02 Jun 1988, 10:30 am - 3:00 pm

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Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 3.17

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SYNOPSIS: 7.3 m high and 280 m long Manggar Besar homogeneous earthen dam resting on 12.0 m thick soft silty clay, is under construction to supply water to the city of Balikpapan in Kalimantan island of Indonesia. To accelerate the anticipated 1.6 m settlement of dam, 30 cm wide strip type drains (Colbond CX 1000) using polyster no-woven fabric are being used 3 m centre to centre. It is expected that 70 percent consolidation shall take place within thirteen months of construction by these drains.

## INTRODUCTION

The drinking water requirement for Balikpapan city located in east Kalimantan island of Indonesia is forecasted for 2000 AD based on 1980 census(1,09,900 persons) with a growth rate of 5.3 percent per year assuming that each house and yard connection would serve one family of eight persons. Water consumption for each house and yard is expected to increase from 145 to 160 and 60 to 90 litres per day respectively during 1985-2000. Water requirement for industrial purposes and for other public purposes such as schools, hospitals, offices etc., has been assumed to be 20 percent of total domestic water consumption. Due to limited availability of water, 60 percent of population would be served by Balikpapan water supply project, 30 percent by Pertamina water supply project and balance 10 percent by shallow wells.

Balikpapan water supply system comprises, (i) a storage dam on Manggar Besar river to supply raw water throughout the year, (ii) raw water intake stations on Klandasan and Manggar Besar rivers, (iii) a treatment plant with a nominal design capacity of 400 lps, and (iv) distribution system. The catchment area of Manggar Besar reservoir is 48.5 sq.km. with an average rainfall of 230 mm/month.

Manggar Besar homogeneous earth dam is 7.3 m high and 280 m long requiring 100,000 $m^3$ of fill material to bridge the valley. 4.0 m high, 600 m long dyke requiring 10,000 $m^3$ of fill material is also constructed on the left bank of river.

## GEOLOGY AND SOIL INVESTIGATIONS

### Foundation

Based on subsoil investigations conducted from December 1978 to October 1982, geological formation in foundation along dam axis is shown in Fig.1. From this figure it can be seen that foundation comprises the following three layers:

i) A soft silty clay stratum of 12 m in the centre of flood plain and of 5.0 m on the hill sides(called soil type A).

ii) A stiff clay layer(called soil type B) below soil type A with a thickness of 4.0 m in the centre of flood plain and of 2 to 3 m on hill side.

iii) A very stiff clay or dense silty sand(soil type C) below soil type B.

It implies that main dam is founded on very compressible soft silty clay. After construction of dam overall settlement in foundation is expected to be 1.75 m in a period of 270 years out of which 1.6 m is expected to take place in first 27 years.

### Fill Material

There are two borrow areas for embankment fill material. Borrow area I situated 500 m away from dam site comprises hard and stiff silty clay with some sand and gravel. Optimum water content for proper compaction (95 percent of Proctor's density) has been assessed at 25 percent on an average giving dry density of 1440 kg/$m^3$ and permeability of the order of $6 \times 10^{-8}$ cm/sec. Borrow area II is situated just adjacent to dam site comp rising silty clay layer(18,000 $m^3$ ) similar to borrow area I. Clayey sand (55,000 $m^3$) is also available at this site.

## DESIGN CONSIDERATIONS FOR DAM SECTION

The elevation of the valley at dam alignment is 0.5mMP and the height of dam is 7.3 m. Dam has been designed at full supply level of 4.0 mMP (FSL I) during the period when subsoil is not yet sufficiently consolidated to withstand the higher water level. This will last for about 5 years after completion of works. After this, spillway gates will become operational and full supply level will be maintained at 5.8 mMP(FSL II). The top of the dam would be constructed at 9.4 mMP after taking into account settlement of 1.6 m ( 0.5 mMP + 7.30 m + 1.6 m).

