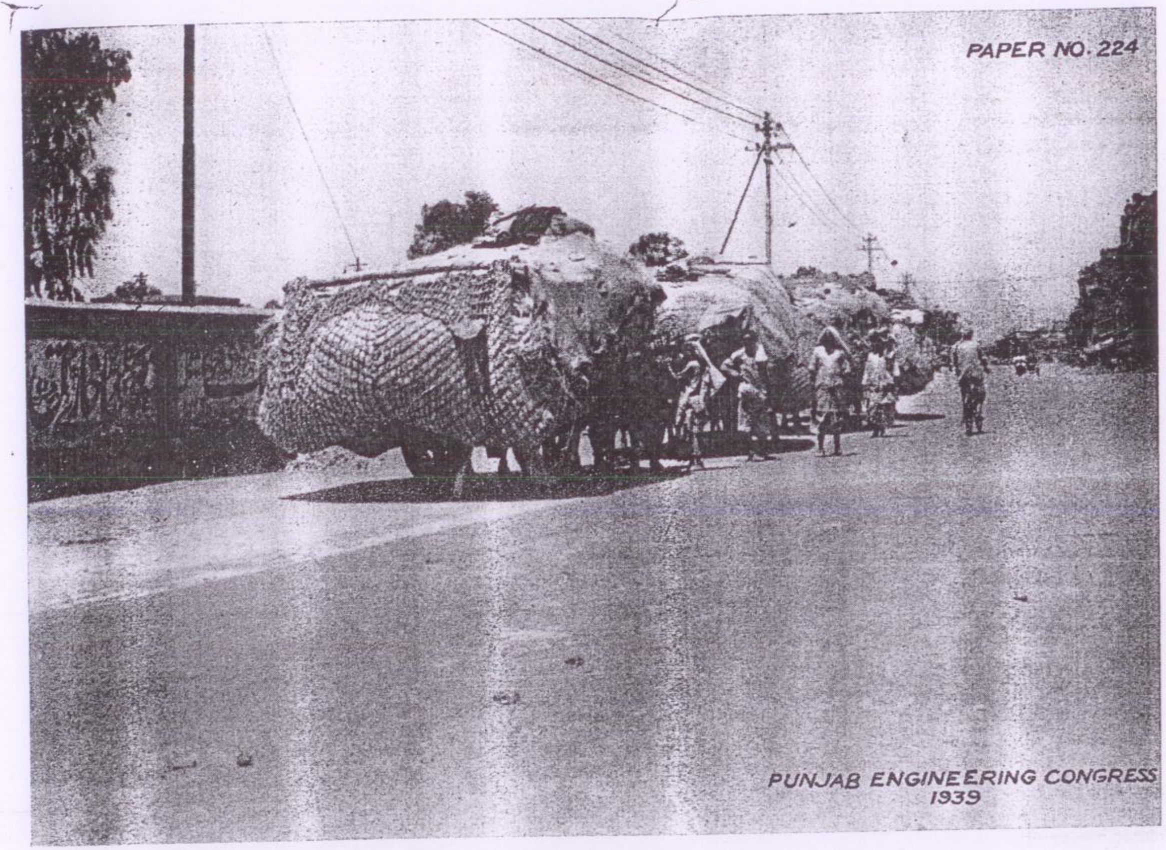
"No expansion jointing material may be used unless it is rot and water-proof, capable of being compressed to 50 per cent of its thickness without any extrusion, and return to at least 80 per cent of its original thickness within 12 hours of being released from compression, that the jointing be sealed with a permanent plastic sealing material that will make perfect adhesion to concrete, will not become brittle or fracture and exclude all weather from getting into the joint and reaching the subgrades."

The use of such a material, which has still to be found, will doubtless provide an efficient remedy for saving the weakest link in the chain from failure, and thus endangering the success of the whole road.

Details of work.

The estimate for the work was sanctioned for Rs. 73,146 and comprised the construction of 1,42,640 square feet or 2·51 miles of concrete track 10 feet wide. As a concession rate for cement had been obtained, it was decided to charge the cement direct to work, and a contract was let out at 10 per cent below the schedule rates for the rest of the items. A provision was made in the estimate for special tools and plant to the extent of Rs. 2,000. This item was however scored out at the time the tenders for the work were called, and the contractor was required to arrange for them himself. After the completion of the work it was discovered that the cost of forms was a considerable item in the cost of execution of the work, and something like Rs. 4,000 had been spent by the contractor on these forms of both steel and wood. The steel ones could probably fetch a reasonable price on sale, but the wooden ones were now entirely a dead loss.

