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THE USE OF FASCINES TO REINFORCE FILL EMBANKMENT ON VERY SOFT CLAY

By

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PREFACE

Construction of roads on soft clay is unavoidable in Thailand since there is a large area in central part of the country which is covered with alluvial deposit. Soft and very soft parts of the deposit are those areas closer to the gulf of Thailand, where big cities are located and higher amount of roads are needed for transportation both within and between the cities. Problems of constructing roads on such a soft foundation which engineers are facing at the present time concern mainly with very high expense rate that comes from high construction cost and maintenance cost. Highly accurate works are needed in investigating, designing, and constructing the roads. Large settlement or even failures occur during and after construction. Depreciation rate of the roads is very high. Design life of the roads is much shorter than the roads on firm foundation. A lot more investigations are needed to set up criteria in design, construction and maintenance.

It is a purpose of the Department of Highways to encourage more research in this field such that only minimum expense will be spent.

Chaleo Vajrabukka

(Chaleo Vajrabukka)

Director - General

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ON VERY SOFT CLAY

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SYNOPSIS

The use of fascines to reinforce the embankment on very soft clay was performed on a section of Tae Pa - Pak Nam Road in the southern part of Thailand. The results show that the height of fill embankment is up to about 3 meters without showing any sign of failure. The settlement is rather high at the first stage after completion of filling, but its rate is reduced with time. The embankment is now floating on this soft soil to serve the traffic as a feeder road.

1. INTRODUCTION

One of the major problems encountered in the construction of roads in Thailand is the very soft foundation soils that cannot support the weight of an embankment to the required height. When a road must be built on this type of soil, such methods as berms and relief piles are designed. The use of plaited wooden sticks, working as reinforcement, called fascines, is one of method to solve this problem. The fascines are placed on the original ground surface before the embankment materials are placed in position.

The use of fascines was tried at km. 2 + 480 of the Tae Pa - Pak Nam Road in the southern part of Thailand where foundation soil is very soft. Before deciding to use fascines, during the filling of the sand embankment, more than 1,500 cubic meters of sand sub-merged into the soft soil. The fascines, made of wooden sticks that could be found around the area, were designed and constructed to support the weight of the embankment up to 3 meters. When the construction is completed the road will serve as a feeder road under light to medium traffic volume.

2. SITE CONDITIONS

A new road from Tae Pa to Pak Nam in the southern part of Thailand was constructed by the Highway Department Mechanical Equipment Training Center at Song Khla. The route starts from km. 0 + 000 at Tae Pa and ends at Pak Nam, km 6 + 550, see Fig.1 The horizontal alignment of the road is almost parallel to Khlong Tae Pa which is a channel flowing to the sea. Generally, sub-soils of the area are silty sand and fine sand. They were used as a subgrade layer of the embankments.

However, it was found that at km. 2 + 480 the subsoil is very soft. This soft soil area is a type of natural deposit formerly occupied by a shallow lagoon. The area on the southern side of the road, as shown in Fig.2(a), is a relief area and a drainage area. The silt and clay intermingled with some decayed organic constituents were brought into the lagoon in suspension by water. With decreasing velocity of the water transporting the particles, the coarser particles, or sand were deposited first, then silt and clay. Because the surface of the deposit has never before carried an overburden, the subsoil is unlikely to be able to sustain the weight of fill more than a few feet in height.

From Fig.2(b), it can be seen that depth of the soft soil layer is down to about 10 meters below the original ground surface. Results from vane shear tests of this soft soil layer showed that the undrained shear strengths are approximately 0-2 t/m^2 and sensitivity is up to 15. Below this soft layer, the soil is medium to stiff clay whose unconfined compressive strengths vary from 3 to 23 $t/m^2$and increases linearly with depth. Silty sand and fine sand were found at a depth of greater than 18 meters.

3. THEORETICAL CONSIDERATIONS

The theoretical considerations of the design of fascines on the base of embankment is based upon the stress distribution caused by the weight of embankment, see Fig. 3(a). The settlement (S) of the embankment causes arching of the granular embankment material. This effect reduces the vertical pressure in the middle of the embankment and increases the pressure at the toes. A horizontal shearing stress is also formed at the base of the embankment and acts outwards towards the toes.

