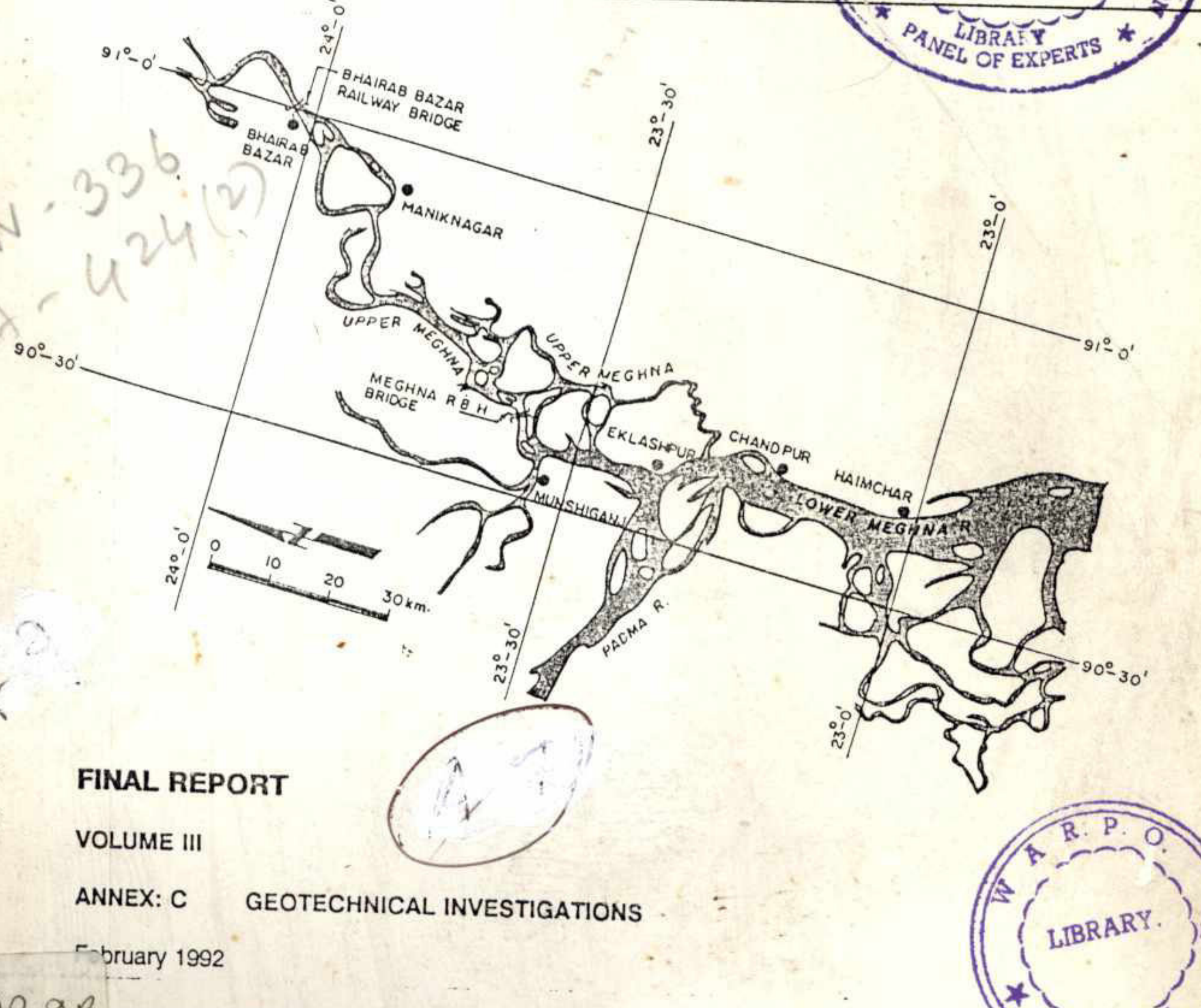
GOVERNMENT OF BANGLADESH

BANGLADESH WATER DEVELOPMENT BOARD

# MEGHNA RIVER BANK PROTECTION SHORT TERM STUDY

IDA Credit 1870 BD (Part D), March 1990








**FINAL REPORT**

**VOLUME III**

**ANNEX: C GEOTECHNICAL INVESTIGATIONS**

February 1992





HASKONING, Royal Dutch Consulting Engineers and Architects

Delft Hydraulics

BETS, Bangladesh Engineering & Technological Services

FAP-9B



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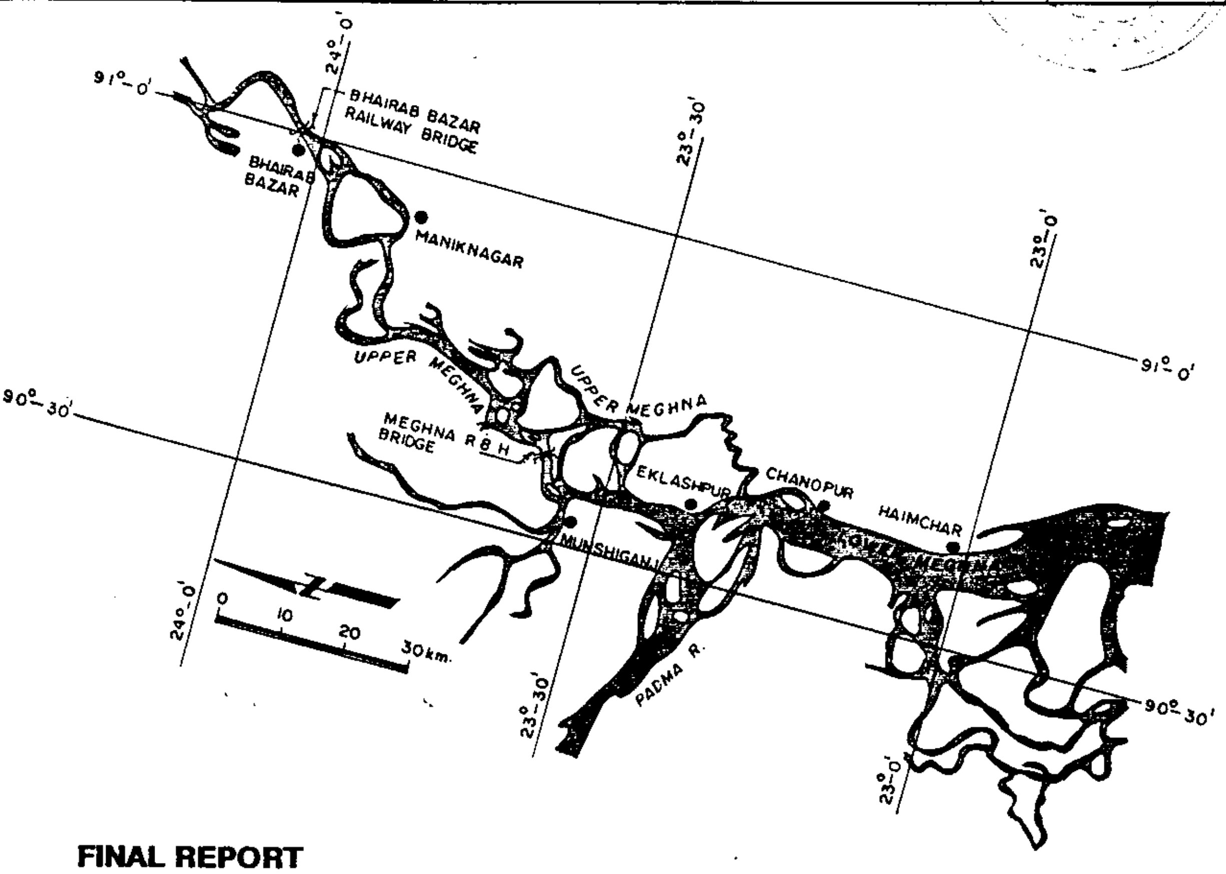


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February 1992


**HASKONING,** Royal Dutch Consulting Engineers and Architects

in association with:

DELFT HYDRAULICS
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD.

**PREFACE**

The Meghna, one of Bangladesh' major rivers, flows through the eastern part of Bangladesh and discharges into the Bay of Bengal.

Like other rivers in Bangladesh the Meghna erodes it banks in many points and this erosion has assumed an alarming magnitude since the severe floods of 1987 and 1988. Consequently, a number of locations requires prompt attention to prevent further damage or even events of a catastrophic nature.

This Final Report describes the surveys, studies, designs, cost estimating and economic evaluation carried out during 1990-1992 as part of the Short Term Study (FAP-9B) for Meghna Bank Protection.

The Report consists of seven volumes comprising a Main Report and eight Annexes A to G and I. Some Annexes are accompanied by a series of APPENDICES containing detailed information or supporting data relevant to them.

| | | | |
|---|---|---|---|
| Vol I | | | Main Report |
| Vol II | Annex | A : | Hydrology |
| | | B : | River Morphology and Geomorphology |
| Vol III | Annex | C : | Geotechnical Investigations |
| Vol IV | Annex | D : | Scale Model Studies |
| | | E : | Mathematical Model Studies |
| Vol V | Annex | G : | River Bank Protection |
| Vol VI | Annex | F : | Economics of Protection Works |
| Vol VII | Annex | H : | (not used) |
| | | I : | Environmental Impact Assessment. |

INTRODUCTION TO THE PROJECT

## 1. Background

There are three major rivers in Bangladesh; the Ganges, the Brahmaputra and the Meghna. Originating form Assam in India, the Meghna River flows through the eastern part of Bangladesh and discharges into the Bay of Bengal. The Meghna River drains an area of 77,000 $km^2$, of which about 46,500 $km^2$ is located in Bangladesh. The major contributors to the river upstream of Bhairab Bazar are the Boulai, the Surma and the Kushiyara rivers, covering an area of 62,960 $km^2$. The Ganges joins the Brahmaputra near Aricha and thereafter takes the name of the Padma. The Padma joins the Meghna at Chandpur. The Lower Meghna River conveys the melt and rain water form the Ganges and Jamuna basins, combined in the Padma River, and from the Upper Meghna basin to the sea. The total catchment area is about 1,637,000 $Km^2$. Maximum flows can be as high as 160,000 $m^3/s$. The major contribution of the discharge originates from the Jamuna River (annual average 19,642 m3/s) and the Ganges River (annual average 10,874 $m^3/s$).

The reach of the Meghna River from Bhairab Bazar to Haimchar is about 160 km in length. Width of the river varies from 1 km to more than 10 km. The river channel is more or less well defined upstream of its confluence with the Padma and is braided in the reach downstream of Chandpur. The river is considerably deep all along and the depth ranges to 35 m in the bends. The river bed and banks consist mainly of clayey-silt which is often loosely packed and is susceptible to liquefaction at some places. Of the three major rivers, the Meghna carries relatively less sediment. The velocity of flow of the river is high during monsoon. The river banks are also subjected to heavy wave action at some points.

Like other rivers in Bangladesh, the Meghna erodes its banks in many points. Erosion at the Meghna since the severe flood of 1988 has assumed an alarming proportion at the following locations which require prompt attention.

- The Railway bridge at Bhairab Bazar;
- Bhairab Bazar Township along the right bank;
- Maniknagar; along the left bank, falling within the proposed Gumti - Phase II Project;
- Meghna R & H Bridge;
- Eklashpur (near Meghna-Dhonagoda Project);
- Chandpur Town;
- Haimchar (adjacent to Chandpur Irrigation Project);

The Dhaleswari River, a tributary of Meghna, has been eroding its right bank at Munshiganj for quite some time and has threatened the existence of Munshiganj Town.

## 2. Meghna River Bank Protection -Short term Study

The study of possible bank protection works at critical locations along the Meghna river commenced officially in September 1990 when BWDB, Bangladesh Water Development Board commissioned HASKONING, Royal Dutch Consulting Engineers and Architects in association with DELFT HYDRAULICS and BETS, Bangladesh Engineering and Technological Services, to carry out the Meghna River Protection Short Term Study, financed under Credit IDA BD-1870, Part D.

The objectives of the study are:

- to provide short term measures for protection against erosion for seven locations on the Meghna river and one location on the Dhaleswari;

- to gradually implement a coherent and phased programme of works, aiming at the control of erosion on the defined stretches of the rivers Meghna and Dhaleswari. The protection of the locations indicated above should logically fit in this programme.

The Inception Phase started in November, 1990 with the mobilisation of the Expatriate Consultants. During the Inception Phase, the inter-action between this study and Flood Action Plan (FAP) Components was identified and maintained as far as possible.

The Meghna River Bank Protection Short Term Study, is now one of the **main components** of the Flood Action Plan for Bangladesh (FAP-9B. MEGHNA LB PROTECTION PROJECT), as included in the Review Report FPCO, December, 1990.

It has been recognised that during the Inception Phase, due to the internal and international situation during November 1990 to February 1991, delays were experienced, hampering the normal development of the activities planned. Therefore, activities in the critical path of the study were delayed (i.e, hydrometric surveys, geotechnical investigations, model investigations at RRI).

Furthermore, during the first phase of the project it became more and more clear that the inclusion of the flood season in the survey would considerably improve the designs of the protection works, the Consultants were supposed to submit at the end of the Study. Moreover, strengthening of the relation with the studies of the Bangladesh Action Plan for Flood Control (FAP) would also have a positive contribution to the outcome of this project. Therefore the BWDB instructed the Consultants to review and update the work plan taking note of the flood season of 1991 and the aforementioned studies of FAP.

As part of the Study a priority ranking was established. Accordingly, it was decided:

- to carry out a feasibility study, detailed designs and tender documents for bank protection works at the following locations:

    - Bhairab Bazar Township and Railway Bridge;
    - Munshiganj Town located on the Dhaleswari River;
    - Chandpur Town;

- to carry out a full feasibility study and prepare tender documents for bank protection works in the following locations:

    - Eklashpur;
    - Haimchar;

- and only a pre-feasibility study for:

  - Meghna Roads & Highways Bridge;
  - Maniknagar, part of Gumti Phase II Project.

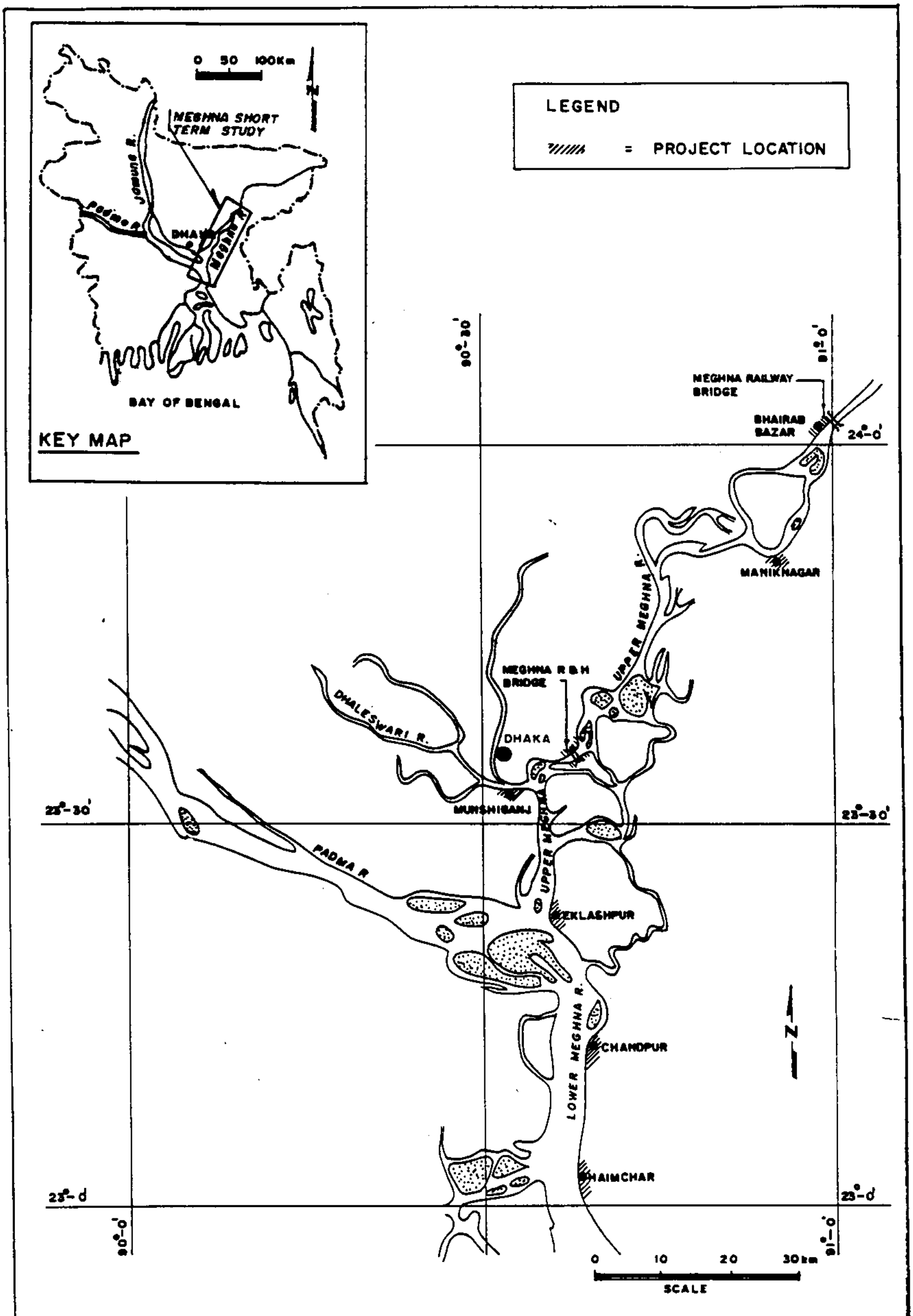
This Final Report submitted in accordance with the (Revised) Terms of Reference comprises all feasibility studies carried out as well as the detailed designs for bank protection works at the three locations mentioned above.

## ABBREVIATIONS AND GLOSSARY OF TERMS

| | |
|---|---|
| ADB | Asian Development Bank |
| | |
| BCSIR | Bangladesh Council for Scientific and Industrial Research |
| BBS | Bangladesh Bureau of Statistics |
| B/C | benefit cost ratio |
| BCL | Bangladesh Consultants Limited |
| BETS | Bangladesh Engineering and Technological Services Ltd |
| BH | Bore hole |
| BIWTA | Bangladesh Inland Water Transport Authority |
| BIWTC | Bangladesh Inland Water Transport Corporation |
| BOD | Biological Oxygen Demand |
| BR | Bangladesh Railway |
| BS | British Standards |
| BUET | Bangladesh University of Engineering and Technology |
| BWDB | Bangladesh Water Development Board |
| | |
| °C | degree Celsius |
| CC blocks | concrete blocks |
| CIF | Cost, insurance and freight |
| CPT | Cone Penetration Test |
| Crore | 10,000,000 |
| | |
| DH | Delft Hydraulics (Netherlands) |
| Dollar (US) | taken at an exchange rate of Tk.36 for the Study |
| | |
| EIA | environmental impact assessment |
| EIRR | economic internal rater of return |
| | |
| FAO | Food and Agricultural Organization (United Nations) |
| FAP | Flood Action Plan |
| F/C | foreign currency |
| Fig(s) | figures(s) |
| FML | fortnightly mean water level |
| FPCO | Flood Plan Coordination Organization |
| | |
| g | acceleration due to gravity |
| GL | ground level |
| | |
| ha | hectare(s) |
| hr | hour(s) |
| | |
| IBRD | International Bank for Reconstruction and Development |
| ICB | international competitive bidding |
| IDA | International Development Association |
| IRR | internal rate of return |
| IWTA | Inland Water Transport |
| | |
| JICA | Japan International Cooperation Agency |

| | |
|---|---|
| kg | kilogramme(s) |
| km | kilometre(s) |
| $Km^2$ | square kilometre(s) |
| km/h | kilometre per hour |
| Kn | kilonewton |
| Lakh | 100,000 |
| L/C | local currency |
| LCB | local competitive bidding |
| LWL | Low water level |
| m | metre(s) |
| MAT | Manual and automatic tidal gauge |
| MCA | multi-criteria analysis |
| m/s | metre(s) per second |
| $m^2$ | square metre(s) |
| $m^3$ | cubic metre(s) |
| $m^3/s$ | cubic metre(s) per second (cumecs) |
| MG | Metre Gauge |
| mm | millimetre(s) |
| MMSS | Mica schist silty sand |
| MN | meganewton |
| MPO | Master Plan Organization |
| MSL | mean sea level |
| N | Newton |
| NEDECO | Netherlands Engineering Consultants |
| NMC | natural moisture content |
| N-value | standard penetration test value |
| ODA | Overseas Development Agency |
| OECF | Overseas Economic Cooperation Fund |
| OMC | optimum moisture content |
| p.a | per annum |
| PDB | Power Development Board |
| PDF | Probability density function |
| PWD | Public Works Department (datum) |
| RC | reinforced concrete |
| RHD | Roads and Highways Department |
| RPT | Rendel, Palmer & Tritton Limited |
| RRI | River Research Institute |
| RTW | river training works |
| s,sec | second |
| SHW(L) | standard high water (level |
| SLW(L) | standard low water (level) |
| SOB | Survey of Bangladesh |
| SPT | standard penetration test |
| SWMC | Surface Water Modelling Centre |
| sq.km | square kilometre(s) |

| | |
|---|---|
| t(tons) | metric tons |
| Tk | taka |
| TOR | Terms of Reference |
| US$(or$) | US dollar(s) |
| USCS | Unified soil classification system |
| WB | World Bank |




INDEX MAP SHOWING PROJECT LOCATIONS FOR
THE MEGHNA SHORT TERM STUDY

# ANNEX C

# GEOTECHNICAL INVESTIGATIONS

**MEGHNA RIVER BANK PROTECTION**

**SHORT TERM STUDY**

**VOLUME III - GEOTECHNICAL INVESTIGATIONS**

CONTENTS

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## LIST OF APPENDICES



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## C.1. INTRODUCTION

### C.1.1 General

Over the recent years, severe erosion occurred at several locations along the Meghna River, inflicting huge loss of properties. The erosion and recession process has also threatened a number of townships, commercial and industrial zones, vital road and railway bridges and also agricultural projects. An earlier study [1] selected 4 locations for an in-depth investigation. Out of eight locations (Bhairab Bazar Railway, Bhairab Bazar Township, Maniknagar, Eklashpur, Meghna R&H Bridge, Chandpur, Munshiganj & Haimchar,), all prone to severe erosion, following sites were selected::

- Bhairab Bazar Railway Bridge and Township
- Meghna R&H Bridge
- Munshiganj
- Chandpur.

In this report geotechnical aspects leading to slope failure are studied and the general design parameters establish. A geotechnical site investigation and laboratory testing, in conjunction with site visits and a study of topographic and bathymetric survey results, was carried out for this purpose.

### C.1.2 Scope of work

The geotechnical investigation comprised:

- Execution of bore holes, depth 30-60m, in conjunction with Standard Penetration Testing and preparation of bore logs;
- Extracting of undisturbed and disturbed soil samples, for selected field and laboratory testing;
- Installation of standpipe piezometers and river gauges for the observation of groundwater and surface water variations respectively;
- Establishment of design parameters for slope design;
- Laboratory testing of disturbed and undisturbed soils samples and compilation an compilation of the results in the form of a report;
- Identification and establishment of the general subsoil characteristics along the river stretch under study;
- Analysis of slope failures and drawing up recommendations for safe slope angles;
- Recommendations for geotechnical details of the river bank protection.

### C.1.3 Conduct of the study

The works of installation of bore holes and laboratory testing were executed through the following agencies of BWDB :

- Groundwater Division-I Dhaka for field work [1]

- Soil Mechanics Section, RRI, Faridpur for laboratory testing [3]

The investigation was carried out between late January 1991 and Mid May 1991, in close co-operation with the BWDB counterpart staffs. The entire investigation work was conducted under the direct supervision of the geotechnical specialists of the Consultants.

### C.1.4 Reporting

This Annex C, the Geotechnical Investigations and Studies, contains an evaluation of field and laboratory data, together with aspects of slope stability and bank protection. The Appendices contain more detailed evaluations of laboratory test results and slope stability analyses.

### C.1.5 Erosion protection characterisation

To facilitate reading of following chapters it should be understood that the origin of receding river banks, located at outer bends, must primarily be sought in the events below river water level.

The process of continuous erosion is sustained by the combined effects of propagating localized slope failures and washing away of slope material. The severity of these events will be further aggravated when already steep and critical slopes are subjected to the effects of falling river levels with respect to ground water level.

The previous phenomena allow the river to encroach upon the land. A condition manifesting itself visually by the undercutting of slopes and breaking away of parts thereof. Wave attack may further intensify erosion.

It can be recognized that the design of a lasting slope protection will have to allow for the choice of a safe slope angle, a macro stability boundary condition, in conjunction with measures to protect this slope from the effects of currents, ground water movements and wave attack. Slope protection design will consequently deal with micro stability aspects.

## C.2. GEOTECHNICAL INFORMATION AVAILABLE FROM SECONDARY SOURCES

### C.2.1 General

During the initial stages of the study, considerable data were collected from various organizations. These data related to projects executed by BWDB, R & H Directorate, Bangladesh Railway etc., as part of development activities, investigations and feasibility studies [4,5,6,7,8 & 9]. They form an integral part of the subsequent evaluation.

In the following sections, an overview of the Geotechnical conditions in the Meghna River Basin is presented.

### C.2.2 Over-all evaluation

The sub-soil investigations, evaluated for the preparation of this report, dealt with an area stretching from Bhairab Bazar to Haimchar. The available data provided valuable additional information, especially with regard to the apparent consistency in stratification.

Samples collected and analyzed for previous studies revealed the predominance of fine sand with traces of silt. A few BH's showed the presence of more sandy silt (sometimes with some clay) in the upper 10-15 m. Deeper layers consisted mainly of fine sand, with grain size gradually increasing with depth. Most of the BH's, along the whole stretch of the Meghna River, reported the occurrence of trace of mica.

### C.2.3 Geotechnical data per site

#### C.2.3.1 Bhairab Bazar Railway Bridge & Bhairab Bazar Township

A total of eight Bhs (20-30m deep) was made for Bangladesh Railway under the supervision of Messrs Development Design Consultants Ltd. [4&5]. These are located along the west bank of the Meghna River, between Jamuna Oil Company Station (downstream side) and Dhaka-Sylhet Road Ferryghat (upstream side). A major bank slide occurred in 1988 at this stretch. The sub-soil investigation program comprised of Standard Penetration Soundings (SPT) in the field. No undisturbed sampling was undertaken. The laboratory tests included the routine Classification tests, comprising of the determination of Grain Size and selected Atterberg Limits.

The sub-soil in the area is fairly uniform, comprising predominantly of non-plastic fine sand with traces of silt. Occasional lenses of slightly plastic fines are encountered. Mica is present over the full depth of investigation. Fine sand constitutes 25-95% of the soil texture. The SPT values, in general, increase with depth, varying between <5 and 60. The presence of a distinct less permeable layer, manifested in SPT values as low as 5-10, can possibly be attributed to a higher piezometric level in the underlying sand layer. During Standard Penetration Testing this may have resulted in some soil softening. No engineering parameters, however, have been established.

#### C.2.3.2 Maniknagar

A very recently conducted study "Gumti phase-II sub-project : Feasibility Study" [6] involved exploratory borings down to 33 m in the neighbourhood areas e.g. Beijni, Nabinagar, Homna etc.

The study report, which contained no Bore Hole log and laboratory test data, indicated the geotechnical condition to be typical in the project area. The sub-soil comprised of very fine sand with some silt and, some times, softer clayey layers in the upper zone.

The study involved analysis of slope stability of a Flood Control and Irrigation embankment. The soil parameter adopted and used for the analysis are: bulk density 17 $kN/m^3$; cohesion(c') 11 $kN/m^2$; angle of internal friction(ø') 25°. Apparently, no specific testing was carried out to establish shear strength parameters.

