INDIAN ROADS CONGRESS

NOTICES AND ANNOUNCEMENTS

NEW ADMISSIONS

LIST OF MEMBERS OF THE INDIAN ROADS CONGRESS ENROLLED FROM 1—8—1957 TO 30—11—1957.

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a scientific basis in our country in the past. Empirical methods have been employed for determining the necessary thickness of pavements. The depths of pavements are normally fixed arbitrarily based on past experience under similar conditions. The results have not always been satisfactory. It thus happened that much the same thickness of pavement was provided in different situations although conditions of subgrade etc., varied from place to place. The design used was uneconomical in some cases while in others, the depth used was found to be insufficient and the pavements were unable to withstand the imposed loads. Investigations of road failures have shown that insufficiently thick pavements have often failed on weak subgrades. Similarly, it is known that unnecessarily thick pavements have been laid on strong subgrades.

1.2. The problem of pavement design is the formulation of methods of calculating the thickness and strength of pavement which has to be placed on a soil foundation to provide a stable riding surface for specified traffic loads. A correct application of reliable methods of design can lead to economies by avoiding costly failures and wastage due to overdesign. Research and investigation on this aspect are very essential.

1.3. Recently study has been taken up in a systematic manner by some Research Organisations in the country and it is hoped that suitable methods of designing the road pavements will be evolved for Indian conditions. At present, however, the methods developed in other countries are being adopted for pavement design and other investigation work.

1.4. Failures in pavements provide us an opportunity of studying the various factors responsible for the behaviour of the pavements and give data and information which can be utilised to prevent such failures. They also provide a basis for evolving suitable methods for design of pavements.

1.5. The U.P., P.W.D. Research Institute has undertaken the study of the performance of pavements and has also carried out investigations into the causes of failures of some roads. The results of such study and investigations are reported and discussed in this Paper.

2. RIGID PAVEMENTS

2.1. Evolution of Thin Pavements

2.1.1. Rigid pavements include all cement concrete road construction. Development of thin concrete pavements in U.P.

has an interesting history[1]. Starting in a small way in 1919–20, when short strips of cement concrete were laid on the Kathgodam—Nainital Road, the cement concrete road construction began in a systematic way in 1925–26, when the first cement concrete road was laid in Varnasi on Goods Shed road followed by concreting of some furlongs of G.T. Road at Varnasi in 1926–27. The thickness of slab laid at that time was 9 in.–6 in.–9 in. with a ½ in. insulation layer of sand placed on the existing road. These roads are still in first class condition. Once these experimental stretches proved successful, it was realised that 9 in.–6 in.–9 in. section was unnecessary and that the thickness of concrete pavements could be reduced and the insulation layer omitted with advantage as it weakened the concrete and caused voids under concrete. In 1929–30, a mile of road with 6 in.–4 in.–6 in. section was laid without insulation layer. This also behaved satisfactorily and it became evident that further reduction in depth of pavement was possible. In 1935 it was decided to lay C.C. slabs on a bigger scale and in 1935–37 slabs of 5½ in.–3½ in.–5½ in. and 6 in.–4 in.–6 in. section were laid on the Grand Trunk Road from Ghaziabad to Bulandshahar and about 25 miles of C.C. pavements were thus constructed (Fig. 1). At the same time, experimental lengths with thinner slabs like 4 in., 3 in., 3 in.-2 in.-3 in. and 2 in. were also laid. The results were very encouraging and it was established that 3 in. thick bonded C.C. slabs could be used successfully for roads and thicker slabs were unnecesssary.

2.1.2. The following considerations were found to be of great importance in case of thin cement concrete slabs :

(1) The foundation had to be firm and well-drained. A minimum of 6 in. of crust of old and properly stabilised road was necessary.

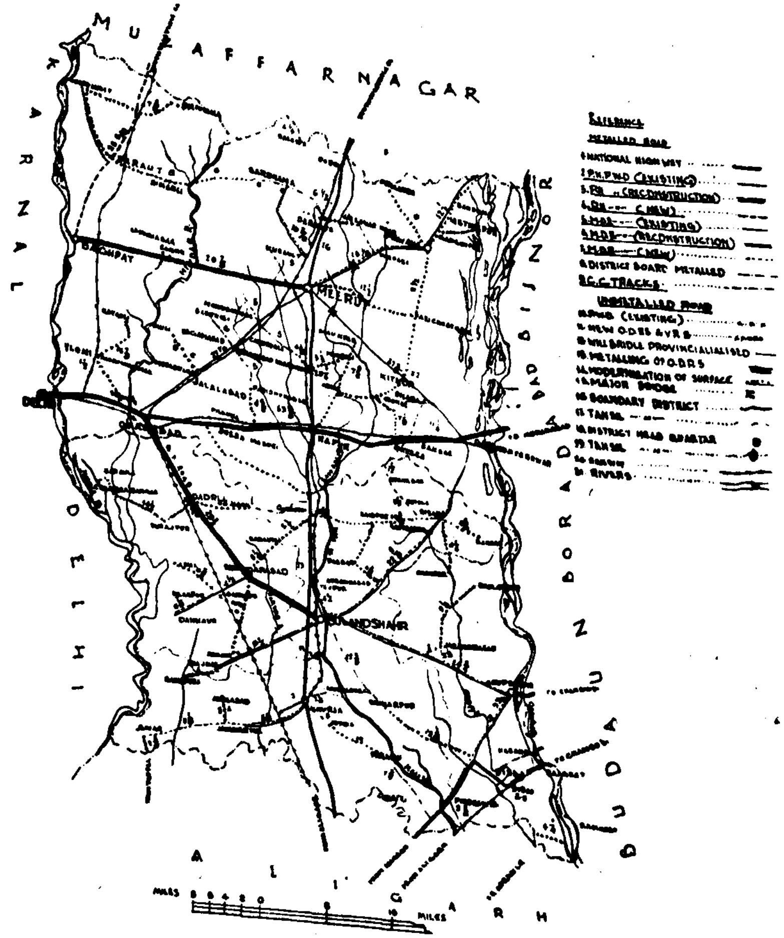
(2) No insulation was necessary. On the other hand, bonding of thin slab with the subgrade was essential.

(3) It was preferable to have slabs of uniform thickness. Thickening of edges was unnecessary.

(4) Expansion joints were necessary for providing for thermal variations.

2.1.3. 3 in. thick slabs soon became the standard for C.C. pavements and from 1939 to 1941 hundreds of miles of C.C. roads of 3 in. thick slabs were laid in the various parts of the State. These stretches behaved satisfactorily for several years.

2.1.4. In the mean time, due to the conditions created by War activities, the traffic went up. Not only the total traffic on the roads increased considerably but heavier vehicles and tractors



INDEX MAP

Fig. 1. Showing G. T. Road & Meerut—Baghpat Road

came on to the roads, causing stresses which were not foreseen. The traffic is still becoming heavier day by day. Diesel trucks laden to full capacity are now plying in increasing numbers on the roads. Due to such heavy loads, 3 in. slabs resting on 'kankar' subgrade have been found to develop cracks as kankar gets crushed under heavy traffic causing hollows particularly near joints. To remedy this defect, a 3 in. coat of stone or overburnt brick ballast was given before laying the concrete slab. Although the results were encouraging, it was found that 3 in. slabs were

not sufficient for the present day loads even with stone macadam subgrade. 4 in. thick slabs are, therefore, now being adopted for C.C. roads and their performance has been quite satisfactory.

2.2. Design

2.2.1. As will be clear from the above description, the adoption of thin slabs bonded to the subgrade consisting of kankar or stone metal has been based primarily on past experience. No rational system of designing the slabs has either been evolved or adopted in this country.

2.2.2. It will be very interesting to study how the various design methods evolved in the U K. and U.S.A. for rigid pavements can be applied in case of thin bonded slabs. In these countries, methods of designing flexible pavements such as C.B. R. and Shear Strength methods, are often used to obtain the overall thickness of concrete and granular base. The structural value of granular base between the concrete pavement and the subgrade is still a matter of controversy and the overall thickness found by the above methods may be conservative. Perhaps a reduction of about 20 per cent may be reasonable to allow for the greater rigidity of concrete, as compared to wholly flexible pavement[2].

2.2.3. The Westergaard's method of design is mostly used for rigid pavements. In this method the thickness of the concrete pavement is designed mainly on the consideration of the stresses within the concrete, the subgrade being considered only so far as it affects these stresses.

2.2.4. Westergaard made theoretical analysis of the stresses created by wheel loads, and evolved formulae for computation of maximum tensile stresses in concrete slabs at corner, at the edge and at a distance from the edge. It was, however, observed that the actual stresses differed considerably from the theoretical stresses calculated by Westergaard's formulae. For corner stresses the formula gave considerably lower stresses. The formulae were subsequently modified by Kelly as well as the Arlington Laboratory, U.S.A.[3]. The latter formulae take into consideration the condition of the slab corner when loaded in warped upward condition and thus having a reduced subgrade support. These modified formulae give higher stresses than Westergaard's formulae. These formulae are described in Appendix 1.

2.2.5. In Uttar Pradesh, as mentioned above, thin slabs are generally used for road work and these are bonded to the subgrade. In order to apply Westergaard's and other formulae to such slabs it is necessary to use them with some modifications and assumptions in regard to the conditions obtaining in the State.

2.2.6. The first assumption is in regard to the wheel load. In foreign countries while applying Westergaard's formulae it is usual to take a wheel load of 10,000 lb. This is considered very high for this country. In his Paper contributed to the Indian Roads Congress Shri Srirangachari[4] had suggested a wheel load of 5,000 lb with 30 per cent impact. This has been taken as the maximum wheel load for our design. Similarly, for *K* (modulus of subgrade reaction) a value of 1000 has been adopted. This high value has been used, as a concrete road is always laid on a well compacted hard crust consisting of kankar or stone or brick ballast[5]. Based on these values, load and temperature stresses in 3 in. to 7 in. slabs have been calculated by Westergaard's and other formulae and are given in Table 1.

2.2.7. It will be seen that the stress in 4 in. slab at the edge comes to 458 lb per sq. inch and the total maximum stress including warping stresses comes to 614 lb per sq. in. In 7 in. slab, the edge stress comes to 208 lb per sq. inch and the maximum stress is 487 lb per sq. inch. The stresses in the corner by Kelly's and other modified formulae are higher. The above stresses are higher than the safe modulus of rupture of concrete permissible for ordinary concrete. Taking 650 lb per sq. inch as the modulus of rupture of concrete, the safe value will be 325 lb per sq. inch. But the maximum stress does not occur frequently and it is only when the maximum temperature stress and maximum load stress come simultaneously that the total stress reaches the maximum as above. According to Agg[6] the design is safe and reasonable if these infrequent high stresses do not exceed 75 per cent of the modulus of rupture i.e. 490 lb per sq. in. This means that a 7 in. slab may be safe for the conditions assumed. However, we have seen that 4 in. slabs are standing the traffic fairly well although, according to stresses calculated, 4 in. thick slabs should crack and disintegrate.

2.2.8. The reasons for this may be[7] :

(1) Probable higher value of *K*-modulus of subgrade reaction of the old metal crust over which thin cement concrete slabs are laid.

(2) Effective bonding of the slab to subgrade which may virtually increase the thickness of slab and hence decrease the stresses.

(3) The Westergaard analysis and the assumptions made may not be fully applicable to thin bonded slabs.

These questions, however, require extensive study both in the laboratory and in the field.

TABLE 1

Showing stresses in different thicknesses of cement concrete slabs

Wheel load = 5,000 lb. Impact 30 per cent. K = 1,000.

Sl. No.	Thickness of slabs	Load stresses lb per per sq. in. Westergaard Formula			Corner stress Kelly Formula	Corner stress Modified Formula	Warping stress lb per sq. in. Interior			Total maxm. stress lb per sq. in. Interior		
		Interior stress	Edge stress	Corner stress			Trans-verse	Longi-tudinal	Edge	Trans-verse	Longi-tudinal	Edge
1.	3 in.	515	635	392	705	954	141	138	117	656	653	752
2.	4 in.	343	458	342	587	634	188	180	156	531	523	614
3.	5 in.	250	346	272	449	451	228	220	195	478	479	541
4.	6 in.	189	268	220	352	341	246	270	234	435	459	502
5.	7 in.	145	208	175	273	371	260	312	273	405	457	481

2.3. Performance

2.3.1. The reports of the behaviour of cement concrete slabs from various locations were obtained for study. Some of the details from these reports are given in Table 2.

2.3.2. These reports indicate that cracks in 3 in. slabs generally occur at joints or corners which means that stresses at edges are high. For ordinary traffic, 3 in. slabs are standing well but for heavy traffic these have failed and 4 in. thick slabs are necessary. At a few places even 4 in. or thicker slabs have failed or cracked and these may be due to ineffective expansion joints, water logging or poor conditions of subgrade combined with heavy traffic as will be discussed later on.

2.3.3. The stresses at the edges or corners of C.C. slab are higher than those at some distance from the edges and this indicates that we can have thinner slabs in the interior and thicker at the edges. As stated before, slabs with thickened edges were laid in 1936–1940 but later on these were replaced by uniformly thick slabs. One of the disadvantages of thickened edge slabs was that the subgrade could not be compacted well and cracks were formed in the slabs. These slabs, therefore, did not prove very successful.

3. FLEXIBLE PAVEMENTS

3.1. Performance

3.1.1. A flexible pavement can be defined as one having little or no inherent resistance to deformation under applied loads. This type of pavement moves in conjunction and stays in contact with the underlying earth subgrade. This type includes all kankar, stone metal and brick metal, water-bound macadam and black top roads. When a concrete pavement is extensively cracked, it also behaves as a flexible pavement.

3.1.2. So far as kankar roads are concerned, a renewal coat is generally provided after every 3 years. This keeps the road going on well for moderate traffic. As traffic increases, the surface becomes uneconomical to maintain, and we have to resort to modernisation which includes provision of stone metal or brick metal water-bound macadam coat followed by surface dressing or premixed carpeting. Most of such roads have been behaving satisfactorily. Occasional failures do, however, occur as will be discussed later.

TABLE 2

Statement of performance of some C. C. roads

Sl. No.	Division	Road	Mile	Month & year of const.	Thickness inches	Insulation	Traffic intensity tons	Performance	Water table
1	Kanpur	G. T. Road	624	1937	3½–2½–3½	Nil	Av. 3027	Pavement completely failed as there is heavy traffic due to brick kilns. Cracks mostly at left side.	Low 13 ft—22 ft
	Kanpur	G. T. Road	569	1942	3	—	—	Cracks in some bays, mostly at joints (flgs. 2–4)	Low 30 ft—40 ft
		,, ,,	578	1942	3	—	—	Few bays affected (3—5 flgs.)	
		,, ,,	580	1942	3	—	—	Cracks in flgs. 1 to 5 mostly at joints.	
		,, ,,	590	1944	3	—	—	Cracks in flgs. 4 to 8 ,, ,,	
		,, ,,	661	1938	3–2–3	—	—	Surface disintegrating under heavy traffic (flgs. 1 to 4) width insufficient.	
2	Sitapur	Lucknow-Bareilly Rd.	20 to 30	—	—	—	—	Cracks and other failures mostly confined to neighbourhood of joints. In some cases no cracks, near joints.	
			47–63	—	—	—	—		
			95–103	—	—	—	—	In the same miles, some furlongs are affected while other are not. Some bays failed completely.	
			113–115	—	—	—	—		
3	Kanpur	Kanpur-Hamirpur-	10	1946	3	—	304	Cracks in most of the bays—pot holes.	30 ft—38 ft
		Sagaur Road	12–13	1944	3	—	,,	Many bays disintegrated in mile 13.	
			14	1946	3	—	,,	Cracks and failures mostly near joints.	
4	Agra	Bombay-Delhi Road	786	—	4	—	—	Road is in fair condition.	
	,,	Agra-Aligarh Road	2	1937	6–4–6	—	1757 Av. 3000 Max.	Heavy traffic, some patches are formed. No other failures visible.	4 ft—17 ft
	,,	Strand Road	1	1940	2½	—	—	Patches are forming on surface. No other failures visible.	
	,,	Agra-Aligarh Road	51 to 53	1940	—	—	—	Superficial cracks at edges and fine cracks at joints. The portion has enough traffic due to being in Aligarh town.	
	,,	G. T. Road	778	1946	4	—	—	Too many cracks—disintegrating.	
			783	1945	4	—	—	Condition is satisfactory except some cracks near joints corner.	
			786	1944	3½	—	—	Too many cracks near joints and corners.	
	Kanpur	G. T. Road	567	1942	3	—	—	Very few cracks.	Very low
			568	1942	3	—	—	Some cracks near joints.	
			570	1942	3	—	—	,, ,,	
			571	1942	3	—	—	,, ,,	
			574	1941	3	—	—	,, ,,	
			575	1941	3	—	—	More bays affected—cracks at joints.	
			576 to 577	1941	3	—	—	Few cracks.	

3.2. Design of Flexible Pavement

3.2.1. The design of flexible pavement consists of the determination of suitable thickness of the pavement which will ensure sufficiently wide distribution of wheel load pressures to prevent the subgrade from deforming in a manner which will cause over-stresses in the base course under repeated loads.

3.2.2. Most of the methods of design take into account some property or properties of the soil. The California Bearing Ratio (C.B.R.) method of design for flexible pavements is probably the most widely used among the methods of pavement design which have been put forward in recent years. This method is in use in the U.S.A. and U.K. and experience has shown that, provided due care is given to the selection of test conditions, the method gives a reliable guide to the thickness of pavement under different soil and trafic conditions. The C.B.R. of soil is an index of its strength and the value obtained for any particular soil will be determined by the condition of the soil at the time of testing. The soil must, therefore, be tested in a condition which is critical to the design and, to ensure this, its moisture content and its state of compaction must be carefully selected.

3.2.3. Strength of soils are very largely determined by their state of compaction i. e., their dry density at a given moisture content, and by their moisture content. It is, therefore, essential that the dry density and moisture content selected for the C.B.R. test should be those that will produce the lowest strength which the soil is likely to have during the life of the road.

3.2.4. For designing the pavement by this method, the anticipated intensity of traffic must be known. Curves are available relating the thickness of pavement with C.B.R. values for some definite wheel loads, and once the C.B.R. values have been found for the sugrade, the total thickness of the pavement can be straight away read from these curves. This method, however, leads to over design in some cases. In the U.K. studies are in hand to obtain the information required for the formulation of a rational method, taking into account the actual wheel loads of the vehicles and their frequency of application. Armstrong[6] has given some design curves* relating C.B.R. value to the depth of construction for six different classifications, A to F (Fig. 2.)

3.2.5. In the absence of any data available for the conditions existing on our roads, the C.B.R. method has been used in investigations described later.

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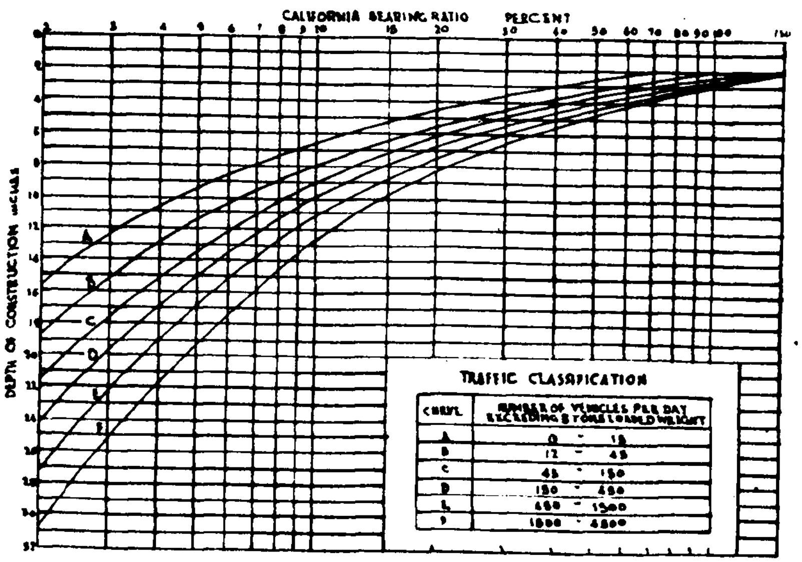

FIG. 3 C.B.R. DESIGN CURVES FOR DIFFERENT CLASSES OF ROAD

Fig. 2.

4. FAILURES IN ROAD PAVEMENTS

4.1. There are several causes of pavement failures :

4.1.1. *Poor condition of subgrade* : This is one of the most important factors responsible for the behaviour of a pavement. The strength of subgrade may not remain the same (in future) as it was at the time of construction. The strength may be higher or lower due to many causes depending on the changes in the moisture content and state of compaction of subgrade which may occur subsequent to the construction of pavement and which may affect the stability of the pavement seriously. It is thus necessary to determine the critical condition of moisture content and state of compaction at which the strength of subgrade, and consequently the thickness of construction required to enable the subgrade to carry the specified traffic loads, can be determined.

When the moisture content approaches the plastic limit of soil, failures are liable to occur even if the thickness of pavement is sufficient.

4.1.2. *Excessive stresses due to heavy traffic loads* :

The subgrade has to carry the whole load due to the road structure and the traffic upon it after it has been distributed through the surface, base and sub-base as the case may be. Excessive stresses may arise in the subgrade leading to an increased deformation with each application of load with consequent failure of the layers above. Excessive stresses in the base or sub-base may lead to failure of the road even though the subgrade does not become excessively deformed.

The cracks may allow the entrance of surface moisture into the base course which hastens the deterioration of the pavement. It has been observed that pavements also fail when ground water rises to a certain height which weakens the subgrade sufficiently causing excessive deflection of the pavement.

Recent research and investigation have shown[9] that there is unusually close correlation between observations of cracking and fatigue type failures in bituminous pavements and the measured deflections which the pavement must undergo with each passing wheel load. These deflections appear to be associated with compression and rebound of the soil, and it is obvious that most pavements will withstand a few such deformations if not too often repeated. Thus the principal destructive force is the energy stored in the subgrade by each passing wheel and the design should take this into consideration.

On our roads heavy bullock cart traffic with iron tyres is another important factor to be considered.

4.1.3. *Excessive stresses due to other causes* : Such stresses in the surfacing or the base may be produced by secondary causes such as temperature or moisture changes which are considered in concrete roads. This has been discussed briefly under rigid pavements.

4.1.4. *Stripping of the surfacing* : This may occur due to insufficient strength of the adhesive bond either between the individual particles of aggregates or between the surfacing and the base. This is confined to bituminous surfaces only.

4.1.5. *Blow ups and cracking in cement concrete roads* : These are due to expansion of C.C. slab at high temperatures combined with defective expansion joints or due to cement-aggregate reaction.

4.2. Changes in the Conditions of Subgrade

The changes in the conditions of subgrade may be due to the following factors :

4.2.1. *Increase of moisture content*: This may cause decrease in strength of the subgrade. The effect is more marked in clayey soils. Moisture content under an impervious pavement can be estimated for clay soils from the suction or consolidation characteristics of the soil, the depth of the water table and the surcharge imposed by the pavement.

For homogeneous clay, with the water table at least five feet below the surface, this equilibrium moisture content is similar to that found at a depth of about 3 ft in the natural exposed soil. Strength of subgrade should be determined when the soil has either this equilibrium moisture content or the moisture content at the time of construction whichever is regarded the more critical.

4.2.2. *Decrease in moisture content*: Although the strength increases with decrease in moisture content, this may involve considerable shrinkage of saturated soils if decrease in moisture content is large. The effect is more marked in clayey soils. This may cause differential movement of concrete slabs or severe longitudinal cracks in a bituminous road.

4.3. **Changes in the Moisture Content of Subgrade**. The principal ways[2] in which changes in moisture content can occur in the subgrade are:

(1) By seepage of water into the subgrade from higher ground adjacent to the road. This occurs in hilly areas.

(2) By rise or fall in the level of water table. Resulting change in moisture content of soil depends on its capillarity and average depth of water table. It is considered that for stable subgrade, the water table should not rise to a level less than 4 ft below the formation.

(3) By percolation of water through the surface of the road. In cement concrete roads, water may percolate through joints and cracks which are not adequately sealed.

(4) By transfer of moisture either to or from the soil in verges as a result of differences in moisture content. It may be that during rainy season, the edges of the road may have higher moisture content than the subgrade leading to movement of moisture. This change may cause differential movement of clayey soil which shrinks or expands on account of changes of moisture content.

(5) By transfer of moisture to or from lower soil layers. Depending upon the time of construction, the subgrade beneath the road may be wetter or drier than the lower soil layers. In this case, the subgrade may tend to reach a state of moisture equilibrium with the lower soil layers. If the subgrade has a moisture content below that of the soil beneath, movement of moisture will occur due to suction forces tending to increase the moisture content of the subgrade.

(6) By transfer of water vapour through the soil. Vapour movements due to difference in vapour pressure arising from the difference in moisture content or temperature difference in different parts of the soil can cause moisture variation.

The clay soil should be at a moisture content well below the plastic limit before any significant movement can occur. Such movements are likely to be more in less temperate-climates where large daily and annual fluctuations of temperature are experienced.

The prevention of changes in the moisture content of subgrade thus calls not only for the correct application of traditional drainage methods but also for the use of new techniques which will prevent the transfer of moisture associated with the 'held water' in the soil.

5. INVESTIGATIONS OF FAILURES ON ROADS

5.1. General

5.1.1. Due to advancement in the science of soil mechanics the behaviour of soil under pavement is now better understood. It is thus possible to find out the various factors responsible for the failures of road pavements and to suggest remedies to repair or to reconstruct such pavements.

5.1.2. One of the main difficulties encountered in investigating the causes of defects or failures in roads is the absence generally of information relating to the conditions of the subgrade at the time when the road was constructed. This difficulty has been partly overcome by a procedure in which comparison is made of the condition both of the subgrade and the pavement at neighbouring portions of the road which had failed and which had remained in sound condition[2]. This procedure has been found in practice to be valuable in determining the various factors responsible for road failures or defects and has been adopted in the investigations of the two cases of road failures now being described.

5.2. Grand Trunk Road (Rigid Pavement)

5.2.1. History—The Grand Trunk road from Ghaziabad to Bulandshahar is one of the very early roads on which cement concrete pavement was laid (Fig. 1). In fact, this is the first road in India on which concrete pavement was laid in a length of many miles at a stretch. The thickness of concrete slab laid was 6″-4″-6″, i.e. thickened edge slab having 6″ depth at the edges and 4″ in the central portion. An insulation layer of cinder and coarse sand was interposed between the concrete slab and the kankar subgrade which was well compacted having a thickness of about 6 in. From miles 843 to 863 and 869 to 870, 12 ft wide concrete slabs were laid during the years 1935 & 1936 while miles 864 and 866 were laid in 1946 in 10 ft width.

5.2.2. Blow-ups and Failures

About a year after the laying of C. C. slab in mile 872, a blow-up occurred during June 1936 in which a piece of concrete suddenly exploded with a loud noise followed by cracks in the bays. No definite cause could be given for this. This blow-up was followed by many others during the subsequent years. Most of these blow-ups were at the joints and the slab lifted several inches above the subgrade and cracked upto some distance on either side. The blow-ups in C. C. slabs continued almost every year and 8 blow-ups were reported during 1939 alone.

In order to find out the causes of these blow-ups, cores of concrete were taken out during 1940 from those portions of slabs which had cracked. It was found that there was sufficient insulation layer in some bays while in others very little insulation layer was present. The concrete at the bottom in some cases was not of good quality. It was thus thought that the blow-ups might be due to expansion of slabs laid on insulation layer. This expansion might have been prevented by slabs that had no insulation layer and the expanded slabs had thus been partly anchored.

It was also thought that the blow-ups might be due to use of fresh cement which contained some free lime and which might have caused expansion.

Specifications for C. C. road construction were revised in 1941 and 3/8 in. expansion joints in between every bay were specified.

5.2.3. Apart from these blow-ups which caused cracks or disintegration in C. C. slabs in some length, the road was behaving quite satisfactorily till 1950 when major cracking in some miles was noticed. Later on, the road pavement in some lengths sank and disintegrated. By 1956, the concrete pavement failed and disintegrated in almost all the miles (See Photos 1 & 2). This has resulted in a longitudinal waviness in the road which is very uncomfortable to drive and the vehicles running at fast speeds get severe bumps. For the last 5 years attempts were made to fill up these depressions with premixed tar macadam using 3/4 in. to 1 in. grit. This improved the position only temporarily as fresh sinkages appeared during rains probably due to entry of water through cracks making the subgrade soft.

5.2.4. Investigations into the causes of these failures were carried out by the PWD Research Institute with a view to give recommendations and suggestions for repairing or reconstructing the road and also to collect data and information in connection with the studies of pavement design.

5.2.5. Field Investigations

For the purpose of investigating the causes of failures, three sites were selected in different miles of the road which had shown severe settlement and where slabs had distintegrated. These sites were in flg. 2 of mile 854; flg. 8 of mile 855 and flg. 4 of mile 857. For the purpose of comparison of conditions in failed and sound sections of this road, a site was also selected in mile 855 flg. 8 which was behaving satisfactorily without cracks and was in sound condition.

3 ft × 3 ft trenches were dug out at these four sites to expose the pavement upto the subgrade. The thickness of concrete was found to be 4 in. in the centre and 6 in. at the edges. Below the cement concrete slab, an insulation layer was also visible followed by 6 in. thick layer of kankar crust resting over the soil subgrade. Concrete blocks were chiselled out of the C.C. slabs from mile 855 both from the portion which was sound and that which was failing for investigation in the laboratory (see Photo 3).

The following tests were carried out on the site :

(i) *In-place Density Tests*—These were done in order to determine the compaction characteristics of the subgrade.

(ii) *Moisture Determination*—Moisture content of subgrade soil collected from different depths below the subgrade was determined in order to study the movement of capillary moisture.

(iii) *California Bearing Ratio (CBR) Test*—This test was carried out on undisturbed soil samples taken from the top one foot of the subgrade at each of these sites at their natural moisture content. This test was made to determine the bearing power of the soil and estimate the probable thickness of pavement required for the traffic moving on this road.

The results obtained are given in Table 3. The position of water table in March 1957 and the formation height of the

TABLE 3

Grand Trunk Road (Bulandshahar District)

Showing results of field tests

Sl No.	Location	In place density of sub-grade (lb per cu.ft)	In place density expressed percentage Proctor density	Field moisture	Thickness of road crust		C.B.R. value	Water table position in March 1957	Formation height
					Thickness of Kankar road	Thickness of C.C. slab			
			per cent		in.	in.			ft
1.	G. T. Rd. mile 854/2	99.9	85.0	17.8	6	4	5.6	4 ft from G.L.	2
2.	G. T. Rd. mile 855/8	100.5	89.0	15.7	6	4	4.5	5 ft 6 in. from G. L.	2
3.	G. T. Rd. mile 855/8	112.9	98.7	13.3	6	4	6.8	5 ft 6 in. from G. L.	2
4.	G. T. Rd. mile 857/4	101.08	85.0	17.3	6	4	5.0	4 ft 8 in. from G. L.	2½

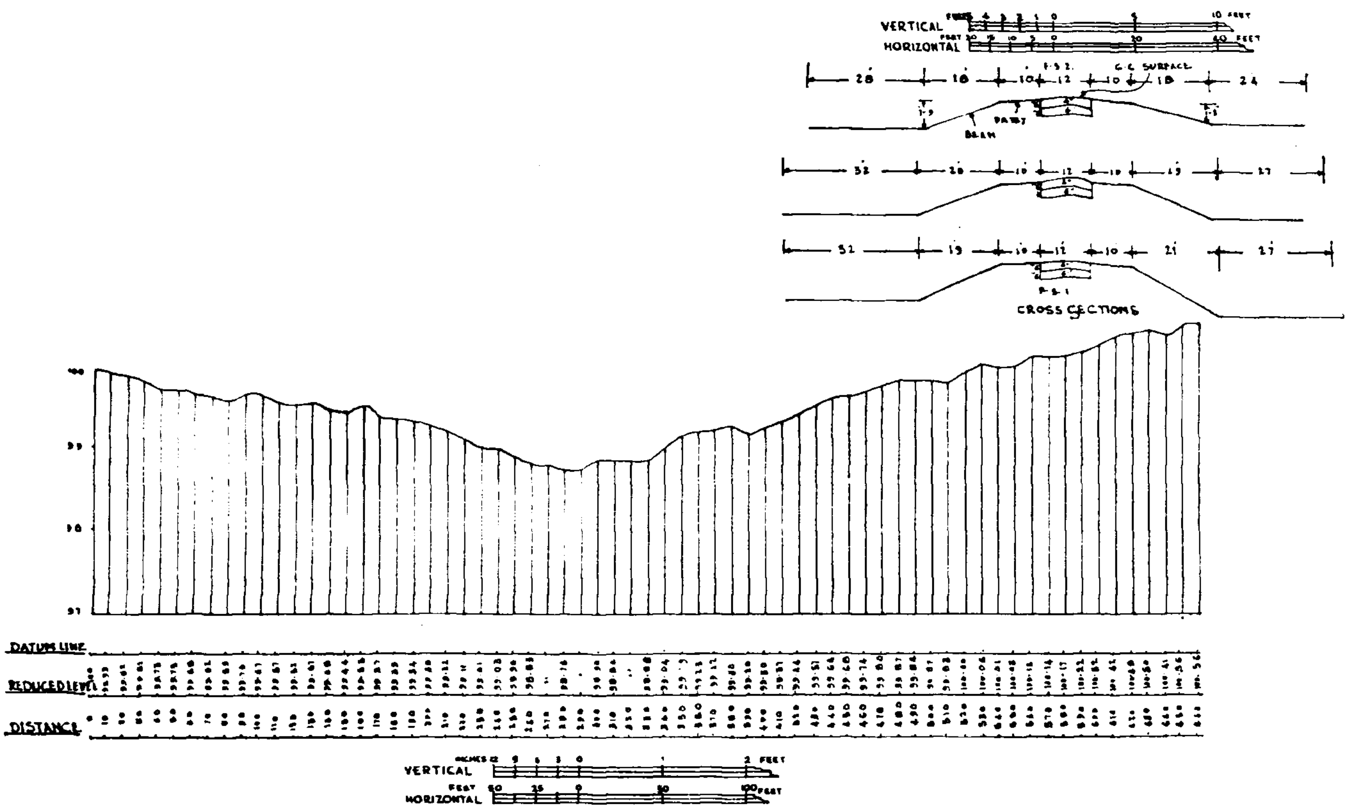

Fig. 3. Longitudinal section of G. T. Road in mile 854 Furlong 2

road are also given in the Table. The water levels of wells on this road from miles 843 to 870 during June and Oct. 1956 are given in Table 4 and traffic intensity based on traffic census taken in mile 862 during Feb. and June 1957 are given in Tables 5 and 6. A typical longitudinal and cross sections of this road (mile 854 flg. 2) are shown in Fig. 3.

TABLE 4

Water level of wells on G. T. Road from miles 843–870 in June & Oct. 1956

Mile	Flgs.	Side of road	Water level to parapets		Country level to parapets		Depth of water from ground			
							Oct.		June	
			ft.	in.	ft.	in.	ft.	in.	ft.	in.
843	6	right	4	2	3	2	1	0	11	0
844	4	left	2	2	1	2	1	0	7	6
844	6	,,	4	11	4	8	3	0	10	5
844	8	right	3	9	2	6	1	3	10	0
845	2	left	3	11	1	8	2	3	11	0
845	6	right	7	0	1	4	0	9	7	2
846	1	left	3	9	0	10	2	11	11	2
846	6	right	6	8	3½	0	3	2	14	10
846	3	,,	5	5	3	0	2	5	13	11
847	3	,,	5	2	2	4	2	10	13	6
850	4	left	7	4	1	3	6	1	15	6
850	6	right	8	9	2	0	6	9	17	3
851	2	,,	9	4	1	5	7	11	19	0
851	4	,,	14	4	2	6	11	10	19	0
852	1	left	10	0	6 in. below the country		10	6	19	6
852	3	,,	7	3	2	0	5	3	14	6
852	8	,,	4	8	0	6	4	2	12	2
853	2	,,	7	8	2	0	5	8	15	8
853	4	,,	11	3	4	0	7	3	18	9
854	4	,,	4	8	4	6	2	0	11	0
855	4	,,	2	4	3	5	1	1	8	5
857	4	,,	3	9	2	0	1	9	7	11
858	1	right	7	9	2	10	4	11	13	0
858	4	left	5	7	1	3	4	4	11	0
859	3	,,	3	4	2	0	1	4	8	9
859	6	,,	4	7	3	0	1	7	10	2
860	3	,,	5	1	2	0	3	1	9	9

TABLE 4—(*Contd.*)

Mile	Flgs.	Side of road	Water level to parapets		Country level to parapets		Depth of water from ground			
							Oct.		June	
			ft.	in.	ft.	in.	ft.	in.	ft.	in.
860	3	,,	2	3	country level		2	3	7	3
861	3	,,	4	3	2	4	1	11	12	6
861	5	,,	5	0	2	3	2	9	11	2
862	5	,,	5	0	4	4	0	8	10	0
863	8	right	5	6	2	10	2	8	12	3
864	1	,,	8	8	3	6	5	2	14	4
865	2	left	8	10	5	6	4	4	12	0
865	8	right	7	0	3	0	4	0	15	6
866	6	left	2	0	2	3	0	3	7	6
866	8	,,	over water		6	0	0	6	5	7
867	3	,,	3	0	2	9	0	3	9	8
868	3	,,	0	4	2	3	1	11	9	10
868	7	right	9	0	4	6	4	6	18	3
869	4	,,	4	4	2	0	2	4	17	4
870	7	left	8	0	country level		8	0	13	0

TABLE 5

Abstract of traffic census taken on 1-6-57 in mile 862 of G. T. Road

Kind of vehicles	Total No.	Weight of vehicles tons	Total weight tons
Bus or light trucks (loaded)	137	4.5	616.5
Bus or light trucks (empty)	9	1.5	13.5
Heavy trucks (loaded)	296	7	2072
do (empty)	78	2	156
Motar car (loaded) do (empty)	75	1	75
Bullock cart (loaded)	227	1.7	386
Bullock cart (empty)	112	0.5	56
Hand driven cart (loaded) do (empty)	6 4	0.75 0.25	4.5 1
Tonga, ekka and rikshaw etc. (loaded or empty)	220	1	220
Total traffic in 24 hours :			3600.5 tons

TABLE 6

Abstract of traffic census taken on 25-2-57 in mile 862 of G. T. Road

Kind of vehicle	Total No.	Weight of vehicle tons	Total weight tons
Bus or light trucks (loaded)	135	4.5	607.5
do (empty)	13	1.5	19.5
Heavy trucks (loaded)	143	7	1001
Heavy trucks (empty)	42	2	84
Motor car (loaded or empty)	204	1	204
Bullock cart (loaded)	65	1.7	110.5
do (empty)	39	0.5	19.5
Hand driven cart (loaded)	9	0.75	6.75
Hand driven cart (empty)	11	0.25	2.75
Tonga, ekka, rikshaw (loaded or empty)	140	1	140
Total traffic in 24 hours :			2195.5 tons

5.2.6. Laboratory Tests

Disturbed soil samples from these four sites from the top of the subgrade and at 12 in., 24 in. and 36 in. from top of the subgrade were also taken and tested in the laboratory for moisture determination, Atterberg limits, materials retained on 200 mesh, PRA classification, particle size analysis, sulphate content, and compaction characteristics. The results are given in Table 7. The particle size analysis is shown in Fig. 4

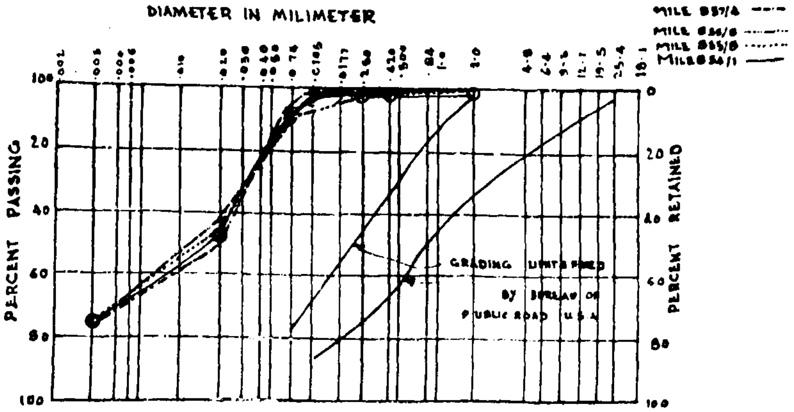

Fig. 4. From G. T. Road Bulandshahar at mile 857/4-855/8 mile 855/8-854/1
Particle size accumulation curve of subgrade soils

TABLE 7

Showing results of tests of subgrade soil samples Grand Trunk Road (Bulandshahar District)

Sl. No.	Lab. No.	Location	Depth at which sample was taken	Existing moisture	Atterberg Limits LL per cent	Atterberg Limits PL per cent	Atterberg Limits PI per cent	Material retd. on 200 mesh sieve	PRA Group classification	Particle Size Analysis Clay	Particle Size Analysis Silt	Particle Size Analysis Sand	Compaction Characteristics Optimum moisture per cent	Compaction Characteristics Max. dry density lb per cu.ft.	Sulphate per cent
1.	SB/131/57	G.T. Road 854/2	top subgarde	17.8	21.0	13.6	7.4	7.5	A-4	24.4	28.8	46.8	14.2	117.5	Nil
2.	SB/131A/57	,,	12 in. from subgrade	19.2	21.0	16.0	5.0	7.8	,,	22.2	24.8	53.0	—	—	,,
3.	SB/132/57	,,	24 in. ,, ,,	19.8	22.2	14.2	8.0	9.4	,,	19.8	26.6	53.6	—	—	,,
4.	SB/133/57	,,	36 in. ,, ,,	19.87	22.0	15.6	6.4	7.1	,,	21.7	30.5	47.8	—	—	,,
5.	SB/134/57	G.T. Road 855/8	top subgrade	15.7	21.8	15.6	6.2	6.0	,,	23.2	24.5	52.3	14.02	113.1	,,
6.	SB/135/57	,,	12 in. from ,,	16.1	20.6	14.5	6.1	7.8	,,	23.4	18.6	58.0	—	—	,,
7.	SB/136/57	,,	24 in. ,, ,,	18.7	18.8	15.6	3.2	9.3	,,	21.9	25.0	53.1	—	—	,,
8.	SB/137/57	,,	36 in. ,, ,,	20.8	22.7	15.1	7.6	7.2	,,	23.9	26.8	49.3	—	—	,,
9.	SB/138/57	G.T. Road 855/8 (Sound portion)	top subgrade	13.3	23.2	19.9	3.3	8.1	,,	29.2	14.8	66.0	14.4	114.3	,,
10.	SB/138A/57	,,	12 in. from ,,	15.0	22.2	18.8	4.2	8.3	,,	24.8	19.6	55.6	—	—	,,
11.	SB/139/57	,,	24 in. ,, ,,	18.0	18.5	15.5	3.0	7.9	,,	28.4	14.8	56.8	—	—	,,
12.	SB/140/57	,,	36 in. ,, ,,	18.7	19.8	14.8	5.0	9.0	,,	23.2	21.2	55.6	—	—	,,
13.	SB/141/57	G.T. Road 857/4	top subgrade	17.3	22.6	17.2	5.2	12.2	,,	27.6	29.6	42.8	14.6	118.5	,,
14.	SB/142/57	,,	12 in. from ,,	18.4	24.0	17.0	7.0	11.4	,,	27.6	16.6	55.6	—	—	,,
15.	SB/143/57	,,	24 in. ,, ,,	18.8	18.3	14.7	13.0	13.0	,,	23.4	11.4	65.2	—	—	,,
16.	SB/144/57	,,	36 in. ,, ,,	19.1	22.1	16.1	6.0	12.2	,,	26.7	16.1	57.2	—	—	,,

Out of the concrete blocks taken from C.C. slabs, 2½ in. cubes were cut and tested for compressive strength (see Photo 4). The results are given in Table 8.

TABLE 8

Compressive strength of concrete cubes from G.T. Road

Serial No.	Identification No.	Mile & fg.	Location	Compressive strength lb/in.²
1.	T. 30	855/8	Failed portion	13,776
2.	,,	,,	,,	5,782
3.	,,	,,	,,	3,512
4.	T. 31	855/8	Sound portion	4,640
5.	,,	,,	,,	5,375
6.	,,	,,	,,	5,625

Micro-sections of coarse aggregates taken out of these concrete samples were prepared and examined. Description is given in Appendix-2.

5.2.7. Results of investigations

From the results of particle size analysis (Table 7) it is seen that the subgrade soils on this road belong to A-4 group of PRA classification of soil and contain silty clay material varying between 87 to 90 per cent. The particle size accumulation curves of these soils (Fig. No. 4) indicate that the soils are not well graded and can be rated to have fair to poor subgrade value. These soils do not satisfy the specifications required for an effective subgrade soil.

From the moisture distribution data (Table 7) it is noticed that the moisture in the top subgrade has exceeded the plastic limit in all the sites which have failed. The moisture content was determined in the month of March when the water table was 4 ft to 5 ft below the ground level. After the rainy season the water table in miles 854 and 855 rises upto the ground level and in some portions even above the ground level. In mile 857, the water table rises upto 1 ft 9 in. below ground level. In such cases the moisture in the top subgrade exceeds the plastic limit of the soil considerably and thus adversely affects the stability of the subgrade. This results in sinking of the kankar into the softened

Photo 1.
A view of G. T. Road showing cracks in the C.C. pavements

Photo 2.
A close view of C.C. pavement of G. T. Road showing settlement and disintegration of C.C. slabs

Photo 3.
Showing concrete blocks taken out of C.C. slabs from G. T. Road for investigation (Note the varying thickness of slab 6 in.-4 in -6 in.)

Photo 4.

Shows concrete cubes cut out of the concrete blocks (G.T. Road mile 855 fig. 8 sound portion)

Photo 5.

Meerut-Baghpat Road showing initial stage of the road surface breaking

Photo 6.

Meerut-Baghpat Road showing further breaking of surface

Photo 7.

Meerut-Baghpat Road showing heaps of earth taken out from below the road surface which has failed

Photo 8.

Meerut-Baghpat Road showing portions of the road surface completely broken

Photo 9.

Meerut-Baghpat Road - A closer view of the road in mile 7, fig. 6 that has failed showing complete disintegration of the crust. The pulpy earth from beneath has come up under the wheel pressure

Photo 10.
Meerut-Baghpat Road showing a large patch under repair

Photo 11.
Meerut-Baghpat Road showing the failure of road again after repairs

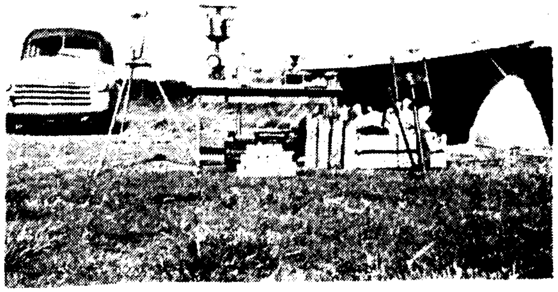

Photo 12.
Meerut-Baghpat Road showing field laboratory set up for investigation work

subgrade, followed by settlement and consequent cracking of the slabs under heavy traffic.

In mile 855, a site which is behaving satisfactorily, the moisture as determined in March was found to be well below the plastic limit of the soil and it is considered that even after the rainy season the moisture content may not exceed the plastic limit due to well compacted condition of the subgrade in this section.