A solution for the stress distribution at the base of an embankment has been proposed by DAVIS and TAYLOR (1962). This solution is based on plastic conditions of a purely frictional material in two zones of the embankment. It is not sensitive to changes in ϕ', the angle of shearing resistance of the embankment material, and generalized values for the distribution of the shear and normal stresses at the base of the embankment have been obtained from this analysis. These values which are in terms of the height and the top width of the embankment are shown in Fig. 3(b) and 3(c).

4. DESIGN CONSIDERATIONS

The wooden sticks used as fascines were cut from the mangroves that are found in the region of the test section. The wooden sticks are about 1-2 meters long and 3-5 centimeters in diameter. These wooden sticks were connected to make a long rod by overlapping 40 centimeters at the ends and the overlap part was tied up by rattan. Test results showed that the average maximum tension force of two connected wooden sticks was 2.8 tons when failure occurred at the connection. In construction, the original ground surface was levelled by a 20 centimeter layer of sand before the rods, with at least their length equals to the width of the embankment base, were placed perpendicular to the longitudinal center line of the road. The stress in the rods is computed by using the stress distribution at the base of the embankment from Fig. 3 due to the surface shear, taking this to be the tension in the rods, while flexural stress induced by the normal pressure is not considered here. Each rod is assumed to be flexible enough so that it will not be broken by the flexural stress. In order to fasten these rods to form a layer of fascines, it is necessary to place the wooden sticks in a longitudinal direction with a spacing of about one meter.

According to the stress distribution at the base of the embankment in Fig. 3 and using the following values for the variables: Density of embankment material, = 1.8 t/m^3, top width of embankment, W = 10 meters, average maximum tension force of rod = 2.8 tons (from test), if rods of about 4 centimeters in diameter are placed 4 centimeters apart as shown in Fig. 4, the fascines should be designed to resist all the shear stress occurring at the embankment base since the subsoil is very soft. A strip of 8 centimeters width covering the whole length of one rod then induces the tension force due to shear stress in one rod.

From Fig. 3 (a) and (c),

L = width of embankment base,
H = embankment height above the fascines,

$$\therefore \frac{L}{2} = 1.73H + \frac{W}{2}$$

$$= 1.73H + 5 \qquad (1)$$

The average normalized shear stress along AB,

$$\frac{xz_1}{H} = \frac{0.33}{2}$$

$$xz_1 = 0.297H \qquad (2)$$

The average normalized shear stress along BC,

$$\frac{xz_2}{H} = (0.332 - 0.0226\,\frac{W}{H}) + \frac{0.33 - (0.332 - 0.0226\,\frac{W}{H})}{2}$$

$$xz_2 = 0.596H - 0.203 \qquad (3)$$

The average normalized shear stress along CD,

$$\frac{xz_3}{H} = \frac{0.332 - 0.0226\,\frac{W}{H}}{2}$$

$$xz_3 = 0.299H - 0.203 \qquad (4)$$

Let the total shear force that acts outwards from the centerline to the left half of road on the base of 8 centimeter wide strip be T which is resisted by one rod, thus

$$T = 0.08\,(xz_1 \cdot AB + xz_2 \cdot BC + xz_3 \cdot CD) \qquad (5)$$

Let H_c = maximum or critical height of embankment above the fascines, below which failure of the rod by tension force does not occur.

Assume $H = H = 6$ m.

$$\therefore \frac{L}{2} = 15.38 \text{ m.} \qquad \text{Eq. (1)}$$

$$AB = 7.92 \text{ m.},\quad BC = 5.28 \text{ m.},\quad CD = 2.18 \text{ m.}$$

$$xz_1 = 1.78 \ t/m^2 \qquad \text{Eq. (2)}$$

$$xz_2 = 3.37 \ t/m^2 \qquad \text{Eq. (3)}$$

$$xz_3 = 1.59 \ t/m^2 \qquad \text{Eq. (4)}$$

Substitute the above values in Eq. (5):

$$T = 2.83 \text{ tons} \sim 2.8 \text{ tons},$$

the average maximum tension force of rod.