During May 1989, a subsoil investigation work was carried out for Gumti-Phase II project at Mukhtarampur (Salimganj) just downstream and very close to Maniknagar. The depth of the two borehole was 33m below Ground level. The field investigations were carried out by Ground-Water Division-I BWDB, Dhaka. Laboratory testing was carried out by the soil mechanics laboratory of RRI. The results of this investigation were presented in their Report Soils-79(89). The borelogs showed a top layer (thick 2.5 m) of medium stiff sandy silt having SPT 'N' values between 4 to 8 and underlain by a layer 25m thick of medium to dense grey fine sand with trace of silt. The SPT ranges between 8 and 36 as the depth increases. Below this layer and upto the end of the borehole, a layer of sandy silt is again present having a thick of 25 m and SPT values upto 49. Laboratory tests for classification (index properties) i.e grain size distribution, normal moisture content, limits of Atterberg, etc were carried out. However, no specific test was conducted to establish shear strength parameters.

More recent studies carried out for the Gumti-Phase II project, including field works and laboratory test in areas such as: Bijni, Nabinagar, Mukhtarampur, Homna, Mohampur and Laulpur outfall on the alignment of the peripheral embankment shown the following soil parameters $\gamma_b$ = 17 kg/m3, cohesion c'= 11 kN/m2 and angle of internal friction ø'= 25°.

### C.2.3.3 Meghna R & H Bridge

A total of four Bore Holes (50-60m deep) were installed during the Feasibility study of the recently completed Meghna R & H Bridge across the Dhaka-Chittagong Highway [7]. Of these, two borings were sunk in the river bed and the remaining two in each bank of the river.

The field investigation comprised of SPT soundings and collection of disturbed samples, used for classification of soil. A limited number of undisturbed samples was extracted to conduct strength tests in the laboratory.

The sub-soil stratification, as appeared from the BH profile, is very consistent. It can be characterised by the occurrence of non-cohesive soil, with fine sand fraction predominating. A thick lens of sandy silt-clay is prevalent between elevations of 28-42m below PWD datum. A general trend of gradual increase in penetration resistance with increase in depth is noticed down to 20m. Below this, the formation appears to be thin but quite firm and uniform as displayed by a rather sharp increase in N-values of 30 to 50. A drastic fall in 'N' value (approx. 10), attributed to the presence of silt formation/lens, is encountered underneath. Below an elevation of 40m -PWD, the sub-soil again displays a distinct and rapid increase in penetration resistance ('N' value >50) which continued till the end of the deep BH's.

### C.2.3.4 Eklashpur

During November 1986 a subsoil investigation was carried out by GWD-II. BWDB [8] at Eklashpur for the Meghna Dhonagoda Irrigation Project (MDIP). Three boreholes were carried out upto depth of 18m. Laboratory testing was done by RRI (Report Soils-3 (87)). The subsoil consist of loose sandy silt layer with SPT values ranging from 2 to 4. The underlying layer is formed by medium dense fine sand with SPT 'N' between 6 to 19. Laboratory tests were carried to determine grain size distribution were carried out. No further test results were available.

In Appendix VII of the Feasibility study for MDIP prepared by C.K.C of Japan in 1977, contains the sub-oil data for the Kalipur and Hadhamdi pumping stations situated north and south of Eklashpur respectively. Bore holes were made upto 33 m. The sub-soil data have been extensively used in the stability analysis of irrigation canal embankments of the Meghna Dhonagoda Irrigation Project. Data as recommended in the C.K.C report is presented as follow:

a) Upper layer, sandy SILT $\gamma_b$: 18 kN/m$^3$ ; c': 10 Kn/m$^2$ ; $\phi'$=10°; and

b) Lower layer, FINE sand $\gamma_b$: 19 k N/m$^3$; c'= 0 ; $\phi'$: 30°.

C.2.3.5 Munshiganj

No data were available.

C.2.3.6 Chandpur

Two Bore Holes (each 22m deep) were sunk using augering technique, one of each in Nutan and Puran Bazar area by Hydraulic Research Laboratory of the then EPWAPDA in 1971 [9]. The two areas are separated by the Dakatia river bisecting Chandpur town.

The sub-soil is comprised of predominantly fine sand-silt size material. The soil test data indicated a bulk density of 17.6 kN/m$^3$. The cohesion intercept is very minor (5-8 kN/m$^2$). The angle of internal friction is 28°. The data, in general, suggest loose to medium dense conditions.

C.2.3.7 Haimchar

Haimchar is situated about 20 km south of Chandpur town at the left bank of the lower Meghna river, downstream of the confluence of the Padma (Ganges) and the Upper Meghna River. The sub-soil condition is expected to be very much similar to Chandpur area.

The general trend of the above mentioned results, stratification, soil composition and strength characteristics, concurs more or less with the findings of this more in-depth report. The results will consequently be weighed in the overall evaluation, however, with the characteristics not being referred to explicitly.

A sub-soil investigation programme was carried out by GWD-I at Haimchar and Chandpur for the Chandpur Irrigation Project (CIP) in December, 1977. Two bore holes were made upto a depth of 16 m each. The upper layer upto a depth of 6m, consists of very loose grey SILT with some fine sand and trace of mica, having 'N' values ranging from 4 to 16. The water table level was only 0.8 m below ground level. The laboratory tests were performed by the Soil Mechanics Division of Hydraulic Research Laboratory (HRL) and compiled in the report No 5(78), 1978.

The following results were obtained from the triaxial test performed:

a) upper layer: SILT with low content of sand; $\gamma_b$ = 17 Kn/m3; $\phi'$=35°; c'= 25kN/m2.

b) lower layer: Fine SAND with some silt; $\gamma_b$ = 18 Kn/m3; $\phi'$=32.8°; c'= 17kN/m2.

2

## C.3. GEOLOGY AND SEISMICITY

### C.3.1 Relief and Geology

#### C.3.1.1 Regional

Bangladesh consists primarily of deltaic alluvial sediments of the three great rivers-the Ganges (named the Padma in Bangladesh), Brahmaputra and the Meghna, and their numerous tributaries. According to Morgan and McIntre [10], the entire Bangladesh is a part of the Bengal Basin filled in the Tertiary-Quaternary geological period. The thickness of sediment cover over the basement rocks, starting from about 600ft (180m) along the Rangpur-Dinajpur axis, increases south-eastward to over 40,000ft (12,000m) in the eastern part of the country.

Physiographically, Bangladesh is more or less a flat plain which occupies about 80% of the land surface. It slopes gently towards the south. The physiographic units delineated in this project are Lower Meghna Flood Plain and Lower Meghna River Tidal Flood Plain.

Structurally, Bangladesh can be divided into two principal Tectonic units. There are the Precambrian Platform covering northwest Bangladesh and Bengal Foredeep covering central, southern and eastern parts. The junction between them, the so-called hinge line runs SW from Mymensingh (50 km north of Dhaka) to Calcutta, the capital of West Bengal in India. The flood plains of Bangladesh were affected by earth movements primarily due to settlements of the deposits, geotectonic movements and mean sea level changes.

The Quaternary geology and tectonics activities of the Bengal Basin are dealt in further detail elsewhere [ 11,12,13,14,15,16 & 17] and more extensively in a recent Master Plan Organisation (MPO) Report [18]. A 1:1,000,000 scale Map entitled "Geological Map of Bangladesh" published by the Geological Survey of Bangladesh [ 19] also shows the generalized Geological, Physiographical and Tectonic feature (Fig. C.3.1) together with the stratigraphical condition across the Bengal Basin.

#### C.3.1.2 Project area & reference levels

The entire project area lies within the delta that has been formed by the deposition of sediments carried by the Meghna (7 sites) and Dhaleswari (Munshiganj).

There is only minor topographical relief within the project area. The available topographic maps indicate that the average elevation contours are as shown in the following table (Table C.3.1).

The top layer in the project area is made up of fluvial deposits of Recent to Sub-recent origin. Very fine textured soils comprise the bulk portion of the project area while the remainder is moderately fine, with a high silt content and a mica admixture as prominent features.

2a

**Table C.3.1 - AVERAGE GROUND SURFACE LEVELS (in m +PWD)**

| Area | PWD |
|---|---|
| Bhairab Bazar | + 7.5 |
| Bhairab Bazar Town | + 7.5 |
| Meghna R&H Bridge | + 3.0 to + 3.5 |
| Munshiganj | + 3.7 |
| Chandpur (Nutan B.) | + 5.5 |
| Chandpur (Puran B.) | + 5.5 |

In general following levels apply to the surveys:

M.S.L................ Mean Sea Level
P.W.D................ Publics Works Department
S.O.B............... Survey of Bangladesh

* To convert P.W.D. level to S.O.B. level, the P.W.D. level is to be reduced by 0.46m

## C.3.2 Seismicity

### C.3.2.1 Slope stability aspects

A large bankslide occurred in the early hours of November 30, 1988, washing away 4 to 5 Ha of land along the Meghna river at Bhairab Bazar Railway Bridge site, about 90 km NE of Dhaka. This slide was preceded by two minor tremors in August 1988 [4].

Reported dam and slope failures abroad, due to liquefaction phenomena, showed a time lag of a couple of days between tremor and slide. This phenomenon can physically be attributed to the time dependent and gradual expansion of a liquefied pocket within the slope body.

Taking into account the permeability of the prevailing strata at Bhairab Bazar it does seem unlikely that tremors will have acted as the triggering mechanism of failure. The actual triggering mechanism must be attributed to the development of too steep a slope in conjunction with a specific layering and a falling water table after a very high water (App. C/5).

The time interval also implies that actual seismic loading does not coincide with failure. In the project area often loose micaceous sand and silt prevail in the upper 10 meters. These layers may be susceptible to liquefaction. Whether or not this susceptibility actually must be regarded as a risk will depend on the shear stress levels developed in the slope and the in-situ density. Consequently a steep natural "critical" slope will present a higher risk than a flatter slope designed with a certain safety factor. Once a sufficiently safe design has been embarked upon these critical conditions will no longer exist.

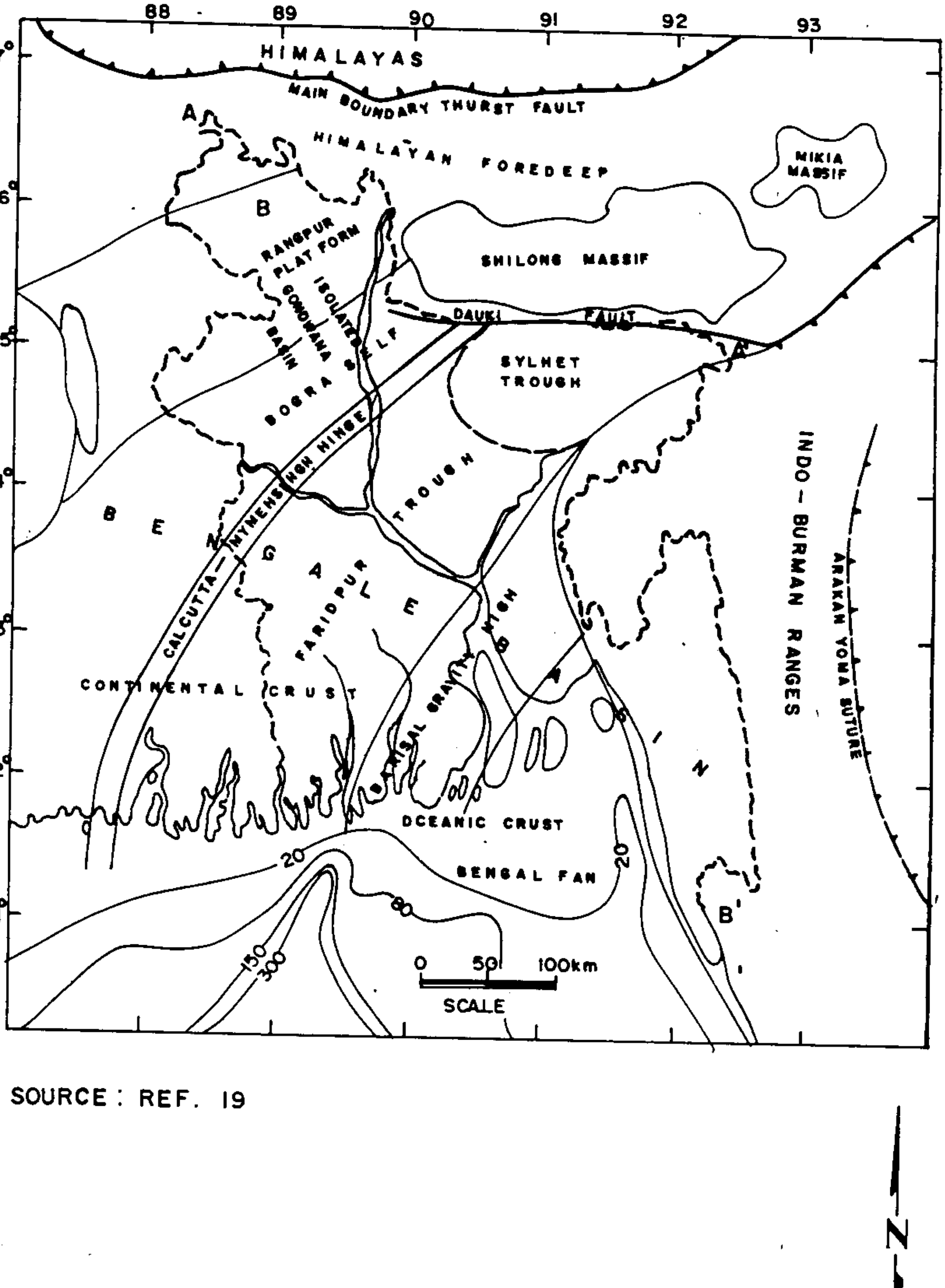
### C.3.2.2 Earthquake history and intensity

Over 200 major earthquakes occurred in and around Bangladesh between August 1833 and July 1971. Though Bangladesh suffered wide spread damage by the great Assam earthquake of 1897 and also locally limited damage in the vicinity of epicentres by the Bengal earthquake of 1885 and Srimangal earthquake of 1918, there seems to be no seismically active fault in the territory. However, the causative faults and regions of high seismic activity exist to the North and East of Bangladesh in neighbouring India and Burma, and earthquakes in these areas affect the adjacent regions in Bangladesh as well.

Recognising this, the seismic event affecting Bangladesh was studied by a Committee of Experts [20] on Earthquake Hazard Minimisation who published the first comprehensive report entitled "Seismic Zoning Map of Bangladesh and Outline of a Code for Earthquake Resistant Design of Structures". The Committee recommended Bangladesh to be sub-divided into three zones I, II and III (Fig. C.3.2). Zone I covers NE Bangladesh and is designated as the most active seismic zone. Zone II runs from NW to SE covering the central part of Bangladesh. Zone III covers the SE part of Bangladesh and is designated as the least active seismic zone. The report describes that earthquake shocks of maximum intensity of IX & VIII in Modified Mercalli Scale are possible in Zone I & II respectively, and the maximum intensity is not likely to exceed VII in Zone III. Thus, the report suggests the basic horizontal seismic co-efficient of 0.08, 0.05 and 0.04 for Zone I, II and III respectively. All sites of this Study are located within zones II & III.

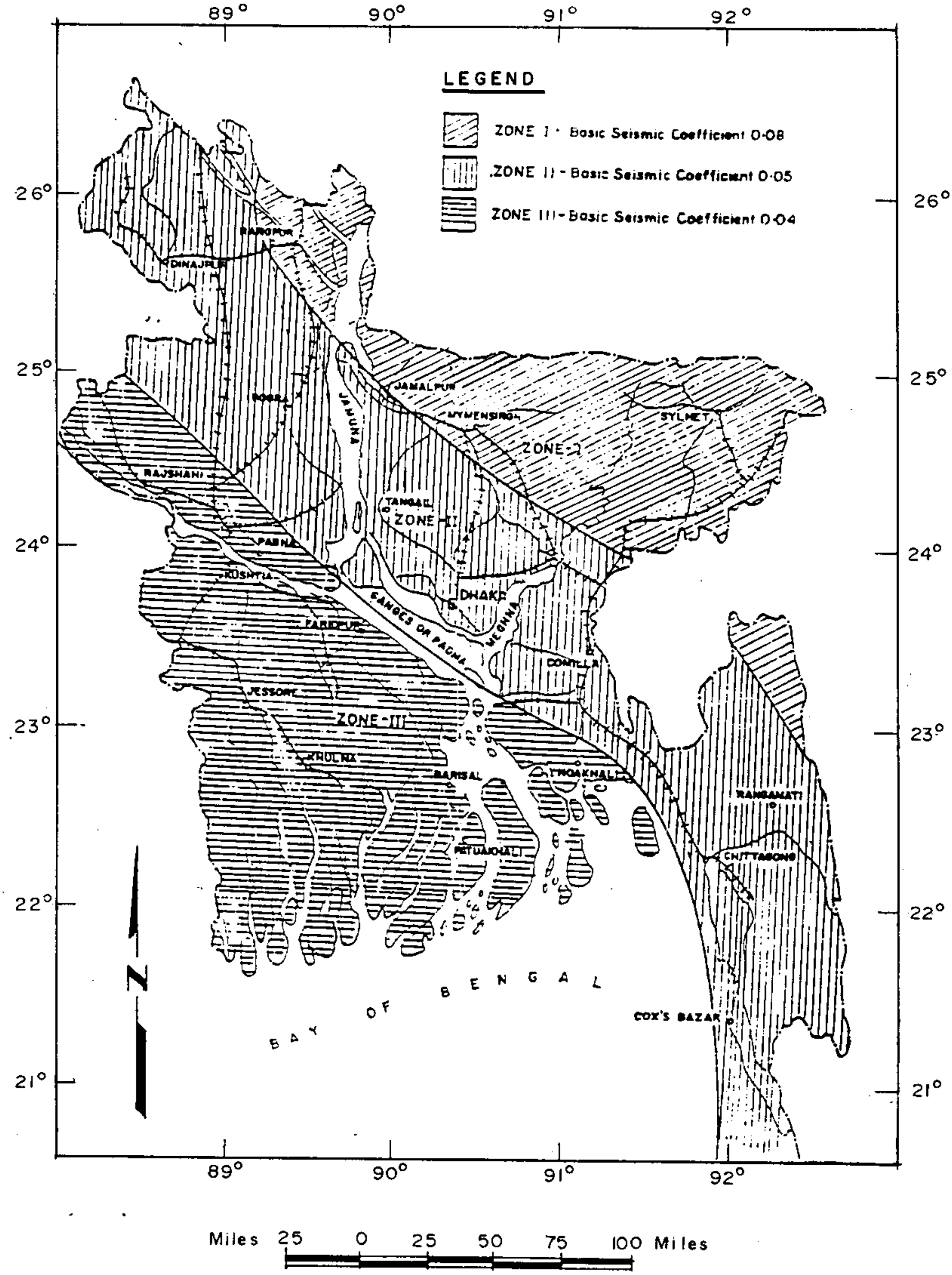
### C.3.3 <u>Seismic coefficient</u>

The project area is situated in Zones II & III, defined in the Committee of Experts Report. Hence a seismic shock, with the maximum intensity of VIII of Modified Mercalli Scale with the possible maximum magnitude in the Richter Scale of 6.5, is possible. Considering the source distance of major earthquakes of the past being well over 100 km from any of the sites (Fig. C.3.3), a value of 0.05 as the basic horizontal seismic coefficient for the slope stability analysis will be adopted.



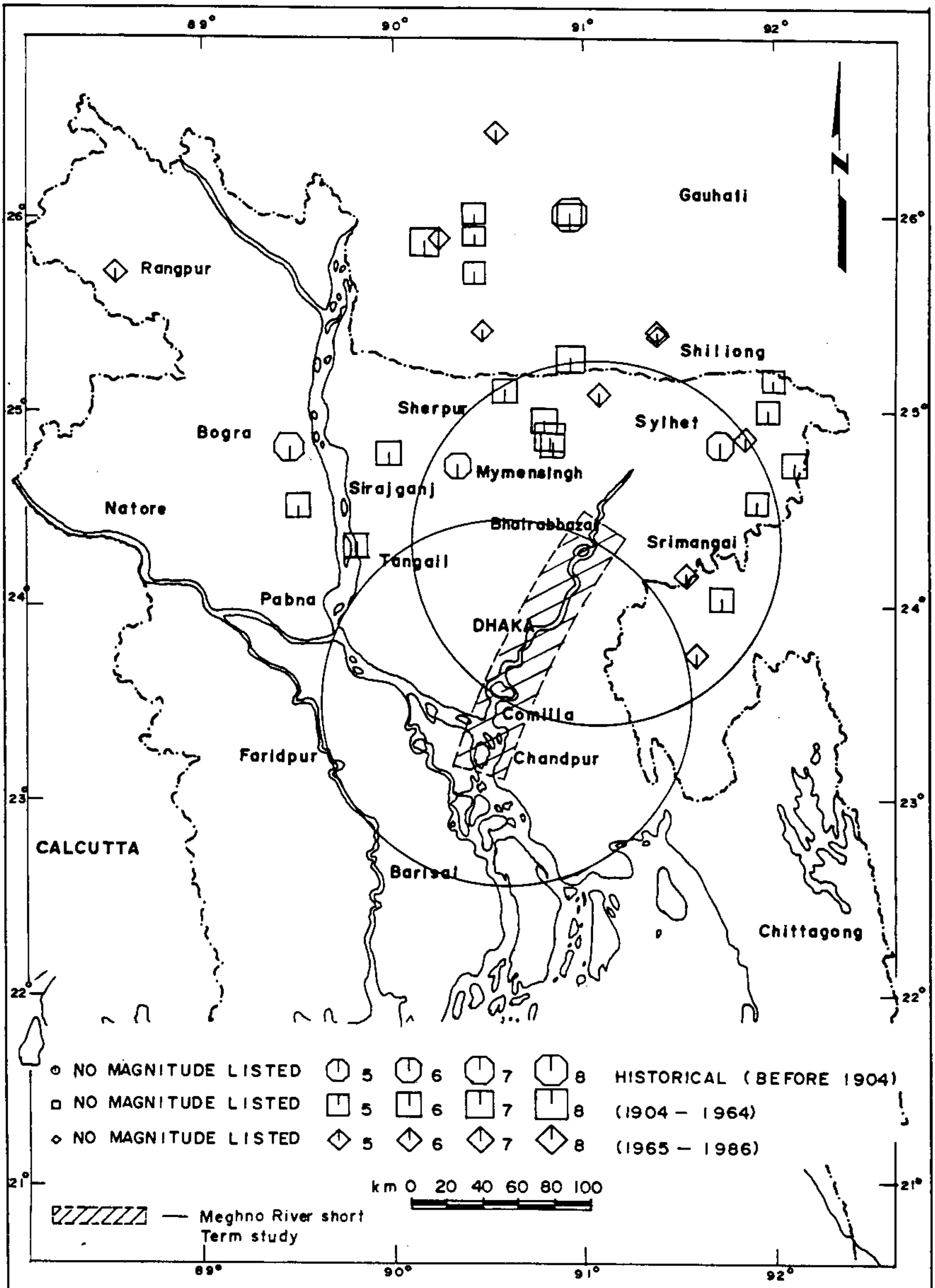

SOURCE : REF. 19

| GENERALIZED TECTONIC MAP OF BANGLADESH AND ADJOINING AREAS | FIGURE NO. C.3.1 |
| --- | --- |




Source : Ref. 20

**SEISMIC ZONING MAP OF BANGLADESH** | **FIGURE NO. C.3.2**




Source : Ref. 21

**Regional Seismicity (Magnitude > 5, distance to site < 250 km)**

**FIGURE NO. C. 3.3**

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## C.4. ASSEMBLY CHARACTERISTICS & THEORETICAL CONSIDERATIONS

### C.4.1 Discussion on micaceous sand characteristics

#### C.4.1.1 General

Any failure in a soil mass results from exceeding its ultimate shear resistance. Basic components comprising the shear resistance are cohesion and frictional resistance generated by the interparticle forces. The latter are a function of the effective stress. For sand, the cohesive part can often be regarded as non-existent.

Saturation in conjunction with shear movement may dramatically affect the magnitude of developed effective stress and hence the shear resistance. The mechanism or process can be explained as follows:

- Induced shear movements in a dense assembly will tend to increase its volume. Negative pore water pressures will thereby develop, augmenting effective stress levels and shear resistance. The volume increase is denoted as "Dilatancy";

- On the contrary, induced shear movements in a loose array will result in a decrease in volume. This causes development of excess pore water pressure whereby effective stresses will be reduced. Ultimately, effective stresses may become zero meaning that no frictional resistance remains. These conditions, turning the assembly into a heavy fluid, is generally defined as "Liquefaction". This phenomenon can also be physically described as collapse of the particle assembly.

Above descriptions of assembly behaviour represent a generally accepted view. Some very extensive sub-soil investigations at the "Jamuna Bridge" location, carried out in support of the " Jamuna Bridge Phase-II Feasibility Study [22, 23,24 & 25] have shown the cohesionless particle assembly to have specific engineering properties that can be attributed to the presence of mica. This component often goes unnoticed during logging of the sub-soil profile. However, its presence was clearly established in all borings, over the full depth at the location of the slide at Bhairab Bazar [4&5]. The implications of the presence of mica, based on findings in the above mentioned reports, will be elaborated below.

#### C.4.1.2 Micaceous sand and its Implications for liquefiability

Soil composition in the Meghna River Basin appears to be extremely consistent over major distances. Apart from the more or less "active" top 4m, one can recognize particle size to change gradually when moving from upstream to downstream locations.

At the "Jamuna Bridge"- location the $D_{50}$ of the predominantly quartz-type sub-rounded grains varies from 220 to 350 micro-m. Granulometric analysis of carefully handled samples showed the presence of 2-5% (in volume) of mica flakes, having dimensions of 2 to 5 times the grain size. This means that the assembly can be expected to have composite characteristics, with flakes connecting adjoining grain pockets. The quartz-particles are then located within an arrangement of randomly oriented flakes. Such a conclusion on orientation resulted from a careful examination of samples. A fair percentage of mica flakes may lead to a "honey-comb" meta-stable particle assembly. Its properties will influence engineering design parameters.

Mica does not introduce any noticeable cohesive properties. But this material is relatively crushable. It breaks up easily when subjected to induced shear movements or compressive stress increase. As a result, some of the mica flakes will turn into less well recognizable pieces, normally classified as silt.

Above mentioned assembly properties will, to a large extent, affect the development of natural slope angles. The following physical phenomenon can be recognized:

- flake length, when compared with grain size, will introduce some sort of intergranular bond. This "bond" will improve assembly stability when compared with an assembly consisting of grains only. This bond may partly show up as a cohesion intercept when samples are tested in the laboratory. A similar effect is obtained when e.g. constructing slopes on the basis of "reinforced earth " or when mixing sand with P.V.C. or steel filaments. In engineering practice, it means that a steeper slope can be maintained when compared with conditions without such measures;

- induced shear movements, e.g. due to earthquake loading, may ultimately result in conditions whereby the crushable mica can no longer withstand the applied bending and tensile stresses. The flakes will break up and as a result a relocation of grains and flakes will take place. Parts of the crushed flakes will find ample free space between the grains. The assembly volume will consequently tend to decrease, implying the onset to a new process of consolidation and densification. In saturated conditions, this phenomenon will result in the development of excess pore water pressures. This event will be initiated at localized pockets where static shear resistance is exceeded, to spread progressively as a time-dependent phenomenon to neighbouring zones where similar soil conditions persist. Ultimately, the entire soil mass will liquefy and pore water will seek its way out. At ground level, this may result in "boiling sand" conditions.

Slope failures resulting from previously described phenomena often lead to mass flows. Such conditions, however, do not allow slope stability to be calculated on the basis of strength parameter $\phi'$ in conjunction with design procedures adopting development of circular failure planes (Bishop a.o.).

### C.4.1.3 Stress and density development in micaceous sand

Constitutive relationships, defining anisotropic assembly behaviour, allow quantification or "stress-interlock" phenomenon. Stress interlock implies conservation of a part of the horizontal stresses developed as a result of a previously experienced higher stress level (i.e. the so-called over-consolidation effect). Such conditions may result from e.g. geological pre-loading effects or scour or man-made activities as dredging and excavation. This physical property is sustained by the relatively high elasticity modulus and low crushability of quartz particles.

The presence of crushable mica, interferes with above mentioned phenomenon. Minor soil movements e.g. due to tremors and earthquakes, will contribute to mica crushing, thus annihilating pre-loading effects. This means that these soils (fine and coarse micaceous sand) can all be regarded to be in a normally consolidated state. Specific laboratory testing to this effect for the "Jamuna - location" resulted in an at-rest stress ratio of approximately $K_0 = 0.44$.

