PAPER NO. 256.

SOIL STABILIZATION AS APPLIED TO ROADS IN INDIA

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Introduction

Soil is the oldest road-making material in use, and yet also unfortunately the one which is the least understood of all in its performance under traffic loads in changing weather conditions. The reason for this is two-fold.

Firstly, road making due to the ignorance of the laymen in power was, till comparatively recently, not recognized to be a science at all in different parts of the world, and so the question of any research in this direction just did not arise.

Secondly, when the authorities were, by conditions created by traffic, forced alive to the fact that there was some science involved even in road making, the pressure of traffic had become so intense that all the attention of the technical staff put on to road works was taken up in superimposing a hard metal crust over the earth subgrade in order to cope with the immediate pressing needs of traffic. No attention whatever was consequently paid either to the subgrade itself, in so far as its behaviour under the metalled pavement was concerned, or to the question whether it was possible to improve the soil as such for economical use in road making.

Having been lost sight of once, the subject remained in the background, till repeated mysterious failures of well-constructed pavements over defective ground drew the attention of the engineers to the ultimate foundation of the road, namely the subgrade.

America was the first country to start the study of soils, but it was not till as late as 1924, that a research section in soil mechanics in relation to roads was set up there. The reason for the setting up of soil research in America was also the fact that it was becoming more and more evident that unless a far cheaper method of road making than the ones in vogue was discovered for the very large mileage of roads required in agricultural areas, they will never be able to afford an efficient system of roads in that vast country. Energies were, therefore, directed towards developing a method of economically improving the soil as such, and using it for the making of roads, fit to take up the light agricultural traffic in changing weather conditions.

The Problem and its Solution

The case of this country is not very different. To metal all the roads in the country is, an obvious impossibility, financially speaking. We shall always have on our hands a very large mileage of unmetalled roads in rural areas which, in their present state, are not only frightfully uncomfortable during the dry weather, but are also impassable during the long rainy season. To improve these unmetalled roads in such a way that they will take throughout the year, the light mixed traffic that passes over them, without detrimental deformation is all we can wish for.

Fortunately for us, America has already developed and tentatively standardised a system of soil research applicable to road making, and all that is required to be done is to adapt that system to the particular requirements of this country with respect to the prevailing traffic and climatic conditions and also the materials locally available. It would obviously be waste of time and money to try and develop an independent system of our own, even if it was possible to do so.

The laboratory study of soils in relation to roads was inaugurated by the Central Government in July, 1937, when a yearly subsidy was granted to the Punjab Irrigation Research Institute, where the fundamental study of soils and the action of salts thereon has been carried out.

In addition to this, the writer, backed by his private laboratory, has been carrying out some field experiments on behalf of the Punjab Government, on the American system since 1937.

Soil Stabilization Theory in Simple Language

The writer has already described all the details of the laboratory procedure and the actual execution of work in the field, on the platform of the Indian Roads Congress from time to time*, and it is not intended to repeat them in this paper. But it will perhaps not be out of place here to give a brief general outline of the American system of soil stabilization that is being followed in the Punjab.

Soil is treated as a mixture of sand, silt and clay, and the functions of these three ingredients within the mixture are very much the same as those of shingle, sand and cement, in concrete. Sand provides

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*1. "The use of soil stabilization in unmetalled and metalled roads in India"—S. R. Mehra.

Proceedings of the 5th Indian Roads Congress, 1939, held at Calcutta.

2. "Stabilization of the unmetalled Berms of Metalled Roads"—S. R. Mehra.

Proceedings of the sixth Indian Roads Congress, 1939, held at Bombay.

3. "The use of soil stabilization in unmetalled and metalled roads in India—II"—S R. Mehra.

Proceedings of the seventh Indian Roads Congress, 1941, held at Delhi.

4. "A lecture and demonstration, on soil stabilization methods, before the council of the Indian Roads Congress at Delhi"—S. R. Mehra.

Proceedings of the seventh Indian Roads Congress, held at Delhi.

structural stability specially in the wet; silt acts as a filler and provides embedment for the sand grains, and clay acts as a binder and provides stability in the dry.

The reason why some soils behave differently from other soils in similar weather conditions is that they contain different percentages of the three essential ingredients—sand, silt and clay.

If a soil contains an excess of sand, it will behave well in the wet, due to the internal friction obtained by the sand grains by virtue of surface tension of water; as soon it gets dry and the moisture evaporates, it will break down quickly under the load as the dry sand grains will then tend to slip over one another.

If, on the other hand, a soil is extra rich in clay, it will wear well during the dry, owing to the binding power of clay. But, when it gets wet, the clay will lose its stability and act as a lubricant, and the soil crust will break down quickly under traffic loads.

The soil, which has no stability either in the dry or in the wet, is the one predominating in silt, which is so fine and devoid of binding properties that it has neither any internal friction in the presence of moisture nor any cohesion in the dry state.

The Mixing of Soils

In order to stabilize a soil, therefore, it is necessary to analyse it and to find the proportions of the various ingredients present, to see if and to what extent it is lacking in any of them.

The percentage of sand is determined by sieving the soil through a standard nest of sieves. The extent to which clay is present is indicated by a simple number called the Plasticity Index, which is the numerical difference between the soil constants Liquid Limit and Plastic Limit. The Liquid Limit and the Plastic Limit are determined by simple laboratory experiments.

From this data the required information regarding the proportions of various ingredients present in the soil becomes available and by collecting similar data for the admixtures locally found, a suitable mixture can be easily designed for the particular requirements of traffic and climate.

Compaction of Soils—"Optimum Moisture"

Soil is capable of compaction to such an extent that it can be rendered fairly waterproof. This can be done by compacting it by means of a Sheep's Foot Roller, at a moisture content indicated by the "Optimum moisture" of the particular soil.

A full-size Sheep's Foot Roller, driven by a tractor, is an expensive affair, and is useful for big projects. But a small roller for use on small projects can be locally made for a matter of a couple of hundred rupees and can be driven by bullocks. (*See* fig. 3.)

"Optimum Moisture" can be determined by a simple laboratory experiment.

Surface Abrasion—Granular Material

Soil as such, when properly graded, offers very little resistance to surface abrasion. The addition of a certain percentage of locally available hard granular material, in the shape of kankar or grit or brick bajjri, specially on the top of the crust, provides the abrasive resistance required and protects the crust from rapid wear under traffic. The most suitable size of granular material is $\frac{3}{4}$ inch downwards (graded).

In addition to providing resistance to surface abrasion, the presence of granular material also affords increased structural stability to the soil crust, the increase depending on the percentage of granular material present.

From the analogy of cement concrete the percentage of granular material for maximum stability should be about 75. But in a stabilized soil crust, it is advisable that the individual fragments of the granular material should be protected by a cushion of soil, and not lie rubbing against one another, as in the case of cement concrete. The granular material which is generally economically available for soil stabilization in this country, such as Kankar or Brick bajjri, is not very hard. A certain amount of crushing of weak protruding corners in contact, of adjoining fragments, is caused by the direct action of load. Also the fast-moving traffic sets up a lot of vibration in a crust of this nature and if the fragments are not padded, as it were, by a thickness of soil all round, there is a danger of the adjoining fragments wearing off by rubbing against one another in the body of the crust, and causing numerous weak spots in the form of minute voids, which would cause small depressions all over the surface when the crust gets further compaction from passing traffic loads. This action would also tend to break up the structural stability of the crust in the dry weather. Consequently, it is advisable to keep the percentage of granular material in stabilized soil only about 35 to 45 per cent. so as to allow space for earth cushioning round the fragments. Incidentally this also results in considerable economy, which is a great consideration in low cost roads.

Detrimental Salts

The most important thing that has to be guarded against in the construction of stabilized soil roads is the presence of detrimental salts in harmful quantities which render perfectly good pavements soft and fluffy in winter.

Very little, if anything, was known about the action of these salts, popularly called "Phulna Kallar," and the lack of this knowledge was a great handicap to any experiments on soil stabilization in this province at least, as such salts are very common here.

Thanks to the work done by Dr. McKenzie Tayler and Dr. Puri, in the Punjab Irrigation Research Institute, in connection with soil road research for the Government of India, the action of the salts is now exactly known, and the road engineer is thus in a position to devise ways and means for counteracting them.

The detrimental salts are Sodium Sulphate and Sodium Carbonate, the former being predominant but the latter very rarely present in detrimental quantities in this province.

The action of Sodium Sulphate is, that it hydrates and dehydrates with the atmospheric temperature and humidity alternating above and below 30° c and 80% respectively, and in its crystalline state it increases in volume to 1·88 times its volume in the amorphous state. Further, it is soluble in its own water of crystallisation.

Now in winter specially, when the changes of temperature and humidity are very favourable for the hydration and dehydration of the salt present in a compact layer of soil, the alternating volume changes break up the structure of the soil crust; and the soil grains pushed out of position on hydration of the salt being unable to fall back into their position when dehydration takes place, the famliar loose and fluffy condition of the soil is brought about, that is of course if the salt is present in sufficiently large quantities for the particular soil. The salt being also soluble in its own water of crystallisation, does not require outside moisture to travel upwards when evaporation takes place at the surface. The breaking up of the crust starts at the top and goes downwards.