Whence $H_c = 6$ m.

The following step is to check the frictional force between the skin of the rods and the surrounding soil. From Fig. 3 (b), the average normalized vertical stress along AB,

$$\frac{z_1}{H_c} = \frac{0.95}{2} \times 1.8$$

$$z_1 = 5.13 \ t/m^2$$

The average normalized vettical stress along BC,

$$\frac{z_2}{H_c} = 0.95 + \frac{(1 - 0.95)}{2}$$

$$z_2 = 10.50 \quad t/m^2$$

The average normalized vertical stress along CD,

$$\frac{z_3}{1.8 H_c} = (0.191 - 0.0128 \frac{W}{H_c})$$

$$+ \frac{1-(0.191 - 0.0128 \frac{W}{H_c})}{2}$$

$$z_3 = 6.32 \quad t/m^2$$

The skin friction of each rod, P_f, can be computed by the following equation:

$$P_f = \pi Dl (z f)$$

where D = average diameter of rod = 4 cm.,

l = length of rod

f = coefficient of friction

(from pile foundation design, the recommended value of f = 0.33 is used for rough surfaces such as cast-in-place, timber or concrete piles). The summation of friction force for one half of a rod can be computed as follows:

$$P_f = \pi \times 0.04 \times 0.33 (z_1 . AB + z_2 . BC + z_3 . CD)$$

$$= 4.55 \text{ tons}$$

Which is greater than 2.8 tons, the maximum tension force carried by one rod.

Since the flexural stress is not considered in the design, the embankment is expected to settle into a saddle shape. Sagging down at the center of the embankment causes a problem of surface drainage that will inturn weaken the pavement. To reduce the magnitude of the sag, surcharge at both sides is recommended to be applied before construction of the embankment.

5. THE TEST EMBANKMENT

The construction of the test fill took place in 1972, during March, which is in the dry season of Thailand. During the construction period the original ground surface was still covered by water.

Fill material used in the test section is fine sand of rather uniform gradation. The fill was placed in layers and the average density, γ , was about 1.8 t/m^3.

The connection of wooden sticks in the fascines is shown in Fig. 5. The first layer of the fascines was placed on the sand layer of about 20 centimeters thick. Its level, then, was about at the Mean Sea Level. The size of the first layer of the fascines is 60 meters by 30 meters as shown in Fig. 6(a). It can be seen that the width of the fascines layer was about 30 meters wider than that of the base of the embankment. The reason for this is that the subsoil is very soft which would cause a large settlement by the weight of embankment. Extending the width of fascines layer and placing the surcharge load at both sides of embankment to form side berms, increases the radius of curvature of the deflected fascines layer during settlement. This reduces the flexural stress occurring at the fascines.

After 7 days filling, the embankment had reached an elevation of approximetely one meter above the original ground surface, when cracks of 3-5 centimeters wide occurred at about 10 meters from the center line to the left side of the road,(see Fig. 6(a)) and the differential settlement along the cracks was about 20 centimeters. In order to find the behavior of fascines underneath, digging along the cracks was performed and it was found that the overlapped ends of the wooden sticks were completely separated. According to the vane shear strengths of B_4 in Fig.6(b), it can be seen that the subsoil at the area of cracks is softer and the soft layer is deeper than at the right side of road. This would cause the differential settlement, and the flexural stress that occurred at the fascines would be so high that they failed. It was therefore decided to place a second layer of fascines, with a width and length of 25 and 23 meters respectively, on the sand to cover all the cracks, as shown in Fig.6(a) and 7. After this filling of sand proceeded until the required level was reached. Lateritic soil was then, placed to serve as a temporary surface of the road and reach the height of about 3 meters above origina ground surface.