The area actually laid was 1,47,090 sq. feet., or about 16,350 square yards (2·59 miles of 10 feet track), and the total outlay on the work is reported to be Rs. 66,600. As this expenditure also includes a sum of Rs. 2,800 paid to the Lahore Electric Supply Co., for the cost of shifting



(VIII) Road Opened to Traffic.
(Concrete Track, G. T. Road.)

some electric poles, and also a further sum of Rs. 3600 for the cost of a new mixer which was charged to this work, the net expenditure on the concrete track was only Rs. 60,200. The overall cost per square yard works out to Rs. 3-11-0 and the cost per mile, 10 feet wide would be Rs. 23,200.

The total quantity of cement used on the work was 515 tons out of which about 150 tons were of the Rapid Hardening kind. This cement was found to be of great help in the congested areas, because traffic could be allowed on the new road much earlier. Its general use for road work would appear to be very desirable, but somehow or other it does not seem to have found much favour with road engineers, and its use is regarded more as an exception than a rule. I am however confident that with the present improvement in the standard of its quality it will certainly replace the ordinary type before long as the usual material for road construction.

Great difficulty was experienced on the work because the contractor was entirely new to the construction and his arrangements were by no means ideal. Often there were short break downs in his supply of materials, either due to rains or some other causes, and eventually the work had to be finished by daily labour. The concreting was actually done on 94 days, which gives an average length of about 156 feet or roughly 5 bays per day. But on some days, 7 or 8 bays were laid.

Brick aggregate experiments.

In order to try the possibility of the use of brick aggregate for cement road work, an experiment was conducted by laying a few bays (about 500 feet length) with brick ballast and ordinary river sand. The section of the road adopted was the same as that for stone, *viz.*, 8″—4″—6″ and the sieve analyses of the brick aggregate and sand are as below.

(*i*) *Brick aggregate.*

(*a*)	Retained on 1″×1″ sieve,	.. 10 per cent.
	,, ½″×½″ mesh,	.. 70 ,,
	,, 3/8″×3/8″ mesh,	.. 15 ,,
	Passed through 3/8″×3/8″ mesh,	.. 5 ,,
	Total	.. 100 per cent.

(*b*)	Retained on 2″×2″ mesh,	.. *Nil.*
	,, 1½″×1½″ mesh,	.. 34 per cent.
	,, 1″×1″ mesh,	.. 52 ,,
	Passed through 1″×1″ mesh,	.. 14 ,,
	Total	.. 100 ,,

(*ii*) *Fine Ravi Sand.*

Retained on No. 30 sieve,	..	2 per cent.
,, No. 50 sieve,	..	71 ,,
,, No. 100 sieve,	..	22 ,,
Dust	..	5 ,,
Total	..	100 ,,

Fineness Modulus = 1·7

Some of the slabs were laid on a sand layer while in other cases the use of various grades of road lining papers, already mentioned, was tried. These slabs did not show many signs of cracking or failure when the work was laid, but after 6 months of wear the cement slurry on top of the brick concrete has worn off almost entirely and the brick aggregate is getting exposed. Some of the slabs have also developed cracks at different places on the surface. It is too early to altogether ban the use of brick aggregate for this type of work, but it is apprehended that the exposed aggregate will before long get crushed under the weight of bullock-carts. It is of interest to state that the crushing strength of 4″×8″ cylinders or 1 : 2 : 4 concrete after 28 days, as used in this experiment was found to be 3941 lb. per square inch, which compares very favourably with that of stone aggregate.

Another experiment was tried with the use of 7″—3″—5″ section and stone aggregate. This is showing signs of cracks, and it would seem that 8″—4″—6″ is about the minimum section that can safely be adopted.

Supervision.

The work was carried out by the Author under the executive charge of Mr. Brij Mohan Lal, Executive Engneer and the superintendence of Mr. R. Trevor Jones, Superintending Engineer, while the Concrete Association very kindly lent the services of two of their experts to assist with their advice during construction, and R. S. Hari Chand of the Concrete Association also very kindly helped with his advice.

APPENDIX I.

TRAFFIC COUNT ON GRAND TRUNK ROAD.