From the data of dry density of the soil in the top 9 in. of the subgrade at different sites (Table 3) it can be seen that the soil in those miles which have failed is not generally very well compacted as the relative compaction expressed as percentage of Proctor's density is less than 90 per cent whereas in mile 855 (site No. 4) the relative compaction is 98 per cent which can be considered as a well compacted soil.

As discussed previously, the C.B.R. method is sometimes used for obtaining overall thickness of concrete and granular base. A reduction of 20 per cent is allowed for greater rigidity of concrete as compared to wholly flexible construction. From the C.B.R. value obtained (Table 3) for the various sites, the thickness of pavement has been calculated from the empirical design curves[2] for heavy and medium traffic which correspond to curves D and E (Fig. 2). From Tables 5 and 6, it would be seen that the maximum number of vehicles passing on this road above 3-ton loaded weight were 433 during June '57 and 278 during Feb. '57. Curve 'D' can thus be used but as the load due to heavy trucks (7-ton capacity) alone is about 50 per cent and the load due to vehicles above 3-ton capacity is 75 per cent of the total tonnage, curve 'E' has been used for determining the total thickness of construction. The thicknesses for wholly flexible pavements and for concrete pavements (with 20 per cent reduction) are given in Table 9. It will be observed that the thickness of construction (with concrete pavement) where the road has failed should be 13.6 in. for heavy traffic as against the existing thickness of 10 in. On the site which has not failed, the CBR value of soil is comparatively more and it thus requires a lesser thickness, viz., 11.4 in. For medium traffic the thicknesses required for the failed and sound portions are 12 in. and 10 in. respectively.

Increase in width is also suggested as one of the ways to distribute traffic and thus reduce the intensity of traffic and stresses.

It will thus be seen that for improving the road surface the total thickness of pavement will be between 12 in. to 13.5 in. As 10 in. thick pavement is already existing, extra 2 in. to $3\frac{1}{2}$ in.

TABLE 9

Grand Trunk Road
Thickness of pavement

Sl. No.	Location	C.B.R. value	Thickness of construction by CBR test method			
			Heavy or curve E† traffic		Medium or Curve D* traffic	
			Flexible in.	Rigid in.	Flexible in.	Rigid. in.
1.	Mile 854/2	5.6	16.0	12.8	14	11.2
2.	,, 855/8	4.5	18.0	14.4	16	12.8
3.	,, 857/4	5.0	17.4	13.6	15	12
4.	,, 855/8 (sound portion)	6.8	14.2	11.4	12.5	10

* Curve D—150-450 vehicles weighing more than 3 tons.

† Curve E—450-1500 vehicles weighing more than 3 tons.

NOTE:—For thickness required for rigid pavement, 20 per cent reduction has been made.

thick pavement should be laid. The best possible solution appears to be to lay 2 in. to 3 in. stone metal followed by surface dressing at the top, care being taken that no water is allowed to go through this pavement. In some miles, the road formation is not sufficiently high above the country level and the water table is either very near the ground level or even above it. In such cases raising of embankment appears to be necessary, care being taken that the soil used in the formation is of desired specifications and is well compacted. Blending of soil by sand may be necessary, but this alternative appears to be impracticable from the cost point of view at present.

The compressive strength of cubes taken out of the concrete samples (Table 8) indicates that the average strength of cubes from the portion that is sound is 5,200 lb/in.^{2} and the strength of cubes from the portion that has failed varies considerably, viz., from 3,512 lb/in.^{2} to 13,776 lb/in^2. From earlier investigations carried out in the laboratory on the properties of concrete by Sonic method[10], it has been found that a linear relationship exists between the flexible strength and compressive strength of concrete made from the same aggregates. The approximate relationship is compressive strength $= 7.1 \times$ flexural

strength. For 5,200 lb/in.^{2} compressive strength, the flexural strength comes to 730 lb/in.^{2} and for 3,512 lb/in.^{2} (the lowest value of the cubes from failed portion), the flexural strength is 490 lb/in.^{2}

According to Westergaard analysis, the maxm. stress in the interior of 4 in. slab is 531 lb/in.^{2} and the maxm. stress at edge in 6 in. slab is 502 lb/in.^{2} (Table 1.) The section is 6 in.-4 in.-6 in. It therefore appears that one of the factors contributing to the disintegration of C.C. slabs may be the high stresses caused by heavy loads.

A study of micro-sections of coarse aggregates (Appendix 2) reveals that there is no deleterious mineral present in the coarse aggregates which may cause alkali-aggregate reaction in the concrete leading to formation of cracks.

5.2.8. **Field Experiments**

Some experiments were carried out in mile 859 of this road during May '56. The experiments were done in order to find out the best possible solution for improving the road surface which has disintegrated. The experiments were as follows :

(i) Resurfacing the existing cement concrete slabs with 3 in. coat of stone ballast with 1st coat of painting. The 2nd coat of painting was to be given within 6 months.

(ii) Resurfacing the existing cement concrete slabs with ¾ in. premixed carpet.

These two experiments were carried out in flgs. 1 and 2 respectively of mile 859. The details are given in Appendix 3.

These surfaces are standing satisfactorily so far. It is now proposed to resurface many miles of this road with these specifications after widening the road pavement to 22 ft width. Where specification No. 1 is to be used, the widened portion will have a soling of bricks and inter coat of brick ballast. The top coat of stone ballast will be laid on full width of the road followed by surface painting. Specification No. 2 will be adopted on those portions which have already been widened.

Success of these experiments may lead to evolution of some definite specifications for the reconstruction of failed concrete pavements as well as to the minimum thickness of pavement required for the existing conditions of subgrade soil and traffic.

5.3. Meerut-Baghpat Road (Flexible Pavement)

5.3.1. This road is an important highway connecting Meerut to Baghpat and it carries quite a heavy traffic including that of sugar cane (Fig. 1).

5.3.2. Failures

The road was showing signs of failures in miles 5 to 11 during 1955–56. The locations of failures in Feb. '56 are indicated in Fig. 5. Miles 9, 10 and 11 had failed in fairly big stretches. Where complete failures had not occurred, the road had become very uneven, depressions and ridges at places being 5 in. to 6 in. Comparatively smaller portions had also failed similarly in other miles.

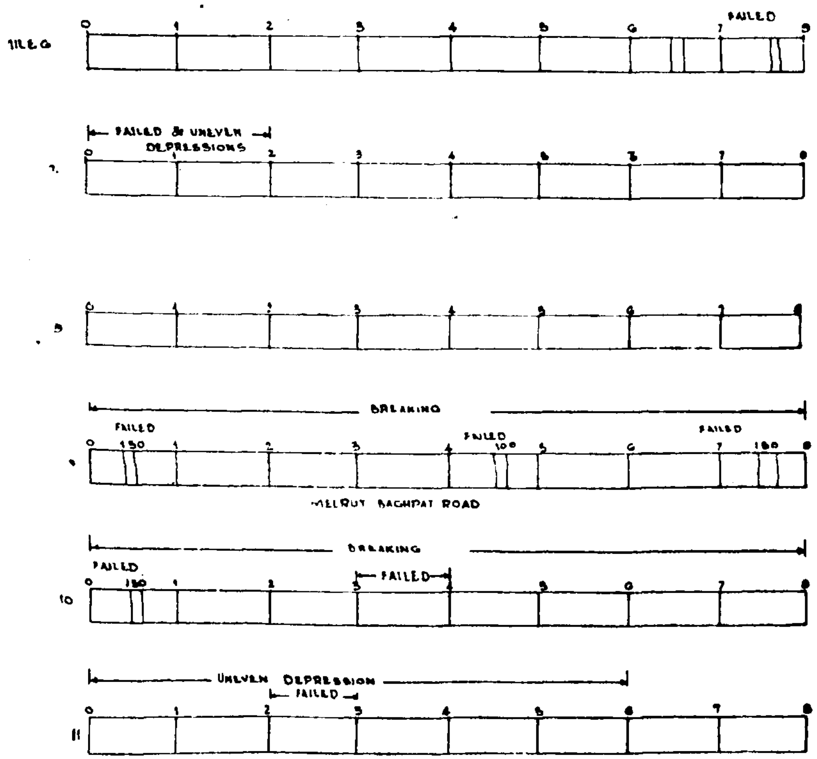

Fig. 5. **Meerut-Baghpat Road. Showing position of failure after the Monsoon as on 1-2—56**

The way in which failure and breaking of road surface started and developed is shown in Photos 5 to 10. Photo 5

indicates the initial stage of the road breaking. The cracks and depressions are clearly visible. Photo 6 indicates further breaking up of the road surface. Photo 7 shows the heap of earth taken out from below the road surface which has failed. Photo 8 and 9 show portions of the road surface which have broken up completely. Photo 10 gives a closer view of the failed portion of the road in mile 7 fg. 6 showing complete disintegration of the crust. The pulpy earth from beneath has come-up under the wheel pressure.

The failed portions on the road were repaired. For this purpose, the broken up stretches were opened up and the existing soil was taken out upto $2\frac{1}{2}$ ft to 3 ft depth. The dug out portion was then filled up with dry soil followed by 6 in. deep sand filling. After that flat brick soling and a layer of metalling was put in and painted over. (Photo 11 shows a patch under repair.)

However, the repaired portions also did not last very long. Investigations to find out the causes of failures were therefore undertaken (See Photo 12) during Sept 1956.[11]

5.3.3. Field & Laboratory Investigations

Three sites were selected for this study. Two sites were very close to failed portions and were showing signs of disintegration or settlement. These were in mile 6 flg. 7 and mile 10 flg. 4. One site was selected in mile 12 flg. 1, which was behaving satisfactorily. A Field Laboratory was set up for investigation.

Trenches about $2\frac{1}{2}$ ft wide were cut through the road pavement on these sites to expose the subgrade. On excavation, it was found that there was no soling in any portion of the road and the depth of crust which consisted of kankar and stone ballast was about 6 in. in the failed portions and about 8 in. in the sound portion. The depth of crust in the various furlongs of the road are indicated in Table No. 10 which also gives the formation height and the depth of water table from ground level.

California Bearing Ratio test was carried out in the field on undisturbed soil samples taken from the subgrade at their natural moisture content.

Besides the C.B.R. test, in situ density was also determined with a view to find out the subgrade compaction characteristics. The results of the field tests are given in Table 11.

Samples of soils were also collected from different depths at these sites in order to study the moisture distribution in the sub-

TABLE 10

Meerut–Baghpat Road — Ground level

Mile	Fig.	DEPTH OF CRUST: Soling	DEPTH OF CRUST: Kankar in.	DEPTH OF CRUST: Stone ballast in.	Formation height	Depth of water in wells from ft.	Kind of soil	REMARKS
6.	2	Nil	3½	3	+6 in.	—	Dry clay	
	4	Nil	4	3	+1 ft.	9	Dry clay	
	6	Nil	5½	3	+6 in.	—	Clay with reh.	Road broken in 60 ft length
	7	Nil (Brick ballast)	2	4½	+6 in.	—		
7.	2	Nil	5	2½	+1 ft	—	Clay with slight reh.	Fig. 1, 2 broken uneven depressions.
	4	Nil	4	3	+1 ft	—	do	
	6	Nil	5	3½	+1 ft	7	Reh soil Usar. No cultivation.	
8.	2	Nil	4½	2½	+2½ ft	4½	Clay with slight reh.	
	4	Nil	4 (kankar & brick ballast mixed)	2¼	+2 ft	—	do	
	7	Nil	4½	3½	+3 ft	7¼	Clay	Broken 5 ft fg. 1
9.	1	Nil	4	3	+3 ft	—	Clay	
	2	Nil	2	4½	+3 ft	—	Clay	Whole surface breaking
	4	Nil	2½	2½	+3 ft	—	Clay	
	5	Nil	3	2½	+3 ft	—	Clay	100 ft in fg. 5. Broken
	6	Nil		4	+3 ft	4	Usar reh soil no cultivation.	
	8	Nil	3	3	+3 ft	—	Usar reh soil no cultivation.	Whole surface breaking. Broken 150 ft fg. 8
10.	1	Nil	3	3	+3 ft	—	Clay	Broken 150 ft in fg. 1
	2	Nil	2¼	2¼	+3 ft	—	Clay	Whole length broken
	4	Nil	2¼	3	+3 ft	6	Reh. soil	do
	6	Nil	5	3	+3 ft	—	Clay	do
11.	2	Nil	3	3	+3 ft	6½	Clay	do
	3	Nil	2¼	3	+2½ ft	6	Clay	Completely broken
	4	Nil	2¼	3	+2¼ ft	7	Clay	Completely broken uneven [depressions
	6	Nil	4	2¼	+2 ft	9	Clay	do

TABLE 11

Investigation on Meerut–Baghpat Road. Results of field tests

Sl. No.	Locations	In place density of subgrade. lb per cu. ft.	In place density expressed as percentage of Proctor density	Field moisture per cent dry weight of soil	CBR value	Existing thickness of crust	Thickness of construction as designed by CBR test for heavy traffic	Water table position below ground level	Formation height
1.	Mile 6 fg. 7	106.25	88 per cent	13.96	9.16	6 in.	11.9 in.	10 ft	6 in.
2.	Mile 10 fg. 4	103.0	84.4 per cent	13.5	10	6¼ in.	11.3 in.	3½ ft	3 ft.
3.	Mile 12 fg. 1	112.5	94.0 per cent	8.6	10	8 in.	11.3 in.	6¾ ft	—

grade and to evaluate the properties of soils. The results of tests are given in Table 12.

5.3.4. Results of Investigations

From the grading analysis of the subgrade soil samples given in Table 13, it is observed that the soils are predominently of A-4 group of PRA classification. Generally speaking these are

TABLE 13

Meerut - Baghpat Road
Gradings of soil samples from subgrade

Sieve	Mile 6 fg. 7	Mile 10 fg. 4	Mile 12 fg. 1
Passing 10 mesh	100	100	100
,, 20	99.48	98.72	99.46
,, 40	98.79	97.85	99.11
,, 60	98.42	97.3	98.83
,, 140	97.54	90.65	96.39
,, 200	94.54	85.3	86.00
,, 0.02 mm. size sieve	48.00	34.8	39.00
,, .002 mm. size sieve	20.8	18.4	14.60

uniformly of fine sand or silty texture with clay content (- .002 mm.) lower than 23 per cent. The particle size accumulation curve (Fig. 6) of the subgrade soil reveals that the soil is not

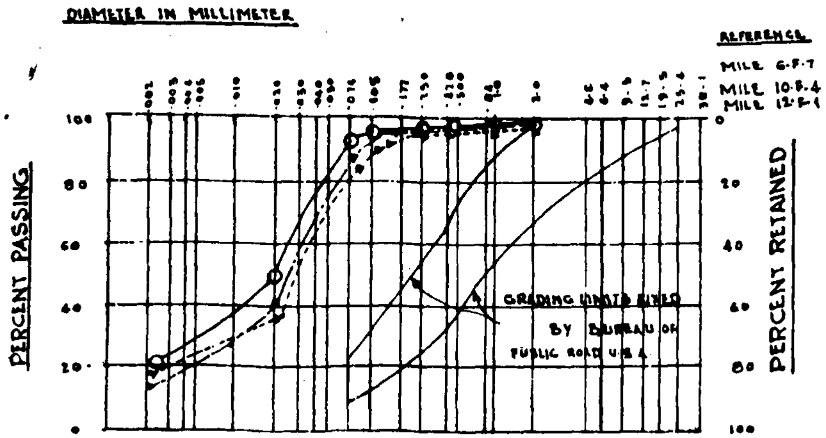

Fig. 6. Meerut-Baghpat Road. Particle size accumulation curve of subgrade soils.

TABLE 12

Meerut—Baghpat Road

Showing results of tests of the subgrade soil samples

Sl. No.	Lab. Index No.	Location	Depth at which sample was taken	Existing Moisture per cent	Liquid limit per cent	Plastic limit per cent	Plasticity index	Material retd. on 200 mesh sieve	P. R. A. classifications	Particle size analysis				Shrinkage factors		Optimum moisture per cent	Max. density lb per cu. ft.	Percentage salts		
										Coarse agg. per cent	Sand per cent	Silt per cent	Clay per cent	Shrinkage limit	Volumetric shrinkage per cent			SO_4	CO_3	HCO_3
1.	SB/637/56	Mile 6 fg. 7	Top subgrade surface	13.96	21.8	15.0	6.8	5.45	A-4	—	52	27.2	20.8	13.02	16.46	12.86	119.7	Nil	0.0135	0.02
2.	SB/640/56		1′	15.3	22.5	16.0	6.5	7.3	A-4	—	55.2	25.9	18.9	14.42	14.80	—	—	,,	0.015	0.054
3.	SB/642/56		2′	15.2	23.3	16.7	6.6	4.75	A-4	—				13.07	19.0			,,	0.010	0.064
4.	SB/644/56		3′	15.6	23.9	16.8	7.1	6.22	A-4	—	44.8	32.2	23.0	13.01	20.82			,,	0.027	0.1
5.	SB/615/56	Mile 10 fg. 4	Top subgrade surface	13.5	19.9	15.2	4.7	14.7	A-4	—	65.2	16.4	18.4	15.137	10.24	11.0	122.0	,,	.008	0.02
6.	SB/617/56		1′	15.2	19.0	15.7	3.3	21.8	A-4	—	73.6	19.7	6.7	14.76	7.83			,,	.0054	0.088
7.	SB/619/56		2′	18.8	20.7	18.1	2.6	20.4	A-4	—	78.4	9.5	12.1	16.45	9.82			,,	Traces	0.046
8.	SB/620/56		3′	21.0	21.0	16.5	4.5	17.3	A-4	—	78.4	10.2	11.4	16.05	8.81			,,	do.	0.05
9.	SB/632/56	Mile 12 fg. 1	Top subgrade surface	8.6	23.6	16.1	7.5	14.0	A-4	—	61.2	24.4	14.6	14.38	17.0	12.1	120.4	,,	do.	0.04
10.	SB/633/56		1′	10.0	25.0	17.0	8.0	12.1	A-4	—	54.8	28.7	16.5	14.70	22.26			,,	.0027	0.044
11.	SB/649/56		2′	12.0	26.0	17.3	8.7	13.7	A-4	—	61.6	21.3	17.1	15.34	17.16			,,	Traces	0.04

well graded and does not satisfy the specification required for an effective subgrade soil. It was, therefore, felt that the soil may be stabilised with some coarse sand so that the gradation of the soil may fall within the standard limit fixed by the Bureau of Public Roads, U.S.A.

As will be noted from Table 12 the moisture content of the top subgrade soil in mile 6 flg. 7 and mile 10 flg. 4 is at present a little less than the plastic limit of the soil. It is just possible that during rains this moisture content may have exceeded the plastic limit of the subgrade soil, thereby affecting the subgrade adversely and causing settlement and disintegration of the road crust under heavy traffic.

It was found that mile 6 flg. 7 was flooded during rains and therefore it appears that the ingress of moisture was from the top surface, as so high a percentage of moisture in subgrade could not have come through capillary rise of water from below. The water table was found to be 10 ft below ground level as noted by the depth of water in a nearby well.

In mile 10 flg. 4, the water collected in the fields on both sides of the road during rains and remained about one foot below the road level. It thus appears that water in this portion entered the subgrade by capillary action and seepage. The moisture at 3 ft depth from the top of subgrade was found to be equivalent to the liquid limit of the soil.

In mile 12 flg. 1 (the portion which is behaving satisfactorily) the water table was 6′—9″ from ground level. There being adequate difference in level of about 3 ft. between the top level of the subgrade and the bed level of the side drain in this particular section of the road, rise of moisture by capillary action has been minimised and the moisture at the top of the subgrade is well below the plastic limit.

From the in situ density test results of top 9 in. layer of subgrade soils at these sites, it is evident that at the two sites which are failing the soil is poorly compacted, as the relative compaction expressed as percentage Proctor density is less than 90% whereas in mile 12 flg. 1 the relative compaction is 94% which can be considered as a well compacted soil.

From the results of the C.B.R. test given in Table 11 the thickness of total construction required for flexible pavement can be evaluated from the curves developed in the U.S.A. or U.K.

The traffic intensity on this road is said to be 4000 tons during cane crushing season and 2,200 tons in other seasons.

5

From the curves relating CBR value to total thickness[2], it is found that for the existing conditions of soil and moisture, the thickness of construction should be about 12 in. for heavy traffic, whereas the existing thicknesses in these portions are 6½ in., 5¼ in., and 8 in. respectively.

It is, therefore, seen that the failures on this road have been due to insufficient thickness of crust in the pavement and also due to increase in the moisture content in the poorly compacted subgrade soil.

5.3.5. Recommendations

The embankment in mile 6 and other miles where formation height is low should be raised by about 2 feet and effective drainage should be provided.

As the existing subgrade in those miles which are failing is not well compacted, the embankment, when raised, should be compacted to the maximum density. The subgrade soil, if necessary, may be mixed with some coarse sand so that its gradation may fall within the standard grading fixed by the Bureau of Public Roads and then compacted.

Waterlogging in areas adjacent to the road should be prevented. It was observed that waterlogging in the abnormal floods of 1955–56 was the main cause of failures in miles 6 to 11.

The thickness of crust is insufficient in miles 6 and 10 which were investigated. The thickness of crust in case of mile 10 should be increased so that the total thickness may be 12 in. or so. In this mile and other miles where the embankment is already high no further earthwork appears necessary. In mile 6 and other miles where the embankment is to be raised and compacted, the usual specifications of brick soling, inter coat and top coat followed by surface dressing appears sufficient.

6. CONCLUSIONS

6.1. Need for Design of Pavement

6.1.1. The investigations of the failures of the roads mentioned above are not yet complete nor the recommendations made have yet been tried in the field. The object of the Authors in writing this Paper is mainly to focus the attention of Highway Engineers to the necessity for study of all the road failures on a scientific and rational basis.

6.1.2. It is also very important to evolve a suitable method or methods design for rigid and flexible pavements for conditions existing in our country. The counrty has embarked upon a huge road construction programme. It is, therefore, important that an economical and suitable design for pavements should be adopted in order to utilise the resources to the maximum extent. Where it is found by investigation that the thickness of the existing pavement is not sufficient, it should be possible to suggest suitable increase in depth of crust for the conditions existing on the road. It may also be necessary to strengthen the existing pavements to withstand the present day traffic.

6.1.3. A detailed study of existing pavements which have failed and which are standing satisfactorily has to be undertaken along with field and laboratory tests for finding out the properties of the subgrade soils, moisture distribution, drainage, soil characteristics, traffic intensity data and other information in different seasons. It would be neesssary to carry out CBR tests, cone penetration tests, plate bearing tests, unconfined compression tests and shear tests to determine the various characteristics of subgrade soil and to correlate these characteristics with the thicknesses of pavements which have failed and those which have not failed in order to evolve suitable values for adoption for design purposes.

6.1.4. Traffic census is generally taken by the State PWD's at regular intervals and this data can be usefully employed. The properties of concrete laid in pavements, its flexural and compressive strength, and distribution of stresses in slabs or top coat, base course and subgrade under wheel loads, have also to be studied. Stresses due to bullock cart wheel loads are to be specially studied. All this data will indicate one or more methods for the design of pavements under different conditions.

6.2. Drainage system

6.2.1. It is essential to know how the drainage under a road pavement can be improved or moisture movement controlled under a subgrade where water-table is high or water-logging occurs.

6.2.2. The investigations described above have revealed that the wetting of subgrade is one of the most important causes of the failures of roads. The subgrade is likely to get saturated due to capillarity of soil when the water table is high reducing the bearing value of the sub-grade considerably. Under these conditions, with the increasing traffic intensity and wheel loads, the existing pavement thicknesses are not adequate resulting in the deformation of the pavement and its failure. One of the solutions in such cases may be to provide increased thickness of pavement.

6.2.3. Movement of capillary moisture can be resisted by interposing a requisite thickness of low capillarity material such as very coarse grained sand, bajri, gravel and kankar. Another way of intercepting the moisture movement is by the use of a horizontal impermeable membrane located beneath the compacted subgrade. The horizontal movement of moisture between the verges and the subgrade can be dealt with in a manner similar to the vertical movement. Changes in the moisture content of subgrade due to horizontal movement can be reduced and possibly eliminated by providing an impermeable surface on the verges. Stabilised soil verges may serve this purpose.

6.2.4. The water table according to some authorities should be maintained at a depth not less than 4 ft below the formation level. This could be controlled by the installation of a suitable drainage system. Another way may be to increase the formation height so that capillary moisture may not affect the subgrade adversely.

6.2.5. At present, sufficient data is not available for the design of drainage system and it would be desirable that studies be undertaken to evolve suitable specifications on this aspect also.

6.3. Other Conclusions

6.3.1. The above study also reveals the importance of grading and compacting the subgrade soil. We must insist on the maximum possible compaction of soil before a pavement is laid. Proper testing of soil and determination of optimum moisture for compaction is essential.

6.3.2. Use of stabilised soil to distribute the load on the subgrade may be made where practicable and economical. Already its use in place of soling and inter coat is being advocated and some States have laid experimental lengths and are watching their behaviour.

6.3.3. In case of concrete roads, which are not considered adequate to take up heavier loads or which are failing, the use of premix carpet on the top of cement concrete slab or laying of a coat of stone metal followed by surface dressing appears satisfactory.

7. Acknowledgments

7.1. The field and laboratory investigations given in this Paper were carried out by the soils section of the P.W.D. Research Institute under the supervision of Shri Manohar Lal, Assistant Research Officer.

7.2. The Paper is being published by the kind permission of the Chief Engineer, U.P., P.W.D.

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Appendix 1

Design of cement concrete slab load stresses

(a) **Westergaard Equations**

(1) Stress in interior $Si = \frac{0.3162}{h^2} P \left\{ 4 \log_{10} \left(\frac{l}{b}\right) + 1.069 \right\}$

(2) Stress at edge $Se = \frac{0.572}{h^2} P \left\{ 4 \log_{10} \left(\frac{l}{b}\right) + 0.359 \right\}$

(3) Stress at corner $Sc = \frac{3P}{h^2} \left\{ 1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6} \right\}$

(b) Kelly's formula for stress at corner

$$Sc = \frac{3P}{h^2} \left\{ 1 - \left(\frac{a\sqrt{2}}{l}\right)^{1.2} \right\}$$

(c) Modified formula developed at Arlington laboratory (for unprotected corner)

$$S = \frac{4.2P}{h^2} \left\{ 1 - \frac{\sqrt{\frac{a}{l}}}{0.925 + .22\frac{a}{l}} \right\}$$

Where $E = 5 \times 10^6$ (modulus of elasticity)

P = wheel load plus impact allowance

h = slab thickness in inches

l = radius of relative stiffness in inches

$$= \sqrt[4]{\frac{Eh^3}{12\,(1-\mu^2)K.}}$$

K = modulus of foundation reaction

b = radius of resisting section

$$= \sqrt{1.6a^2 + bh^2} - 0.675\,h$$

a = radius of wheel load distribution in inches.

Warping stresses

Stress due to temperature difference between top and bottom of the slab derived from Westergaard analysis

Stress in interior

$$\sigma x = \frac{E\,e\,t}{2} \times Cx + \frac{\mu\,Cy}{1-\mu^2}$$

$$\sigma y = \frac{E\,e\,t}{2} \times \frac{Cy - \mu\,Cx}{1-\mu^2}$$

Stress at edge $\sigma xe = \frac{Eet}{2} \times Cx$

Where σx and σy are max. stresses in lbs per in. in the extreme fibre at the interior of the slab in the direction of the slab length.

e = Coefficient of thermal expansion and contraction per degree Fah. $= 5 \times 10^{-6}$.

t = difference in temperature between top and bottom of slab in degree F assumed as 3° per inch thickness.

Value Cx and Cy are taken from the graph given in the book 'Construction of Roads and Pavements' by Agg. Lx has been taken as 83 ft (396 in.) and $Ly = 12$ ft (144 in.)

Assumptions

1. $P = 5000$ lb plus 30 per cent impact*
2. $K = 1000$ (for compacted water-bound macadam)†
3. Value of radius of wheel load distribution 'a' was taken from the Tables given in the "Concrete Pavement Design" by Portland Cement Association, U.S.A. For $P = 6500$ lb, $a = 5.25$ in.

* 'Design of road beds' by Srirangachary—Indian Roads Congress Journal, April 1952.

† A study of cement concrete roads with special reference to Bombay Province—Aminbhave, Vol. XIII-1, Indian Roads Congress Journal.

Appendix 2

Study of micro-sections of coarse and fine aggregates from concrete samples (G.T. Road)

Coarse Aggregates :

(1) **Sample T-30 :**—(Portion that has failed)

It is pinkish quartzite with fine grained texture. The rock is essentially composed of quartz. Other minerals present are Iron Ore, Zircon, Rutile, tourmaline and white mica (Muscovite). The only deleterious mineral present in the stone is white mica which occurs in minute flakes. This is a soft mineral and proves detrimental to the strength of the stone if present in good amount. In the present case, the mineral is not so abundant as to render the stone weak. Secondly, it is considered that this mineral is not capable of promoting alkali-aggregate reaction. There is no other mineral constituent which may be expected to promote such a reaction.

Sample (T-31) (Sound portion)

This is also a quartizite almost of the same character as the above. The only difference is that it contains iron ore in a very subordinate amount. Another marked difference is absence of white mica in it. No deleterious mineral is present.

Fine Aggregates:

It has not been possible to make a petrographic examination of the sand properly as generally sand grains are more or less coated with lime. However, a few grains were seen which indicate that the sand is mostly composed of quartz.

Appendix 3

Experiments on resurfacing of G.T. Road (mile 859)

(1) Resurfacing and regrading with 3 in. coat of stone ballast (from Delhi). $1\frac{1}{2}$ in. gauge was consolidated during May 1956 followed by 1st coat painting soon after with $\frac{1}{4}$ in. to $\frac{3}{8}$ in. gauge Delhi stone grit and Tar RT-2. The second coat of painting was given with Delhi grit 1/8 in. to 3/8 in. size and Mexphalt 80/100 during June 1956*. The cost of this treatment in a furlong length came to Rs 2,770.

(ii) Resurfacing and regrading with $\frac{3}{4}$ in. premix carpet. The idea behind this experiment was to give a water tight surface. But as the surface was to be finished to a suitable longitudinal section, it was found necessary to fill up the depressions to bring the surface originally to a long section devoid of waviness. This was done by means of 3/8 in. to 1 in. grit premixed with mexphalt 80/100 spread and rolled. Over this a uniform thickness of $\frac{3}{4}$ in. carpeting was laid during May 1956.

About 600 cu ft. of 3/8 in.–1 in. grit and 1.15 tons of Mexphalt was used for filling up the depressions. For premix carpet, 250 cu. ft. of 1/8 in.–3/8 in. grit, 638 cu. ft. of $\frac{1}{4}$ in.–$\frac{3}{4}$ in. grit and 1.93 tons of Mexphalt were used. Before laying the carpet, Shelspra B.S. was used as a tack coat @ 15-20 lb per 100 sq. ft. 15 lb per 100 sq. ft. sufficed on concrete surface and 20 lb per 100 sq. ft. was sufficient on filled up portions. The total cost of this treatment in a furlong length came to Rs 3,030.

A seal coat was given during June 1957.

* The quantity of stone ballast consolidated was 1942 cu. ft. For first coat painting, 275 cu. ft. of $\frac{1}{4}$ in.—$\frac{3}{8}$ in. grit and 2 tons of RT—2 were used. For second coat painting, 175 cu. ft. of $\frac{1}{8}$ in.-$\frac{3}{8}$ in. grit and 0,66 ton of Mexphalt were used.

Paper No. 204

"SCIENTIFIC ASPECTS OF THE ROAD TRAFFIC PROBLEM"

By

TEJBIR S. KHANNA*

CONTENTS

SYNOPSIS

This Paper is an outline study of the road traffic problem in India.

The seriousness of the traffic problem in India has been pointed out and a scientific approach to the problem has been suggested.

Reference is made to the different agencies like traffic police, traffic laws and courts and other agencies that could be engaged to tackle the traffic problem in a well planned and co-ordinated way.

Tentative recommendations are made regarding organization required for handling the problem.

1. INTRODUCTION

So far, in India, highway engineers have concerned themselves mostly with the construction of roads but now as the traffic increases resulting in more and more congestion and accidents, there seems to be a real need for the highway engineers to tackle the traffic problem scientifically.

The logical and practical approach to solve the road traffic problem lies in application of traffic engineering techniques,

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sound and uniform traffic regulations, fair and strict enforcement, psycho-analysis of traffic violators for selecting proper punishment by traffic courts, education and public co-operation.

Leaving aside the traffic delays and economic losses due to the same, high death rate due to accidents in our big cities points out to the necessity for scientific treatment of the problem. If the efforts to meet this problem are delayed, higher concentration of motor vehicles expected as a result of the Second Five-Year Plan will deteriorate the situation considerably.

Regardless of what action is initiated to secure better roads, there should be continuous efforts to secure the best possible efficiency of roads as they exist at any one time. Thus there is need for a well planned and co-ordinated attack on the traffic problem. For this purpose, not only the three E's, i. e. Engineering, Education and Enforcement are necessary but the three C's, i. e. Co-ordination, Co-operation and Courtesy are just as important.

No formula or research alone can solve the traffic problem overnight. A balanced programme after due study and investigation with active public support can gradually produce the desired results. What is most immediately needed is a complete understanding of the problem ; the urge for a scientific approach for its solution will follow itself.

In the first instance, a quick and economical solution of the problem on broad lines has to be found and then at a later stage details will have to be worked out according to the needs and finances available.

The object of the Paper is mainly to stimulate interest and work in the field of traffic engineering in India not only to meet the existing traffic problem at the minimum possible cost but also gradually to prepare the way for meeting the future traffic requirements as well. Due emphasis has been given to the need for pubic co-operation through public education and for the use of scientific methods for law enforcement side by side with concentrated research.

2. EXISTING TRAFFIC CONDITIONS

Traffic conditions in the U.K. and the U.S.A. are bad. In the U.S.A., about 38,000 persons are killed and about 125,000 persons are injured every year due to road traffic accidents. The cost of motor vehicle accidents in terms of assessable danger is no less than 4.4 billion dollars per year. The National Safety

Council, Chicago, forecasts that at the present rate of increase there will be 53,000 deaths due to road traffic accidents by 1966. There will be 82 million motor vehicles on American roads and 90 million drivers operating those vehicles at various times.

Unfortunately, full statistical data is not available in India, but whatever statistics are available clearly point out to the seriousness of our traffic problem. The present death rate per 10,000 motor vehicles in India is in the range of 70's against 16 and 8 in the U.K. and the U.S.A. respectively. This high death rate occurs inspite of the fact that India has only 1.2 motor vehicles per mile of road (including non-motorable length) whereas in the U.K. and the U.S.A. there are 17.6 and 16.0 motor vehicles per mile of road respectively. The number of persons killed and the number of road accidents in India are rising at a fairly high rate every year. According to the Second Five-Year Plan, about 60,000 motor vehicles per year will be added on our roads. This will be more than double the present rate. Thus the traffic problem will become much more serious unless necessary and effective steps are taken.

There is, therefore, hardly any doubt that in India a scientific approach to the problem is absolutely necessary. Besides carelessness of road users, obsolescent geometric and physical features of our roads and mixed traffic pattern are other major causes of accidents. So far the traffic problem in our country has been handled by the traffic police as best as they could but the engineering approach has been lacking. Now a stage has been reached when simultaneously with police measures, a correct analysis of the problem, from traffic engineering point of view, is indispensable. Without such a co-ordinated approach, money spent to meet the traffic problem cannot yield full returns.

It is a common delusion that traffic accidents are inevitable on any road. Most of the accidents can be eliminated by simple traffic engineering techniques and not necessarily by strict restrictions or by building ideal, foolproof roads.

The different departments, e.g., Traffic Engineering (Planning and Research), Traffic Police, Traffic Laws, Courts and Town Planning should closely collaborate for a well co-ordinated attack on the problem. Besides that there is need for setting up other helping agencies like Vehicle Administration, Public Education and Publicity, Public Support Organizations, Social Clubs, etc.

In the following paragraphs, the functions and use of the above mentioned organizations have been discussed with a view to introduce the subject in a little more detailed manner.

3. TRAFFIC ENGINEERING

Traffic Engineering is comparatively a new science. Broadly speaking, the functions of traffic engineering could be divided into three parts, i.e., (1) Planning, (2) Geometric design, (3) Traffic control. A general definition of traffic engineering as given by the Institute of Traffic Engineers, New Haven, Conn., U.S.A., is as follows: "Traffic Engineering is that phase of engineering which deals with the planning and geometric design of streets, highways and abutting lands and with traffic operations thereon as their use is related to the safe, convenient and economical transportation of persons and goods."

The traffic engineer, therefore, serves as an important connecting link between the automotive engineer who is responsible for the design and performance of mechanically-propelled vehicles and the highway engineer who is responsible for the structural performance of streets and roads. Remarkable achievements have been made in the science of highway building and even greater improvements have been made in the design and performance of mechanically-propelled vehicles. Now it is the job of the traffic engineer to make sure that both the vehicles and the road can be put to use at maximum safety and efficiency. Performance characteristics of all types of vehicles and roads in combination is the traffic engineer's responsibility. The traffic engineer has also to guide the traffic police to cope with intricate problems created by congestion and accidents that grow out of the limited physical conditions of the roadway. Due consideration to the highly variable psychological and emotional nature of different drivers and other road users on road safety is also the traffic engineer's job.

Ordinarily, the traffic engineering studies should include the following:

1. Traffic Statistics

Statistics are probably the most useful tool of the traffic engineer. Statistics, which are known as 'the handmaiden of reality', are well used in making the most probable predictions. Statistics are necessary in finding out as to where we are, which way we are tending to go and then judge what to do and how to do it scientifically. Statistical approach to the traffic engineering problems is, probably, the most scientific.

Traffic statistics can be used for analysing (a) the danger spots, (b) public co-operation in meeting the traffic problem, (c) different causes of congestion, (d) need for better roads and financial justification, etc. For proper use of statistics, the traffic engineer must also give consideration to the psychological factors involved.

2. Traffic Surveys

Traffic surveys include field studies of (i) traffic volumes, (ii) parking, (iii) cordon counts, (iv) origin and destination, (v) pedestrian counts, (vi) main road congestion, or study of speed and delay, (vii) psychological attitudes of road users, and (viii) roadway capacity.

(i) **Traffic Volumes.** This study is necessary to obtain a record of all types of vehicles moving on the roads. It further helps to analyse the traffic regarding its direction and fluctuation in number of vehicles through various intersections and major roads. Traffic count study also provides the basic data for planning of traffic control, roadway maintenance, roadway changes and construction of new facilities.

Traffic volume studies can be further applied (a) to justify the existence or installation of automatic traffic signals and their timings, (b) to evaluate accident rate, (c) to show the relationship between day and night accidents to the respective traffic volumes, (d) to determine the necessity of greater street space, (e) as a basis for assigning police personnel on duty at different places at different times, (f) to help judge trends in the traffic pattern in order to plan for future needs.

There are mainly two methods of making counts, e.g., (a) automatic, (b) manual.

Automatic recorders are of two types, fixed and portable. The fixed type is employed for continuous counts at control stations on permanent count stations. A photo-electric cell or magnetic device is used in automatic traffic counters. The portable type is generally used for short periodic counts. It has a rubber tube that is stretched across the road and as a vehicle passes over the tube air pressure developed in the tube operates the counter. This type of counter can be used where there is only pneumatic tyre traffic. Automatic counters do not tell the direction of flow, vehicle classification and turning movement on the intersection.

The manual method consists in employing field enumerators to record the volumes of flow on prepared forms.

Flow maps are prepared as a result of the study of traffic volumes. A flow map indicates basic data for planning of traffic control and law enforcement, roadway maintenance, roadway changes and construction of new routes.

(ii) **Cordon Counts.** This study consists in counting all the vehicles and persons entering and leaving a district during a typical week day. Facts obtained should include time distribution, geographic location, traffic volumes and modes of transportation. This type of study is useful in determining (a) needed traffic engineering measures such as one-way streets; (b) off-centre lane movements; (c) traffic signal re-timing to favour directional flow; (d) time and location for posting traffic police personnel; (e) the concentration characteristics for both vehicles and persons with regard to time and area, and the relative loads on streets; (f) the modes of transportation used and the relative importance of each; (g) the overall measures of transportation changes and trends by similar cordon counts obtained previously; (h) service needs for public transport companies.

For this study a cordon line is drawn around the city and observation posts are located at all major points of entry and exit along the cordon line and all vehicles, passengers and pedestrians, are counted by half-hour or 15-minute intervals as they pass into or out of the cordon area.

(iii) **Origin and Destination Survey.** This study is a determination by number and types of vehicles, regarding their origin and destination, using any particular street or a series of streets. This would reveal where new and more direct thoroughfares and transit lines are needed. The origin and destination studies are most essential for planning, design and operation of traffic routes and terminals.

Origin and destination survey is also necessary for properly locating a new highway required to pass through a city. This study further helps to determine the situations where (a) vehicles, lacking a direct route, are forced to use an existing less direct route; (b) commercial traffic and tourist traffic on a major road or in a busines area could be diverted to avoid congestion and traffic hazards; (c) it is required to study economic gains derived if a new 'cut off,' between areas of principal origin and destination, is constructed.

There are several methods of making origin and destination studies commonly known as O and D study, e.g., (a) roadside interview, (b) licence plate, (c) return postal cards, (d) tag on car, (e) home interview.

Roadside interview is a more accurate method and consists of stopping vehicles and asking each driver about the origin and destination of his trip. An O.D. survey of Delhi has been made very successfully by roadside interview method.

In licence plate method, licence plate numbers are noted at each O and D survey station by short periods such as one minute. As a vehicle passes each station, its number is recorded which enables the recorder to trace the vehicle trip in the area under study. The station at which the number of the vehicle was first recorded may be considered its origin.

Return postal cards system requires advanced publicity for public co-operation. Post cards are handed over to the vehicle drivers at the station. The station should be at the spot where vehicles are very slow and the traffic heavy. This method can bring back detailed information such as length of the trip, whether business or pleasure, how often made, or any other information that may be considered desirable.

Another way of making O and D survey would be to mail returned addressed stamped postal cards to owners of vehicles living within the study area.

Tag on car method involves fastening a pre-coded card to the vehicle entering the study area. As the vehicle leaves the area, the tag is removed and the time, station, direction of travel and any other readily observed information is recorded.

Home interview is the most comprehensive type of O-D study.

(iv) **Pedestrian Study.** This study apparently may not sound as important as it really is. In the U.S.A., two out of every five persons killed in traffic accidents are pedestrians. Pedestrian accidents occur mostly on urban roads inspite of the safety measures adopted for them. What is most needed, after the provision of adequate facilities, is education.

Pedestrians, in our cities, are subjected to little control and their uncontrolled movements and inadequate provision for their safety on road create a great hazard. There is a great need in our cities to control pedestrian movements and to construct facilities for them which may enable them to walk safely and properly. While designing intersections and timing of signals, walking speed of about 4 ft per second must be taken into consideration so that the pedestrians may not be caught unprotected in the middle of the road. In western countries special walk signals are installed where pedestrian volumes warrant such measures on intersections and mid-blocks.

Furthermore, pedestrian volume count is important with regard to safety aspect. This study consists in physical count of pedestrians crossing the roads at intersections, problem locations or even at mid-blocks if necessary. Volume counts are taken to distinguish between those crossing within the cross-walk (marked path for pedestrians) and those crossing elsewhere. Pedestrian volume count is necessary (a) to determine the type of control and timing of the signals at an intersection; (b) to decide whether turning movements of vehicles should be stopped during particular periods to eliminate danger to the heavy volume of pedestrians at an intersection; (c) to determine if the pedestrian barriers such as fences or railings are warranted; (d) to determine the safety measures for school children; (e) as a planning data in studying trends by comparison with previous years' counts; (f) in the analysis of pedestrian accidents; (g) to assess the necessity of stricter enforcement by better education and cooperation of road-users.

(v) **Road Congestion or Speed and Delay Study.** This study involves recording of the causes, locations and amounts of delay to buses and street cars, trams, passenger cars or other fast moving vehicles on major roads and streets.

This study is made on important routes during the periods and in the direction of peak traffic flow. Average speed of the vehicle is found out by making about twelve test runs. Out of the two-man team the man sitting with the driver records the duration, location and cause of each stop and the cause for the vehicle to slow down or travel slow continuously. With the help of such studies, time contours can be drawn to illustrate relative congestion on routes radiating from centre of city.

Insufficient roadway capacity, inadequate traffic control at intersection, improper road signs, parked vehicles, pedestrians etc., could be causing congestion. Economic justification is then studied by comparing the improvement costs with the time lost due to delay in terms of money.

(vi) **Road–Users Psychology.** A thorough field study of the psychology of road-users is of utmost importance. In fact, for practical solution of any problem, approach to the human psychology is important and this approach is most important to solve traffic problems. Road users behaviour is affected by factors both external and internal. External factors are weather, land, its use and activities, type and intensity of traffic on the road, physical condition of roadway, road signs, signals and markings, etc. Internal factors affecting the behaviour are consumption of alcohol, physical deficiencies like weak eye sight, etc., emotional disturbances like anger, hurry, etc.

It has been well said that the very traffic conditions which grow out of human behaviour feed back to affect the performance

of road-users. When a person is on the road he is in a special society with additional restrictions imposed by road-traffic regulations. Individuals react differently to this total road situation.

Study of the behaviour of road-users is useful in many ways. Based on this study should be built safety-engineering methods to cover the psychological weaknesses of road-users. Improvements could be obtained by a psychological screening of drivers in the initial driver licensing examination or re-examination of accident-prone drivers to gauge their social and emotional stability. Study of the road-users psychology further helps (a) in the field of traffic engineering research, (b) in designing the vehicles, intersections, curves, road signs, road marking, road signals, etc.

The study of road-users' behaviour may not be treated as an independent problem but it forms an important sub-head in every traffic engineering, traffic police and traffic court problem. Based on this study, safety design features, methods of law enforcement and methods of punishment to violators can be improved.

In the Western Countries, many useful results have been yielded by the application of the principles evolved through the road-users' psychology study.

Standards regarding the relationship between the distance (from destination) of parking space available and the length of time for which parking is required are based on this study. Design and location of traffic control devices like signs, signals, markings, are based on this study. This study has further helped to evolve many channelizing methods and other built-in road safety devices. Even in designing the motor vehicles this study is becoming increasingly useful.

(vii) **Roadway Capacity.** Roadway capacity is the ability of a roadway to accommodate traffic. Capacity is generally defined as the number of vehicles that can pass a point on a roadway in one hour. Capacity depends directly on the speed of the vehicles. The capacity of a roadway under crowded operating conditions differs radically from that when freedom in operation of the vehicle is possible on the same roadway during non-peak hours.

This is one of the *most important* studies in the field of traffic engineering and highway design. The study consists in relating the effect of cross-section, alignment, sight distance, and intersections on traffic flow. Factors such as weather, interruptions in flow due to pedestrians and parking on the road, type of vehicles, speed, the number of overtaking manoeuvres required to maintain a desired speed and many other factors must be studied in order to assess the relative effect of each factor on traffic flow and capacity.

This study enables the engineer to give out a design close to the requirements of traffic supposed to use the roadway. It further helps in selecting the priorities for road improvements and relieve congestion from the roads loaded beyond their capacities.

Measures should be taken to avoid overloading a roadway beyond its practical capacity. In India, field studies have to be conducted to establish the roadway capacity standards under the existing conditions. Proper application of the results would lead to safe and efficient use of roads and also help in selecting improvement priorities.