After 10 months of carrying a light volume of traffic, the embankment was bored, in the month of January, 1973, to find the elevation of both the layers of fascines. According to the plan in Fig.6(a), the cross - sections along A - A, B - B and C - C were taken as shown in Fig.8, and the settlement of the embankment was observed to be about one meter without showing any cracks. In order to keep the embankment height to 3 meters above original ground surface, more fill material was put on the road. After completion filling, the embankment height above the fascines was about 5 meters which is less than the critical height of embankment as calculated.

6. CONCLUSIONS

Due to the non-uniformity of subsoil at the test section, the large differential settlement that occurred, produced a high flexural stress at the layer of fascines. The design of fascines based on uniform subsoil is only a guide. In order to check the design of the fascines for a large construction, a test section will be needed. It is inevitable for settlement to occur during and after filling the embankment on the fascines. This settlement can be divided into two parts as follows:

1. The settlement due to flow of the subsoil

This settlement occurs during and shortly after completion of filling. Some soft soil heaves up at the edges of the fascines. Settlement of this type reduces with time until it stops and the embankment floats on the soft soil with the weight of embankment in equilibrium with the subsoil reactions.

2. The settlement due to consolidation of subsoil

As time goes by, the embankment still undergoes settlement of this type because of the compression that takes place in the subsoil. Nevertheless, the amount of settlement within a certain period of time is not as large as the settlement due to flow of the subsoil.

7. ACKNOWLEDGEMENT

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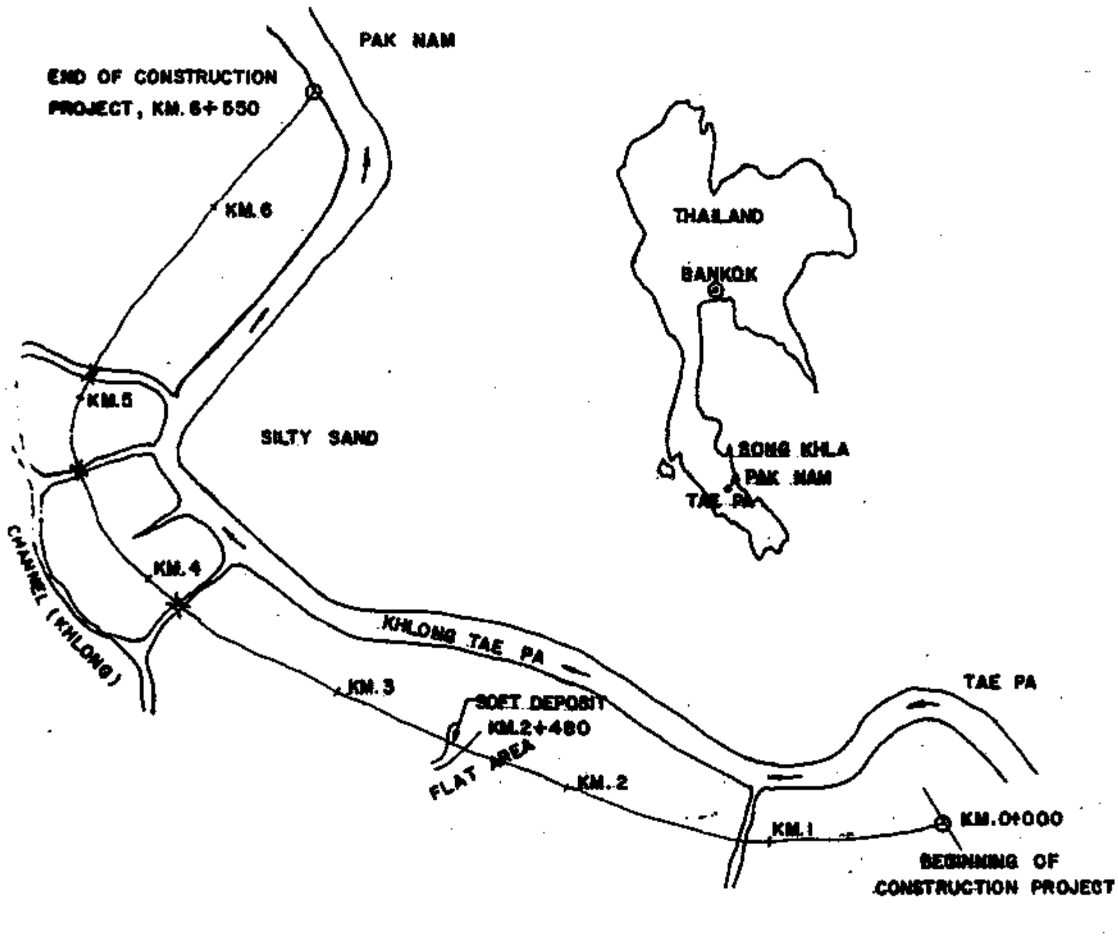