To speed up the consolidation process, vertical drains have been provided in the foundation. The top width of dam is 4.5 m and the design side slopes are 3 H : 1V but during the construction stage when consolidation has not yet been completed, side slopes would be 2.4 H : 1V. Two berms each of 5.0 m width have been provided at ultimate design elevation of 4.9 mMP. As natural stone for rip rap is not available in Balikpapan area at reasonable cost, upstream slope is being protected by sand cement bags consisting of gunny bags filled

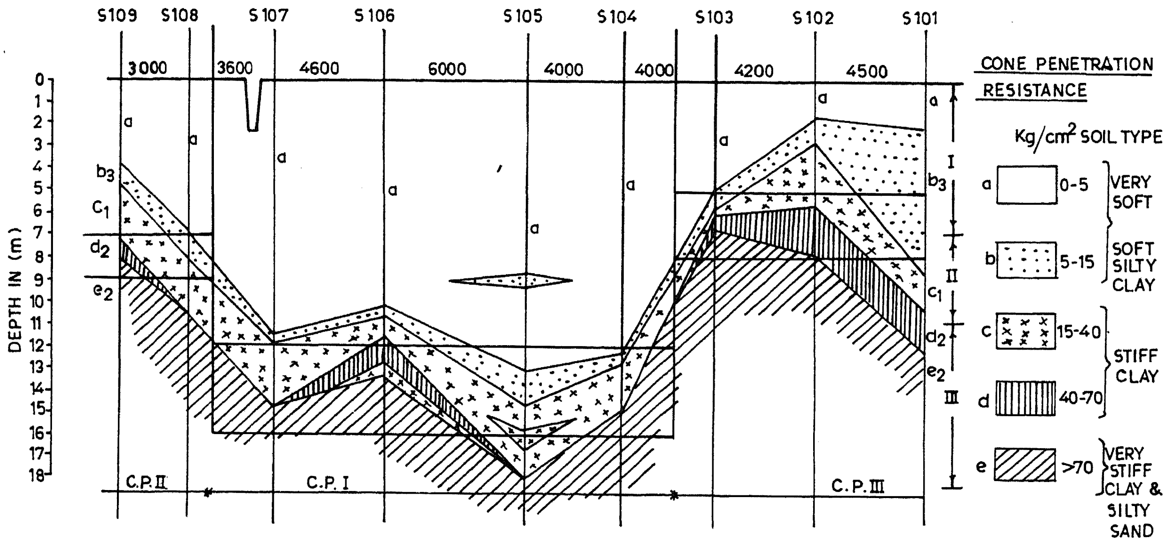


FIG. 1. GEOLOGICAL FORMATION DETAILS IN FOUNDATION ALONG AXIS OF MANGGAR BESAR DAM

with one volume of cement with six volumes of sand. A typical cross-section of dam is shown in Fig. 2.

Three stages are considered for stability analysis of embankment. Stage I refers to end of construction stage when embankment is constructed upto top (9.4 mMP) with no consolidation, no earthquake and no drawdown. The aimed factor of safety against sliding is 1.0 for this stage. Stage 2 refers to one year after completion when 70 percent consolidation has taken place and dam top is at 8.5 mMP. At this stage, factor of safety of 1.5 is required for normal steady seepage condition(FSL I at 4.0 mMP). With earthquake (0.1 g) or rapid drawdown, factor of safety of 1 was aimed at. Stage 3 is the final condition when 100 percent consolidation has taken place attaining crest level of 7.80 mMP and full supply level at 5.80 mMP(FSL II). The desired factors of safety in this stage, are the same as for stage 2.

## DESIGN OF VERTICAL DRAINS

### Various Alternatives

For structures resting on compressible soils with large foundations, such as dams, the usual practice is to consolidate the soft foundation strata in the minimum possible time by providing suitable drainage, as piles, wells and cassions are uneconomical. Earlier practice was to form sand columns by filling sunken lost head casing with coarse sand and subsequently withdrawing the casing. Lost head driven casing was replaced by jetting because the former has adverse effect on horizontal flow of excess pore water towards drain due to densification and remoulding of soil around driven casing.