This is a very complex study to be made under the prevalent mixed traffic conditions in India. Both space occupancy and potential speeds of different types of vehicles vary tremendously. Research work is being carried out by the Central Road Research Institute on this aspect to evolve studies for judging the point where segregation of traffic becomes essential keeping safety, efficiency and economy in view. There is a special urgency to find the solution of this problem in the urban areas of India.

(viii) **Parking.** Parking problem is acute in many cities in the Western Countries. It is discouraging the use of private vehicles. Main central business districts are being abandoned due to lack of parking facilities resulting in great economic losses. There are four factors which influence parking problem, viz., (1) land use, (2) continuing and rapid growth of vehicular traffic, (3) the competition for city street space between moving and standing vehicles, and (4) size, type and manoeuvreability of the vehicles. The parking problem is not a matter of concern only to the individual operating the vehicle but is more of a general traffic problem to be handled and remedied by the authorities concerned. Parking problem involves interests of (a) business-men and merchants in the city whose business depends upon the provision of parking facilities in the town, (b) fleet-operators wanting space for unloading, (c) mass transit (buses, street cars, etc.), wanting greater freedom in movement resulting in better average speed, (d) police concerned with enforcement of parking regulations, (e) traffic engineer wanting safe and free movement for all road users.

Parking studies include (a) space inventory, (b) parking practices, (c) cordon counts.

Space inventory study consists in listing and classifying all types of parking space in the area under consideration.

Parking practices should be observed in the field regarding the use of various types of parking space. Attempt should be made to interview 100 per cent of parkers to find out the destination, purpose of trip and time of arrival and departure.

Cordon counts around town areas consist in recording the number of vehicles, the number of occupants in each and the number of pedestrians entering or leaving the area by time unit of 15 minutes or half hour. This would give accumulation of vehicles in the area at any particular time interval.

This study enables the engineer to provide or reserve suitable places for storage of vehicles and loading and unloading zones in relation to the needs of local traffic. Uncontrolled parking reduces roadway capacity and safety.

In India, at present, even though the number of mechanically-propelled vehicles is very low, due to higher concentration of such vehicles in more advanced cities like Bombay, Madras, Calcutta and Delhi, the parking problem is becoming more serious every year. Unless proper parking spaces are developed along with the new and more crowded shopping centres, the parking problem will become acute in the next few years.

3. Traffic Control through Traffic Engineering

Since there can never be enough traffic police to control traffic on all the roads at one time and, further, a foolproof design of street or road with properly built-in safety engineering is more dependable, it is advisable to make a concentrated effort to control traffic through proper road design. That is where the road engineer can play a major part. Safety aspect deserves first attention in road design. Omission of one or two seemingly minor details can materially affect the safety and traffic carrying capacity. In this connection, experience of black spots, *i.e.*, where accidents occur frequently, should be made use of by the road engineers. This experience under our mixed-traffic conditions will be a valuable guide for proper road design. Traffic police control may be used only in those cases which cannot be controlled through engineering,

Roadway markings, road signs, light signals, pedestrian safety-zones, traffic circles, simple and easy design of intersections, staggering the entries of minor roads, fit operating condition of the vehicles in use and proper training for road users are some of the tools of traffic engineering. These traffic control devices are self-enforcing.

At many places in the U.S.A. and the U.K., traffic accidents have been reduced through intelligent traffic engineering at a nominal cost. In terms of money there have been heavy returns for the small investment made in the way of building traffic engineering safety. 'Before and after' study *i.e.,* traffic records before the improvement and after the improvement, is a useful measure of traffic engineering improvement.

Here is an example taken out of the issues of "Getting Results through Traffic Engineering," published by the Association of Casualty and Surety Companies, New York City. In Burlington, Iowa, five accidents occurred during a year on the signalized intersection of Agency and Osborn Streets marked for three lanes—the middle lane reserved for left-turn into Agency Street (keep to the right in the U.S.A.). Entering traffic volumes totalled 473 vehicles for two hours, *i.e.,* from 3 to 5 p.m., while there were only 4 vehicles turning left from the Agency Street to the northbound Osborn Street (Fig. 1). The signals were timed to

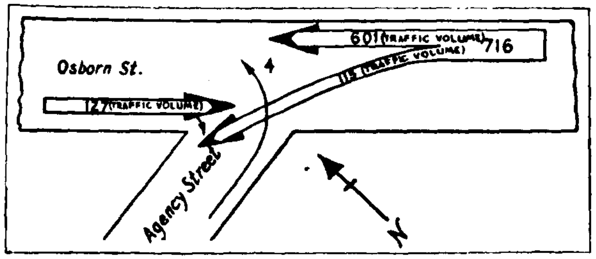

Fig. 1.

display green indications simultaneously through northbound Osborn Street. Inspite of this small left-turn movement, four out of five personal injury accidents reported involved collisions between these left-turn and northbound movement. But no sooner a traffic engineer was employed by the City, the improper signalization of this intersection was realized. Volumes fell far below the minimum warranted for the installation of traffic signals.

Signals were removed and 'STOP' (Halt) signs were installed to control traffic entering the Agency Street. Negligible cost on this improvement resulted in 'No Accident' in the following six months.

Traffic signal is one of the most restrictive types of control devices and must not be installed without an approval from the traffic engineer.

Many traffic situations can be greatly improved by simple traffic engineering applications. Here is another example of how accidents can be eliminated by traffic engineering techniques.

Modern Park Cross Road west of Bournemouth, B. 3075 secondary road, carries a great deal of coach traffic in summer. Conditions were dangerous where it crossed straight over A-35, the direct route between Bournemouth and Dorchester.

The layout was altered by staggering the entries of the minor road, Fig. 2. There was 100 per cent reduction in accidents through the simple technique.

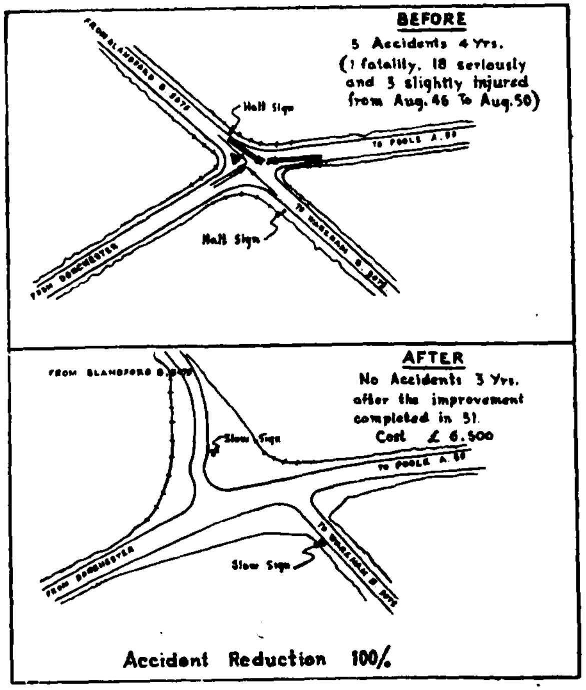

Fig. 2.

Various traffic problems, however, have to be solved by appropriate engineering principles and techniques. Proper design of different road-signs and their installation at proper places is also the traffic engineer's job. Regulatory signs and signals should be largely self-enforcing to serve their purpose efficiently. In India, as much as possible, road-signs should also bear pictures so that uneducated people may be able to follow them. There is necessity of more research work on the type, size, shape, colour, etc., of road-signs used on our roads.

4. Traffic Accident Records

A well planned and standardized system of reporting road traffic accidents is very necessary for useful analysis of the information recorded.

The uses of accident records are many. On the administrative side these records provide a measure of (a) the importance of traffic safety programme, (b) the progress of a safety programme, and (c) costs of accidents. On the enforcement side, the accident records can be used (i) in finding out the relative importance of traffic, (ii) as background for planning the law enforcement and personnel assignment, (iii) as aid to supervisors and (iv) for planning the budget with economic justification. Engineering uses of road traffic accident records are even more important: (1) These records are used in 'before and after' study of many traffic situations and through these records engineering deficiencies contributory to accidents can be spotted. (2) These records are further used in preparing spot-maps showing high accident-frequency places. (3) In developing road design standards, and their installations, in speed zoning and in improving pavement surfaces, these records serve a useful purpose. (4) Also, there are many educational uses of accident records.

Before any solution may be suggested it is essential to have thorough comprehension of the problem. For this purpose, the traffic engineer has to study the accident records carefully to trace out all factors contributing to an accident.

5. Traffic Planning

For a convenient, safe, smooth and efficient flow of traffic town planning engineers and traffic engineers should work in close collaboration. Town planning consists in striking the most calculated balance between the industrial, business and residential areas and between built-up areas and open spaces. The factor of traffic safety must not be ignored for a moment while planning a town because this is the only time when the town-planner can deal with the traffic problem at the source. It is true that with the help of traffic police a number of traffic problems can be solved, but nothing should be done through enforcement which can be effected by proper layout and construction. The techniques of town planning and road traffic control are inseparable and must be properly co-ordinated.

Photo 1.
Traffic volumes beyond roadway capacity start causing congestion

Photo 2.
Origin destination traffic survey of Delhi being conducted by road-side interview method

Photo 3.
Pedestrians with restricted visibility on the road are a source of great danger

Photo 4.
Street hawkers on sidewalks force pedestrians to walk on the roadway

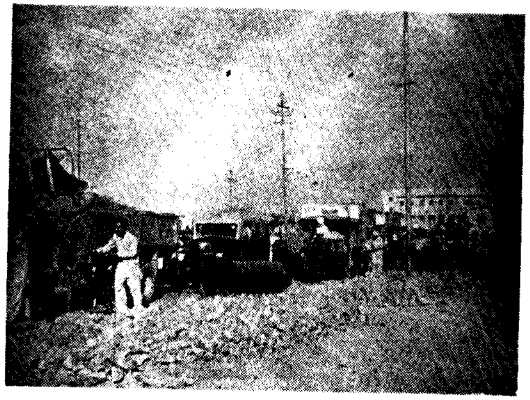

Photo 5.
An example of traffic congestion on the roads

Photo 6.
Parking demands are increasing every day

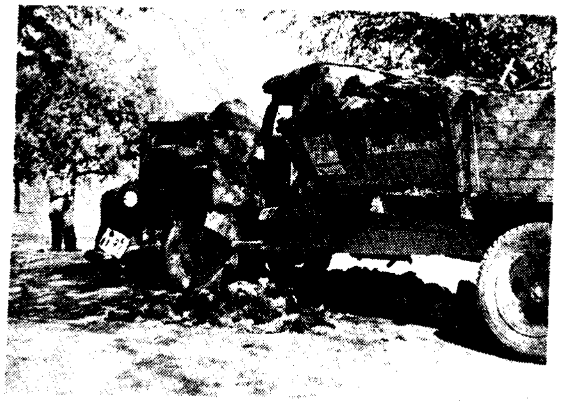

Photo 7.
A scientific investigation of accidents is most important

In India, probably, like most other countries, the basic layout and design of the existing roads has been out-dated by the present traffic conditions. However, proper care should be taken to meet this difficulty and, where it is hard to alter the human nature, design and layout of the existing roads will have to be altered or improved suitably.

Modern cities have two basic functions, viz., (a) as workshops and (b) as places for living. In both these functions the traffic consideration holds high priority. As workshops, they cannot be efficient unless traffic congestions and delays are eliminated and, as living places, from traffic point of view, they must be as safe as possible. Cities, generally, continue to grow and many changing factors continue to operate in producing new conditions. So, at any one time, there cannot be submitted what may be called the final solution of the problem of traffic. Unless there is constant planning in regard to city growth, it would become impossible to meet the future traffic problem and the money waste in terms of traffic congestion, delays and accidents would create most undersirable living conditions.

To have a well planned road and street system, a more reasonable approach would be to study the purpose of movement of people. Movement of people may be classified under five general heads for a proper road and street plan of the cities. The five general heads are: (i) Home to work at industry or town, (ii) Home to shopping centres, (iii) Transit and bus service, (iv) To and from railway stations, air ports, etc., and (v) Home to recreation.

6. Traffic Research

Enormous research work is necessary on various subjects in the field of traffic engineering. Research work is needed to improve vehicles, roads and road conditions. In conducting all types of traffic research the foundation of technical knowledge must be laid on a competent study of human behaviour. A knowledge of the attitude and reactions of road-users to traffic control devices, traffic engineering designs, traffic law enforcement, road-discipline education and other traffic situations is very useful to draw useful conclusions from research work.

Each country has its own problems demanding research work. In India, broadly speaking, the major concern of the traffic engineer should be to find devices for a safe operation of all types of mixed traffic. Research work should be started mainly along these lines. Then, of course, there are finer problems for research work, e.g., (a) effectiveness of the improved street lighting in the prevention of night accidents, (b) how do the road conditions differ in their effect on night and day accidents. There is a necessity of scientific analysis and recording of road accidents with a view to find preventive measures specially in urban areas under mixed traffic conditions. The problem of next importance is to analyse the causes of congestion in urban areas. Next comes the problem of traffic economics and financing the traffic requirements. (c) Annual economic losses due to road accidents against the cost of their prevention. (d) Standards for road markings, road-signs, signals and road capacity under the existing conditions. (e) How roads in built-up areas may be modernized to meet the needs of present and future traffic. (f) Future trends of the traffic problem. (g) Allocation of cost and benefit.

Study of the availability of finances and technical personnel would be essential for setting priority on each research problem of traffic.

7. Road planning and Traffic Economics

No engineering problem is complete without due consideration of the economic aspect. A sound study of road traffic economics is extremely important for efficient planning, programming, selecting priorities and proper allocation of cost and benefit to the road-users and the public.

Traffic economics is not a problem for the public Finance-Expert and its implications may not be treated in an ordinary way under the general tax system. The traffic engineer has to tackle the problem of road traffic economics in his own way to assure flow of steady income for a long range plan and systematic improvement of roads and traffic flow.

In the field of road traffic economics, work is necessary on the following main issues in India: (a) Economics of joint highway use for mixed traffic, (b) economic study of bullock-cart and improvements in its design from economic point of view, (c) cost assignment for different types of traffic and other beneficiaries keeping in mind relative use, value of services, differential benefits, differential space occupancy, total road benefits and users' willingness and capacity to pay and the general welfare due to roads.

8. Vehicle Inspection

For full justice to his profession the traffic engineer must be fully aware of the types and conditions of the vehicles being used. Regarding the operating conditions of vehicles, from engineering point of view, certain minimum standards should be fixed and each vehicle including private cars should be required by law to

undergo a periodical check. At present only commercial vehicles are checked periodically. Regarding weight, size, passengers and load to be carried by different vehicles, there should be fixed and uniform standards (for further discussion see item 6-A).

9. Special Events

Scientific handling and planning of traffic on special events is also one of the traffic engineering functions. Special events include parades, sports events, social gatherings, festivals, big funerals, State guests' visits, fires and other disasters. Advance planning in handling such events is extremely important and its dividends in terms of road safety, reduced police force and reduced confusion and hazard can be realised. There is need for research to evolve standards for planning the control, regulation and segregation (time segregation) of traffic for such occasions, keeping in view the public convenience.

4. TRAFFIC POLICE

In tackling the traffic problem, traffic police have many functions to perform. With the help and guidance of a traffic engineer, traffic police can go a long way to solve various traffic difficulties. The basic aims of traffic police should be to: (1) Enforce traffic laws. (2) Maintain and encourage good police-public relation. (3) Help the traffic engineering department in many ways, e.g., (a) recording traffic violations in detail, (b) making traffic accident studies and investigations in co-operation with the traffic engineering department, (c) maintaining drivers' records, (d) making traffic safety reports concerning mainly with the number of traffic accidents, number of accidents investigated, number of persons killed and injured and other pertinent data on traffic safety activities, (e) carrying out traffic safety programmes, (f) making available all other information desired by the traffic engineering department. All this information should be provided in a systematic manner as may be desired and prescribed by the traffic engineering department.

With the guidance of the traffic engineering department, the traffic police should: (a) determine the requirements for installation, proper placing, timing and maintenance of different types of traffic control devices, (b) conduct engineering analysis of traffic accidents and devise remedial measures, (c) conduct engineering investigations of traffic conditions, (d) plan the parking, loading and unloading and traffic operation on minor and major roads, (e) if necessary, make and enforce temporary experimental regulations to cover emergencies and special conditions.

For adequate performance of such duties trained police would be required. For this reason, it is felt that traffic police should be separated from the general pool and attached to the highway department. It may be worthwhile mentioning that law enforcement agencies should specially concern themselves about developing, maintaining and encouraging good public relations. Law enforcement itself is not very conducive to good public relations; therefore, the traffic police should seek public acceptance so that they may be able to perform their duties effectively. Some people are hard to deal with but it is the policeman's job to handle them firmly and yet politely and tactfully. A planned programme designed to gain and hold the goodwill of people should be based on discharging the duties with zest, enthusiasm, tact, personality and showmanship in most friendly, fair and cordial fashion. All the employees of traffic police department should make a special effort to implant in the minds of road-users the idea that the policemen willingly serve the country at large in a friendly and intelligent way. Every policeman must possess a sound knowlodge of traffic regulations and be able to drive different mechanically-propelled vehicles.

To perform the duties effectively, it is recommended that every traffic policeman on active duty must be a practical diplomat with a fair knowledge of motor vehicle mechanism, physics, mathematics, psychology and first-aid treatment.

Every employee of the traffic police department is a vital stabilizing influence in road-users' community. So a special training for developing and maintaining good police-public relations should be given to each employee before he is put on active duty. This training should include instructions on (a) not to show off or misuse authority, (b) to be honest and polite in dealings, preferably with a smile on the face, (c) not to lose temper, (d) to be free from prejudice, (e) to be acquainted with the general principles of traffic engineering.

5. TRAFFIC LAWS AND COURTS

1. Traffic Laws

Adequate, clear, simple and uniform road traffic laws are necessary for safe and efficient operation of vehicles.

Uniformity of traffic laws throughout the country is of great importance. Conflicting traffic laws in different cities or States are likely to create confusion and hazard. In the same way, lack of uniformity in signs, signals, markings and their legal meaning can cause traffic confusion.

As recommended by the Committe on Laws and Ordinance, 1949-Washington, D.C., the traffic regulations should (a) be clear and explicit in language and requirements, (b) be aimed at safety, public convenience and general good, (c) be reasonable and meet actual needs, (d) conflict, as little as possible, with community habits, (e) be comprehensive, covering those type of traffic situations where directive control is required, (f) recognise the innate common sense of the public whose respect and acceptance of the laws must merit due consideration, (g) be flexible to fit new conditions as they arise, (h) be consistent, brief and as few in number as possible, (j) conform as far as possible with practices which are uniform in each State and throughout the country.

These recommendations are also applicable in India and must be given a consideration before making new traffic regulations, and the existing regulations should be revised with this view point.

2. Traffic Courts

In the enforcement of traffic laws the judicial process plays an important role. Traffic courts have a distinct function to perform in helping to solve the present day traffic problem.

The traffic law-breaker differs from the average criminal in the sense that he is not aware of the possibilities of grave consequences of his act. A traffic offender does not consider himself to be an enemy of society whereas a criminal knowingly violates the social codes with full intention of harming others. While dealing with traffic cases, traffic courts must not ignore the main fundamental psychological difference between a criminal and a traffic offender.

The primary aim of traffic courts should be to impress upon the violators the importance of traffic law and its observance rather than penalize them. The penalty for traffic violators should be chosen on psycological basis. The fact that the traffic offender lacks a clear conception of the consequences of his action is a factor that should affect the choise of punishment and its method. However, this factor must not affect the procedural treatment. Each traffic court should see to the fact that the violator leaves the court thoughtful about road safety and co-operatively inclined for the future. So at times it might be better to sentence a violator to attend a number of traffic safety lectures or to visit a traffic victim in the nearby hospital than to impose any fine or imprisonment on him.

6. OTHER AGENCIES

The present and future road traffic problem can be solved more effectively and efficiently with additional help of other agencies like (A) Vehicle Administration, (B) Public Education and Publicity Organization, (C) Public Support Organization.

A. Vehicles Administration. Vehicle administration has to perform many functions, e.g., (a) registration and classification of all the different vehicles in use, (b) maintenance of files on ownership and transfer of ownership of vehicles, (c) collection and financial accounting of periodical taxes, (d) issuing, renewing, suspending and revoking driver licences, (e) collecting the fixed fines on different traffic violations when the violator pleads guilty (this would save the violators from going to the court.), (f) checking periodically all the vehicles in use regarding their fitness for operating conditions.

The work of the vehicle administration may be divided into five main categories, i.e. (1) Licencing, (2) Vehicle Inspection, (3) Financial Responsibility, (4) Driver Training, (5) Records and Correspondence.

1. **Licencing.** Proper licencing for driving plays an important part in controlling the drivers and traffic accidents. Before issuing a driver licence the applicant should be given a test for eyesight, knowledge about traffic laws, understanding about road signals, and driving ability. Before renewing a driving licence a fresh test may be given to those whose driving records have not been satisfactory

2. **Vehicle Inspection.** Periodical vehicle inspection contributes a lot towards road safety. All accidents that are caused due to defective vehicles could be eliminated. Sudden breakdowns and stalling of vehicles are also reduced by periodical inspection of motor vehicles regarding brakes, lights, windshield wipers, steering and front wheel play and alignment, silencer and tyre conditions and registration certificates. In the same way, inspection should be made of all other types of vehicles as well. These periodical checks may be six monthly or quarterly.

Furthermore, inspection of vehicles including bullock-carts regarding their size and weight would be of great use. It would help (a) establish one of the fundamental prerequisites of highway design, (b) establish a basis for regulation of the many relationships between the dimension and weight of vehicles and strengths and capacities of the existing roads, (c) promote road safety and road efficiency in the countrywide vehicle operations.

Five elements are responsible for all road accidents: the vehicle operator, the vehicle, the pedestrian, stray animals and the road. It is within the scope of the administration to put a check on the first two items. Vehicle inspection programme should follow standard driver licencing and examination, road safety education and traffiic law enforcement. Afterwards, a well planned programme should follow of road construction and improvement with application of the requirements of traffic engineering.

3. **Driver Training.** This administration should provide facilities for learning driving. Applicants for driver's licence, who have had no previous training in driving a motor vehicle, may be given driving lessons and charged a reasonable fee. This way the administration can help to produce better drivers.

4. **Records and Correspondence.** Complete records of all the activities of the administration would be essential for check on its work and efficiency. Records of driving licences issued, suspended, revoked, fines collected, vehicles checked, vehicles registered, taxes collected, etc., would be useful to the different traffic engineering sections. At present centralization of such records is lacking.

Correspondence in response to the public inquiries about licences, vehicle registration, etc., should also be one of the functions of this administration.

B. Public Education and Publicity Organization. Existing traffic conditions in India are already too serious to escape the notice of a road-user and in addition to that the traffic problem tends to be even more acute in the coming years. A well planned public education programme regarding the safe and efficient use of road can help a great deal in solving the present and the future problems. This kind of education in schools and colleges would develop in students' minds certain attitudes that would influence their behaviour on the road all through their lives.

To carry out the public education programme succesfully it would be necessary (a) to educate the students from the elementary through the university level, (b) to specially train teachers for the purpose, (c to plan the instruction programme for different classes and age-groups of people, (d) to educate about an adequate accident reporting system, (e) to educate for understanding the evaluation of public education programme results, (f) to seek public support for making the public education programme a success.

Special courses as guides in traffic safety should be prepared for schools, colleges and different classes and age-groups of people. These courses should include instructions on different techniques required for traffic safety and day by day instructions based on the needs of local situations. The lessons should be preferably positive and preventive, making the individual more conscious of traffic safety. Safety instructions could also be given through specially made films, advertisements and big maps and diagrams on display at important and busy places.

In India, research is needed to find out the best methods of approach to the uneducated classes for traffic safety education. Through personal and community approach, the development of desirable attitudes, interests and understanding of the need for improving traffic conditions would be possible. Study of local traffic problems, evaluation of driver and pedestrian practices and appraisal of traffic accident records would be helpful in developing proper means of spreading safety education.

Traffic safety responsibily is two-fold, that of the official agencies to bring out the best possible programme and that of the individuals to conduct themselves as road users with constant regard for the traffic laws and other rights. The individual's choice matters most; either he can play safe to himself and to others or he can choose to nullify the efforts of the official agencies employed to make the road safety programme a success. So it is recommended that the justification for and the advantages of the enforced traffic laws must be fully demonstrated so that the individuals may be convinced of them. Publicity through radio, newspapers, magazines, posters and other means would be useful in bringing to light various road safety rules and their justification.

C. Public Support Organization. There is a definite need of an organized public support for execution of every road safety programme. An organization is necessary to stimulate public co-operation. Without significantly increasing public co-operation added expenditure in the way of law enforcement and other road safety programmes would not bring enough dividends in terms of safety. The public support organization could further (a) help in the co-ordination of different road safety activities, (b) help in the development of road safety programmmes of different agencies, (c) work closely with other agencies in advisory and consulting capacity, (d) appraise the existing traffic conditions and needs of different neighbourhoods, (e) foster the spirit of competition through informal inter-city traffic operation safety contests, etc.

The Public Support Organization should be a non-official body sponsored by insurance companies, automobile associations, social clubs and other private organizations.

7. RECOMMENDATIONS

As a result of the foregoing study, some tentative recommendations are made as follows. Also see Plate 1.

(i) In the bigger cities with traffic problems there is a need of setting up Traffic Engineering Units, on a small scale in the first instance, attached to the State highway departments. These units may be handled by a highway engineer with a specialized knowledge of traffic engineering. Regional traffic engineering units may be set up in the States attached to the P.W.D. Divisions.

The main functions of the traffic engineering unit should be (1) installation, operation and maintenance of traffic control devices, such as road signs, signals, markings, street name signs, etc.; (2) checking all the proposed designs of new roads and streets from safety point of view; (3) studying the accident black spots in the built-up areas and removing the causes of accidents arising out of lack of safety design features; (4) designation of cross-walks, parking zones, loading zones, bus stops, silence zones, speed zones, etc.; (5) conducting traffic surveys and studies with the help of the police whenever necessary; (6) collection and compilation of such traffic data as may be of engineering use; (7) compilation and analysis of accident records; (8) traffic planning and traffic channelization; (9) checking the plans for the extention or new location of roads or streets keeping in mind the economic studies of different types of traffic operating on our roads with a view to establish some standards of equitable taxation; (10) making a special study of traffic regulations in relation to traffic engineering and road-users' psychology; (11) making any other studies like congestion, safety and efficiency on roads and intersections; (12) traffic research; (13) co-operating with other interested agencies for public education of traffic regulations and their advantages of proper use of the road; (14) developing other ways and means to improve traffic conditions.

(ii) There is a necessity for setting up a "Traffic Advisory Council" at least in each big city in our country to start with. The Traffic Advisory Council should have representation of (1) Chief of Traffic Police, (2) Municipal Engineers, (3) Traffic Courts, (4) Transport Department, (5) Traffic Engineering Unit, (6) Town Planning Department, (7) Any other officials connected, (8) City Bus and Tram Service, (9) Taxi-cab companies, (10) Trucking or other transportation companies, (11) Automobile and Insurance companies, (12) Educational Institutions, (13) Safety organizations, (14) Newspaper Editors, (15) Other non-officials having public-spirited interest in traffic.

The Traffic Advisory Council should hold periodic meetings and the main functions of the Council may be: (1) to advise regarding the official activities of all the concerned departments in any phase of the traffic problem ; (2) to suggest remedial measures for complaints and for removing local complaints; (3) to issue traffic reports designed to capture public interest in the required traffic improvements and provision of new facilities and in creating general traffic-mindedness ; (4) to maintain close liaison with the activities of the various concerned departments.

(iii) There is a need of establishing a public support organization and a vehicle administration in each big city where Traffic Advisory Councils and Traffic Engineering Units are set up.

(iv) It is recommended that a "Traffic Engineering and Planning" Division may be opened in the Ministry of Transport and Communications, Roads Wing. This division may co-ordinate the activities of several traffic engineering units and give advice whenever required.

(v) Traffic Police should be specially trained in properly helping the traffic engineering units in maintaining traffic statistics and in conducting traffic surveys.

(vi) Special attention should be paid to selective enforcement planning to get the maximum efficiency out of the available police personnel.

(vii) Traffic laws should be revised in relation to the requirements of the country and for easier and better enforcement these laws should be uniform, as far as possible, all over the country.

(viii) For fair and strict enforcement political and social influences should not come in the way. Suitable steps should be taken in this direction.

(ix) Traffic courts should award the punishment to traffic violators on psychological basis. The main purpose of the punishment should be to make the violators safety-conscious for future. A traffic safety school for traffic violators may be opened, if necessary.

(x) Drivers' licence examination should be strictly on scientific basis. Before granting the licences, psychology of the applicants should also be studied.

(xi) The object of traffic engineering does not end in making the traffic flow smoothly, safely and efficiently. This must be further stretched to bringing about the desirable future development of the city. To achieve this objective, close co-operation of city planner and traffic engineer is recommended. It is further recommended here that in the planning of new towns or townships a traffic engineer should also play his legitimate part. This is the time when the root cause of many traffic problems can be prevented.

(xii) Future traffic cannot be predicted with great accuracy but it is very important to give consideration to all such factors as give rise to increase in traffic. It is in the interest of overall economy that due provision should be made in the design of roads for future traffic requirements.

(xiii) It is recommended that a comprehensive city planning and traffic engineering survey of all our important cities may be made with several view points, *e.g.* (i) to measure deficiencies in existing road and street system, (ii) to plan and locate the new required facilities and to fix the construction priorities, (iii) to assure the protection and acquisition of future rights-of-way at reduced costs, (iv) to evolve means to match expected revenues to total estimated costs for improving the traffic conditions.

The Indian Roads Congress is the right body to deal with this matter and lay down the procedure for conducting such a survey.

(xiv) Solution of the existing traffic problems and prevention of the future problems depend, to a large extent, on town and regional planning. So town planners should be given training in those aspects of highway and traffic engineering which relate to town planning. This training can better be given in engineering faculty as it does not fall within the scope of architectural faculty. Selective courses in traffic engineering should be started in engineering colleges in India to cope with the future demand for traffic engineers.

(xv) Every science has its origin and growth in research and without continuous research work in any scientific field the science is likely to be outmoded and will start decaying. Research work is just as important in the field of traffic engineering as in any other scientific and technical branch and especially so in India. Traffic engineering research consists mostly of field work and, for this purpose, an organized team work is required to achieve the desired results. All the traffic engineering studies, as suggested in the body of the Paper, are necessary for the furtherance of traffic engineering research.

It is most essential to implement the recommendations for the necessary organized team work directly and indirectly contributing to the most wanted research in the field of traffic engineering in India. These recommendations form a basis for initiating simple studies in traffic engineering which are a pre-requisite to many other useful research studies.

ACKNOWLEDGMENT

The Author wishes to express his deep sense of gratitude to Shri S. R. Mehra, Director, Central Road Research Institute, for the keen interest taken and for his valuable guidance in preparing the Paper. The Author is equally thankful to Dr. R. K. N. Iyengar, Deputy Director, Central Road Research Institute, for all the encouragement given and for reviewing the Paper.

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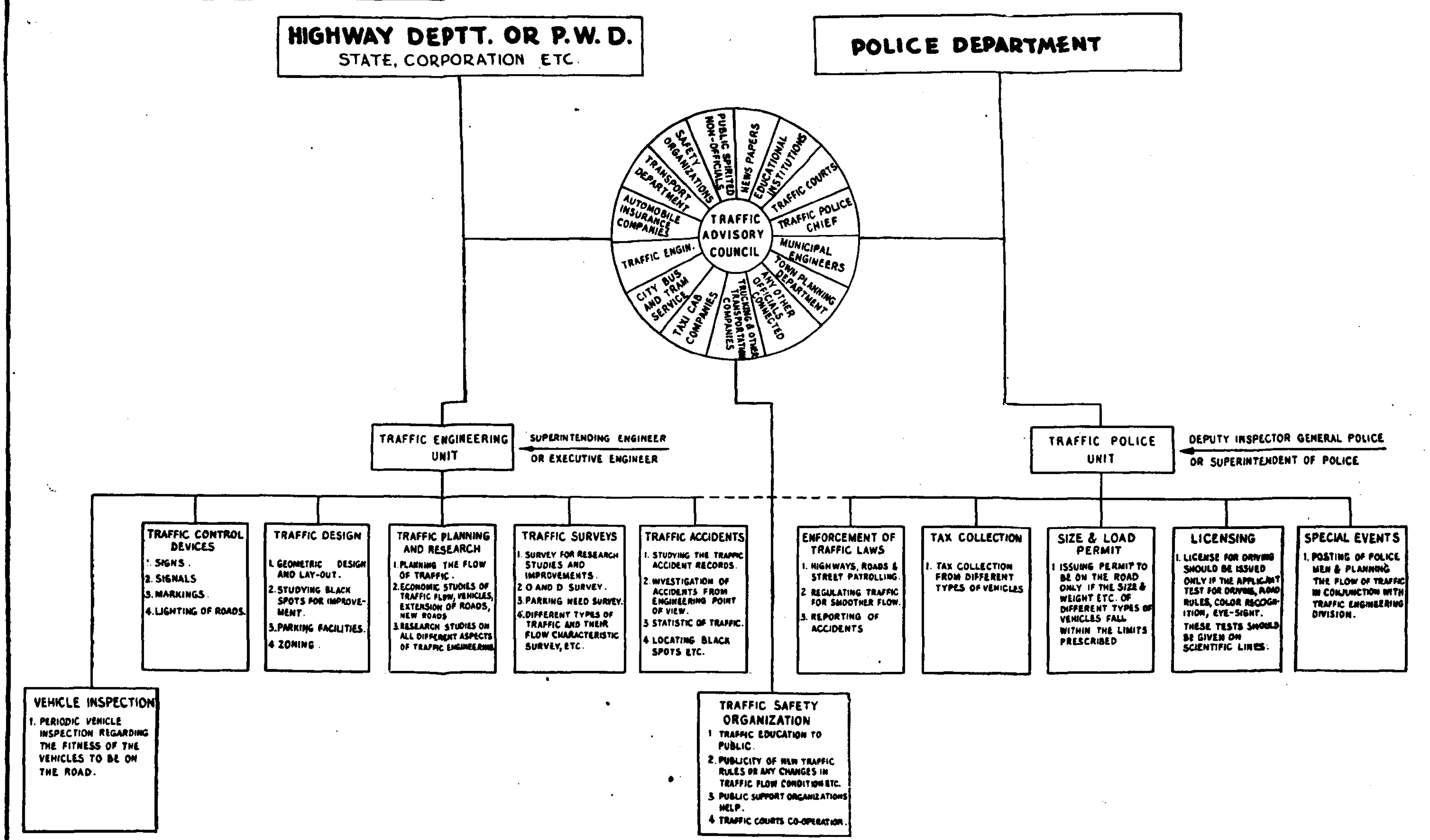
PLAT



A SKELETON PROPOSAL FOR TRAFFIC ADMINISTRATION FOR STATE REGIONS OR FOR BIG CITIES

Paper No. 205

"THE IMPORTANCE OF SUBGRADE COMPACTION IN THE ECONOMIC DESIGN OF FLEXIBLE PAVEMENT"

By

S. R. MEHRA & H. L. UPPAL*

CONTENTS

SYNOPSIS

The Paper presents a case for proper compaction of the subgrade so as to substitute a part of the thickness of the pavement with processed soil.

Effects of heavier traffic in dry areas and of increasing moisture content in the subgrade even with normal traffic on the settlement of the subgrade are demonstrated.

The conclusion is that by compaction of the subgrade soil on new roads the thickness of pavement which is found inadequate today can be made sufficient for the heavier traffic of the future.

1. INTRODUCTION

1.1. During the last few years, it has been noticed that the flexible pavements, generally speaking, are getting progressively poor in riding quality as a result of surface deformation. This deformation is produced mainly due to the following factors:

(a) progressive non-uniform compaction of the subgrade under the wheels of heavier vehicles now plying on the roads and also due to the rapidly growing

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intensities of traffic even without a change in moisture content of the subgrade soil.

(b) deformation under traffic load as a result of further compaction due to alteration in subgrade moisture resulting directly or indirectly from the normal weather cycles.

(c) deformation produced by a combination of (a) and (b) above coupled with the fact that certain areas for various reasons are getting water-logged and, therefore, a state of saturation of subgrade soil is being progressively brought about by capillary moisture from the rising water table, causing subgrade failures in varying degrees.

1.2. The phenomenon may be further amplified as follows :

Table 1 gives the stress gradients of vehicles of different load capacities showing the theoretical stresses[1] caused in a flexible pavement and the subgrade below at various depths, Fig 1. It will be seen for instance that the stress produced by a 2–3 ton vehicle at a depth of 8 inches is only 8.88 lb per sq. inch, whereas the stress produced at the same depth by an 8–ton vehicle is 18.81 lb per sq. inch. The corresponding stress produced by a bullock cart is 9.47 lb per sq. inch only.

1.3. It can therefore be imagined that in the case of an old 8 in. thick flexible pavement, whereas the stress immediately under the pavement or on top of the subgrade was of the order of only 9 lb per sq. inch in the old days when bullock carts and 2-3 ton vehicles were predominant loads on the road, the intensity of stress at the same depth today, when 8–ton (and over) buses and trucks have become the rule of the day, has increased to 19 lb per sq. inch and above i.e., at least twice as much. The typical effect of increase of stress on an alluvial soil in the subgrade in causing compaction or settlement within itself and consequent deformation on the surface is shown in Figs. 2 and 3. Fig. 2 shows how density increases with increase in applied stress (the moisture remaining the same). Fig. 3 gives by calculation an idea of the amount of settlement that can take place in one foot depth of a soil due to increase in density under higher loading. It will be seen that the effect is quite significant.

1.4. It can also be easily imagined that with change of moisture towards optimum, the effect would be substantially increased with the same intensities of loading, and more so with higher intensities. This is clearly illustrated by the set of typical moisture density curves[2] in Fig. 4, for increasing compactive

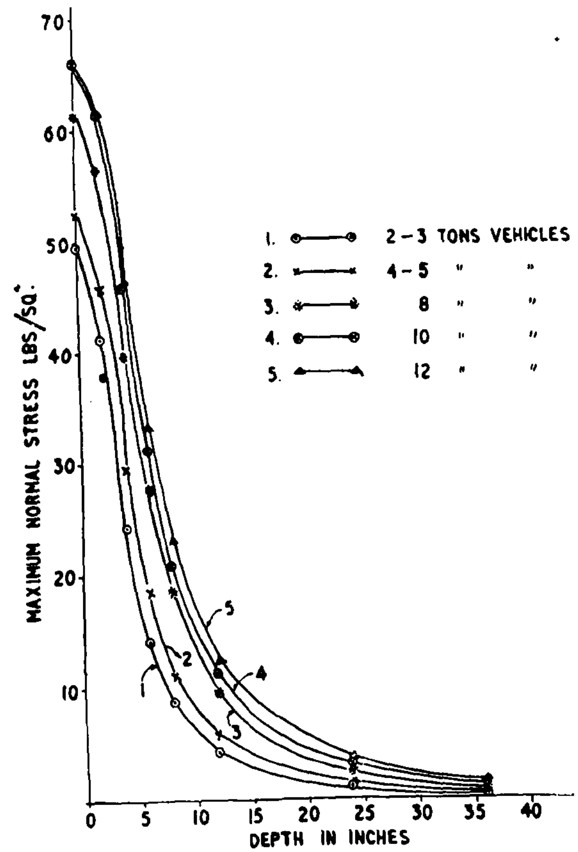

Fig. 1. Showing Load Transmission through Pavement by various vehicles.

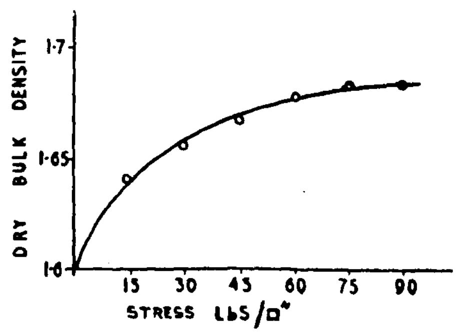

Fig. 2. Showing Effect of Increasing Stress on the Compaction of Subgrade Soil.

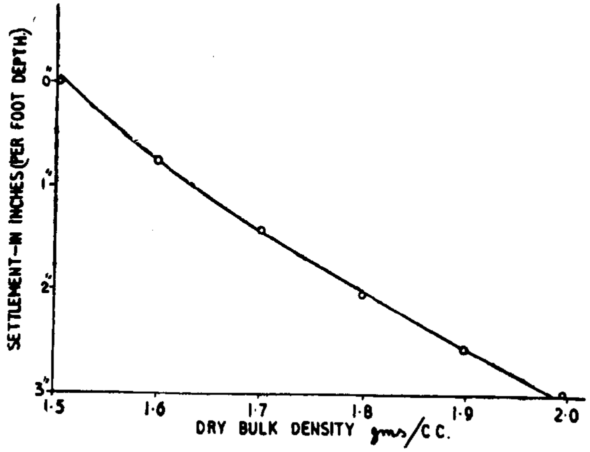

Fig. 3. **Settlement per foot depth with Increase of Dry Bulk Density**

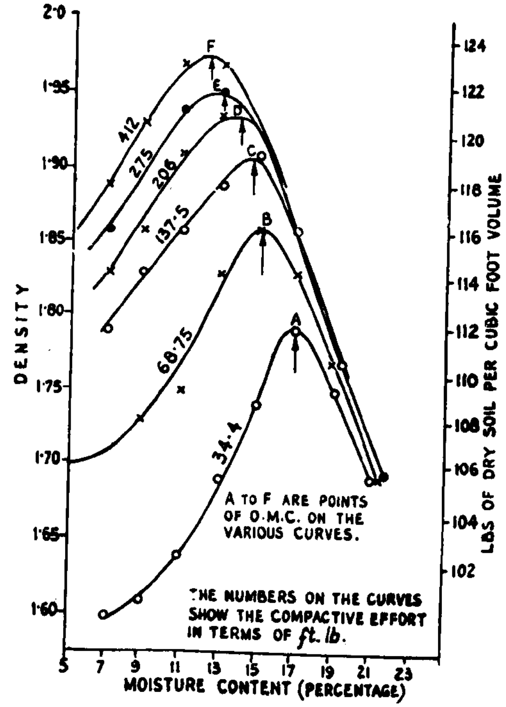

Fig. 4. **Effect of Compactive Effort on the Moisture Density Curve**

effort. The curves show that at suitable moistures the same loads can increase the density of a soil considerably and that the effect is further enhanced at higher loads It is easy to imagine that with changes in weather conditions, the moisture in the subgrade keeps changing and that it is possible for changing loads to catch the subgrade soil at moistures most suitable for producing maximum possible compactions and consequent deformations.

1.5. The damage outlined above can be further aggravated as a result of repetition of loading[3] under the various conditions referred to before. Figs. 5 (a) & 5 (b) show the result of repeatedly applying increasing loads through a circular plate (equivalent to area of contact of tyre) on a flexible pavement and measuring

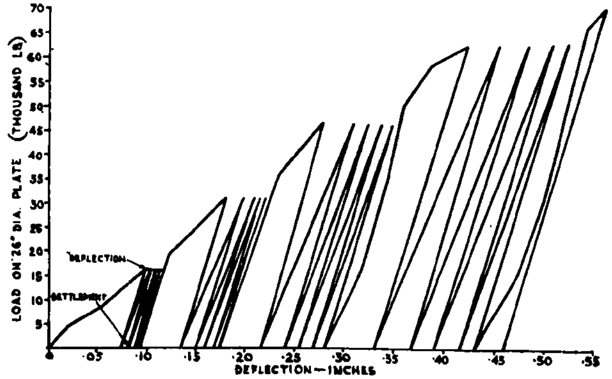

Fig. 5. (*a*) **Typical Field Test Plot—Flexible Pavement**

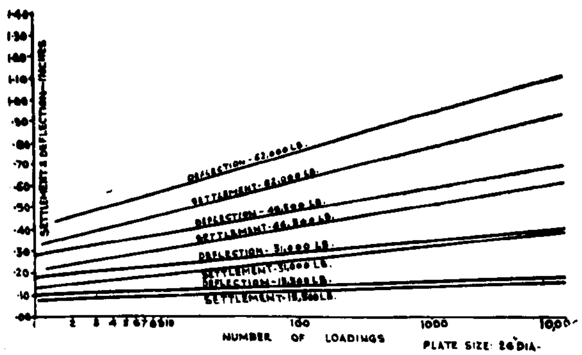

Fig. 5. (*b*) **Deflection Settlement Curves—Flexible Pavement**

the residual settlement. It will be seen that not only does eac repetition of loading leave an increasing permanent settlemer in the pavement, but also that as the loads increase these settle ments are much higher.

1.6. In cases where the subgrade gets saturated due to watei logging etc., the applied load is taken up immediately by the por water and, due to the suddenness of application of load, an up ward pressure is exerted on the pavement and if the thickness o the pavement is not adequate, then settlement under the load and bulging on the sides is possible causing a partial failure of the subgrade due to plastic deformation[4], Fig. 6.

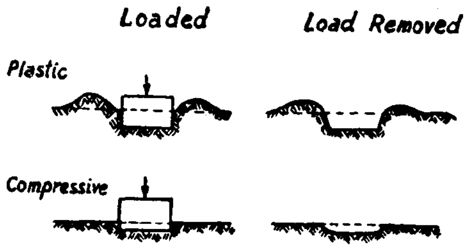

Fig. 6. Types of Deformation

This in turn can bring about a complete failure of the pavement as a result of repetition of loading. Such failures are of common occurrence in badly water-logged lengths of road, the complete failure being accelerated in most cases by ingress of moisture from the top as a result of local flooding during the monsoons when flowing water causes the stripping of the bituminous binder and makes the surface treatment pervious.

1.7. The progressive deformation of the subgrade due to the causes described above is repeated on the surface of the flexible pavement and is naturally causing inconvenience to traffic on an increasing scale. But what is even more important is the fact that the continuous putting right of this unevenness is normally a very expensive business. As the deformation occurs slowly, the surface in the case of surface treated roads is put right from time to time by means of heavy patch work. This method, the only one available under the circumstances, is not only expensive but also unsatisfactory as, in course of time, the excessive thickness of uneven open textured carpeting that is produced gradually as a result of heavy patch work starts creeping and thus becomes, in itself, an important contributory cause of surface roughness.

1.8. In so far as new roads or roads requiring reconstruction or widening are concerned, there is a case therefore for designing the pavement thickness in such a way that the likelihood of damage from the above causes, in the foreseeable future, is reduced to the minimum.

1.9. It would be realized that in a large majority of cases, the settlement of the road starts from the subgrade because of its low degree of compaction in relation to the loads imposed on it. Since the increased loading results in further compaction of the subgrade, it will not be illogical to assume that if the subgrade when laid is at a high degree of compaction the increased loading will not be able to do much damage to it.

2. OBJECT AND SCOPE OF THE STUDY

It is intended to show in this Paper that even though the scientifically designed thickness of pavement would come out to be more than the prevalent thickness based on past experience, substantial portion of the designed thicknesses can be provided merely by a proper compaction of a corresponding depth of the subgrade or embankment soil, immediately below the hard crust. This would considerably reduce the required depth of the hard crust and would cut out the risk of damage to the pavement from the above mentioned causes. The extra cost involved would be very small, indeed, in comparison with the inescapable alternative of providing a similar extra thickness of hard crust.