Fig. I Location of Tae Pa - Pak Nam Road

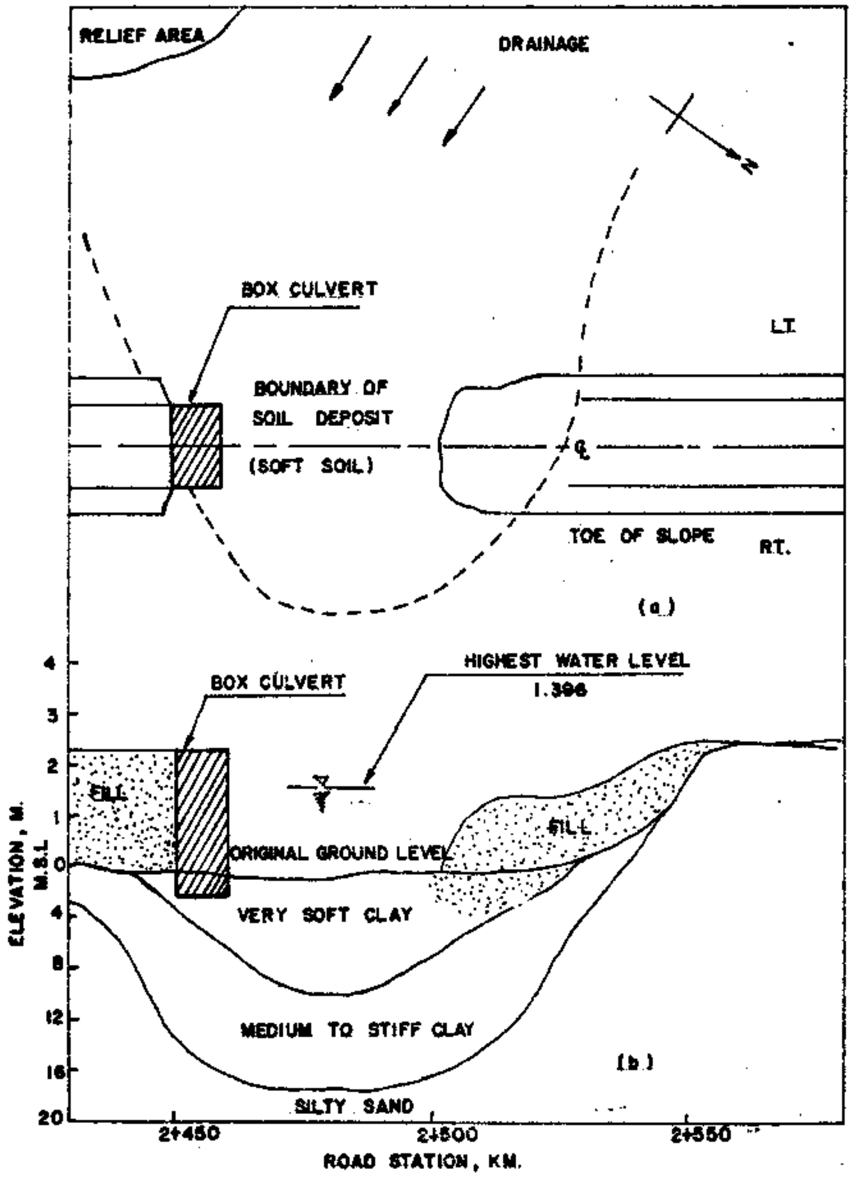

Fig. 2 Plan and Profile along Center Line of Road at Test Area.