No. of Miles.	Date.	*Motor traffic.*			*Non-Motor traffic.*			Total weight of traffic for 24 hours. (tons)	REMARKS.
		Buses over 25 seats.	Buses up to 25 seats.	Motor Cars.	Bullock-Carts.		Passenger vehicles.		
					With iron tyres.	Without iron tyres.			
306-2	6-36	130	540	116	1020		700	5324	
	12-36	295	208	172	110	450	670	3956	
	6-37	439	329	143	149	266	703	4655	
	1-38	415	280	272	121	328	680	4626	
	6-38	814	392	311	354	353	969	7477	
308-2	12-35	83	430	207	1070		1350	5687	
	6-36	100	570	176	659		1400	5377	
	12-36	375	255	241	140	391	1442	5258	
	6-37	489	174	169	106	169	1228	4596	
	1-38	470	185	209	105	269	1124	4713	
	6-38	521	201	201	68	222	1487	5156	

APPENDIX II.

Specifications for Cement Concrete Road.

MATERIALS.

CEMENT.

Quality of Cement:—The whole of the cement shall be obtained from approved manufacturers in India and shall comply in all respects with the provision of the British Engineering Standards Association Specifications for Portland Cement No. 12 in force at the date of the construction of the concrete road slab.

FINE AGGREGATE.

Quality of Fine Aggregate:—All the fine aggregate shall consist of clean, hard, strong, durable, uncoated particles from Pathankote. When incorporated in the concrete mixture, the fine aggregate shall be free from frost, frozen lumps, injurious amounts of dust, mica, shells, soft or flakey particles, shale, alkali, organic matter, loam or other deleterious substances.

In no case shall fine aggregate be accepted containing more than two per cent by dry weight, nor more than three and a half per cent by dry volume, nor more than five per cent. by wet volume, of clay, loam or silt. If any sample of fine aggregate shows more than five per cent of clay, loam or silt in one hour's settlement after shaking in an excess of water the material represented by the sample will be rejected.

If necessary, the fine aggregate shall be washed or screened and regraded.

All fine aggregate shall be stored on the works in such a manner as to prevent the intrusion of foreign matter.

Silt Test:—The percentage of silt by volume in the sand shall be determined in the following manner. Select two glass bottles, jars or graduated vessels which have uniform bores over a depth of eight (8) inches or more. The minimum diameter should not be less than one and one half ($1\frac{1}{2}$) inches. Select two representative samples of the materials under test, each sufficient to fill a vessel to a depth of two and one half ($2\frac{1}{2}$) inches. Add enough water to make the total depth of the mixture of sand and water five (5) inches after shaking. Cover the top with hand or cork and shake vigorously for at least thirty (30) seconds. Hold the vessel in an upright position and tap its sides with the finger to level the top of the sand. Allow it to stand for one hour. Then read the depth of the silt to the nearest one hundredth (1/100)

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Test for organic impurities:—The presence of organic matter in the fine aggregate shall be determined by the calorimetric test, which shall be made as follows:—

Fill a graduated 12 ounce bottle to the four and one half (4½) ounce mark with the sand under test. Add a three (3) per cent solution of sodium hydroxide (caustic soda), until the level of the liquid reaches the seven (7) ounce mark after the mixture has been shaken. After thoroughly shaking allow the mixture to stand eighteeen (18) to twenty four (24) hours, and observe the colour of the clear supernatant liquid. If clear or light straw colour, the sand is free from harmful proportions or organic matter. If the colour of the liquid is dark amber to black, the sand shall not be used before it has been subjected to the further tests.

COARSE AGGREGATE.

Quality of Coarse Aggregate:—The whole of the ingredients of the coarse aggregate shall consist of crushed rock, or other inert materials. The particles of coarse aggregate shall be of clean, hard, tough, durable materials, free from vegetable or other deleterious substances and shall contain no soft, flat or elongated pieces and shall be obtained from Pathankote quartzite.

All coarse aggregate shall be stored on the works in such a manner as to prevent the intrusion of foreign matter.

Grading of coarse aggregate. The size of the coarse aggregate shall be such that it shall all pass a two inches square opening, and be retained on a ¼ inch sieve and shall be uniformly graded within these limits:—

The following mixture will be used:—

75 per cent of 2 inches to 1 inch stone and 25 per cent of 1 inch to ¼ inch stone	The void percentage shall not exceed 40.

WATER

Quality of Water :—The water used in mixing the concrete shall be clean, free from oil, acid, alkali or vegetable matter and of a quality fit for drinking purposes.

CONSTRUCTION

(*a*) *Subgrade*:

Definition :—The subgrade will be considered as that portion of the highway upon which the concrete slab is to be placed.