For purposes of the present study, six subgrade soils were chosen. In order to study the effect of compaction of subgrade on required thickness of pavement, these soils were compacted to varying densities at different moisture contents and then the required thickness of crust was determined by the C.B.R. Method.

2.1. Soils Selection

The six soils representing typical subgrades selected varied in texture from predominantly sandy to loamy, and silty to highly clayey. The consistency limits etc., are given in Table 2 and the mechanical grading in Fig. 7.

2.2. Densities Studied

The range of densities studied is 1.5 to 2.0. The idea was to see what reduction of thickness of pavements can be brought about by increasing the density of the subgrade from that normally

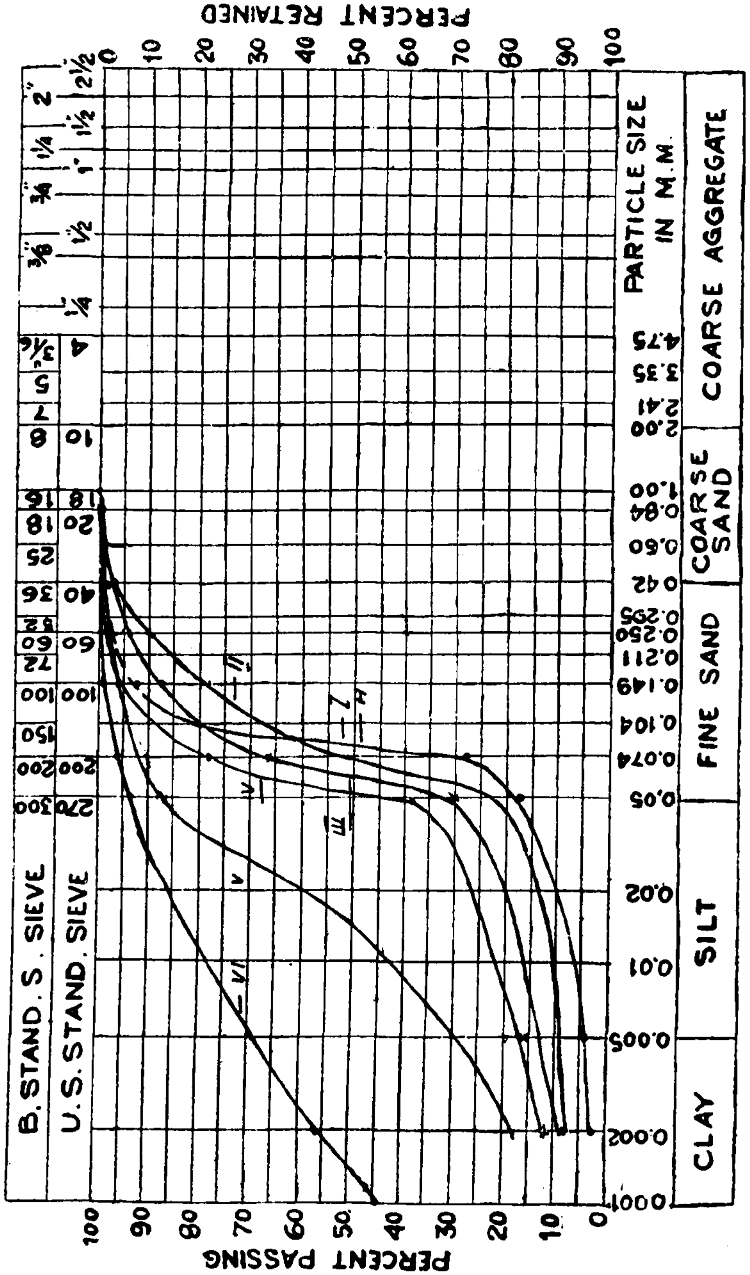

Fig. 7. Grain Size Distribution Curve of Soils Used in the Study

attained in practice to that which can be attained by compaction. The lower range of densities were attained by static method and higher densities by dynamic method as per procedure given in Soil Mechanics for Road Engineer's[5] (Pages 162 & 385).

In normal practice, the embankment whether it is low or high is made up with loose soil and left as such through the rainy season. Before starting pavement work, the bank is rolled down whenever convenient and consequently, in most cases, the moisture is far from being correct. Also the effect of such rolling goes not much more than about six inches deep. In many cases a trench is dug to accommodate the crust and the little advantage thus attained is also lost. An idea of the density gradient normally attained in practice by these means is given in Table 3 which shows the densities of a freshly compacted embankment recently constructed. It will be seen that the density varies from 1.52 on the top to 1.37 at 2 to 3 feet depth.

An all-India survey recently carried out by the Central Road Research Institute in connection with subgrade moisture study reveals that the dry-bulk density in various parts of India under the surfaced portion normally varies from 1.4 to 1.9. The data given in Table 4 shows the dry bulk density of the top 12 in. of the subgrade. It should be noted that compaction of the subgrade to varying degrees has already taken place under traffic on these roads of different ages.

2.3. Moisture

Compaction was carried out on the six soils at moistures of 3 per cent, 9 per cent and saturation. 3 per cent is generally the hygroscopic moisture of sandy soils and about 8-12 per cent is the optimum moisture. The moisture in the subgrade is likely to vary from hygroscopic moisture to saturation and the maximum compaction is likely to take place at optimum. Hence the three moistures were selected.

3. DETERMINATION OF THICKNESS OF PAVEMENT

3.1. There are as many as fifty different design methods[5] and each one of them differs widely from the other in the assumptions made or the results produced. These methods can broadly be classified in the following four groups :

1. Empirical methods using no soil strength test but based on the physical and mechanical analysis of soil.
2. Empirical methods using soil strength tests such as penetration and bearing test.

3. Methods based partly on theory and partly on experience, making use of the stress-strain properties of the subgrade and shear test.

4. Wholly theoretical methods based on analysis of stress-strain in the pavement and subgrade.

3.2. The C.B.R. method which belongs to the second category has been used in this study, as it is based on long experience[6] of actual behaviour of flexible pavements and is the most popular method in use.

3.3. The apparatus[7] consists of a mould 6 in. diameter and 7 in. high into which soil is compacted either statically or dynamically. A cylindrical plunger with 3 square inches face area is forced into the soil at a rate of 0.5 in. per minute. The load required for a penetration of 0.1 in. is recorded and expressed as a percentage of 3,000 lb which is considered to be the load required to penetrate the plunger for the same depth in standard crushed stone. The test is normally performed at saturation* moisture but C.B.R. at 3 per cent (near hygroscopic) and 9 per cent (near optimum) moisture has also been determined to see the advantage of compaction in cases where subgrade moistures remain below saturation in practice.

3.4. The thickness of pavement has been determined from curves recommended by the Road Research Laboratory, Harmondsworth[8], U. K., for light, medium and heavy traffic. These traffic intensities correspond to curves B. D. & F., Fig. 8.

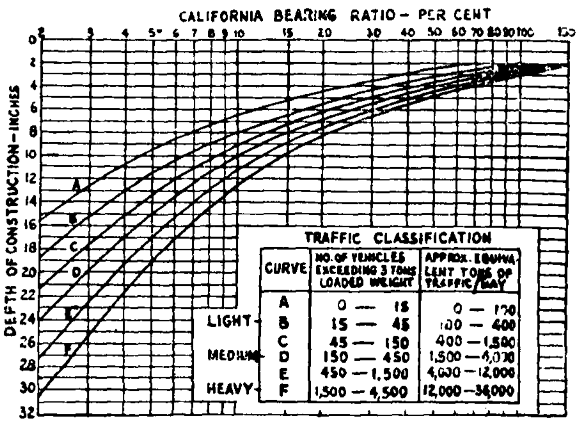

Fig. 8. **C.B.R. design curves for different classes of road.**

* In standard procedure the sample is soaked for 4 days from top and bottom and almost invariably saturation is attained.

3.5. Tables 5, 6 and 7 give the C.B.R. values and corresponding thicknesses of pavement for light, medium and heavy traffic at moistures near hygroscopic, near optimum and at saturation.

4. DISCUSSION OF RESULTS

4.1. A study of the Tables 5 to 7 and Figs. 9 to 13 based on them will show the following general trends for soils I to V.

(a) The higher the initial density of the subgrade, the higher is its C. B. R. value and the lesser is the safe thickness of hard crust required above it.

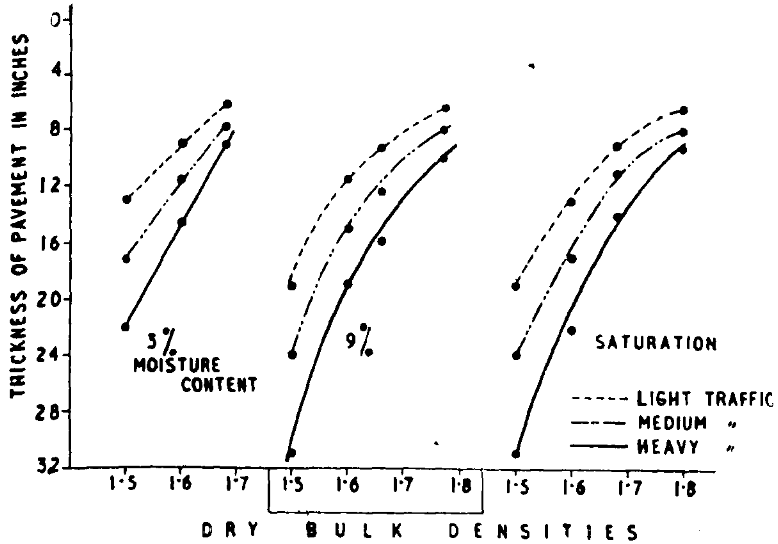

Fig. 9. **Showing the effect of density at various moistures on the thickness of pavement required—Soil No. 1.**

(b) The higher the initial subgrade density, the lesser is the difference in the safe additional thickness of hard crust required over it for increasing intensities of traffic.

(c) The higher the initial density, the lesser is the fall in C.B.R. value as a result of increased intake of moisture by the subgrade, and consequently the lesser the additional safe thickness of crust required.

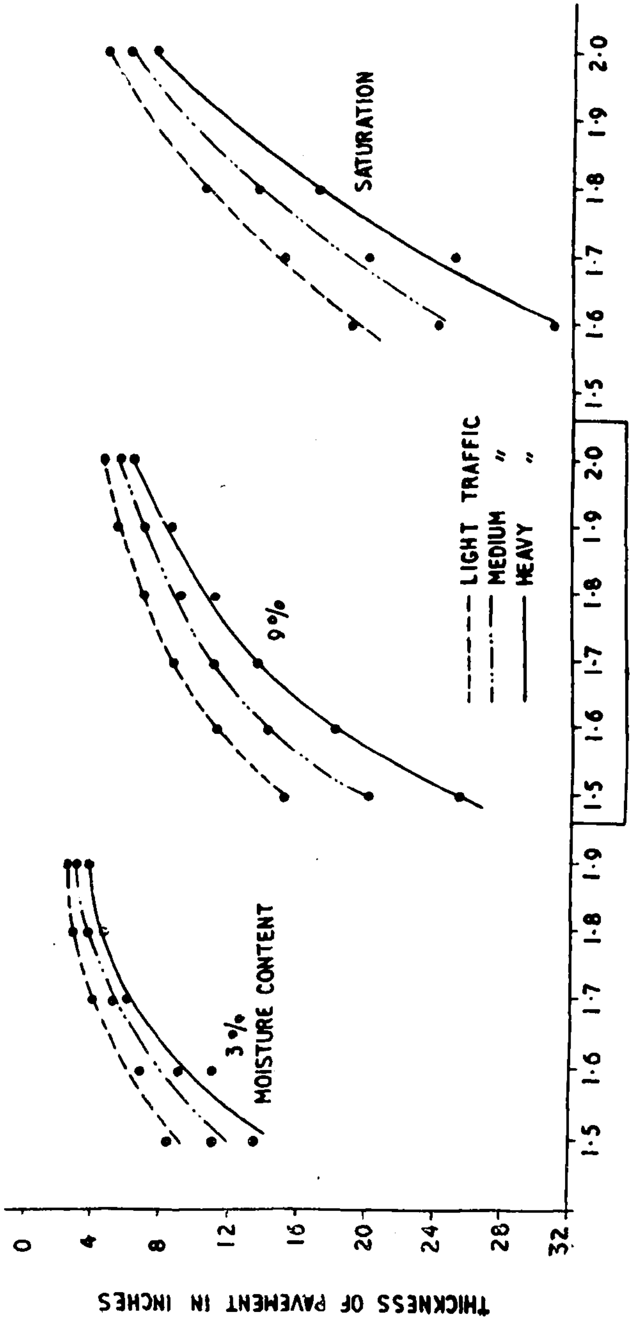

Fig. 10. Showing the effect of density at various moistures on the thickness of pavement required—Soil No. II.

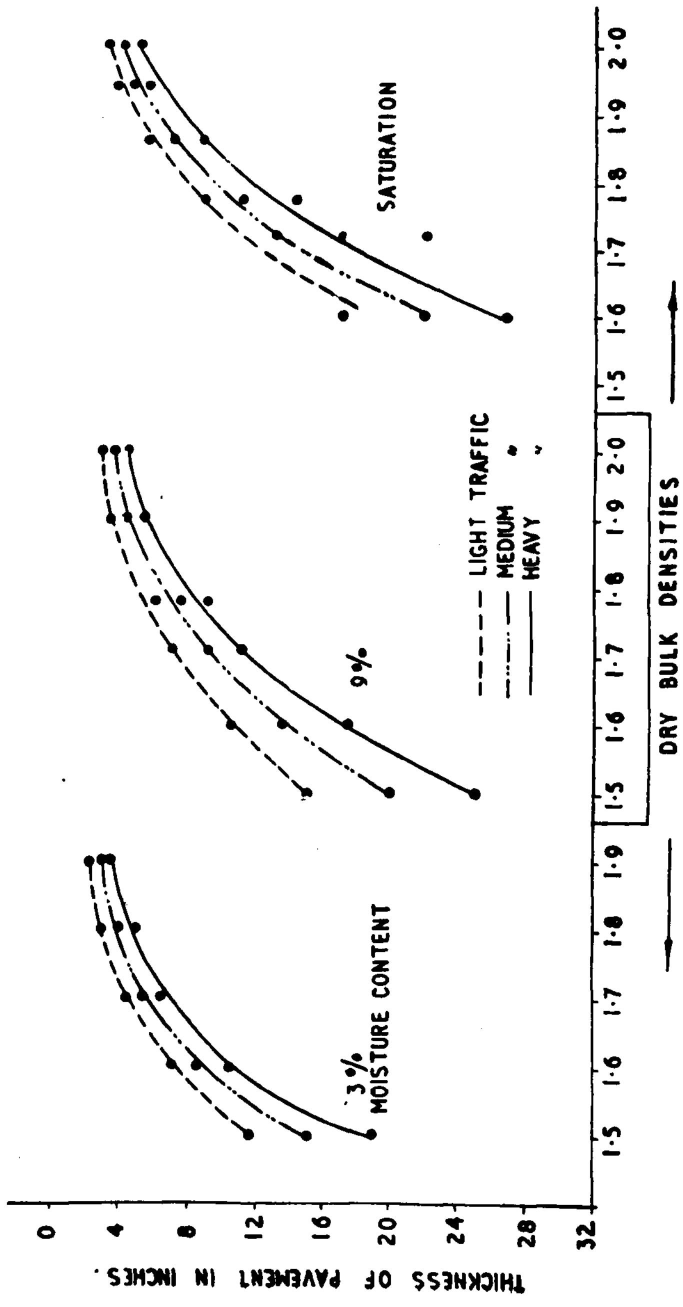

Fig. 11. Showing the Effect of Density at various moistures on the Thickness of Pavement required—Soil No. III.

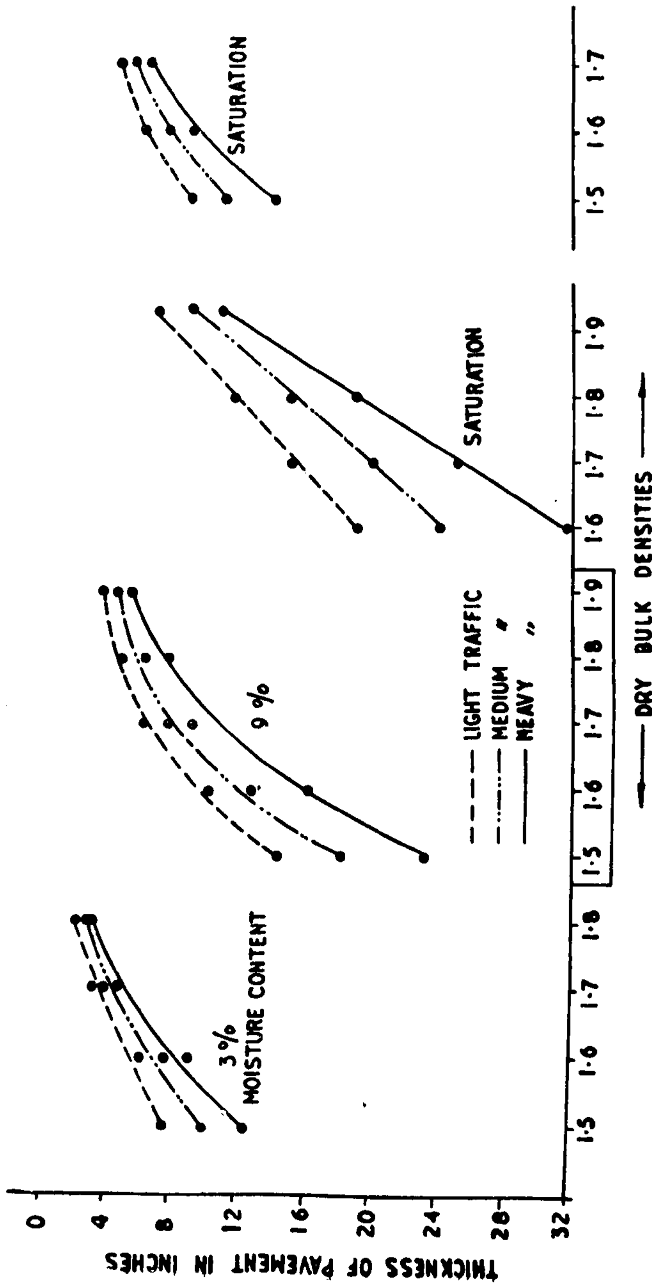

Fig. 12. Soil No. IV.
Showing the Effect of Density and various Moistures on the Thickness of Pavement required

Fig. 13. Soil No. V.

Photo 1. **Muzaffarnagar-Shamli Road, mile 9/1 showing excessive deformation**

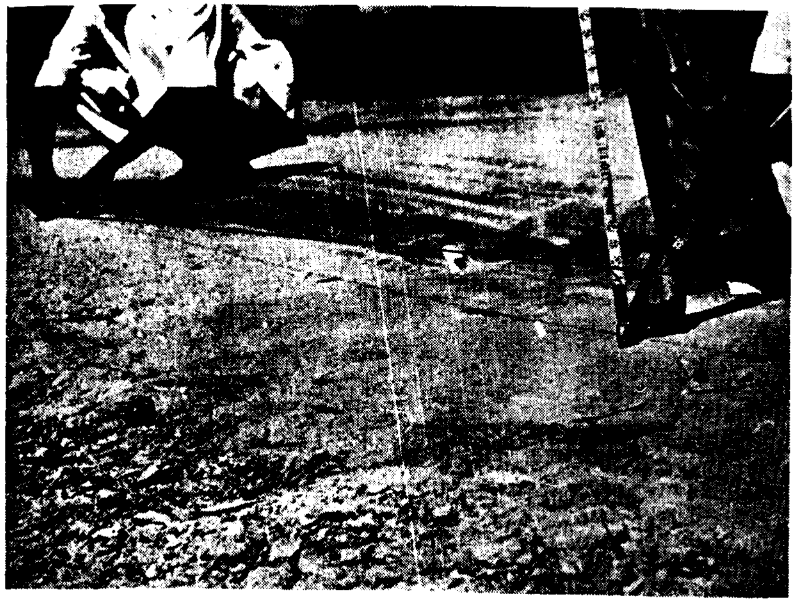

Photo 2. **The same settlement being measured. It is about 4½ in.**

Photo 3. **Delhi-Meerut Road. Deterioration of surface in settled lengths.**

Photo 4. **Delhi-Meerut Road. Excessive deformation leading to failure of road which is dug out and is being relaid.**

(d) So far as the black cotton soil (soil No. VI) is concerned neither has it been possible to compact it to a density higher than 1.7 nor has the C.B.R. value increased with density.

4.2. It has also been stated[9] that in case of soils like black cotton soil which have a very high swelling power, the compaction of the subgrade may be actually detrimental to the pavement above due to non-uniform swell pressure it might exert—the greater the density the greater the potential swell.

4.3. It is, therefore, felt that black cotton and similar soils should not be compacted as such for purposes of improvement of subgrade support.

4 4. The above trend of results shows that for soils I to V it would be advantageous all round to compact the subgrade as much as circumstances will allow before placing a pavement over it. Also, that in order to obviate damage to the expensive hard crust later on, due either to ingress of moisture from below or to increase in traffic, the minimum safe thickness of hard crust required in relation to these two factors should be provided to start with.

4.5. It will also be seen from the results that the C.B.R. values at the same density are widely different for different soils.

4.6. This fact can be utilized to a great advantage in the alluvial plains of India, where due to the rapidly changing texture of soils in comparatively short distances, it is an economic possibility in most cases to blend different local soils to produce a mixture which will be a positive improvement on the local subgrade soil. This mixture could be utilized to further reduce the required thickness of hard crust, after full advantage has been taken of the natural subgrade soil by proper compaction. It goes without saying that the blended soil mixture should, for maximum economy satisfy as far as possible standard requirements for soil base courses which would be something like soil No. II. It will be seen from Tables 5 to 7 that soil No. II compacted to a reasonable density can provide a layer which, under saturated conditions can still give a higher C.B.R. value than the subgrade soil and to that extent it does economically provide an improvement on the bearing value of the built-up subgrade.

4.7. The reason why the subgrade in its saturated condition has been taken as the main factor affecting the behaviour of roads is that except in U.K. where it has been established that the equilibrium moisture content of the subgrade is constant and far below the saturation moisture, the other countries, in the absence of such information, are still using saturation moisture for design purposes.

4.8. General experience shows that there are areas in India where saturation of the subgrade never seems to have taken place, yet it is also a fact that some most unlikely areas have recently got water-logged.

4.9. Densities Attainable in the Field

Before the economics of the case can be taken up, it should be clear as to the densities which can be practically attained in the field with an ordinary flat power roller of about 8 tons weight which is the only compaction equipment usually available these days to an average highway engineer in India.

4.10. Investigations carried out on compaction of different soils in U.K. [10] and India [11] show that generally speaking densities of the order of 1.9 can be attained in most soils when compacted at optimum moisture in layers not exceeding 9 inches loose soil.

5. ECONOMY POSSIBLE

5.1. A reference to Table 3 will show that the densities to which subgrades are compacted these days do not normally go beyond 1.55 or so. Taking 1.6 as the present ruling density, and assuming that proper compaction can raise it to 1.9, the resulting saving in thickness of crust for medium traffic (equivalent of 1,500 to 4,000 tons) would be of the order of 9-16 inches as per Table 8 worked out by interpolation from curves in Figs. 8 to 12 for saturated conditions.

5.2. Surface treated water-bound macadam, the most common flexible pavement at present, costs on the average round about Rs 4,000 per inch thickness per 10 ft wide mile. The corresponding cost of proper compaction of soil is not more than Rs 500.

5.3. Assuming that the pavement is to be properly designed, the saving as a result of improving the subgrade by compaction and thereby reducing even by 9 in. the thickness of hard crust required by standard practice would be of the order of Rs 31,500 per 10 ft wide mile. This figure might look unconvincing on the surface. But it is common knowledge that unsurfaced water-

bound macadam roads have had large thicknesses added on gradually in the course of maintenance, before they started taking the load satisfactorily. In the case of surface treated roads, this thickness is gradually provided by heavy patching with bituminous binders as and when deformation occurs. The choice, therefore, lies between providing the requisite thickness to start with by a judicious selection of material or starting with inadequate thickness consisting of expensive material and adding further thickness of even more expensive material in an attempt to set right deformations during usage.

5.4. It is significant that for a properly designed crust, both for thickness and for material, the hard crust (over 10 to 15 inches of compacted subgrade) vide Table 8, will not have to be more than 8 to 10 inches which happens to be the thickness of hard crust in vogue at present in most States. This means that by spending an additional sum of about Rs 8,000 or so per 10 ft wide mile the pavement would substantially be ensured against deformation from increase of traffic and ingress of moisture into the subgrade.

5.5. It is obvious that when the various States are provided with laboratory facilities for proper design of pavements, the thicknesses of compacted subgrade soil, compacted base course soil, and other available aggregates would be properly determined. But since it will be some time before many States become ready for such work, it would be an unquestionable advantage to compact 12 to 15 inches of the embankment's subgrade immediately under the hard crust to a density of about 1.9 with the available compaction equipment at optimum moisture. This will require very modest equipment and staff, vide Appendix 1 for proper control.

6. CONCLUSION

In view of the foregoing analysis it is recommended that it should become the standard practice (except in black cotton soil areas) to provide a 12 to 15 inch thick layer of soil compacted to a density of about 1.9 under all future flexible pavement construction.

ACKNOWLEDGMENT

The Authors acknowledge the assistance given by Shri Dalip Singh in the collection of the laboratory data included in this Paper.

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TABLE 1

Showing calculated values of load transmission through pavement by various vehicles

Laden load of the vehicle tons	Tyre size	Wheel load lb	Contact area sq. in.	Average surface pressure lb per sq. in.	Radius of contact area in.	Maximum normal stress lb per sq. in.
2–3	6×20	1,400	28.2	49.6	3.0	0 = 49.6 2 = 41.13 4 = 24.20 6 = 14.11 8 = 8.88 12 = 4.31 24 = 1.14 36 = 0.51
4–5	7×20	1,950	37.0	62.7	3.43	0 = 52.7 2 = 45.96 4 = 29.62 6 = 18.14 8 = 11.20 12 = 5.82 24 = 1.55 36 = 0.71
8	9×20	3,450	56.1	61.5	4.20	0 = 61.50 2 = 56.66 4 = 39.91 6 = 27.83 8 = 18.81 12 = 9.78 24 = 2.72 36 = 1.18
10	10×20	4,000	60.7	66.0	4.39	0 = 66.0 2 = 61.29 4 = 45.82 6 = 31.27 8 = 20.82 12 = 11.34 24 = 3.18 36 = 1.45
12	11×20	4,500	68.5	65.8	4.66	0 = 65.8 2 = 61.76 4 = 46.25 6 = 33.35 8 = 23.31 12 = 12.48 24 = 3.57 36 = 1.61
Cart load	(1.25 ton)	1,400	100	140	1.75	0 = 140 2 = 80.32 4 = 32.28 6 = 16.05 8 = 9.47 12 = 4.36 24 = 1.11 36 = 0.51

TABLE 2

Showing consistency limits and sand content of soils used in the study

Serial No.	Textural classification	Liquid limit per cent	Plastic limit per cent	Plasticity index	Sand content -40+200 fraction	Classification according to PRA system
I	Sandy soil	21	18	3.0	73.0	A-4
II	Sandy soil	25.5	18.7	6.8	50.1	A-4
III	Sandy loam	30	19.5	10.5	33.5	A-6
IV	Sandy clay loam	35.2	21.2	14.0	23.0	A-6
V	Clay loam	59	36	23	7.0	A-7
VI	Black cotton soil	67	32	35	7.0	A-7

TABLE 3

Showing density gradient of a freshly compacted embankment

Depth	Dry bulk density
0–6 in.	1.52
6–12	1.48
12–24	1.39
24–36	1.37
36–48	1.27

TABLE 4

Showing average dry bulk densities of the top 1 ft of the subgrade (0-12 in.) under road or airfield pavement in different parts of India

Serial No.	Location	Dry bulk density every 1000 ft apart				
1.	National Highway No. 8 Ahmedabad	1.68	1.56	1.60	1.63	1.6
2.	Surat-Dhulia Road	1.65	1.78	1.72	1.74	
3.	Surat-Dhulia Road Jalgaon	1.65	1.59	1.57	1.52	
4.	Bhopal-Sehore Road	1.90	1.88	1.73	1.70	1.81
5.	Baroda-Karjan-Makarpur Road	1.84	1.77	1.86		
6.	Agartala-Assam Road	1.75	1.74	1.65	1.84	1.83
7.	Safdarjang Airfield	1.75	1.72	1.60	1.62	
8.	Bombay-Santa Cruz Airfield	1.54	1.48	1.72	1.56	
9.	Gauhati Airfield	1.46	1.70	1.39	1.57	
10.	Agartala Airfield	1.6	1.6	1.62	1.67	1.62

TABLE 5

Showing C.B.R. values of soils at 3 per cent moisture content at various bulk densities

Soil No.	Dry bulk density	CBR value per cent	Thickness of pavement in inches for light, medium & heavy traffic		
I	1.5	4.0	13	17	22
	1.6	7.6	9	11.5	14.5
	1.68	17.6	6	7.5	9.0
II	1.5	5.0	11.5	15.0	19.0
	1.6	13.6	7.0	8.5	10.5
	1.7	30.0	4.5	5.5	6.5
	1.8	50.4	3.0	4.0	5.0
	1.9	78.4	2.3	3.0	3.5
III	1.5	8.8	8.5	11.0	13.5
	1.6	12.0	7.0	9.0	11.0
	1.7	35.4	4.0	5.0	6.0
	1.8	57.6	2.8	3.5	4.5
	1.9	80.8	2.5	2.8	3.5
IV	1.5	10.4	7.5	10.0	12.5
	1.6	16.8	6.0	7.5	9.0
	1.7	55.0	3.0	3.8	4.5
	1.8	88.3	2.0	2.5	3.0
V	No tests were conducted as hygroscopic moisture of soil was above 3 per cent.				
VI	,,	,,	,,	,,	,,

TABLE 6

Showing C.B.R. values of soils at 9.0 per cent moisture content at various dry bulk densities

Soil No.	Dry bulk density gms/cc	CBR value per cent	Thickness of pavement in inches for light, medium & heavy traffic		
			B	D	F
I	1.5	2.0	19	24	31
	1.6	4.7	11.5	15	19
	1.66	6.7	9.5	12.5	16
	1.77	14.8	6.5	8.0	10
II	1.5	3.2	15	20	25
	1.6	5.8	10.5	13.5	17.5
	1.71	12.4	7	9	11
	1.78	17.2	6	7.5	9
	1.9	36.8	3.5	4.5	5.5
	2.0	56.0	3	3.8	4.5
III	1.5	2.8	15	20	25.5
	1.6	5.6	11	14	18.0
	1.7	8.8	8.5	11	13.5
	1.8	12.8	7.0	9	11.0
	1.9	20.0	5.5	7	8.5
	2.0	28.0	4.5	5.5	6.5
IV	1.5	3.6	14.0	18	23
	1.6	6.4	10	12.5	16
	1.7	16.0	6	7.5	9
	1.8	23.2	4.5	6.0	7.5
	1.9	40.0	3.5	4.5	5.5
V	1.5	51.0	3.0	4.0	5.0
	1.6	80.0	2.3	2.8	3.5
	1.7	163.0	—	—	—
VI	No test was conducted because even hygroscopic moisture of the soil was above 9 per cent.				

TABLE 7

Showing C.B.R. values of soils at saturaion having previously been compacted at various densities

Soil No.	Dry bulk density	Moisture at the time of testing	CBR value per cent	Thickness in inches for light, medium & heavy traffic		
				B	D	F
I	1.5	23.58	1.8	19	24	31
	1.6	20.85	4.13	13	17	22
	1.68	19.12	8.32	9	11	14
	1.80	14.15	14.40	6.5	8	9.5-21
II	1.5	20.1	0.77	0.0	0.0	0.0
	1.6	19.3	2.6	17.0	22.0	27.0
	1.72	13.6	4.0	13.0	17.0	22.0
	1.77	12.3	8.5	9.0	11.0	14.0
	1.86	10.8	20.00	5.5	7.0	8.5
	1.94	10.0	39.0	3.5	4.5	5.5
	2.0	9.6	50.0	3.0	4.0	5.0
III	1.5	21.4	0.96	—	—	—
	1.6	20.2	1.8	19.0	24.0	31.0
	1.7	18.0	3.2	15.0	20.0	25
	1.8	17.3	5.9	10.5	13.5	17
	2.0	10.35	24.0	4.5	6.0	7.5
IV	1.5	21.5	0.77	—	—	—
	1.6	20.75	1.70	19.0	24.0	31.0
	1.7	19.14	2.90	15.0	20.0	25.0
	1.8	18.14	5.12	11.5	15.0	19.0
	1.93	11.44	12.8	7.0	9.0	11.0
V*	1.5	25.88	8.0	9.0	11.0	14.0
	1.6	23.85	16.0	6.0	7.5	29.0
	1.7	20.40	27.2	4.5	5.5	6.5
Black cot-ton soil	1.46	39.7	1.92	19.0	24.0	31.0
	1.56	39.75	2.0	19.0	24.0	31.0
	1.67	40.3	1.8	19.0	24.0	31.0

* Not fully saturated.

TABLE 8

Showing thickness of pavement required over subgrade compacted to a dry bulk density of 1.6 and 1.9 (values interpolated from Figs. 9 to 12 for saturated conditions)

Soil	Traffic intensity	Thickness of hard crust in inches for two densities		Saving in hard crust
		1.6	1.9	
I	Medium 1500–4000 tons per day	17	8	9
II		22	6	16
III		24	9.5	14.5
IV		24	10	14.0

V Soil No. V being clayey could not be saturated in 4 days soaking and the values have therefore not been included.

Appendix 1

List of equipment required for tests regarding compaction of subgrade

Serial No.	Apparatus	No.		Rate (per unit)	Total cost Rs
1.	Modified Abbots Cylinder	1		150	150
2.	Proctors compaction apparatus	1		500	500
3.	Oven 110°C 18″ × 14″ × 14″	1		300	300
4.	Sieve set 8″ size, 10, 40, 200	1	each	200	200
5.	Drying trays 24″ × 16″	6		15	90
6.	Pestle and mortar wooden	2		15	30
7.	Apparatus for determining dry bulk density in the field	1		160	160
8.	Moisture sampling tubes (collapsible)	100		1	100
9.	Measuring cylinders, beakers, flasks, canvas bags, distilled water etc.,				250
				Total	1780
				Say	1800

	List of staff		Grade	No.
1.	Research Assistant:	M. Sc. or B.Sc. in Physics, or Chemistry with 5 years experience	250–25–500	1
2.	Laboratory Assistant:	F.sc. or Matric in Science with experience	60– 5–100	1
3.	Laboratory bearer:		30– 1–50	2

RESEARCH SECTION

"A LABORATORY INVESTIGATION ON THE STRIPPING OF BITUMINOUS BINDER FROM A COATED ROAD STONE IN THE PRESENCE OF WATER"

By

C. G. SWAMINATHAN* & K. P. NAIR*

CONTENTS

SYNOPSIS

With the help of a static water immersion test and using Delhi quartzite as the aggregate, the various factors that influence the stripping of a bituminous binder from a coated road stone were studied. Based on the experimental data certain broad conclusions are indicated. However, it should be noted that definite conclusions can be made only after studying various other types of aggregates and this work is being continued in the Central Road Research Institute.

1. INTRODUCTION

A vast majority of the black top surfacings in India today have as the wearing course either an open graded thin premix carpet or a bituminous surface dressing. Except for a few cases where the surfaces are laid over a bituminous macadam, almost all have water-bound macadam as the base course. Well designed hot mixed and hot laid bituminous pavements exist only in and around certain major cities. Whereas, a dense graded bituminous pavement derives its strength from the structural and viscous resistance of the mixture as a whole, an open textured

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bituminous layer depends for its stability on the simple phenomenon of adhesion, and, its success or otherwise, rests mainly on the existence of a proper adhesive bond between the coated aggregates as well as between the binder and the aggregate. In the absence of either, the road metal gets dislodged from its seat and this results in ravelling and subsequent failure of the surface. If the binder is alive and if the aggregates are coated properly, there will be a cohesive bond amongst the coated stones. But, if inspite of it, the aggregates get loosened, it is obviously as a result of the binder being stripped from the road stones. And one of the main reasons for this happening is the action of water. It is obvious that this lack of adhesion between binder and stone is more prevalent with open textured carpets, bituminous macadams and surface dressings, than with dense graded surfacings. For, in the case of the former three, water is likely to be entrapped for a longer duration either in the base course or in the wearing course which are open voided to a much greater degree than the dense carpet. This water could be either the ground water which rises up to the surface or rain water. Widespread stripping is noticed especially if the rain falls immediately after the surface is freshly laid or when the aggregates were wet at the time of construction. In the former case the binder has not built up sufficient viscosity to resist its displacement by water and in the latter case the binder may not be able to coat the stone at all, since the road stones have a greater affinity to water than for the binder.

The object of this note is to study in the laboratory in detail the various factors that influence the stripping of the binder from a road stone.

2. METHOD OF TESTING

Although there are quite a number of methods to study the stripping of the binder films from aggregates, there is not as yet a single universally accepted standard quantitative method of evaluation in the laboratory. The best method would of course be one which simulates the action of both traffic and water and at the same time yields results which are correlatable to service or field performance. Such a method might entail costly equipment. One of the simplest methods is obviously a static water immersion test. It is true that this method suffers from quite a number of drawbacks. For example, the estimation is qualitative and as such is likely to be influenced by personal factors. Also, being a static immersion test, it does not take into account the rigorous abrasive effect of traffic. But if the tests were to be conducted by an experienced and seasoned technician it is

quite possible to arrive at a reasonable and reliable estimation regarding the ability of the stone to be bound by a given binder. The principle underlying the static water immersion test is quite simple and consists of coating the aggregates with a bituminous binder and immersing the coated aggregates in a tray of water under specified conditions of temperature, time, etc. After the lapse of the stipulated time the coated aggregates are visually examined to see whether the binder has stripped or not. If the binder has stripped, the percentage area of the aggregate surface uncoated is taken as a measure of stripping indicating thereby that the lower this value the better is the bond between the binder and the road stone.

There are quite a few different types of water immersion tests, but on the whole the principle underlying them all is the same. However, while going through some of the tests, (details of which are given in Table 1), some interesting facts emanate. For example, the size of the aggregates chosen are not always the same in all the cases. So is the case with the quantities of binder used. Also different test procedures for liquid bitumens as against semi-solid ones are specified in certain cases. The curing period, the temperature and duration of immersion all vary from one test to another. How far do these variables influence the test results ? To what extent can the test data help in formulating a simple but effective method of estimation of stripping ? How best can the information so obtained be put to use for effecting a code of practice or specification from the point of view of stripping ? These are some of the questions for which answers are attempted to be sought in this note.

3. FACTORS INVOLVED IN THE STRIPPING OF BINDER FROM AGGREGATE

The various factors which are likely to influence the stripping of the binders from the aggregates in a static water immersion test can be classified into the following groups :

(a) **Effect of Binder:**

(i) Nature and viscosity of binder

(ii) Percentage of binder

(b) **Effect of Aggregate**

(i) Size of aggregate

(ii) Shape

(iii) Surface texture

(iv) Sound or weathered

(c) **Effect of Surface condition of the aggregate**

(i) Dust

(ii) Moisture

(d) **Effect of Testing Conditions**

(i) Temperature of the aggregate at the time of mixing

(ii) Atmospheric temperature at the time of mixing

(iii) Duration of curing after mixing

(iv) Temperature of curing after mixing

(v) Duration of immersion in water

(vi) Temperature of water during immersion

4. ADOPTED TEST PROCEDURE

In order to study the effects of the above mentioned variables, the tests were conducted by keeping all the variables but one as constant and then by evaluating the amount of stripping for different values of one of the variables. For example, in order to study the effect of the duration of curing, all the factors such as size of aggregate, binder, temperature etc. were kept constant and only the duration of curing was varied and the stripping evaluated.

As said earlier the testing as such is quite simple. The aggregates were coated with the bituminous binder at various temperatures, then cured at different temperatures for different periods of time, and then immersed in water at varying temperatures and duration. The aggregates were not disturbed in this state but the amount of stripping was examined visually and expressed in terms of a percentage area of aggregate surface uncoated. The higher this value, it is obvious that stripping is more.

For studying the effects of the various factors involved, unless otherwise stated, the conditions of testing adopted were as under:

Straight run bitumens 30/40 and 80/100 were heated to a temperature of 350–375 deg. F., road tars to a temperature of 220 deg. F. and the two fluxed bitumens to a temperature of 270–275 deg. F. Where aggregates were to be coated with either of the two straight run bitumens the aggregates were also heated normally to a temperature of around 350 deg. F. In the case of the road tars and the fluxed bitumens the aggregates were at room temperature. The quantity of binder employed was 5 per cent by weight of the aggregates for all the binders. The duration of curing was 2 hours at room temperature. The period of immersion was 24 hours at a temperature of 40 deg. C. (104 deg. F.). The reason for the choice of these figures is given in the various sections under discussion.

5. THE AGGREGATE CHOSEN FOR THIS STUDY

The stone metal used throughout this investigation was Delhi quartzite whose physical properties are given in Table 2. It was felt that it would serve as a very good material for purposes of this study. It can be seen from the data in Table 2 that from the point of view of Los Angeles Abrasion and crushing value, it can be considered as a good and above the average type of road stone. Further, it has been used quite extensively and with reasonable success in and around Delhi, both for pre-mix as well as for surface dressing purposes. But quartzite is not always considered to be a good road stone from the point of view of adhesion. For its surface texture is very rough and its crystalline structure is between medium to coarse. Also since the S_iO_2 content is as high as 97 per cent the Delhi quartzite would come under the classification of acidic stones which are usually considered to be hydrophilic.

6. DISCUSSION OF RESULTS

6.1. Effect of Binder

6.1.1. Nature and viscosity of binder

In this investigation, six different binders which are normally used for bituminous road construction in India were employed. They are two straight run bitumens 30/40 and 80/100, two road tars RT2 and RT3 and two fluxed bitumens, and their properties are given in Table 3. Whereas with the straight run bitumen it was found necessary to heat the aggregates to the same temperature as the bitumen to enable proper coating of the aggregates, this was not found necessary with the road tars or the fluxed bitumens. As a matter of fact it was found that with tar even when the aggregate was heated to 220 deg. F. (Table 13) the amount of stripping was the same as when the aggregate was coated at room temperature of 95 deg. F. (Table 18).

The data in the various Tables such as 4,10,15 etc. clearly indicates that once the aggregates are completely coated, stripping is directly a function of the viscosity of the binder, the higher the viscosity of the binder, the stronger is the adhesive bond and less is the stripping. In the order of the E.V.T. (vide Table 3) it is seen that the viscosities of the various binders used are in a decreasing order, namely bitumen 30/40 having the highest, then bitumen 80/100, fluxed bitumen 1, fluxed bitumen 2, RT3 and RT2 respectively. In the various Tables also it can be seen that the stripping is more with RT2 than with RT3 and also more with fluxed bitumen 2 than with fluxed bitumen 1. With straight run bitumen of course there is no stripping observable, since the aggregates were heated to enable proper coating and also because of the higher viscosities of the binders. But when comparing the behaviour of the other four binders, it appears that stripping is most excessive with fluxed bitumen 2, (Tables 7, 10, 14 and 18), although it has a higher viscosity than RT2 or RT3. With weathered aggregates (Table 7) the two road tars and fluxed bitumens behave alike. When the aggregates at low room temperature are mixed with the binders (Table 14) RT3 comes first, then comes RT2, fluxed bitumen 1 and lastly fluxed bitumen 2 in the order of adhesion. At higher room temperatures, however, fluxed bitumen 1 serves better than RT2 or RT3 (Tables 14, 11, 18). But on the whole the superiority of road tars over the fluxed bitumens at lower room temperatures is indicated, namely, that even though the resultant viscosities of the latter two are higher than that of the road tars, the initial adhesion of the tars to the road stone is better because of the presence of hydroxyl compounds in tars. Comparing the behaviour of the various binders it can be said, that, if the aggregates are heated prior to mixing, the straight run bitumens are the best. If the aggregates are to be coated at a room temperature of about 100 deg. F., fluxed bitumen 1 is better than RT3 or RT2, but at temperature of coating below 90 deg. F., the road tars are the best from the point of view of initial adhesion and subsequent stripping in the presence of water.

On the whole it can be said that from the point of view of initial wetting a lower viscous binder may be better, but from the point of view of the ultimate resistance to stripping the residue left over the aggregate should possess a high viscosity. This seems to suggest the use of high viscous road tars or hard penetration grade asphaltic bitumens fluxed with a minimum necessary percentage of oil fractions.

6.1.2. Percentage of binder

The percentages of binder chosen for this investigation were 4 per cent, 5 per cent and 6 per cent by weight of the aggregates. This range was chosen because of the fact that in most of the open textured construction, the quantity of binder employed is about 5 per cent.

From the results in Table 4 it is seen that there is no appreciable difference in the amount of stripping as a result of different percentages of binder for the various types of binders and sizes of aggregates, except perhaps with a low viscous binder such as RT 2 with small size aggregates. In the case of smaller sizes the surface area per unit weight of aggregate is more and so at low binder contents there is a possibility of the aggregates not being completely coated initially. But, for most of the normally employed sizes, since too low a percentage may not coat all the aggregates initially and since a very high percentage of binder will not be conducive for a proper estimation of the amount of stripping, a percentage of about 5 per cent by weight for the usual sizes of aggregates, and for most binders, can be suggested for all experimental work for the evaluation of stripping. For, so long as the aggregates are initially coated, the subsequent stripping of the binder is in no way dependent on the quantity of binder employed.

6.2. Effect of Aggregate

6.2.1. Size

The sizes chosen for this investigation were those which are commonly employed for surface dressing and for open graded premix carpets. The sizes were:

(a) Passing 1 in., retained on $\frac{1}{2}$ in., or standard $\frac{3}{4}$ in.

(b) Passing $\frac{3}{4}$ in., retained on 3/8 in., or standard $\frac{1}{2}$ in.

(c) Passing 3/8 in., retained on 3/16 in., or standard $\frac{1}{4}$ in.

Sizes finer than 3/16 in. and coarser than 1 in. were not taken. From the results given in Table 4, it can be seen that under identical conditions of test for any given percentage of binder, the amount of stripping is more as the size decreases. This is probably because for the fact that in the case of smaller size aggregates, the total area in contact with water is more than that with the larger ones. Also the smaller size aggregates are more flaky and their edges sharper with the result that at the corners there is only a very thin film of binder which gets ruptured easily and water enters quite easily at the interface between the aggregate and the binder. Also it can be seen that whereas with the standard $\frac{3}{4}$ in. aggregate the variations in the amount of stripping as a result of the variations in the percentage of binder is not very much, with standard $\frac{1}{4}$ in. aggregate, the results tend to be erratic because of the reasons mentioned above. Here it should also be remembered that the surface texture of the fines of an aggregate differ considerably from the coarser fraction of the same stone metal and, as such, information regarding stripping characteristics based on the finer fraction will not always be applicable to the behaviour of the coarser aggregate of the same stone. For this reason also fractions finer than 3/16 in. were not used in this investigation.

And results seem to indicate that from the point of view of stripping, in the case of open textured carpets, the size of the aggregate should reasonably be well above 3/8 in. and the quantity of aggregates smaller than $\frac{1}{4}$ in. size should be very much limited.