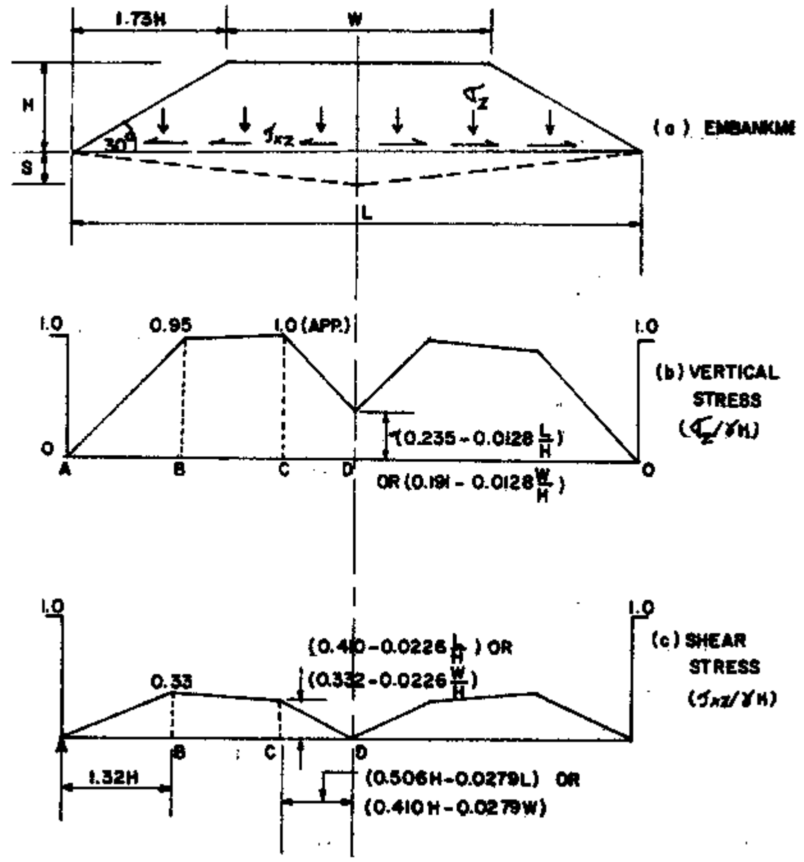

Fig. 3 Stress Distribution at Base of Embankment.