The action of Sodium Carbonate is more or less the same.

The remedy that suggests itself, to protect the road crust from salt action from underneath, in a salt affected area, is to interpose a layer of cellular material which will stop the rising of salts from below due to its lack of capillarity. Experiments on a small scale have shown that a three-inch layer of ordinary pit sand or any other equally sharp sand prevents the rising of salts. Experiments on a larger scale are in hand.

It is also evident from this that a soil containing such salts in detrimental quantities is unfit for use in stabilizing the road crust. Careful local enquiries as to whether any particular area gets soft and fluffy during winter, and making a practice of avoiding grassless areas for the making of borrowpits, will in most cases meet the situation.

Field Experiments

Following is a brief description of some of the more important experiments carried out by the Punjab Government:

Experiment I (Figures 1 to 5)

Constructing a link road to Kot Lakhpat Railway Station, from mile 8 of Lahore-Ferozepur-Ludhiana Road.

This experiment was undertaken only to see what is the best that a stabilized road is capable of. The road carries almost as much traffic as the Lahore-Ferozepur-Ludhiana Arterial road, which is metalled and surfaced, and widened to 18 feet. The traffic is about 1,300 tons per day consisting of bullock carts, heavy motor trucks, etc.

The link was completed in December, 1939, and is now over two years old.

The traffic being exceptionally heavy for this kind of construction, it was decided to give it a proper foundation, which consisted of 5 inches of loose graded soil, compacted at "Optimum Moisture" by means of a Sheep's Foot Roller. The top crust consists of 5 inches (loose) of graded soil, with 40 per cent. granular material in it. The centre 9-foot width being of the above specification, a 3-foot wide berm was added on each side, consisting of only a wearing course of 5-inches (loose) graded soil, with 40 per cent. granular material on the top 2 inches (loose) only. The total formation width of the road is 20 feet.

This road was constructed in three different specifications.

In the first length of 3 furlongs the soil was properly balanced and crushed brick was used as granular material. This section has behaved excellently for over two years now. There has been as much as three inches of rain overnight, and the traffic has continued to pass without any trouble and without making any ruts due to softening. There have been dry spells lasting over three months, and though due to shortage of water it has not been possible to give the monthly sprinklings of water that a crust of this kind should get, there has been no rutting whatever. The road did, however, get slightly dusty, but not more so than a metalled road without surface treatment.

In the second length of 2 furlongs, the granular material used was local kankar and an excess of clay was deliberately used in the soil mixture. The idea in using excess clay was to determine the maximum possible proportion of clay that could be used in this locality, without the crust getting too soft during wet weather. It was intended to add controlled quantities of sand, till the crust started behaving well, so that the optimum proportions of ingredients may be determined. Measured quantities of sand were spread on the softened crust during the wet weather and traffic allowed to pass over it, so as to mix up the sand. The experiment was a failure, because of uneven mixing of sand under traffic and this portion has been persistently patchy.

In the third length of 3 furlongs the soil was properly balanced, and the granular material was kankar. This portion behaved perfectly during the summer, but started getting soft and fluffy during winter. On analysis it was discovered that the soil contained as much as 3 to 4 per cent. of Sodium Sulphate (kallar). This came as a bit of a shock, because the soil used in the road crust was free from Sodium Sulphate. On investigation, however, it was found that the pond water, which had been used in this area for compaction of the road crust, was saturated with Sodium Sulphate. It was found necessary to use this pond water, as the irrigation water supply failed us at the eleventh hour and at the time it was not suspected by the staff that the water contains Sodium Sulphate.

In lengths 2 and 3, it has also been noticed that the kankar used is not strong enough for the extra heavy traffic that the road carries and is getting crushed under the wheels. The crushed brick, on the other hand, in length I is behaving magnificently.

The cost of the different parts of the road crust are as follows :

Foundation for the centre 9 feet portion .. Rs. 500 per mile
Wearing course for centre 9 feet portion .. Rs. 1,500 per mile.
Berms 6 feet wide in all .. Rs. 800 per mile.

Experiment II (Figures 6 and7) .—Stabilized soil road in mile 42 of Hoshiarpur-Bharwain Section.

This experiment was undertaken to see what are the possibilities of soil stabilization in a submountainous country with a sandy strata and frequent rainfall. This mile lies between two hill torrents (*chows*) and the soil was purely sand. The average rainfall in this area is about 40 inches. During the short dry spells, the road used to break up badly under the mixed bullock cart and lorry traffic that the road carries, the total average traffic being 122 tons per day.

A clay deposit was discovered close to the site and gravel $\frac{3}{4}$ inch downwards, was collected from nallahs close by.

The soil mixture was designed with a lesser percentage of clay than in Experiment I, because of the wetter climate, and also because it was intended to surface-treat the road after it had received its final compaction under traffic during the rainy season.

The existing foundation as improved by the ordinary maintenance gangs in the course of their work was considered adequate. A wearing course of 5 inches soil (loose) including 40 per cent. gravel $\frac{3}{4}$ inches downwards, was provided.

Due to various reasons, it was not possible to surface-treat the road for many months after the rainy season, with the result that it started showing patches in places during dry spells.

Tarring was consequently done after giving the surface a tack coat of a cold penetration bitumen cutback, but in order to make up for the slight damage caused due to the delay in surfacing, the cost of the same was higher than what it normally should have been. The road is reported to be behaving very well.

The cost of this work excluding the surfacing was Rs. 1,450 per mile 12 feet wide or Rs. 1,100 per mile 9 feet wide. The exact figures for the cost of surfacing are not yet available but under normal conditions it should not be more than Rs. 330 plus the cost of ordinary surfacing over water-bound macadam.

Experiment III.—The use of stabilized soil foundation in widening miles 8, 9, 10 (part), 11 (part), 27, 28, 29, 31 and 33 of Lahore-Ferozepur Road.

With a view to reducing the cost of foundation course, a stabilized soil foundation was used in the widening of the above-named nine miles. 4½-inches thickness (loose) of graded soil, containing 40 per cent. of kankar, was compacted at optimum moisture, and the wearing course was consolidated over it and surfaced in the usual manner.

The experiment is over one-year-old and is behaving very well.

The cost of the foundation course on the average was Rs. 650 per mile 6 feet wide.

Experiment IV (Figures 8 to 10).—Stabilizing the *kacha* berms in miles 10 and 11 of Lahore-Ferozepur Road.

The dustiness of the berms of this road in crossing and overtaking used to be the talk of the province. Miles 10 and 11 used in addition to be dangerous in the wet weather through slipperiness. The soil in these two miles was the worst type of cohesionless silt.

On digging up, it was found that below about two inches of soft silt the foundation was quite firm and consisted of well-graded soil. It was, therefore, decided not to disturb this good foundation, and to put down 3 inches (loose) of graded soil including 40 per cent. kankar.

The centre metalled width of road being 12 feet, a width of five feet on each side of it was stabilized, making a total usable width of 22 feet.

The experiment was completed in December, 1939, and was in excellent condition in March, 1940, when it was decided to surface-treat three-foot width on each side of the metalled edge, in order to conform to the rest of the road which had by now been widened (metalled and surfaced) to 18 feet.

The general wear on the stabilized berms, during the 15 months before surfacing them, was of the order of about half an inch, and in the ordinary case, it would have been all right to surface-treat them after applying the necessary tack coat. But in many portions the stabilized berm had to be kept about an inch lower than the level of the road, due to defects in the metalled surface, and so in order to make up the levels, a skin of stone metal was grafted on the stabilized crust in these portions and surface-treated in the ordinary manner.

During the 15 months before surfacing, the stabilized berms behaved perfectly during the dry as well as during the wet weather, and whereas before stabilization, the traffic, in crossing or overtaking, used to wander away and spoil the whole width of the berm; after stabilization, it used the 5-foot wide stabilized strip on each side of the metalling with perfect confidence for crossing or overtaking, with the result that the rest of the berm, still *kacha*, was left in good condition and required no attention. The service value of the road was, to all practical purposes, comparable to that of a 22-foot wide metalled and surfaced road.

The cost of this work was Rs. 900 per mile, 10 feet wide in all.

Economic Possibilities

Low Cost Roads.—The economic possibilities of soil stabilization are unlimited. The cheapest all-weather road, *viz.* a water-bound macadam pavement surfaced with tar, costs about Rs. 10,000 for a 9-feet wide mile.

According to the current practice of road making, therefore, an all-weather road can be provided only if the considerations of traffic and the economic position, justify spending Rs. 10,000 per mile at least, on the pavement alone. It is needless to say that under these conditions the opening up of most rural areas in this agricultural country, will remain an economic impossibility.

With the help of soil stabilization, on the other hand, it is possible to provide a fairly comprehensive range of pavements to suit various intensities of traffic at compatible costs. The types shown in fig. 11 give an idea of the kind of pavement, the average cost and the intensity of traffic that each type is considered fit for.