The crushability of mica also imparts, because of the geological age of layers, to influence soil density with depth. When monitoring in-situ densities (bulk density) up to 60 m of depth, using nuclear density testing equipment, a gradual increase of density with depth was monitored. This observation confirms the previous observations regarding the effects of mica crushing.

These observations are also confirmed in this study by a comparison of in-situ densities and critical densities. Especially in the top 10 meters one can recognize a tendency for the in-situ density to be lower than the critical. Deeper layers suggest all layers to have a critical density, an observation confirmed by the development of negative pore pressures only in de CU-triaxial tests. Grain size analyses on some silty fine sand, being carried out twice on the same sample, showed the effect of handling by a slight shift to fines after the second analysis.

When assessing N-values (or cone resistance) with respect to density, it eventuates that low readings do not necessarily signal extreme loose conditions but much more the effect of reduced confinement due to the presence of mica. Based on this observation, there seems to be a risk in applying text-book procedures to assess liquefiability. In fact, the presence of mica is an aspect that has not extensively been dealt with in literature as yet.

### C.4.1.4 Compactability of micaceous sand

It is a generally accepted phenomenon that shear properties of loose sand can be improved by means of compaction. But it is to be recognized that in dealing with micaceous sands, compaction energy will partly be absorbed (and lost) by the crushing of mica. This was confirmed by a number of field experiences: the compaction efforts often yielded results below expectation.

### C.4.1.5 Development of negative pore pressures

During the process of erosion one must expect the soil layers in the slope to be in a constant process of stress reduction, i.e. decompression, especially in surface layers. This means that in saturated fine grained material, e.g. silt, negative pore pressures (cavitation) will develop. In more fine sandy material this phenomenon will develop as well, however, to a lesser degree. Development of these negative pore pressures has clearly been established in laboratory tests. These stresses contribute to the development of a temporary cohesion intercept.

The negative pore pressure will initially contribute to the development of shear resistance, reflected in a steep slope angle. In a static situation, however, such negative pore pressures will dissipate in time. Consequently a shear reduction takes place and an oversteep slope remains. Induced shear movements will consequently result in mica crushing, hence promoting instability.

Negative and positive pore water pressures may develop as a result of the cyclic effect of earthquake loading. The latter will then promote instability.

## C.4.2 Modes of slope failure

### C.4.2.1 General

Causes of slope failure are often of a composite nature. Main elements involved in the slope instability entail strength parameters, slope angle and the influence of ground water on the shear resistance governing effective stresses and dynamic forces, e.g. earthquake. A slope must fail when the induced shear stresses exceed the ultimate shear resistance. This will result in rapid or progressive displacements. A study of case histories often signals a combination of destabilizing phenomena to be the origin of slope failure, ultimately resulting in exceeding the shear capacity.

Without any other effect of the presence of ground water other than buoyancy it is commonly accepted that the angle of internal friction $\phi'$ will approximately define an infinite slope angle with a safety factor $n=1$. However, external loadings, e.g. due to earthquake loading and seepage forces, may render such a slope unstable. Therefore, standard codes of practice recommend stable slope to be designed for a safety factor $n = 1.5$. Considerations for the choice of safety factors as function of loading condition are elaborated upon in Section C.4.2.5.

An evaluation of slope stability phenomena in sandy soils will require a distinction to be made between macro- and micro-stability aspects. In general, it can be concluded that unprotected slopes may exhibit both modes of failure. The installation of a well designed slope protection serves to enhance micro-stability. However, such a measure will never directly contribute to macro-stability. Indirectly, however, one can expect that micro-stability measures will enhance conditions to maintain macro-stability as well.

In the following sections, a discussion of the various aspects of natural slope unbalancing leading up to failure is given. A general understanding of these aspects may serve as a guide line for bank stability evaluation along the Meghna River. It then follows that the slope angle of unprotected banks is very much affected by river morphology, i.e. exposure to currents.

Distinctions can then be made between slopes located at outer and inner bends, in conjunction with seasonal effects of free and ground water levels.

### C.4.2.2 Natural (critical) slope angle

When exposed to the continuous effect of erosion too steep underwater slope angles may develop. Such slopes may form part of the underwater river bank and flow channels in the river bed itself. The steepest slope angles, derived from topographic and bathymetric surveys, can be regarded as critical natural slopes. Slope angles of 1:1 and 1:1.5 have been established. Such slope angles should match the shear properties established in the laboratory and the boundary conditions leading up to failure; i.e. layering. piezometric head and supposed shape of failure plane.

Slope failures as a result of erosion and subsequent instability will often occur as localized events over the entire slope length. Slope parts will fail, causing the development of steeper sections in areas above. This will result in a sequential failure mechanism, being part of the erosion process. Specific conditions, however, may also result in overall slope failures as noticed in Bhairab Bazar.
An analysis to this effect indeed confirms that soil layering and piezometric levels at this location, after a very high water, provided the critical conditions resulting in a slope failure.

### C.4.2.3 Phenomena governing slope stability

The normal regime of a river, with falling and rising water levels, affects ground water tables in the land adjoining the river. Next to the effects on stability due to these changes the erosion, the washing away of dislodged material, will contribute to the overall behaviour of an exposed slope. Following effects can be recognized:

(a) Macro-stability

Too steep a slope angle, with or without a slope protection, will result in a failure due to exceedance of the ultimate shear resistance. Within the sand mass, the governing strength parameter will then be the angle of internal friction $\phi'$.

Without any ground water flow between ground and free water the hydraulic gradient equals zero (Figs. C.4.1 and C.4.2). Overburden stresses only will govern shear resistance. An in- or outwardly directed gradient perpendicular to the slope face will increase or reduce the overburden stress level. Allowing for loading conditions above and the consistency of fine and silty fine sand layers, a potential failure plane will have an approximately circular shape.

Macro-stability will also be at stake in case of liquefaction. This condition, resulting in extremely flat slopes after failure, has a different failure mechanism when compared with the circular failure plane. This condition is covered in more detail in Section C.4.1.2.

Analysis of macro stability, often termed as overall stability, will be covered in more detail in App. C/5, and conclusions drawn in Section 8.2.1. The following conditional events can be recognized:

(i) With water levels in the river rising, the rise of the ground water table will lag behind. As a result the slope will be subjected to an inwardly directed seepage force. This force, acting perpendicular to the slope, will increase overall slope stability. In conjunction with the erosive action of the river at an outer river bend, a relatively steep and critical underwater slope can then be developed and maintained;

(ii) The body of a developed natural slope may become oversteep when ground water flow due to subsequent falling water levels in the river results in a reduction of effective stresses due to uplift forces. Simultaneous reduction of shear resistance will then reduce its safety against sliding and may, ultimately, render a slope oversteep;

(iii) Critical slope angles must, by definition, represent a safety factor of n = 1;

(iv) The presence of a slope protection is required to suppress erosion phenomena and to maintain a required overall slope angle with n>1. **The protection, however, does neither reduce nor increase the macro-stability**.

Previously described phenomena lead to the conclusion that next to the common erosive action of an exposed slope falling water levels in the river will introduce the most severe risks of loss of micro- and macro-stability. These risks, most prominent directly after very high water levels, on its turn will depend on the developed ground water gradients and soil layering. Aspects of erosion accompanying such phenomena are elaborated in the next paragraph.

(b) Micro-stability

Soil stratification and current velocity will have a bearing on the mechanism leading up to loss of micro-stability. Following conditions may occur:

(i) With water levels in the river falling the direction of a previously mentioned seepage force will be reversed. The ground water table will lag behind the falling river level and groundwater will escape at the slope surface. The resulting uplift force, quantified via the ground water gradient, will reduce effective stresses and, consequently, reduce stability.
The river current passing along the slope will also induce a pressure head difference perpendicular to the slope, resulting in some increase of the ground water gradient;

(ii) The uplift condition is governed by the gradient of the ground water flow. Total reduction of effective stresses in an unprotected slope, an extreme condition, will result in dislodging of particles, causing local instability and removal of material.

Following typical conditions can be recognized:

- Single Layered Soil

  Homogeneous conditions, with fine to medium sand, as encountered at the "Jamuna Bridge" location, result in a ground water flow net as shown in Fig. C.4.3. The dashed lines, with arrows, define the direction of ground water flow. The solid lines, when at close distance, define the developed gradient. High gradients appear to develop just above and below the free water level. This will consequently be the zone of dislodging of particles and soil softening, initiating local failure. This phenomenon can be recognized as the common erosion process of river banks. The river current, washing away collapsed bank material, will further aggravate this process.

- Stratified Soil

  Soil stratification will introduce layers with different permeability characteristics. Ground water flow will quantitatively be concentrated in layers with the highest permeability. Such conditions are depicted in Fig. C.4.4.

  It eventuates that this condition aggravates the localized failure mechanisms due to concentration of flow lines at ground water level. A slope failure results in a reduction of the overall stress level and consequently elastic assembly properties may then result in the temporary development of negative pore water pressures, especially in the low permeability layers. These pressures in turn will result in sustained shear resistance. They will create more stable horizons that are easily undercut by the erosive action of underlying high permeability and

cohesionless layers. Low permeability layers will then fail in shear and tension, often exhibiting vertical faces above the water line.
Additionally, dissipation of negative pore water pressures may result in a degeneration of shear strength characteristics.
In Fig. C.4.4, the following mechanism can be recognized :

- ground water escapes from the surface of the top sand layer, flowing over the slightly more stable layer. Sand will be removed causing development of a steeper slope. This condition will continue as long as major quantities of groundwater will escape in this way.

- flow lines in the second sand layer will curve upwardly below the more stable layer (1). A concentration of flow lines, signalling a high gradient, will initially result in a softening of the sand below the more stable layer (1). This layer will loose its bearing and collapse due to lack of support. The slope of the failure plane in layer (1) will often have a practically vertical face, deteriorating with time. This failure in turn will have propagating effects on the overlying layers. The erosion process will consequently be intensified.

- when silty and clayey layers form part of the top layers vertical faces will become typical for the river bank (Fig. C.4.5).

- a similar layering at greater depth may experience toe-softening, e.g. at Bhairab Bazar). Similar propagating erosion effects may then affect the slope body as a whole, bringing about overall failure phenomena (Fig. C.4.6).

It can be recognized that, depending on the more specific site conditions, above micro-stability affecting phenomena may induce a more extended failure mechanism, i.e. loss of macro-stability.

- <u>Man-made damage and borrows</u>

  Micro-stability of surface layers may be also be affected by the activities of man, such as;

  - mooring of boats

  - surface layers being used as quarry, for the manufacturing of bricks

Additionally, the presence of borrows of e.g. rats may contribute to piping during high waters.

### C.4.2.4 Capillarity and negative pore water pressure

The effect of capillary forces within the particle assembly is restricted to the unsaturated zone. Its effect, of a temporary nature only, introduces a particle bond that enhances stability. Physical properties of particle water contact imply this effect to become more prominent with decreasing particle size. Though being above the ground water line its density will practically remain that of saturated material. In a slope stability analysis this effect will be realized by means of the introduction of the wet density above the ground water table.

The result of temporary bond is recognizable in the fine grained vertical faces above the free water level of the eroded river bank.

A similar type of temporary bond can develop in saturated fine material below the water table (Section 4.1.5).

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## C.4.2.5 Safety factor and procedures for slope stability analysis

### (a) Safety factor

The numerical analysis of slope stability should be accompanied by the choice of an appropriate safety factor "n", defining the ratio of developed over ultimate shear stress. A certain safety factor must be applied for the overall slope (macro) as well as any structural element of the slope protection (micro). The magnitude of "n" is, among other things, a function of:

(i) variation in the design parameters, shear strength & density;

(ii) type and frequency of various loading types (self weight, ground water, surcharge on bank and earthquake loading);

(iii) slope deformation and maintenance criteria, the former referring to a predominantly elastic behaviour under permanent loading and the latter too a loading condition where some plastic deformation can be accepted.

**Design parameters**

The establishment of shear strength parameters of soil will primarily be based on the results of CU-triaxial tests. These tests have been carried out on undisturbed samples. An effective cohesion intercept has been observed in all test results, being consolidation stress and soil composition dependent. This effect, however, must be regarded as temporary only as negative pore pressures will be the main source of this effect (Section 4.1.5). Dissipation of this effect with time will render these layers as practically cohesionless in the long term. This will transpire into a slight increase of the angle of internal friction. Taking into account these effects and the suggested safety factor when allowing for earthquake loading, a lower bound approach is preferred when selecting design parameters.

The in-situ density, a less sensitive parameter in a slope analysis, has been selected on the basis of approximate averages, established in conjunction with triaxial testing.

The interface shear properties of soil-geotextile and geotextile-geotextile can, at this stage, be defined on the basis of data published in literature. Lower boundary conditions will be defined to ensure that any manufacturer can be requested to prove the material properties, pertinent to conditions on site.

**Safety factor for static loading**

The most common loading, to be regarded as a quasi static condition, results from the static effects of gravity on the soil mass in conjunction with the effects of falling high water levels and currents on piezometric heads. The loading frequency of this condition and the wish to ensure plastic movements not to become a design element of the overall slopes (macro) and/or the bank protection (micro) results in the adoption of a minimum safety factor of n = 1.5. The latter value is concurrent with international design codes for this loading condition. Its magnitude ensures predominantly elastic phenomena to post-construction slope deformation.
The introduction of a lower safety factor will allow elasto-plastic deformations to take place. This introduces a risk of damage to the slope protection and consequently, to the overall slope as well.

**Safety factor for static + dynamic loading**

The combination of previous loadings with the effect of an earthquake (0.05g) will have a much lower incidence. The earthquake load will act on the whole soil mass, affecting overall stability only. It has to be recognized that, on the one hand, such an event may have some effect on the integrity of the works. On the other hand it is a known phenomenon that the event of earthquake loading does not coincide with actual failure. The physical process of time dependent progressively developing collapse of a loose assembly can be avoided only by suppressing the allowable shear stress level. A weighing of the combination of above effects, in conjunction with the choice of lower-bound values for shear strength parameters, resulted in the adoption of a minimum safety factor of n = 1.1 for the macro stability.

(b) Circular failure plane

The numerical slope stability analysis, assuming development of circular failure planes, will be carried out on the basis of Bishop's method of slices. The principles of this method are supposed to be well defined through various text books. They do not need to be elaborated here. The applied computer programme is denoted as BISEIS (HASKONING, Netherlands). Particulars of this program can be summarized as follows:

- Pore water pressures are defined for the upper and lower boundary of each defined layer. The maximum number of layers is 10.

- Linear interpolation of water pressures between locations with defined change in piezometric head;

- Division of the sliding mass in minimally 20 vertical slices;

- Horizontal earthquake forces, as a percentage of the vertical force, supposed to be acting in the centre of gravity of the respective slices;

- Slip circles being considered are introduced through a grid of circle centre points or a fixed centre point and lower tangent lines;

- Output data being presented as print-out, defining developed safety factors, and as plot, showing critical slip circles.

(c) Straight failure plane

Taking into account the great length of the slope, localized slips may be the result of practically straight failure planes, in surface layers parallel to the slope surface (Fig. C.4.7). Following phenomena will then govern stability:

(i) The magnitude of uplift forces is a function of the gradient in the ground water flow and the head increment due to ground water velocity. It suffices to define this gradient "i" as piezometric head difference, between ground water and river level. The maximum head difference (for the whole slope) is selected at approx. 3.5m. For more localized sections a limited head increment may occur due to localized increases in the current velocity;

(ii) In a natural "critical" unprotected slope the gradient "i" may become 1 at the free water level, causing collapse of the layers above. This is one of the causes of receding river banks!;

(iii) In a design slope (1:3.5) with open protection, e.g. when using boulders, gradients will be reduced dramatically. The gradient will approximate 0.03 to 0.05, averaging 0.04;

(iv) Additionally the gradient within the slope protection, as function of current velocity and wave attack, must be taken into account when detailing the slope protection. These aspects will be covered in "Design of Bank Protection", Volume V, Annex G;

(v) When analyzing very long slopes a macro-stability analysis, resulting in slip circles with radii approaching infinity, will asymptotically approach the equilibrium conditions defined on the basis of an infinite slope.

A stable slope surface (protection) implies any element of a the surface to be stable by itself. It means that not only a rupture plane in the soil itself must satisfy equilibrium conditions but also any discontinuity in the section. Such a discontinuity may e.g. result from the introduction of geotextile, depending on the frictional properties at the interface soil-geotextile.

Critical surface layers will be evaluated on the basis of above mentioned influences. For such an analysis it is assumed that a temporarily exposed natural slope, during construction, will assemble predominantly cohesionless material on its surface. Consequently a lower bound angle of internal friction $\phi'$ will be regarded as the sole parameter to define sub-soil conditions directly below the bank protection. Reference being made to the loading models depicted on Fig. C.4.7 following general equations can be established to define the allowable slope angle $\alpha$;

(i) Interface geotextile-soil & geotextile-geotextile (saturated condition)

Design parameters:

- friction angle at interface: $\beta$
- safety factor: n
- allowable slope angle: $\alpha$

$$n = \left\{\frac{\tan\beta}{\tan\alpha}\right\} \qquad (1)$$

(ii) Gravity, no ground water gradient

Design parameters:

- angle of internal friction $\phi'$ ($c' = 0$)
- safety factor: n
- allowable slope angle: $\alpha$

$$n = \left\{\frac{\tan\phi'}{\tan\alpha}\right\} \qquad (2)$$

(iii) Gravity, with ground water gradient

Design parameters:

- angle of internal friction $\phi'$ ($c' = 0$)
- ground water gradient (perp. slope): i
- safety factor: n
- allowable slope angle: $\alpha$

$$n = (1 - i)\cdot\left\{\frac{\tan\phi'}{\tan\alpha}\right\} \qquad (3)$$

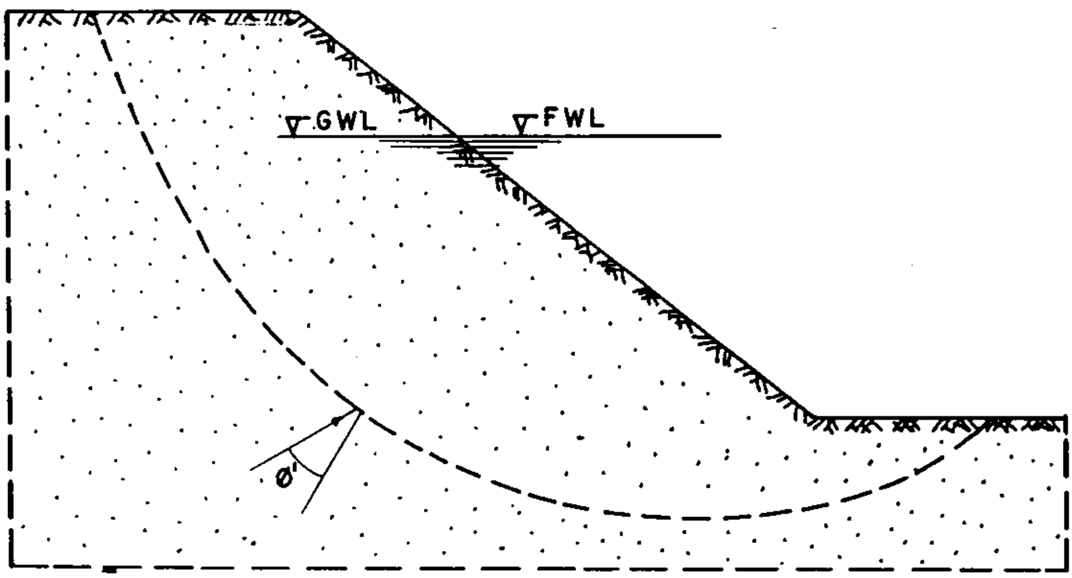
**Note:** Gradient "i" defines the effect of groundwater flow perpendicular to the slope face, below the slope protection.

**BOUNDARY CONDITION**

Macro – stability
Soil type : Medium dense to dense sand
Ground water level = Free water level

**FAILURE PHENOMENON**

Oversteep slope
Exceeding angle of friction (ø')



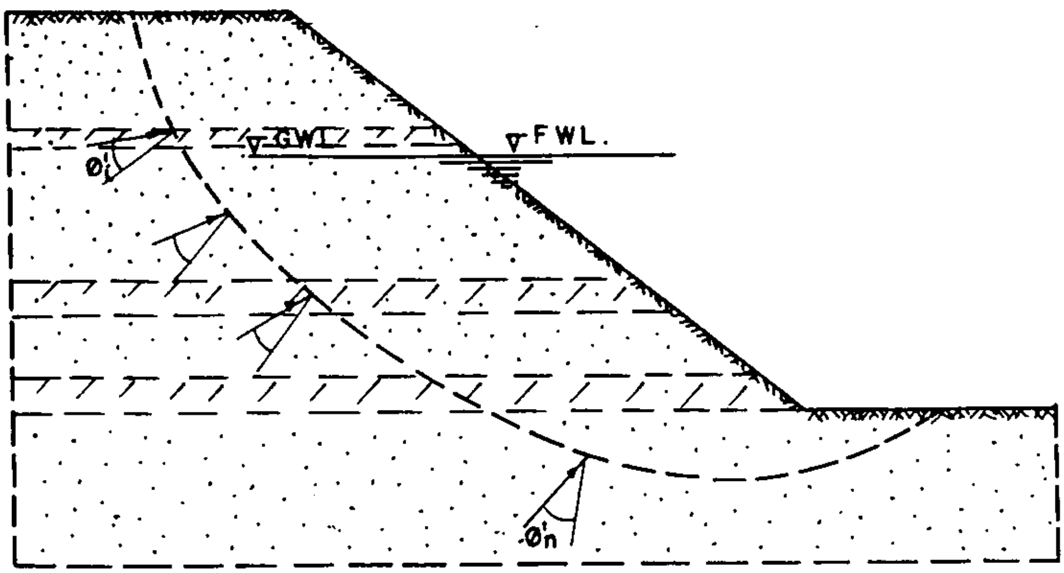

| MACRO – STABILITY IN SINGLE LAYERED SOIL | FIGURE NO. C. 4.1 |
|---|---|

## BOUNDARY CONDITION

Macro – stability
Soil type : Layered sand and silty sand
Ground water level = Free water level

## FAILURE PHENOMENON

Oversteep slope
Exceeding angle of friction ($\phi'_i$)



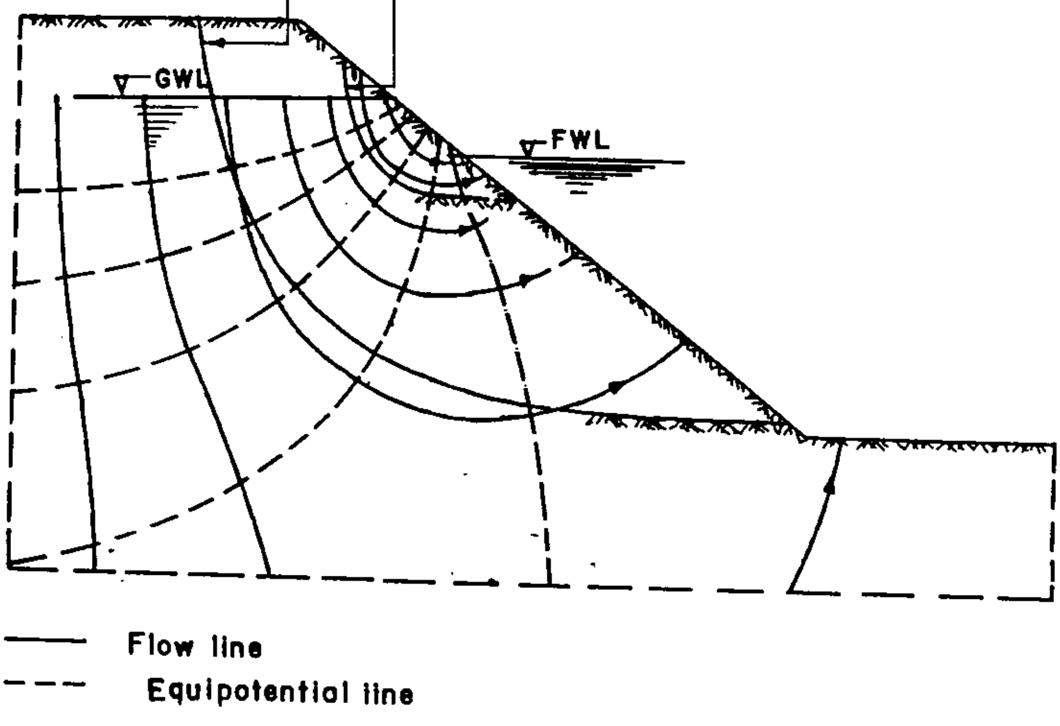

| MACRO – STABILITY IN MULTI LAYEREO SOIL | FIGURE NO. C. 4.2 |
| --- | --- |

BOUNDARY CONDITION

Macro- stability and micro-stability
Soil type : Medium dense to dense sand
Ground water level > Free water level

FAILURE PHENOMENON

Reduction effective stress
Loss of micro-stability near top +
Loss of macro-stability inside =
Combined phenomenon