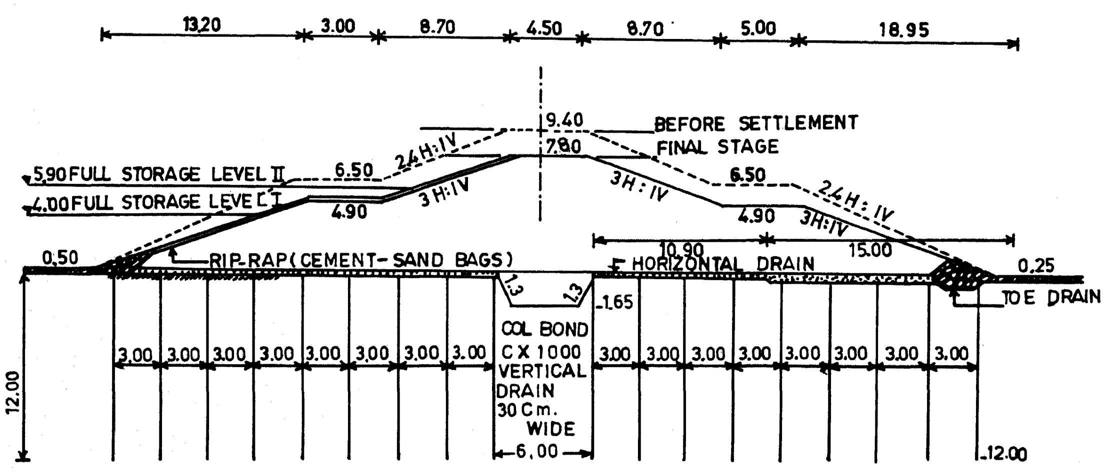


FIG.-2 TYPICAL CROSS SECTION OF MANGGAR BESAR DAM

Parallel to the development of sand drain, Kjellman(1948) developed strip type of cardboard vertical drain of size 4x100 mm. Kjellman method is based on the assumption that the drains are placed in a regular pattern and that each drain serves a cylinderical soil column of exactly the same length as the drain. It is assumed that (i) the increase in vertical load is evenly distributed over the consolidation area, (ii) horizontal layers remain horizontal throughout the consolidation process, (iii) permeability of cohesive soil, remains unchanged throughout consolidation process, and (iv) internal resistance of drain is negligible. The formula for design of strip drains is as under :

$$t = \frac{D^2}{8.C_h} \times \alpha . \log_e \left(\frac{1}{1-U_h}\right) \quad (1)$$

where,

t = consolidation period in years

D = diameter of drained soil cylinder(m)

= 1.05 S for triangular grid spacing of drains (1a)

= 1.128 S for square grid spacing of drains (1b)

S = centre to centre spacing of drains

$C_h$ = horizontal consolidation coefficient ($m^2$/year)

$$\alpha = \frac{n^2}{n^2-1}\left[\log_e(n) - \frac{3}{4} + \frac{1}{n^2}\left(1-\frac{1}{4n^2}\right)\right] \quad (1c)$$

n = D/d

d = equivalent diameter of drain (m)

For prefarbicated drain installations, usually $D/d > 8$ and the term $n^2/n^2-1$ and $\frac{1}{n^2}(1-\frac{1}{4n^2})$ in Eq. (1c), approaches 1 and 0 respectively and hence Eq. (1) reduces to

$$t = \frac{D^2}{8C_h}\left[\log_e(D/d) - 3/4\right] . \log_e\left(\frac{1}{1-U_h}\right) \quad (2)$$

For the purpose of calculations, of equivalent drain diameter, the drain is assumed cylinderical. For strip type drain, the draining effect depends upon absorbent surface i.e. the periphery. The effective periphery of strip type drain is 2 x width x f, where 'f' is correction factor allowing for (i) less favourable inflow of water to the drain because of rectangular section, and (ii) a possible disturbance due to densification and remoulding of the soil when installing the drain.

Based on the theoretical approach discussed above, design monograms for 10, 15 and 30 cm wide Colbond drains are given in Fig. 3.

Strip Drains for Manggar Besar Project

Tests under semifield conditions were carried out by Royal Adrain Walker Group Akzo Research under supervision of Delft Laboratory of Soil Mechanics, Netherland to decide the best design of drains for Manggar Besar project. Hence the drainage effect of 30 cm wide Colbond drain was compared with that of traditional sand drains under 3 m layer of sand with base area of 20 x 80 $m^2$. The area was split up into four sections of equal sizes, three of which were provided with Colbond drains at different spacings and fourth for conventional sand drains. From measurements of 40 settlement plates and piezometer readings taken for 600 days, it was concluded that Colbond drains accelerated consolidation process at least as much as that from traditional sand drains. Tests conducted on 4 mm thick KF 650