This straightaway makes the conversion of numerous miles of fair-weather roads into all-weather roads, an immediate economic possibility.

Berm Stabilization.—Taking the case of the unmettalled berms of metalled roads, these are a potential source of danger to the modern fast traffic. Except in the case of three small sections of road in the whole province, where the metalled width allows two lanes of traffic, the width of metalling ranges from 9 to 12 feet only, with the result that use has to be made of the unmetalled berms, by one or both vehicles, every time one vehicle crosses or overtakes another. In the dry weather there are clouds of dust set up, which cut out all vision in front and in the wet weather there is always the danger of skidding.

The obvious remedy is to widen the metalling. But this is a very expensive affair, not only in the first cost which is about Rs. 1,000 per foot mile, but also in maintenance which is about Rs. 100 per foot mile extra every alternate year, and with the amount of money available annually for such work, it will not be possible to keep pace with the growth of traffic.

Stabilization of berms, on the other hand, will in most miles cost not more than about Rs. 900 for a width of 10 feet, *i.e.* 5 feet on each side of the metalling. The wear on the surface being of the order of about $\frac{3}{8}$ inches per year, the first cost of such a crust can be spread over about 5 years, *i.e.* Rs. 180 per year. Allowing Rs. 70 per year for maintenance, *i.e.* $\frac{1}{4}$th of a cooly per mile (Rs. 36) and Rs. 34 for patch materials, the cost including maintenance of providing a five-foot wide stabilized berm on each side of the metalling, would thus be about Rs. 250 per mile per year, as against Rs. 225 per mile per year, already being spent by the Punjab P.W.D., B. & R. Branch, for the upkeep of berms in their present dangerous state. So that, for an extra Rs. 25 per mile per year, you will have roads which will be safely negotiable in all kinds of weather. It is noteworthy that after this much width of the berm has been stabilized, the traffic confines itself to this width and leaves the remaining unstabilized part of the berm intact.

Base Stabilization.—Considering the use of a stabilized soil foundation for the metalling of roads, the cost of such a foundation being only Rs. 108 per foot mile, as against Rs. 356 for a brick on edge and Rs. 237 for a flat brick foundation, the great economy involved is self-evident. An additional advantage is, that whereas a brick soling is perfectly useless for the dispersion of wheel loads, a stabilized soil foundation disperses the loads in the same way as the metalling on top, and thus helps in keeping down the intensity of pressure on the subgrade, which in turn adds to the life of the road.

Surface-treatment of Stabilized Soil Pavements.—Now that it has been possible to surface-treat a stabilized soil crust successfully, it is for consideration, whether the orthodox type of crust, *viz.* the water-bound macadam, should not be gradually replaced by the more scientific stabilized soil crust.

The water-bound macadam has one very great drawback. It is essentially a cellular mass and under the combined action of the static load and the fast-traffic vibration, the sharp interlocked corners of adjoining pieces of metal, get rubbed off in course of time, causing local settlements in the body of the mass, which are seen on the surface in the shape of ruts and small depressions. The proof lies in the fact that when an old water-bound crust is dug up, the pieces of metal no longer have sharp corners, but are found to be rounded off all over.

A recognized practice now, to counteract this drawback, is to spread a layer of "good clay" under the wearing coat, so that during consolidation with water, the "good clay" should work upwards towards the surface and fill up the voids. This process certainly minimises the drawback, but does not remove it. There being always an excess of water in water-bound consolidation, when the "good clay" in the crust dries out, a certain percentage of voids are formed again. Besides, more often than not "good clay" is not available at site and whatever stuff is available, is made use of. In any case there is no definition of this "good clay" given anywhere.

If a stabilized soil crust were to be used instead, with the usual 40 per cent. granular material, the elastic padding provided by the soil round the fragments of granular material, will prevent them from abrasion within the crust. Further, the mass having been compacted to the fullest possible extent at "Optimum Moisture," there will be no further possibility of any more compaction under traffic, with the result that there will be no forming of ruts or small depressions, as in the case of water-bound macadam. It is also to be noted that the stabilized soil crust will be much cheaper than the water-bound macadam crust as the quantity of granular material will be only 40 per cent.

Conclusion

It may be argued that the work is yet essentially in an experimental stage in this country, and that therefore bold conclusions cannot be drawn from small experiments.

This is true enough, but the point to be considered is that unless large-scale experiments are undertaken, how will this work ever get out of the so called experimental stage? If the system can be made a success in America, where thousands of miles of road have been already constructed and have been in use for over a decade, there is no reason why similar success cannot be obtained in this country by suitably adapting the system to its peculiarities of traffic and climate.

From his personal knowledge of the vast improvement made in hundreds of miles of unmetalled roads in Sweden and Norway by the scientific use of soil, the writer is convinced that there is a great and a definite future for this subject in India.

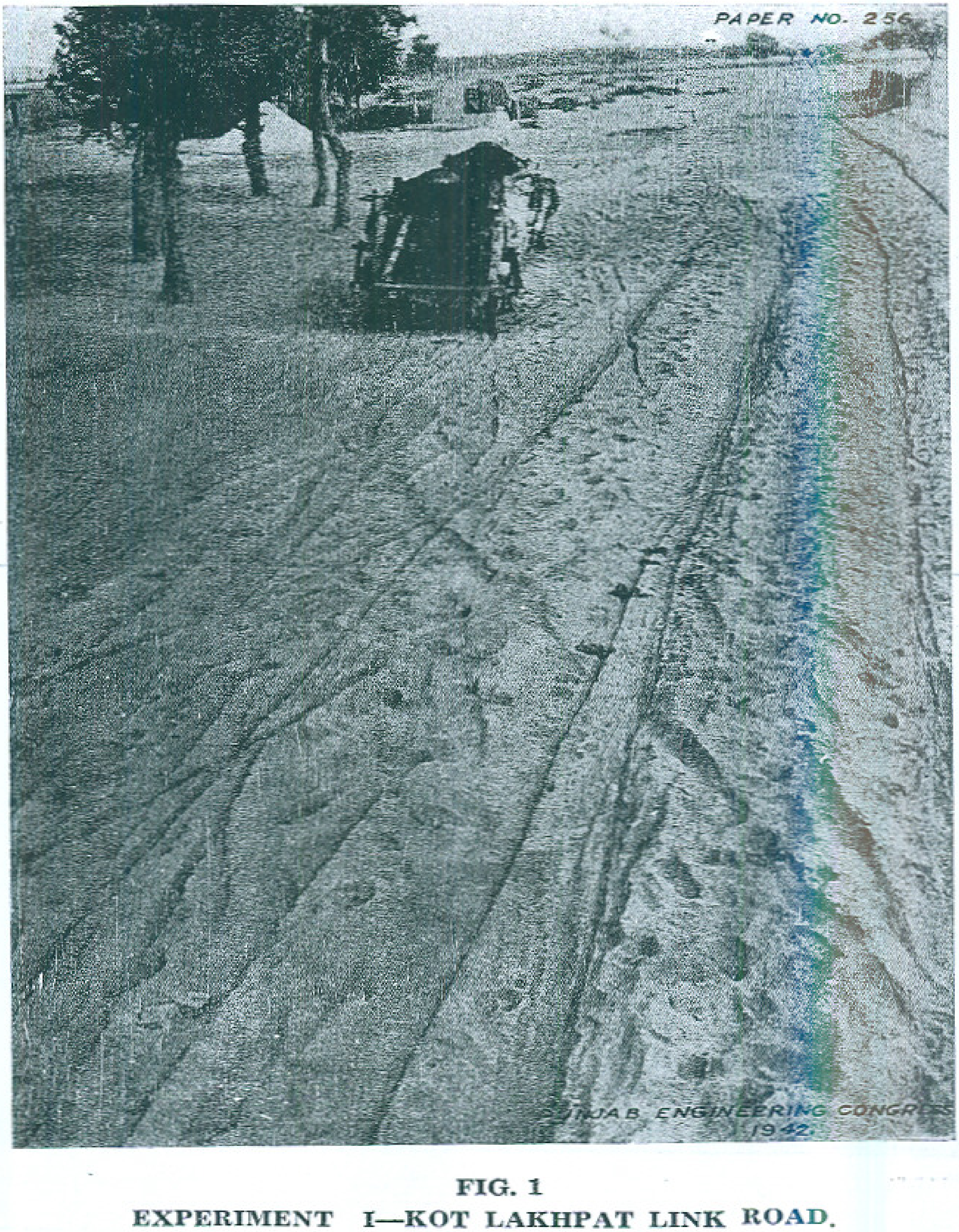

FIG. 1

EXPERIMENT I—KOT LAKHPAT LINK ROAD.

SHOWING THE STATE OF THE STABILIZED AND UNSTABILIZED PORTIONS IN THE DRY WEATHER. STABILIZED PORTION IS IN THE BACKGROUND.

FIG. 2

EXPERIMENT I—KOT LAKHPAT LINK ROAD.

SHOWING THE STATE OF THE STABILIZED AND UNSTABILIZED PORTIONS IN THE DRY WEATHER. STABILIZED PORTION CAN BE SEEN IN THE BACKGROUND.