Preparation and maintenance :—The subgrade shall be constructed to have as nearly as practicable a uniform bearing power throughout its entire width. Any compression of the subgrade shall be accomplished by a road roller weighing not less than five tons. Some portions where directed may be compacted by hand ramming. The suface shall be maintained free from ruts so that it will drain properly at all times. All depressions in connection with rolling shall be filled with a mix of mud and brick ballast and thoroughly compacted. Rolling and compacting shall be continued until the subgrade is uniform, properly shaped and true to grade and alignment. All soft and spongy parts of the subgrade shall be excavated and refilled with approved material.

Trenches shall be dug to the required depth along the existing metal road so as to enable the side forms to be placed such that the top of these forms is flush with the road.

Checking and acceptance :—Immediately prior to placing concrete on subgrade, it shall be checked by means of an approved scratch template, resting on the side forms, having the scratch points placed not less than 8 inches apart and the exact elevation and cross section for the subgrade surface. The scratch template shall be drawn along the forms so that the plane of the points will be at a right angle to the grade line and the axis of the template at a right angle to the centre line of the road. All high places indicated by the scratch points shall be removed to true grade, any low places back filled with suitable materials and rolled or hand tamped until smooth and firm. The subgrade shall be checked and completed in accordance with these requirements for a distance of not less than 100 feet in advance of the concrete.

No concrete shall be laid on the subgrade until the subgrade has been passed by the Engineer.

Insulation Layer—An insulating layer of half an inch of clean sand shall be placed between the slab and subgrade. Nowhere will the thickness of this insulating layer be allowed to exceed half an inch. If ordered some grade of road lining paper shall be spread over the subgrade.

FORMS

Metal Forms:—Metal forms shall be of shaped steel sections such as channels, not less than 10 feet in length for tangents and for curves having radii of 150 feet and over. For curves of less radii, sections 5 feet long may be used. They must have a depth equal to the the side thickness of the slab. Forms shall be made of steel plate of approved section. At least three bracing pins or stakes shall be used to each 10 feet of form, and the bracing and support must be ample to resist the pressure of the concrete and the impact of tamper without displacement.

Setting forms.—Forms shall be set to exact grade and alignment at least 100 feet in advance of the point of depositing concrete. Before setting, the form must be thoroughly cleaned. After setting, they shall be thoroughly oiled before concrete is placed against them. Forms in place will be subject to check and correction of line and grade at any time.

It is essential that forms should be rigid, as on this depends the evenness of the finished surface.

Before placing the concrete the surface of the side and cross forms shall be well smeared with some crude oil.

Cross Forms:—The cross forms shall be made of steel and shall be of the exact cross section of the proposed slab. They may be made in wood which will have to be properly protected and planed to remove defects of warping. These forms must be placed absolutely vertical.

CONCRETE

Ingredients:—The concrete shall be composed of water, Portland cement, fine aggregate and coarse aggregate.

Measurement of Materials:—All the materials for the concrete shall be carefully and accurately measured for every batch.

The cement shall be measured by bags. One bag of Portland cement weighing 110½ pounds net shall be considered equal to 1·20 cubic feet. The fine and coarse aggregates shall be measured by volume. The water shall be measured by volume or height.

Proportion of ingredients:—The ingredients shall be mixed in one part of cement, two parts sand, and four parts stone by volume.

Slump Test :—In order to test the consistency of the mixed concrete, slump tests shall be made by the contractor when and where required by the Engineer, and these slump tests shall be carried out in the following manner.

(*a*) The test specimen shall be formed in a mould of number 16 gauge galvanized metal in the form of the frustrum of a cone with the base eight inches diameter, the upper surface four inches in diameter, and the altitude 12 inches. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mould shall be provided with proper foot pieces and handles.

(*b*) When the test is made at the mixer, the sample shall be taken from the pile of concrete immediately after the entire batch has been discharged.

(*c*) The mould shall be placed on a flat, non-absorbent surface such as a smooth plank or a slab of concrete and the operator shall hold the form firmly in place where it is being filled, by standing on the foot pieces. The mould shall be filled to about ¼th of its length with the concrete which shall be then puddled, using 20 to 30 strokes of a ½inch rod pointed at the lower end. The filling shall be completed in successive layers similar to the first and the top struck off so that the mould is exactly filled. The mould shall then be removed by being raised vertically, immediately after being filled. The moulded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

(*d*) The consistency shall be recorded in terms of inches of subsidence of the specimen during the test which shall be known as the slump.