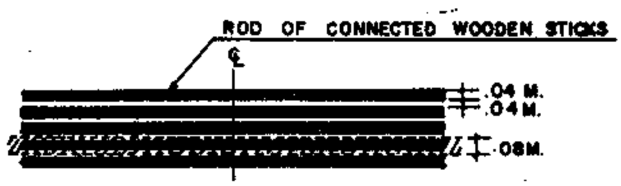

Fig. 4 Plan of Fascines on Embankment Base

Fig. 5 Fascines

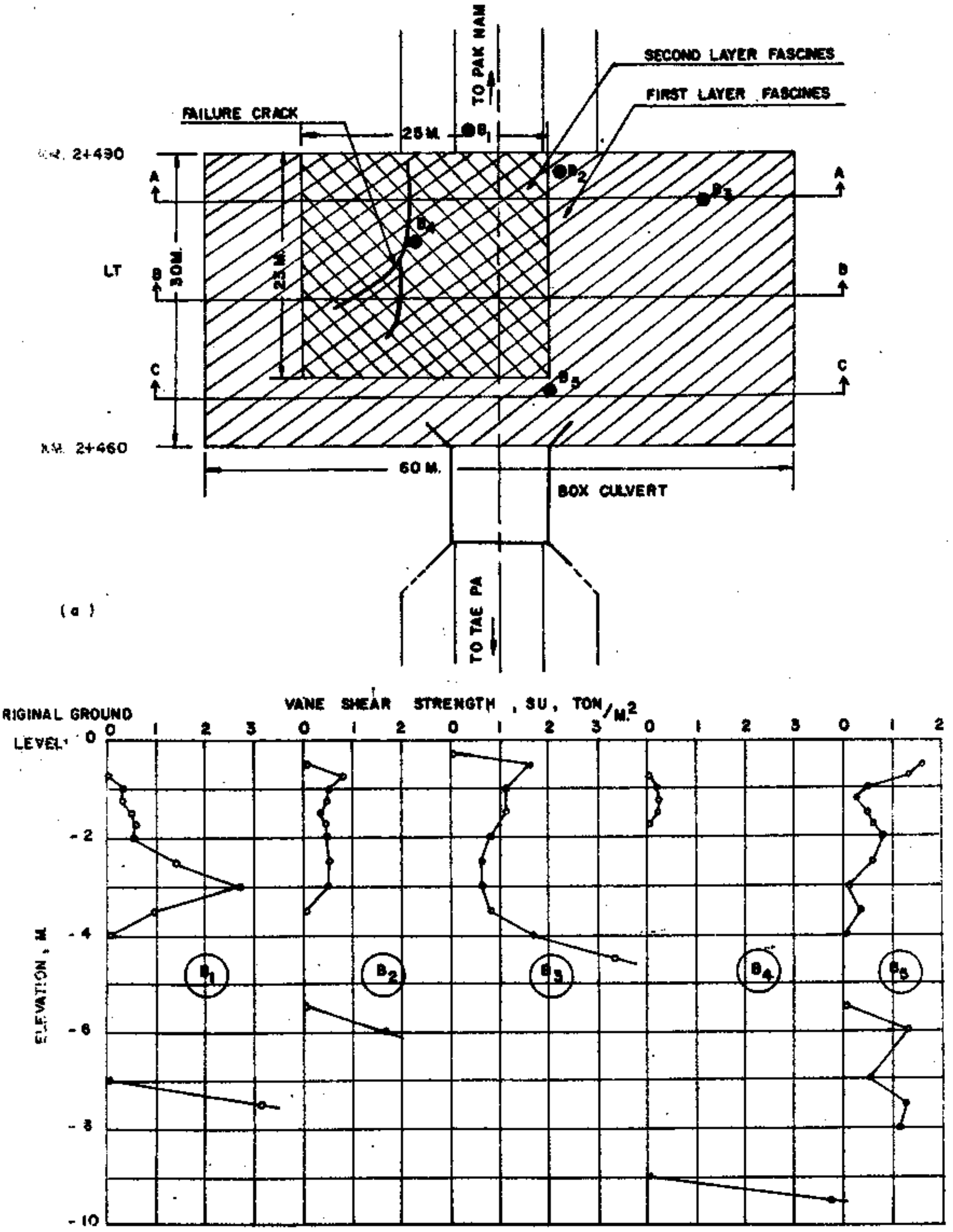

Fig.6 Area of Fascines and Vane Shear Strength of Subsoil.

