Failure of Highway Fill and Investigation into Its Causes

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SYNOPSIS A section of a highway carrying heavy traffic was located on fill of height ranging from 2-3m. The total thickness of the pavement was of the order of 550mm and consisted of bituminous surfacing, granular base and sub base. Although the expected life of the pavement was ten years, severe distress including transverse deformations and cracking of the pavement was experienced within one year after traffic started plying on this section. However, the adjoining stretch, built at the same time, continued to perform satisfactorily. A study consisting of comprehensive testing program was taken up to establish the causes of distress. Particular attention was paid to the properties of fill material. It was found that failure of the pavement was due to the poor quality of the fill material used for construction of the embankment. Some of the peculiar properties of these fill materials are discussed in this paper.

INTRODUCTION

A number of major highways radiate out of Bombay Metropolitan area which is a hub of industrial activity. These highways carry traffic of high intensity and a high level of performance is expected from the pavements of these highways. One such highway was opened to traffic for the first time in July 1982 and included approach embankments leading to the bridge across a creek. During the following three monsoon nonths, the pavement experienced sever distress, which manifested itself in the shape of longitudinal, as well as transverse deformations and formation of pot holes. Remedial measures such as leveling of undulations and filling of the pot holes were adopted to maintain the road surface. Additional pavement thickness was also provided but the pavement continued to experience sever distress. Detailed investigations comprising of field as well as laboratory studies were carried out to understand the causes of the poor performance of the pavement. During the course of the study, it transpired that the fill material had peculier properties, which eventually resulted in the failure. Properties of the fill materials were evaluated.

DESCRIPTION OF THE PROBLEM

The general topography of the area under investigation has two distinguishing features.

i) Relatively flat terrain criss crossed by a number of creeks and

ii) Large number of hillocks of low heights, widely scattered through out the area. These hillocks generally serve as the source of construction material for the highways.

A section of the highway crosses a creek for which approach embankments have been built. Over most of the length involved, the height of the approach embankments where earth fill was involved, is of the order of 2-3m. Due to flow of backwater, as well as accumulation of water during the monsoon season, standing water of 1.0 to 1.5m height is present for about 8-9 months in a year, along the slopes of the embankment.

The subsoil consists of shallow soft marine clay layer of 2-3m thickness underlain either by sand or sand clay mixture. The properties of the soft marine clay are given in Table I.

TABLE - I. Engineering Properties of Subsoil

Depth of soft clay layer	2-6m
γ_s	1.60 t/m3
Natural moisture content	50%
Liquid Limit	70%
Plasticity Index	38
Initial void ratio e_o	1.2
Co-eff.of consolidation Cv	0.94×10^{-4} cm^2/s
Compression Index Cc	0.75

Placement of fill started in march 1978. Stage construction, consisting of four stages at the site where the height of fill was about 12m was adopted. Full height of the embankment was attained in December 1980. The area was instrumented to monitor the settlements and performance of the embankment. Periodic observations were made and the data was analysed. Time versus settlement curve is shown in Fig.1. Upto October 1982, settlement of the order of 80cm was observed near the bridge approach where the height of embankment was about 12m. The rate of settlements due to consolidation was found to be low enough at this time leading to the assumption that distress in the pavement is unlikely to occur on this account.