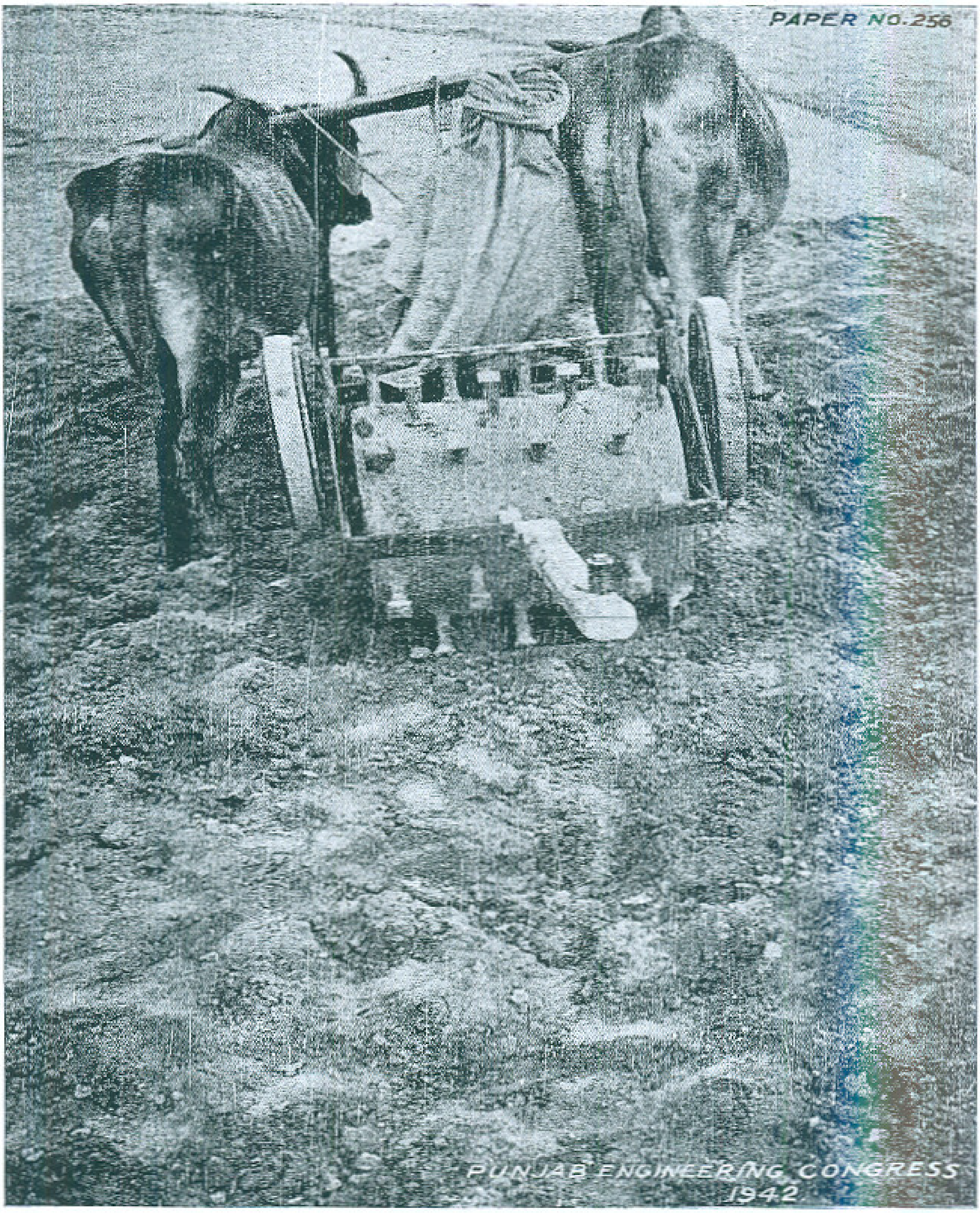

FIG. 3

EXPERIMENT I—KOT LAKHPAT LINK ROAD.

SHOWING A SMALL SHEEP'S-FOOT ROLLER DRIVEN BY A PAIR OF BULLOCKS.

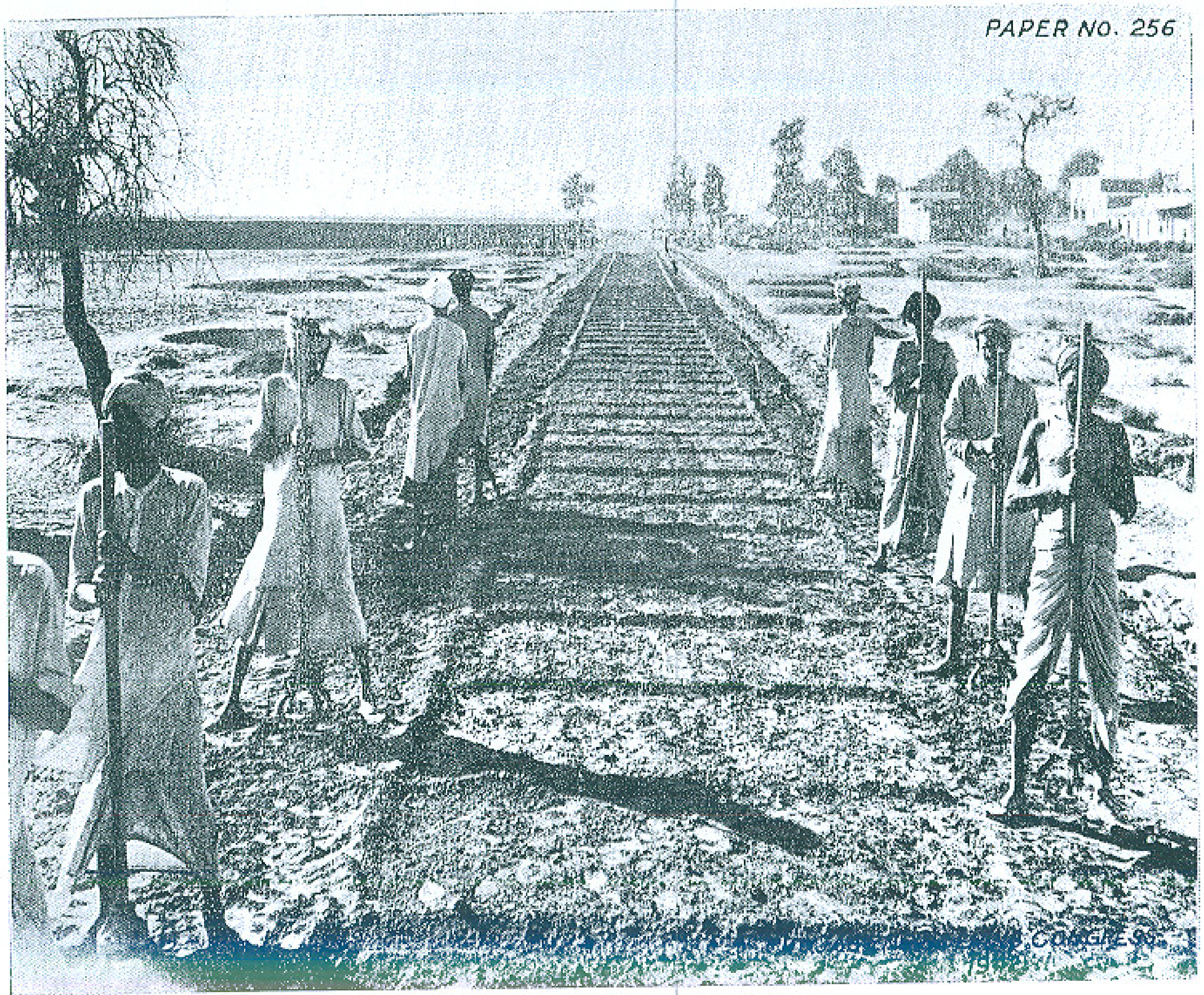

FIG. 4

EXPERIMENT I—KOT LAKHPAT LINK ROAD.