Slump=12 inches –(minus) inches of height after subsidence.

The allowable slump for concrete in the road slab shall be up-to ¾" but not more than ½" will be generally permitted.

Machine Mixing. All concrete used for road work shall be mixed in a batch mixer. The capacity of the drum shall be such that only whole bags of cement are used in each batch. Mixing shall continue for at least 1½ minutes after all materials, including water, are placed in the drum and before any part of the batch is discharged. The drum shall be revolved not less that 14 nor more that 18 revolutions per minute. The drum shall be completely emptied before receiving materials for the succeeding batch. The volume of the mixed material in each batch shall not exceed the mixer manufacturer's rated capacity of the drum.

Retempering. Mortar or concrete which has partially set shall not be retempered by being mixed with additional material or water.

Method of Construction. The alternate bay method of construction shall be adopted.

ALTERNATE BAY METHOD

(*a*) *Slab* :—The concrete road slab shall be laid in the alternate bay system and of the cross sectional dimensions shown on the plans. The length of the bay shall be determined by the Engineer to suit to the nature of the joints and the method of tamping. Where tamping is done from longitudinal side forms, the length of the bay shall be 33 feet.

(*b*) *Joints* :—The joints shall be plain butt joints at right angles to the longitudinal axis of the road. Expansion joints to be filled with approved material shall be provided at distance of about 100 feet.

(*c*) *Alternate Bays* :—The Engineer shall decide the order of laying the bays and also the time that shall elapse before commencing the intermediate bays. Before concreting in the alternate bays the ends of the completed slab shall be painted over by either a thick oil or bitumen whichever the Engineer shall decide.

(*d*) *Surface finishing* :— All tools used and the method used must be approved by the Enginner before work is commenced.

Screeding and tamping shall be carried out either for the transverse forms or from the side forms whichever the Engineer shall decide.

After the operation of screeding and tamping the surface of the slab shall be floated longitudinally. The final surface shall be given by means of a belt as described further on.

Placing concrete :—Concreting shall be placed only on a moist subgrade, but there should be no pools of standing water. If the subgrade is dry, it shall be sprinkled with as much water as it will absorb readily. It may be advisable to have the subgrade sprinkled or made thoroughly wet from 12 to 36 hours in advance of placing concrete, where such procedure seems necessary.

All operations from the time mixing water is added to the completion of the tamping shall be completed within the setting time of the cement.

The mixed concrete shall be deposited rapidly on the subgrade to the required depth, and for the entire width of the slab section in successive batches and in continuous operation without the use of intermediate forms, or bullheads between joints. While being placed the concrete shall be vigorously sliced and spaded with suitable tools to prevent formation of voids or honeycomb pockets. The concrete shall be especially well spaded and tamped against the forms.

All concrete shall be transported from the mixer or mixing board to the place of final deposit by methods which will prevent segregation or loss of the ingredients.

SURFACE FINISHING

Screeding and tamping. The concrete shall be brought to the specified contour by means of a heavy screed or tamper fitted with handles weighing not less than 7 pounds per linear foot and not less than 3 inches wide. This screed or tamper may be of steel or of wood. It shall be shaped to the cross section of the slab and have sufficient strength to retain its shape under all working conditions. The tamper or screed shall rest on the side forms and shall be drawn ahead with a sawing motion in combination with a series of lifts and drops alternating with lateral shifts of about an inch. At transverse joints, the tamper shall be drawn not closer than three feet towards the joint, and shall then be lifted and set down at the joint and drawn backwards away thereform. Surplus concrete shall then be taken up with shovels and thrown ahead of the joint.

Immediately after the screeding or tamping has been completed and before the concrete has hardened the surface shall be inspected for high or low spots and any needed correction made by adding or removing concrete.

Longitudinal Floating:—The entire surface shall then be floated longitudinally, with a float board not less than 12 feet long and 8 inches wide. This board shall have convenient plough handles at each end. It is operated by two men, one at each end, each man standing on a bridge spanning the road. The lower surface of the float board shall be placed upon the surface of the concrete with the long dimensions parallel to the centre line of the road. The float is then drawn back and forth in slow strokes about 2 feet long, and advancing slowly from one side of the slab to the other. The purpose of this operation is to produce a uniform, even surface on the concrete, free from transverse waves. The two bridges on which the workmen stand should be placed about 14 feet apart. When the entire width of the slab has been floated in this manner from the position of the bridges, they are moved ahead about 8 feet so that the next section to be floated overlaps the one previously so floated from three to four feet. After this floating has been completed and all transverse waves eliminated, the surface shall if necessary be finished by the belting process as indicated below.