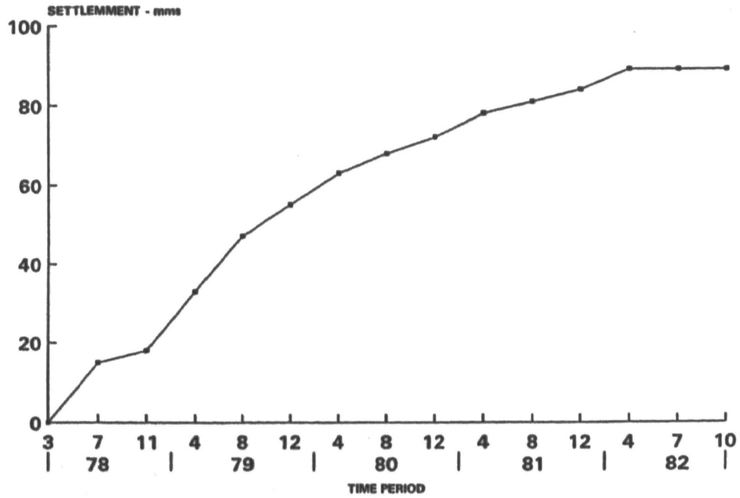

Fig.1 TIME VERSUS SETTLEMENT CURVE

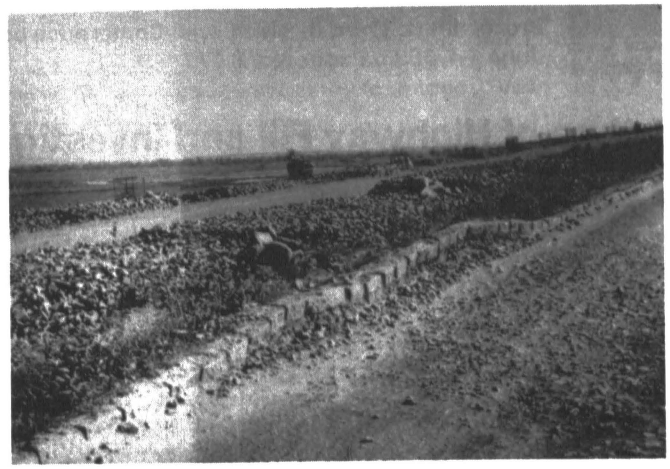

Fig.2 Typical transverse deformation

Construction of approach embankments in the stretch was completed in 1980-81. Subsequently the pavement was built. A total design thickness of 550mm was proposed. In the first stage, a pavement of 425mm thickness was built. This consisted of 150mm layer of graded quarry spells, 150mm thick WBM, 75mm layer of built up spray grout and 50mm full grout layer. Subsequently 50mm bituminious macadam and 40mm asphaltic concrete layers were added to the pavement.

The stretch was opened to traffic in july 1982 and during the following three monsoon months, the pavement, especially the stretch over the approaches to the creek, experienced severe distress, which manifested itself in the shape of both longitudinal and transverse deformations, as well as formation of pot holes. Transverse deformations, longitudinal deformations and rutting had occurred where fill was upto 3m in height and the standing water was so high that little or no freeboard relative to the base of the pavement was available. A typical transverse deformation is shown in Fig. 2. Patch work on the damaged pavement can also be seen. Remedial measures such as filling of pot holes were adopted to maintain the road surface. Additional crust thickness was also provided. But the pavement continued to experience severe distress. Such an early failure of the pavement necessitated that the cause of such distress be identified. In this instance, the causes of the failure were not associated with the pavement thickness and thus detailed investigations were carried out to study the properties of fill material and the subsoil to find out the possible causes of distress. These investigations were essentially in the nature of getting first hand data regarding the fill material used, field densities achieved and the soaked CBR values of the subgrade.

PROPERTIES OF FILL MATERIAL FROM THE DISTRESSED STRETCH

In order to evaluate the role of fill materials in the problem, a number of samples were taken from fill, at different depths on the distressed stretch. These were tested in the laboratory to evaluate their engineering properties. Table II represents summary of these evaluations.

TABLE II. Properties of the Fill Materials

Pit No	Insitu Dry Density t/m3		moisture percent	OMC	Proctor density t/m3	Wl	Ip
	just below the pav.	one mtr below the pav.	just below the pav.				
1	1.45	1.20	27	33	1.39	59	14
2	1.35	1.34	33	26	1.45		
3	1.47	1.48	30	31	1.45	54	14
4	1.50	1.25	25	32	1.45		
5	1.35	1.25	33	32	1.40	58	14
6	1.46	1.21	31	33	1.41		
7	1.45	1.26	30	24	1.54	55	20

During the course of investigations it was found that the materials had low plasticity index and may be grouped under the category MH on the A-line chart ie. inorganic silts or silty clays of medium to high compressibility. Compacted standard Proctor density was found to be very low. On the other hand, insitu density of the fill was even lower at most of the locations as may be seen from table II. The optimum moisture content was also high and near the plastic limit of the soils. The soils were found to be non swelling and "inactive to normal" on the basis of Skempton's definition of "Activity". The fill materials fall in the category of inorganic silts of high to medium plasticity and compressibility and such soils are normally considered to be unsuitable as fill materials. The prevalent recommended practice for construction of fills for highways requires that:

(a) Soils with a maximum Proctor density less than 1.44 t/m3 are unsuitable for fills of 3m or less in height, and not subject to excessive flooding.

(b) In the case of fills exceeding 3m in height and fills of any height subject to prolonged flooding, the fill soils should have a minimum density of 1.55 t/m3.