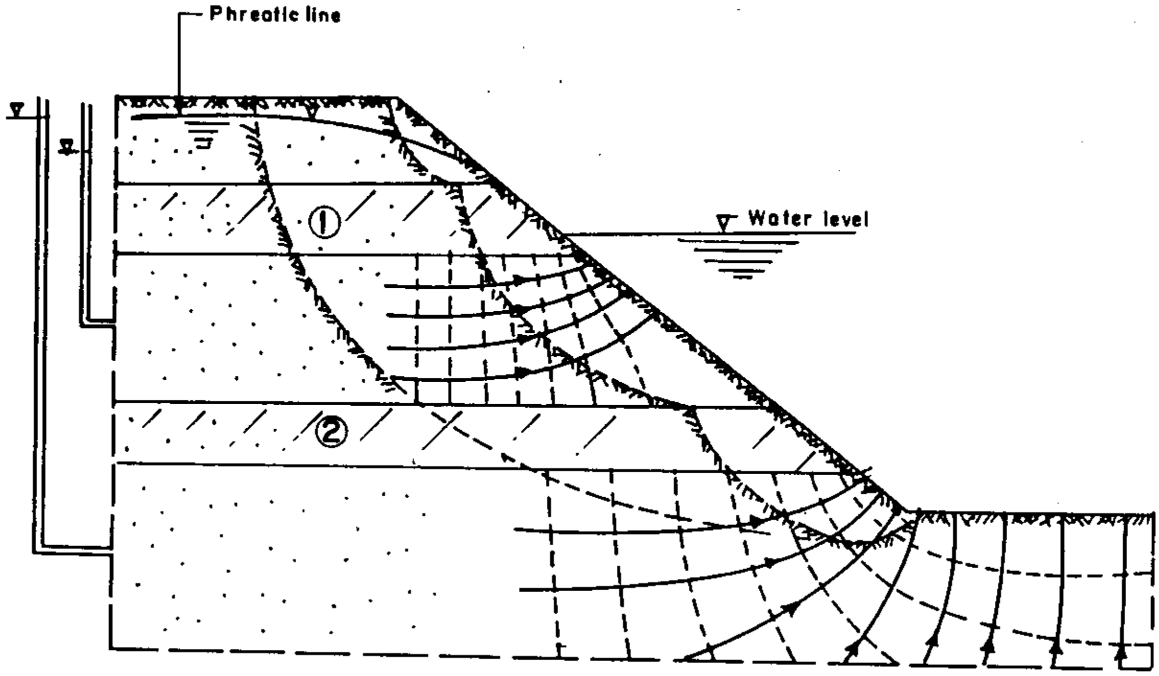

| MACRO AND MICRO – STABILITY IN SINGLE LAYERED SOIL | FIGURE NO. C. 4.3 |
|---|---|

## BOUNDARY CONDITION

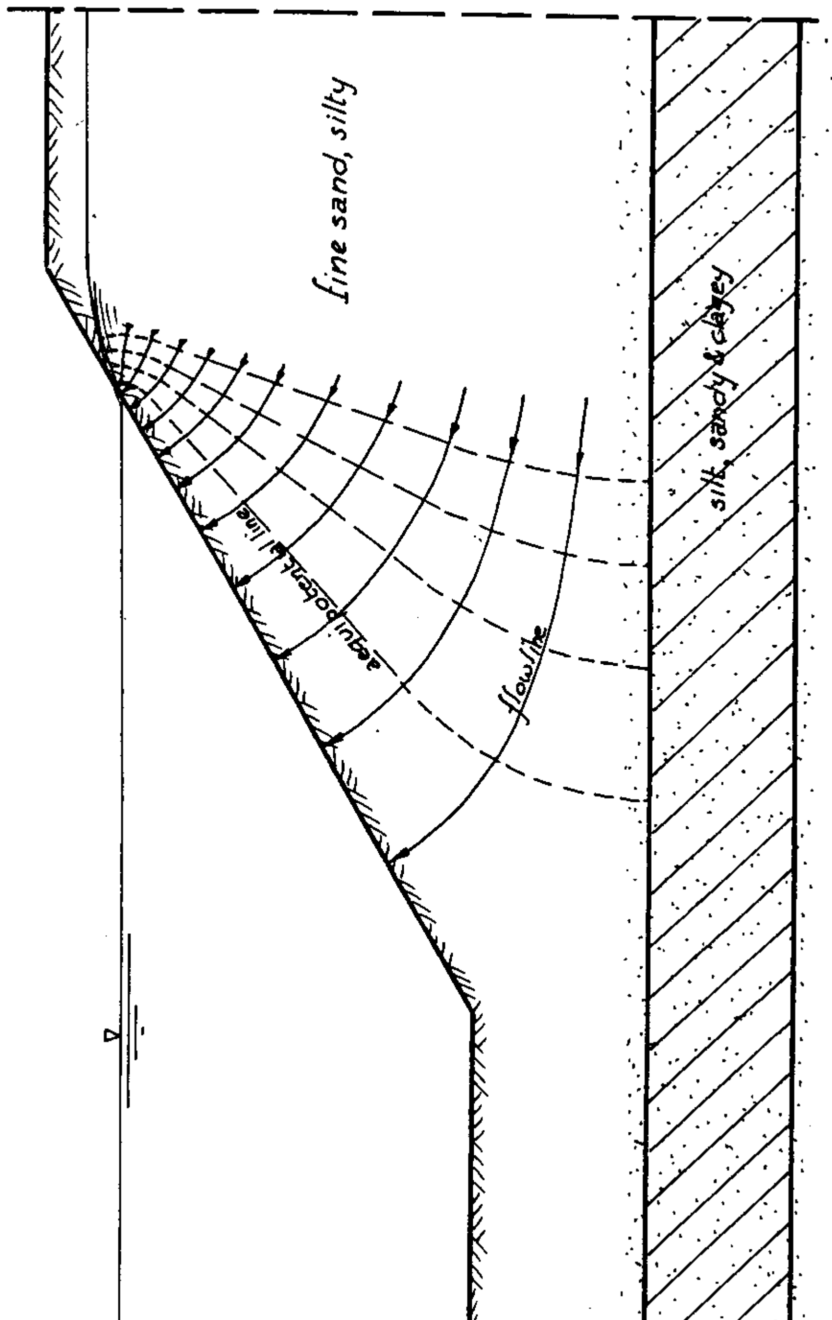
Micro - stability ⇒ macro - stability
Soil type : Layered sand and silty sand
Ground water level > free water level

## FAILURE PHENOMENON.

Erosion of top Embankment
softening below (1), followed by collapse
Toe softening, followed by collapse




| | |
|---|---|
| MACRO AND MICRO – STABILITY IN MULTI LAYERED SOIL ( GWT : HIGH) | FIGURE NO. C.4.4 |




TYPICAL CROSS SECTION AT BHAIRAB BAZAR

| GROUND WATER FLOW CONDITIONS AT BHAIRAB BAZAR | FIGURE NO. C.4.5 |
|---|---|

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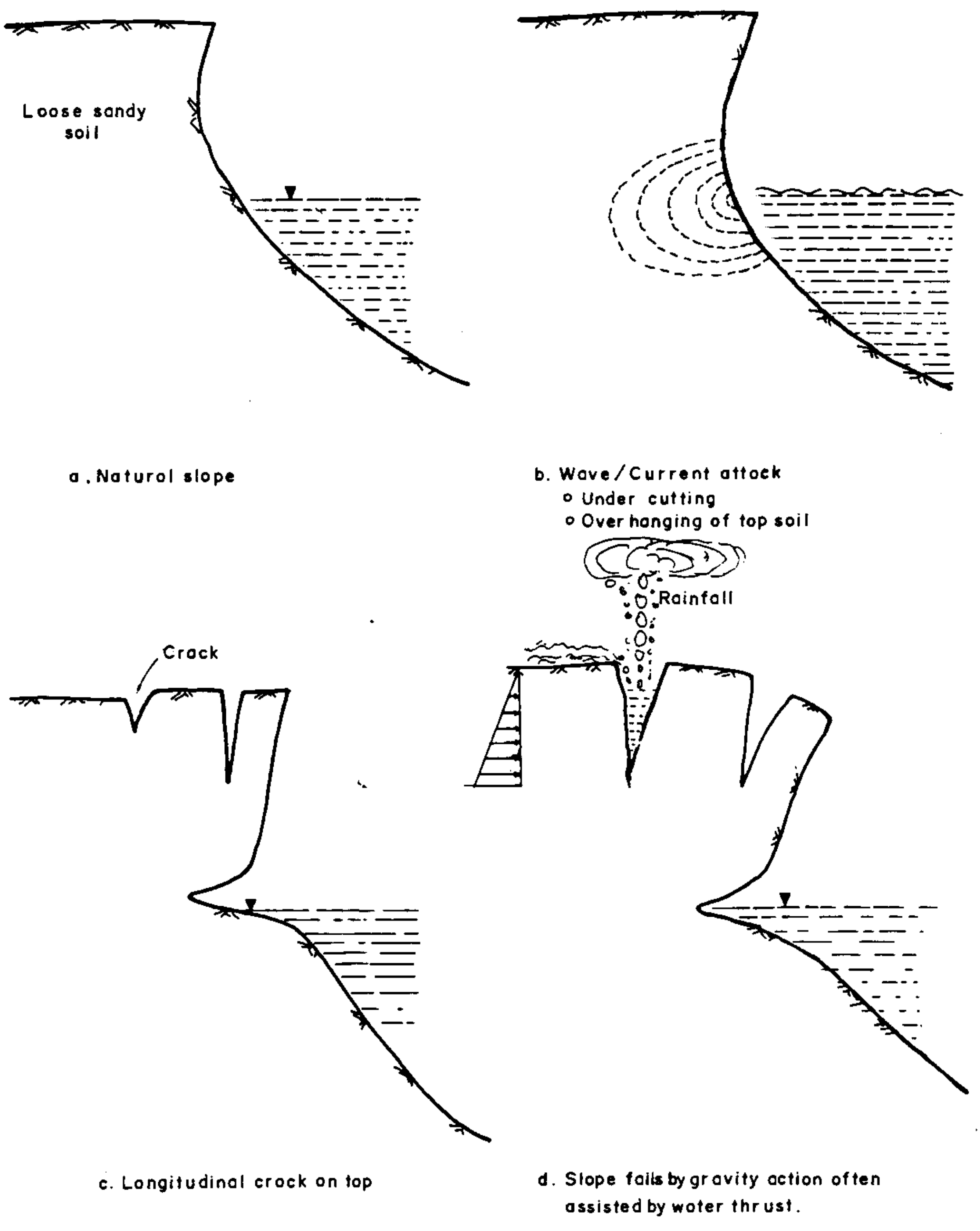
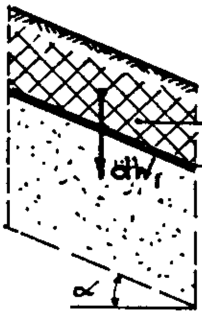



| Micro to Macro mode failure cycle | FIGURE NO. C.4.6 |
| --- | --- |

# EQUATIONS FOR $\Sigma H = 0$

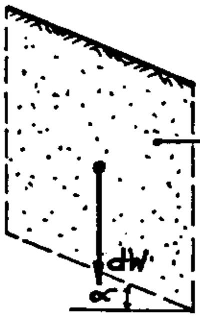
## INTERFACE GEOTEXTILE-SOIL




$$dW' \cdot \sin\alpha \cdot n = dW' \cdot \cos\alpha \cdot \tan\beta$$

$$\therefore\ n = \frac{\tan\beta}{\tan\alpha}$$

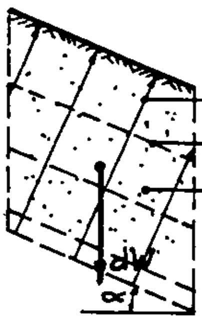
## SOIL, NO GROUND WATER GRADIENT




$$dW \cdot \sin\alpha \cdot n = dW \cdot \cos\alpha \cdot \tan\varphi'$$

$$\therefore\ n = \frac{\tan\varphi'}{\tan\alpha}$$

## SOIL, WITH GROUND WATER GRADIENT




$$dW \cdot \sin\alpha \cdot n = dW \cdot \cos\alpha \cdot (1 - i) \cdot \tan\varphi'$$

$$\therefore\ n = (1 - i) \cdot \frac{\tan\varphi'}{\tan\alpha}$$

$\beta$ = friction angle geotextile
$\alpha$ = slope angle
$\varphi'$ = angle of repose
$i$ = ground water gradient
earthquake load: 0.05g

| EQUILIBRIUM IN INFINITE SLOPE | FIGURE NO. C.4.7 |
|---|---|

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## C.5. GEOTECHNICAL INVESTIGATION PROGRAM

### C.5.1 General

The investigation was carried out in three stages; (1) desk study of the existing data (2) field investigation comprising of drilling, sampling and testing (3) laboratory testing and analysis.

### C.5.2 Field investigation

#### C.5.2.1 Bore holes

Eight 101 mm diameter bore holes were installed. The location of the holes are shown in Figs. C.5.1 to C.5.6. Table C.5.1 presents a compilation of data pertinent to sinking of the bore holes, testing, sampling and ground water table.

**Table C.5.1 - DETAILS OF BORE HOLES**

| site number | Location/area | Bore hole no.: | Depth below G.L. [m] | Ground water - G.L. [m] | SPT (NO.) | Sample (dist.) | Sample* (und.) |
|---|---|---|---|---|---|---|---|
| 1 | Bhairab Bazar Railway Bridge<br>Bhairab Bazar Town ship | BR-1<br>BR-2 | 50<br>30 | 5.40<br>5.13 | 25<br>18 | 29<br>19 | 7<br>4 |
| 2 | Meghna R&H Bridge | MG-1<br>MG-2 | 50<br>30 | 2.36<br>2.13 | 32<br>15 | 32<br>15 | 1<br>3 |
| 3 | Munshiganj | MN-1<br>MN-2 | 50<br>30 | 1.07<br>3.50 | 18<br>16 | 20<br>16 | 2<br>5 |
| 4 | Chandpur (Nutan Bazar)<br>Chandpur (Puran Bazar) | CH-1<br>CH-2 | 60<br>40 | 4.20<br>3.75 | 27<br>20 | 27<br>20 | 5<br>3 |

* "no recovery" samples not being counted

Two skid mounted drill rigs were employed for the establishment of the bore holes. The bore holes at Meghna R&H Bridge and Chandpur were advanced by "Chopping wash"-technique, using a drill machine manufactured by Boyles Brothers. Those at Bhairab and Munshiganj were made by "Rotary wash"-method, using an Acker (D-II) drill rig. In the latter case the holes were usually unsupported except for the top 3m, where a 150 mm casing was used. Bentonite slurry was used, whenever required, to support the bore holes walls from caving in. Special care was taken during drilling, sampling and field testing to ensure that the water level inside the bore hole was always maintained above the ground water table. This precautionary measure was taken to eliminate the possibility of boiling conditions at the bore hole bottom.

The BH Logs along with all the relevant information (location, soil sampling, groundwater table and soil stratification are given in Appendix C/1.

#### C.5.2.2 Undisturbed sampling

"Undisturbed" samples were taken at selected depths, to allow shear strength and physical characteristics to be established in the laboratory. These samples, taken mainly in the predominantly silty layers, were extracted by means of thin-walled shelby tubes of 70 mm internal diameter and 900 mm length. The recovery of these samples varied between 20 and 50%. Unsuccessful attempts were also made to secure undisturbed samples from sand layers using shelby tube.

The position of all undisturbed samples is shown in the bore hole logs.

Due account shall be given to the almost inevitable adverse affects of tube sampling on the state of stress and density in predominantly sandy soils. Such samples will always be affected. This effect will be less when sampling in silt and more cohesive layers.

C.5.2.3 Standard Penetration Test and disturbed sampling

The disturbed samples were collected from the bore holes during Standard Penetration Test (SPT) sounding. These SPT's were, in turn, conducted at 1.5 -3.0 m interval, in accordance with the ASTM Specifications, to determine the in-situ soil parameters. The number of blows for each 150 mm penetration of split spoon sampler for a total length of 450 mm penetration was recorded. The blows for the last 300 mm penetration was recorded as the measured 'N' value.
The SPT values, obtained from the tests, are shown in the BH logs and Fig.C.6.1 through C.6.7.

C.5.2.4 Installation of standpipe piezometers (observation wells)

Three separate standpipe piezometers with perforated strainers at different depth were installed in clusters, to observe the piezometric heads. The tentative depths of piezometer tip (strainer) are 8, 15 and 25 m below ground surface. The location is shown in Figs. C.5.1 through C.5.6 while the details of piezometer installation and development is given in figs. C.5.7 & C.5.10. Two pictures, Fig.'s C.5.11 and C.5.12, give an impression of the installation procedure. Piezometer installation data and their present state are given in Table C.5.2.

**Table C.5.2 - INVENTORY OF THE PIEZOMETER INSTALLATION**

| Area | Location | Installation | Depth (m) of pz.tip | | | Remarks (08.91) |
|---|---|---|---|---|---|---|
| Bhairab-Bazar | Office compound of SAE Railway, adjoining Railway Bridge | 19-22 March 1991/23 March, 1991 | 25.4 | 17.00 | 7.9 | |
| Meghna R&H Bridge | Compound of mosque at Old ferryghat (Comm. side), Village Tetoitola/Gazaria upazila | 22-24 March 1991/25 March, 1991 | 29.2 | 17.00 | 9.2 | |
| Munshiganj | In the compound of a Nurse villa at Munshiganj Launch ghat | 1-4 April 1991/5 April 1991 | 30.7 | 17.00 | 9.4 | |
| Chandpur | In Nutan Bazar area, adjoining the mosque at the end of R. Station | 5-8 April 1991/9 April 1991 | 30.5 | 16.9 | 7.9 | washed away during cyclone 29 April 1991 |

To install the piezometers, the bore holes were drilled by Wash Boring method. Prior to installation, a check was made against any leakage of water at the junction of the strainer and the PVC pipe. Filter material, 1 - 3 mm size, were used around the strainer to prevent clogging while bentonite lumps were used for the sealing.

C.5.2.5 In-situ permeability testing

In-situ permeability tests, employing the "falling head method", were performed inside the piezometers in accordance with the procedure laid down in BS 5930 (1981) under the supervision of the Engineer-in-charge. To perform the test, the PVC pipe was filled with clear water upto a certain level above the groundwater table. Prior to this, the static ground water level was measured in the PVC pipe. The test was conducted by measuring, at 1 minute intervals, to a maximum of 5 minutes the amount of drop of water in the pipe. The data was analyzed using the equation to define permeability "k" [cm/sec] by means of:

$$K = \frac{r^2}{2L \cdot (t_2 - t_1)} \cdot \ln(\frac{2r}{R}) \cdot \ln(\frac{H_1}{H_2}) \quad (4)$$

The analysis of monitored falls in water levels, with the tests being carried out in predominantly fine sand, appeared to result in unrealistic low k-values. Though actual reasons cannot be determined it could well be that a short monitoring period and internal sealing have contributed. Taking into account the more realistic k-values established in laboratory testing (par. 7.2.2) these latter values will be used in design.

### C.5.3 Laboratory Testing

A significant number of selected laboratory tests was performed on both undisturbed and disturbed soil samples to establish the soil properties. The tests comprised index properties, to classify the soil according to the
Unified Soil Classification System (USCS), and strength tests and mica content. The laboratory tests were performed at the Soil Mechanics Laboratory of the River Research Institute, BWDB, Faridpur while the Mica content was determined at the Soil Laboratory of BUET, Dhaka.

Testing was carried out in accordance with ASTM [27] specifications, unless otherwise specified. An overview of the number of tests performed in the laboratory is presented in Table C.5.3.

**Table C.5.3 - LABORATORY TESTING IN SUPPORT OF SLOPE STABILITY ANALYSIS**

| Area | BH | Test Type | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | NMC | S | SH | SG | TA | Dsn | DSr | PY | AL | CD | |
| Bhairab B. R.B. | BR-1 | 13 | 9 | 9 | 8 | 2 | 2 | | 2 | | | |
| Bhairab B. T.S. | BR-2 | 9 | 4 | 9 | 5 | 1 | 2 | | 3 | | 1 | |
| Meghna R&H Bridge | MG-1 | 8 | 10 | 4 | 5 | 2 | 2 | 2 | 1 | 3 | 1 | |
| | MG-2 | 9 | 4 | 8 | 6 | 2 | 3 | 3 | 2 | 2 | 2 | |
| Munshiganj | MN-1 | 11 | 4 | 6 | 11 | 1 | 2 | 2 | 2 | 4 | 2 | |
| | MN-2 | 11 | | 18 | 11 | 3 | 5 | 5 | 5 | 11 | 3 | |
| Chandpur-N.B. | CH-1 | 15 | 4 | 13 | 14 | 2 | 2 | | 2 | 6 | | |
| Chandpur P.B. | CH-2 | 9 | 1 | 11 | 9 | 3 | 3 | | 1 | 2 | | |

Legend:
NMC; Natural Moisture Content
S: Sieving
SH: Sieving + Hydrometer
SG: Specific Gravity
TA: Triaxial (CU)
DSn: Direct Shear - natural
DSr: Direct Shear - remoulded
PY: Permeability
AL: Atterberg Limits
CD: Critical Density

The results of laboratory testing carried out by RRI are compiled in Appendix C/1. The results of Mica content analysis are shown in Appendix c/2 of this report.

## C.5.4 Chemical analysis

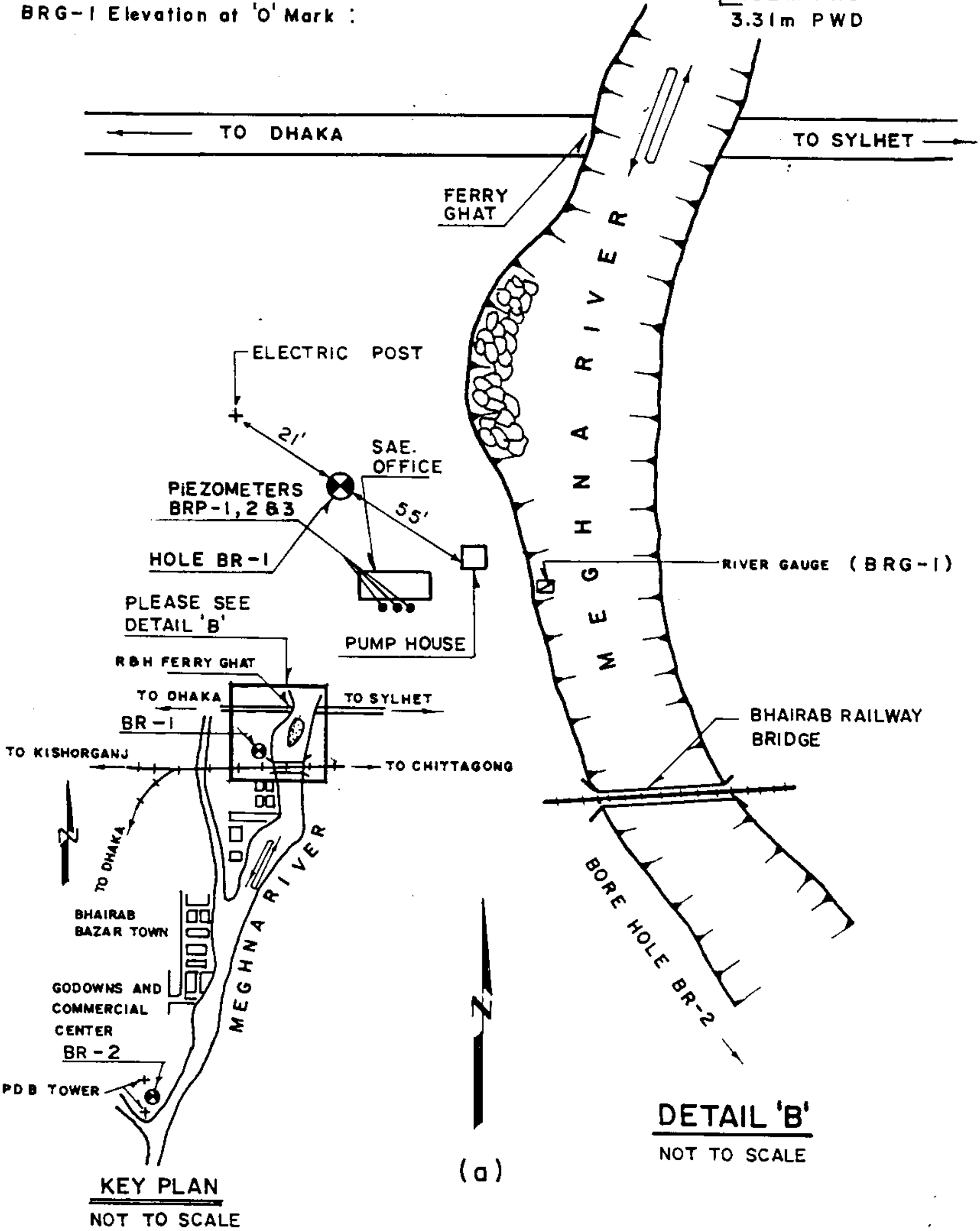
Chemical analyses on selected soil samples taken from the surface were conducted to determine the chemical composition of the soil. The tests were carried out at the Chemistry Department of Bangladesh Council for Scientific and Industrial Research(BCSIR). The soil samples were collected from the proximity of MG-1, MN-1 and CH-1. The relevant letters, with results, are presented in App. 3.

The procedure of the Chemical analysis is given elsewhere [ 27] while the summary of results is presented in Table 7.3.

## BORE HOLE DETAILS

BR – 1 Lat.: 24°-02'-55.5"N Long.: 90°-59'-49.0"E GS. Elev.: 7.39m PWD

| | | | |
|---|---|---|---|
| BRP-1 | 24°-02'-54.6"N | 90°-59'-48.0"E Pipe top | 7.65 m PWD |
| BRP-2 | | | 7.56 m PWD |
| BRP-3 | | | 7.62 m PWD |
| BRG-1 Elevation at 'O' Mark: | | | 3.31 m PWD |

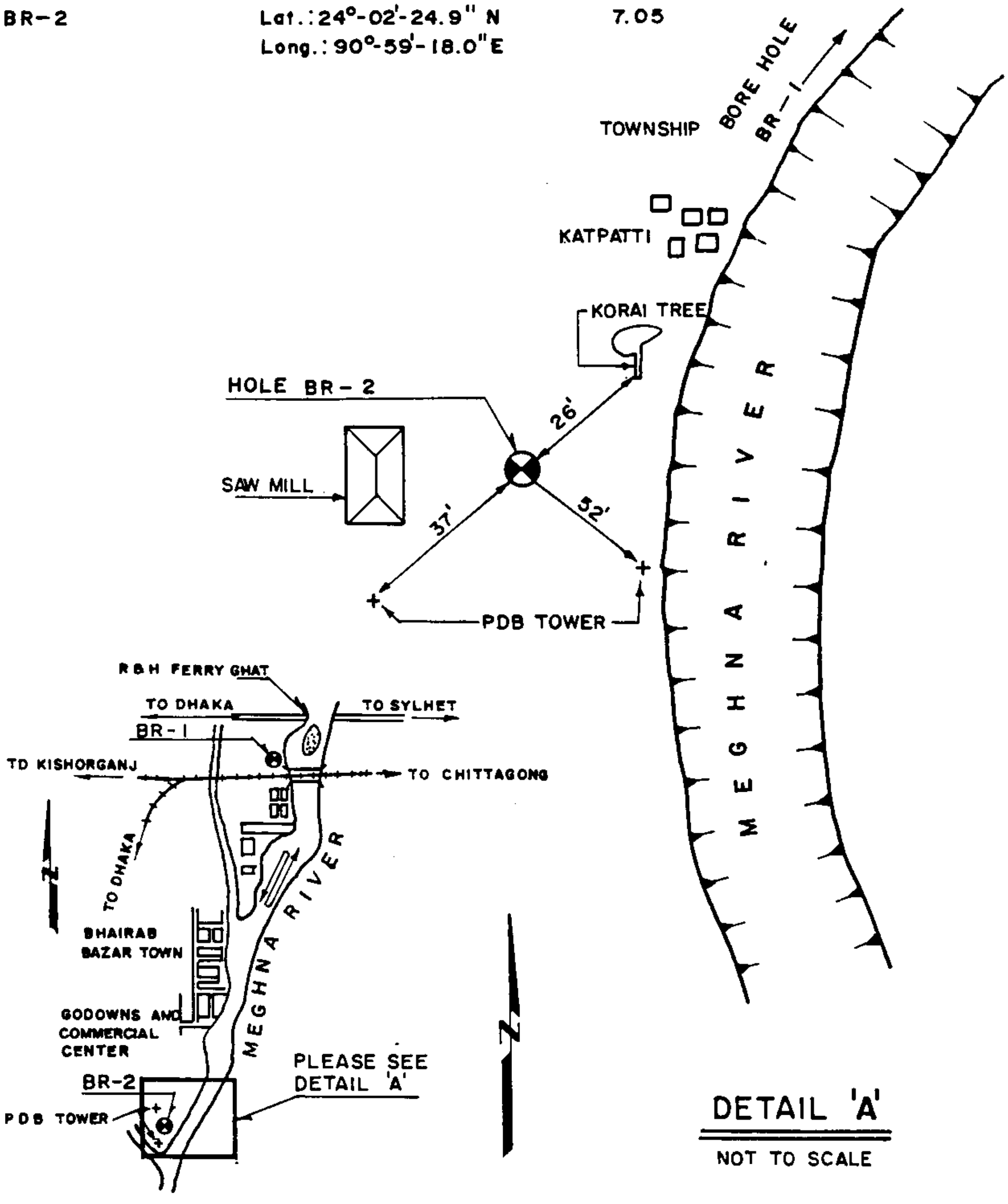



(a)

| LOCATION MAP FOR BORE HOLE BR-1 AT BHAIRAB BAZAR RAILWAY BRIDGE | FIGURE NO. C.5.1 |
|---|---|

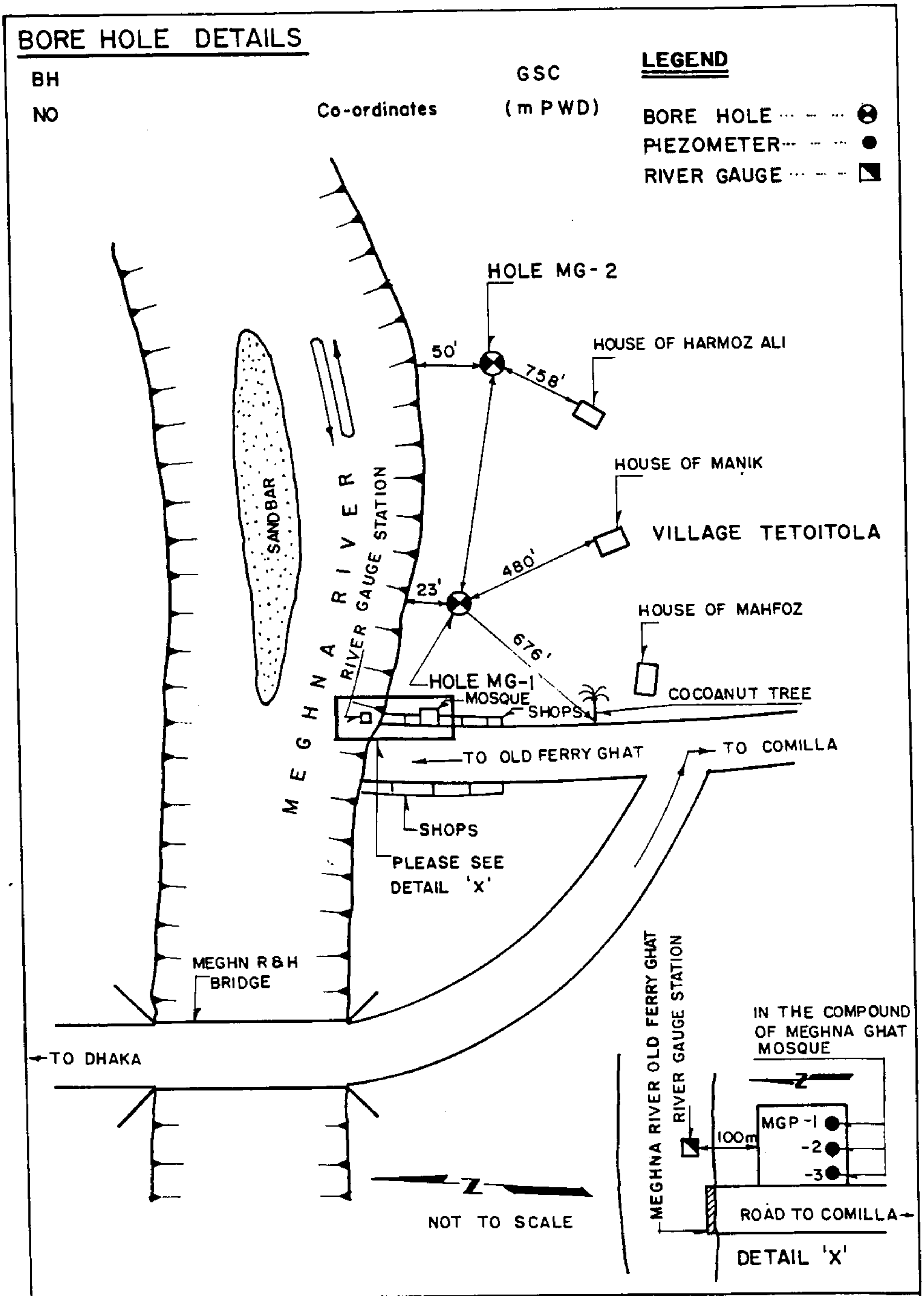
## BORE HOLE DETAILS

| BH NO | Co-ordinotes | GSE (m PWD) |
|---|---|---|
| BR-2 | Lat.: 24°-02'-24.9" N<br>Long.: 90°-59'-18.0"E | 7.05 |