Belting. The concrete shall be finished by using a belt of canvas or rubber, not less than 6 nor more than 12 inches wide and at least 2 feet longer than the width of the pavement. The belt is to be applied with a combined crosswise and longitudinal motion. For the first application, vigorous strokes at least 12 inches long are used, and the longitudinal movement along the pavement is very slight. The second application of the belt should be immediately after the water sheen disappears, and the stroke of the belt should be not more than four inches and the longitudinal movement should be greater than for the first belting.

(Where concrete is laid in 10 feet strips, one belting will generally be sufficient, and finishing operations can be reduced usually to two screedings and one belting).

Finishing at joints :—A suitable split float or split roller, having a slot to fit over expansion joints, shall be used at all joints. The device shall be so arranged as to float the surface for a width of at least $1\frac{1}{2}$ feet on each side of the joint simultaneously and shall be used in such manner as to produce a level surface across the joint. Edges of the slab at the sides shall be levelled for a width of 2 inches and transverse edges of the slab at the joints should be rounded to $\frac{3}{8}$ inch radius.

Trueness of surface. The finished surface of the slab must conform to the grade, alignment and contour shown on the plan, just prior to the final finishing operation, the surface should be tested with a light straight edge 10 feet in length laid parallel to the centre line of the road.

The maximum deviation allowed shall be $\frac{1}{4}$ inch in 10 feet.

Any deviation shall be immediately corrected.

Carborundum brick and water may be used to remove high spots.

Note :—The ideal concrete road surface should have a mosaic appearance, that is, the coarse aggregate is exposed and this can only be attained by reducing all finishing operations to a minimum, and by using as dry a mixture as possible.

CURING.

Protection :—Immediately after the final finishing operations, the surface of the concrete slab shall be covered with wet canvas or empty cement sacks. This covering shall be kept moist by spraying with water in such a manner that the surface of the concrete will not be damaged. The slab shall be kept moist until the concrete has taken its final set.

Wet Earth Cover :—As soon as it can be done without damaging the concrete, the surface of the slab shall be covered with not less than

6 inches of earth. The cover shall be kept continuously wet by spraying for 10 days after the concrete is laid, and the surface may be cleaned off at the end of 15 to 20 days.

Corners :—All corners of the completed bay are to be well covered with earth and kept moist.

Hardening concrete surface :—A solution of sodium silicate shall be sprayed from a watering can and continuously brushed over the surface with a soft broom for several minutes to obtain an even penetration. Three applications shall be given in this manner allowing 24 hours to elpase between each, and a canvas cover shall be replaced on the surface between each application.

The solution shall be in the proportions of one part of an 8 per cent solution of commerical sodium silicate to six parts of water. One hundred-weight of sodium silicate in a 1:6 solution covers 300 square yards in three coats.

This solution may be applied either 21 days after the initial set or immediately after the initial set. The surface of the concrete must be dry and free from dust before the application.

Clearing. After 21 days the earth or other cover may be removed.

Cold weather protection :—Concrete must not be mixed or deposited when the temperature is below freezing, except under such conditions as the Engineer may direct. If at any time during the progress of the work the temperature is, or in the opinion of the Engineer, will within 24 hours drop to 38° F. the water and aggregate must be heated, and precautions taken to protect the concrete from freezing until it is at least 3 days old. In no case shall concrete be deposited upon a frozen subgrade, nor shall frozen materials be used in concrete.

DISCUSSION.

The **Author** in introducing his paper apologized for bringing forward a subject very similar to one which had been before the Congress only a few years ago. His justification lay in the fact that during the last few years concrete has come to be recognized, almost universally, as the premier surfacing material for high class road construction. Also that many thousands of miles of concrete roads had now been laid in various countries of the world. He then proceeded to supplement his paper with the following remarks :—

" In the U.S.A., which produces approximately two-thirds of the world's supply of oil and bitumen, excellent concrete highways have been laid even in the shadow of the oil rigs of California while in Germany most of the new roads are concrete throughout, only about 5 per cent. of the total area having a bituminous surface, and about 3 per cent being surfaced with small setts. In India concrete is rapidly gaining ground over other types of road construction and the recent activities in this direction in Hyderabad State, Bombay Presidency, the U.P. and Delhi, all tend to show that a great field is open to the concrete road builder in this country.