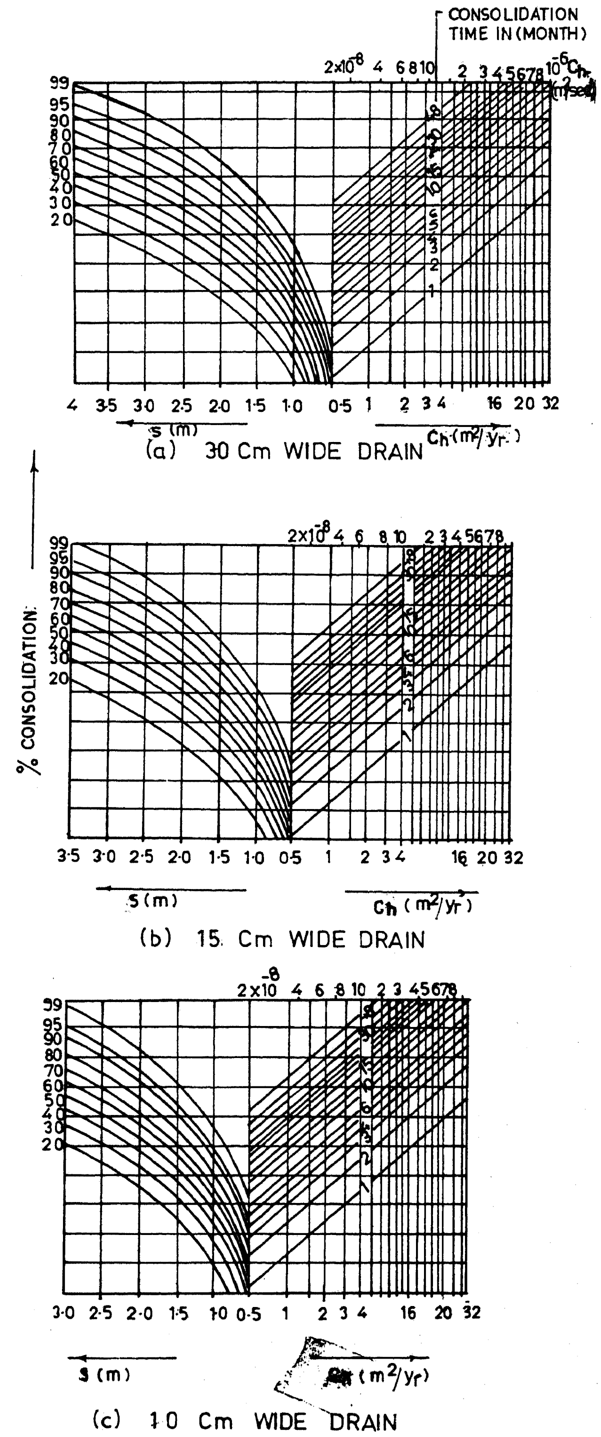


FIG. 3. DESIGN MONOGRAMS FOR COLBOND DRAIN

Colbond drains (polyster non-woven fabric) indicated some problem of reduction in drainage capacity in case of thick deposits of compressible layers. To produce a drain suitable for use in thick deposits, the drain was modified by (i) increasing the thickness to 5 mm, (ii) making core more coarser and (iii) improving its rigidity. This modified drain is named as CX1000 and retains 80 percent of its original volume under 3 kg/cm$^2$ pressure.

Laboratory tests on soft silty clay in foundation of Manggar Besar project has shown that on an average the value of horizontal coefficient of consolidation ($C_h$) is 2.4 m$^2$/year. The total base area of dam is 18725 m$^2$ and 70 percent consolidation is to be attained in 13 months period after construction of dam. Using design monograms given in Fig. 3, it was found that for 10, 15 and 30 cm wide CX1000 Colbond drains, the spacing required is 2.527, 2.673 and 2.989 m respectively and the corresponding number of drains are 2932, 2621 and 2096 respectively. This shows that number of 10 cm drains would be 1.4 times that for 30 cm wide drains. For Manggar Besar dam, Colbond CX1000, 30 cm wide drains at 3m centre to centre spacing were adopted.