(c) Soils with maximum dry density less than 1.65 t/m3 are not considered suitable for use in top 500 mm soil layer immediately below the pavement crust.

The fill materials used fail to satisfy the prevalent norms for such materials as well as the densities required to be achieved. The distress experienced by the pavement can thus be attributed to the poor quality of the fill material as well as the low densities recorded.

PROPERTIES OF FILL MATERIALS FROM DIFFERENT QUARRIES

A number of highway projects were planned to be taken up in the peripheral area of Bombay, and it become clear that failures due to improper fill materials have the potential to cause substantial economic losses. Within 15-20 kms. of Metropolitan Bombay region, hillocks of low height dot the area. These hillocks generally serve as the source of construction material. Yellowish brown soil of granular texture, locally called "moorum" it excavated from a number of a quarries in these hillocks and used as fill material for highway fills. These are tropical residual soils derived from weathering of traps. As a result of failures of a number of embankments in the area due to use of improper fill materials, it was considered necessary to delineate satisfactory and unsatisfactory fill materials so as to provide guidance to the construction agencies. With this objective in mind, multiple samples of fill materials were taken from each source and a number of such sources were studied. On the basis of compaction characteristics, it was found that these materials can be devided in three groups designated as A, B, C respectively which are described below:

Group A

The maximum density as per standard Proctor compaction was high for this group of samples, and ranged from 1.8 to 1.9 t/m3. These materials were well graded, non-plastic or had a low plasticity index. Experience has shown that these are suitable as fills. In the present instance, pavements in the stretches located on such fill materials were performing satisfactorily. Typical compaction characteristics of satisfactory fill materials are shown in Fig.3.

Group B

The materials under this group were found to have standard Proctor density in the range of 1.45 to 1.65 t/m3 and higher plasticity index compared to materials under group A. Materials under this group having Proctor density greater than 1.52 t/m3 may be used as fills in the case of non availability of materials of group A.

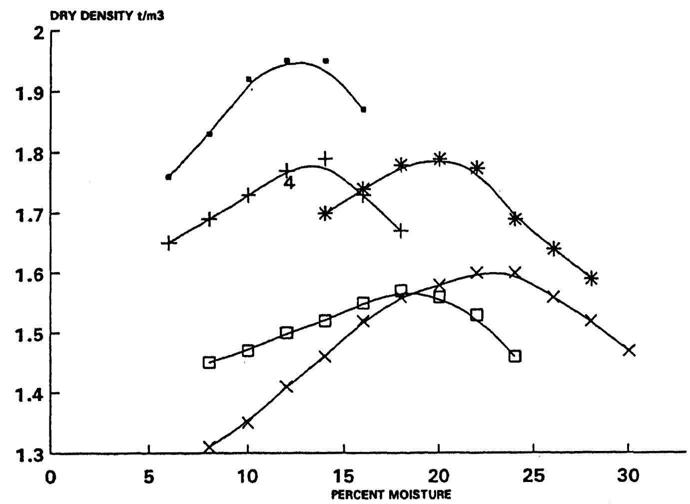

FIG.3 TYPICAL COMPACTION CHARACTERISTICS (MATERIALS SATISFACTORY AS FILL)

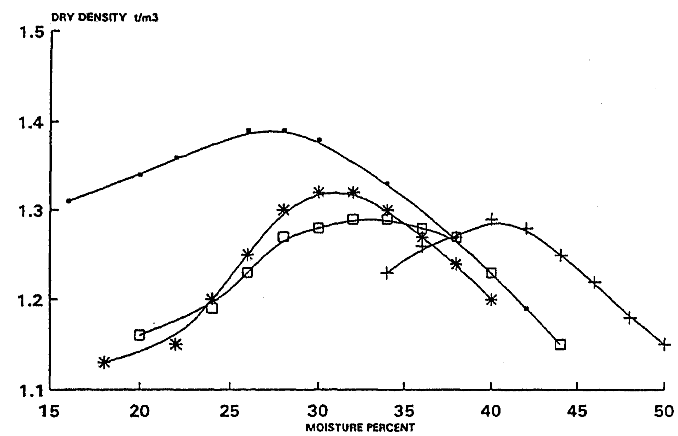

FIG. 4. COMPACTION CHARACTERISTICS (MATERIALS UNSATISFACTORY AS FILL)