The advantages of a concrete carriageway are its smooth riding properties, its durability, its low maintenance cost and the good definition it affords for night driving. It may be possible to give a wearing concrete surface a further lease of life by " retreading" it with a bituminous carpet or a new concrete slab. The only disadvantages are its fairly high cost, and possibly its rigidity: also the perfect connecting joint has yet to be devised. Research in this direction is well in hand, and before long we may hope to find a material which will prevent the extrusion of joint fillers. Extremes of temperature, as we have in some parts of the province, probably do more to disintegrate concrete than anything, else, but no one who has examined or travelled over some miles of concrete roads will doubt that the future of the world's principal roads will be intimately associated with the use of concrete.

At the very outset I should like to mention that the work reported on in the paper was largely experimental, and any failures which might occur should not be taken to mean that the use of concrete be banned as altogether unsuitable for this province, but as tending to show that further scientific investigation is necessary. The slab was laid on virgin soil, and the science of soil mechanics had been given little attention in this province when the work was carried out. It was hoped that a reasonable compaction with a steam road roller would be quite adequate to carry the slab, and the superincumbent load thereon. The soil was mostly clay, compacted in layers from time to time, but the behaviour of clay is so very uncertain, especially when moisture creeps in, that considerable doubt might reasonably be felt about the adequacy or proper bearing of the subgrade. When I inspected the road in December last after a sharp spell of cold weather, I noticed a few of the slabs had developed cracks. All that I could then ascribe these cracks to, was, perhaps, a faulty subgrade, but there is no doubt that the work needs to be watched carefully with an open mind and for a long time. In other places where concrete roads have been laid, and adequate uniform bearing surface has been provided either by rolling 3 inches of clinker or by consolidating stone metal or kanker. These items only put upon the cost, and if an economy can be obtained by their omissions, it seems certainly worth experimentation.

Another item that needs careful attention is the treatment at joints. In this particular case they had been filled with a patent bitumastic jointing material but it did not behave very satisfactorily. Some thing more elastic seems to be necessary.

The use of subgrade papers, which is now universally accepted as an essential adjunct of the concrete road, was only tried in a very short length; and the peculiarly interesting behaviour of the concrete in the slabs laid on the first day over this paper, is a matter which is worth pursuing still further. The cracks that appeared immediately after the initial set in the concrete, have not developed nor do they appear to have in any way weakened the structure of the concrete. It would perhaps be of interest to drill out cores from the two different slabs, and to compare their compressive strengths. A core-drilling machine is another asset which is essential for careful investigation of failures.

Another point that I would like specially to mention is the high compressive strength of concrete cylinders tested after 28 days at Rasul. These varied from 3,650 lb. per square inch to 6,950 lb. per sq. inch, while the average strength was 4,800 lb. per square inch. Even if on ordinary work a 20% reduction might be easily counted for it is obvious that a crushing strength of about 4,000 lb. per square inch might reasonably be hoped for. Is there any reason why we should adhere to the time honoured stress of 600 lb. per square inch in concrete design? The I. R. C. have in their new code of practice suggested a compressive stress of concrete as 750 lb. per square inch. Even this would give a factor of safety of over 5.

Perhaps we could increase the working stress still further and thus cut down the quantity of concrete in all structural work.

Perhaps a few words about the brick aggregate experiment would not be without interest. Even though the crushing stress of cylinders made with the aggregate was about 3,300 lb. per square inch the material does not seem to have behaved satisfactorily. Within less than 6 months after the section of the road was opened to traffic the surface developed pits and the cement mortar slurry on top of the concrete disappeared in most places, and brick aggregate started getting crushed under the weight of traffic. This tends to prove that brick aggregate is not at all suitable for this type of work. The slabs with 3″ section have also developed several cracks, thus showing that this section is perhaps inadequate for the loads that come on the road.

Sardar Sujjan Singh spoke of the difficulty in obtaining suitable fillers for the expansion joints in concrete road construction. He pointed out that they were nearly all patented materials and, while they might be suitable for one locality, they might not necessarily be suitable for all localities. He stressed the desirability of preparing a mastic, to be used as a filler, which would be suitable for local conditions.

This is particularly applicable to the Punjab, where the range of temperature to which roads are subject over a year might be as much as 140° F.