6.2.2. Shape of the aggregates

Using RT3 as the binder and choosing aggregates which pass $\frac{3}{4}$ in. but are retained on $\frac{1}{2}$ in., a series of tests under identical conditions were conducted with varying flakiness indices for the stones. The range of flakiness index chosen was from 0 to 100 at intervals of 25. The data in Table 5 clearly indicates that the flaky material gets stripped to a greater extent than a cubic chipping. The percentage of stripping goes on increasing with an increase in the flakiness index. The reason for this is obviously because of the sharper edges and corners of the aggregates which are either not completely coated or which have only a very thin and brittle film, which in course of time allows the water to get into the interface. In actual road practice also, there would be a tendency for the sharp edges of the flaky aggregates to get broken enabling the water to dislodge the binder from the coated aggregate. This obviously suggests that as far as possible only cubic chippings should be employed and a maximum permissible flakiness index should be stipulated. If the permissible amount of stripping is about 15-20 per cent, it appears that the maximum permissible value for the flakiness index could be fixed at 25 per cent. But stripping alone is not the only criterion, and behaviour with other types of road stones should also be known before an exact limit can be specified.

6.2.3. Surface texture

Data in Table 6 seem to indicate that the nature of the surface is perhaps more important than the flakiness. The stripping of the binder from the aggregate is most when the aggregate is smooth, even though it is nonflaky and it is least when the material is rough and nonflaky. Even in the case of asphaltic bitumen 80/100, for which the aggregates were also heated prior to coating to ensure complete coating, it is seen that inspite of the higher viscosity, the binder gets stripped because of the surface smoothness of the aggregates. So, from the results obtained it can be inferred that as far as possible smooth and water worn aggregates would get stripped much more easily. Such types of aggregates should be avoided, but if they must be used, they could be used in a crushed form and with a very high viscous binder. It is obvious that with tar also (when the aggregates are not heated), stripping is found to result to a greater extent with smooth aggregates than with rough ones.

6.2.4. Sound and weathered condition

Table 7 shows comparison of the behaviour of a weathered aggregate as against a sound aggregate under identical conditions of testing. From the results it can be seen that the adhesion in the case of weathered aggregate is better than with a sound one. This is probably because of the fact that the surface texture of the former is rougher than that of the latter and the behaviour can also be explained because of the various oxides formed on the surface of the aggregate owing to weathering. But it should be noted here that the weathered aggregates are more brittle and have very low strength or toughness characteristics, as for instance the crushing value (BSS) of a weathered quartzite is 35.4 as against the value of 23.68 for the sound quartzite. So under the action of traffic weathered quartzites will get crushed much earlier than the sound ones with a consequent creation of innumerable fresh surfaces, to coat which there may not be adequate binder and this would result in the ravelling of the road.

6.3. Effect of Surface Conditions

6.3.1. Effect of dust

Often in the field, the road metal is dumped on the side of the road and the aggregates get coated with a film of dust. In order to study the effect of this dust, aggregates of size passing 1 in. and retained on $\frac{1}{2}$ in. were coated with different percentages of dust and then again coated with 5 per cent by weight of binder. The binders chosen were 80/100 bitumen and RT2. The dust used was clay and completely passed 200 mesh sieve. To simulate field conditions the dust was introduced in three different ways, namely:

(a) Loose dry dust mixed with dry aggregates.

(b) Wet aggregates coated with dust and then dried.

(c) Wet aggregates coated with dust but not dried.

The results are shown in Table 8. In the case of bitumen 80/100 both 'a' and 'b' were heated to the same temperature as the binder for coating while for 'c' the aggregates were not heated and so could not be coated. It can be seen that with 'a' and 'b' there was no stripping of the binder, but it was noted that when the percentage of dust was more than 5, there was no cohesion amongst the bitumen coated aggregates.

In the case of road tar, when the dust is dry and loose, the percentage of stripping goes on decreasing as the dust percentage is increased. This is as a result of the increase in viscosity of the tar as the dust is added. And at 5 per cent of dust there is no stripping, but there is no cohesion between the coated aggregates. When the aggregates are wet and then coated with dust, and then subsequently dried, it is noted that the amount of stripping is the same up to a dust percentage of 3. But at percentages of 5 and more, in addition to the lack of cohesion amongst the coated aggregates, there is also increased stripping. In the case of the dust coated wet aggregate it is seen that the amount of stripping goes on increasing upto 3 per cent and then with 5 per cent of dust stripping is less. The reason for this probably is that 5 per cent of dust acts as a blotter over the wet aggregates and so there is no free water to dislodge the binder at the time of coating. Here also it is seen that with 5 per cent of dust there was no cohesion.

The results indicate that a dust coating over the aggregates in any form is injurious to the stability of the open textured carpet. When the adverse effect of the presence of dust is noticeable even with a static immersion test, it is apparent that under the dynamic action of the traffic the extent of stripping as enhanced by the presence of dust would be still more predominant. The ravelling of an open graded bituminous carpet wherein the coated aggregates get loosened from the road could be attributed to a presence of dust of an amount of 5 per cent or more.

From the data it is seen that if the aggregates are wet and coated with dust, stripping is extensive. If, on the other hand, the aggregates are dry, and if the permissible amount of stripping is limited to 20 per cent, then upto 3 per cent dust could be tolerated. But it is suggested that preferably there should be no dust on the aggregates prior to their being coated with binder. And from the point of view of tolerance, to be on the safe side, the percentage of dust permissible (in a loose dry form) should not be more than 2 per cent by weight of the aggregate.

6.3.2. Moisture

During construction it often happens that the aggregates are not always bone dry. So in order to simulate the field conditions three groups of aggregates based on the dryness of the surface of the aggregates were taken. Group 'a' aggregates had a bone dry surface, group 'b' ones were soaked in water and then surface dried, whereas group 'c' aggregates were soaked in water but not surface dried. For the two sizes chosen, the percentages of moisture retained by each were also determined and the results are given in Table 9. From the results it can be seen that the percentage of moisture retained both by the surface dried and non-surface dried aggregates increases as the size decreases. It can reasonably be said that a surface dried aggregate would have between 0.5 and 2.5 per cent of moisture depending on the size of the aggregate. Similarly for the wet aggregates, the percentage of water retained would be between 1.5 to 4 per cent, the lower value for the $\frac{3}{4}$ in. aggregates and the higher one for the $\frac{1}{4}$ in. aggregate. It must be noted here, however, that these percentages of moisture will depend on the porosity of the aggregates, but for most of the road stones, such as the Delhi quartzite, these values can be taken to be universal.

In order to see as to how far the percentage of moisture influences stripping, the three types of aggregates, namely the dry, surface dry and the wet aggregates were coated with the binder and tested under identical conditions. Tables 10, 11 and 12 give the test results for these three types respectively. In Table 12, the percentage of moisture for the wet aggregates was based on the findings of Table 9 and the percentage of moisture was fixed as 2 per cent, 3 per cent and 4 per cent respectively, for the three sizes, namely $\frac{3}{4}$ in., $\frac{1}{2}$ in., and $\frac{1}{4}$ in. and the aggregates were tested with RT 2 in order to note the extreme differences of behaviour.

From the Tables it can be seen that it is possible to coat only the dry aggregate with straight run bitumen but not the surface dried or wet aggregates. It is also seen that for any one binder (say tar RT2) and for the $\frac{3}{4}$ in. aggregate, under the same conditions of testing, stripping is most with the wet aggregate and least with the dry aggregate. Comparing Tables 10 and 11, it is seen that under identical conditions of testing, for any one binder, the amount of stripping from a surface dry aggregate is very much higher than from a dry aggregate, and in certain cases the stripping is more or less doubled. From Table 12 it is seen that even though the aggregates appear to be coated with tar initially, especially when the test is done at 40 deg. C., the binder gets stripped excessively. The stripping is more with the smaller sized aggregates because of the greater quantity of water retained in them and also because of the greater surface area. Even if it is assumed that a percentage stripping of 15-20 per cent is permissible under a testing temperature of 40 deg. C., it is seen that only the bone dry aggregate, when coated with RT2, RT3 and fluxed bitumen 1, passes the test. And this suggests that there should be absolutely no moisture at all. But if the aggregates are dusty within permissible limits, then perhaps moisture upto 0.5 per cent or 1.0 per cent at the most may be tolerated.

6.4. Effect of Test Conditions

6.4.1. Effect of the temperature of the aggregate on stripping

In this investigation, two straight run bitumens namely 30/40 and 80/100 and RT3 were employed. The aggregates were heated to various temperatures prior to mixing. Whereas with the 30/40 bitumen (see Table 13) stripping takes place only when the temperature of the aggregate is 100 deg. F. and below, with 80/100, stripping takes place even if the temperature of the aggregate is 250 deg. F. This implies that in the case of straight run bitumens, if the binder is fluid enough to coat the aggregates at the time of mixing and once it coats the aggregate completely, the higher viscous binder is preferable since for a given difference in temperature between the binder and the aggregates, stripping is less with a high viscous binder. In general, however, the lower the temperature of the aggregate, the greater is the amount of stripping.

Similarly, if the aggregates are heated to a temperature more than that of the binder prior to mixing, detrimental effects are noted. If prior to mixing, the aggregates are heated to a temperature of 220 deg. F, which is the same as the temperature of the binder for tar, there is a slight stripping. If the temperature of the aggregate is 300 deg. F. or above prior to mixing, no stripping is observed, but at the same time it is found that these coated aggregates possess no cohesion and the binder coating the aggregates is completely burnt.

So from both the above observations it is clear that if there should be no excessive and detrimental stripping the aggregates should neither be overheated nor should it be very cold at the time of mixing. Also, whereas the aggregates should never be heated to any temperature beyond that of the binder, as far as possible, it is better to have as low a difference as practicable between the temperatures of the aggregate and the binder at the time of mixing. Best results will be obtained when the two are at more or less the same temperature.

6.4.2. Effect of atmospheric temperature at the time of mixing on stripping

Whereas straight run bitumens would not coat the aggregates completely unless the aggregates are also heated just as the binder, in the case of fluxed bitumen, it is possible to coat at room temperature at or above 100 deg. F. and in the case of RT2 and RT3 it is possible to coat the aggregates at average room temperatures. The results of the effects of different atmospheric temperatures on stripping are given in Table 14. It can be seen that under identical conditions of testing, with all the four types of binders employed, the stripping is more as the temperature (of the atmosphere or the aggregates) at the time of mixing is lower. This stresses the importance of keeping the difference between the temperature of the hot binder and that of the aggregate to as least a figure as possible.

In addition to road tars, two straight run bitumens (30/40 and 80/100) were also tried but the mixing was done after heating the aggregates to a temperature of 200 deg. F. only. Data in Table 15 shows clearly that even if the aggregates were heated, in the case of the less viscous of the two, namely 80/100 bitumen stripping is more as the atmospheric temperature at the time of mixing is lower. This is not noticed in the case of the more viscous 30/40 binder, showing thereby the superiority of the higher adhesive strength of this binder, once it coats the aggregates.

From Table 14 it can also be seen that the stripping of binder RT3 and fluxed bitumen 1 is much lower than that of RT2 and fluxed bitumen 2 respectively, showing thereby the effect of the higher viscosity of the two binders. From the results of Table 14 it is suggested that if cold mixing is resorted to best results could be obtained by using a high viscous but sufficiently fluid binder and that the temperature of the atmosphere at the time of mixing or construction should be around 95–100 deg. F. Any stripping test should also be done at this temperature.

6.4.3. Duration of curing

It is well known that the binder coating the aggregate requires some time before the viscosity of the binder is built up to its maximum. This period depends on the nature of the binder as, for example, whereas straight run bitumens set by cooling, cutbacks, fluxed bitumens and road tars set not only by cooling but also by the evaporation of the volatiles. In order to study the effect of this curing period on stripping, the aggregates after being coated were kept for varying hours before immersion in water. Table 16 gives the results of a series of such tests, the temperature of curing being that of atmosphere at 82 deg. F. From the Table it can be seen that with the straight run bitumen 80/100 there is no effect. But with road tar 3 and with fluxed bitumen 2, the effect is quite noticeable. The longer the period of curing, the less is the stripping up to a certain stage after which period the stripping is constant. This is so even if the aggregates were wet, though, as discussed earlier the amount of stripping with the wet aggregates is more. It is seen from the results that at an atmospheric temperature of 82 deg. F. after 24 hours the amount of stripping tends to be constant, showing that the binder has reached its maximum viscosity possible under laboratory conditions and any further period of curing does not serve any purpose. In the case of the fluxed bitumen and in the case of RT3 it is seen that if the period of curing is only ½ hour and the samples are immersed in water, excessive stripping takes place. So it is obvious that under actual working conditions, there should not be any rainfall soon after the surfaces are freshly laid. Similarly, no traffic should be allowed during this period of curing. From the point of view of laboratory testing, however, a period of 24 hours for curing may not be absolutely necessary. Too short a period of curing in the case of tars, cutbacks, etc. will only exaggerate the amount of stripping. So a period of 2 to 5 hours appears to be quite reasonable.

6.4.4. Temperature of curing

In an earlier section it was found that the atmospheric temperature at the time of coating does influence the extent of stripping. Also the rate at which the viscosity is built up would depend on the temperature of curing. In Table 17 are given the results of stripping of a coated aggregate kept at varied temperatures of curing before immersion. The temperatures chosen were 30, 45, and 60 deg. C. A temperature of 60 deg. C, was chosen as the uppper limit since most of the stability tests for bituminous mixtures are done at this temperature and also, a value higher than this would be a very unusual road temperature. A temperature lower than 30 deg. C. was also not chosen since most bituminous constructions should be done during summer months and a temperature of 30 deg. C. is the usual minimum summer temperature in most parts of India. RT2 was chosen as a typical binder so that the differences in the amount of stripping may be more marked.

From the test results it can be seen that the amount of stripping increases as the temperature of curing is higher. This is to be expected since at higher temperatures, the binder would still be in a liquid condition when the test specimens are immersed in water ; and moreover the volatiles would not have completely evaporated in such a short time at the temperatures chosen. So, water easily displaces the binder ; the lower the viscosity (at higher temperatures of curing) the greater is the stripping. This happens both when the aggregates are dry and wet. Since the

normal temperatures of curing during construction are usually around 95 deg. F. it becomes obvious that a higher temperature of curing such as 45 deg. C. (113 deg. F.) or 60 deg. C. (140 deg. F.) would only exaggerate the amount of stripping and as such is not warranted. A room temperature of about 95-100 deg. F. seems to be a reasonable value.

6.4.5. Duration of immersion

In order to find out the effect of the duration of contact with water on the amount of stripping, aggregates coated with binder were kept under identical conditions in water for varying periods of time. From the data in Table 18 it is seen that with aggregates coated with straight run bitumens there is no effect even when the duration is for a period of 24 hours. In the case of the two road tars, the effect becomes noticeable only when the duration of immersion is more than 3 hours in the case of RT2 and 4 hours in the case of RT3. This difference of one hour between the two is obviously because of the higher viscosity of the latter. Similarly in the case of the two fluxed bitumens, the one which is of a harder penetration grade (No. 1) starts to strip only after 24 hours of immersion, whereas for the other, stripping commences even after one hour of immersion. However, it appears in all the cases that the amount of stripping increases slightly with the increase in the duration of immersion (at a temperature of 40 deg. C.). The amount of stripping for an aggregate coated with fluxed bitumen 2 is not appreciably higher when it is immersed for 24 hours as when it is immersed only for 3 or 4 hours. It appears therefore that the duration of more than 3-4 hours of immersion does not have such a pronounced effect on stripping as, for example, the duration of curing. However, for all testing purposes in order to facilitate an easier and more accurate visual determination a period of 24 hours for the duration of immersion is suggested, although in the actual field, the coated aggregates may be in contact with water for days together.

6.4.6. Temperature of water during immersion

In order to study the effect of temperature of water during immersion on stripping, the coated aggregates were kept immersed in water at varying temperatures but under other specified conditions.

Tables 10 and 11 give the test results for dry and surface dry aggregates respectively. The data indicate that there is no effect on the aggregates coated with straight run bitumens but that the effect is only on aggregates coated with road tars or fluxed bitumens. Also, in all the cases the amount of stripping increases as the temperature of water is increased. At low temperatures, such as 20 deg. C., no stripping is observed whereas at higher temperatures and especially with low viscous binders such as RT2 and fluxed bitumen No. 2, stripping is quite high. The reason for this is possibly because of the fact that at these temperatures the coated binder is in a very fluid condition, and its viscosity is so low that water easily dislodges it. So, since at low temperature stripping is not noticeable and since at higher temperatures the amount of stripping is exaggerated more by the change in the viscosity of the binder rather than caused by the intrinsic affinity of the stone to the binder, it is felt that a temperature midway between the two should be chosen to give reliable information. A value of 40 deg. C. appears to be a satisfactory temperature to adopt, since the values that are obtained for the various types of bitumens are quite reasonable and sufficient for purposes of differentiation. Further, in most parts of India a temperature of 40 deg. C. is a normal summer temperature for the road surface.

6.5. General

Estimation of stripping visually as a percentage of the area of the aggregate uncovered gives only a qualitative measure and depends to a very great extent on the experience and judgment of the examiner. The test being done under static conditions does not represent the effect of traffic as on a road. In addition to the various criticisms which can be levelled against such a test there are so many factors affecting the extent of stripping and as such the results are reproducible only if these factors remain exactly the same. Among these the atmospheric temperature, the flakiness index and surface texture of the aggregate are worth mentioning for which due importance may be given while comparing stripping. A few illustrations are given below:

There is not much difference in the per cent of stripping from aggregates of size $\frac{3}{4}$ in., $\frac{1}{2}$ in. and $\frac{1}{4}$ in. coated with tar RT2 (5 per cent by weight of aggregates) as seen in Tables 4 and 12. Dry aggregate is used in Table 4 while wet aggregate is used in Table 12. The low atmospheric temperature of 60 deg. F. in Table 4 compared to 92 deg. F. of Table 12 is thus responsible for the anomaly of the results of stripping.

In Tables 5 and 6 the per cent stripping from 100 per cent flaky aggregates are 40 and 30 respectively with tar RT3. Considering the part played by atmospheric temperature the extent of stripping should have been more in Table 6. This can be explained by the fact that even though the aggregates in both cases are 100 per cent flaky the degree of flakiness of the aggregates in Table 5 should have been more with sharp edges resulting in a higher percentage of stripping.

In all the tests only the weathered pieces were removed before use and the flakiness index of the aggregates at different times may also be affecting the test results as well as the variation in the surface texture of the aggregates, even when the conditions of testing remain identical.

Atmospheric temperature remains the same in Tables 10, 11 and 17 and the percentage of stripping from the dry, surface dry (0.6 per cent moisture) and wet aggregates (2 per cent moisture) coated with tar RT 2 are respectively 15, 20 and 20 per cent at a water temperature of 40 deg. C. which looks quite erratic. This can be attributed to the curing period of 3 hours at 86 deg. F. for the wet coated aggregates compared to 2 hours at 95 deg. F. for the other two before immersion in water.

Thus it is seen that a visual estimation of stripping is only a relative measure and comparison is possible only when all the factors which are responsible for the stripping of binder from a coated aggregate remain exactly the same.

7. CONCLUSION

It may be noticed that in the course of the discussions set forth above, a series of broad conclusions could be drawn; but it may not be completely justifiable to draw definite conclusions which are applicable to all the types of road stones that are usually employed, since the above study was concerned only with a static water immersion test (whose draw-backs are quite well known) and also since the data collected pertain only to one type of stone, viz, Delhi quartzite. However, it may be observed that the broad conclusions that are indicated in the various sections of the discussions are quite in conformity with the findings elsewhere and appear to correlate with the actual field performance of the Delhi quartzite as far as stripping of the binder in the presence of water is concerned. It is obvious that some more work is necessary to be done on other types of aggregates as well before various limits and specifications that have been indicated by the experimental data of this study could be taken as universally valid.

ACKNOWLEDGMENT

The Authors wish to thank Shri M. S. Rajappa, Junior Scientific Assistant, for his help in conducting the various tests in the laboratory. The Authors also wish to thank the Director, Central Road Research Institute, for his permission to publish this note.

TABLE 1

Some static water immersion tests

Sl. No.	Name of test	Size of aggregate	Per cent binder by wt.	Nature of binder	Curing period in hours	Temperature of water in deg. F.	Duration of immersion in hours	Remarks
1.	Static Immersion Stripping Resistance Test (A. S. T. M.)	Passing ⅜ in. sieve retained on No. 4 sieve	5.5	(a) Semi-solid	Cooled to room temp.	140	16—24	A wet test is done with liquid bitumens only by adding 2 per cent of water by weight to the aggregate. Estimation of stripping as percentage area of aggregate remaining coated.
				(b) Liquid	2 hours at 140 deg. F.	77	16—24	
2.	Total Water Immersion Test (Shell Development Co.)	1½ in.-¾ in. (graded)	7.0	Cutbacks	½	105	3	Surface dried aggregates after soaking in water for ¼ hour prior to mixing is used for a wet test. A value of '1' is given if 10 per cent of the aggregate remain coated.
3.	Road Research Laboratory Test (Harmondsworth, England.)	¾ in. or ½ in.	3.5	Tar	½	86	24	Estimation is done at intervals and expressed as percentage area of the aggregate surface exposed.
4.	Missouri Boil Test, Missouri State Highway Department.	Passing ⅜ in. sieve retained on No. 10 sieve	6	Semisolid	2	Boiled for one minute		Estimation done as percentage area of aggregate surface uncovered while specimen is out of water. Conditions modified for cutbacks.

TABLE 2

Physical properties of the Delhi quartzite aggregate

1.	Crushing value (B.S.S.)	23.68	per cent
2.	Los Angeles abrasion resistance	25.80	,,
3.	Impact value	26.40	,,
4.	Specific gravity	2.68	
5.	Absorption	0.20	,,
6.	S_iO_2 content	97.0	,,
7.	Flakiness index ¾ in.-½ in.	23.0	,,
8.	Elongation ¾ in.-½ in.	26.0	,,
9.	Surface texture	Rough	
10.	Grain size	Medium to coarse	
11.	Colour	Greyish	
12.	Petrological name	Metamorphic quartzite	

TABLE 3

Physical properties of the binder used

Binder	Penetration (original)	Loss on heating per cent	Penetration (residue after loss on heating)	E. V. T. deg. C.	Distillation fractions per cent (by weight).	Softening point deg. C.	Diazo reaction	Phenol per cent (by vol.)
Bitumen 30/40	32	—	—	108	—	64.5	Negative	—
Bitumen 80/100	85	—	—	90	—	48.0	do	—
Tar RT 2	—	—	—	44.75	$<$ 200 deg. C-0.42 200-270 deg. C-7.32 270-300 deg. C-4.82	34.0	Positive	2.0
Tar RT 3	—	—	—	46.25	$<$ 200 deg. C-0.40 200-270 deg. C-6.82 270-300 deg. C-5.12	34.0	do	2.0
Fluxed bitumen 1.	115	2.5	31	82	—	45.0	Negative	—
Fluxed bitumen 2.	210	1.6	110	66	—	32.0	do	—

TABLE 4

Effect of the size of aggregate and per cent binder on stripping

Atmospheric temperature — 60 deg. F.

Condition of aggregate — dry.

Aggregate size	Binder used	Per cent binder			Remarks.
		4	5	6	
Passing 1 in. sieve and retained on ½ in. sieve.	Bitumen 30/40	Nil	Nil	Nil	
	Bitumen 80/100	Nil	Nil	Nil	
	Tar RT2	30	30	35	
	Tar RT3	25	20	25	
Passing ¾ in. sieve and retained on 3/8 in. sieve.	Bitumen 30/40	Nil	Nil	Nil	
	Bitumen 80/100	Nil	Nil	Nil	
	Tar RT2	35	35	45	
	Tar RT3	35	25	30	
Passing 3/8 in. sieve and retained on 3/16 in. sieve.	Bitumen 30/40	Nil	Nil	Nil	
	Bitumen 80/100	Nil	Nil	Nil	
	Tar RT2	45	45	30	
	Tar RT3	35	40	50	

TABLE 5

Flakiness index versus stripping

Atmospheric temperature – 93 deg. F.
Condition of aggregate – dry.
Size of aggregate – $\frac{3}{4}$ in. – $\frac{1}{2}$ in.

Binder used	Flakiness index					Remarks
	0	25	50	75	100	
Tar RT3	10	15	25	30	40	

TABLE 6

Effect of shape and surface texture of aggregate on stripping

Atmospheric temperature – 68 deg. F.
Condition of aggregate – dry.
Size of aggregate – $\frac{3}{4}$ in. – $\frac{1}{2}$ in.

Binder used	Nature of the aggregate			Remarks
	Flaky	Non-flaky smooth	Non-flaky rough	
Tar RT3	30	60	10	*Nonflaky.* Selected cuboidal pieces flakiness index 0.
Bitumen 80/100	Nil	20	Nil	*Flaky.* Flakiness index 100.

TABLE 7

Effect of sound and weathered aggregate on stripping

Atmospheric temperature ... 84 deg. F.
Condition of aggregate ... dry
Size of aggregate ... 1 in.–$\frac{1}{2}$ in.

Nature of aggregate	Binder used						Remarks
	Bitumens		Tars		Fluxed bitumens		
	30/40	80/100	RT2	RT3	1	2	
Sound	Nil	Nil	25	20	25	80	Crushing value (B.S. S.) 23.68 per cent
Weathered	Nil	Nil	15	15	15	80	35.40 per cent

TABLE 8

Effect of dust on stripping

Atmospheric temperature ... 85–90 deg. F.
Condition of aggregate ... a,b and c.
Size of aggregate ... 1 in.–$\frac{1}{2}$ in.
Nature of dust ... Passing No. 200 sieve.

Binder used	Per cent dust by weight					Remarks
	0	1	3	5	10	
Bitumen 80/100	Nil	Nil	Nil	Nil	Nil	(a) Loose dry dust with dry aggregates.
Tar RT2	20	20	10	Nil	Nil	
Bitumen 80/100	Nil	Nil	Nil	Nil	Nil	(b) Aggregates wetted, coated with dust and dried in the open for one day.
Tar RT2	20	20	20	30	30	
Bitumen 80/100	Could not be coated					(c) same as above but not dried.
Tar RT2	40	50	50	20	Nil	

TABLE 9

Percentage of moisture in Delhi quartzite aggregate under different conditions

S. No.	Conditions	Group	Aggregate size		Remarks
			¾ in.	¼ in.	
1.	Aggregates soaked for half an hour and surface dried.	b.	0.60	2.37	a. Bone dry b. Surface dry c. Wet.
2.	Aggregates soaked for one hour but not surface dried	c.	1.04	2.91	
3.	Aggregates soaked for two hours but not surface dried	c.	1.61	4.09	
4.	Aggregates soaked for four hours but not surface dried	c.	1.61	4.20	

TABLE 10

Effect of temperature of water on stripping using dry aggregates

Atmospheric temperature – 95–100 deg. F.
Condition of aggregate – dry
Size of aggregate – 1 in.–½ in.

Binder used	Temperature of water in deg.C.					Remarks
	20	30	40	50	60	
Bitumen 30/40	Nil	Nil	Nil	Nil	Nil	
Bitumen 80/100	Nil	Nil	Nil	Nil	Nil	
Tar RT2	Nil	5	15	40	50	
Tar RT3	Nil	Nil	10	25	50	
Fluxed bitumen No. 1	Nil	Nil	5	10	20	
Fluxed bitumen No. 2	—	25	35	50	70	

TABLE 11

Effect of soaked surface dry aggregates on stripping

Atmospheric temperature – 95 – 100 deg. F.
Condition of aggregate – soaked for ½ hour and surface dried.
Size of aggregate – ¾ – in. – ½ in.

Binder used	Temperature of water in deg. C.					Remarks
	20	30	40	50	60	
Tar RT2	Nil	10	20	70	80	
Tar RT3	Nil	5	20	50	65	
Fluxed bitumen 1.	—	10	15	15	30	
Fluxed bitumen 2.	—	30	50	70	75	
Bitumen 30/40 Bitumen 80/100	Could not be coated					

TABLE 12

Effect of wet aggregate on stripping

Atmospheric temperature – 92 deg. F.
Size of the aggregate – ¾ in., ½ in., ¼ in.
Percentage of moisture by weight – 2, 3, 4

Binder used	Temp. of water in deg.C.	Size of aggregate			Remarks
		¾ in.	½ in.	¼ in.	
Tar RT2	40	30	30	45	
Tar RT2	20	Nil	Nil	Nil	
Bitumen 80/100	Could not be coated				

TABLE 13

Effect of temperature of the aggregate on stripping

Atmospheric temperature – 82 – 84 deg. F.
Size of the aggregate – 1 in. – ½ in.

Binder used	Aggregate temperature in deg. F.								Remarks
	500	400	350–375	300	250	220	200	100	
Bitumen 30/40	—	—	Nil	Nil	Nil	—	Nil	15	
Bitumen 80/100	—	—	Nil	Nil	15	—	30	50	
Tar RT3	Nil	Nil	—	Nil	—	10	—	—	

TABLE 14

Effect of atmospheric temperature on stripping (cold mixing)

Condition of aggregate – dry
Temperature of curing – atmospheric temp. shown.
Size of aggregate – 1 in. – ½ in.

Atmospheric temp. or Aggregate temp. deg. F.	Binder used				Remarks
	Tars		Fluxed bitumens		
	RT2	RT3	(1)	(2)	
95 – 100	15	10	5	35	
82 – 84	25	20	25	80	
59 – 61	30	20	40	90	

TABLE 15

Effect of atmospheric temperature and under heating of the aggregate on stripping (hot mixing)

Aggregate temperature ... 200 deg. F.
Size of aggregate ... 1 in.–½ in.
Temperature of curing ... At atmospheric temp. shown.

Binder used	Atmospheric temperature in deg. F.			Remarks
	95–100	82–84	59–61	
Bitumen 30/40	Nil	Nil	Nil	
Bitumen 80/100	15	30	50	

TABLE 16

Effect of duration of curing on stripping

Atmospheric temperature ... 82 deg. F.
Size of aggregate ... 1 in.–½ in.
Condition of aggregate ... (a) dry
(b) surface dried after ½ hour soaking.

Binder used	Condition of Aggr.	Curing period in hours					Remarks
		½	2	5	24	48	
Bitumen 80/100	Dry	Nil	Nil	Nil	Nil	Nil	
Tar RT3	Dry	30	15	15	10	10	
Tar RT3	Wet	50	30	25	20	20	
Fluxed bitumen (2)	Dry	90	—	—	40	—	

TABLE 17

Effect of temperature of curing on stripping

Atmospheric temperature — 95 deg. F.

Size of aggregate – 1 in. – ½ in.

Condition of aggregate — (a) dry (b) wet (2 per cent moisture).

Binder used	Condition of aggt.	Temperature of curing			Remarks
		30 deg. C./86 deg. F.	45 deg. C./113 deg. F.	60 deg. C./140 deg. F.	
Tar RT2	Dry	15	30	40	curing period 3 hours
Tar RT2	Wet	20	30	45	

TABLE 18

Effect of duration of immersion on stripping

Atmospheric temperature — 95–100 deg. F.

Condition of aggregate – dry

Size of aggregate — 1 in. – ½ in.

Binder used	Duration of immersion in hours					Remarks
	1	2	3	4	24	
Bitumen 30/40	Nil	Nil	Nil	Nil	Nil	
Bitumen 80/100	Nil	Nil	Nil	Nil	Nil	
Tar RT2	Nil	Nil	10	10	15	
Tar RT3	Nil	Nil	Nil	5	10	
Fluxed bitumen 1.	Nil	Nil	Nil	Nil	5	
Fluxed bitumen 2.	20	25	30	30	35	

Information Section

1. ROLE OF CALCIUM CHLORIDE & SODIUM CHLORIDE IN SOIL STABILIZATION
2. TRAINING HIGHWAY ENGINEERS IN THE APPLICATION OF AERIAL SURVEYS
3. SAND-BITUMINOUS STABILIZATION FOR ROAD CONSTRUCTION

"ROLE OF CALCIUM CHLORIDE & SODIUM CHLORIDE IN SOIL STABILIZATION"

By

I. S. UPPAL & B. P. KAPUR

Calcium chloride has been used as dust palliative and a soil stabilizer for more than 30 years. Its use is mainly due to its deliquescent properties by the virtue of which it retains moisture and retards the rate of evaporation of moisture from a mechanically stabilized soil. This fact is of great importance in stabilization since one of the fundamental factors of stabilization is not only to supply the correct amount of water during construction in order to obtain maximum density by compaction but also to prevent the thickness of water film from changing. The use of sodium chloride in soil stabilization also reduces the rate of evaporation of moisture on account of the lower vapour pressure and higher surface tension of the sodium chloride solution. The retention of moisture in the properly maintained stabilized soil roads for a longer period helps to increase their density with the increase in traffic. It has been investigated by various groups of workers that the addition of both these chemicals improves the density of the compacted soil and also minimises its shrinkage and thus reduces the tendency to form shrinkage cracks. Besides, the addition of $CaCl_2$ and $NaCl$ in the soil lowers the freezing point of the soil-water thus rendering it more resistant to the weathering conditions. Addition of $CaCl_2$ in cement also helps in its rapid hardening.

Since soil stabilization with cement is now a well established and practical method of constructing bases for roads, air fields and other paved areas, it was considered desirable to study the effect of varying quantities of $CaCl_2$ and $NaCl$ on the engineering properties of soil-cement mixtures.

Four types of Punjab soils having chemical and physical characteristics given in Table 1 were selected for this study.

Effect of $CaCl_2$ & $NaCl$ on the P. I. of soils

Effect of increasing quantities of the two salts on their P.I. was tried on three soils having initial P.Is as 13.4, 8.4, & 7.65 and the results are given in Table 2. It would be seen therefrom that the effect of addition of $CaCl_2$ upto 1 per cent in a

TABLE 1

Characteristics of soils selected for study

No.	Description	L.L.	P.L.	P.I.	Sand content	Sulphate	Optimum moisture	Total soluble salts	Exchangeable	
									Ca m.e./100 gms	*Na & K* m.e./100 gms
1	Sandy loam	22.6	16.2	6.4	54	Nil	11.0	.40	6.2	.9
2	Silty loam	28.6	16.6	12.0	17.3	,,	12.5	.35	9.6	1.6
3	Silty clayey loam	37.4	22.2	15.2	8.0	,,	12.0	.26	12.4	1.10
4	Loam	26.8	16.5	10.3	41	,,	11.5	.28	9.95	1.14

more clayey soil having initial P.I. of 13.4 was not appreciable while there was a definite decrease in the P.I. when the quantity of salt was increased to 2.5 per cent. In the case of the other two soils, the effect of increasing quantities of $CaCl_2$ was not appreciable. In the case of $NaCl$, its addition in increasing quantities did not have any effect on P. Is of the clayey and sandy soils while its addition above 0.5 per cent in the graded soil reduced the P.I. from 8.4 to 7.0.

TABLE 2

Effect of increasing quantities of $CaCl_2$ & $NaCl$ on the P.I. of soil

Per cent chemical added	Sandy soil		Clayey soil		Graded soil	
	$CaCl_2$	$NaCl$	$CaCl_2$	$NaCl$	$CaCl_2$	$NaCl$
0	7.6	7.6	13.4	13.4	8.4	8.4
0.1	7.2	7.4	13.4	13.3	7.3	8.1
0.25	7.4	6.8	13.4	14.1	7.2	8.0
0.5	7.4	6.6	13.3	13.5	7.0	8.6
1.0	7.4	7.1	13.2	13.0	7.5	7.0
2.5	7.7	6.9	12.3	13.6	7.4	7.0

Procedure

Blocks of each soil containing varying proportions of cement and the two salts $CaCl_2$ and $NaCl$ individually were prepared at optimum moisture determined for each mixture, in the usual compaction apparatus. Those containing cement were allowed to cure under wet sand for a fortnight and then dried first in the sun and then in the electric oven at 70 deg. C. The blocks were then subjected to the various tests e.g. dry bulk density, compressive strength, resistance to softening action of water and resistance to abrasion. For the determination of volumetric shrinkage of the blocks on drying, the volume was first determined (by employing mercury cup method) immediately after compaction and then after curing the blocks for a week and subsequent drying in the oven. The results of all these tests are shown in Tables 3 to 7 and graphically represented in Figures 1 to 14.

DISCUSSION OF RESULTS

Effect of the two salts on the density of cement : soil mixtures

It would be seen from the results given in Table 3 and Figures 1 to 4 that in all the four soils the addition of increasing quantities of $CaCl_2$ or $NaCl$ increased the density of blocks which otherwise had a tendency to decrease with increasing quantities of cement. It would be interesting to note that whereas the addition of both the salts in loam and sandy soils, containing no cement, had practically no effect on their density, the densities of the cement-soil mixtures prepared from the same soils appreciably increased with the addition of these two salts and the density reducing effect of cement was adequately compensated by the density increasing effect of these two salts.

Effect of the two salts on the compressive strength of the blocks

The compressive strength results (average of 3 readings) determined by means of laboratory carver's press are shown in Table 4 and graphically represented in Figures 5 to 8. Except in the case of silty soil the addition of increasing quantities of both the salts in all the blank soils had a detrimental effect on the compressive strength. In case of silty soil, however, the salts had no effect on the strength. But when the salts were added to the cement-soil mixtures of all soils, they helped to increase their strength appreciably, the beneficial effect being more pronounced in the case of soil mixtures richer in cement. In the case of sandy soil containing 2.5 per cent cement, the

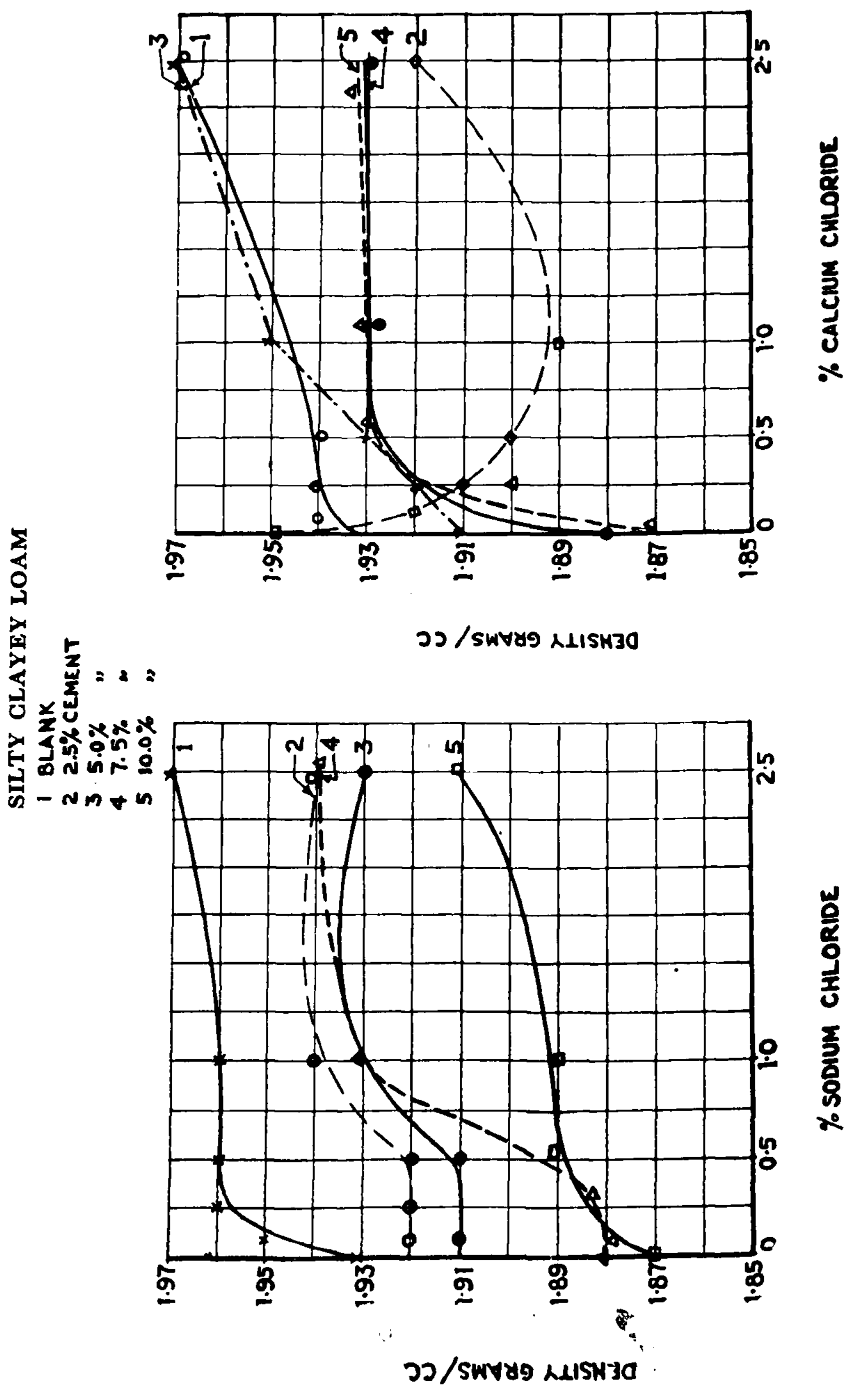


Fig. 3. Effect of Calcium Chloride and Sodium Chloride on the Dry Bulk Densities of Soils Containing Varying Proportions of Cement.

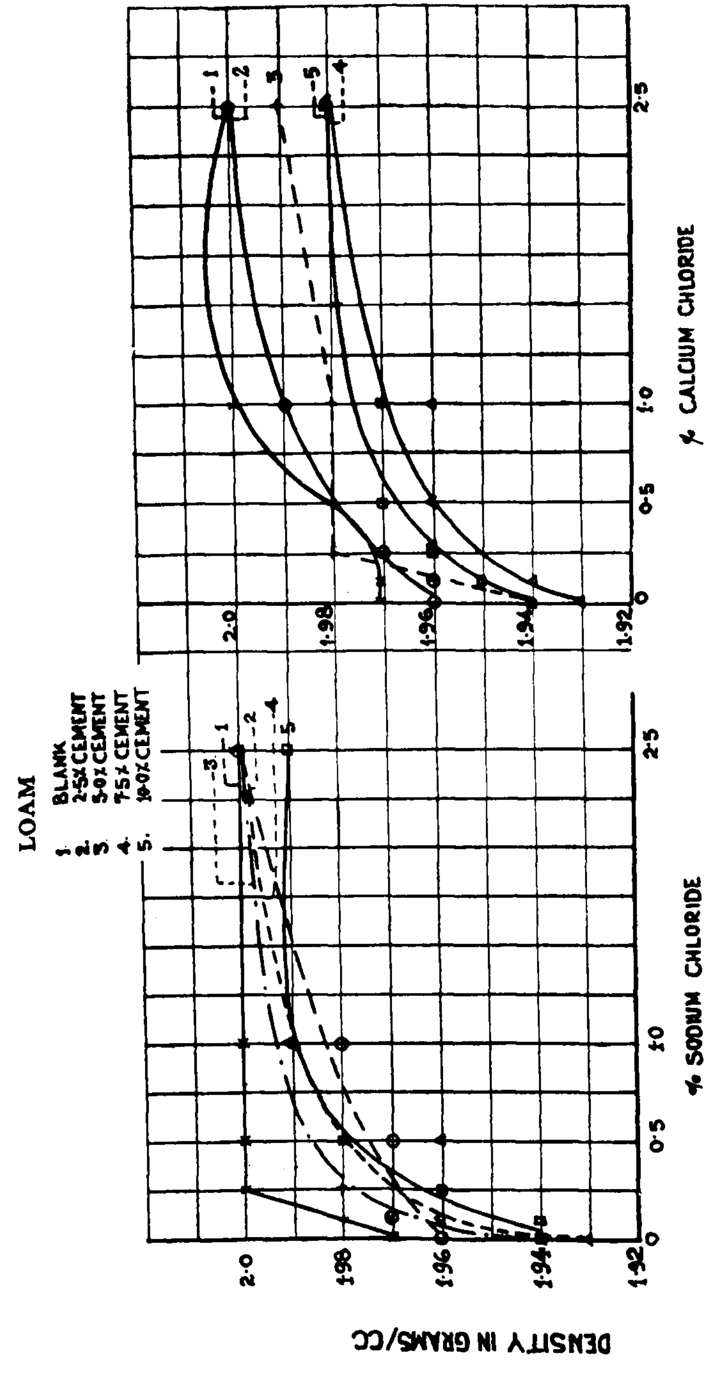
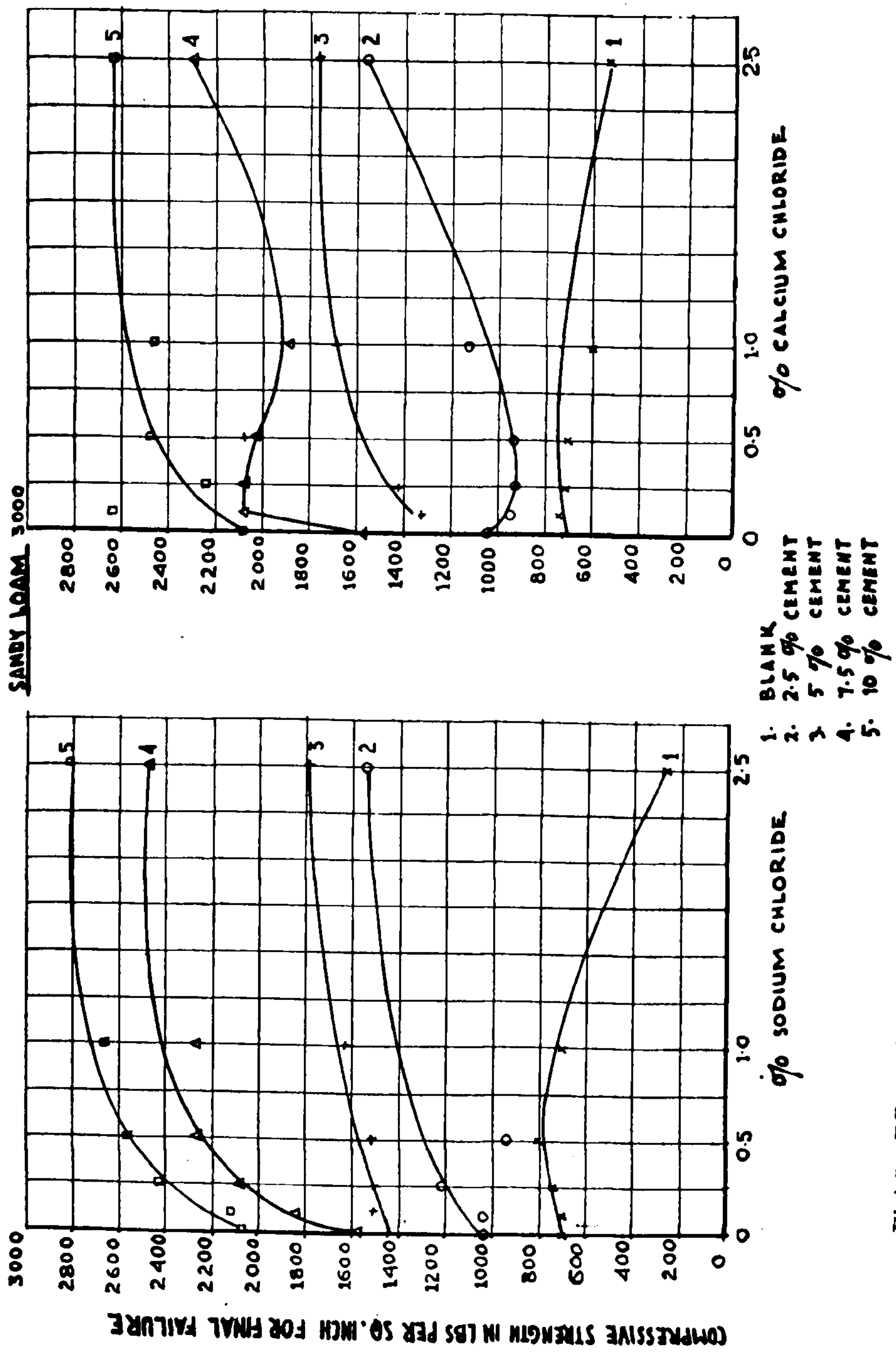


Fig. 4. Effect of Calcium Chloride and Sodium Chloride on the Dry Bulk Densities of Soils Containing Varying Proportions of Cement.