(b)

| LOCATION MAP FOR BORE HOLE BR-2<br>AT BHAIRAB BAZAR TOWNSHIP | FIGURE NO. C.5.2 |
|---|---|

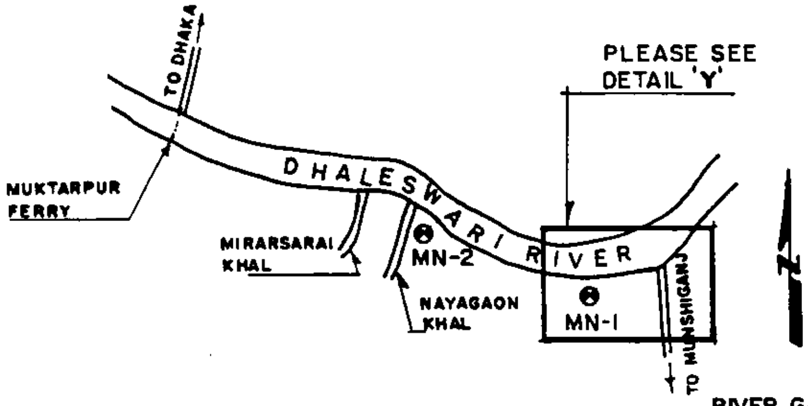



LOCATION MAP FOR BORE HOLES MG-1 AND MG-2 AT MEGHNA R & H BRIDGE

FIGURE NO. C.5.3

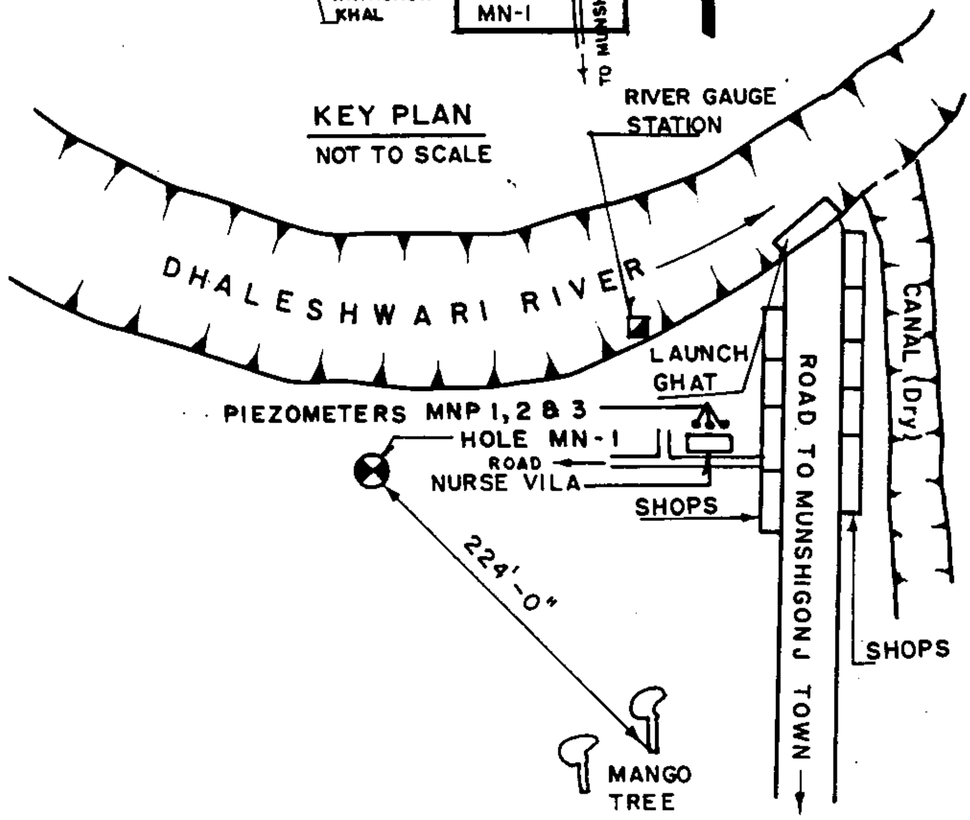
# BORE HOLE DETAILS

BH NO | Co-ordinates | GSC (m PWD)




KEY PLAN

NOT TO SCALE




DETAIL 'Y'

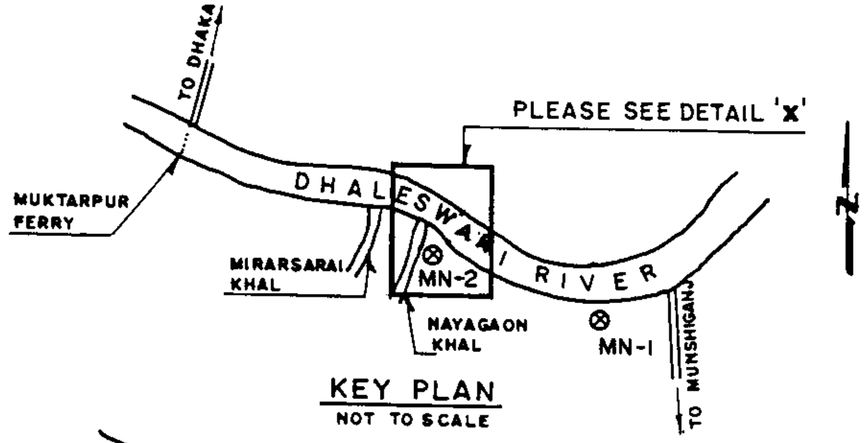
NOT TO SCALE

(b)

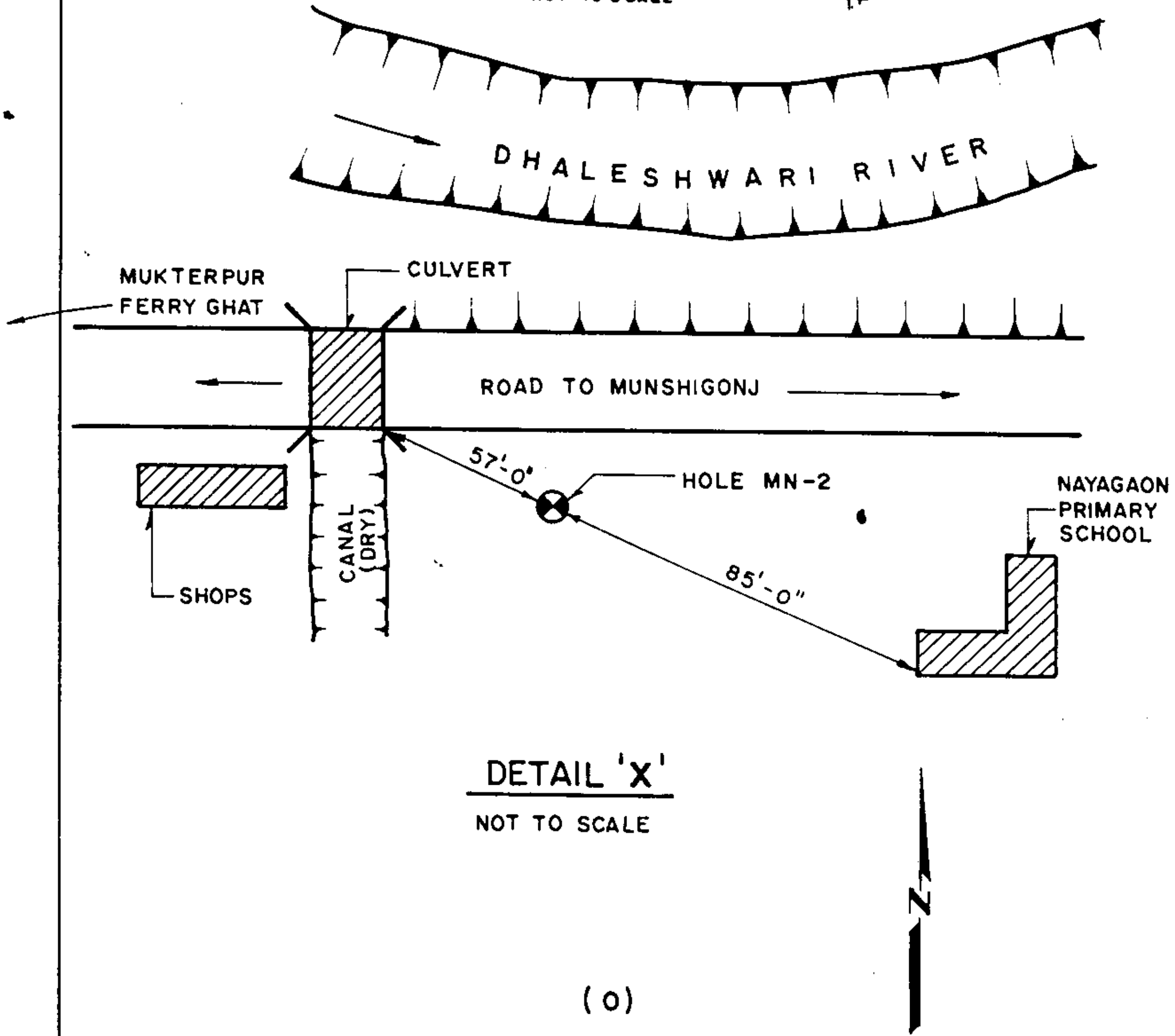
| LOCATION MAP FOR BORE HOLE MN-1 AT MUNSHIGONJ | FIGURE NO. C.5.4 |
|---|---|

## BORE HOLE DETAILS

| BH NO | Co-ordinates | GSC (m PWD) |
| --- | --- | --- |




KEY PLAN
NOT TO SCALE



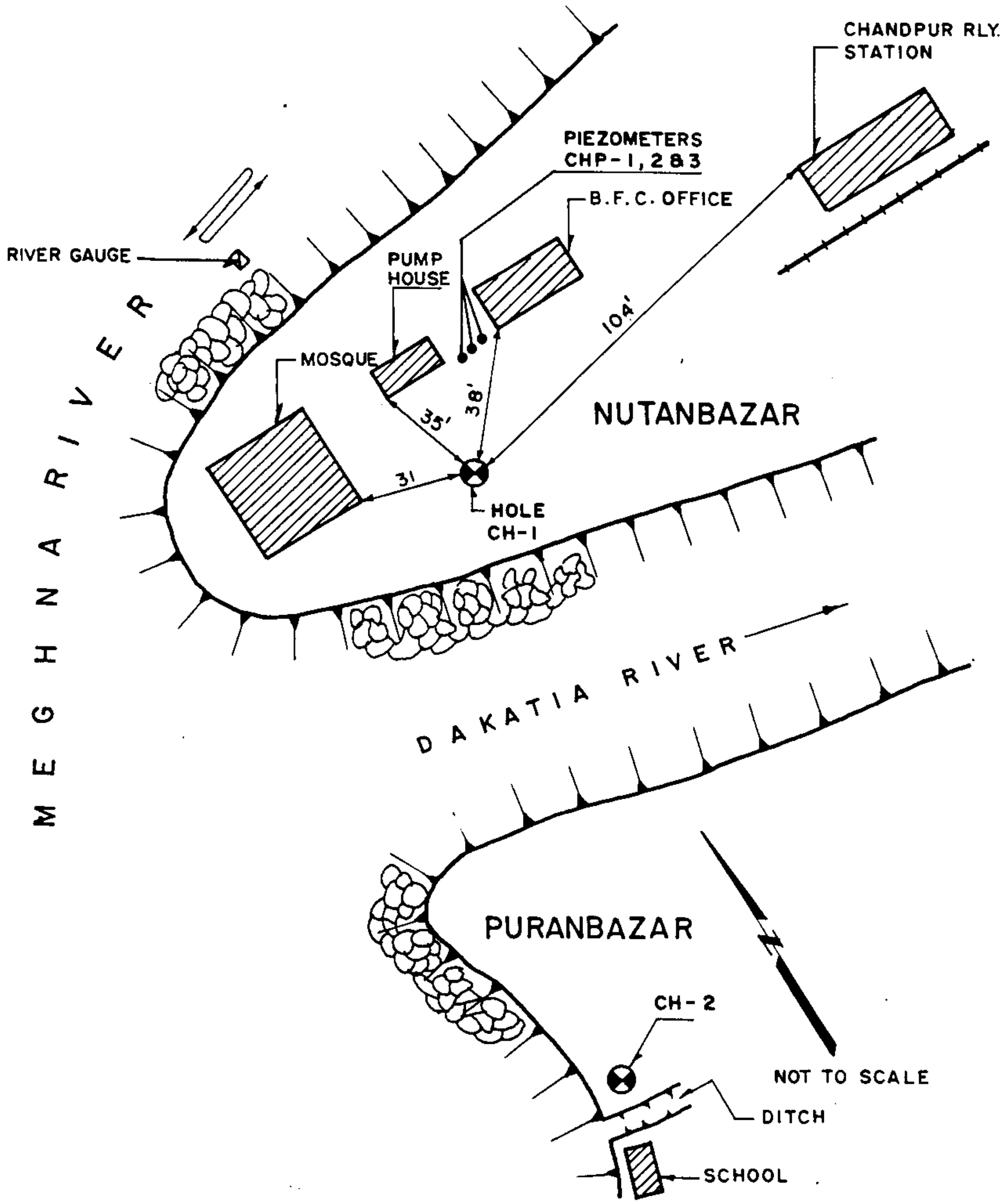

DETAIL 'X'
NOT TO SCALE

(o)

LOCATION MAP FOR BORE HOLE MN-2 AT MUNSHIGONJ | FIGURE NO. C.5.5

## BORE HOLE DETAILS

| BH NO | U.TM Co-ordinates | GSC (m PWD) |
|---|---|---|




| LOCATION MAP FOR BORE HOLES CH-1 AND CH-2 AT CHANDPUR | FIGURE NO. C.5.6 |
|---|---|

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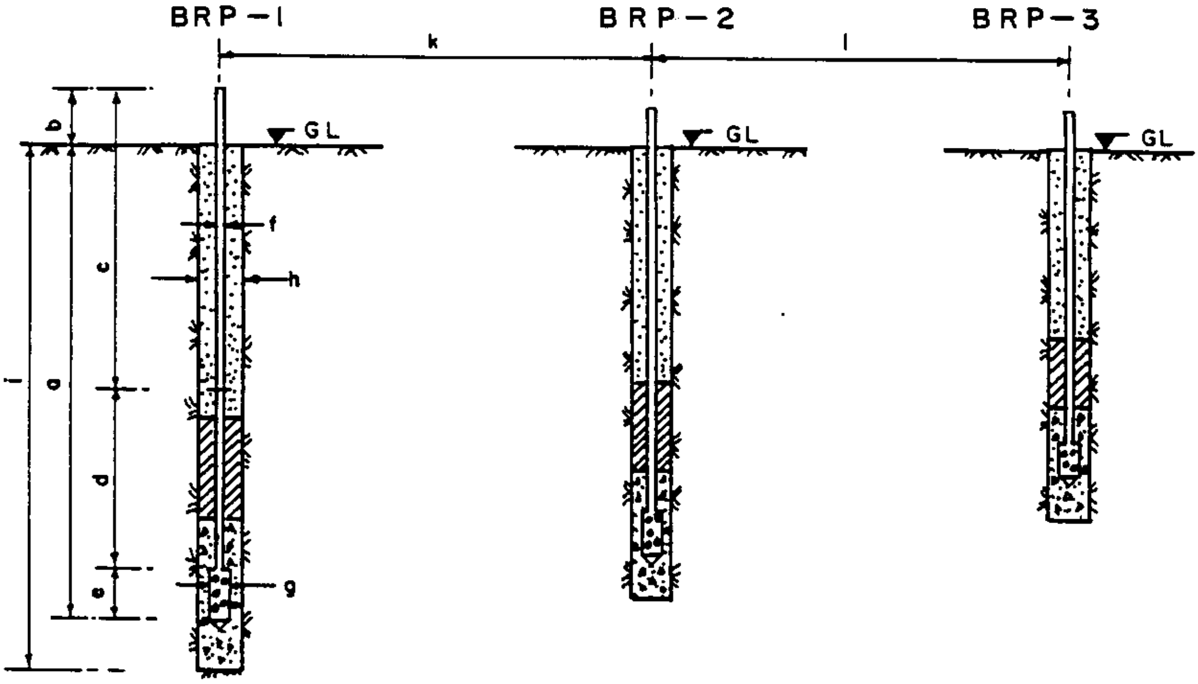



TABLE: PARTICULARS OF STANDPIPE PIEZOMETERS AT BHAIRAB BAZAR (BRP - 1, 2 & 3)

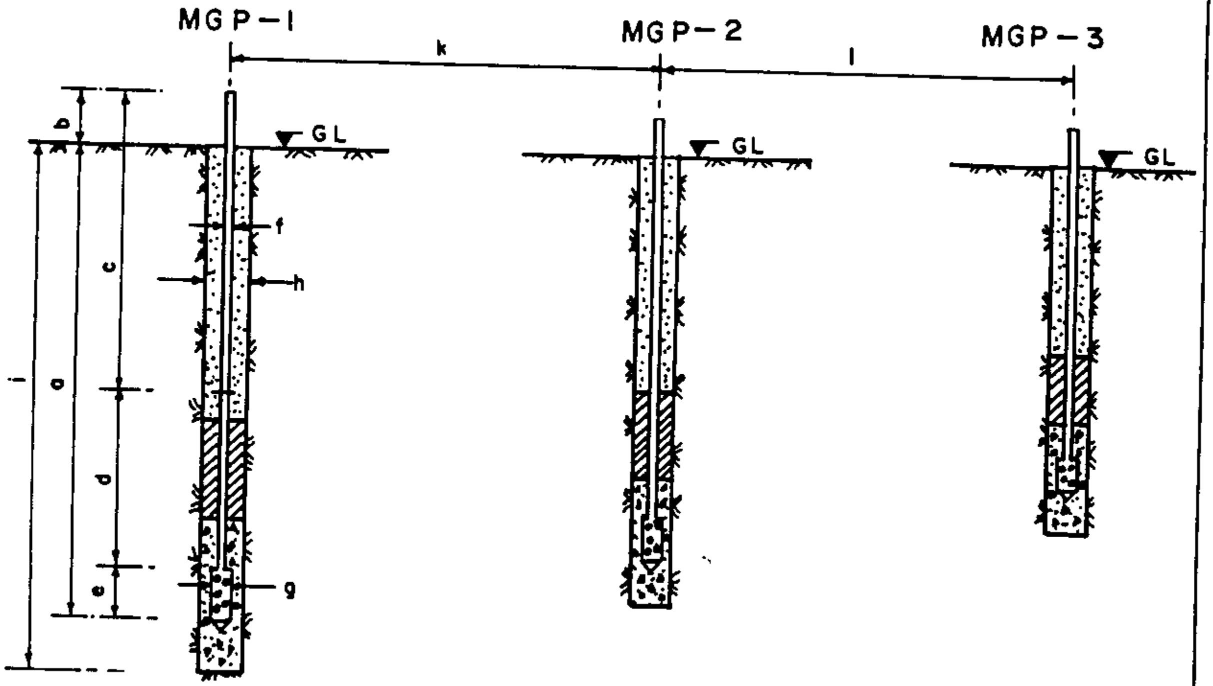
LOCATION: IN THE OFFICE COMPOUNO OF SAE RAILWAY IN THE PROXIMITY OF THE RAILWAY BRIDGE (SEE FIG. NO. 5·1a)

DEVELOPMENT/COMMISSIONING : 19–22 March 1991/23 March 1991

| PARTICULARS | | BRP-1 | BRP-2 | BRP-3 |
|---|---|---|---|---|
| Total Depth (m) | a | 25·39 | 17·00 | 7·86 |
| Projection above GL- (cm) | b | 21·60 | 16·30 | 22·90 |
| Length of upper GL Pipe (m) | c | 1·52 | 0·76 | 0·76 |
| Length of PVC Pipe (m) | d | 22·87 | 15·24 | 6·10 |
| Length of Strainer (m) | e | 1·00 | 1·00 | 1·00 |
| Dia. of GI. and PVC pipe (mm) | f | 25·00 | 25·00 | 25·00 |
| Dia. of Strainer (mm) | g | 50·00 | 50·00 | 50·00 |
| Boring Oiameter (mm) | h | 100·00 | 100·00 | 100·00 |
| Boring Depth (m) | i | 26·39 | 18·00 | 8·86 |
| Shrouding materials (mm) | j | 1 to 3 | 1 to 3 | 1 to 3 |
| Distance BRP-1 to BRP-2 (m) | k | 0·91 | | |
| Distance BRP-2 to BRP-3 (m) | l | | 1·13 | |

PARTICULARS OF PIEZOMETERS AT BHAIRAB BAZAR

FIGURE NO. C.5.7

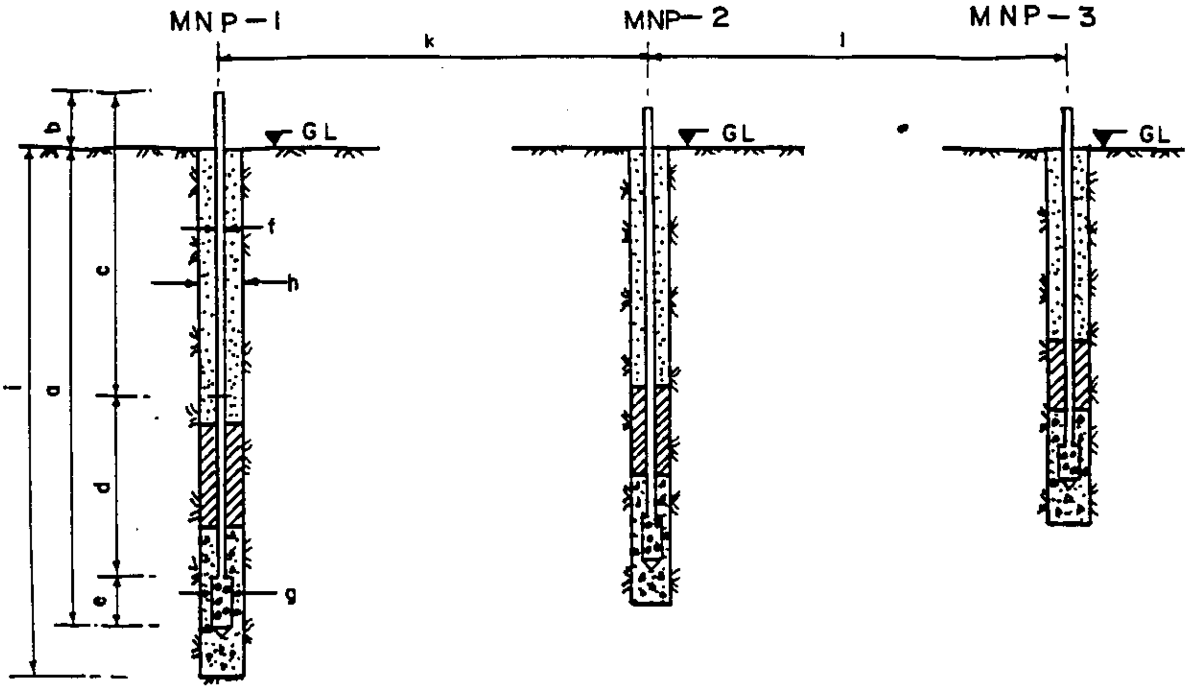



| TABLE: PARTICULARS OF STANDPIPE PIEZOMETERS AT MEGHNA R & H BRIDGE SIDE |
|---|
| LOCATION: IN THE COMPOUND OF GHAT MOSQUE ADJACENT TO THE SHOPS (SEE FIG. NO. 5.2) |
| DEVELOPMENT/COMMISSIONING 22-23 March 91 / 25.3.91 |

| PARTICULARS | | MGP-1 | MGP-2 | MGP-3 |
|---|---|---|---|---|
| Total Depth (m) | a | 29.20 | 17.02 | 9.21 |
| Projection above GL (cm) | b | 215 | 215 | 255 |
| Length of upper GL Pipe (m) | c | 1.52 | 0.76 | 0.76 |
| Length of PVC Pipe (m) | d | 26.26 | 15.24 | 7.66 |
| Length of Strainer (m) | e | 1.00 | 1.00 | 1.00 |
| Dia. of GI. and PVC pipe (mm) | f | 25 | 25 | 25 |
| Dia. of Strainer (mm) | g | 50 | 50 | 50 |
| Boring Diameter (mm) | h | 100 | 100 | 100 |
| Boring Depth (m) | i | 30.20 | 18.02 | 10.21 |
| Shrouding materials (mm) | j | 1 to 3 | 1 to 3 | 1 to 3 |
| Distance BRP-1 to BRP-2 (m) | k | 0.91 | | |
| Distance BRP-2 to BRP-3 (m) | l | | 1.13 | |