He suggested blown bitumen, sometimes known as 'Asphaltic Rubber', as a suitable material to be used in expansion joints in the Punjab. He further suggested that the blown bitumen might be mixed with sand in the ratio 70% sand to 30% blown bitumen. The bitumen to have a penetration of 40/50. The sand to be used should be capable of passing a 10 mesh screen but should be retained on a 200 mesh screen. The sand and bitumen to be heated separately to 375° F. and then mixed together and poured into the joint while still hot.

Mr. **R. Trevor Jones** stated that Mr. Nayar's paper was of great interest to road builders in this Province as our experience in concrete road construction is very small. Although the Punjab might have a reputation for good road construction nevertheless it is very far behind in concrete road construction. It seemed to him that the idea that concrete should only be employed for the use of bullock carts was a very misguided one. Why should we go to the trouble of making a road with such accuracy of detail and finish to provide for a vehicle which was originally designed many centuries ago to travel over mother earth? His opinion was that concrete should be used to withstand the effect of mixed traffic within circumscribed limits and that bullock carts should, where possible, be segregated from the main traffic.

He contented that, from the bullock carts' aspect, the road sections laid in miles 308 to 310 were a mere waste of money and that it would have been better from the point of view of safety of traffic to lay down a water bound road beyond the berms.

In regard to the note regarding brick aggregate on page 104, it is noticed that this is already showing signs of wear and it is apprehended that the exposed aggregate will before long get crushed under the weight of bullock carts. Recent tests on the road track at Calcutta have been very disappointing as regards the reputed hardness of Pathankot aggregate, and it is doubtful whether any of our stone available in the Province can resist for very long the abrasive action of iron shod wheels. Recently at the Roads Congress, there was some discussion as to the range of practicability of surface concrete roads. The opinion held appeared to be somewhat pessimistic. However, it is for note that the concrete bridgeway over the Chenab and Palkhu have been successfully surfaced and there seems no reason why a concrete road should show signs of wear and should not be thus rehabilitated.

It is of interest to note on page 103 that the cost is 23,000 a mile and the over-all cost is Rs. 3-11-0 per sq. yard. As our standard methods now-a-days of using water bound macadam, plus two coats of tar, cost Rs. 1-14-0 to 2-2-0 the case for increasing our concrete mileage appears worthy of consideration. Anyway, it is most desirable the small lengths of this nature are constructed with a view to gain experience in the technique, and the most suitable methods to be adopted, and Mr. Nayar's Paper is in this respect a very valuble one.

Mr. **Nayar** replied to the criticisms as follows :—

My apprehension is that the mastic proposed by S. Sujjan Singh may not be fluid enough to flow satisfactorily into the joints. The slabs laid on the alternate bay system have very little allowance for the mastic and it really requires a thin grade of bitumen to work satisfactorily into the interstices. It is for this reason that the premoulded joint filler is an advantage because then the concrete can be laid straight against the filler and thus an allowance for expansion is ensured. If the joints are to be filled in after the slabs have been cured slits will have to be left which might prove to be the weak points of the structure.

Certainly tar or non-elastic bitumens are not very desirable for filling in the joints because they become brittle and are liable to be knocked about. The real trouble with them is that they are bound to be squeezed out when the slabs expand but on contraction they cannot recede and thus fill in the voids. What is certainly needed is something that is elastic i.e., which can expand and contract with the changes in the voids and thus keep the joints always full. I have had no experience of "Blown Bitumen" referred to by the speaker but it would certainly be worth a trial.

In reply to Mr. Trevor Jones, I have to remark that segregation of bullock cart traffic from the fast vehicular traffic is the eventual solution of road problems in this country. But it will take many years before this can be adopted as a policy. An attempt has recently been made in some of the sections of the Grand Trunk Road to make a beginning in this direction and the results obtained so far can be called definitely hopeful.

The road which is the subject of my paper was primarily meant for bullock carts, but actually it is being used by motorists perhaps much more than by carts. The reason for this is obvious. The concrete track has been laid with great accuracy of levels and finished with great care, whereas the metalled and surfaced road alongside is rather uneven and rough. Attempts are being made to set it right but such attempts have not been very successful. It would have been an ideal affair to lay the whole of the road in concrete but this proposal was turned down on the score of expense. Perhaps in another ten years or so traffic will warrant the whole of the formation being surfaced with concrete.

Mr. Trevor Jones' observations regarding the hardness of Pathankote stone are rather disappointing for the average man. Pathankote Quartzite has been considered so far to be the best material available for roadwork and I am not sure whether anything better can be found in this Province. Granite would of course be ideal but it is hardly available. Till something better can be found we have got to rely on the Pathankote metal and hope for the best.