Eigi 5. Effect of Calcium Chloride and Sodium Chloride on the Compressive Strength of Soils Containing Varying Proportions of Cement.

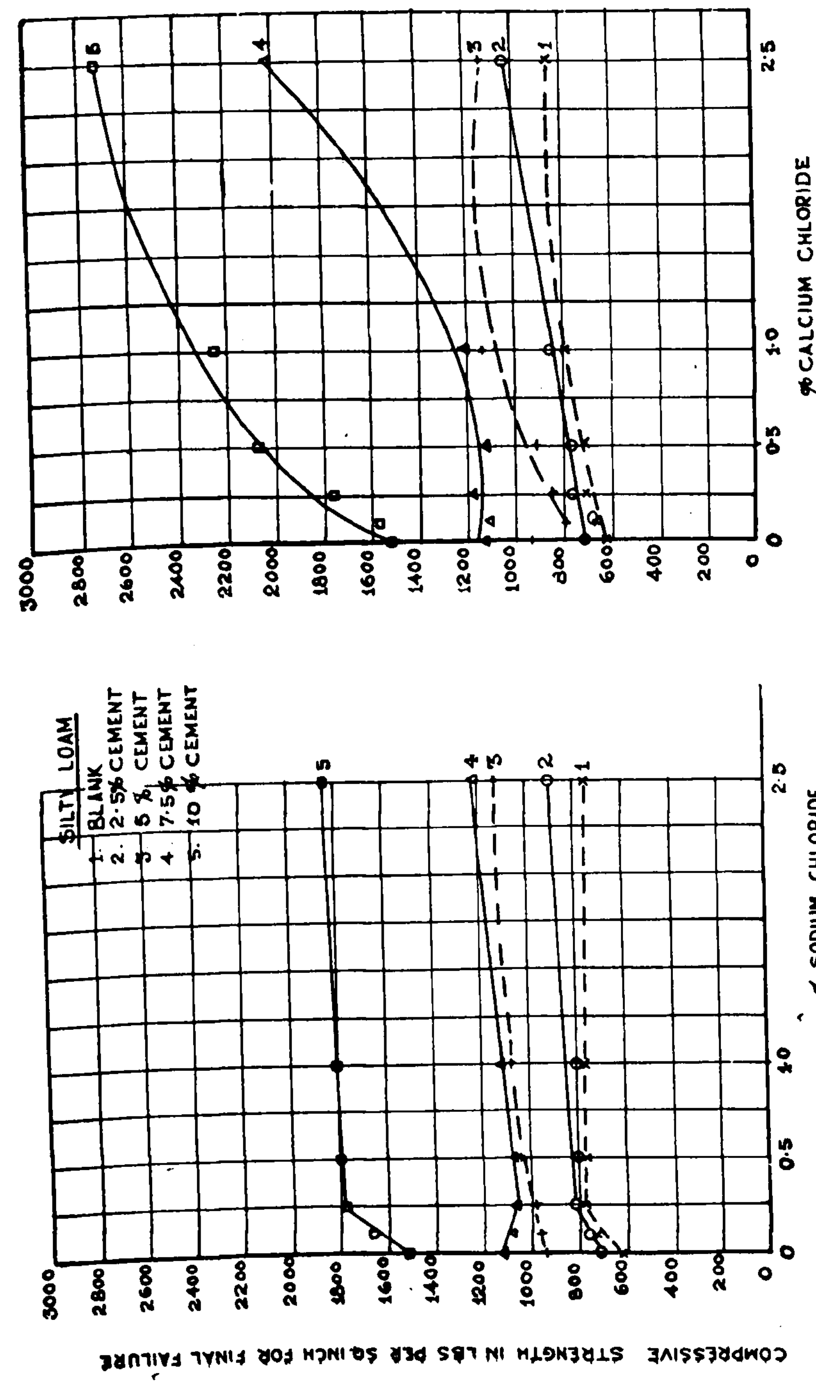


Fig. 6. Effect of Calcium Chloride and Sodium Chloride on the Compressive Strength of Soils Containing Varying Proportions of Cement.

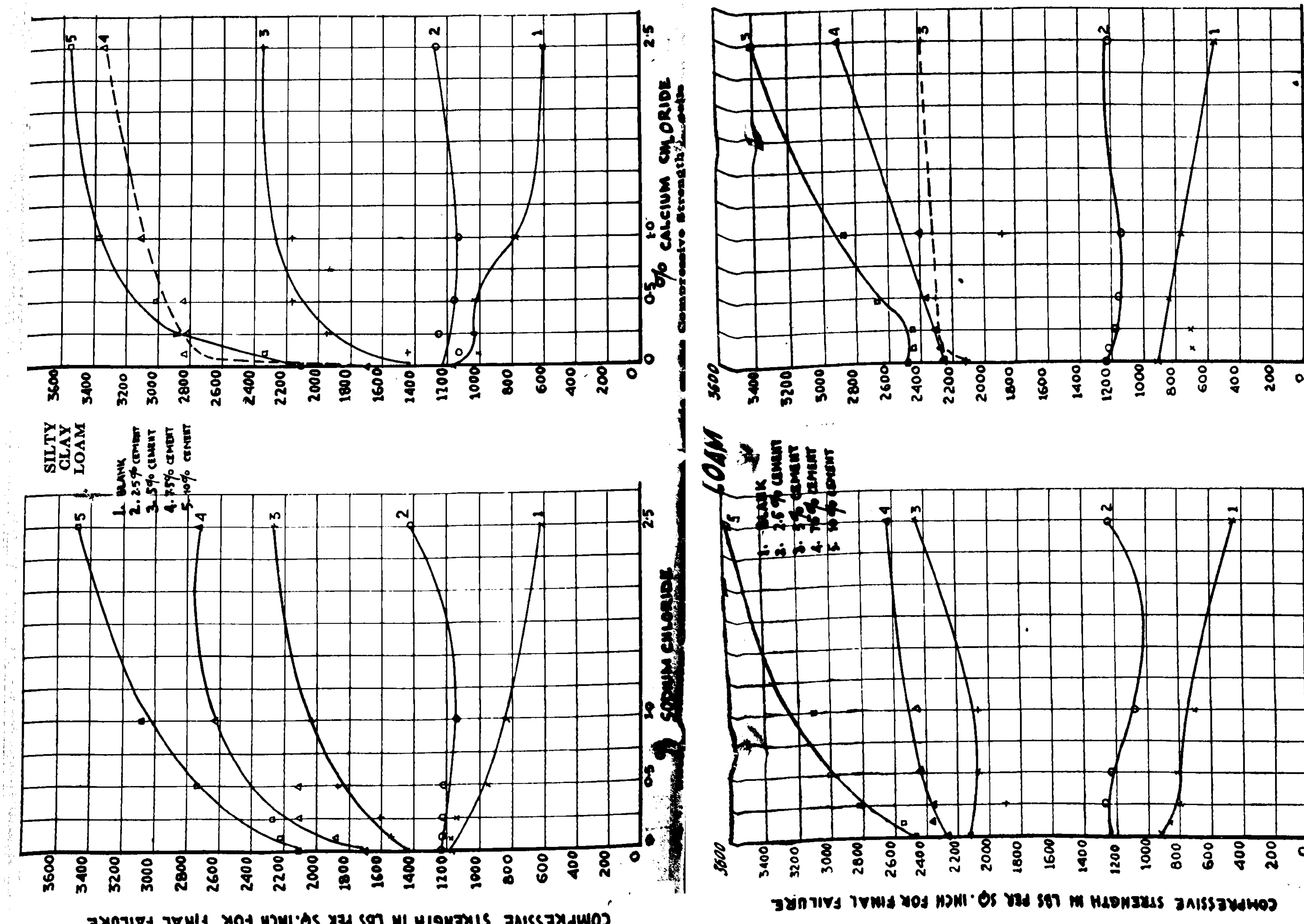


Fig. 8. Effect of Calcium Chloride and Sodium Chloride on the Compressive Strength of Soils Containing Varying Proportions of Cement.

addition of both salts upto 1 per cent did not show any improvement in strength but the addition of 2.5 per cent *Nacl* or $CaCl_2$ increased the strength of the mixture by about 50 per cent. Similarly in the case of this soil containing 5 per cent cement, addition of 2.5 per cent of any of these salts improved the strength. But when the cement content of the soil mixture was increased to 7.5 per cent and 10 per cent even the addition of 0.1 per cent and 0.25 per cent showed marked improvement in the strength of the mixture. In the case of silty soil-cement mixtures, only higher quantities of salts showed improvement even in the case of mixtures rich in cement. In the silty clayey soil even the higher quantities of $CaCl_2$ did not improve the strength of mixture containing 2.5 per cent cement whereas addition of 2.5 per cent $NaCl$ did show a marked improvement. Addition of 0.25 per cent and more of both the salts in the silty clayey soil containing 5 per cent and more of cement, showed very remarkable improvement in the strength of resultant blocks. In the case of graded soil-cement mixtures, even higher quantities of salts when added to the mixture containing 2.5 per cent cement did not show any encouraging results. With 5 per cent cement content of the mixture, however, 2.5 per cent of $CaCl_2$ and $NaCl$ showed some improvement in strength. The mixtures containing 7.5 and 10 per cent cement steadily improved in strength with increasing quantities of these salts from 0.25 per cent to 2.5 per cent.

Effect of the two salts on the volume shrinkage of the cement-soil mixtures

Perusal of Table 5 and Figures 9 to 12 will show that the volumetric shrinkage of the soils on drying decreased with the increasing quantities of both the salts. This effect was more pronounced in the case of cement-soil mixtures than in blank soils. Although the addition of cement to soils had a marked shrinkage reducing effect, yet the addition of salts enhanced it. Sodium chloride was found better than calcium chloride in this respect. In the case of silty soil addition of 1 per cent $NaCl$ in conjunction with 2.5 per cent cement, gave the same results as obtained with 10 per cent cement, while the use of only 2.5 per cent $NaCl$ in the soil gave the results equivalent to 5 per cent cement. The volumetric shrinkage steadily decreased with the increasing quantities of $NaCl$ in all the mixtures (containing cement) and the shrinkage with 2.5 per cent $NaCl$ was about 50 per cent of the original mixture in which no salt was added. In the case of the other three soils also addition of 1 per cent $NaCl$ in conjunction with 2.5 per cent cement to the blank soil had the same volume shrinkage reducing effect as 7.5 per cent cement. With the addition of $CaCl_2$ there was reduction in volume shrinkage upto a certain percentage beyond which the shrinkage

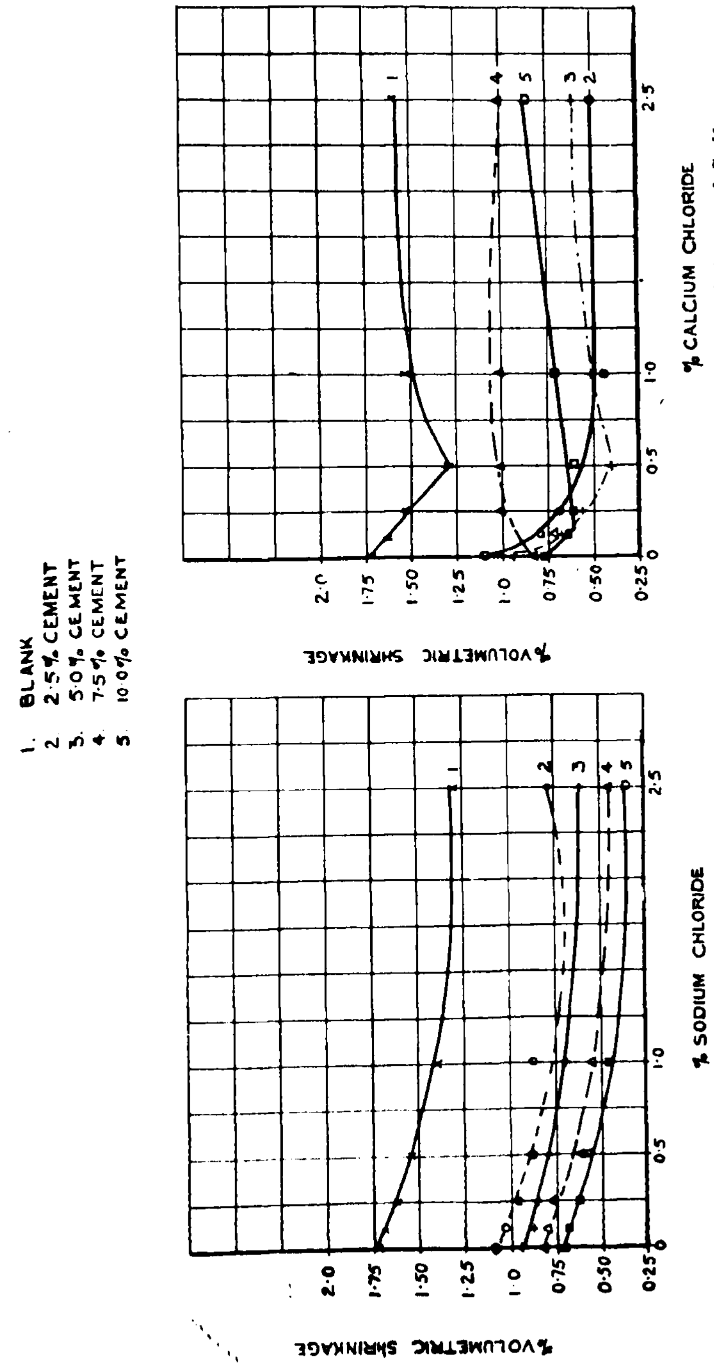


Fig. 9. Effect of Calcium Chloride and Sodium Chloride on the Volumetric Shrinkage of Soils Containing Varying Proportions of Cement—Sandy Loam.

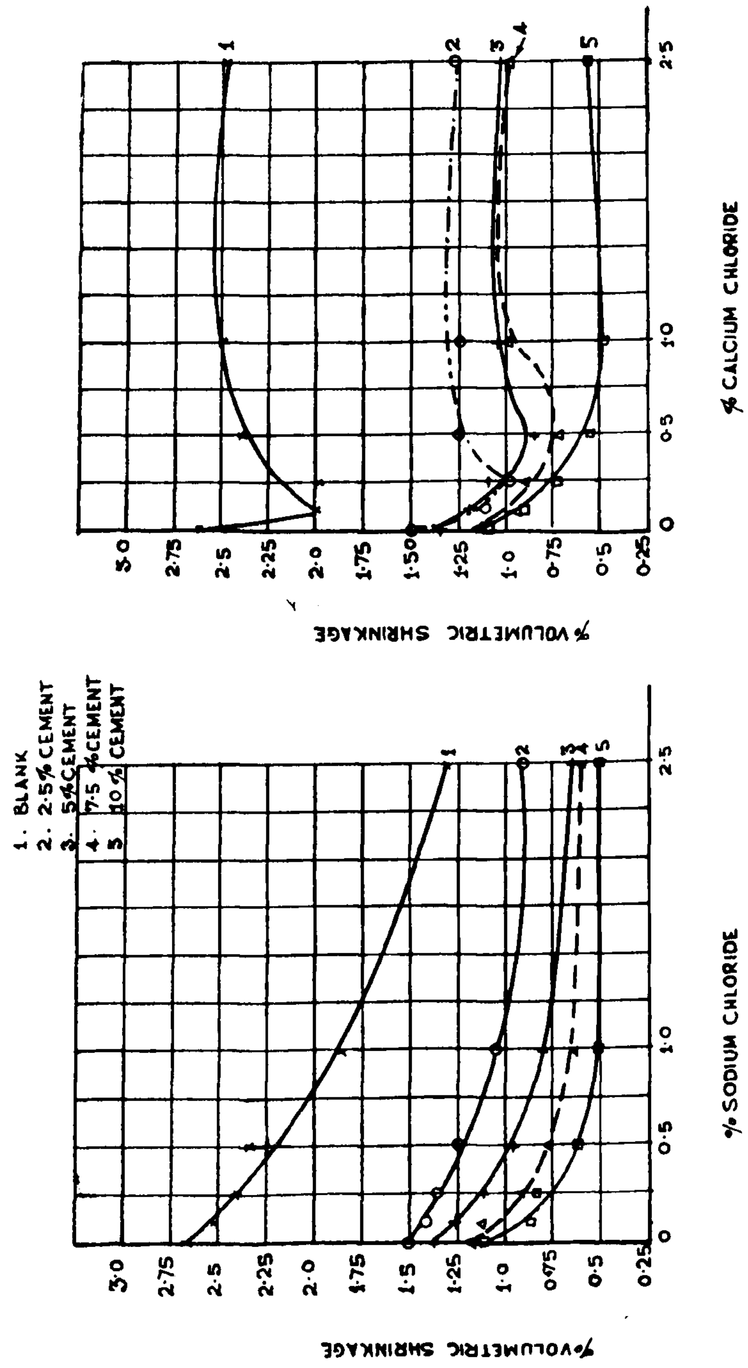


Fig. 10. Effect of Calcium Chloride and Sodium Chloride on the Volumetric Shrinkage of Soils Containing Varying Proportions of Cement—Silty Loam.

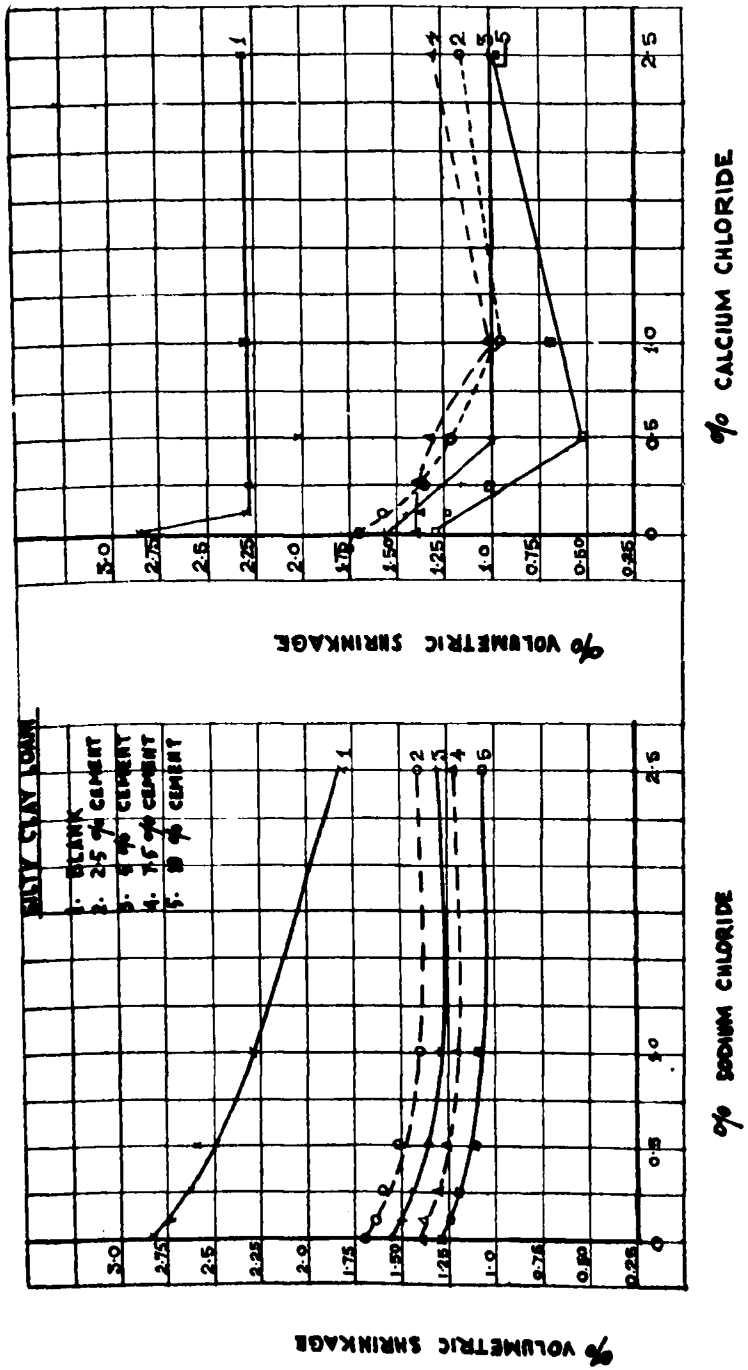


Fig. 11. Effect of Calcium Chloride and Sodium Chloride on the Volumetric Shrinkage of Soil Containing Proportions of Cement.

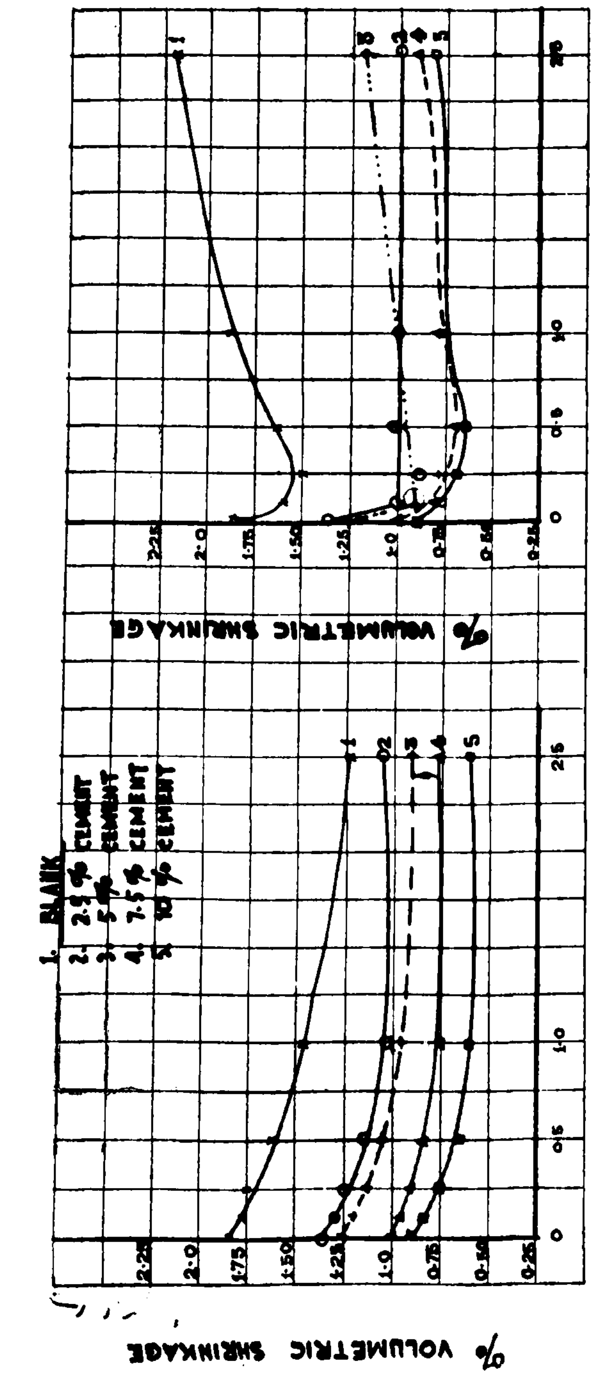


Fig 12. Effect of Calcium Chloride and Sodium Chloride on the Volumetric Shrinkage of Soils Containing Varying Proportions of Cement—Loam.

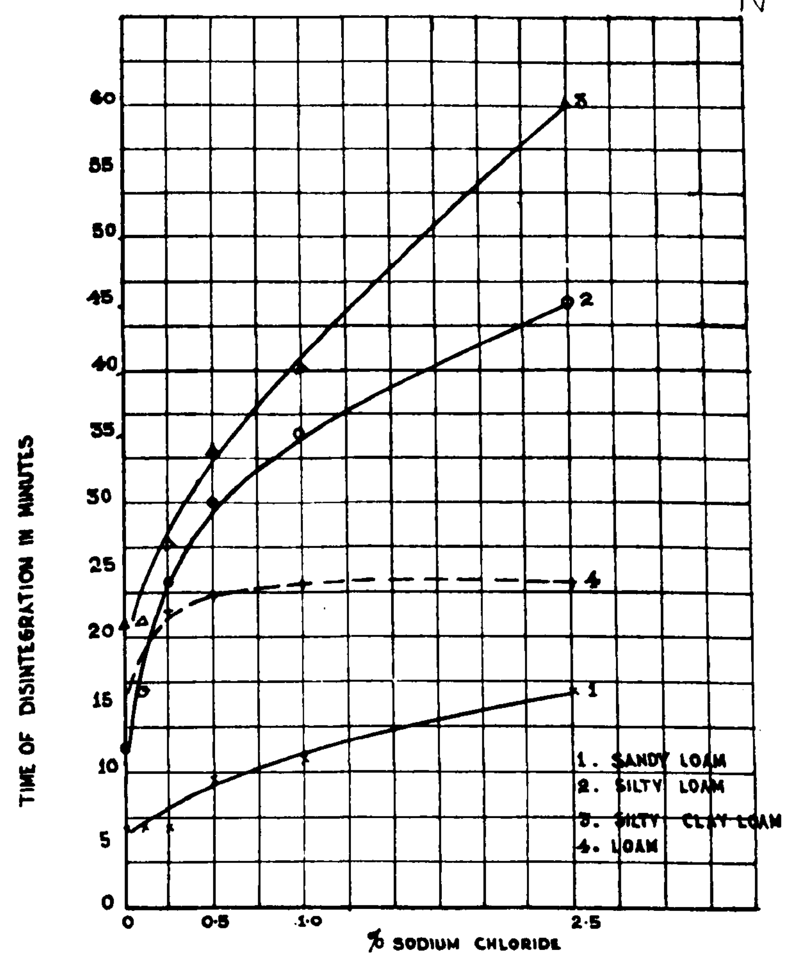


Fig. 13. Effect of Increasing Percentages of Sodium Chloride on the Resistance of Soil Blocks to Softening Action of Water.

began to increase. This limit was 0.25 & 0.5 per cent in the case of silty and loam soils, 0.5 per cent in the case of sandy loam and 1 per cent in the case of silty clayey soil.

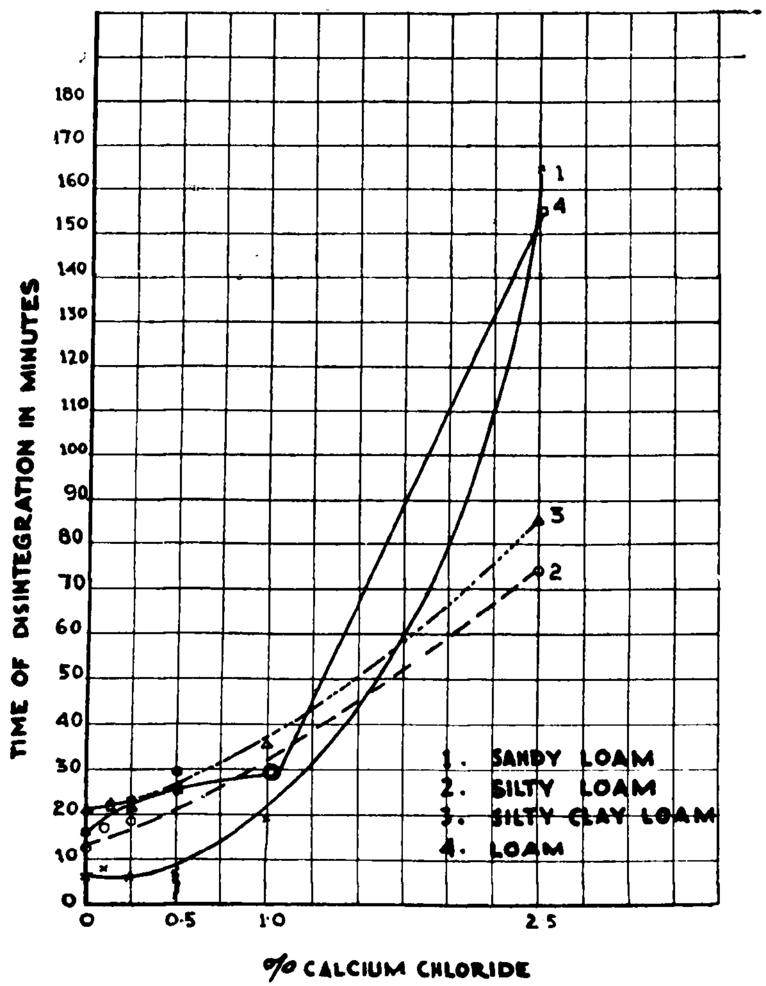


Fig. 14. **Effect of Increasing Percentage of Calcium Chloride on the Resistance of Soil Blocks to Softening Action of Water.**

Effect of the two salts on the abrasive resistance of the blocks

Blocks of all the four soils containing varying quantities of cement were prepared at optimum moisture with increasing percentage of sodium chloride and calcium chloride.

The test was performed in Dorry type abrasion testing machine using—10+40 coarse sand and the loss in weight was determined after 1000 revolutions. During the test the blocks were kept under 200 gms weight. The loss in weight per sq. inch of surface area was determined and results are shown in Table 6. It would be seen therefrom that the addition of both the salts considerably improved the resistance of all the soil blocks to the abrasive action.

Effect of $CaCl_2$ and $NaCl$ on the resistance of different soils to softening action of water

Blocks from all the four types of soils containing no cement but containing varying quantities of the two salts, were prepared and allowed to dry as usual. They were then immersed in water contained in a glass trough and their time of disintegration noted. The results are given in Table 7 and reproduced in Figures 13 & 14 from which it would appear that the resistance to water steadily increased with the increasing quantities of both the salts. The effect of 2.5 per cent $CaCl_2$ was more pronounced.

SUMMARY

Effect of calcium chloride and sodium chloride, the two common inorganic salts generally recommended as dust palliatives, on the engineering properties of the four types of soils generally available in Punjab and their admixtures with varying proportions of cement, has been studied. It has been found that addition of small quantities of these salts considerably improves the density, compressive strength and volumetric shrinkage properties of all the four soils containing cement, the beneficial effect being more pronounced in the mixtures richer in cement. The addition of the salts also improves the resistance of the soils to softening action of water and abrasion.

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TABLE 3

Effect of $CaCl_2$ and $NaCl$ on the dry bulk densities of soils containing varying proportions of cement (density in gm/cc)

Salt per cent	Per cent cement in soil-cement mixture																			
	Sandy loam					Silty loam					Silty clay loam					Loam				
	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0
NaCl																				
0	2.0	1.91	1.91	1.94	1.93	1.78	1.75	1.76	1.76	1.76	1.93	1.95	1.91	1.88	1.87	1.97	1.96	1.94	1.93	1.94
.1	2.0	1.91	1.93	1.95	1.95	1.78	1.75	1.77	1.76	1.78	1.95	1.92	1.91	1.88	1.88	1.97	1.97	1.98	1.96	1.94
.25	2.0	1.93	1.94	1.96	1.95	1.81	1.75	1.77	1.77	1.79	1.96	1.92	1.90	1.88	1.88	2.0	1.97	1.98	1.97	1.96
.5	2.0	1.93	1.95	1.96	1.95	1.81	1.76	1.79	1.78	1.81	1.96	1.92	1.91	1.89	1.89	2.0	1.97	1.98	1.96	1.98
1.0	2.0	1.93	1.95	1.97	1.97	1.81	1.77	1.78	1.78	1.81	1.96	1.94	1.93	1.93	1.89	2.0	1.98	1.99	1.99	1.99
2.5	2.0	1.93	1.95	1.97	2.0	1.81	1.80	1.78	1.78	1.81	1.97	1.94	1.93	1.94	1.91	2.0	2.0	2.0	2.0	1.99
$CaCl_2$																				
0	2.0	1.91	1.91	1.94	1.93	1.78	1.75	1.76	1.76	1.76	1.93	1.95	1.91	1.88	1.87	1.97	1.96	1.94	1.93	1.94
.1	2.0	1.94	1.91	1.94	1.93	1.78	1.74	1.76	1.76	1.77	1.94	1.92	1.90	1.90	1.90	1.97	1.96	1.96	1.94	1.95
.25	2.0	1.94	1.91	1.92	1.93	1.80	1.75	1.77	1.76	1.74	1.94	1.91	1.92	1.92	1.9	1.97	1.97	1.98	1.96	1.96
.5	2.0	1.96	1.93	1.96	1.93	1.81	1.75	1.77	1.77	1.77	1.94	1.90	1.93	1.93	1.93	1.98	1.97	1.98	1.96	1.97
1.0	2.0	1.96	1.94	1.97	1.94	1.82	1.77	1.80	1.78	1.77	1.95	1.89	1.95	1.93	1.93	2.0	1.99	1.98	1.96	1.97
2.5	2.0	1.96	1.95	1.97	1.96	1.83	1.78	1.82	1.82	1.82	1.97	1.92	1.97	1.93	1.93	2.0	2.0	1.99	1.98	1.98

TABLE 4

Effect of $CaCl_2$ and $NaCl$ on the compressive strength of soils containing varying proportions of cement (compressive strength lb per sq. inch for final failure)

Salt per cent	Per cent Cement in soil-cement mixture																			
	Sandy loam					Silty loam					Silty clay loam					Loam				
	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0
NaCl																				
0	708	1037	1443	1556	2075	621	701	943	1132	1525	1174	1226	1415	1698	2106	924	1238	2123	2264	2476
.1	708	1037	1510	1832	2123	735	750	958	1085	1668	1180	1226	1541	1887	2217	874	1283	2360	2358	2546
.25	732	1226	1510	2075	2421	786	830	982	1062	1792	1152	1226	1609	2110	2263	801	1274	1900	2358	2830
.5	800	943	1509	2264	2570	778	800	1040	1066	1792	958	1226	1875	2104	2736	811	1239	2075	2434	3019
1.0	768	708	1636	2264	2674	777	801	1085	1132	1798	838	1132	2028	2641	3081	708	1085	2075	2452	3113
2.5	260	1556	1793	2475	2830	755	900	1128	1212	1839	613	1415	2264	2736	3492	452	1249	2453	2641	3585
$CaCl_2$																				
0	708	1037	1443	1556	2075	621	701	943	1132	1525	1174	1226	1415	1692	2106	924	1238	2123	2264	2476
.1	732	943	1321	2075	2641	660	660	791	1125	1573	1004	1132	1446	2854	2341	700	1226	2264	2264	2453
.25	708	936	1415	2075	2242	708	755	846	1179	1160	1038	1254	1953	2830	2893	707	1179	2311	2311	2453
.5	708	943	2075	2025	2475	708	755	909	1132	2081	1038	1051	2170	2854	3019	850	1163	2311	2358	2713
1.0	604	1132	1678	1887	2453	792	814	1132	1209	2264	780	1132	2170	3100	3380	778	1132	1887	1406	2877
2.5	547	1157	1762	2296	2641	849	1039	1132	2004	2735	613	1273	2358	3349	3553	566	1226	2389	2925	3400

TABLE 5

Effect of calcium chloride & sodium chloride on the volumetric shrinkage of soils containing varying proportions of cement

Salt per cent	Per cent cement in soil-cement mixture																			
	Sandy loam					Silty loam					Silty clay loam					Loam				
	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0
NaCl																				
0	1.74	1.1	.95	.83	.72	2.65	1.5	1.35	1.15	1.1	2.86	1.7	1.56	1.40	1.29	1.84	1.35	1.25	1.0	.90
.1	1.70	1.04	.88	.8	.69	2.5	1.4	1.25	1.10	.85	2.72	1.63	1.5	1.40	1.24	1.77	1.30	1.19	.95	.82
.25	1.63	.96	.85	.77	.62	2.42	1.35	1.1	.9	.82	2.62	1.6	1.45	1.3	1.2	1.75	1.25	1.14	.9	.75
.5	1.55	.88	.8	.6	.59	2.33	1.25	.95	.75	.6	2.6	1.52	1.36	1.25	1.10	1.62	1.15	1.05	.82	.65
1.0	1.40	.87	.7	.55	.45	1.85	1.05	.8	.62	.5	2.3	1.4	1.30	1.2	1.1	1.48	1.05	.95	.75	.6
2.5	1.30	.79	.6	.45	.35	1.3	.9	.65	.6	.5	1.8	1.40	1.3	1.2	1.05	1.23	1.05	.9	.75	.6
$CaCl_2$																				
0	1.74	1.1	.95	.83	.72	2.65	1.5	1.35	1.15	1.1	2.86	1.7	1.56	1.40	1.29	1.84	1.3	1.25	1.0	.9
.1	1.63	.79	.67	.7	.65	2.0	1.1	1.2	.95	.9	2.29	1.57	1.45	1.38	1.24	1.60	1.0	.9	.81	.77
.25	1.54	.69	.58	1.0	.6	2.0	.97	1.1	.90	.73	2.28	1.35	1.16	1.36	1.0	1.50	.9	.79	.78	.68
.5	1.30	.59	.4	1.0	.6	2.4	1.25	.85	.73	.55	2.02	1.23	1.0	1.32	1.5	1.65	1.0	.97	.7	.63
1.0	1.54	.44	.5	1.0	.7	2.5	1.26	1.05	1.0	.47	2.3	.96	1.0	1.0	.7	1.90	1.0	1.0	.79	.75
2.5	1.58	.50	.61	1.0	.84	2.5	1.28	1.05	1.0	.57	2.3	1.16	1.0	1.30	.97	2.2	1.0	1.2	.9	.81

TABLE 6

Effect of $CaCl_2$ and $NaCl$ on the abrasive resistance of soils containing varying proportions of cement (loss due to abrasion in gms per sq. inch area of contact after 1000 revolutions)

Salt per cent	Per cent cement in soil-cement mixture																			
	Sandy loam					Silty loam					Silty clay loam					Loam				
	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0	0	2.5	5.0	7.5	10.0
NaCl																				
0	84	71	22	14	13.5	52	48	30	18	15	20	14.5	12	7.2	6.4	52	46	17.5	13	11.4
.1	82	55	18.5	12.5	11.5	44	43	28	17.5	11.5	18	14	11.0	6.6	5.0	51	43.4	17.5	11	9.4
.25	77.5	57.4	17.4	10.5	8.7	39	38	24	18.0	10.0	18	13.0	10.0	6.5	5.0	49.6	40.6	16.2	11	7.0
.5	67.6	58	16.5	10.5	8.0	31	30	23.4	15.5	9.5	18	12	9.2	6.5	4.5	47.0	39.0	15	11	6.6
1.0	64.0	52.4	16.6	9.0	7.6	29	27.5	17.2	11.0	9.0	11.5	11.0	9.0	4.5	3.8	45	36	12	11	6.6
2.5	50	44.2	16.0	9.0	5.5	27	22	15.5	10.0	7.0	11.5	10.0	9.0	4.5	3.3	43	36	11	9	5.4
$CaCl_2$																				
0	84	71	32	14.0	13.5	52	48	30	18	15	20	14.5	12.0	7.2	6.4	52	46	17.5	13	11.4
.1	75.6	56	17.5	12.4	9.8	45.4	25.6	25	16	10	18.4	13.5	9.0	5.0	5.0	46	45.2	16.0	8.0	7.3
.25	70.6	51.4	17.5	11.0	9.0	43.0	28.6	21	11	9.5	18.4	11.5	8.0	4.5	4.5	45	36.6	15.5	8.0	7.0
.5	66.6	47.4	16.0	10.5	8.4	41.0	28.8	18	11	9	19.0	10.5	7.0	4.5	3.5	37	32	13.8	7.5	6.5
1.0	50	40	12.5	10.0	8.0	28.2	27.0	14	10.4	9	11.5	10.5	6.0	4.5	3.6	32	28.2	12.7	5.0	4.0
2.5	40	32.1	11	10.5	8.0	26.2	10	10	9	6	11.0	10.6	5.0	3.5	3.3	29	23.2	10.0	4.8	3.6

TABLE 7

Effect of increasing quantities of $CaCl_2$ & $NaCl$ on the resistance of soil blocks to softening action of water. (Time of disintegration in minutes)

Salt per cent	Sandy loam	Silty loam	Silty clay loam	Loam
NaCl				
0	6	12	21	16
.1	6	16	21	16
.25	6	24	27	22
.5	9½	30	34	23
1.0	11	35	40	24
2.5	16	45	50	24
$CaCl_2$				
0	6	12	21	16
.1	8	17	21	21
.25	6	18	21	23
.5	7	29	29	25
1.0	19	29	35	29
2.5	165	74	85	155

Comments of members on the Research Note "Role of calcium chloride and sodium chloride in soil stabilization"

Comments by Shri K. F. Antia

1.1. It is well known that chlorides are used as accelerators in concrete. It is worth the while to find out whether the increase in strength is maintained over a long period or is it a manifestation only during the initial stages with no reserve left.

1.2. It is presumed that the percentage of admixtures stated is in relation to cement. This has nowhere been stated. If the percentage is with respect to the soil, the use of admixtures would be most uneconomical.

1.3. As the difference in the effects of the two salts is not appreciable, it would be economical to concentrate on the use of sodium chloride as an admixture.

1.4. It would be an advantage to determine the optimum percentages of admixtures for different types of soils.

1.5. It is considered that the value of such research notes would be enhanced if recommendations are given as a corollary to the general conclusions.

2. Following are his remarks on a few specific items.

2.1. Effect on plasticity index : In the case of graded soils the addition of 0.5 per cent $CaCl_2$ reduced the P.I. value from 8.4 to 7.0 whereas with 1 per cent it was 7.5. This suggests an optimum percentage of the additive which is not confirmed by the other results. The values, therefore, need a recheck.

2.2. Effect on Density

The increase in density of the blocks through the use of admixtures is not significant. The maximum increase in density is only 3.5 per cent and an average figure is about 1.0 per cent. These percentages are well within the limits of experimental error. It would therefore appear that the admixtures used in these experiments have no effect on the density of the blocks unless confirmed by a further set of experiments.

2.3. Effect on Compressive Strength

It does not appear to be correct to say that the salts did not improve the compressive strength of blank silty soils. The results of compressive strength of blank silty soils without any admixture and with 2.5 per cent sodium chloride were 621 and 755 p.s.i. respectively. The result with 2.5 per cent $CaCl_2$ was 849 p.s.i. These results represent an improvement of 22 and 37 per cent respectively.

Comments by Shri D.C. Chaturvedi

In the research note entitled 'Role of Calcium Chloride and Sodium Chloride in Soil Stabilisation' the Authors have studied the effects of addition of varying quantities of calcium chloride and sodium chloride on the engineering properties of soil-cement mixtures and the results have been compared with those of the untreated soil-cement mixtures. In the procedure for tests detailed in the note, it is mentioned that all the tests were carried out on soil-cement blocks dried in the oven at 70 deg. C. but this drying test of specimens at 70 deg. C. does not represent the true field conditions. The soil-cement mixture treated with $CaCl_2$ will behave differently in the field than the untreated sample because during the nights when relative humidity increases the specimens containing $CaCl_2$ will absorb more moisture than specimens without it and also during drying in the day time under similar conditions of temperature and relative humidity the vapour pressure of $CaCl_2$ solution is always lower than that of water which means a lower rate of evaporation in the treated specimen. It is therefore obvious that the soil-cement specimens containing $CaCl_2$ is likely to absorb and retain more moisture than an untreated specimen. It is also known that soil loses strength with moisture and therefore it is likely that under field conditions the results of compressive strength test may not show any appreciable increase in strength and similarly loss due to abrasion may also be affected.

It is important to study whether the improvements noticed in dry condition in various engineering properties in soil-cement mixtures by the addition of $CaCl_2$ and $NaCl$ are continued to be maintained in wet conditions as well in view of the fact that the soil loses strength considerably in the wet condition and due to hygroscopic nature of the salts, the soil-cement mixture containing the salts is likely to remain wet in the field conditions.

Comments by Shri S. L. Kumar

This note is to be dealt with under two main sub-heads: They are:

(i) Stabilisation of soil with and without binding material so that it may be used as a wear resisting surface for roads, or for strong blocks as a base course; and

(ii) The effect of adding chemicals such as calcium chloride or sodium chloride in soil stabilization.

2. It is an accepted fact that soils whose plasticity index is above 10 and the liquid limit less than 30, can be very conveniently stabilised with or without a stabilising agent, the object of mixing the agents such as cement being mainly to give improved compressive strength and some amount of resistance to erosion. Using cement hardly prevents capillary rise if the material is employed for a base course. When the stabilised material has got to stand erosion either very high percentages of cement such as 10 per cent or asphaltic binding agents have to be used.

3. In the tests carried out by Dr. Uppal and Shri Kapur, soils selected are obviously the ones which can be easily stabilised. It is not known if they are fairly well graded also in which case the problem of stabilisation is not at all complex. With an already low plasticity index, the effort made to reduce it by a small margin further by mixing sodium chloride or calcium chloride is not easily understood. The shrinkage phenomenon does not appear to be very important with the soils as tested. The compressive strength again seems to have been determined with dry blocks which, as is well-known, is not an accepted method, particularly when dealing with stabilised soil samples. For that matter, all soil samples are generally tested after full saturation or at least in the circumstances in which they are supposed to be used in work.

With the points expressed in the earlier paragraphs, regarding the basic consideration for soil stabilisation, it would be more appropriate to take up peculiar soils which are either not well graded or have values of plasticity index and clay content beyond the normal permissible limits. If by adding any chemicals to such soils, the problem of stabilisation can be tackled, it would be work in the proper direction. Such chemical treatment may, in most cases, relate to dealing with only certain aspects of soil properties such as shrinkage and cracking, resistance to wear and maintenance of constant compressive strengths, etc., and based on the nature of work the soils are utilised for, the practical application of such treatment can be exploited consistent with economy of treatment.

Comments by Shri. K. K. Nambiar

1. Deliquescent salts like calcium chloride and sodium chloride have been used as dust palliatives and soil stabilizing

agents over the last three or four decades. These salts have certain characteristic properties which make their use desirable under many conditions. These properties include its ability to attract moisture from a humid atmosphere, its ability to hold moisture by reducing the rate of evaporation and its effect in speeding up the compaction process. The effect of calcium chloride on portland cement is also known to produce early setting. Workable concrete mix gave higher ultimate strengths and lower volume change (i.e. shrinkage). Hence calcium chloride suggests itself as an useful admixture for soil cement. The knowledge on the use of the calcium chloride as an admixture in soil-cement construction is not extensive and hence any test report which throws light on the problem is of value.

2. Calcium chloride is not only a deliquescent but also an electrolyte and hence can enter into base exchange reactions with soils and there can be increase in cohesive forces and compressive stresses on drying, lower liquid limits, P.I. and volume change.

3. The text report has shown that the P.I. is slightly reduced by the addition of calcium chloride and sodium chloride for the three types of soils. But the effect of addition of salts on the P. I. of soils detailed in Table 1 is not given. It would have been of interest if gradation curves had also been given for these soils.