SHOWING THE COMPACTION OF BERMS WITH SHEEP'S FOOT RAMMERS

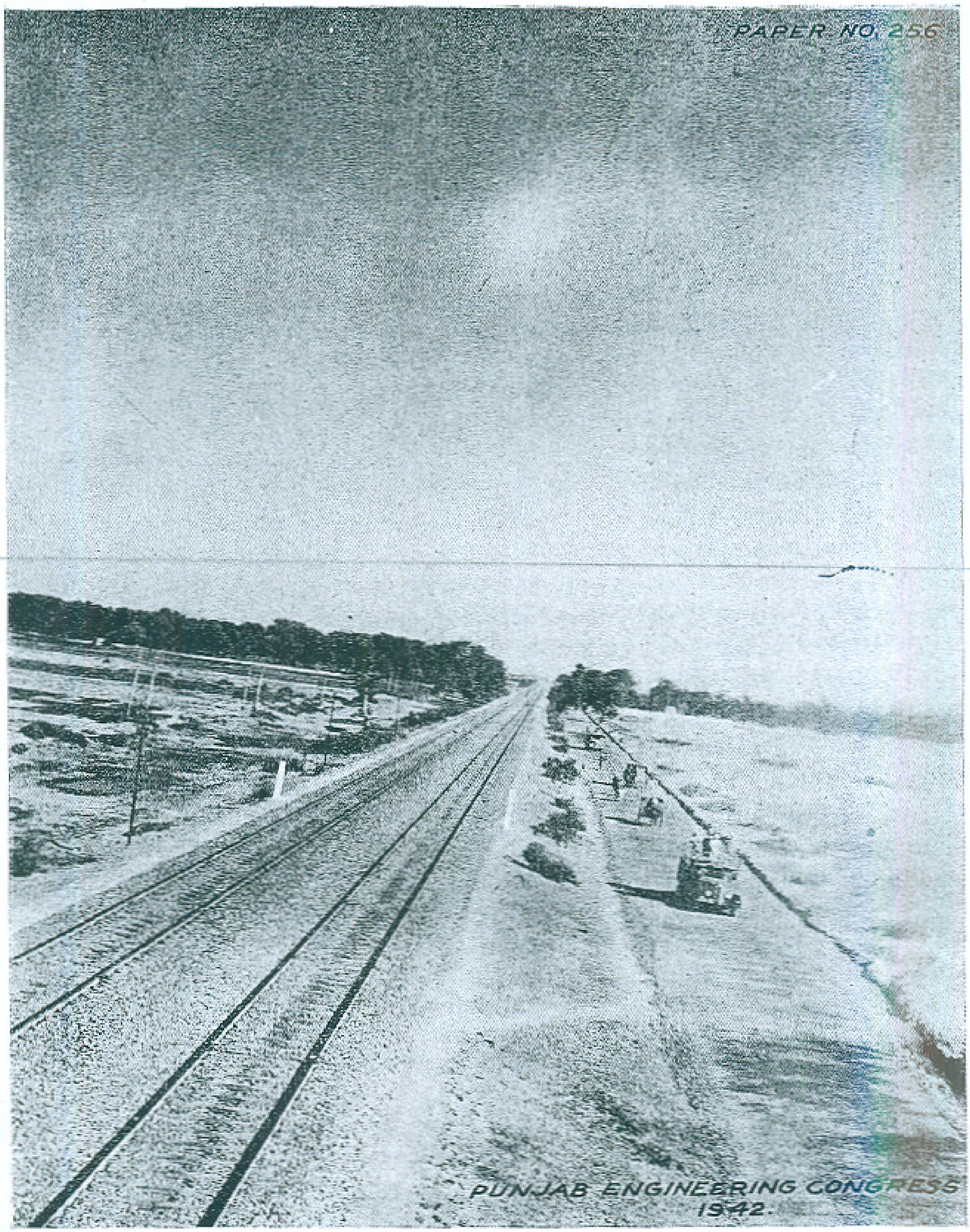

FIG. 5

EXPERIMENT X—KOT LAKHPAT LINK ROAD.

THE FINISHED ROAD AFTER IT HAD BEEN UNDER TRAFFIC FOR TEN MONTHS.

FIG. 6

EXPERIMENT II—HOSHIARPUR-BHARWAIN ROAD.

SHOWING THE STATE OF THE STABILIZED ROAD, IMMEDIATELY BEFORE THE COMMENCEMENT OF SURFACING, A YEAR AFTERWARDS.

FIG. 7

EXPERIMENT II—HOSHIARPUR-BHARWAIN ROAD.

SHOWING THE SURFACING IN PROGRESS. THE TACK COAT CAN BE SEEN IN THE BACKGROUND.

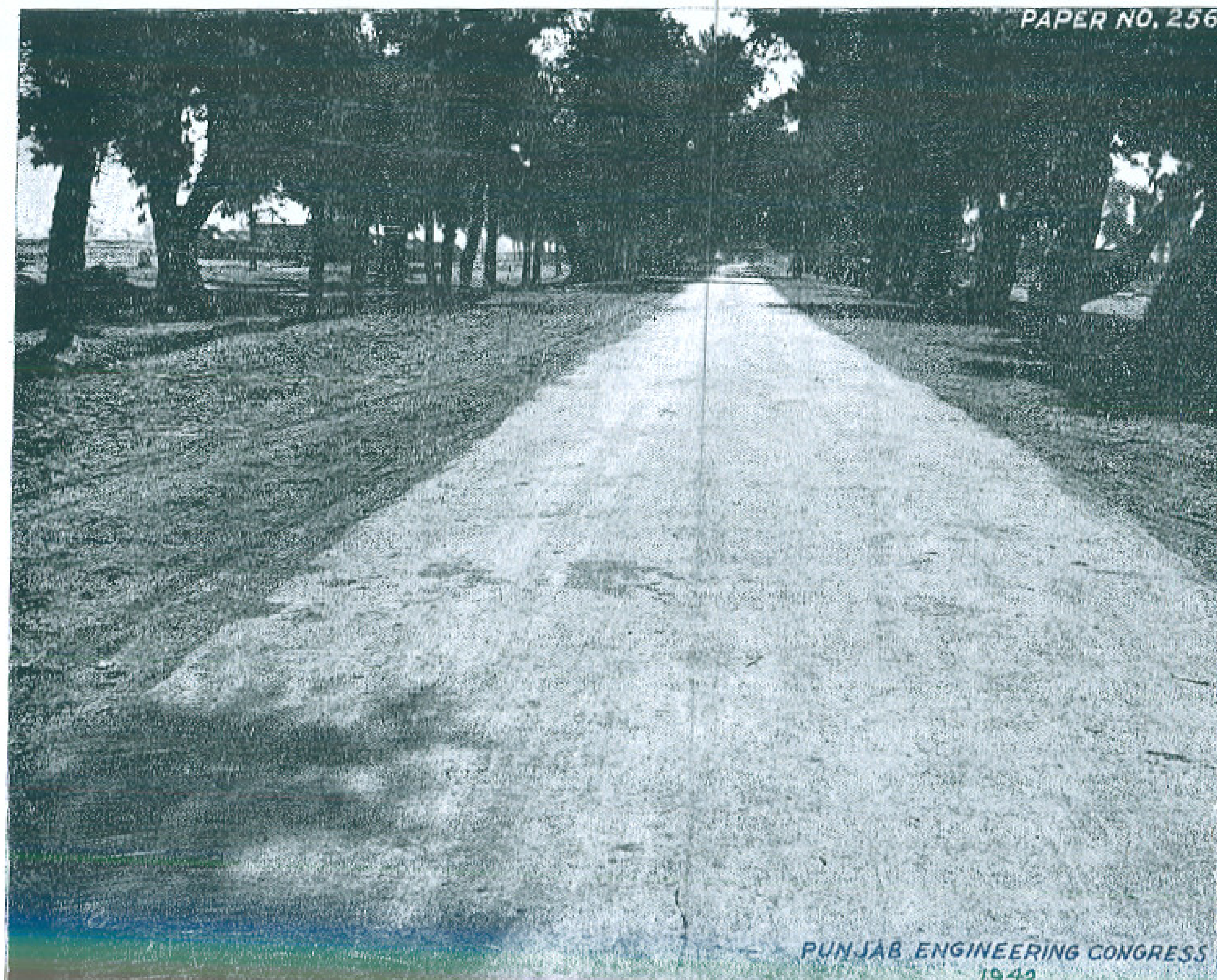

FIG. 8
EXPERIMENT IV—BERM STABILIZATION ON LAHORE-FEROZEPUR ROAD.
THE STATE OF THE BERMS "A" BEFORE STABILIZATION.

FIG. 9

EXPERIMENT IV—BERM STABILIZATION ON LAHORE-FEROZEPUR ROAD.

WORK IN PROGRESS.

FIG. 10

EXPERIMENT IV—BERM STABILIZATION ON LAHORE-FEROZEPUR ROAD.

STATE OF THE BERMS SIX MONTHS AFTER COMPLETION. THE UNSTABILIZED PORTION OF THE BERM IS ALSO IN GOOD CONDITION.

FIG. 11
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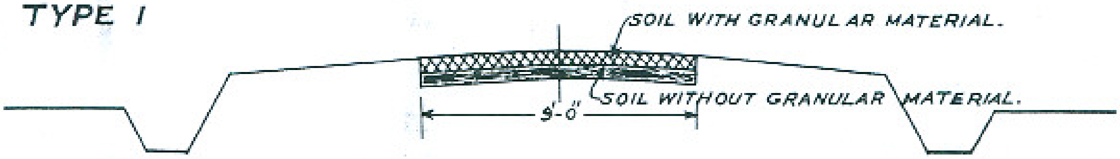
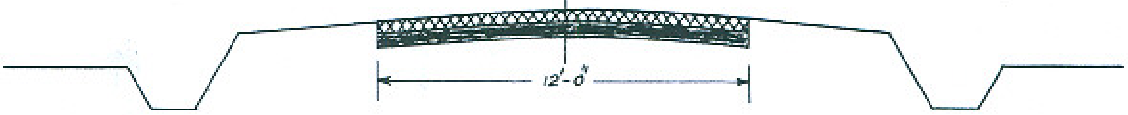
5" LOOSE SOIL COMPACTED WITH SHEEPS FOOT ROLLER WITH 40% GRANULAR MATERIAL IMPREGNATED IN THE TOP 1½ INCHES ONLY. COST RS. 750/- PER MILE. 9' WIDE. TRAFFIC UPTO 100 TONS. PER 24 HOURS.