PARTICULARS OF PIEZOMETERS AT MEGHNA R & H BRIDGE SIDE

FIGURE NO. C.5.8




| TABLE: PARTICULARS OF STANDPIPE PIEZOMETERS AT MUNSHIGANJ (MNP-1, 2&3) | | | | |
|---|---|---|---|---|
| LOCATION: IN THE COMPOUND OF A NURSE VILLA CLOSE TO THE LAUNCH GHAT (SEE FIG. NO. 5·3b) | | | | |
| DEVELOPMENT / COMMISSIONING 1–4 April 1991 / 5 April 1919 | | | | |
| PARTICULARS | | MNP–1 | MNP–2 | MNP–3 |
| Totol Depth (m) | a | 30·70 | 17·00 | 9·38 |
| Projection above GL- (cm) | b | 20·30 | 10·20 | 15·20 |
| Length of upper GL Pipe (m) | c | 1·52 | 0.76 | 0·76 |
| Length of PVC Pipe (m) | d | 28·20 | 15·24 | 7·62 |
| Length of Strainer (m) | e | 1·00 | 1·00 | 1·00 |
| Dia.of GI. and PVC pipe (mm) | f | 25·00 | 25·00 | 25·00 |
| Dia. of Strainer (mm) | g | 50·00 | 50·00 | 50·00 |
| Boring Diometer (mm) | h | 100·00 | 100·00 | 100·00 |
| Boring Depth (m) | i | 31·72 | 18·00 | 10·38 |
| Shrouding moteriols (mm) | j | 1 to 3 | 1 to 3 | 1 to 3 |
| Distance BRP-1 to BRP-2 (m) | k | 0·94 | | |
| Distance BRP-2 to BRP-3 (m) | l | | 1·91 | |

PARTICULARS OF PIEZOMETERS AT MUNSHIGANJ

FIGURE NO. C.5.9

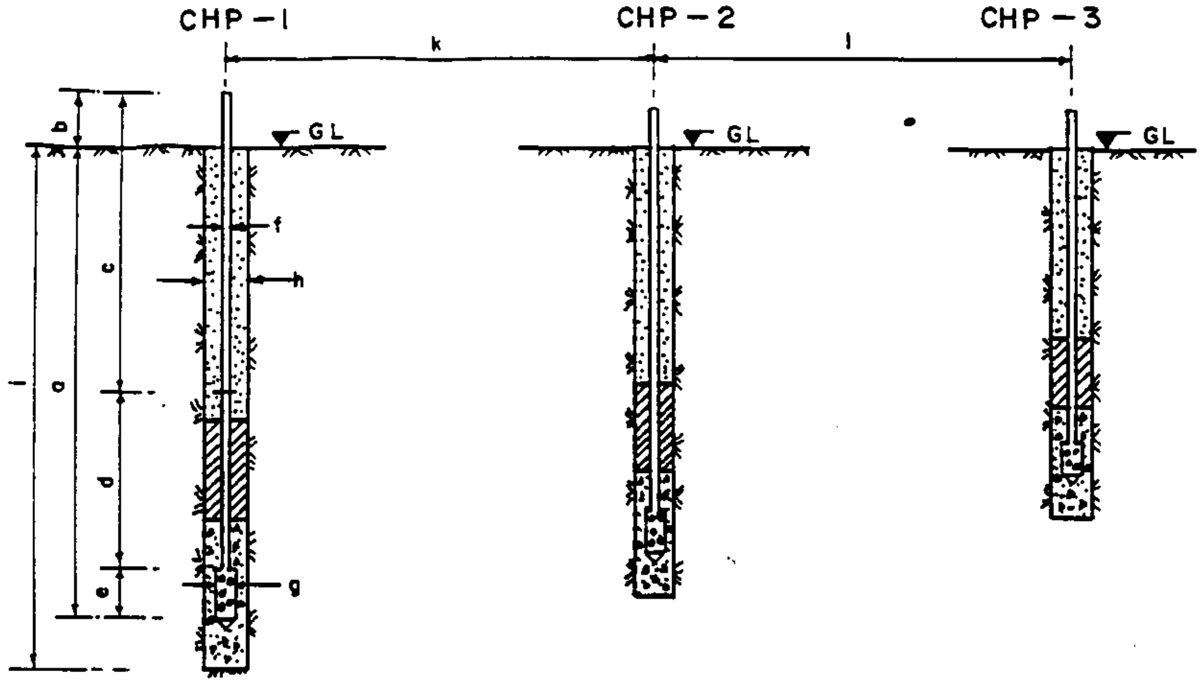



TABLE: PARTICULARS OF STANDPIPE PIEZOMETERS AT GHANDPUR (CHP– 1, 2 & 3)

LOCATION: IN NUTAN BAZAR AREA, IN THE PROXIMITY OF MOSQUE AT THE END OF RAILWAY STATION (SEE FIG. NO. 5·4)

DEVELOPMENT COMMISSIONING: 5 – 8 April – 1991 / 8 April 1991

| PARTICULARS | | CHP-1 | CHP-2 | CHP-3 |
|---|---|---|---|---|
| Total Depth (m) | a | 30·48 | 16·93 | 7·86 |
| Projection above GL- (cm) | b | 17·70 | 17·70 | 10·20 |
| Length of upper GL Pipe (m) | c | 1·52 | 0·76 | 0·76 |
| Length of PVC Pipe (m) | d | 28·96 | 15·24 | 5·95 |
| Length of Strainer (m) | e | 1·00 | 1·00 | 1·00 |
| Dia. of GI. and PVC pipe (mm) | f | 25·00 | 25·00 | 25·00 |
| Dia. of Strainer (mm) | g | 50·00 | 50·00 | 50·00 |
| Boring Diameter (mm) | h | 100·00 | 100·00 | 100·00 |
| Boring Depth (m) | i | 31·48 | 19·00 | 9·80 |
| Shrouding materials (mm) | j | 1 to 3 | 1 to 3 | 1 to 3 |
| Distance BRP-1 to BRP-2 (m) | k | 0·86 | | |
| Distance BRP-2 to BRP-3 (m) | l | | 0·96 | |
| Lattitude :! 24°- 02'- 54.6" N | | | | |
| Longitude : 90°-59'-48.0" E | | | | |
| Elevation of pipe top (m PWD) | | 7.65 | 7.56 | 7.62 |

PARTICULARS OF PIEZOMETERS AT CHANDPUR

FIGURE NO. C.5·10

Fig. C. 5.11 Strainer for Piezometer

Fig. C.5.12 Installation of Piezometer

y2

## C.6. EVALUATION OF GEOTECHNICAL DATA

### C.6.1 General

The present investigation is part of a major study involving the Meghna River Bank Protection. The four investigated sites (Bhairab Bazar, Meghna R & H Bridge, Munshiganj and Chandpur) are locations where the erosion problem has been identified as most severe, hence needing immediate attention.
Two bore holes were made at each of these locations. Detailed information is given in Appendix C/1, presenting the Bore Hole Logs, Grain Size Distribution Charts and the results of Laboratory tests. Below follows a brief summary of the soil conditions, with some of the physical parameters for each location. The results are more visually supported by the diagrams shown on the Figures C.6.1 through C.6.7.

A more detailed evaluation of strength characteristics is presented in Appendix 4. The conclusions from this evaluation are presented as general design guide lines at the end of this chapter.

### C.6.2 Bhairab Bazar Railway Bridge and Township

#### C.6.2.1 Site visit

Bhairab Bazar is one of the important river ports of Bangladesh. Bank erosion, at this stretch of the Meghna River, is noticeable at the right bank at both upstream and downstream of the Railway Bridge, covering the Bridge itself, Oil Terminal, Township and PDB Tower area. The first two locations refer to the Railway Bridge while the other two locations represent the Town Area. Surface water level variations between the high and low water is reported to be as high as 5 m.

In places, even vertical bank sections can be noticed. Bank protection works, after the 1988 bank slide, have been carried out in the proximity of the bridge, in conjunction with some reclamation works. The latter works comprised the initial construction of a containment bund composed of jute sand bags (1.2 million), placed in water depths of 12m to 15m, behind a toe protection consisting of driven steel sections and a toe consisting of boulders. The slopes of the bund approximated an angle of 1:1. Ships with sand, taken from the nearby char (sand bank), were allowed to enter the now sheltered area via a lowered section in the containment bund. The sand was deposited with the help of buckets from the eroded shore line allowing the sand to move downwards via the slope. Excess water was automatically evacuated via the lowered section. Ultimately the outer side of the containment bund received a boulder protection, a measure to be followed up continuously to allow for the downward movement of this layer.

Embankment failures at Bhairab Bazar, just upstream of the Railway bridge, are encroaching upon and damaging buildings, located directly on the naturally sloping unprotected river bank. Directly above the free water level of the river fresh failures, with vertical faces, appear to develop in very slightly clayey silt layers. Most likely they represent failure phenomena as described in Section 4.2.4. It can also be recognized that these events are only one stage in an already longer process of gradually receding river banks due to morphological changes in the river. This shows up in old steps, leading from the houses to the river, which recently have been eroding at considerable height above the present ground level. In the past these steps were possibly a direct connection with the sloping river bank.

A petrol station for ships supply, between the township and the bridge, has received a slope protection consisting of closely set concrete blocks with a thickness of approximately 0.2m. The blocks, apparently set directly on existing ground, were not provided with any specific filter or drainage to release excess pore water during falling water levels. It can be seen that the lower part of this slope protection has suffered considerable damage due to lifting and separation of blocks, allowing them to slide downwards.

The most dramatic effect of loss of macro-stability has occurred north of the Railway bridge. A slip, details of which are presented in the Inception Report, did result in major loss of land and material. The maximum width of land loss approximated 120 m. With a total height of the embankment of some 20 m, the average slope angle after the slip amounted to approximately 9°. This slip occurred when, after a long period of very high waters, the river water levels receded. A major part of the washed away area has now been reclaimed and a temporary bank protection using boulders have been placed along the whole stretch of the endangered area.

There seems to be good reason to believe that these conditions resulted from major exposure to the erosive action of the river.

C.6.2.2 Sub-soil condition

Two borings, BR-1(50 m) and BR-2(30 m), were made, with undisturbed and disturbed samples being extracted and SPT soundings carried out. The soil conditions are summarized in Fig.'s C.6.1 and C.6.2 respectively. They show the soil description, Natural Moisture Content(NMC), SPT data, textural composition of the soil along the entire depth.

A sub-soil profile in the proximity of the Railway Bridge, incorporating an investigation by Development Design Consultants Ltd. [4], is also shown. Fig. C.6.1 indicates that the sub-soil consists of cohesionless materials(sand). The upper 4-5 m, however, is slightly silty containing both fines and coarse fractions. Moreover, irregular patches of silts are also found in the top 10 m. The sub-soil contains mica flakes, upto 5 mm size (picture), over the full depth of the bore hole (Fig. C.6.3). The mica flakes consists of Muscovite and some Biotite.

Though fine sand prevails in this area a distinct difference can be noticed between the two borings due to the presence of a sandy silt layer encountered in boring BR-1. This layer may, due to a concentration of flow lines, have contributed to the experienced slide.

The 'N' values range between 5 -12 over the top 8 m. In general, These values have an increasing trend with depth. Below 10 m depth, however, the SPT values remain fairly constant at 20-25 down to 40 m after which 'N' values again increase consistently with depth to a range between 22 and 34m. The groundwater table was encountered at C.5.4 m below the existing ground surface during the month of march, 1991.

## C.6.3 Meghna R & H Bridge

C.6.3.1 Site visit

The Meghna R&H Bridge has received its own river bank protection at both sides of the river, using gabion and geotextile mattresses around the revetments.

The river bank at the Comilla side of Dhaka-Chittagong Highway at this stretch of the river is almost vertical. The bank erosion in the proximity of the bridge appears to be the result of major morphological changes of the river bed and current patterns. During the visit a continuing process of retrogressive erosion could be observed through practically vertical failures. Freshly broken-away bank material and development of tension cracks behind the vertical faces, showing the effects of the softening and/or erosion of the unprotected banks.

C.6.3.2 Sub-soil condition

Two borings, MG-1(50 m) and MG-2(30 m), were drilled at the site and SPT soundings were performed at 1.5 m interval. Both undisturbed and disturbed samples were extracted.

The results from field testing along the southern bank of the Meghna River, at a location about 200 m to the East of the ex-Ferryghat, are shown in Fig.'s C.6.4 en C.6.5. A soil profile is also shown. In Fig. C.6.4, the profile was supplemented by the exploration of five borings in the region in connection with the construction of the Meghna R & H Bridge by JICA [7].

The sub-soil profile, derived from both borings, shows a deep layer of non-plastic sub-angular to sub-rounded sand that can be classified as SP according to the Unified Soil Classification System (USCS). This sand, which consists predominantly of Fine Silica, contains mica to a considerable extent. A surface layer(<6m) of sandy silt provides the basis for the erosion pattern signalled in the previous paragraph. In the river bed, however, this silty layer is seen to prevail at a depth of 30 m too. The USCS Classification of the soil is ML.

Recorded SPT sounding values range from 3 to 20m over a depth of 10 m from the ground level. A general trend of gradual increase in penetration resistance is noticed. Below 10 m, the 'N' values remain fairly constant at 18-22 down to 16 m and then shoot up high well above 50 (range 50-70) showing a trend of consistent increase in 'N' with depth.

### C.6.4 **Munshiganj**

#### C.6.4.1 Site visit

Munshiganj Town is an important commercial and industrial centre of Bangladesh. The town is situated on the southern bank of the Dhaleswari River. It is an important river port of the country. Many Industries, Rice Mills, Cotton Mills, Jute Mills, Oil Mills, Pulse Mills, Glass Factories and Cold Storage exist in the Munshiganj Town area. The Town is badly eroded along the industrial and commercial belts. The bank slope is almost vertical. Attempts have been made in places to support the bank slope with Bullah and Bamboo piling. But the earth filled materials already show signs of downslope movement.

The originally unprotected slopes near the town of Munshiganj seem to be affected by a similar phenomenon as mentioned in the previous item. Temporary protection, consisting of polythene sand bags, seemed to be have deteriorated considerably. The road directly on top of the river bank and also a bridge suffered already major damage.

#### C.6.4.2 Sub-soil condition

Two bore holes, MN-1(40 m) and MN-2(30 m), were made, undisturbed and disturbed samples were extracted and SPT soundings were performed.

The soil condition is shown in Fig. C.6.6. The deep bore hole (MN-1) drilled near the Ferryghat indicated that the soil profile consists of an upper layer of soft and slightly plastic silt of 10 m thickness. This is underlain by more non-plastic sand. Mica is conspicuous in the sand. The sand is remarkably uniform being classified as SP according to the USCS. For the upper layer, classified as ML-OL, the SPT values range from 3 to 10m. Within the sand layer, however, the 'N' values remain fairly constant at 20 - 25. The groundwater table was encountered within the upper layer at a depth of 1.1 m. BH MN-2 located also along the Dhaleswari River at about one km west of MN-1 reveals the presence of a deep layer of soft black clayed silt and sandy silt, down to the end of the bore hole (30 m).

The site is characterised by a partial break in the depositional sequence as revealed in the change in the sub-soil condition from sandy to almost slushy peat rich in organic content (decomposed organic matter) in bore hole MN-2. The sub-soil, quite distinct from others, is comprised of dark black silt with LL of over 60 and silt fraction of 78 - 98%. The soil is highly erodible. The variation of the bore hole lithology is indicative of the channel switching and abandonment characteristics of the meandering river. MN-2 possibly represents the swampy area adjacent to the meander belt. This low lying area might have received considerable fine sediments during the flood inundation. The deposits are laminated black silts and clays which contain organic matter, some of which are fresh (woods and plant roots). The drainage is poor in this soil and surface flows are hardly gravity induced due to clay plugs.

C.6.5 **Chandpur Town**

C.6.5.1 Site visit

Chandpur Town, the district headquarters, is an old business centre and a major inland port of Bangladesh. Located on the left bank, just below the confluence of the two great Rivers, the Padma and Meghna, the town is bisected by the Dakatia River into Nutan and Puran Bazar areas. The bank slope above water, is almost vertical and temporary support by timber and bamboo piling is a common feature along the river bank.

Chandpur has a long erosion history, with the eroding river bank more and more encroaching upon the town area. In the past, considerable studies were directed towards the protection of the Chandpur Town [31 & 32]. This included a study by a National Committee set up by the Government in the year 1977 to recommend measures for erosion protection. The threat by bank erosion and recession over the recent years has been so severe that the Government had to embark upon costly revetment construction to eliminate or reduce loss of material due to bank erosion.

The erosion process at the left bank of the river is related to geomorphological development of the Padma and Lower Meghna in combination with river wave attack. The severity of bank erosion is not constant but cyclic. During 1988 severe erosion took place along the left bank of the Lower Meghna. Presently erosion is taking place both at Nutan and Puran Bazar area. In the Nutan Bazar area, the almost 100 year old Railway Station is threatened in its existence by a very recent ( 29 - 30 April, 1991) tidal surge that hit the southern part of the country and wave attack caused by heavy wind affected Nutan Bazar and Puran bazar in the Chandpur area.

C.6.5.2 Sub-soil condition

Two bore holes, one each at Nutan Bazar (CH-1) and Puran Bazar(CH-2) area were made to depths of 60 and 40 m respectively, undisturbed and disturbed samples were taken, SPT soundings were performed.

The soil conditions at CH-1 and CH-2 are shown in Fig. C.6.7. The figure also presents a summary of geotechnical properties including the soil description, penetration test results and basic physical properties. The soil composition shows the prevailing presence of fine sand and/or silt, resulting in more or less alternating layers, with one of both components dominating. The SPT is generally increasing with depth. Mica is invariably present throughout the entire depth of the bore hole.

The soil profile indicates that the thickness of the upper silt layer varies between 4 and 5 m. The SPT 'N ' values range between 2 and 10 showing a general trend of increasing order with depth down to 16.5 m. The SPT values within the sand underneath are well over 50. The presence of silt layers, however, is associated with much lower 'N' values of 20 to 25 irrespective of depth. The groundwater level is marked in the BH Log. As shown, it is located marginally within the surface layer at a depth of 3.5 - 4.5 m.

C.6.6 **Maniknagar**

C.6.6.1 Site Condition

The Meghna River is eroding her left bank along an outer bend over a stretch of 14 km and has engulfed a considerable tract of land falling within the Gumti-Phase II FCD project. Maniknagar Bazar is also located along this eroded area. Maniknagar is an important medium size market centre of paddy, rice, milk and fish in the area. Six villages are located upstream of Maniknagar and three downstream, which are being affected by erosion. The launch ghat has to shift its position 3 to 4 times per year due toe erosion. No bank protection works were visible in the area affected. The annual rate of erosion varies between 25 to 30 m during moderate flood conditions such as those of 1990. The proposed alignment of the flood embankment (Gumti-II) is presently at about 400 m from the river bank. The thalweg is close to the eroding bank. The slope of the bank (underwater) is about 1:1 and 1:2. The erosion problem is strongly related to the river geo-morphology. The oversteep slopes and soil characteristics at the outer bend in combination with current attack accentuate the failure of the bank and erosion process.

C.6.6.2 Sub-soil condition

In the absence of sub-soil investigation carried out in the area of study, the information obtained from the secondary sources on sub-soil characteristics has been used as representative. The details are presented in Section C.2.3.2. The sub-soil layering has been found very similar to those of Bhairab Bazar are, consisting of sandy SILT in the upper layer and fine SAND with trace of silt in the lower layers. The geotechnical design parameters for a pre-feasibility level study have been established in accordance with the similarity of the soil type as obtained from laboratory tests for other sites of the study.

## C.6.7 Eklashpur

C.6.7.1 Site Condition

Eklashpur is located along the left bank of the Lower Meghna River, downstream of the confluence of the Padma and Upper Meghna. A long stretch of the bank has been eroding for decades and has engulfed a large area of agricultural land and infrastructure. The rate of erosion at this site is high (as presented in Annex B). During 1988, part of the MDIP flood embankment was washed way and a retired embankment was constructed to protect the MDIP. Due to the continuous erosion process, the river bank is at present very close to the flood embankment and infrastructure of the MDIP.

At eklashpur the typical river cross-sections show comparatively more gentle under water slopes (1:4 to 1:10), except for the upper part of the bank were the slopes are steeper (1:1.5 to 1:3). This slope is the result of wave attack, currents and soil characteristics.

C.6.7.2 Sub-soil conditions

No bore holes were made at Eklashpur during the short-term study. Hence, the subsoil investigation carried out for the MDIP as mentioned in Section C.2.3.4 has been used to establish the soil parameters required for the design of the protection works at Eklashpur.

## C.6.8 Haimchar

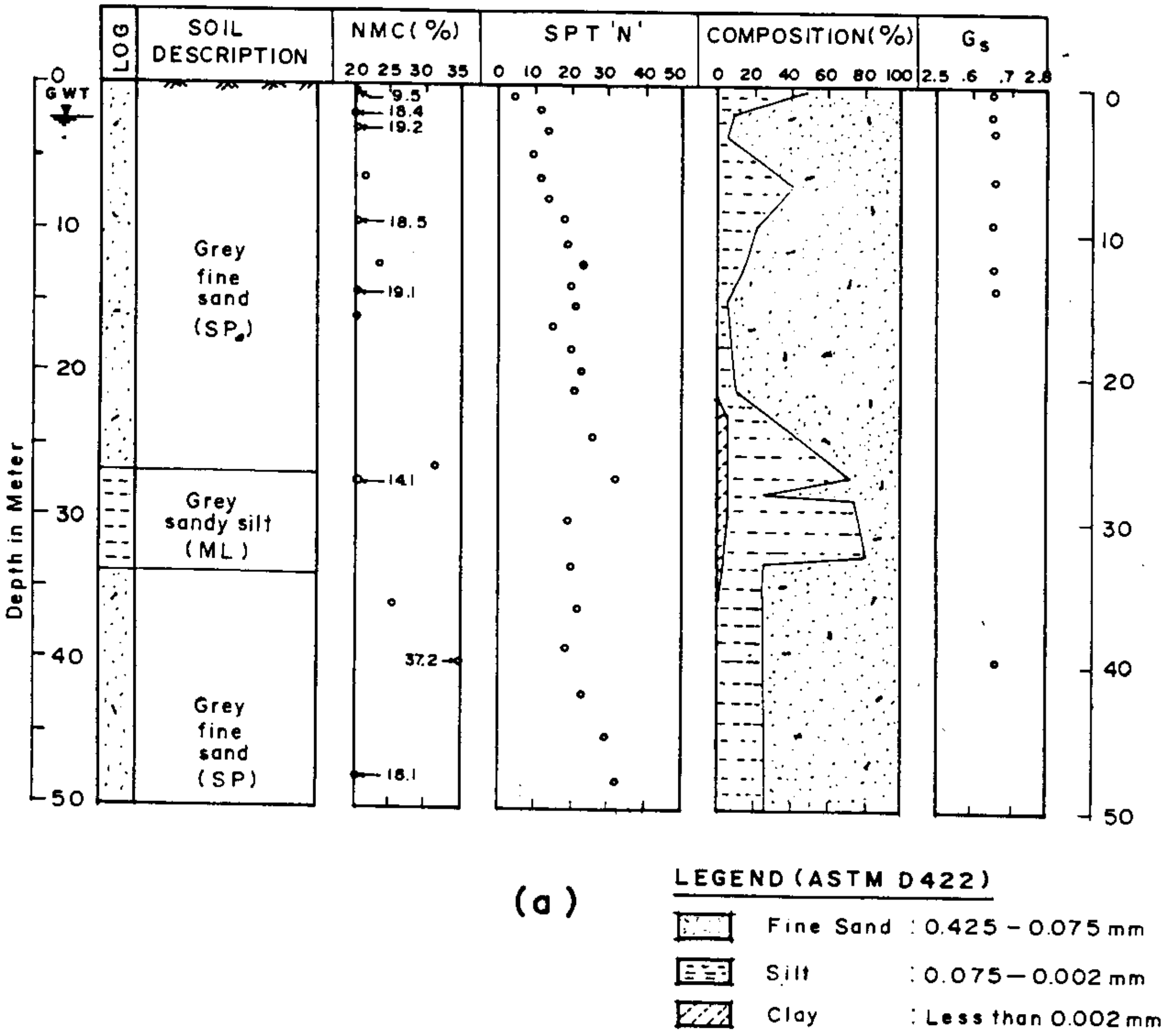
C.6.8.1 Site condition

Haimchar is the Upazila headquarters of a market centre situated about 20 km south of Chandpur along the left bank of the Lower Meghna River. The river bank has been eroded for decades and this erosion process has become more severe during the last years. At present, the bankline is near the Upazila headquarters. For safety reasons the Upazila headquarters had to be abandoned and shifted to another place. A long stretch of the CIP flood embankment has been eroded and replaced by retired embankment constructed to protect the CIP area. The erosion process in going on due to the fact that no bank protection works have been implemented yet.

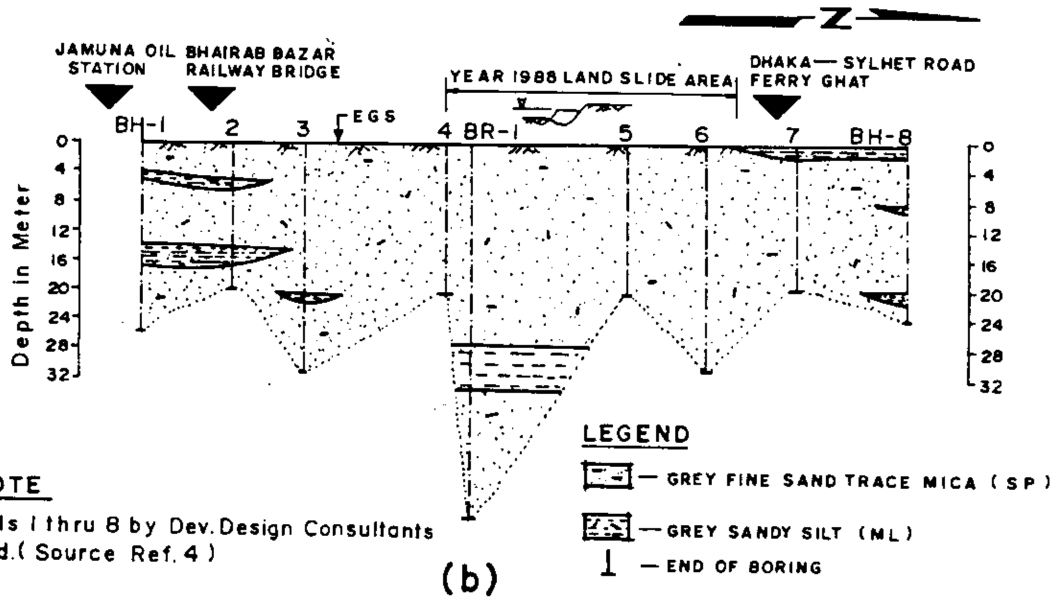
Bank erosion in the stretch are associated with morphological changes of the river, current attack ad wave attack. The river cross sections obtained during the bathymetric surveys shown steep slopes near the bank and gentle slope towards the river thalweg. Development of tension cracks in the river bank induce the effect of softening and/or erosion of the sub-soil materials underwater of the unprotected bank.

C.6.8.2 Sub-soil condition

The sub-soil data was obtained from the geotechnical investigation works carried out in the area for the Chandpur Irrigation Project as described in Section C.2.3.7. These data have been used for the design of the protection works proposed in the short-term study.