Group C

The materials under this group represent fill materials having distinctly dissimilar properties to those from group A and group B. Typical compaction characteristics are shown in Fig. 4. It was found that all the materials in this group may be classified as inorganic silts or silty clays of medium to high compressibility i.e. ML to MH groups fig.5. These soils were found to be of non swelling nature and may be termed as inactive to normal, on the basis of Skempton's activity ratio. Standard Proctor density of these materials was found to be very low, of the order of 1.3 t/m3 only. Optimum moisture content ranged from 30% to 40% which is in the range of plastic limit of these soils. In the case study described earlier, major portion of the embankment on which the pavement was placed, was found to have been made up of materials of similar characteristics. In this embankment, it was

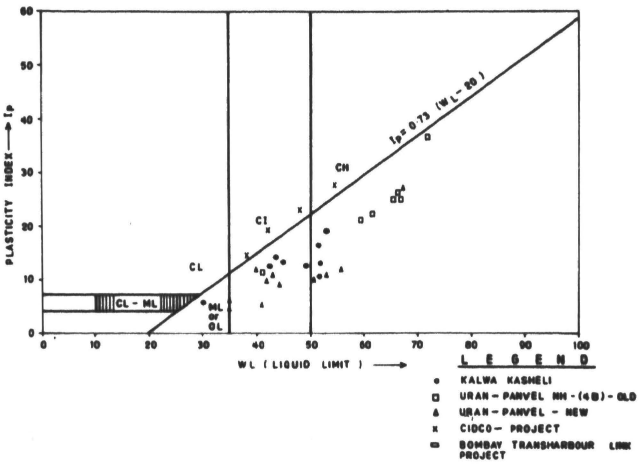

Fig.5 Properties of fill materials

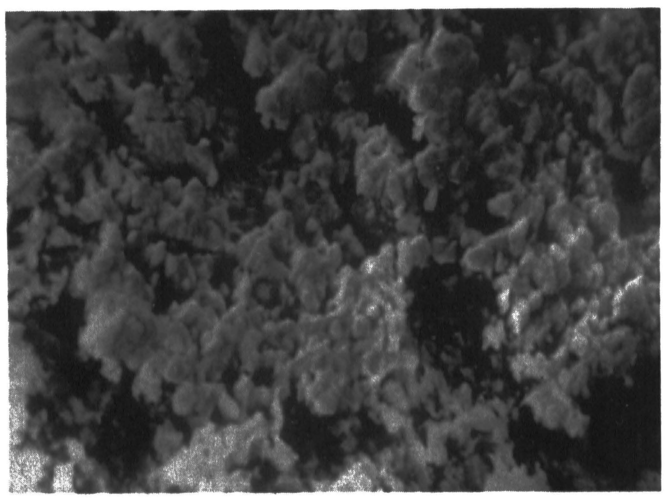

Fig.6 Limited Scanning Electron Micrograph of clay particles

found that even in the relatively dry season, insitu moisture content was high. Limited Scanning Electron Microscope (SEM) studies were carried out which indicated the likely presence of Allophane in the materials of this group. Fig.6 shows SEM of the clay particles magnified 10,000 times. Fill materials have low Ip combined with relatively high Wl and Wp. There is predominance of silt size particles in the soils. The materials are having low compacted density with high OMC. These materials were also found to retain significantly high water contents. Comparison of the properties of these materials with the properties of soils from other parts of the world show that these soil properties fit in very well with those of tropical residual soils derived from weathering of volcanic material, such as those found in Java (Wesley, 1973)

While the materials from Group A,B,C had widely differing compaction characteristics, the soils did not differ appreciably in simple identifying characteristics such as color and textural feel. It appears, that inadequate testing, coupled with lack of easily differentiable characteristics has resulted in the use of potentially unsatisfactory materials in the fill, eventually leading to the failure of the pavement.

CONCLUSION

The investigation clearly established that the failure of the pavement has resulted from the use of poor quality fill. The study has indicated that large variations exist in the properties of the fill materials used near approaches though these were obtained from sources not very distant from each other and these materials lack simple and easily distinguishable characteristics. These observations are indicative of the erratic distribution and variable nature of local soil formation. This case history of failure brings out the need for a frequent and careful check on the properties of the fill materials from the quarries. Soils having close resemblance to Allophanes were not reported earlier in India and this is the first known instance. The lack of such earlier experience is also a contributing cause for the local field staff to have overlooked the possibility of such materials being encountered.

ACKNOWLEDGEMENTS

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