TYPE I



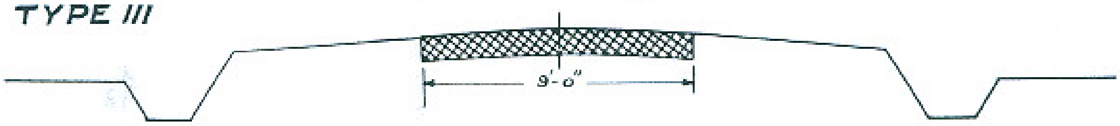
SAME AS TYPE. 1. BUT 12 WIDE.
TRAFFIC UP TO 200 TONS. COST RS. 1000/- PER MILE.

TYPE II



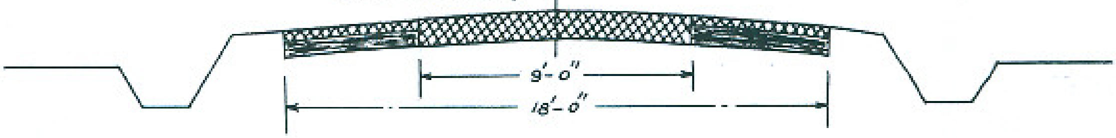
5" LOOSE SOIL MIXTURE 60% SOIL 40% GRANULAR MATERIAL 9' WIDE. TRAFFIC UP TO 500 TONS.
COST RS. 1250/- PER MILE.

TYPE III



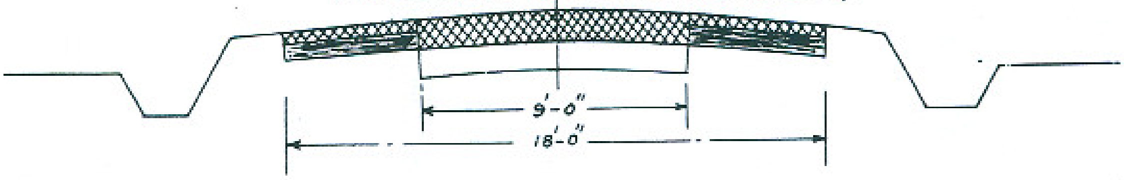
CENTRE 9' SAME AS TYPE. III.
4½' WIDE BERMS. SAME AS TYPE. I.
TRAFFIC UP TO 750 TONS.
COST RS. 2000/-

TYPE IV



CENTRE 9' FOUNDATION COURSE 5" LOOSE SOIL MIXTURE COMPACTED WITH SHEEPS FOOT ROLLER.
WEARING COURSE SAME AS TYPE. III.
4½' WIDE BERMS SAME AS TYPE. I.
TRAFFIC UP TO 1000 TONS. COST RS. 2500/-

TYPE V



TYPE VI

SAME AS TYPE. V. BUT SURFACE TREATED WITH TAR OR BITUMINOUS BINDER.
TRAFFIC UP TO 2000 TONS.

PUNJAB ENGINEERING CONGRESS
1942.

DISCUSSION

MR. MEHRA while introducing his paper remarked that his paper might rightly be described as being rather sketchy and lacking in detail, but there was a definite purpose in that.

He said that the subject of soil mechanics had been persistently considered by the highway engineer in this country, to be a legacy of the scientist only and had consequently been left alone. It was true that without the help of the scientist they should not have had available the data and information required for the solution of their great problem of the low-cost road that they now had. For that they were of course deeply indebted to the scientist. But it must not be forgotten that there was a limit up to which the scientist could go towards the solution of the engineer's problem and it was not his fault either, because he had had neither the necessary engineering training nor the essential engineering experience required to solve the problem outside his laboratory. Therefore, it was the highway engineer, and not the scientist, who would be required ultimately to find a practical solution for this problem.

He further stated that he had avoided detail of theory in his paper, as he knew from personal experience that the subject was far from having been universally studied yet, and as such this detail would interest very few people. He had made it the object of this paper to make out in a general way a case for the use of soil stabilization for low-cost road construction, and thus to get more highway engineers interested in the immense possibilities of the subject, than there were at present.

This was hardly a task that could be tackled by one, or even a few people. This was a problem that must be attacked by all the highway engineers together.

He concluded by saying that there was one appeal he had to make to his brothers in profession. That was not to go looking for soft spots only in this new venture, lest they got lost in them, because there were bound to be very many. They should look for some good ones also, as those were the ones which were going to provide them with the courage to assume the responsibility for the stupendous task of finding a solution for the low-cost road problem in this country, which they would have to do sooner or later.

MR. SAWHNEY thanked the author for writing this paper on a very urgent and important subject concerning our country. He did not agree with the twofold reasons given by the author. In his opinion, it was the scientific outlook of the Road Engineer for the introduction of new and advanced methods and the great opportunity for the supplier of materials to make money that put the usage of sub-grade for road making out of thought. He invited attention to the huge buildings and monuments that were put up all over this country and some of them even at not very easily accessible sites, in the past, and to which no roads seemed to join with quarries. This could not have been accomplished if they did not use the sub-grade thoughtfully. The troubles caused by the automobile, one of latest tools of civilization, were no doubt not known to them in the past, and it was to guard against damaging action by such traffic only that the present-day Engineer had freshly to think about, the rest of the trouble being ages old. It would thus be worthwhile to enquire into what was done in this country in the past, and at the same time follow the best that we could copy out of the American experience; but should not wholesale go in for following what was done or had been in America even if better and more suitable solutions could be found at home.

He remarked that what had already been done in connection with berm and base stabilization and surface treatment was really a great step towards advancement. He hoped the good results obtained from these experiments coupled with the encouraging conclusions arrived at by the author, would be sufficient inducement for the department to go ahead with a really big programme of soil stabilization of unmettled road all over the province. The District Boards spent a very considerable amount each year on the so-called maintenance of roads. They should be made to follow good advice given in this paper and with proper supervision the countryside would be much better served, even without incurring any extra cost.

Dr. Jai Krishna Malhotra congratulated the author on his very interesting paper, in which he had presented the theory of soil stabilization and the results of road research carried out in the Irrigation Research Institute by Dr. A. N. Puri and Dr. A. G. Asghar, in a language which even the laymen could understand.

On page 141 the author had dealt with the mixing and compaction of soils. In this connection he drew his attention to the work done in America by the Bureau of Public Roads. As a preliminary to stabilization, a knowledge of the optimum proportions in which the various ingredients should be present in a soil-mix was necessary. The next problem usually was to find the proportion and grading of the stabilizer which may be added to a soil of known constitution to enable it to stand up to traffic, in case it is not considered stable enough to do so on its own. The experiments carried out by the Division of Tests, Bureau of Public Roads, U.S.A., had greatly advanced the knowledge of the optimum proportions of fractions of various grades, and in the absence of any *ad hoc* experiments, their results might temporarily be accepted as standards. The Bureau had not, however, expressed their results in a numerical form, and, at the instance of Dr. Puri he (the speaker) had carried out a preliminary examination of the optimum proportions for a soil-mix, for which the Bureau of Roads had given certain gradation curves.

The results of his examination had been published as part of Dr. Puri's report in "Indian Roads".

Summarising those he stated that the optimum gradation curves prepared by the Bureau were based on their analysis or what they considered to be the best soil-mortar. Their selection rested on the following observations :

(*i*) If the density, D of the mortar was plotted against its moisture content, M, the density moisture curve showed a well-defined maximum density, Dm, which was different for different mortars.

(*ii*) The value of Dm was higher for the best soil mortar than for any other mortar, and corresponded to a comparatively low value of M.

The value of Dm for the best soil-mortar was given by Hogentogler as 129·3 pounds of dry weight per cubic foot, the corresponding value of M being 9·6 per cent.

The analysis of the gradation curves of the optimum soil mortar showed that it should include clay and fine, medium and coarse silts. The Punjab definitions of the fractions are that these are respectively formed by particles below ·002, ·002 to ·075, ·075 to ·200 and ·200 to ·600 mm. in diameter. According to Hogentogler's curves the optimum soil mortar required approximately the following ingredients :

Clay	..	5 %
Fine silt	..	20 %
Medimum and Coarse silts	..	40 %
Coarser material	..	35 %

The optimum gradation curve had also been reduced by him to a mathematical formula, the values given by the formula agreeing very well with those read from the curve.