(a)



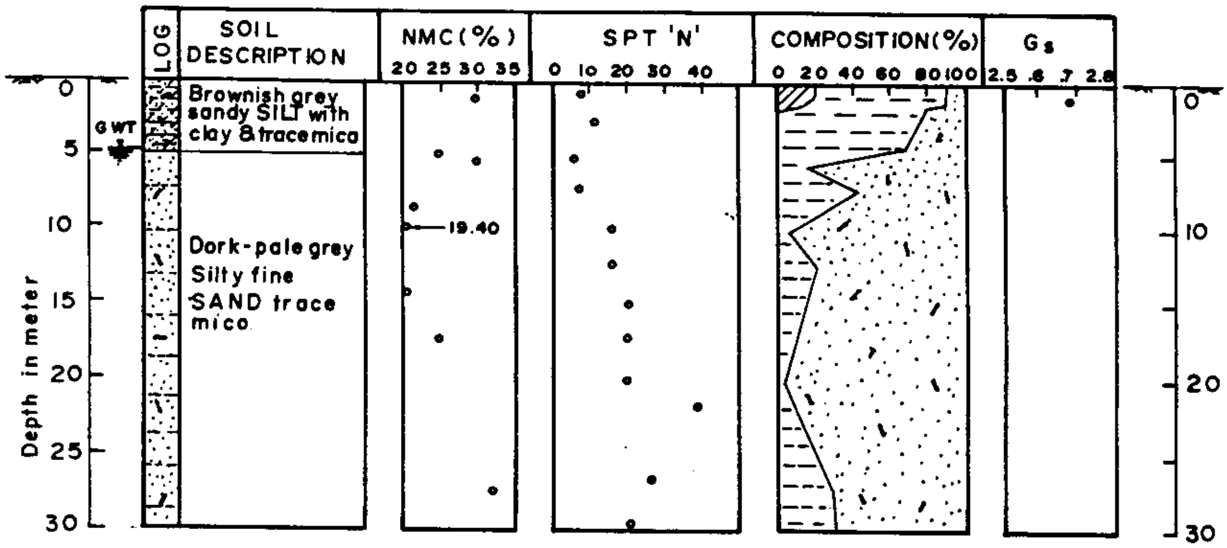

**NOTE**

BHs 1 thru 8 by Dev. Design Consultants Ltd. ( Source Ref. 4 )

(b)

Scale. 1 : 3,000 Horizontal

| | |
|---|---|
| a) TEST RESULT FROM BR-1 AT BHAIRAB BAZAR RLY. BRIDGE SITE<br>b) STRATIGRAPHY AT WEST BANK OF THE MEGHNA RIVER AT BR-1 | FIGURE NO. C.6.1 + C.6.2 |




## BR-2

**LEGEND (ASTM D422)**

| | | |
|---|---|---|
| Fine Sand | : | 0.425 – 0.075mm |
| Silt | : | 0.075 – 0.002 mm |
| Clay | : | Less than 0.002mm |

| | |
|---|---|
| TEST RESULTS FROM BR-2 AT BHAIRAB BAZAR | FIGURE NO. C. 6. 2 |

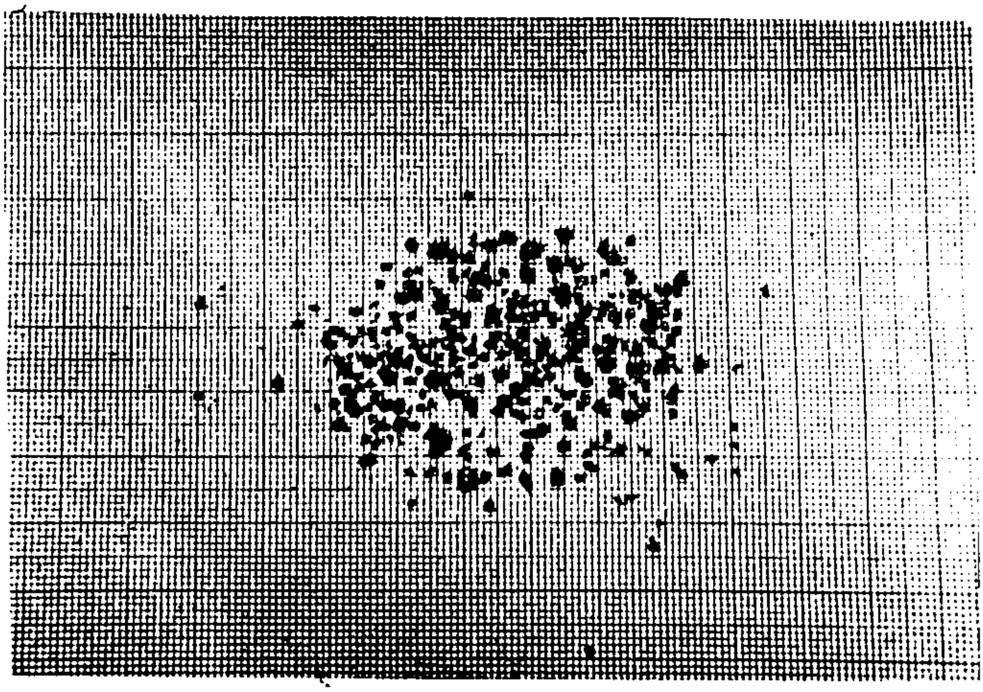
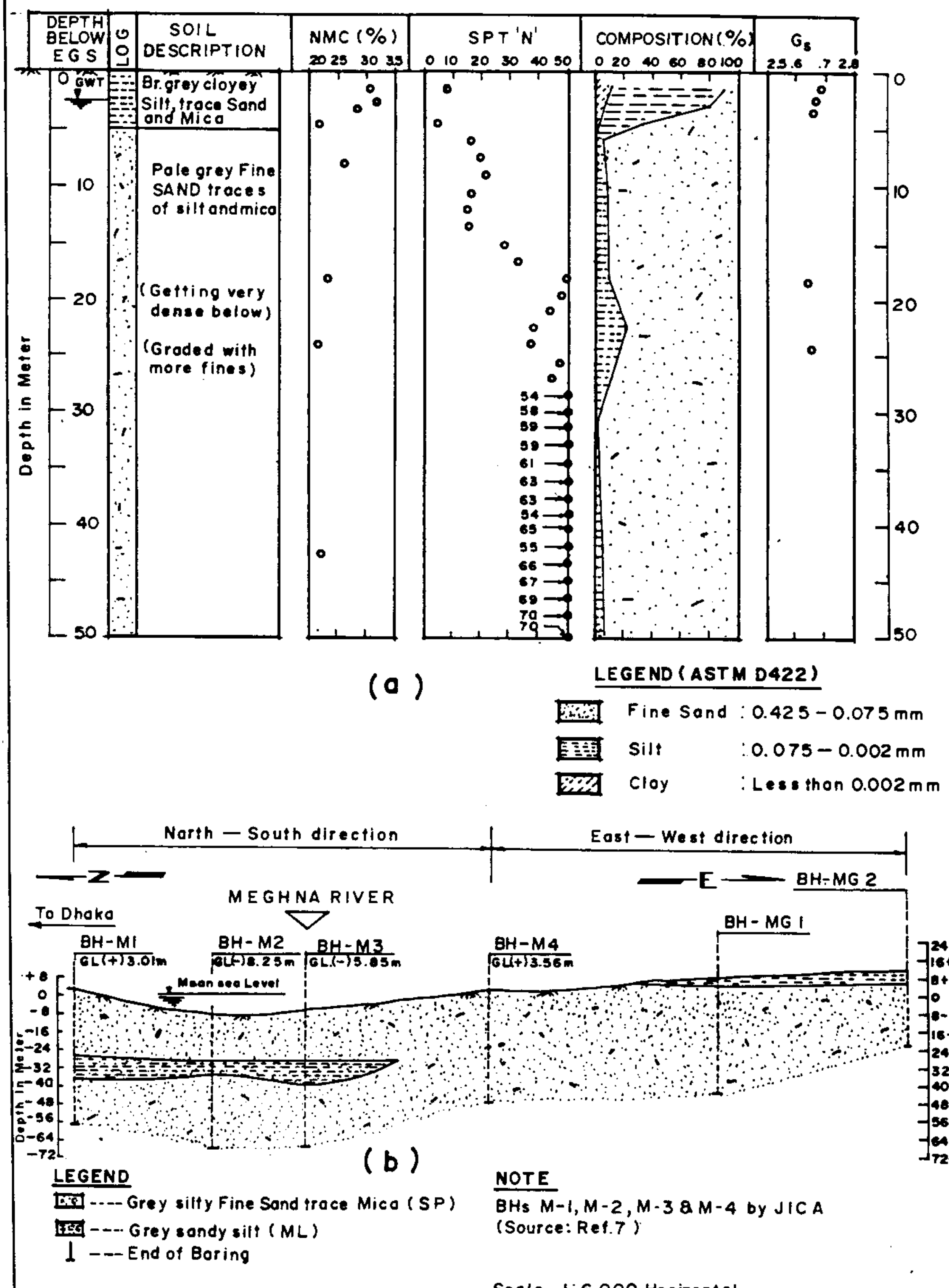
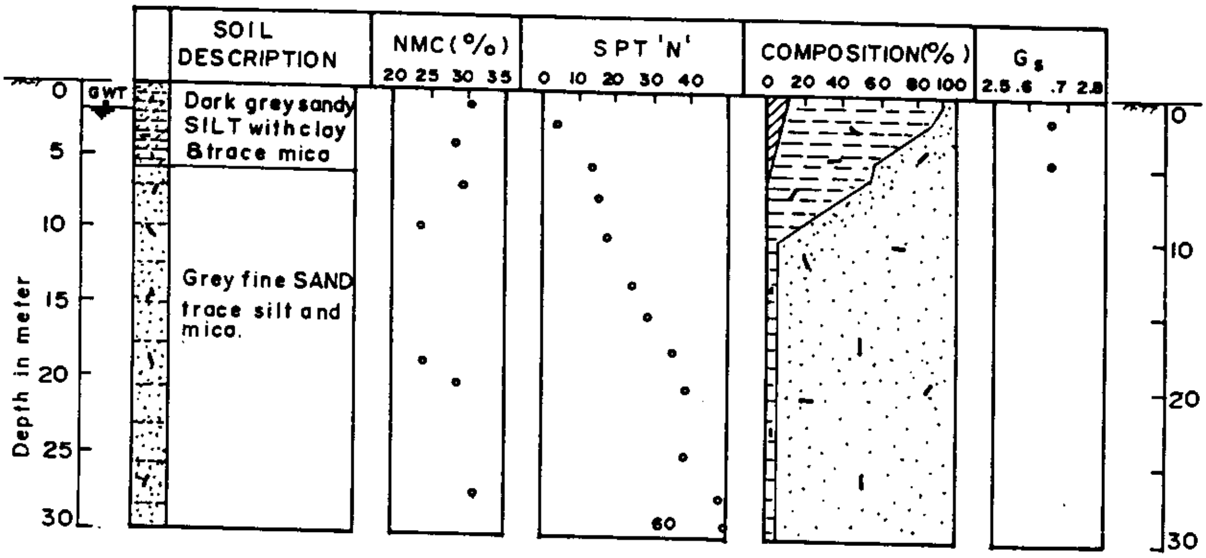


Fig. C.6.3 . Bhairab Bazar, Bore hole 2. Mica flakes.
( Moscovite and some biatite )




| | |
|---|---|
| a) TEST RESULTS FROM MG-I AT MEGHNA R&H BRIDGE SITE<br>b) STRATIGRAPHY THROUGH THE SITE | FIGURE NO. C.6.4 + C.6.5 |

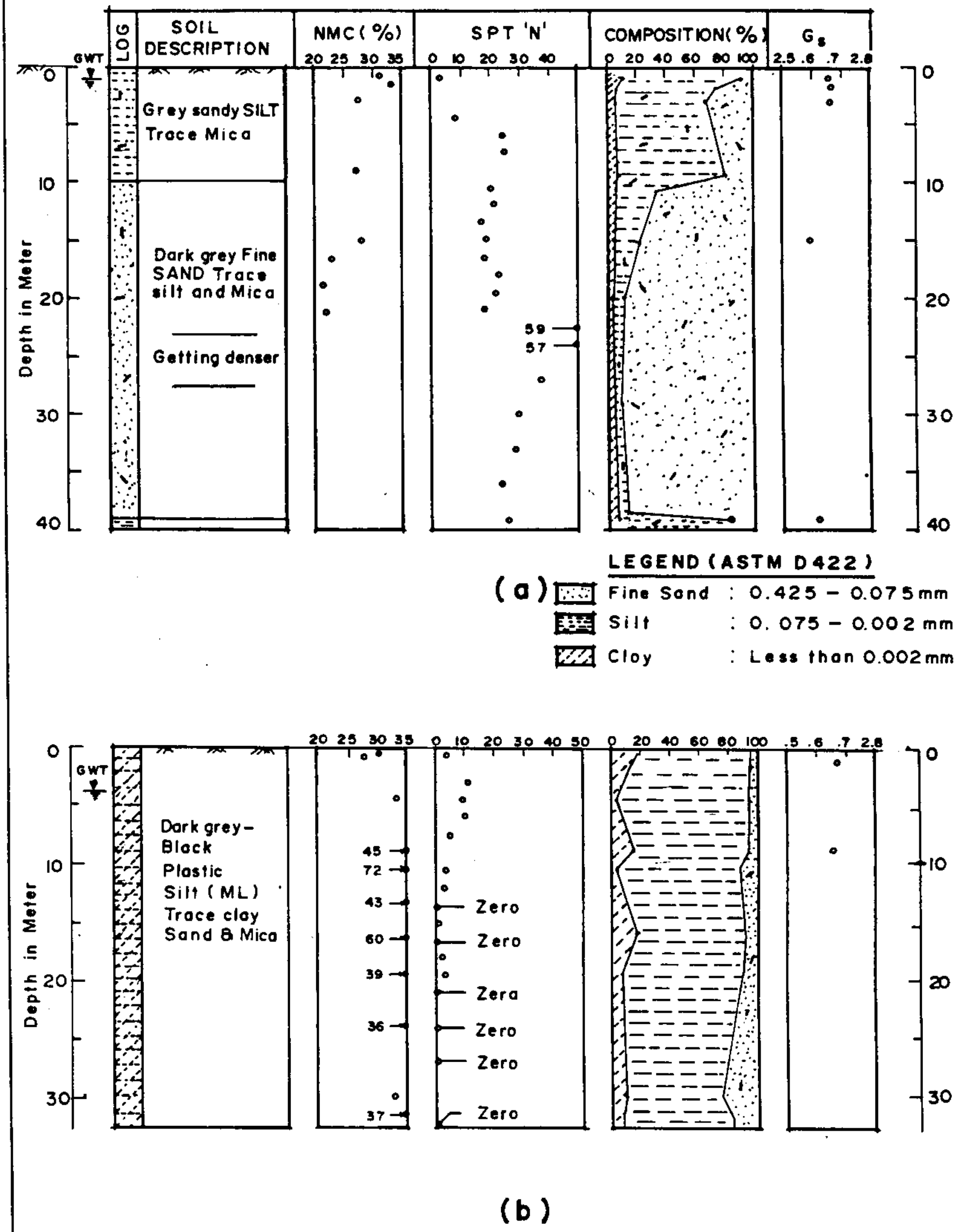



MG-2

**LEGEND (ASTM D422)**

| | | |
|---|---|---|
| Fine Sand | : | 0.425 – 0.075mm |
| Silt | : | 0.075 – 0.002 mm |
| Clay | : | Less than 0.002mm |

| | |
|---|---|
| TEST RESULTS FROM MG-2 AT MEGHNA R & H BRIDGESITE | FIGURE NO. C.6.5 |




| | |
|---|---|
| a) TEST RESULTS FROM MN-1 AT MUNSHIGANJ<br>b) TEST RESULTS FROM MN-2 AT MUNSHIGANJ | FIGURE NO. C.6.6 |

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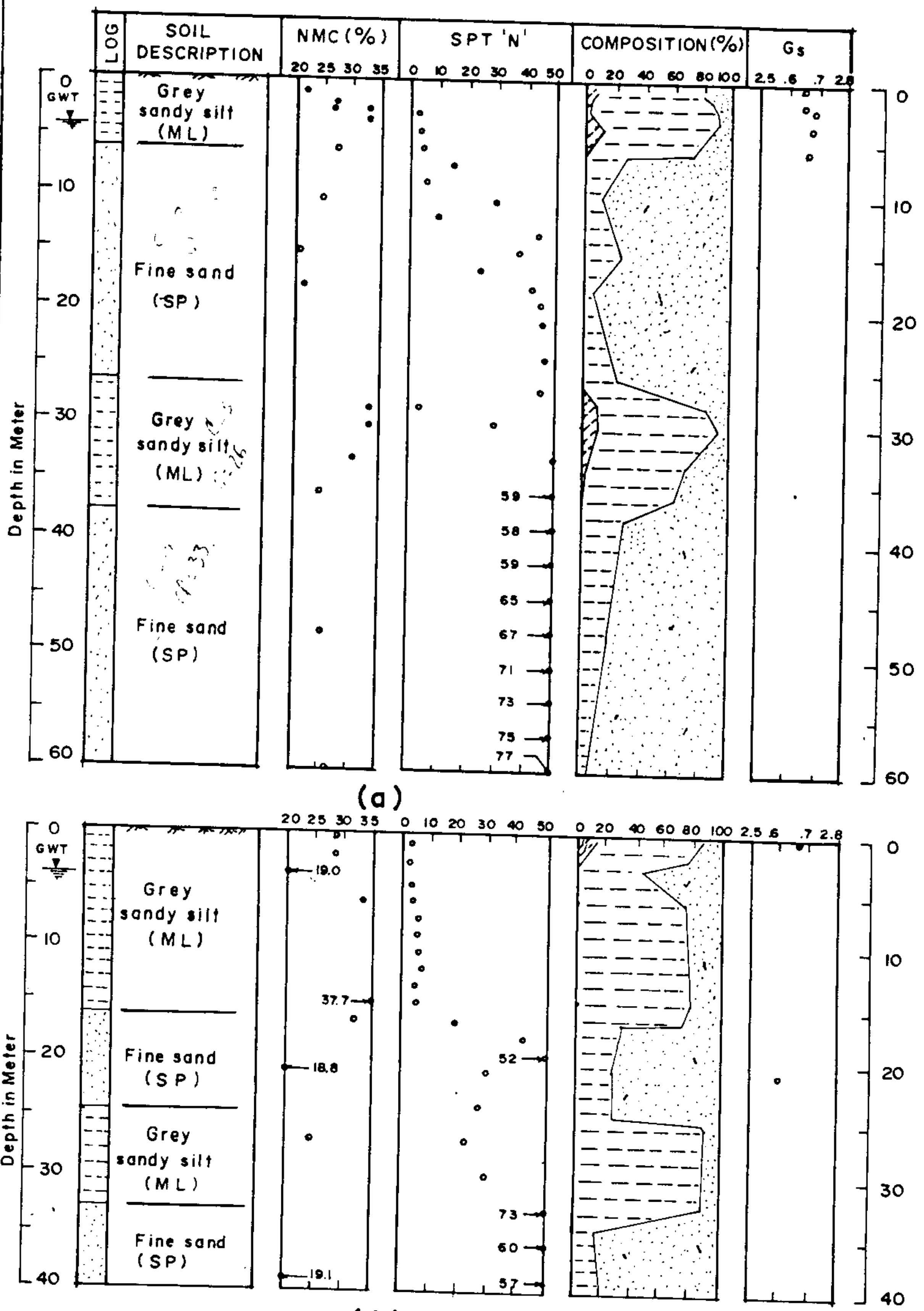


a) TEST RESULTS FROM CH-1 AT CHANDPUR

b) TEST RESULT FROM CH-2 AT CHANDPUR

FIGURE NO. C.6.7

# C.7. GEOTECHNICAL DESIGN PARAMETERS

## C.7.1 General

An evaluation of all soil investigation results regarding soil composition & stratification and strength properties reveals the consistency in layering, so typical for major parts in this deltaic area. Allowing for this consistency the attention will be focused on the identification of a limited number of layers exhibiting different strength characteristics. Such an approach will dramatically increase the possibility of problem identification and slope stability modelling once a proper bore log has been established. However the consistency should never serve as an excuse to omit site investigation. Such an investigation should always be carried out, to avoid surprises in layering, and to justify the grounds to apply one of the relevant design parameters.

## C.7.2 Sub-soil characteristics

### C.7.2.1 Extent of investigation

The encountered layering per location served, when possible, to establish the likely course of failure. Consequently, specific layering may affect details of bank protection works as well. It can be concluded that:

(a) The consistency of layering in general warrants the conclusion that the engineering characteristics of present sites have been explored sufficiently;

(b) The evidence of three distinct layers allows general design parameters to be established for each of them;

(c) New locations can be investigated in a similar way unless specific anomalies with the general trend emerge.

### C.7.2.2 Stratification and recorded water levels

Site investigations carried out in the past and in support of this study reveal the consistency of soil composition and stratification over the whole project area, a stretch of some 120km. Table C.7.1 presents a compilation of layer specification and designation. This classification neither signals sequence nor thickness but can be used to classify layers once bore logs and laboratory test results have become available.

**Table C.7.1 - LAYER DESIGNATION FOR MICACEOUS SAND AND SILT**

| Layer | Description | Composition (%) | | |
|---|---|---|---|---|
| | | fine s. | silt | clay |
| I | FINE SAND, with silt | 60-95 | 5-40 | - |
| II | SILT, with f. sand and clay | 5-40 | 60-80 | 2-10 |
| III | SILT, with f. sand and clay | 5-10 | 70-80 | 10-20 |

There is a general trend for the layers to be more silty in the upper layers (10 - 15m) and to be more sandy at greater depth. The grain size of the fine sand ranges from 100 to 150micro-m. One boring near Munshiganj shows the presence of a distinct clayey silt layer (III) to a depth of approx. 30m. A similar, more isolated layer, has also been encountered at Bhairab Bazar, at the location of the bankslide.

Piezometers and river gauges have been installed at the locations as indicated on Figures C.5.2 to C.5.6. The former are read 3 times and the latter once a day. An example of readings by WDB, being presented graphically, is shown in Fig. C.7.1. The daily readings of the water level in the river have been compared with the average reading per day of the piezometers. Based on the readings during the month of April 1991 the following approximate differences between piezometric head and river level have been monitored:

(a) Bhairab Bazar $\Delta H$ = 3.5m

(b) Meghna R&H Bridge $\Delta H$ = 3.5m

(c) Munshiganj $\Delta H$ = 2.75m

(d) Chandpur $\Delta H$ = 3.5m (est.)

#### C.7.2.3 Material characteristics

Following general material characteristics will govern design:

(a) Practically all encountered fine sand layers contain a fair quantity, (5%), of recognizable mica flakes, their dimensions often exceeding 3 to 5 times $D_{50}$ of the grains;

(b) The presence of mica because of its crushability must be regarded as an engineering parameter governing material property. Especially the larger particles will introduce a sensitivity for collapse when loaded in shear or under increased normal loading;

(c) The presence of mica becomes evident in the results of field testing. The crushability of mica will reduce SPT-resistance when compared with monitored N-values in quartz sand of the same density [24].

(d) Though some layering can be recognized a limited effect has to be allowed for when establishing average shear strength parameters (see Section 7.3.7 ).

(e) Distinct layering will affect ground water flow patterns. Consequently this may contribute to some of the failure phenomena now being observed.

### C.7.3 **Laboratory testing**

#### C.7.3.1 Grain size analysis and Atterberg Limits

Grain size analyses next to visual logging confirm the earlier mentioned consistency in layering. In some cases some of the reported results seem to signal the presence of predominantly clay, a conclusion more being based on the observation of Plasticity than the Particle Size Distribution. Silt and fine sand are the most prominent parts in all analyzed samples! Fig. C.7.2 shows the envelopes of the established distributions, revealing the presence of the typical layers as defined in Section 7.2.2.

Some samples were analyzed twice in order to signal any effect of handling on the particle size distribution. When being sandy, and containing larger mica flakes, a shift towards more fine material could be observed which is due to mica crushing.

Practically all silty layers are classified as having a low Plasticity Index (Att. Limits). A compilation of results is shown in fig. C.7.2. Plasticity Indices in the prevailing sandy silt vary between 8 and 18. These values will serve to allow a comparison to be made with interface geotextile-soil behaviour as reported in literature for similar soils.

### C.7.3.2 Specific Gravity

Specific Gravity values appear to be very consistent. However, it must be born in mind that the quoted values do include the influence of mica, having a higher Specific Gravity (>2.7) than quartz.

### C.7.3.3 Mica content

The quantitative presence of mica has been established in 3 samples of fine sand by means of particle counting and weighing. Results are presented in Appendix 2. The counted particles, per sieve, show that the percentage of mica particles may be as high as 5%, 10.1% and 12.1% respectively.

### C.7.3.4 Permeability

Laboratory permeability test results signal the variations in layer composition. Average k-values (cm/sec) to be attributed to mentioned layers earlier are:

**Table C.7.2 - DESIGN PERMEABILITY VALUES PER DEFINED LAYER**

| Layer | Description | k [cm/sec] |
|---|---|---|
| I | FINE SAND, with silt | $3.5 \times 10^{-3}$ |
| II | SILT, with sand & some clay | $10^{-4}$ to $5.10^{-5}$ |
| III | SILT, with clay * some sand | $5.10^{-5}$ to $10^{-6}$ (est.) |

In situ permeability tests seem to be affected by some monitoring deficiencies (Section 5.2.5). Consequently, above k-values given in the Table will be used in design.

### C.7.3.5 Chemical composition of soil

Three soil samples where analyzed for their chemical composition. The results are presented in Table C.7.3. A report of the test laboratory is presented in Appendix C/3.

**Table C.7.3 - RESULTS OF CHEMICAL ANALYSIS ON SOIL SAMPLES**

| Area | Oxide | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | Mgo | Ct | $SO_3$ | $CO_2$ | moisture at 110°C | loss on ignition (Organic Matter) |
| MG-1 | 74.49 | 13.30 | 1.22 | 5.09 | 3.80 | trace | Nil | Nil | 0.35 | 1.30 |
| MN-1 | 80.53 | 10.54 | 0.58 | 4.48 | 2.78 | trace | Nil | Nii | 0.26 | 0.60 |
| CH-1 | 87.01 | 13.95 | 0.75 | 2.51 | 2.20 | 0.50 | Nil | Nii | 0.10 | 1.20 |

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#### C.7.3.6 Critical and in-situ density

Critical Density tests on reconstituted samples at varying dry density were carried out to establish at what density zero volume change occurs as a result of induced shear stresses. Preference was given to an analysis of samples extracted from the top layers (<10m) in which low N-values signalled low density and/or collapsibility. The compilation of test results, for a parametric evaluation, is presented in Appendix C/4.

When comparing the density [kN/m$^3$] of a condition exhibiting zero-volume change with the measured in-situ densities (e.g. from Triaxial Test samples) conclusion can be drawn with regard to the susceptibility for liquefaction. For the three layers mentioned earlier average results are as follow:

(a) Layer I, representing the results of a limited number of tests only (2), seems to have a density slightly less than critical. This suggests this layer to have some susceptibility for liquefaction due to particle assembly collapse;

(b) Layer II, representing the mean of approx. 7 tests, signals this layer to have a critical density. It means in practice that liquefaction phenomena are not likely to affect this layer. In laboratory testing such a condition suggests the practical absence of excess (positive) pore water pressure due to absence of assembly collapse. This conclusion is concurrent with observations during triaxial testing. In general negative pore water pressures were monitored only;

(c) Layer III, representing the results of 2 tests only, signals an evidently lower in-situ density than the critical one. This would suggest this layer still to be in a state of consolidation. This condition may be the origin of low N-values encountered in such layers (boring MN-2). Though under-consolidated conditions seem to prevail such layers do not need to be regarded susceptible to liquefaction due to the presence of clay (>10%). When compared with the previous layers one must expect soil properties to be reflected in the shear strength parameters established by laboratory testing.

#### C.7.3.7 Shear strength parameters

Shear strength parameters have been established on the basis of Triaxial (CU) and Shear Box Tests. Because of better defined stress-strain conditions emphasis will be placed on the analysis of the results of CU-triaxial testing. A compilation of test results, in support of a parametric evaluation, is presented in Appendix C/4.

(a) CU-triaxial test

Because of prevailing normally consolidated conditions (nc), sustained by effects of tremors and mica crushing, samples for triaxial testing were first consolidated anisotropically using a stress ratio of $K_o$ = 0.44.
Subsequent undrained loading simulates conditions where sudden failures or earthquakes induce shear strains in a saturated fine grained and undrained soil mass. The effects of undrained deformation and crushing of mica are reflected in developed pore water pressures. Following observation govern data interpretation:

(i) In general negative pore water pressures were monitored at peak strength;

(ii) Based on the comparison of critical and in-situ density it can be concluded that dilatation and collapse phenomena are not likely to occur. This suggests monitored negative pore pressures to result from interparticle flow phenomena accompanying induced shear movements.

(iii) Previously mentioned assembly properties affect shear parameters (effective stress), being defined via an envelope of Mohr's circles. The developed cohesion intercept in predominantly silty specimens reflects the effect of developed negative pore water pressures. They appear to be more prominent in the silt layers than in the fine sand layers;

(iv) The effects of this pore pressure development with respect to total stress levels appears to be limited, resulting in a minor difference between drained and undrained parameters;

(v) Previous observation allows the conclusion to be drawn that even upon sudden loading, e.g. earthquake, the effective stress parameters can be used for slope stability analysis;

(vi) In practice negative pore pressures will dissipate in time, reducing the stabilizing effect of negative pore pressures. It must be expected that after dissipation slope stability will mainly be governed by the peak interparticle friction angle.