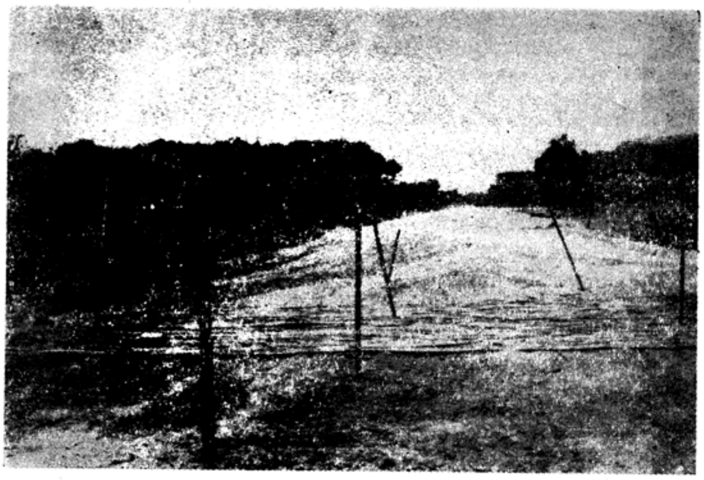

Fig. 7 Second Layer Fascines

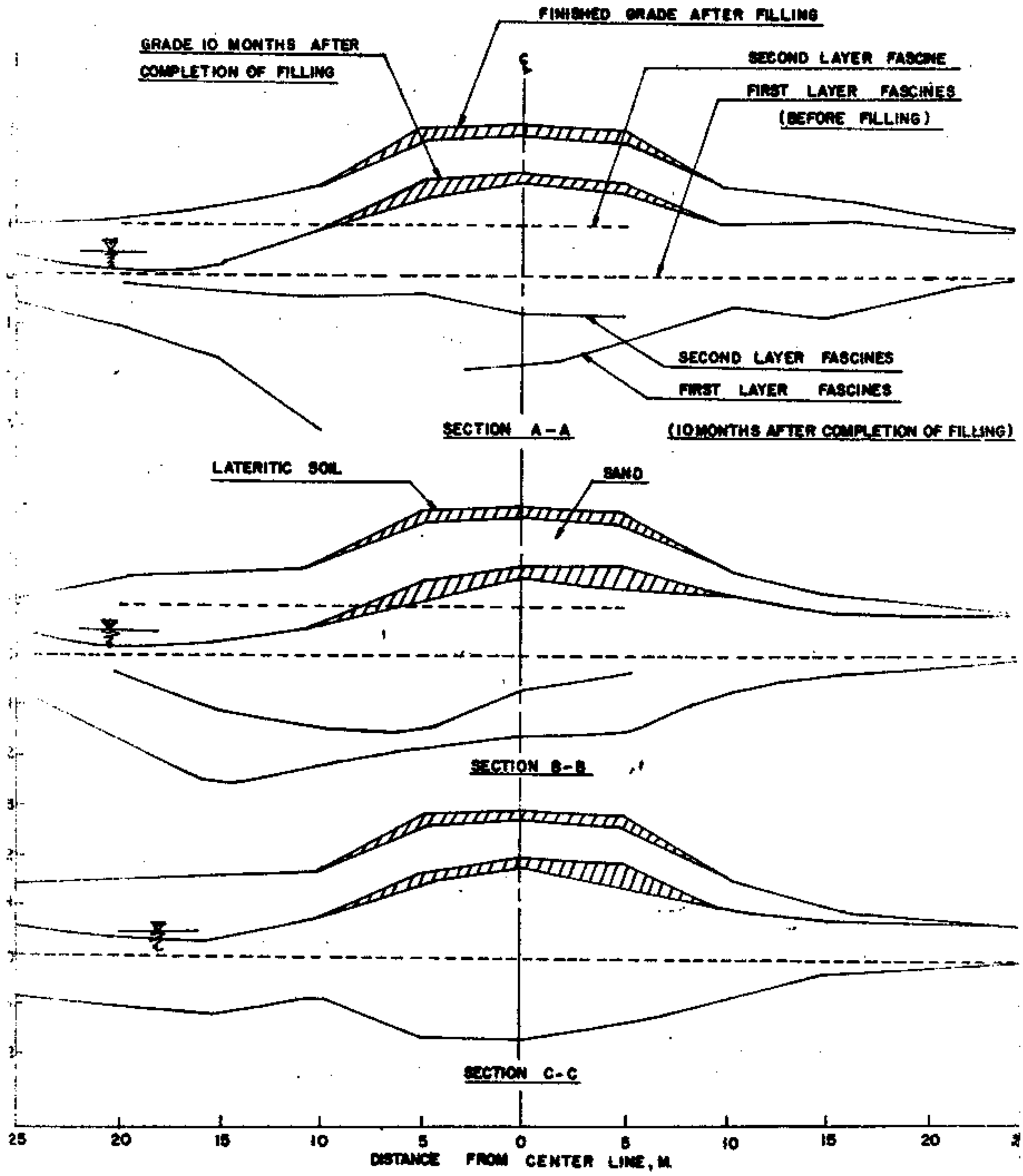

Fig. 8 Cross Section of Test Embankment 10 Months after Completion of Filling

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