However, on Hogentogler's showing, the best mortar must contain at least 25 per cent. of particles above ·6 mm. in diameter, the optimum value being about 34 per cent. It was obvious that for soils which were rich in clay, or otherwise inclined to the fine side, the ratio of the weight of the coarse stabilizer (required to bring them up to the level of the best mortar), to the weight of the soil sought to be stabilized might often exceed unity. The availability and transport of the large volumes of the stabilizer involved might not always be possible.

He therefore suggested to Dr. Puri that instead of blindly adopting Hogentogler's curves as quantitative standards, it would be sufficient if they were only accepted qualitatively. He also suggested that the Punjab soils should further be examined on the following lines :

(*i*) Analyses of typical soils from a region where the roads are proposed to be stabilized should be carried out (in case not done already).

The same thing should be done with the stabilizers which are likely to be available.

(*ii*) Using stable proportions, based on the qualitative results obtained from Hogentogler's curves, it would perhaps be possible to find the types of the stabilizers which would suit a given soil.

(*iii*) By adding to the soil the proportion of the stabilizer, which could be economically added in the field, the resulting soil mortar should be subjected to compaction and optimum moisture tests, and from the results it should be seen if the mortar is likely to stand up to traffic.

He further stated that another way for finding the composition of stabilized soils was by an examination of soil roads, which had stood up to traffic. By analysing samples taken from stable sites, it was possible to roughly determine the composition which would suit a particular region. Sometime back the results of analyses of over 40 such samples were referred to him by Dr. Puri, and it was found that :

(*i*) If the clay content was less than 10 per cent. the road would be bad, even if the other finer fractions of silts predominate over the coarse.

(*ii*) If the clay content was above 16 per cent., the road was, in the majority of cases, good.

(*iii*) If the clay content was between 10 and 16 per cent., and the silts were present in a large quantity, the road was likely to be good, but nothing definite about its performance could be stated.

For these results a reference was invited to page 36, Table VIII, of report on " Soil Research by Dr. Puri, for the half year ending 31st December, 1937," which was published in " Indian Roads."

This of course referred to the mechanical composition of the soils, and the conclusions were likely to be modified, as pointed out by Mr. Mehra, by the presence of detrimental salts.

Mr. Murari Lal remarked that Mr. Mehra had said in his paper that the soil was treated as a mixture of clay, silt and sand. He had also shown how by sieving through a standard set of sieves, the percentage of sand could be determined but he had not indicated how clay and silt could be separately determined.

Plasticity index did not give the percentage of clay and silt but only indicated in a very rough manner the order of the content of clay.

There were, however, methods by which the percentage of clay could be found but these were laborious laboratory methods and by no means easy to be undertaken by an Engineer in the field. Hence the method of determining the soil ingredient reduced itself to finding the percentage of sand or coarse material and the plasticity index which could be done by any Engineer in his office room with a simple equipment. So far, however, no practice had been evolved by which having found the percentage of coarse material and plasticity index of a particular soil, the proportions of ingredient going to make a stabilized mixture might be easily determined. Unless some such formula was evolved the science of soil stabilization would remain more as a matter of academic interest than of practical utility.

Generally speaking, plasticity indices of about 3 or less indicated sufficient binder constituent for stabilized roads to be constructed in locations subject to unusually wet conditions, 4 to about 8 for conditions of average mixture, 9 to 15 for drier and arid condition. Plasticity indices exceeding 15 were hardly suitable for this type of construction.

Within the limit of the above plasticity indices it should be possible to lay down exact percentage of the constituents that should go to make up an established soil. When this was done it should be possible for an average Engineer in the field to design his mixture and apply it to his own particular problem. Then and then only would the science of soil stabilization receive the impetus which it really deserved.

He further stated that the writer had stressed the need of adding granular material to withstand abrasion. This addition was not only necessary for overcoming abrasion but also to meet the pounding action of the heavy traffic and it was for this latter reason that the gritty material was not only confined to the surface but was to be incorporated into the body of the stabilized crust, so that the crust as a whole resisted the pounding action of the traffic as well as abrasion. The reason why only some earth roads in this submountainous regions behave well was directly traceable to the presence of this gritty material in the whole body of this soil crust. Hence the need of impregnating the whole body of the wearing coat with granular material and not confining it to the top only as might be inferred from the writer's remarks on page 142 under head surface abrasion.

The writer had not given any reason why the stablized soil in mile 42 of Hoshiarpur-Bharwain Road could not stand without surface treatment, while that on Kot Lakhpat Road had stood without it. It would be interesting and useful to find out the reasons.

On page 147 the writer said with regard to unmetalled road berms that in the dry weather there were clouds of dust set up which cut out all vision in front and the obvious remedy he suggested was to widen the metalling. The widening of metalling without surface treatment would not remove the dust nuisance which would be ever present because the earth which formed the major portion of the stabilized road must be sucked up by the action of fast traffic and must create dust.

If on the other hand the stabilized crust were surface-treated, then the annual maintenance of berms would shoot up to Rs. 600

per mile as against Rs. 250 which is the same as that of the water-bound macadam surface-treated.

Hence the picture painted by Mr. Mehra would not appear to be so rosy as he would have us believe and it was not therefore desirable that berms should be stabilized that way. The cheapest method of doing this consisted in using 3 inches of water-bound macadam with or without soling coat followed by two coats of tar. He even suggested widening by cement concrete where traffic conditions so demanded as was being done at present on the G. T. Road and the Lahore-Multan Road in Lahore proper. This kind of construction though expensive in the beginning was cheap in the long run.

Mr. Baker congratulated Mr. Mehra, not only on his paper but on the very good examples of soil stabilization he had performed in the field.

There was one point he did not mention.

In these days of hustle and bustle, when strategic roads were demanded at short notice, and when machinery of any description was difficult to obtain, it would appear that stabilized earth roads were likely to fill a very important breach.

He enquired if Mr. Mehra could kindly let them have his views on the possible rapidity of construction of stabilized earth roads, without machinery and with some indication of their ability to carry fast-moving convoys of cars, trucks, tanks, etc.

Dr. Puri remarked that Mr. Mehra, in accordance with the American system, divided the soil into three fractions: clay, silt and sand, showing increasing diameter of particles. He went on then to the method of determination of these three fractions. Sand and silt, according to him, was determined by passing through standard sieves but the clay was indicated by a simple number called the "plasticity index". Apart from the logical inconsistency of determining a fraction based on size by a method based on entirely a different principle, the system was unsound because there is no correlation between clay content and plasticity index. The objection might be got over by supposing that plasticity index determined the active clay and from the practical point of view this served our purpose. But the advocates of this system would find it very difficult to define activity in terms of any easily comprehensible physical measurement. From an examination of hundreds of soils taken from actual earth roads it had been shown by them at the Irrigation Research Institute that there was a definite correlation between the clay content determined by the conventional methods and the road performance. Another easily determinable property of soils, namely cohesion, was also correlated with clay content, and all experimental evidence pointed to the conclusion that active clay was identical with conventional clay as regards cohesion. Plasticity index, on the other hand, bears no correlation with either the road performance or cohesion, It neither bore any correlation with the clay content. Measurements like liquid limit and plastic limit were so inexact and vague that they were not included in any system of exact measurement of single value constants for soils by soil scientists. The difficulty seemed to have been that these empirical measurements were devised before the scientific study of soils had established itself, and the engineers were still carrying on with these empirical measurements in utter disregard of the advances that had taken place in soil science during recent years. No one could deny the usefulness of empirical methods but by advocating these methods they were definitely hindering the progress of soil science. Nor should they suppose that because a method had been imported from America it must be scientific. When work in the Irrigation Research Institute on soil stabilization was started the efforts of American workers were well known to them. It was no waste of money or time to have tried to improve upon the empirical methods and give them a scientific background. They had succeeded in doing so. They had not evolved any new system but improved upon the old one. They had only shown the weakness and faults of the American system and supplied, where it lacked, scientific background and it was up to engineers like Mr. Mehra to give these methods as fair a trial as the so-called American system which he had been trying to introduce in this country.

Mr. G. C. Khanna remarked that the author was doing a pioneer's work both in theory and practice of soil stabilization for roads in the Punjab. This subject should be of great interest to every Road Engineer, as in it lay the solution of communication problem of the rural areas.

The paper under discussion was of a general nature and gave no details, therefore it was difficult to comment on it. The author had given no indication, whatsoever, regarding the composition of soil mixture, with which the granular material was to be mixed. A greater detail regarding the percentage of clay, silt and sand in the soil mixture, and how it was to be determined, would have been of interest to many engineers for making experiments of their own.

In order to make the subject within the grasp of every overseer and Road Inspector, the author should give a greater detailed information about designing of stabilized earth.

It was suggested that the sections should be tested in a Test Track and then their behaviour should be studied. It was very doubtful if these sections could take up even half the traffic intensities, given in the paper. It was no use launching on big schemes until they knew something more about their behaviour.

The costs given seemed to be very much on the low side. If the soil was to contain imported sand, silt or clay which were to be compacted at the optimum moisture, the costs would rise to much more than given by the author.