4. From Table 3 it is seen that density is reduced by the addition of cement. It is not clear if the quantity of cement is stated on volume basis or weight basis and so also the percentage of admixture. It is observed from Tables 3 and 4 together that compression strength is increased by decrease in dry density which is rather unusual. It would have been of interest if the moisture content at which the samples were compacted had also been given in the Table so that the moisture content-density relationship will be clear.

5. The principal requirement of a hardened soil-cement mixture is that it should be sufficiently durable to withstand exposure to elements. Hence performance test like wetting and drying test is of considerable value. Strength might be considered a principal requirement; however, as most soil-cement mixtures possessing adequate durability also possess adequate strength it would have enhanced the value of the test report if these standard tests had also been conducted and results given.

6. It has been reported from the U. S. A. that shear strength of the soil is improved by the use of calcium chloride. The report under review does not throw light on this aspect of the problem.

7. It is felt that it is always best to correlate the laboratory results with the field performance studies. There are two factors that are of importance while considering the use of deliquescent salts. The evaporation condition in the field may not be the same as in the laboratory and the effect of rain and subsoil moisture conditions must not be ignored. The leaching of calcium or sodium chloride may adversely affect the effectiveness of the admixture. The continued wet condition or alternate wet and dry condition of the base may cause variation in calcium-chloride content of the soil and the properties of the soil may undergo considerable changes. It has been reported from the U. S. A. that when calcium chloride is added in normal amounts, approximately one half of the calcium chloride can be expected to remain in the base after 5 years. Hence it is suggested that field observations may also be conducted to correlate the results obtained in the laboratory.

It is felt that any solution to an engineering problem must have a practical bias. Hence practical implication and the economy involved by the use of hygroscopic salts in the soil-cement stabilization might have been dealt with in the report.

REPLIES OF THE AUTHORS TO THE COMMENTS OF MEMBERS

I. Reply to the Comments of Shri K. F. Antia

1.1. The point has been noted for carrying out further work on this useful suggestion. A reference is, however, invited to page 10 of publication "Admixtures in concrete construction, 1954 issue"—issued by the Concrete Association of India where it has been mentioned that with the use of calcium chlodrie as accelerator in the concrete mixture the increase in the strength continues up to a year and insignificant decrease in ultimate strength is likely to result. Since this reaction of the chloride is due to the presence of cement it is presumed that in the case of cement-soil mixture also the increase in strength will be maintained over a long period.

1.2. The percentages of admixtures studied in the note are in relation to soil-cement mixture and not in relation to cement as presumed by Shri Antia. Since the addition of 0.5 to 1 per cent of the chloride considerably improves the properties of the soil-cement mixture in most of the cases, their use cannot be said to be uneconomical as compared to the improvement. For instance in the case of sandy loam containing 5 per cent cement, the use of about 6 per cent sodium chloride or calcium chloride gave the same compressive strength as mixture containing 7.5 per cent cement. This shows that 2.5 per cent cement can be replaced by only .6 per cent of the chlorides. Similar results were obtained in the other soils.

1.3. There is no objection to concentrate on the use of sodium chloride as an admixture instead of calcium chloride. The study has been carrid out to find out the effect of both.

1.4. The optimum percentages of admixtures for different types of soils also depend on the percentage of cement used. 5 per cent cement is usually the upper limit used for mixing in soils for stabilisation purposes and the following optimum percentages of two chemicals are recommended in view of the results given in the note.

Optimum quantity of chlorides required for each soil containing 5 per cent cement:

	NaCl per cent	$CaCl_2$ per cent
Sandy loam	1	1.0
Silty loam	0.5—1.0	1.0
Silty clayey loam	1.0	1.0
Loam	1.0	1.0

1.5. Necessary recommendations are given under 1.4 above.

2.1. The change in plasticity characteristics with the addition of chlorides is not very appreciable except that it shows a slight fall with increasing percentage of chlorides for all the soils. Since the standard test for P.I. determinations is not very precise, so the errors of ±.5 per cent on the overall results can be expected. The basis for reducing the optimum quantity of chemical required mainly depends on the other properties such as improvement in compression, density, abrasion, shrinkage, etc.

2.2. The density of the test specimens was determined by Mercury Displacement method which is very precise and gives accurate figures. It may, however, be added that even small increase in density beyond figures obtained after compaction at optimum moisture without addition of chemicals plays a very significant part in improving its strength and softening chracteristics. The results already reported are the average of 3 test specimens in each case.

2.3. Correction may be made accordingly.

II. Reply to the Comments of Shri D. C. Chaturvedi

All the blocks were dried at 70°C to constant weight to ensure their complete drying so as to bring them first to the uniform moisture conditions. These were then allowed to stand in open for about a week before performing various tests. This was purposely done to allow the blocks to acquire their normal condition under the existing climatic conditions. Perusal of Table 4 and Figures 5,7 & 8 of the note will show that in all the blank soils except silty loam, the compression strength decreased appreciably with the increasing quantities of calcium chloride and sodium chloride. This decrease can be attributed to the increasing quantities of moisture absorbed by the blank soils containing increasing quantities of calcium chloride and sodium chloride. It is therefore obvious that the addition of these salts to blank soils is not beneficial from the compressive strength point of view whereas it has proved considerably helpful in this respect when cement is used for soil stabilization.

III. Reply to the Comments of Shri S. L. Kumar

It is true that a well graded soil can be stabilized without any admixtures like cement, etc., but even such stabilized soil cannot withstand the action of water and fails under saturated conditions. The cement is added to bind the soil particles so that the stabilized mass can withstand the softening action of water and retain its original form and also to give it more strength. The addition of cement also considerably improves the resistance to abrasion of the stabilized soil mass. The soils selected for the study were typical Punjab soils having P.I. varying from 6 to 15 and sand content from 8 to 54. One of these soils, viz., No. 4 in Table 1 was fairly graded. The study was not conducted with a view to make an effort for reducing the P.I. but the effect of two salts on P.I. was determined as a part of these investigations. The same was the case with regard to the determination of shrinkage properties. As regards the compressive strength, the position has been explained in his replies to the comments of Shri D. C. Chaturvedi. The dried blocks were kept in a room under the prevailing climatic conditions for about a week before testing them.

IV. Reply to the Coments of Shri K. K. Nambiar

Paras 1 & 2. No comments.

3. It has already been proved that the addition of calcium chloride reduces the P.I. of various soils as would be seen from the results given in Table 7 page 13 of the "Proceedings of the Conference on Soil Stabilization", Massachussetts Institute of

Technology, June 18–20, 1952. The results given in the present note confirm the same.

4. The quantity of cement was taken on the weight basis of the total soil-cement mixture. The addition of cement has the tendency to reduce the densities of almost all types of soils and the results given in Table 3 for the mixtures containing no salt confirm the observations made in Table 3 by M/S Mehra and Uppal in their Paper Use of Stabilized Soil in Engineering Construction, Section IV" published in I.R.C. Journal Vol. XV-2, November 1950. The increase in compression strength, inspite of decrease in densities with the addition of cement, is a common observation and can be attributed to the binding properties of the cement. The compaction was done at optimum moisture of each mixture which was first determined separately.

5. Wetting and drying tests on the cement-soil blocks have already been performed by this laboratory and reported by M/S Mehra and Uppal on pages 195 & 196 in the I.R.C. Journal, Vol. XV-1, August 1950. The compressive strength results after wetting and drying cycles of the cement-soil blocks have also been reported by the same Authors in the same volume of the Journal at page 202.

6. The effect of calcium chloride on the shear strength of the soil can be studied during further investigation on the subject.

7. The results reported in the note are only on the basis of laboratory study and further investigations are required with regard to the stability of two salts and the durability of their improvements under the field conditions. It is proposed to carry out more work on these lines in this laboratory and the results will be reported in due course.

"TRAINING HIGHWAY ENGINEERS IN THE APPLICATION OF AERIAL SURVEYS"

By

OLIN W. MINTZER*

INTRODUCTION

Aerial surveys have for many years been used in engineering practice in countries including India. The general application of aerial surveys has been in the preparation of topographic and planimetric maps of large areas. In recent years, particularly since World War II, aerial surveys have become an important tool for the highway engineer, now that under-developed countries depend upon development of their roads and railroad systems to raise their standards of living, i.e., increase the country's wealth, by implementation of their five-year plans. Aerial surveys have become an important consideration particularly in reducing engineering costs and time delays as relating to project planning. The reader may ask " What is An Aerial Survey"? The term aerial survey may be defined as the compilation of engineering data for use in planning and feasibility studies, design or completion stage or stages of a given highway improvement, using aerial photography as the major source of information. The aerial photography may be one or a series of vertical photographs, either a stereopair or the diapositive glass plate, or a mosaic, as may be required for a specific purpose.

WHERE AND WHEN ARE AERIAL SURVEYS USED

In the planning or feasibility stage of a given highway improvement, the engineer generally makes a study of ground conditions, first, to determine the need for the improvement and, second, to determine the best and most economic site, or route location, for the given improvement. The aerial photographs in the form of glossy or semimatte paper prints are studied by means of stereoscopes and simple measuring tools. The engineer studies the soil and drainage conditions, determining where poor and good soils exist, and where a potential route will cross the least number of streams, or will require the shortest length of bridging for economy sake. In addition, the engineer estimates general roadway alignment conditions such as the ground

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and grade line and earthwork, or rock volumes to be excavated at each given site. Along with these data the engineer can estimate the value and type of property to be acquired as formation right-of-way, and with other data, he will be able to establish which route is economically feasible. The final result of the use of the aerial survey at this stage is the estimate of the cost of a given feasible alignment for a highway improvement.

In the design stage, the engineer uses larger scale photographs, a series of photographs giving greater ground details. This set of photographs is usually supplied to him either on paper, or glass plates, or in the form of a mosaic, an assemblage of serveral overlapping photos of the given area. Usualy the photography scale is about 4 times larger than that used in the feasibility stage. The working scale will then make possible the compilation of maps having an RF of about 1/1000, with contour interval of one foot. Generally, when final location of a route has been decided and staked out on the ground, design data are then procured from the field. In the past these data have always been supplied by means of ground surveys; ground surveys were particularly required to obtain formation and longitudinal levels, cross-section data or topographic details of bridge sites and the necessary field surveys were expensive.

Now, after several years of intense experimentation and research, the aerial survey has been proved to be an efficient and accurate tool. It is also much less expensive than former methods. The data are obtained from the study of glass-plate diapositives reproduced at negative scale. The image on the glass plate is projected at a working scale about 7 times the negative scale. This enlarged image, when controlled by a limited network of ground surveys, gives a wealth of information about the surface of the earth over which a highway improvement is to be constructed. For example, with ground control data, such as location and spot elevations of points positioned about 400 feet apart, the longitudinal-section ground line can be plotted at a scale of, say, 1/1000, by means of the photogrammetric plotting equipment. The ground is seen as a three-dimensional image by the plotting operator. As he visualizes the ground image he measures the rise and fall of the ground in much the same way as a surveyor does in the field with staff, level, chain, and theodolite. In the same manner, elevations, distances and direction of and to points of interest at right angles to longitudinal section are determined. For bridge sites the mapping may be done at a scale of say, 1/500 to 1/1000. For bridge site surveys the plotter operator draws the contours to represent the ground surface at intervals of one foot and at a large scale and on a plane sheet on which the design can be drawn. This detailed map can be used then to establish

the actual design of the bridge and preparation of final working drawings.

WHY USE AERIAL SURVEYS

There are many advantages to applying aerial surveys in highway engineering practice, and, of course, there are some limitations. The primary advantage is seen in overcoming a shortage of technically trained man power. Using aerial surveys to replace some ground surveys reduces the man-hours of technical labour to a minimum. Large areas can be surveyed photographically in one tenth the usual ground survey time. Ground surveys are not eliminated but are merely expanded from the wealth of details visualized on the photograph by means of such equiqment as the Kelsh Plotter. Survey lines on the ground, called control lines, are used as a skeleton or framework upon which the aerial survey is completed. Some hill-road projects are in forests where ground surveys may take a year or more to complete. These same areas can be completed by aerial surveys in a matter of months. The more rugged the terrain the more applicable become the aerial surveys. In hilly and inacessible terrain, aerial surveys are much more accurate than the usual ground methods, especially where large-scale mapping is concerned. However, this is not necessarily true in the plains, where the aerial survey depends upon the accuracy and the density of ground control. The sooner a projéct is completed and in use the sooner communications are available to help in raising the living standard of a community. Aerial surveys make it possible to plan and design projects at a much faster rate than by usual ground methods.

Limitations are inherent in the photograph. If the pilot of the aircraft has been careless, or if nature creates an air disturbance during flight, conditions such as unexpected gusts of wind or clouds, these elements can cause image distortions in the photo. The camera lens can cause some distortions near the edge of the photo. Images may not be observed clearly by the operator of the plotter, or his judgement may be poor. The paper and the negative of the photo may shrink. All these conditions can combine in curious ways to enlarge or reduce the scale of some part of the photo in relation to another part. Usually these distortions cause images of ground objects not to agree in position or size with actual conditions. Generally, these inherent errors are not serious. It is assumed that since the photo records all features of the ground in greater detail than can be supplied by man, these limitations may be neglected. If they cannot be neglected, and this is usually possible, then ground surveys must be employed in the first place and thus a more expensive time consuming method becomes necessary.

HOW TO APPLY AERIAL SURVEYS

There are three choices open whereby highway engineers may make use of aerial surveys, i.e., (1) by contract with a private agency, (2) by contract with the Surveyor General of India or (3) by organizing an aerial survey unit within the Public Works Department, Roads Branch. Possibly the best choice is that of organizing the Public Works Department to handle aerial surveys; whichever avenue of approach the department elects to take, there will be requirements in the department for trained personnel, photogrammetric equipment and aerial photography. The degree to which the department makes use of aerial surveys will establish the amount, type and quality of the personnel training. Each of these requirements will be discussed in later paragraphs.

Staff training of the P.W.D. personnel is of importance no matter which agency has the choice of making the aerial survey. There is only one private agency and one government agency having capabilities requisite for doing aerial surveys for highway engineering purposes, but it is not likely that either can take the work required by the Public Works Department without giving it a very low priority. Whether the Public Works Department formed its own agency or contracted with an outside agency for aerial surveys, it will be necessary for the engineers to have a basic knowledge and training in the application of aerial serveys to Highway Engineering. Therefore, the content of this requisite training is now of immediate interest.

TRAINING PUBLIC WORKS DEPARTMENT PERSONNEL

There are two staff levels of personnel requiring training in aerial survey methods, i.e., (1) the assistant and executive engineer level and (2) the overseer level. At either level the training programme will have these objectives:

1. To give the engineer trainee appreciation of the basic principles and practical uses of aerial surveys in highway engineering practice in order that the ultimate may be achieved, i.e., full exploitation of the airphoto for highway engineering purposes.
2. To give the engineer trainee through actual performance of basic techniques a proficiency in the art and science of making measurements from the airphoto.

Both the staff engineer and the overseer should go through a similar training. However, the overseer should have the more

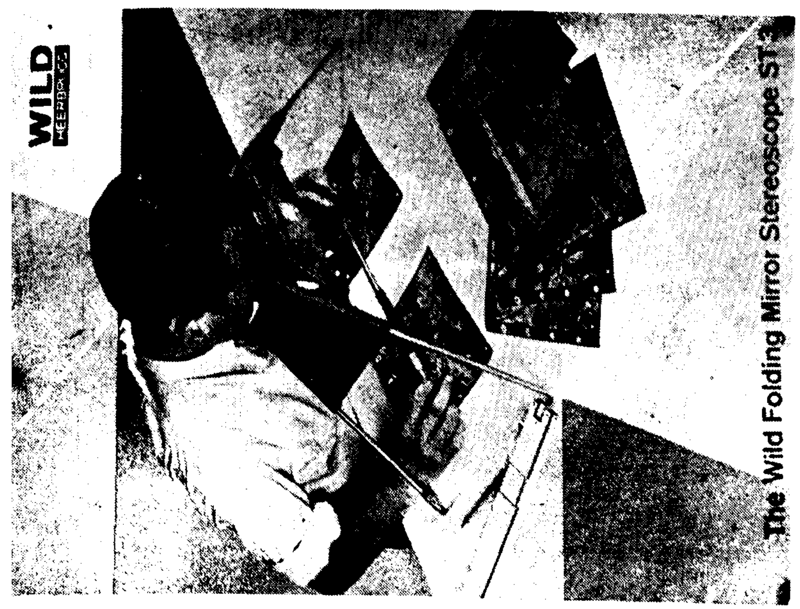

Photo 1. The Wild Heer Brugg folding Mirror Stereoscope ST3 and Stereometer. These instruments assist the highway engineer to study stereopairs of air photos during road improvement planning and feasibility studies.

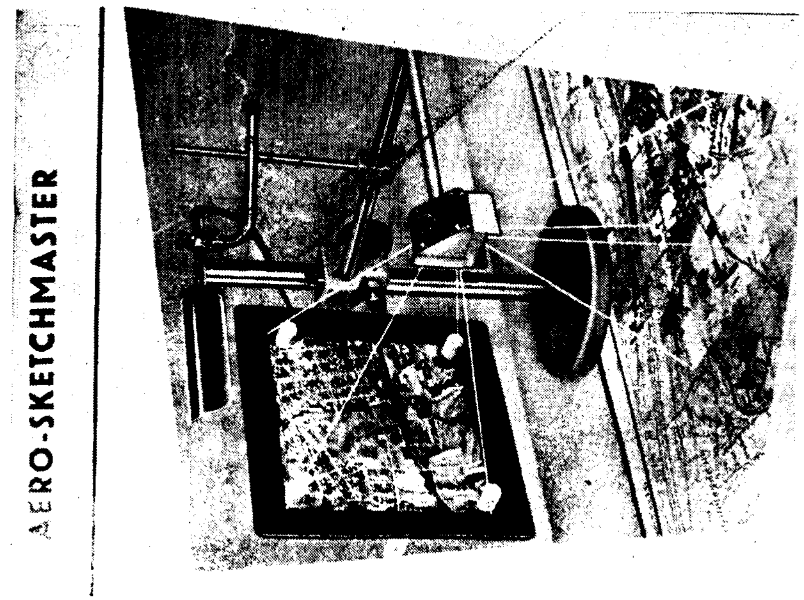

Photo 2. The AERO-SKETCH MASTER. This instrument is very useful in the preparation of planimetric maps from airphotos during preliminary engineering studies.

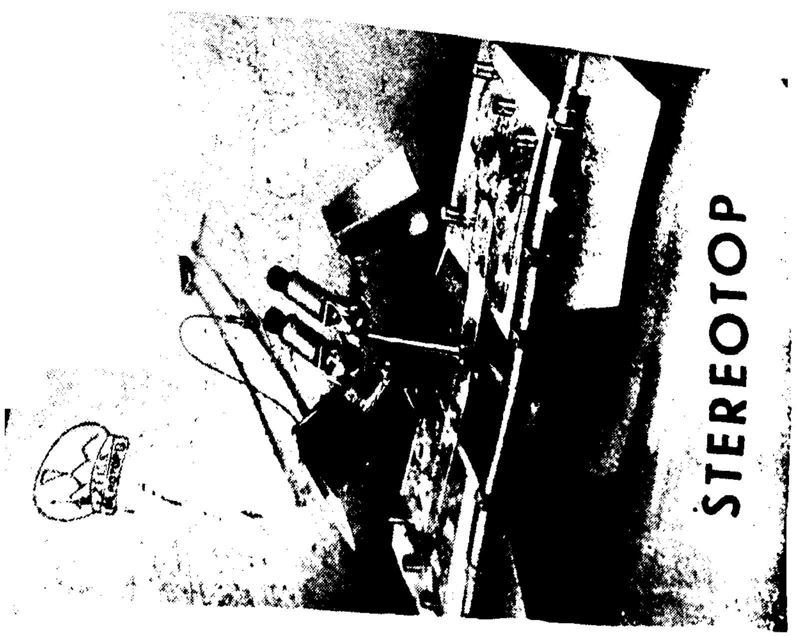

Photo 3. The Stereotop is a versatile instrument. Planimetric as well as contour maps may be economically compiled using the stereotop. Other useful highway engineering data may be compiled, such as longitudinal, cross-section and formation levels during the preliminary survey phase of road improvement studies. Courtesy ZEISS AEROTOPO.

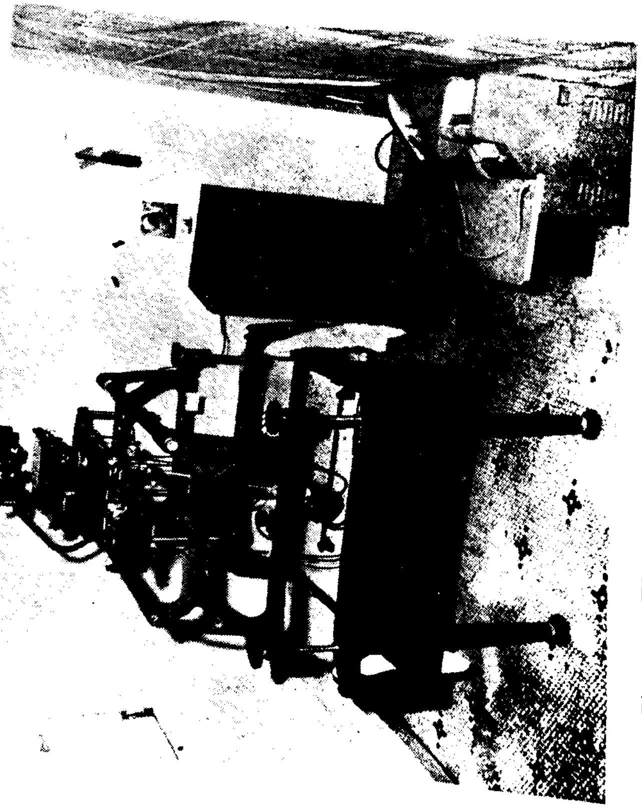

Photo 4. The Kelsh Plotter. This projection-type plotter is used to compile large-scale (four to seven times photo negative scale) bridge site maps. The instrument is also useful in compilation of data such as cross-section and formation levels used in calculation of volumes of earthwork to be moved on a project. Courtesy of Ohio Department of Highways, U.S.A.

intensive training with actual techniques and making measurements on airphotos. The type of training for the engineer is discussed here but the training for overseers may be the subject of a later note if such is of interest.

Training of engineers may be handled in two ways, i.e., through the post-graduate programmes now in effect in India, or through the specialist courses, if the demand for more engineers to be given this training is of sufficient interest. The training courses, which are a part of the highway engineering post-graduate programmes at three Indian institutions, and which now give the basic training and technical aspects in the application of photogrammetry to Highway Engineering, are open only to a limited number of engineers. Since it is not possible for a great number of engineers to receive such training, specialist courses are required. A six-week specialist course is now contemplated at the Punjab Engineering College with effect from June 1, 1958.

NATURE OF SPECIALIST COURSE

The six-week course includes both the quantitative and qualitative aspects of aerial surveys. On the quantitative sides, the engineer receives a basic knowledge and training as to how to make the necessary measurements on airphotos. The following typical headings will give a general idea of how the measurement side of photogrammetry is developed in the course: Definition of terms, principles of flight planning and principles of photo scales, assembling mosaics, principles of stereoscopy, parallax, and spot height measurements, use of graphic and projection type instruments in preparation of maps required in highway engineering, map control and compilation and procurement of profile, cross-section, longitudinal-section data, and formation levels from airphotos. The qualitative side of photogrammetry involves the science and art of photo interpretation. Most of the data regarding soils and drainage, which are required for the planning and design stage of highway improvement studies, can be procured from the aerial photograph with some field work as a check. The trainee attending the specialist course receives instruction in the basic procedures followed by actual work with projects. The procedures for soil, drainage, and road-metal surveys using aerial photography are included in the course. In addition, instruction in the convergent evidence method of soil mapping is included, i.e., how soil mapping of a given area is done using all information available such as topographic, geological, agricultual, forestry, and general engineering data. The data from each of these sources is translated into useful engineering terms and related to a soil or aggregate-source map of a given area. The aerial photograph, however, is usually the source of most of the detailed information. The other sources give background and general information which can be of use in the final map preparation.

During the first two weeks lectures on basic principles are given. In the last four weeks while working on the assigned projects the students apply their knowledge of height measurements, planimetric and contour mapping, and of photo interpretation to soil and drainage mapping, and thereby begin to have a complete understanding of the applications of aerial surveys to highway engineering.

EQUIPMENT REQUIRMENTS

To begin the application of aerial surveys in highway engineering it is not necessary for the Public Works Department to purchase camera or aircraft. The initial quantity of equipment will depend upon how much the initial effort of the aerial engineering will be. However, assuming some engineers are trained, there are certain pieces of photogrammetry equipment which are necessary. The pocket stereoscope is a must. The stereometer and mirror stereoscope are also essential. Other very useful equipment are the sketchmaster and the streotop. Two each mirror stereoscopes and stereometers, and one each sketchmaster and stereotop will be sufficient. The useful drafting equipment in a design office is required such as millimeter and engineer scales, triangles, dividers, mechanical drafting machines and the pantograph, a device for enlarging or reduding scaled drawings. Initially, all the equipment required can be purchased for less than Rs 20,000 an amount which can be justified by savings in surveying costs during the first year of operation. Later on, the Public Works Department will find it feasible to purchase a Kelsh Plotter at a cost of less than Rs 50,000. However, if the Survey of India can supply large-scale (RF = 1/1000) manuscript maps for bridge sites, longitudinal and cross-sections data for earthwork quantities, as well as large-scale topographic drawings, then expensive equipment need not be purchased by Public Works Departments. If the Surveyor General is not able to do so, except as a very low priority, then the Public Works Departments will require compilation equipment such as a Kelsh Plotter.

Table I gives the type and cost of photogrammetric equipment suitable for the aplication of aerial surveys to highway engineering in India.

AERIAL PHOTOGRAPHY

There are two types of aerial photography required for work of the Public Works Department. One type is the small scale, say 1/10,000 to 1/30,000. The other type is the larger scale, say, 1/1,000 to 1/9,600. By far the larger requirement will be the small-scale photography. Fortunately, most areas in India have already been flown for the Surveyor General of India. Hence, after a geographical area has been selected where a road improvement is required, copies of the previously flown aerial photographs can be ordered from Survey of India at a nominal cost. These will cost about Rs 1/8/- per print, depending upon the quantity of prints desired. It is usually best to order two sets of photography for any given area, i.e., one set for mosaic and the other for stereoscopic study.

If there is a bridge site requirement or if cross-sections, longitudinal sections and earthwork data are desired for a given highway improvement, then an original order for the large-scale photography must be placed with an establishment dealing with this type of work. The cost of this photography depends upon good many factors, i.e., length of flight line (length is usually the same as the length of road to be constructed), distance of site from the base of operation, and other considerations. Early in the stage of applying serial surveys in highway engineering practice, when the Public Works Department has a large-scale mapping requirement, the order should be placed on contract rather than handled by the Department. As the Department observes the saving in time and money accruing with the application of aerial surveys, then more elaborate steps can be taken to procure the equipment and establish the aerial survey unit to do the work. The ground control will cost as much as 50 per cent or more of the total map cost, but the ground survey can be handled by the department in co-operation with the agency doing the flying. The rest of the cost may be estimated at 30 per cent for flight and 20 per cent for manuscript-map preparation. For the mapping projects where only one flight strip is required along the road alignment, the flying alone may be as much as 50 per cent of the entire map cost. It is generally best to contract for several projects to be flown together where these projects are located in the same general area. This will make each project more economical, since the cost of flying the aircraft will be distributed between the several projects.

TABLE 1

Photogrammetric instruments

Type and name of equipment	Approx. cost Rs	Uses	Scales etc. Photo-scale R. F.	Map-scale R. F.	Contour interval possible	Remarks
Graphic type					ft	
(a) Pocket stereoscope and parallax wedge	100	i. Preliminary engineering studies	1/20,000	1/20,000	50	Spot height accuracy about 20 ft.
(b) Mirror stereoscope and stereometer	1,800		1/10,000	1/10,000	25	In this case, contours are not obtained directly but from spot height measurements on photograph.
(c) Sketchmaster	1,000					
(d) Stereotop	10,000	ii. Reconnaissance map compilation	1/20,000	1/20,000	25	Although more costly than (a & b), its use is very economical and efficient. Contour maps may be plotted directly.
Projection type						
(a) Kelsh Plotter	40,000 to 50,000	i. Reconnaissance stage				
(b) Multiplex		(a) Kelsh Plotter	1/28,000	1/4,000	5	
		(b) Multiplex	1/28,000	1/9,000	10	
		ii. Design stage				
		(A) Bridge site survey				
		(a) Kelsh Plotter	1/1,680	1/240	1	Kelsh Plotter generally best for larger scale work because of greater contour interval limitation and projection enlargement of multiplex.
		(b) Multiplex	1/1,680	1/672		
		(B) Hilly areas				
		(a) Kelsh Plotter	1/8,400	1/1,200	2	
		(b) Multiplex	1/8,400	1/3,360	5	

"SAND BITUMINOUS STABILIZATION FOR ROAD CONSTRUCTION"

By

L. R. CHADDA & H. R. AGGARWAL*

[Following precedent, the Note received for publication was circulated to the Members of the Research Organisation Committee for comments. The comments received were sent to the Authors for their reply. The Note along with the comments and the reply of the Authors were circulated to referees for advice and as decided by them, the Note is now published for information of Members.]

Use of sand-bitumen and tar mixtures is widely adopted for base course construction in sandy areas remote from suitable materials and where scarcity of water is a big problem for the construction of conventional type of roads. The development of sand-bitumen mixtures for road construction was initiated by the State of Florida, where it proved a great success. The main function of bitumen and tar binders is to supply sufficient cohesion to non-cohesive materials, like sand, for stabilizing their resistance to displacement. The supporting power of such mixtures is, however, considered to be mainly due to frictional resistance.

Bituminous materials are mostly used in the form of cut-back bitumen, tar or bituminous emulsion. Selection of any material for sand stabilization will largely depend on the ultimate strength of the mechanically compacted resultant sand-bitumen mixtures attained within a reasonable period.

For this purpose an extensive study has been conducted in the Laboratory with different bituminous materials using ordinary river sand and a sandy loam soil. Results obtained are presented in this note.

Physical characteristics of sand and soil selected for the study are given below :

Mechanical grading of sand

		per cent
Retained on 10 mesh sieve	...	= Nil
,, ,, 40 ,, ,,	...	= 4.9
,, ,, 60 ,, ,,	...	= 27.9
,, ,, 100 ,, ,,	...	= 50.2
,, ,, 200 ,, ,,	...	= 14.8
Passing 200 ,, ,,	...	= 2.2

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Characteristics of sandy soil

Liquid limit	P. I.	per cent sand	Sulphate per cent
22.5	5.2	57.0	Nil

Bituminous materials tried for the experiments are listed below :

(1) Abode cut-back
(2) Tar No. 3
(3) Bitumen 80/100 containing 50 per cent high speed diesel oil
(4) Bitumen 80/100 ,, 40 per cent ,, ,, ,, ,,
(5) Bitumen 80/100 ,, 30 per cent ,, ,, ,, ,,
(6) Bitumen emulsion (slow breaking emulsion).
(7) Shelmac R.C.—3
(8) Liquid asphalt No. 2

TEMPERATURE OF APPLICATIONS

Tar and bituminous materials were heated to required temperatures, as indicated in Table 1 and then mixed with sand or soil which was also slightly warmed to ensure uniform mixing. No water was added except in the case of bitumen emulsion.

PREPARATION OF TEST SPECIMENS

Sand-bitumen blocks were prepared by compacting in Abbot's compaction apparatus 300 grams of sand or soil after having been mixed with varying percentages of different binders. These blocks were allowed to aerate in the air for different periods and then tested for compressive strength. Cylindrical bitumen-sand or soil blocks of size 3 in. × 1½ in. for shear strength tests were prepared by hand compacting sand-bitumen mixtures in standard metallic moulds to a maximum density.

COMPRESSIVE STRENGTH OF SAND-BITUMEN & SANDY LOAM-BITUMEN MIXTURES

The blocks prepared as above were allowed to remain in open air for about 3-4 weeks and subsequently heated in the oven for

4 hours at 100 degrees C. followed by overnight cooling. The curing period of 3-4 weeks was considered essential as the sand-bitumen blocks did not attain sufficient strength with shorter periods. Results obtained are given in Table 1.

TABLE 1

Nature of binder	Percentage binder used	Sandy loam-bitumen blocks		Sand-bitumen blocks	
		Density gms per cc	Compressive strength lb per sq. in.	Density gms per cc	Compressive strength lb per sq. in.
Abode cut-back	4	1.63	50.0	1.57	3.6
(mixed in cold	6	1.73	60.0	1.59	3.6
condition)	8	1.79	40.0	1.67	3.4
	10	1.88	39.0	1.64	2.6
	12.5	1.88	46.0	1.69	3.0
	15.0	1.88	44.0	1.72	3.0
Tar No. 3	4	1.66	12.0	1.57	2.2
(mixing temp :	6	1.66	40.0	1.56	2.6
200-220 deg. F.)	8	1.76	44.0	1.63	2.6
	10	1.78	38.0	1.61	2.6
	12.5	1.85	39.0	1.64	2.6
	15.0	1.88	40.0	1.71	3.0
Bitumen	4	1.69	26.0	1.60	1.4
80/100=50 parts	6	1.74	54.0	1.64	1.9
High speed	8	1.76	44.0	1.66	1.8
diesel oil=50 parts	10	1.81	38.0	1.70	2.2
(mixing temp :	12.5	1.83	40.0	1.70	2.0
250-275 deg. F.)	15.0	1.88	39.0	1.71	2.6
Bitumen 80/100	4	1.70	26.0	1.64	1.8
=60 parts	6	1.76	42.0	1.61	2.0
High speed diesel	8	1.84	60.0	1.64	2.2
oil=40 parts	10	1.84	45.0	1.65	2.6
(mixing temp :	12.5	1.89	50.0	1.67	2.6
250-275 deg. F.)	15.0	1.90	36.0	1.72	2.6
Bitumen 80/100	4.0	1.74	60.0	1.56	3.0
=70 parts	6.0	1.73	88.0	1.59	3.2
High speed diesel	8.0	1.74	100.0	1.66	4.0
oil=30 parts	10.0	1.86	108.0	1.64	3.6
(mixing temp :	12.5	1.88	130.0	1.66	3.0
250-275 deg. F.)	15.0	1.91	80.0	1.70	4.2

TABLE 1—(*Contd.*)

Nature of binder	Percentage binder used	Sandy loam-bitumen blocks: Density gms per cc	Sandy loam-bitumen blocks: Compressive strength lb per sq. in.	Sand-bitumen blocks: Density gms per cc	Sand-bitumen blocks: Compressive strength lb per sq. in.
Bitumen emulsion (mixed in cold)	4.0	1.70	36.0	—	—
	6.0	1.69	40.0	—	—
RC–3	3.0	Blocks could not be compated without the addition of water	—	1.49	25.7
	4.0		—	1.51	30.7
(mixing temp: 200 deg. F.)	5.0	1.50	32.5	1.52	37.5
	6.0	1.53	39.5	1.54	40.0
	7.0	1.55	43.1	1.57	41.8
	10.0	1.67	64.5	1.61	33.2
Liquid asphalt No. 2 (mixed in cold)	3.0	Blocks could not be compacted without water	—	1.55	9.5
	4.0		—	1.58	18.0
	5.0	1.63	26.0	1.58	22.0
	6.0	1.66	32.7	1.59	20.0
	7.0	1.66	35.0	1.60	15.0
	10.0	1.69	24.2	1.67	4.0

It will appear from Table 1 that the compressive strength of sandy loam-bitumen mixtures increases with the concentration of binder upto its optimum percentage, beyond which it starts decreasing. Unlike other binders, liquid asphalt No. 2 does not impart sufficient strength to such mixtures. But in the case of sand-bitumen, RC-3 undoubtedly gives the best performance out of all the bituminous materials tried.

Another set of experiments was tried by mixing sand with bitumen 80/100 and bitumen 80/100 containing 10 per cent high speed diesel oil. Blocks prepared with both these binders were kept in the open air for 2-3 weeks and then tested for compressive strength. Results obtained are given in Table 2.

TABLE 2

Nature of binder	Percentage binder	Compressive strength lb per sq. in.
Bitumen 80/100	3	45.13
	10	36.06
Bitumen 80/100 H. S. diesel oil	10 90	
	3	11.22
	5.0	9.24
	7.0	8.12
	10.0	7.78

It will appear from Table 2 that with bitumen 80/100 fairly high strength can be obtained, but its mixing uniformly with sand will be a formidable problem in the field.

EFFECT OF HEATING

While carrying out the above experiments, it was noticed that with prolonged heating, the compressive strength of blocks showed remarkable improvement. Results obtained with bitumen-soil blocks prepared with varying percentages (bitumen 80/100-50 per cent and high speed diesel oil-50 per cent) as above and heated for 16 hours at 100 degrees C. are given in Table 3.

TABLE 3

Binder	Percentage binder	Compressive strength in lb per sq. in.: 4 hours heating at 100°C.	Compressive strength in lb per sq. in.: 16 hours heating at 100°C.
50 per cent bitumen 80/100 + 50 per cent high speed diesel oil	4	26.0	30.0
	6	54.0	48.0
	8	44.0	80.0
	10	38.0	136.0
	12.5	40.0	240.0
	15.0	39.0	120.0

EFFECT OF ATMOSPHERIC TEMPERATURE

It was also observed (Table 4) that the development of strength of bitumen-sand blocks is considerably influenced by atmospheric temperature. The blocks were prepared with RC-3 and tested after exposure for 2-3 weeks.

TABLE 4

Percentage RC-3	Density	Blocks kept in the sun temperature: 33-39°C. Compressive strength lb per sq. in.	Blocks kept in shade temperature: 26-30°C. Compressive strength lb per sq. in.
3	1.49	26.0	9.8
4	1.51	27.6	11.6
5	1.52	32.8	16.4
6	1.54	37.0	16.4
7	1.57	37.6	18.0
10	1.61	38.0	20.0

EFFECT OF ADDING SMALL PERCENTAGES OF FINE MATERIAL TO SAND

Addition of small percentages of fine materials like soil to sand before compaction also increases the compressive strength of sand-bitumen blocks as shown in Table 5. Soil added has P. I. = 10.3 and sand content = 13 per cent.

TABLE 5

Nature of binder	Percentage binder used	Percentage fines	Density gms. per c.c.	Compressive strength lb per. sq. in.
RC-3	5	Nil	1.53	34.0
		2.5	1.56	37.3
		5.0	1.54	39.4
		7.5	1.59	46.5
		10.0	1.57	45.5

The above sand-bitumen blocks containing small percentages of fines, were kept in the open air for 30 days and then tested in the usual way.

EFFECT OF AERATION

In order to explore the possibilities of accelerating the setting of bituminous-sand mixtures, the experiments were further continued in a slightly different manner. Before making blocks, the sand bitumen mixture was allowed to aerate in the open air for 2 days and then blocks were made by compacting in Abbot's compaction apparatus giving 40 blows. The blocks thus prepared were tested for compressive strength after 3-4 weeks exposure to atmospheric conditions in the usual way. Results obtained are given in Table 6.

TABLE 6

Percentage binder	Aeration for 2 days		No aeration	
	Density gms. per c.c.	Compressive strength lb per sq. in.	Density gms. per c.c.	Compressive strength lb per sq. in.
3	1.47	45.6	1.49	25.7
4	1.45	45.6	1.51	30.7
5	1.44	53.5	1.52	37.5
6	1.40	49.4	1.54	40.0
7	1.40	41.7	1.57	41.8
10	1.51	32.9	1.61	33.2

It will appear from the above results that with aeration prior to compaction there is an appreciable increase in the compressive strength of bitumen-sand blocks, although they possess comparatively low density which is probably due to evaporation of lighter oil fraction which has a lubricating effect similar to moisture in soils. The results also reveal that for successful stabilization of sand for base-course construction, use of 5.0 per cent RC-3 can be safely recommended since it gives maximum strength.

SHEAR STRENGTH OF SANDY LOAM-BITUMEN MIXTURES

Shear strength of sandy loam-bituminous blocks prepared in standard moulds was also determined by subjecting them to triaxial compression tests. In calculating shear strength, the value of normal load has been assumed as 40 lb per sq. in. which is the intensity of pressure at a depth of 4 inches for a wheel load of 5000 lb calculated from Fraohile's stress distribution formula.

Shear strength test blocks prepared with varying percentages of different binders were immediately heated over a sand bath for 4 hours after compaction and subsequently tested after 4 hours cooling. Results obtained are given in Table 7.

TABLE 7

Nature of binder	Percentage of binder	Shear strength lb. per sq. in.
Abode cut-back	3.0	6.0
	5.0	6.5
	7.0	8.1
	10.0	10.5
Tar No. 3	3.0	6.8
	5.0	7.1
	7.0	8.3
	10.0	10.3
Bitumen 80/100 = 50	3.0	17.97
parts	5.0	13.47
High speed	7.0	16.05
diesel oil = 50 parts	10.0	9.78
Bitumen 80/100	3.0	10.78
= 60 parts	5.0	14.73
High speed	7.0	18.84
diesel oil	10.0	23.27
= 40 parts		
Shellmac	3.0	—
RC-3	5.0	12.5
	7.0	16.0
	10.0	19.5

It will appear from Table 7 that treatment with RC-3 and bitumen 80/100 diluted with 40-50 parts high speed diesel oil gives maximum shear strength.

SHEAR STRENGTH OF SAND-BITUMEN MIXTURES

Shear strength of sand-bituminous blocks prepared with RC-3 and liquid asphalt No. 2 was also determined for a normal load of 40 lb per sq. inch. In this case too, sand-bituminous test specimens prepared in standard moulds prior to testing were heated over a sand bath for 4 hours, after aeration for 20 days, followed by 4 hours cooling. Results obtained are given in Table 8.

TABLE 8

Shear strength of bitumen-sand blocks

Binder	Percentage binder	Shear strength lb per sq. in.
RC-3	3	18.0
	4	19.0
	5	20.0
	6	25.0
	7	22.5
	10	24.6
Liquid asphalt No. 2	3	8.0
	5	9.5
	7	7.3
	10	7.0

It will appear from Table 8 that RC-3 gives higher shear strength as compared to liquid asphalt No. 2, and for each binder there is an optimum concentration beyond which there is a gradual fall in the strength.

Field-experiments

A small experimental length 20 ft long and 3 ft wide was laid by compacting with hand rammer 4½ in. loose layer of bitumen-sand mixtures in small lengths using different specifications as given below:

(1) Sand with 5 per cent RC-3 compacted just after mixing.

(2) Sand with 5 per cent RC-3 compacted after 12 hours aeration.

(3) Sand with 5 per cent RC-3 compacted after 24 hours aeration.

(4) Sandy loam soil compacted with 5 per cent RC-3.

(5) Sand with liquid asphalt No. 2 compacted after mixing.

RC-3 was heated to 200° F. before mixing with sand. Compaction was done with hand rammers, spreading 4½ in. loose layer, and finished with 1 ton roller. The penetration resistance of experimental length was determined with spring-scale cone after lapse of 15, 20, 25 and 30 days. Results obtained are given below :

Setting period	Temperature when penetration was recorded at 4.0 p.m.	Spring-scale cone reading in kilograms				
		1	2	3	4	5
15 days	33.0°C.	5.5	8	8	Above 15	1.8
20 days	31.0°C.	8.0	10.0	9.0	Above 15	2.5
25 days	35.0°C.	8.0	6.0	6.0	15	1.3
30 days	38.0°C.	6.0	5.0	5.0	14	1.4
General condition		Plastic	Plastic	Plastic	Hard	Poor

It will appear from the above data, that a fairly long time is required for a bituminous-sand base course to attain reasonable hardness under field conditions.

Two blocks from each experimental length were taken out after different periods and tested for density and compressive strength.

Results obtained are given in Table 9

TABLE 9

Description	Density in lb per cu. ft. after			Compressive strength lb per sq. inch after		
	1 month	3 months	5 months	1 month	3 months	5 months
5 per cent RC-3 with sand. No aeration	103.6	104.8	105.4	19.9	51.4	67.1
5 per cent RC-3+sand compacted after 12 hours aeration	103.6	104.8	105.4	17.7	57.8	73.7
5 per cent RC-3+sand compacted after 24 hours aeration	103.6	105.4	106.0	18.2	60.9	78.5
5 per cent RC-3+sandy soil. No aeration	101.7	103.6	104.2	19.2	64.7	83.9
5 per cent Liquid asphalt No. 2. No aeration	88.6	90.5	91.0	very low	8.2	10.8

It will appear from the above results that in field construction with bitumen-sand mixtures, slight aeration of the mixtures prior to compaction proves helpful in improving strength when RC-3 is used.

CONCLUSIONS

Bituminous materials in the form of cut-back bitumen, tar and bituminous emulsion have been tried to stabilize sand for base course construction in sandy regions. Among all the bituminous materials tried, RC-3 has been found to give the best performance, with 5 per cent concentration. It is also indicated in study that sandy soils owing to the presence of fine materials give better strength as compared to sand when treated with the same percentages of bituminous materials. Presence of lighter oil fraction in the bituminous materials is no doubt an aid to compaction, but for attainment of high strength, its evaporation is highly desirable.

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2. The Scientific Basis of Road Designs, by F. L. D. Woolterton.
3. Cement Road Problems, Bulletin No. 12.
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Summary of comments on the Research Note entitled "Sand-Bituminous Stabilization for Road Construction"

Shri N. N. Mazumdar

1. In bituminous stabilization work in the field a very important point is the determination of the minimum maturing period before which traffic should not be allowed to pass. In the absence of this information many bituminous stabilized pavements have failed. This research note does not give any clue to that.

2. During the compressive strength test there must be some deformation before failure. The amount of permanent deformation (settlement) is also an important point. Cases have come to notice where the deformation had been so much just after opening the road to traffic that the road needed immediate repair though the pavement had not actually failed. This was because the pavement was not adequately matured.

3. It may be noted in this connection that the points raised in paras 1 & 2 above are interconnected. So without having a thorough investigation on these points it is risky to use bituminous stabilized pavement.

Shri P. L. Varma

The stabilization of sandy soil with bitumen and tar is considered very expensive and can be used only to a limited extent.

Dr. I. S. Uppal

Compressive strength of soil-bitumen mixture

The Authors have concluded that the strength of bitumen-soil mixture increases with the concentration of binders. This does not appear to be correct as the strength of the blocks prepared with Abode cut-back decreases with the increase of binder percentage beyond 6 per cent. Similarly in the case of tar No.3 the strength increases upto 8 per cent and beyond this percentage it decreases. Similar results were obtained in the case of bitumen 80/100 also. Only in the case of bitumen emulsion, RC. No. 3 and Asphalt No. 2 the strength has increased with the increase in percentage of the binder upto 10 per cent. It would have been better if the Authors had discussed these results in more detail and represented them graphically.

Effect of heating

Under this heading the Authors have tried only one temperature (100° C.) and two heating periods, viz., 4 hours and 16 hours. It would have been desirable to try some more periods and also varying temperature of heating.

Shear strength of soil-bitumen mixtures

In the case of bitumen emulsion the Authors have used 5 per cent water on the weight of soil and concluded that this gives the maximum shear strength. It would have been desirable if a few more percentages of water had been tried to find out an optimum quantity of water required for obtaining the best shear strength. Some time back similar work on the use of bitumen for stabilization of sand and soil was carried out and it was found that the addition of small quantity of moisture to the soil bitumen cutback mixture was found very helpful in increasing the stability and strength of the soil blocks. The Authors should have tried to see the effect of varying moisture content on the strength of soil or sand blocks compacted with bituminous materials.