## CONSTRUCTION OF COLBOND DRAINS

### Preparation of Area

Temporary cofferings were provided on left and right side of the river by making 1.5 m high dykes with side slopes of 1H:1V and area dewatered by six pumps. Then top soil was removed and the material dumped in spoil dump area located at 1.5 km downstream of dam. This was backfilled by stiff clay and work was done by machines. Horizontal trenches (100 x 100 mm) were excavated along the path of vertical drains manually. For preparation of area, following equipment was used:

| | | |
|---|---|---|
| Bulldozer | 15t | 1 unit |
| Swamp dozer | 13t | 1 unit |
| Wheel loader | 1.3 m$^3$ | 1 unit |
| Backhoe | 0.7 m$^3$ | 1 unit |
| Dump trucks | 8t | 6 units |

### Choice of Equipment and Installation of Drains

After taking into account relative merits and demerits of different construction equipment, it was decided that Colbond CX1000 30 cm vertical drains be installed by vibrations using light dragline and mandrel. For this, the following equipment was required.

| | | |
|---|---|---|
| Dragline and attachment (drawler crane) | 30t | 1 unit |
| Vibrohammer | 4.8t | 1 unit |
| Mandrel | 13.5m | 1 unit |
| Generator set | 250 KVA | 1 unit |

For easier movement, generator set required for vibrohammer was fitted with crawler crane unit. Rolls of Colbond CX1000 were fitted to the front of crawler crane. Mandrel was prepared at job site and its details are shown in Fig. 4. Colbond drain was fitted to the shoe of mandrel to be left in situ after pushing the drain upto required depth of vibrations and then mandrel was withdrawn. After installation of vertical drain, it was cut off about 20-30 cm above ground surface level of horizontal drain and the trench of the same was filled manually by sand of suitable grade.

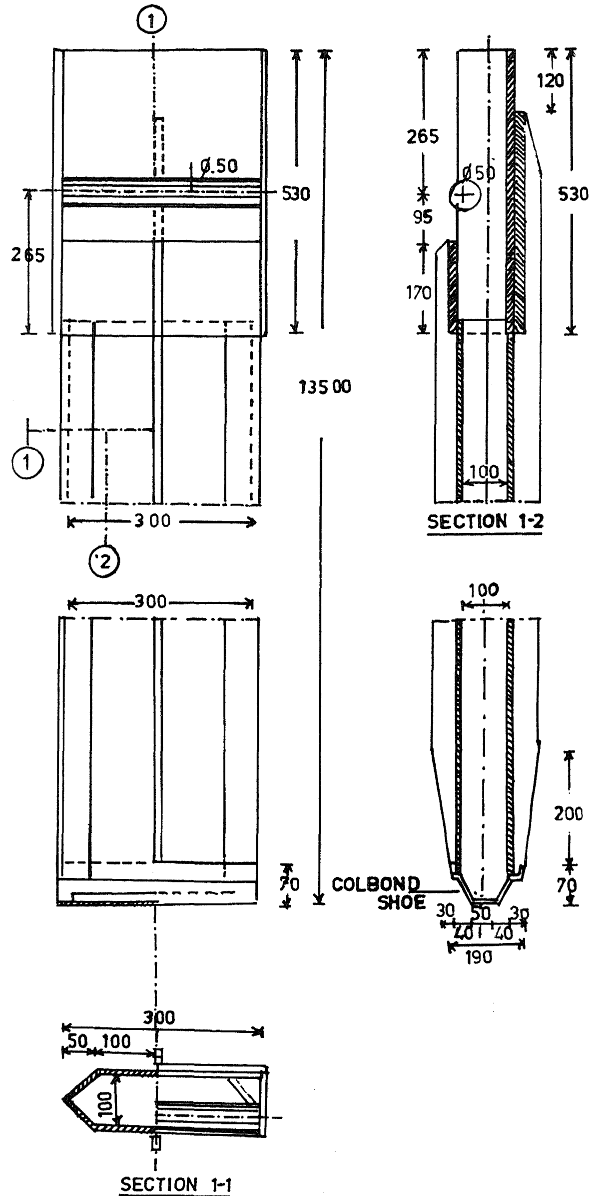


FIG.-4 MANDREL DETAILS

## CONCLUSION

To accelerate the consolidation process of 12.0m thick soft silty clay foundation layer of 7.3m high Manggar Besar dam, Colbond CX1000-30 cmx5mm polyster no-woven fabric, 2096 nos. vertical drains have beenprovided which are 3m centre to centre spaced in square grid. These drains have been installed by light weight crawler crane using vibro hammer and mandrel.

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