On page 147, the cost of maintenance of berms was given as Rs. 225 per mile. This figure seemed to be incorrect as the average expenditure was about half of what is stated therein. The gangs which were employed on roadside, carried out patch work, jungle clearance, made trackways besides maintaining the road berms, and therefore their whole pay should not be charged to maintenance of road berms.

Mr. Freak remarked that soil stabilization has to be done with the optimum moisture content and he enquired if tar, bitumen, cement or chemicals could be economically added so as to retain this optimum moisture content. In the stabilization work done on the Jullundur—Hoshiarpur—Dharamsala Road, it has been noticed that after dry weather, say just before the monsoon or sometimes before the winter rains, the stabilized surface cracked up. This happened both before the stabilized work had had surface treatment and after. Due to the cracking, the surface treatment will not stand. It seemed therefore, that something was needed to keep the soil from getting too dry.

In his reply Mr. Mehra stated that he was in full agreement with the sentiment expressed by Mr. Sawhney regarding the use of soil stabilization and as a staunch advocate of the subject he was deeply grateful to him, though he must insist, on the basis of available record, that road making in the past had not been dealt with in a scientific manner, unless Mr. Sawhney was referring to prehistoric times.

Referring to Dr. Malhotra's remarks, he said that he was afraid Dr. Malhotra had missed the mark completely when he said that in his paper he (Mr. Mehra) had presented the results of road research carried out in the Irrigation Research Institute by Dr. A.N. Puri and Dr. A. G. Asghar, as the only reference to this research was in connection with detrimental salts. The rest of the research had been carried out entirely by him in his private laboratory, and the experiments had been carried out by him on behalf of the Punjab Government, and neither of these had any reference whatever to work done in the Irrigation Research Institute.

Dr. Malhotra had further given a resumé of the scientific work done in America and in the Irrigation Research Institute which he (Mr. Mehra) had scrupulously avoided in his paper in order not to confuse the highway engineer, because enough confusion had already been caused by high-sounding scientific reports on soil stabilization published in the "Indian Roads Magazine." What was required was a simple and practical treatment of the subject, as against a complicated theoretical treatment, and he was glad that in the end Dr. Malhotra comes to the same view himself.

Dr. Mahotra's suggestion regarding the lines on which Punjab soils should be examined further was probably useful from the academic point of view, but he could assure him that this was exactly the sort of thing which the Irrigation Research Institute on behalf of the Government of India had indulged in for four years without coming to any results of practical value to low-cost road construction as such. On the other hand, he had taken up the subject in a simple straightforward manner, assuming that the ultimate solution of the problem lay more in the field than in the laboratory, and he had tried to produce low-cost roads by an intelligent use of local materials. He thought he could claim that he had succeeded in his pioneering efforts to produce a cheap soil all-weather road from locally available materials, which would be suitable for the peculiar traffic and weather conditions in different parts of this province ; the various experimental lengths, which had stood the test of time, were a standing proof of his statement. What remained to be done, in his opinion, was the launching of large-scale experiments on the lines followed by him, with the dual purpose of standardizing the methods of construction and maintenance (the latter being even more important) and of training the staff in the new methods of road making.

In the end Dr. Malhotra had referred to certain proportions of soil constituents which had been found in the laboratory to indicate good, bad, or indifferent kinds of soils, but the oft-repeated question arose again—What was the practical use of all that ? It was a pity that the scientists almost invariably ignored that the engineer was essentially a practically-minded man. In the classification given by Dr. Malhotra there was no account whatever taken of weather conditions, a factor which was all important in soil roads.

He further stated that he failed to understand why Mr. Murari Lal thought it necessary that the percentage of clay in the soil or its admixtures should be determined before he could proceed to stabilize the soil, when he admitted himself that the direct method of finding the clay content was very laborious while the finding of plasticity index, which gave an indication of the effective clay present in the soil, was practically much simpler. Mr. Murari Lal had only to read the various papers, etc., written by him (Mr. Mehra) and referred to on page 140 of this paper, to know exactly how soil mixtures were to be designed for various traffic and weather conditions.

Mr. Murari Lal seemed a little confused in his reference to the pounding action of the traffic. Far from the fact that granular material gave additional resistance to the direct effect of load, the comparatively soft granular material, economically usable in soil stabilization, had to be provided with an elastic cushion of soil all round it in order to prevent its crushing under the action of load by rubbing against and resting directly on the adjoining fragments. It was true, however, that the addition of granular material gave added resistance to the soil crust, but that fact had already been acknowledged in the paper. It was quite unnecessary to impregnate the whole body of the crust with granular material.

In mile 42 of Hoshiarpur Bharwain road the clay content of the crust had been kept low for the reason that it was intended to give it surface treatment subsequently. For surfaces, which were supposed to resist abrasion, a higher percentage of clay binder was allowed, as was done in the case of Kot Lakhpat Road.

As regards Mr. Murari Lal's remarks regarding the dustiness of stabilized roads, he could assure him from personal experience that it was not even a fraction of the dangerous dusty state of affairs of unstabilized berms and that it was a real boon to traffic, in comparison. He remarked that if they had the money, they could put in metal and concrete berms by all means, but the question of low-cost road construction arose only if they were short of funds, which they definitely were in this country.

With regard to Mr. Baker's remarks, he stated that considering that the number of road rollers available for stereotyped all-weather road construction was essentially very limited, the kind of road suggested, as per type 6 in figure 11 of his paper, would form an excellent substitute, as it could be constructed with the help of bullock rollers and manual labour, of which there was no dearth. This type of road could carry all the traffic that their orthodox type of pucca road was capable of carrying.

Referring to Dr. Puri's remarks, he stated that it was painful to see that a research worker of the calibre of Dr. Puri should have taken up the attitude that he had chosen fit to do in his criticism on the paper. The fact could not be denied that the problem given to the Research Institute was to evolve a cheap all-weather soil road suitable for the peculiar climatic and traffic conditions in this country. This did not appear to have been done in a matter of four years, in spite of a fully staffed and equipped laboratory, and the effort seemed to have had to be abandoned. He put this down to the reason that the persons responsible for this research had allowed themselves to get lost in unnecessary detail, and thus to have completely lost sight of the main problem. The reason why he had been called illogical, unscientific, and empirical was that he had kept the major issue in full view at all times and ignored unnecessary detail, with the result that he could claim that day that he had solved the problem in the main. The proof of the pudding was in the taste of it. His various experiments were standing examples of what had been achieved single-handed by him with the help of an ill-equipped laboratory run from his necessarily meagre resources. If the method that he followed had the backing of a properly equipped and suitably staffed laboratory, he was confident that soil stabilization would have been a popular subject by then, and the average engineer would not have been scared of it, as he was at present, due to the confusion created in his mind by the self-contradictory and long-winded reports of the so-called advocates of science.

As Dr. Puri had answered his criticism himself by saying that the plasticity index determined the active clay and that from the practical point of view, this served their purpose, he thought it would be wasting their time if he said any more about it.

Mr. Mehra then stated that Mr. Khanna had complained that the paper lacked details. If he referred to page 140 of the paper, he would find that he had already given a list of the publications which should be studied in order to know the various details of the system.

The various road crusts suggested by him in figure 11 were based on whatever experience he had gained during his long travels, in Europe and his four years' work in this country. As a result of this very experience, he was strongly of the opinion that if any real results had to be obtained on soil stabilization large-scale experiments should be undertaken as soon as possible.

As regards the question of costs, these were based on costs actually incurred in various experiments carried out by him, and when the labour and staff get more generally used to the subject, these costs should actually be very much less.

The cost of maintenance of berms as quoted by him was taken from a departmental circular and appeared to him to be correct considering that the total cost of all the items enumerated to Mr. Khanna was Rs. 500 per month.

In reply to Mr. Freak's remarks, the Author said that the use of tar, bitumen, cement or chemicals in soil stabilization, due to its heavy expense, is justified only if soil admixtures are not locally available within economic distance.

The stabilization work done on the Jullundur—Hoshiarpur—Dharamsala Road was carried out with the object of giving the crust a surface treatment after the rains. The crust was consequently designed accordingly, with a low clay content.

During the rains the crust behaved excellently, as calculated, but as the surface treatment was not carried out till long afterwards, the crust cracked up in places and has given trouble all along.

If the crust had been surfaced in time, *i.e.*, immediately after the rains, there would have been no trouble about it.

ERRATA TO PAPER No. 257

Page 149 in line 1 of para 4 *read* Density* *for* Density.

Page 157 in line 4 of para 4 *read* 50 *for* 30.

Page 157 in lines 2 and 5 of para 6 *read* K_1 *for* K.

Page 157 in lines 2 and 5 of para 7 *read* K_2 *for* K.

Page 159 in line 2 of para 3 *read* bevel *for* level.

Page 159 in line 2 of para 4 *read* 9 inch *for* 19 inch.

Page 160 in line 8 *read* compaction *for* compactoin.

Page 162 in line 6 of para 4 *read* 20 *for* 25.

Page 168 in line 1 *read* 4 feet *for* 4 inches.

Plate IV. { *After the words* 6″ x 4″ Knobs *add* "3″ high."
Add under the heading "Weight 1·3 tons-4′ wide."