Shri S. L. Kumar

Use of sand bitumen and tar admixtures for stabilizing sandy soils is a well-recognised method, particularly when the stabilized material has to be water repellent. As has been mentioned by the Authors, use of cement calls for water and where water is not easily obtainable, there is no choice but to use bituminous materials for stabilization purposes. However, the issue will have to be studied in the context of economy as it is likely that for a base course where wear resistance is not an important issue, a smaller percentage of cement may be sufficient for stabilization than 5 per cent bitumen or tar mixture as reccommended by the Authors.

For a base course, the essential qualities required are that the stabilized layer must be impervious to surface water and should serve as a capillary break for moisture rise from below, in addition to its being strong enough to take the wheel load as distributed. The Authors, by elaborate tests using Abode cutback, tar No. 3, bitumen with high speed diesel oils in different proportions, bitumen emulsions and liquid asphalt No. 2 have determined the compressive strength of samples as obtained in Abbot's apparatus. There is no indication regarding the property of impermeability and also obstruction to capillary rise. Though it can be assumed that sandy soil will prevent capillary rise, an erosion test and also a permeability test could be interesting to note. It is clear from the test results that the compressive strength also is not very high. The blocks so made do not seem to have been tested in the worst condition, viz., when they are very hot nor are the samples of the standard size with the heights nearly double the diameter, absence of which, to some extent, vitiates the compressive strength results.

The Authors have carried out further tests in a triaxial shear apparatus and determined the shear strength. Instead of testing in a triaxial apparatus, samples could have been crushed in a standard compression machine so that straight away the crushing strength would have been available instead of the shear strength, as determined by the Authors.

A number of variations in heating the blocks with different binders for long and short periods and cooling them etc. has been adopted, but, in actual practice, it is considered that such variations are not very relevant. The standard test for bituminous material for road surface as per the A.S.T.M. should be quite sufficient even in those cases which call for impression test made at the standard temperature on a bituminous surface and also erosion and other tests common for stabilized soils. Determination of the C.B.R. value as a base material would also have been more important than the shear value. In short, getting the compressive strength or the shear strength at the lowest temperature is not likely to represent what takes place in nature.

The information given regarding the pre-aeration of sandy soils and also mixing some percentages of fine materials like soil with bituminous materials for stabilization purposes is interesting, though, in practice, stabilization of the sandy layer in situ under these conditions may not be as easy as in the laboratory.

Shri M. S. Bisht

It is noted that the period of aeration of the blocks before testing has been kept different in different experiments. This should have been kept the same in order to get comparable results. For example, in case of soil-bitumen mixes, blocks were kept in air for 20 days, then heated at 100° C. for 4 hours and then cooled before testing for compressive strength. For shear test, blocks were immediately heated for 4 hours after compaction and cooled before the test.

In case of sand-bitumen mixes, blocks were kept in the air for 30-35 days, heated for 4 hours, cooled and tested for compressive strength. In another set of experiments 15 days aeration was allowed. For shear test, blocks were kept for 20 days in the air, then heated for 4 hours, cooled and tested.

The practical signficance of heating the blocks at 100°C. for 4 hours and then cooling before the tests is not clear and this may be explained by the Authors.

Use of other fillers like lime, surkhi etc. should also have been tried with sand bitumen mixes. Suitable soil may not be available in sandy areas.

Under field experiments, it is stated that with sand-bitumen (RC-3) mixes, the surface remained plastic for a long time, while soil-bitumen mixes became hard. The compressive strength of blocks taken out from the surface and tested after one month do not however show much variation in different treatments. Stability test might have given more useful imformation.

The economics of the treatment should be given.

Summary of Authors' reply to the comments

Shri N. N. Majumdar

Fixing up of minimum maturing period of sand-bituminous mixtures when used on base-course construction will be governed by the following considerations:

(1) The nature of asphaltic binder to be used.

(2) Minimum shear strength or compressive strength required to take up the desired wheel load. With RC-3 when used in base course construction a period of 3 months may be considered reasonable as indicated in Table 9.

Recommendations in the note are made for using bitumen-sand mixtures in base-course construction only, and if the thickness of pavement is properly designed, there will be little chance for any undesirable settlement taking place under traffic load.

Shri P. L. Varma

It is a fact that at present sand-bituminous stabilization is an expensive affair, and as such it has limited application in India. However, in sandy regions where scarcity of water and availability of road materials is not within easy reach, this type of stabilization may have an ample scope.

With the setting up of a large number of oil refineries in India in the near future, the position is likely to improve and there may be an increasing application of sand-bituminous stabilization for road construction.

Dr. I. S. Uppal

For each binder there is an optimum concentration upto which the compressive strength of the mixture goes on gradually inceasing, and beyond that percentage there is a gradual fall. A similar indication has been given under Table 8.

The main object of the study was to select a suitable type of binder for sand-bituminous stabilization for base course construction from a study of comparative behaviour. Effect of trying different periods of heating at varying temperature would have been quite irrelevant to the study.

Soil stabilization with bituminous material is usually tried with sandy loam or sand which can be easily mixed with bituminous materials without water or by using a limited amount of mixing water. Scarcity of water is a main problem in sandy regions and use of a large percentage of water had to be avoided; otherwise, mechanical stabilization for base construction would be more economical in practice. In view of this consideration it was not considered desirable to try more than 5 per cent of water; even this much quantity was added to ensure uniform mixing of emulsion.

Shri S. L. Kumar

In deciding upon the type of stabilization to be adopted for base course construction in sandy regions, the economics involved for each method had to be taken into consideration. Stabilization with 5 per cent RC-3 is to be only tried if considered economical.

Capillary absorption test is no doubt essential for bitumen-soil mixtures in those areas where there are frequent fluctuations in water-table. Performance of such tests for dry sandy regions is quite unnecessary. Testing of compressive strength of bitumen-soil mixtures under very hot condition is not warranted by actual atmospheric temperature prevailing in summer in sandy areas of Punjab. So the testing was carried out under normal conditions prevailing in May-June with a temperature range of 85-90° F. The length of blocks tested for compression ranged from $1\frac{1}{4}$ to $1\frac{1}{2}$ times the diameter and a recent study conducted in the Central Road Research Institute, New Delhi has shown that these ratios give same results as standard specimens.

Both compression and shear strength tests have been carried out.

In carrying out the laboratory experiments, the number of variations have been kept as low as possible. For want of proper equipment standard tests as per A. S. T. M. specifications could not be performed and maximum use was made of the existing equipment in the laboratory.

Determination of C. B. R. value is necessary for designing thickness of flexible pavement. Shear strength test which is an indirect measure of the supporting power is quite a useful test. Compression and shear strength tests were performed under normal atmospheric temperatures prevailing in May-June and these temperatures resemble more or less those obtained under field conditions.

Regarding the effect of aeration and soil mixes on the strength of bitumen-sand mixtures, there should not be much difficuty in reproducing similar results in situ under field conditions.

Shri M. S. Bisht

Fixing up period of aeration for bitumen-sand or soil blocks was determined by minimum time required for the blocks to attain reasonable strength to be tested for compressive strength. It was due to this fact that the time of aeration varied for soil and sand blocks. For shear strength tests, accelerated aeration was performed by heating the blocks. This was done to have quick results. Experiments were performed under varying conditions, but for each set of experiments, the same period of aeration was maintained.

There is no special significance of heating the blocks except to have accelerated aeration in order to have quick results. Before testing the blocks, these were cooled to room temperature.

Use of lime is generally tried with bitumen-emulsion and one set of such an experiment has been performed. Use of surkhi unless mixed with lime is not likely to have any beneficial effect.

Penetration resistance test with spring scale cone to test the hardness of the compacted surface has been tried along with compression tests. For want of suitable equipment, stability test could not be tried. As the quantity of binder is the same, there is not likely to be much variation in the compressive strength. Compressive strength and surface hardness are two different physical properties.

PANEL DISCUSSION

XXII SESSION OF THE INDIAN ROADS CONGRESS

With a view to obtaining and exchanging up-to-date information and experience on the use of soil in all-weather road construction, the questions given below will be discussed at the 22nd Session of the Indian Roads Congress to be held at New Delhi in January 1958. Since soil can be used in the different layers comprising the road structure, it is essential that the nomenclature of the various layers should be defined. The terms used in the questionnaire and their definitions* are given below:

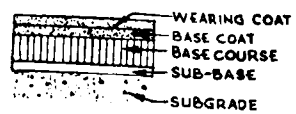
(a) **Subgrade**: The natural earth foundation as prepared and shaped to receive the actual road structure.

(b) **Sub-base**: A layer of material placed between the base course and the subgrade.

(c) **Base course**: That part of the construction resting upon the sub-base, or in its absence the subgrade, and through which the load is transmitted to the subgrade.

(d) **Base coat**: An intermediate course between the base course and the wearing coat.

(e) **Wearing coat**: A wearing coat laid upon a prepared foundation in the form of a continuous surface layer.



QUESTIONNAIRE

USE OF SOIL IN ALL-WEATHER CHEAP ROAD CONSTRUCTION

General

1. (a) Do you use soil in road construction either as a base course or base coat?

* Journal of the Indian Roads Congress, Volume XVIII-3, Jan., 1954.

(b) If so, what is the length of such roads constructed in your State ?

(c) How does the cost of such roads compare with other types of conventional roads ?

2. (a) Do all your stabilized soil roads have bituminous wearing coat ?

(b) If so, what length ?

3. (a) What is the type and intensity of traffic on such roads ?

(b) If bullock carts ply, what is the nature and width of the tyre ?

4. How are the roads behaving where soil has been used both with and without bituminous wearing coat ?

5. What is the climatic condition of the area where such roads have been laid ? Give rainfall and position of the water table.

6. What are the reasons for not using soil more freely in road construction in your State ?

7. **Specifications**

(a) What are the specifications for the material used in

(i) stabilised soil base course,

(ii) stabilised soil base coat, and

(iii) wearing coat.

(b) How do you pulverize the soil and to what degree ?

(c) How are admixtures added to the soil ?

8. **Compaction**

(a) What thickness of loose layer is generally laid for compaction, at a time ? Give details both for base course and base coat.

(b) What is the compacting unit, and how do you find its performance ?

9. **Soft aggregates**

What are the inferior types of aggregates such as moorum, laterite, kankar, soft stone, shale etc. available in your State ?

10. **Surfacing**

(a) What is your experience of the performance of bituminous wearing coat over a stabilized soil base coat ?

(b) In such cases, do you find a priming coat necessary ? If so, at what rate ?

11. **Design of pavement**

What design methods do you adopt for determining the pavement thickness for

(i) stabilized soil road, and

(ii) other types of flexible pavement.

12. **Black cotton soil**

(a) Do you have black cotton soil area in your State ?

(b) Has it ever been treated for use as a subgrade or base course ?

(c) What is the treatment adopted ? Give details.

(d) How does the surfacing behave in such cases ?

13. Which of the following methods of soil stabilization has been used in your State ?

(i) Mechanical stabilization without soft aggregate.

(ii) Mechanical stabilization with soft aggregate.

(iii) Stabilization with cement.

(iv) Stabilization with bitumen.

(v) Stabilization with chemicals.

(vi) Stabilization with resins.

(vii) Stabilization with various by-products from industry like molasses, lignin, " Katha ", waste, etc.

14. (a) Do you have any soil-gravel* roads in your State? If so, what is the length?

(b) What is the behaviour of such roads with and without bituminous wearing coat?

(c) What is the rainfall of the area where such roads are constructed?

(d) What are the specifications for the mixture used?

(e) What is the compacting unit employed?

(f) How is segregation of gravel avoided?

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* Gravel means "Small stone usually waterworn, sometimes mixed with finer materials, occurring in natural deposits".

GENERAL REPORT ON ROAD RESEARCH IN INDIA

GENERAL REPORT ON ROAD RESEARCH IN INDIA*

CONTENTS

1. INTRODUCTION

For the first time in its annals, the Indian Roads Congress during the Shillong Session in 1957, had discussed in an open session the progress so far made in this country in the field of Highway research with a view to co-ordinate the activities of the various research organisations working in this field. A review of research work done dating from thirties was brought out as a 'General Report on Road Research' and was presented at the Shillong Session. The discussion had aroused much interest among the engineers engaged in construction and the research workers working in various fields of research. It is believed that such an open discussion on the subjects of common interest will help a great deal for the proper blending of research and its utility in actual practice, which is a prerequisite for scientific advancement of highway engineering.

The general discussion on the co-ordination of research that took place at Shillong not only helped in knowing the different types of approaches made by the various organisations in the mighty task of the advancement of highway engineering but also

* Compiled by the Director, Central Road Research Institute, New Delhi.

helped in modifying some of the proposed schemes in the light of the useful suggestions which emanated from the discussion.

For furtherance of the same objectives this general report on road research in India has been prepared for the current year from the available information received from the various organisations in the country. As the reports of all the research organisations were not received by the time the compilation of this report was done, it is quite likely that there may be some interesting and important contributions made by some of the organisations during the current year and which are not covered by this report. Hence the members are requested to bring such omissions to focus during discussion, so that the report can be made more comprehensive and complete.

A brief review of the work of importance is given at the beginning of each section, and the points of interest that emanate from the various studies are presented under each sub-head as "*Salient Points*", with a view to initiate discussion.

I. DESIGN, CONSTRUCTION AND MAINTENANCE

2. RIGID PAVEMENTS

2.1. Design

In the field of design of rigid pavements no notable contribution is found from the reports received from the various road research organisations. In an approach towards the rational design of rigid pavements, the project taken up by the Central Road Research Institute, as a first phase, for evaluating the thermal stresses in concrete pavements is in progress.

2.2. Construction and Maintenance

2.2.1. General

There is no significant increase in the total milage of concrete roads during the period under review.

2.2.2. Field experiments

Pavement for tracked vehicles

Under the action of tracked vehicles the surface of a road, either of bitumen or concrete, is usually destroyed very rapidly. College of Military Engineering, Kirkee, Poona, has taken up a comparative study of the behaviour of stone-set paving with

concrete underlay against that of concrete pavements having different specifications as under :

(a) Stone sets 10 in. × 6 in. × 8 in. deep set on a firm base of rolled crushed rock or moorum 6 to 8 inches in thickness at 6 inches apart and filled with 1 : 2 : 4 cement concrete.

(b) Stone sets 10 in. × 6 in. × 8 in. deep placed on top of 4 in. concrete slab of 1 : 2 : 4, keeping the spacing between the stones to a minimum and filling the gaps with a cement-sand mixture of 1 : 3 and 1 : 4 proportion. The concrete slab was in turn laid on four inches thick water-bound macadam base.

(c) Concrete slabs 8 in. thick cast with specially designed mixes to give a minimum compressive strength of 5,000 lb per square inch at 28 days. The concrete was laid over 6 in. to 8 in. thick crushed rock or moorum base.

(d) Concrete slabs cast to 6 in. thickness and topped with 2 in. thick special mix using admixtures such as ironite and hardonate were laid over a base of rolled crushed rock 6 in. to 8 in. thick.

The results on the above sections so far obtained indicate that the specification covered under item (b) is the best of the lot for the tracked vehicles.

Grouted concrete

In order to know more about grouted concrete construction, a field experiment of two miles comprising two sections of grouted concrete 4 in. and 5 in. thick each and that of two sections of premix concrete of the same thickness of 4 in. and 5 in. is proposed to be constructed on Delhi-Mathura road. The project which has been sponsored by the Ministry of Transport is to be constructed by Punjab P. W. D., with the technical assistance of the Central Road Research Institute and the Concrete Association of India. The actual construction of the experimental stretch is expected to be commenced shortly.

Failure investigations

The recent field investigations conducted by the Central Road Research Institute in some parts of the country reveal that some of the concrete pavements 4 in. thick together with about 20 in. of granular base, constructed on red soils, are behaving satisfactorily whereas, on the same road, pavements of the same thickness constructed over expansive black soil have developed longitudinal as well as transverse cracks. The results of plate bearing tests over the granular bases and the flexural strength of concrete beams cut from the actual pavement reveal no significant difference between the failed and sound portions of the concrete pavement.

Thus the investigation brings out the effect of highly expansive subgrade soils on the design of concrete pavements. The investigation is in progress.

2.3. Laboratory Research

2.3.1. Joint sealing compound

A number of joint sealing compounds were tested and tried by the College of Military Engineering, Kirkee[1], for suitability for use on air fields to withstand the action of jets and jet spillage. Although the laboratory tests on all these proprietary joint sealing compounds satisfied British Standard Specifications yet it was found in field trials that, on exposure to sun during summer, blisters appeared in joints at many places with one of those compounds and the compound spread out of the joint having been punctured by the traffic. Causes of formation of blisters and methods of their removal are being studied. Investigations are in progress with other sealing compounds manufactured in their laboratories.

2.3.2. Air entraining agents

The preliminary tests carried out at the Military Engineering College, Kirkee, have shown that admixture of Ritha[1] (soap nut powder) of the order of 1.5–2 per cent has produced air entrainment in concrete and is found satisfactory. Further work is in progress.

The studies made at Bhakra Dam[2] in connection with the evaluation and efficiency test of some air entraining agents, reveal that the reduction in water demand was of the order of 1.2 gallons per bag of cement with all the air entraining agents to get the same slump as with plain concrete. The reduction in compressive strength and flexural strength of various air-entrained mixes is reported to be within 15 per cent of strength of plain concrete. The study also indicated that there is no significant difference in shrinkage between the plain and the corresponding air-entrained concrete bars made with different air entraining agents. In the various tests carried out at the Bhakra Dam, necessary adjustments in the air-entrained mixes

were made to get the same slump as in the case of control plain concrete mixes. If the mixes were further adjusted so as to get the workablity, as measured by V.B. test, remoulding test or compaction factor test and without caring for the slump in the air-entrained mixes, equal to that of plain concrete mixes, it would have been possible to further reduce the W/C ratio in the former mixes and even this nominal loss in compressive and flexural strengths might have been offset.

2.3.3. Alkali aggregate reaction

The presence of reactive aggregates in many regions of the country has been established. Fundamental research work is in progress at the Central Road Research Institute with a view to understanding more about the mechanism of alkali aggregate reaction.

2.3.4. Testing of cement and concrete

Tensile test

A suitable method using HERL Compactor[3] to cast tensile strength briquette specimens for testing the quality of portland cement has been evolved by the Central Road Research Institute. The Indian Standards Institution has proposed this method of testing as a tentative standard. The main advantage of this method over the standard spatula method (B.S.S.) is that it eliminates the variable factor of the skill of operator.

Vibratory compaction of beams

The limited study conducted at the P.W.D. Research Institute[4], Lucknow, on 1 : 2 : 4 concrete beams with 0.5 water-cement ratio, some compacted by hand method and others by vibration, showed that the hand compacted specimens possessed less strength than the corresponding vibrated concrete beams. It was also seen that in the case of hand compacted concrete the strength decreased after certain period whereas in the case of vibrated concrete this did not occur.

2.3.5. Use of pozzolanas in concrete

The work carried out at Bhakra Dam on the use of local material as pozzolana in concrete has indicated that the use of calcined shale should be restricted to the extent of 20 per cent by weight of the total cement in concrete.

The compressive strength of the concrete at early ages is slightly reduced with use of calcined shale, while at the age of one year, there is practically no loss in strength compared to plain concrete.

It is also reported that the adiabatic temperature rise of concrete is considerably reduced with use of calcined shale. Due to the reduction in heat generation, use of this material in concrete for mass concrete work is strongly advocated.

2.3.6. Salient Points

(1) Advisability of popularising vibration compaction[4] in concrete pavement construction in place of hand tamping.

(2) Use of air-entrained[2] concrete for highway pavement construction in India.

(3) Manufacture of pozzolana on a commercial scale for use with cement.

(4) Manufacture of pozzolana as a small scale industry both for use with cement to effect saving, and for brick masonry as lime mortar.

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3. FLEXIBLE PAVEMENTS

3.1. Bituminous Pavements

3.1.1. Design

Pavement thickness

Even though much has not been achieved in the development of design procedures for the flexible pavements in this country during the period under review, it is encouraging to note that more and more number of organizations have begun to realize the importance of the scientific aspect of the subject. The programme for evolving a suitable method of design of flexible pavements for our conditions of climate and traffic, presented by the Central Road Research Institute at the Shillong session is being executed. Considerable research work has been done abroad with a view to understand fully the nature of load stresses induced in highway pavements due to pneumatic tyred traffic. But, no work has so far been done for evaluating the nature of stresses induced in highway pavements due to iron tyred bullock carts as prevalent in this country. Hence with a view to have a better idea of the nature of stresses induced in pavements due to bullock cart traffic, a systematic study has since been commenced at the Central Road Research Institute. As a first step towards this end, theoretical stresses have been worked out based on the actual contact area between the bullock cart wheel and different types of road surfaces. This will be followed up by the actual measurement of stresses using pressure cells embedded in the pavement. The work done so far reveals that the actual contact areas of the iron tyred cart of four feet diametre as used in Delhi with 1½ inch tyre width and ¾ ton wheel load varied anywhere from 1.3 to 4 square inches on different types of surfaces such as bitumen and concrete.

Dense carpets

Design of dense carpets, using different stability tests, is on hand in the Central Road Research Institute. Various tests such as Hubbard and Field, Hveem stabilometer, Taylor stability, and Swelling tests are being conducted on the same mixture so as to suggest a suitable standard test that could be adopted and also with a view to fix the limits of stability. The object of the design is to have as coarse a gradation as possible without sacrificing either stability or the permissible voids. The limited work on the effect of grading and binder content on the stability and density of the bituminous road carpets, conducted at Karnal Laboratory, indicates that proper gradation of the aggregate is very essential to obtain the desired density and stability[1]. Subject to the condition of the test, the most suitable range of grading suggested by B. & R. Research Laboratory, Karnal, for one inch carpet is as follows:

Passing	Retained	Material in per cent
1/2 in.	1/4 in.	40–50
1/4 in.	10 mesh	10–20
10 mesh		30–50

A binder content of 7 to 8 per cent was found to be most satisfactory. It was also found in the same study that 30–40 penetration bitumen was superior to 80–100 penetration bitumen.

3.1.2. Construction and maintenance

Field experiments

Plastic sand

The laboratory investigations at the Central Road Research Institute indicated that fine desert sands can be stabilised satisfactorily by using suitable quantity of bituminous cut-back. A test track consisting of nearly 53 specifications suitable for desert areas, like Rajasthan, using locally available materials such as desert sand and kankar has been constructed at the Central Road Research Institute and the traffic tests on this test track will be commenced early in 1958. Some small lengths laid in Rajasthan by the P.W.D. are also watched.

Flexible overlays on rigid pavements

One of the serious problems that is facing the highway engineer in some parts of the country is the necessity for reconditioning the badly cracked concrete pavements. Of late, some of the old concrete pavements which have served for 15 to 20 years have been developing extensive cracking under the present day heavy traffic. Even though such cracked old pavements could be strengthened extensively by overlays, this phase of construction has not been widely adopted on our highway system. The important point that is to be considered in this direction is, whether it is advisable to delay reconstruction till the pavement is completely destroyed or whether it is better to strengthen such pavements during the early stages of cracking as a result of structural failure.

The available information on the widely adopted practices abroad in similar conditions indicates that either flexible or rigid overlays laid at the early stage of failure have been found

to be more satisfactory. In this connection the theoretical considerations presented by S. K. Bose[2] and the small scale field experiments undertaken by the P.W.D. Research Institute, Lucknow comprising of the following two specifications are of interest[3]:

(1) Superimposing the existing cracked cement concrete pavement with three inches thickness of stone ballast finished with one coat of bituminous surfacing immediately and the second coat within six months.

(2) Superimposing the existing cracked cement concrete slabs with $\frac{3}{4}$ in. bituminous premix carpeting.

Systematic observation of these experiments under traffic will help in dealing with similar cases.

Field investigations

The field investigations undertaken by the Central Road Research Institute [4,5], and P.W.D. Research Institute, Lucknow[3], indicate that many of our highways possess poorly compacted subgrades and also have inadequate hard thicknesses to meet the growing demands of heavy traffic.

3.1.3. Laboratory and theoretical work

Monographs

A thorough knowledge of the existing practices and methods is a prerequiste for any progress in research.

In this direction, the monographs prepared on physical[6] and chemical[7] tests for tar and bituminous materials by Central Road Research Institute will be of interest for those who are engaged in this branch of science.

Fundamental studies

For furtherance of research, fundamental work is as important as applied research. On the fundamental side the work done so far at the C.R.R.I. on the analysis of bitumens using an absorptiometer is of particular interest [8]. Based on the extinction constants, as observed by Absorptiometric analysis, the nature of asphaltenes in a bitumen as influenced by the nature of the selective solvent used can be evaluated to a certain extent.

The exact percentage of asphaltenes present in a bitumen and as extracted with a given solvent can be calculated directly from the values of the extinction constants for the bitumen, asphaltene and malthene, using the same solvent for the absorptiometric analysis. For, the extinction constant of a bitumen is a proportionate addition of the extinction constant of the constituents, the proportion being their percentages in the bitumen.

Surface dressings

Laboratory investigations[9] at the Central Road Research Institute bring out the relative sizes and quantities of aggregate required for single and two coat surface dressings. The same study has also indicated that it is a better practice to proportion aggregate quantities in the field, by weight than by volume.

Work at the College of Military Engineering, Kirkee[10] has shown that high melting point bitumens could also be used by changing their properties by the addition of kerosene and diesel oils. The same College is also carrying out investigations on the addition of softer grade bitumens and softening agents like creosote, etc.

Stripping and adhesion

Study of adhesion between binders and roadstones was undertaken at the Central Road Research Institute [11] and it was found that the road stones, cubic and angular in shape, should be preferred. The binder to get better adhesion should have a low viscosity initially and should be capable of building up a high viscosity later. Use of adhesive agent to prevent stripping is advocated in case of wet aggregates.

Influence of additives on the adhesion between stone and binder has also been studied at the P.W.D. Research Institute Lucknow[3], where two commercial additives were tried to improve adhesion of wet aggregates with mexphalt and tar.

It is concluded that the effect of these additives is more pronounced in case of mexphalt and in case of stones which possess very poor adhesion.

Based on a static water immersion test, the various factors that influence the stripping of Delhi quartzite have been studied at the Central Road Research Institute[12] and certain broad conclusions regarding suitable flakiness index, percentage moisture etc., have been obtained. For example, the results indicate that in the case of open textured carpets, the quantity of aggregates smaller than $\frac{1}{4}$ in. size should be very much limited. Also, allowing a reasonable percentage of stripping, it appears that the maximum permissible value for the flakiness index of the aggregates should be fixed at 25 per cent,

It was found that although in the case of weathered aggregates, the stripping was very much less, yet because of the crushing value of the weathered aggregates, the quantity of weathered aggregates should be very much limited. The percentage of dust permissible over the aggregates should not be more than 2 per cent by weight of the aggregates and the percentage of moisture that could be tolerated is between .5 to 1 per cent. Further work on the aggregates is in progress.

Foaming of binder

To prevent frothing or foaming of tar and mexphalt during heating in field, work was undertaken in the P.W.D. Research Institute at Lucknow [3]. Five antistripping agents like wet fix, Adhevia—T (I.C.I. product), lime, cement and common salt were tried with tar and mexphalt. Except common salt, the others were found effective. In view of the high cost of wet fix and adhevia—T, it is recommended that an addition of four per cent lime or two per cent cement can effectively prevent foaming or frothing of tar or mexphalt. It was also seen that these additives have no effect on the properties of the binder.

Low temperature tar

Production of low temperature tar on a pilot plant scale has been undertaken at the Regional Research Laboratory, Hyderabad[13] Deccan. An experimental low temperature carbonisation plant of the Lurgi-spulgas type of a capacity of 25 tons a day to test the suitability of non caking Indian coals has been set up. The plant produces about 1.3 tons of low temperature tar per day. Attempts have been made at the Regional Research Laboratory, Hyderabad, to prepare road tar from this low temperature tar. It is found that a suitable base material can be prepared by blowing air through the tar at 250 to 300°C. for 2 to 3 hours. Blending of this base material with suitable tar fraction is in progress.

It is stated that low temperature tar samples produced by carbonising Andhra Pradesh and Ranigunj non-caking coals in the experimental plant were sent to Germany for evaluation and report received from them confirmed that the road tar produced from the low temperature tar samples compares very well in performance with standard high temperature road tars.

Work connected with utilisation of this low temperature tar, addition of rubber in bitumen and weathering and oxidation of road binders is in progress at the Central Road Research Institute.

3.1.4. Salient points

(1) Reconditioning of old cracked cement concrete pavements.

(2) Suitability of low temperature tar for highway construction.

(3) Use of dense carpets on our heavily trafficked roads in place of open graded premixes.

(4) Advisability of introducing mechanical spreaders and sprayers for surface dressing work.

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3.2. Water-bound Macadam and Gravel Roads

Low grade aggregates.

3.2.1. Even though there are better alternatives of pavement contruction, it is quite unlikely for a long time to come that the water-bound macadam construction and gravel roads will be dispensed with in our country under the existing economic conditions. To a large extent this type of construction will be economical if only we can utilise the locally available low grade aggregates especially in places where hard aggregates are scarce. Even though it is a common practice in some parts of the country to use locally available low grade aggregates such as kankar and laterite, the same are not put to the best advantage in other parts of the country. The studies conducted at Central Road Research Institute on laterites available in various parts of the country indicate that the aggregate impact values of most of the samples range from 20 to 50 per cent and hence are suitable for sub-base and base construction[1]. Further studies on other types of low grade aggregates are in progress.

Waterlogging

3.2.2. In recent years in some parts of the country with more and more introduction of irrigation channels running in embankment above the level of the adjoining terrain with insufficient drainage out lets, vast areas have been subjected to waterlogging. It goes without saying that unusual rains in some years still worsen the situation. The continous supply of seepage water from such well netted irrigation channels, insufficient drainage facilities from such grids blocked by either canal bunds, railroads or highway embankments, have become the potential factors for creating waterlogged conditions for most of these areas. The seriousness of this water logging is aggravated by the general practice of constructing highways flush with the adjoining terrain in these areas. Hence building of new highways and maintenance of old pavements in these areas has become a serious problem.

With a view to evolve suitable specifications for construction of highways in such waterlogged areas, essentially the following field experiments have been undertaken by Central Road Research Institute at Palwal, near Delhi.

(1) Bituminous enveloping of road crust by spreading 40 lb of primer for 100 sq ft. on the subgrade and on the sides of the crust with a view to observe its effectiveness in preventing capillary rise of moisture.

(2) Road construction on embankments high enough to minimise the effect of capillary action within safe limits.

(3) Provision of enough thickness of blanket course below the road crust to cut off capillary rise.

(4) Provision of soil cement sub-base with stabilised base and wearing coat including surface dressing.

3.2.3. Salient Points

(1) Suggested devices for arresting the detrimental effects of waterlogging in roads such as:

(1) Enveloping the required thickness of road bed with waterproofing membranes.

(2) Introduction of blanket courses with coarse sand for capillary cut off.

(3) Use of soil cement sub-bases.

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3.3. Soils Roads including Stabilisation

3.3.1. General

With the passing out of this year under review, the country has made some advance in the field of soil stabilisation and construction of stabilised soil roads. In addition to continuing work on evolving suitable methods of stabilising soils, the research activities of different organisations in India have covered other important fields such as (i) Evolving a suitable system of soil classification and (ii) Study of various low-grade road material for highway construction, etc.

These organisations have also extended their laboratory results to the field by laying a number of experimental stretches in many States and the results are expected before long. As a result of recent study[1] made at the Central Road Research Institute, it has been shown how proper compaction of subgrade influences the overall thickness of pavement crust required, thereby resulting in considerable economy.

3.3.2. Soil classification system for Indian conditions

The need for evolving a uniform soil classification system for the whole country as a single system for various engineering projects was being felt since the last so many years as the various laboratories were depending on individual choice and convenience, in choosing one or the other of the systems of classification which are vogue in foreign countries.

Some of the popular systems that are being used in India at present by the different laboratories are (i) P.R.A. system of classification and (ii) Casagrande's classification. The P.R.A. system is being adopted by West Bengal and U.P. Laboratories and the Casagrande's system by the Military Engineering Organisation. With this background, the Central Road Research Institute[2] had conducted a critical study of all the existing systems of soil classification with the object of proposing a single system of soil classification comprehensive for all engineering purposes. Based on this study, keeping in view the behaviour of some of our soils, a further modification in Casagrande's modified system is recommended for use in India.

3.3.3. Mechanical stabilisation

Further lengths of road using soil and soft aggregate have been constructed in the Punjab. To extend this system to other parts of the country, small pilot lengths of road are being constructed by the Central Road Research Institute using local soil and

soft aggregates in different parts of the country. After successful completion of these stretches, it is hoped longer lengths will be constructed in the various States to effect economy in road construction.

3.3.4. Stabilisation of black cotton soil

On the basis of work carried out in the Central Road Research Institute it was reported last year that black cotton soils become friable with the admixture of about 5 per cent lime. In continuation of this, the same institute had constructed small stretches in the field in the predominantly black cotton area near Bhopal with a view to study the success of lime-soil admixture experiments in the field. The experimental stretches were laid with 5 per cent and 10 per cent of lime. Lime-soil mixing was achieved with disc harrows and it was rolled with a steam-roller. Initial tests have given encouraging results and further field lengths are proposed to be tried in Bhopal and in Andhra areas.

3.3.5. Chemical stabilisation

The only item of interest in this branch of stabilisation that has been reported during the current year, is the work carried out by the B. & R. Research Laboratory, Karnal[4], on the suitability of sodium silicate to stabilise sands and sandy soils. This laboratory had reported that in the case of pure sands and non-plastic soils the addition of small quantities of sodium silicate imparts greater strength to the mixture than what could otherwise be achieved with higher quantities of cement. Sodium silicate was also found to impart better resistance to abrasion than what could be achieved by addition of cement.

3.3.6. Bituminous stabilisation

During this year, some of the laboratories worked on finding the suitability of some bituminous products for soil stabilisation in road bases with a view to make the base more water resistant. Based on the laboratory work using some of these products the B. & R. Research laboratory, Karnal[4] had reported that the following binders gave encouraging results :

1. Liquid asphalt No. 2.
2. Cutback made from 80/100 bitumen.
3. Bitumen emulsion with lime.

The same laboratory recommended[4] that if the road after treatment with the above admixture is used for base course or sub-base construction, the rise of capillary moisture can be minimised to a considerable extent. They also reported that an addition of 5 per cent cutback (4 per cent active bitumen) prepared from 80/100 bitumen to the Punjab soils will increase the resistance of the soil to the softening action of water. On the basis of this work, use of 5 per cent of this admixture has been recommended for stabilising and waterproofing the commonly available soils in Punjab for base course construction in waterlogged areas.

Comparative tests on use of bituminous and other products as waterproofing agents in mudplasters have been carried out in the Central Road Research Institute on behalf of the National Building Organisation. This investigation revealed that Janata emulsion (H.R.P), a patent of the Shalimar Tar Co. when used in a concentration of 5 per cent can effectively waterproof ordinary mud plasters.

3.3.7. Cement stabilisation

Cement stabilised wearing courses

Work reported by various laboratories in this branch of soil stabilisation, mainly comprises field trials using soil-cement wearing courses and laboratory work on the suitable test criteria for finding the cement content necessary to stabilise any soil. The Research Institute of the U. P., P. W. D[5]. reported various field experiments using soil cement in wearing course. The wearing course for Beni-Harauni Road was designed with a cement content of 7 per cent by weight. Soil-cement wearing course using 6 and 8 per cent by weight was also laid in some of the approach roads to local Institutes at Lucknow. For a comparative study, the conventional U. P. specification was also used along with the above specifications.

Criteria for cement content

Laboratory work was carried out by the Central Road Research Institute to investigate whether compressive strength can be adopted as the sole criterion for finding the cement requirements of any soil. In the United States of America, specifications have been laid down separately for the behaviour of cement stabilised soil in wetting and drying cycles and freezing and thawing cycles. British specifications have laid down compressive strength values to assess the cement requirement for imparting water resisting quality to the soil mass. Recent research work carried out by the Central Road Research Institute had indicated that for some of the types of soil met with in this country, a cement stabilised soil developing a strength of 150 lb per sq.in. (based on tests on cylinders of 2 in. diameter 4 in. height) can successfully stand the moisture absorption, volumetric shrinkage and the wetting and drying specifications laid down by the States. It had also been found that for making the cement soil mass resistant to freezing and thawing, moisture absorption, shrinkage, etc., the cement content should be such as to impart a compressive strength of 450 lb per sq. in. to the mixture (size of block for compressive strength test being a cylinder of 2 in. dia. and 4 in. height).

3.3.8. Low-grade aggregates in soil stabilisation

Use of locally available lowgrade aggregates in soil stabilisation has received further impetus during this year as revealed by various reports received regarding laying a number of experimental stretches using Mehra's method of stabilisation. The U. P., P. W. D. Research Station[5] reported work on the design of stabilised soil base courses and wearing courses with 40 per cent brick ballast suspended in soil for various road constructions.

A pilot plant project of the Central Road Research Institute was taken up at Gwalior and experimental lengths of stabilised soil road had been constructed using Mehra's specification for base and wearing course with a view to extend the method to many areas in Madhya Pradesh where stone is scarce and brick or other soft aggregates are easily available.

A laboratory investigation[6] conducted by the U.P., Research Station using kankar as an admixture had showed that the addition of kankar to soil increases the maximum dry density of the soil kankar mixture and, for maximum stability, it was recommended that the percentage of kankar aggregate should be between 35 per cent and 40 per cent which is in agreement with the present practice of Mehra's method of stabilisation.

A comprehensive study of all types of common soft aggregates has been taken up by the Central Road Research Institute. The performance of materials like laterites, moorum, kankar, etc., is being investigated by subjecting them to standard aggregate tests. A preliminary examination of the results shows that quite a large majority of these 'so called soft materials' can be economically used in road construction especially for bases and sub-bases.

3.3.9. Testing technique

The Central Road Research Institute had developed a new method[7] for determining liquid limit of soils using a cone with half angle of 15°—30′. It is reported that this device will be more useful in correctly evaluating the plasticity index of soils having liquid limit less than 25 and plasticity index in the region of 4—7, compared to the present standard method of Casagrande which is not quite convenient to use in this range.

3.3.10. Salient Points

(1) Necessity for subgrade compaction in highway construction.

(2) Stabilisation of black cotton soils.

(3) A uniform soil classification system for India.

(4) Use of local low grade aggregates for maximum advantage in road construction.

(5) Compressive strength as a single factor in determining the cement requirement of soil stabilization.

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II. TRAFFIC AND TRAFFIC SAFETY

4. Geometrics, Economics, Statistics and Safety

General

It is encouraging to know that the work in Traffic Engineering is appreciably extended this year as compared to previous years. During the current year, the Central Road Research Institute has carried out some work in this field with the co-operation of various organisations such as Town Planning Organisation, Traffic Police, Indian Institute of Public Administration and Punjab Engineering College, Chandigarh.

4.1. Geometrics

4.1.1. Geometric design of roads

For a long time to come our roads will have to be carrying mixed type of slow and fast traffic. Keeping that in view, a study has been made at the Central Road Research Institute for rural highways, regarding the sight distance requirement, pavement and shoulder width requirements and safe speed for night travelling.

As a result of the study, a minimum of 500 feet for sight distance is recommended on curves on rural highways. Where the available sight distance is less than 500 feet, an extra width of six feet is indicated to be paved without superelevation but with very little slope for drainage only on either side of the roadway for the length for which 500 feet sight distance is not available. This is to facilitate the bullock carts or any other slow type of traffic to keep the main roadway clear in the portion of restricted visibility as such traffic prefers a flat surface to a sloping one.

Roadway and shoulder width requirements have been studied. In areas where single lane is not sufficient and it is not economically feasible to have two paved lanes, stage construction of highways is recommended with 15 feet width of paved roadway, and five feet and six inches of well-compacted stabilised shoulder and eight feet of soil shoulder on either side to serve mixed type of traffic reasonably well.

From visibility point of view on rural highways with mixed traffic, maximum safe speed is recommended as 35 miles for night travelling in dry weather and 30 miles per hour in wet weather. Maximum safe speed for night travel can, however, be raised to 50 miles per hour if every bullock cart and other slow moving traffic units on the highway are carrying light (lantern) with them and subject to the provision that other physical features of the highway permit that speed.

For urban areas work has been carried out on some geometric design aspects for cycle tracks. As a result of the study, different lengths have been recommended for different grades keeping in view the maximum temperature of a particular region. With a maximum temperature of 106 degrees fahrenheit to 110 degrees fahrenheit, the length of 5 per cent grade should be restricted to 70 feet for cycle tracks and for 3 per cent grade length should be restricted to 770 feet. Width of each lane is recommended as three feet and six inches with a minimum of two lanes for either direction.

4.1.2. Bullock cart effect on motor vehicle flow

Study has been carried out by the Central Road Research Institute to judge the effect of bullock cart traffic on motor-vehicle traffic flow on two lane highways from the point of view of safety. The study points out that when there are more than four bullock carts in either direction on a two lane highway they should not travel in singles but in caravans. The number of bullock carts per caravan should be directly proportional to the total number of bullock carts on the highway. From practical point of view, keeping in view geometric design standards of rural highway, it has been recommended that bullock carts should travel in caravans with six bullock carts in each. However, in urban areas, bullock carts should travel in singles.

4.1.3. Origin destination survey

The Central Road Research Institute and the Town Planning Organisation, Delhi, have jointly conducted 'Origin and Destination Traffic Survey of Delhi'. The survey was conducted by roadside interview method at 33 different stations on important roads. Roadside interview included five questions e.g., (i) points of origin and destination, (ii) purpose of the trip, (iii) frequency of the trip, (iv) occupation and (v) income of the person interviewed. Five per cent sampling for cycles and 10 per cent sampling for other categories of traffic was used.

The survey data is being analysed. This survey will help in locating new and more direct roads to pass through the city or bypass it. This way it is hoped congestion will be relieved in many areas of the city. The survey will further help in planning facilities for different types of traffic in relation to different income group residential colonies and other neighbourhood units.

4.1.4. Roadway capacity study

Work is being carried out by the Central Road Research Institute on roadway capacity study under mixed slow and fast traffic conditions. Study was made by 'test run' method to find the relationship between speed and traffic volumes. Analysis of the data has shown that there is a direct relation between the speed and the traffic volumes.

Further work is being carried out to find the optimum volumes of mixed slow and fast traffic that a particular road may be able to accommodate per hour. Work is also being done to find the maximum volumes of different types of traffic when segregation becomes essential specially in urban areas keeping in view safety, efficiency and economy.

Because of the mixed type of slow and fast traffic in India, roadway capacity study is complicated.

4.1.5. Public transport study

Study of public transport system of Delhi is being carried out by the Public Transport Study Group under the auspices of the Indian Institute of Public Administration, New Delhi. The object of this study is to suggest improvements in the existing transport system from the points of view of both public and administration. Technical aspects of the problem are also being given due consideration. The study report is expected to be ready by June 1958.

4.2. Economics

4.2.1. Economics of different types of highways

A study has been undertaken in the Central Road Research Institute to compare the economics of different types of highways. The first stage of the work attempts to compare various thicknesses of water-bound macadam and stabilised soil road.

4.3. Statistics and safety

4.3.1. Use of sampling techniques in road traffic counts

Detailed traffic data are necessary to an intelligent solution of many highway problems. Measuring the total traffic on any given section of a highway with exact certainty would require 24 hours counts on each day of the year. This will, however, involve huge expenditure.

The purpose of this study, being carried out by the Central Road Research Institute, is to develop sampling procedures for estimating annual and average daily traffic. A rigorous sampling design based on the theory of stratified random sampling, with some modifications to suit the study, has been evolved to estimate the average daily traffic in urban areas by counting traffic only for 10 per cent sample size in a year. Traffic counts which started in April 1957 are now in progress and counting work has been completed for the first two strata.

An attempt is also being made to use the data of this study to evolve a method for estimating daily traffic from extremely short counts.

4.3.2. Road users behaviour study

Pedestrian behaviour survey was made by the Central Road Research Institute at a busy urban intersection and it was found that over 64 per cent of pedestrians were jay-walkers. These, jay-walkers, not only reduced the efficiency of the intersection but also were a great traffic hazard. Railing barrier was installed alongside the kerb on all sides of the intersection and location of crosswaks was changed. This showed improvement by reducing the number of jay-walkers to 19 per cent. Study on the behaviour of cyclists, bullock cart operators and motor-vehicle drivers is also being carried out. The behaviour is studied from engineering, education and enforcement points of view.

4.3.3. Scientific investigation of road accidents

Scientific analysis and recording of road accidents is being started by the C.R.R.I. with the help of traffic police in Delhi. The purpose of scientific investigation of road accidents will be to find out mainly (i) the actual cause of an accident, (ii) the type of vehicles involved (iii) age group, income group, sex, education level of persons involved, (iv) possible factors both physical and psychological contributing to an accident occurrence, (v) effect of different intensities and types of road lighting on accidents, (vi) the types of accidents, their relative frequency and severity, (vii) location of accidents, and (viii) number and cost of accidents.

This investigation will help to find preventive measures.

4.3.4. Use of plastic markers

Possibility of the use of plastic markers under mixed type of traffic as prevailing in urban areas of India is being studied by the C.R.R.I. Plastic markers have been tested on the test track (C.R.R.I.) by passing different types of traffic over them. Results have been encouraging and now it is intended to fix these markers in the field on a busy intersection of Delhi to study their durability and economics as compared to other methods of marking.

4.3.5. Reaction time study of drivers

Reaction time study of drivers of different types of motor-vehicles is being made by the C.R.R.I. with a view to compare the same with the data collected in Western countries. Reaction time study is necessary for proper design of geometric features of roads.

4.3.6. A technique to assess the riding quality of road surfaces

The unevenness of road surfaces has been studied using the Bump-Integrator by the Central Road Research Institute with the co-operation of Punjab Engineering College, Chandigarh.

With the improved techniques being evolved from time to time for having better highways, the study of road unevenness is important from the following aspects :

(i) To assess the quality of construction ;

(ii) To fix acceptable standards of unevenness for renewal of old surfaces ;

(iii) To create healthy competition in the construction industry for producing more and more even and better surfaces ;

(iv) To promote good public relations because they judge the acceptability of a road surface largely in terms of its riding qualities.

The Bump-Integrator originally designed by the Bureau of Public Roads and modified by the Road Research Laboratory, England, has been used in the study. This machine indicates the total unevenness in inches for the length of the highway covered by it. The unevenness index is expressed in terms of inches per mile.

Based on the limited work carried out so far in this study, tentative pavement unevenness indices are proposed for the highway surfaces which are usually classified as good, fair, poor and bad.

4.3.7. Salient Points

(a) Studying the effect of the presence of slow traffic on roads on the sight distances particularly at night.

(b) Observation of scientific principles in the geometric designs of cycle tracks with a view to attract more and more cyclists to the cycle track and to increase the traffic capacity of the adjoining streets.

(c) Advisability of introducing the devices for measuring the unevenness of road surfaces particularly with a view to create competitive spirit in construction industry for producing more and more even surfaces.

(d) Scientific investigation and recording of road accidents is important with a view to find preventive measures from engineering education and enforcement points of view. Because of the mixed type of slow and fast traffic, accident problem needs special attention to assess the effect of mixed nature of traffic on accidents.

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