Consequently, the following shear parameters have been chosen to define effective stress conditions:

**Table C.7.4 - SHEAR STRENGTH PARAMETERS**

| Layer | Description | Short term stability | | Long term stability | |
|---|---|---|---|---|---|
| | | ø'(·) | c'[Kn/m²] | ø'(·) | c'[Kn/m²] |
| I | FINE SAND, with silt | 25 | 5 | 27 | - |
| II | SILT, with sand & some clay | 24 | 5 | 25 | - |
| III | SILT, with clay * some sand | 19 | 20 | 20 | 10 |

Slope stability analysis for design of the protective works must be based on long term behaviour. The separate analysis of the stability of the protective layer, assumed to be infinite, should take due account of the composition of underlying layers. The accretion of loose material on the slope surface will result in an angle of internal friction of approximately 25·. When e.g. coarse backfill has been used an angle of interparticle friction of ø' = 30· can be used.

(b) Shear box test

Evaluation of shear box tests or direct shear tests show a similar but more variable pattern of shear resistance development, possibly under influence of sample preparation. Consequently preference is given to the use of the more consistent results of the triaxial tests.

(c) Interface friction angle (geotextile)

Based on a literature study [ 35] design boundary conditions can be set by simply stating that the residual interface friction angle for the geotextile-soil interface should be equal or higher than 25·. This angle matches the lower bound properties of layer II.
It must be expected that the interface friction angle at an interface woven-non-woven geotextile will be dramatically lower, being estimated at 15·. This means that when using a multiple layer on a slope angle >15· a major part of the applied surcharge (with a safety factor to be included) on the layer will have to be carried by an effective bond between the two layers.
In general it can be concluded that:

(i) The required interface friction angle of 25· can be met by a number of manufacturers;

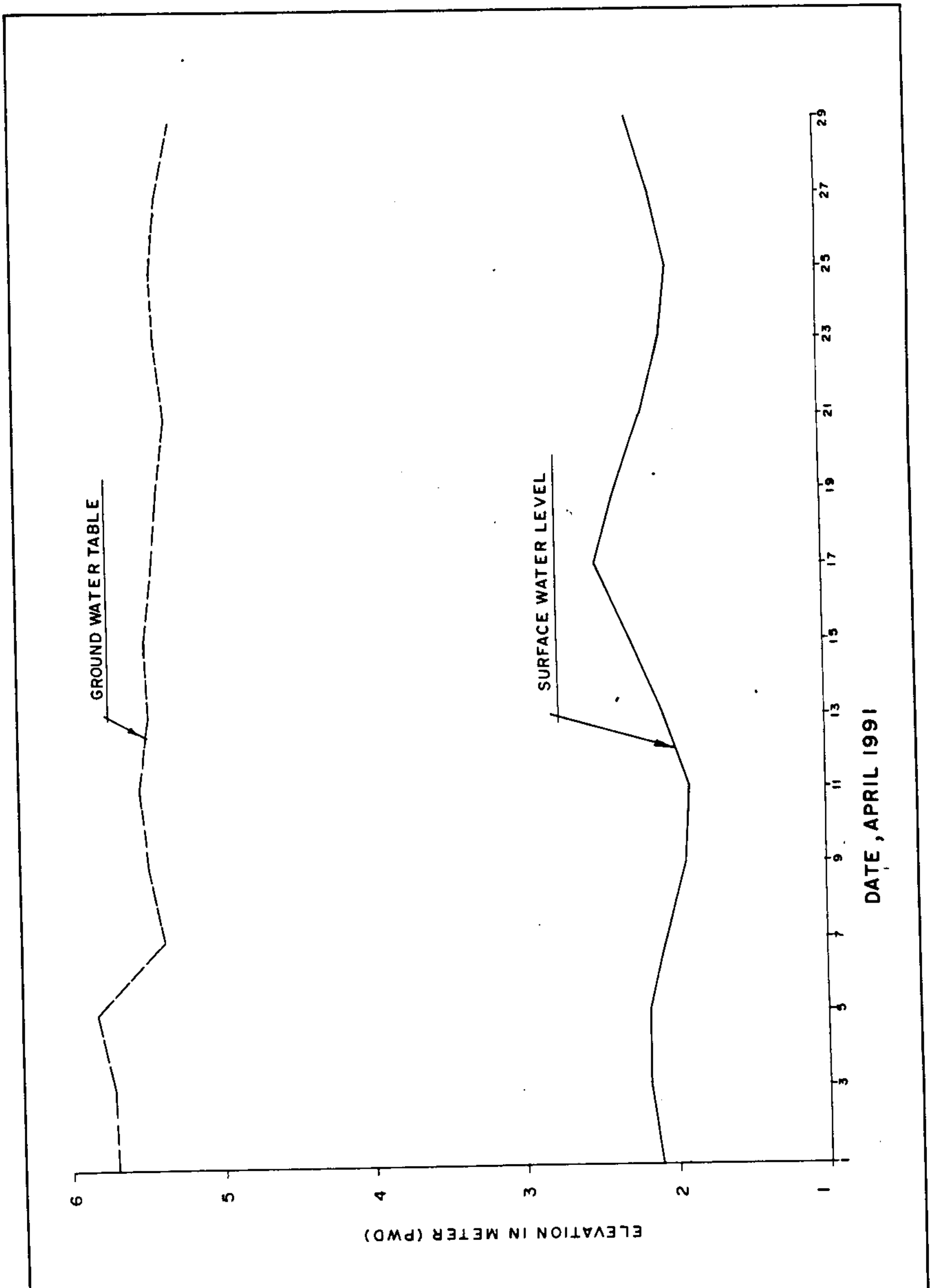
(ii) Consideration of the use of a certain geotextile must be based only on the results of testing under saturated conditions and matching soil composition and loading conditions;

(iii) quantitatively sufficient bond must accompany the use of multiple layers. No special measures will be required when geotextile-geotextile interface friction can be defined by a friction angle of 25° as well.

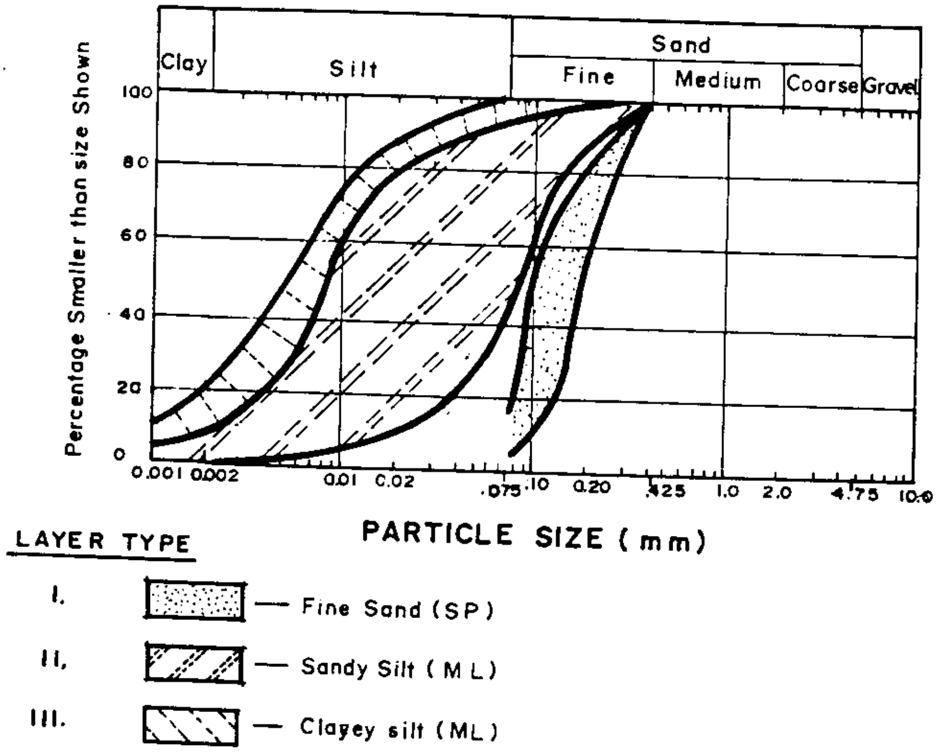
When selecting a particular material a.o. the following characteristics have to taken into account:

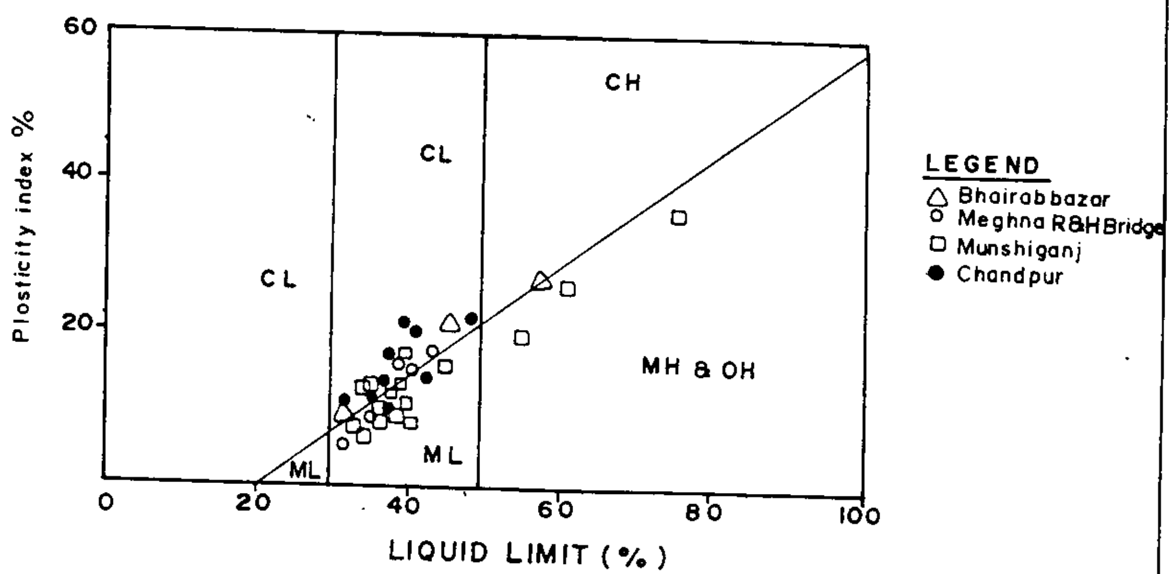
- granular characteristics of sub-soil
- type of geotextile; surface roughness, woven, non-woven, HDPE, polythene, PVC, etc.
- confining stress and stress history
- tensile strength, elasticity modulus,
- wet or dry conditions

Bearing in mind the importance of such a material in design certified proof of properties, supported by relevant testing certificates, should accompany any application. This proof should be applied to the material as well as to the interface characteristics.




| GROUND AND SURFACE WATER LEVELS OF RIVER MEGHNA AT BHAIRAB BAZAR (APRIL/91) | FIGURE NO. C.7.1 |
|---|---|




**PARTICLE DISTRIBUTION ENVELOPE AND PLASTICITY CHART.**

**FIGURE NO. C.7.2**

## C.8. SLOPE STABILITY

### C.8.1 General

Subsequent review of slope stability analyses refers to the more detailed information presented in Appendix C/5.

The approach to the evaluation of failure mechanisms covers the followings steps as described in Sections C.8.1.1 to C.8.1.3.

#### C.8.1.1 Data Collection

(a) Field visit to the sites, to assess the present situation of the slope. In many cases, however, such an impression is superficial only. Much of the visual damage, above the water line, finds its origin in slope angle reduction and/or erosion below water level;

(b) In cases of major visual damage topographic and bathymetric survey results, defining slope angles under water, will play an essential role when deciding on the elements involved in the calculation of slope stability;

(c) Collecting geotechnical engineering data to allow calculations to be carried out in support of macro and micro slope stability.

Previous sections cover all aspects detailed above, which ultimately having resulted in quantitatively defined design parameters.

#### C.8.1.2 Procedure for slope stability analysis

The consistency in soil composition, mainly governed by its prevailing long term cohesionless characteristics, allows a relatively straight forward slope stability analysis to be adopted. This applies for a check of the actual conditions, with natural (critical, i.e. n = 1) slopes as well as design slopes. The latter will have to represent a certain safety factor (>1) against sliding. To ensure optimal design procedures for overall slope stability a parametric verification should be carried out prior to actual design.

Consequently, the following approach has been adopted:

(a) Establishment of river bank sections where apparently steep under water slopes have developed. Such a slope must represent critical conditions, numerically exhibiting a safety factor of 1.
Geotechnical calculation of the slope stability, using data generated by the geotechnical investigation, by means of a HASKONING Computer Package (BISEIS) based on Bishop's Simplified Method [26]. Verification of the applied Package will then follow from the calculated safety factors when n-values of approximately 1 are found;

(b) Having verified the program an analysis will now serve to investigate the most adverse conditions, allowing for layering, piezometric head differences and slope angles, all with and without the effect of earthquake loading. Based on some approximative analyses definite slope angles of 1:3 and 1:3.5 will be evaluated.

C.8.1.3 Summary of design parameters

Slope stability analyses will have to satisfy different safety factors, with:

- n = 1.5 : for permanent loading (incl. effects of ground water flow), governing macro- and micro-stability;

- n = 1.1 : when allowing for the effect of earthquake loading as well but for macro-stability only. The acting horizontal load will be introduced on the basis of a horizontal acceleration of a = 0.05g.

Piezometric head differences governing worst loading conditions, different for various sites, are indicated on the relevant cross sections shown in App. 5. (Fig.'s C.5.1 through C.5.5).

The geotechnical design parameters for natural soil, adopted for the above mentioned analysis, are summarized in Table C.8.1.

**Table C.8.1 - GEOTECHNICAL DESIGN PARAMETERS FOR SLOPE STABILITY ANALYSIS**

| Layer | Description | Density [kN/m³] | | Long term stability | |
|---|---|---|---|---|---|
| | | dry* | saturat. | ø'(°) | c'[kN/m²] |
| I | FINE SAND, with silt | 15.50 | 19 | 27 | - |
| II | SILT, with sand & some clay | 14.4 | 19 | 25 | - |
| III | SILT, with clay * some sand | 15.2 | 18 | 20 | 10 |

When backfilling with coarse material, e.g. for the containment bunds, the angle of internal friction can be chosen at ø' = 30°.

Note: (*) The use of a dry density above ground water applies to completely dry conditions. However, in the fine top layers, with water practically kept in place by negative pore water pressures, saturated conditions will persist. Consequently a saturated density has also been introduced to define the weight of layers above the ground water table.

## C.8.2 Summary of results

### C.8.2.1 Critical slope angle

(a) Macro-stability

Actual profiles, with relatively deep under water slopes, were selected to assess their in-situ stability. They reflect natural equilibrium conditions. At all (4) selected sites steepest slope sections can be recognized that numerically match the critical condition defined by average slope angles of approx. 1:1.5. Some low safety factors at Bhairab Bazar, <<1, with very small circles intersecting the slope, much more reflect the accuracy of the specific numerical input at that location than the actual equilibrium condition. The results from an extensive and detailed analysis, compiled in Appendix 5, are summarized in table C.8.2.

Table C.8.2 - SAFETY FACTORS, FOR CRITICAL, 1:3 AND 1:3.5 SLOPE ANGLES

| Site | Critical slope | | slope 1 : 3 | | slope 1 : 3.5 | |
|---|---|---|---|---|---|---|
| | section | whole | n > 1.5 | n > 1.1 | n > 1.5 | n > 1 |
| Bhairab Bazar | 1.0 & 1.2 | 1.2 | 1.40 | 1.10 | 1.55 | 1.14 |
| Munshiganj | 1.1 | 0.8 | - | - | 1.59 | 1.14 |
| Chandpur | - | 1.0 | - | | 1.85<br>1.76<br>1.68* | 1.33<br>1.27<br>1.22* |

The results presented above indeed show that the existing steepest slope angles do develop a safety factor of practically n = 1, hence confirming the apparent critical state and the effectivity of the applied computer program.
The critical slope circles appear to develop in the surface layers of the slope, thus approximating a condition where an (infinitely) long slope can be analyzed on the basis of straight failure planes (Section 4.2.5, eq. (2)).

The results marked with an asterix (*) result from slip circles with radii of 264, 335 and 429m respectively! Further increase of this radius will reduce the safety factors. Ultimately, with a radius of infinite length, a condition transpires of a failure plane parallel to the slope. This means that for the very long slope apparently micro-stability will govern its behaviour.

In general the following features, affecting critical stability, have been noticed:

(i) At Bhairab Bazar and Chandpur a slope angle of 1:1.5 has been developed over practically the full depth, 14m & 40m respectively;

(ii) The specific layering at Bhairab Bazar, with a lower permeability layer at some depth below the slope toe, will have promoted uplift water pressures in the toe section at falling water levels in the river (Fig. 4.6). This effect, in conjunction with an already steep slope, must be regarded as one of the main causes for the overall failure, a straight forward geotechnical phenomenon. This also means that the absence of such a steep slope, adopting design requirements defined hereafter, would not have resulted in a critical conditions. Additionally it is understood that the tremors did not result in failure phenomena that could be linked with liquefaction.

(iii) Cross sections at R&H bridge and Munshiganj show steeper sections as a part of the overall slope.

(iv) Some flow channels even show slopes >(1:1.5). Taking into account the sudden effects of scour and induced negative pore pressures such angles can easily be sustained by the temporary cohesive properties after sudden decompression.

The results above confirm the validity of the applied Computer program.

Though the effect of seismic loading has been evaluated on the basis of the same parameters, resulting in a tendency for "n" to become <1, reality will introduce effects of negative pore pressures at the event of earthquake loading. This will partly off-set the reduction in safety coefficient.

(b) Micro-stability

The critical stability of surface layers, supposed to be a part of an infinite slope, can easily be investigated on the basis of the eq.'s presented in Section C.4.2.5.

The micro-stability requirements can be met by the construction of natural filter layers or the use of geotextile.
With reference to Section 7.3.7 (c) & Appendix C/5, it is recommended that the interface frictional angle matches soil properties. Such condition will ensure that geotextile will not become a slope angle governing material property. It will allow the stability analysis to be carried out as if homogeneous conditions prevail.

C.8.2.2 Design slope angle

(a) Macro-stability

Detailed numerical analyses, presented in Appendix C/5 and summarized in Table C.8.2, show that without exception a slope angle of 1:3.5 (just under) will be required to meet the safety factors for macro-stability, whether or not some layering can be expected. It then follows that:

(i) The governing loading condition will develop when combining static load with the effect of an piezometric head difference.
(ii) Slope angle 1:3.5 will result in n>1.1 when introducing earthquake loading.

(b) Micro-stability

Reference being made to a more detailed macro slope analysis presented in Appendix C/5, the data in table C.8.2, show that a low interface friction angle (e.g. 17°) would render this parameter to govern the design slope angle.
When requiring the slope to satisfy a safety factor of n (= 1.5), taking into account an outwardly directed gradient of i = 0.04, equation 3, Section C.4.2.4, can be used. The admissible slope angle can then be written as:

$$\tan\alpha = \frac{(1-i)}{n} \cdot \tan\beta \qquad (5)$$

Introduction of a interface friction angle of $\beta$ = 17° results in a slope angle of $\alpha$ = 11°, i.e. 1 : 5.1.

Introduction of an interface friction angle of $\beta$ = 25° results in a slope angle of $\alpha$ = 16.5°, i.e. 1 : 3.4.
The last result shows that, whether one designs a natural filter or introduces a geotextile, lower bound shear parameters defining soil and geotextile properties will govern the slope angle. The minimum shear parameter is defined by a friction angle of 25°.

(c) Geotextile

Geotextile membranes have been tested for their interface frictional properties [35], using 0.3 x 0.3m specimen. The latter publication, however, deals in detail with products that have been tested in contact with various soils compacted at a few percent of the Optimum Moisture Content (OMC). This means that a phenomenon to be attributed to suction or negative pore pressures will have affected the result. This shows up in relatively high friction angles and some adhesion. A soil type approximating the soil type under consideration is denoted as "Saprolite" (Sapr.). This soil type is described as a non-plastic subangular to angular fine sand with a small (0.5%-1%) percentage of mica.
Quoted in the same publication from other sources, and tested in smaller samples, are also presented the interface friction properties when being tested under saturated conditions. A soil type approximating

the soil under consideration is denoted as "Mica schist silty sand" (MMSS), having an angle of internal friction of $\phi' = 26°$. The results of both test series are presented in table C.8.3.

**Table C.8.3 - GEOTEXTILE INTERFACE FRICTION PARAMETERS**

| Test nr. | Interface specification | β(°) | a[kN/m²] |
|---|---|---|---|
| **Non-saturated conditions** | | | |
| 1 | Sapr./HDPE, smooth 60-mil lining | 21 | 0.4 |
| 2 | Sapr./PVC, 30-mil membrane | 28 | 0.5 |
| 3 | Sapr./Typar 3401, nonwoven filament | 28 | 0.8 |
| 4 | Sapr./Trevira 1155, non-woven filam. | 30 | 1.5 |
| 5 | Sapr./Nicolon 900-M, woven polyester | 31 | 1.5 |
| **Saturated conditions** | | | |
| 6 | MMSS/EPDM | 24 | - |
| 7 | MMSS/PVC (rough) | 25 | - |
| 8 | MMSS/PVC (smooth) | 21 | - |
| 9 | MMSS/CSPE | 23 | - |
| 10 | MMSS/HDPE | 17 | - |
| 11 | MMSS/Crown Zellerbach 600 | 25 | - |
| 12 | MMSS/ Mirafi 500 X | 23 | - |

The results above do clearly signal that caution should be exercised when selecting a specific geotextile. Only two of the quoted products appear to have the required interface friction angle of 25°!

C.8.2.3 <u>Summary</u>

The evaluation above transpires into straight forward boundary conditions for slope design. They can be summarized as follows:

(a) Allowing for an overall stability a slope angle of 1:3.5 will be required to satisfy a safety factor of n = 1.5;

(b) An interface friction angle of $\beta = 25°$ will be required to satisfy the required safety factor of n = 1.5 when allowing for micro-stability;

(c) Slope angles can increase only when a higher interface friction angle and a higher soil shear parameters can be expected, a condition requiring the presence of predominantly fine sand ($\phi' = 27°$);

(d) Present geotextile interface friction parameters suggest a friction angle of 25° as most likely. This result, together with the overall stability requirements, can be sustained only when the geotextile is placed on a slope angle not steeper than 1:3.5;

(e) The recommended slope angle does well match the construction requirements of underwater profiling.

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## APPENDIX C/1

RRI-REPORT ON SITE INVESTIGATION
AND
LABORATORY TESTING
(it is presented as a separate report)

## APPENDIX C/2

MICA CONTENT,
COUNTED AND BY WEIGHT

[illegible] University of Engineering and Technology, Dhaka
Department of Civil Engineering

No-BRTC 2310/90-91 Dt.31.03.91
Sent by :HASKONING-DH-BETS LTD.,ELLAL CHAMBER (10TH FLOOR)
11, Motijheel C/A, Dhaka-1000.

Your Ref. No.5146.21.330/14 dt 28.3.91

Sample ID: GH-1
Sample Location: Local Sand
Location: Chandpur

TEST RESULT OF MICA CONTENT OF SAND

A) Calculation of Results of Particle Counts

Composition of Fractions Retained on Sieves Shown Below

| | Sieve No-8 | | Sieve No-16 | | Sieve No-30 | | Sieve No 50 | | Sieve No 100 | | Sieve No 200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent |
| Micas | - | - | - | - | 96 | 68.6 | 291 | 97.0 | 76 | 25.3 | 6 | 2.0 |
| Others | - | - | - | - | 44 | 31.4 | 9 | 3.0 | 224 | 74.7 | 294 | 98.0 |
| Totals | - | - | - | - | 110 | 100.0 | 300 | 100.0 | 300 | 100.0 | 300 | 100.0 |

(B) Weighted Percentages of Constituents in Each Sieve Fraction

| | No.8 | No.16 | No.30 | No. 50 | No.100 | No.200 | Weighted Composition of Sample(%) |
|---|---|---|---|---|---|---|---|
| Micas | - | - | 0.1 | 0.5 | 8.2 | 1.3 | 10.1 |
| Others | | - | 0.0 | 0.0 | [illegible]1.4 | [illegible] | 87. |
| Total in Sieve Fraction | - | - | 0.1 | 0.5 | 32.6 | 64.0 | 97.2 |

Total Mica Content: 10.1%

Countersigned by: [signature]

[signature] 3/4/91
Tested By: Dr.Md.Delwar Hossain
Asstt. Professor of Civil Engg.

*(Dr M D. HOSSAIN)*
*Assistant Professor*
*Dept. of Civil Engineering*
*BUET, Dhaka, Bangladesh.*

26

Bangladesh University of Engineering and Technology,Dhaka
Department of Civil Engineering

No-BRTC 2037/90-91    Dt. 4.3.91    Your Ref. No.5140.21.330/10 dt. 2.3.91

Sent by :HASKONING-DH-BETS LTD., Elial Chamber (10 floor)
11, Motijheel C/A, Dhaka

Sample ID: MG-I
Sample Location: Local Sand
Location: **Meghna R & H Bridge Site.**

TEST RESULT OF MICA CONTENT OF SAND

A) Calculation of Results of Particle Counts

Composition of Fractions Retained on Sieves Shown Below

| | Sieve No-8 | | Sieve No-16 | | Sieve No-30 | | Sieve No 50 | | Sieve No 100 | | Sieve No 200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent |
| Micas | - | - | 1 | 5.3 | 26 | 8.7 | 13 | 4.3 | 18 | 6.0 | 10.0 | 3.1 |
| Others | - | - | 18 | 94.7 | 275 | 91.3 | 287 | 95.7 | 282 | 94.0 | 308 | 96.9 |
| Totals | - | - | 19 | 100.0 | 300 | 100.0 | 300 | 100.0 | 300 | 100.0 | 318 | 100.0 |

(B) Weighted Percentages of Constituents in Each Sieve Fraction

| | No.8 | No.16 | No.30 | No. 50 | No.100 | No.200 | Weighted Composition of Sample(%) |
|---|---|---|---|---|---|---|---|
| Micas | - | 0.0 | 0.1 | 1.8 | 2.8 | 0.3 | 5.0 |
| Others | - | 0.2 | 1.6 | 39.2 | 44.2 | 9.5 | 94.7 |
| Total in Sieve Fraction | - | 0.2 | 1.7 | 41.0 | 47.0 | 9.8 | 99.7 |

**Total Mica Content: 5.0%**

Countersigned by:    Test Performed by:

ড: মোঃ দেলোয়ার হোসেন
সহকারী অধ্যাপক
পুরকৌশল বিভাগ
বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়, ঢাকা

Bangladesh University of Engineering and Technology, Dhaka
Department of Civil Engineering

No-BRTC 2215/90-91 Dt.20.3.91

Your Ref. No.5140.21.330/1. dt.20.3.91

Sent by :HASKONING-DH-BETS LTD., Dilal Chamber (10 floor)
11, Motijheel C/A, Dhaka

Sample ID: M-1
Sample Location: Local Sand
Location: Munshiganj.

## TEST RESULT OF MICA CONTENT OF SAND

### A) Calculation of Results of Particle Counts

Composition of Fractions Retained on Sieves Shown Below

| | Sieve No-8 | | Sieve No-16 | | Sieve No-30 | | Sieve No 50 | | Sieve No 100 | | Sieve No 200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent | No of Particles | Percent |
| Micas | - | - | - | - | 270 | 90.0 | 125 | 41.7 | 48 | 16.0 | 8 | 2.6 |
| Others | - | - | - | - | 30 | 10.0 | 175 | 58.3 | 252 | 84.0 | 300 | 97.4 |
| Totals | - | - | - | - | 300 | 100.0 | 300 | 100.0 | 300 | 100.0 | 308 | 100.0 |

### (B) Weighted Percentages of Constituents in Each Sieve Fraction

| | No.8 | No.16 | No.30 | No. 50 | No.100 | No.200 | Weighted Composition of Sample(%) |
|---|---|---|---|---|---|---|---|
| Micas | - | - | 0.3 | 1.4 | 9.9 | 0.5 | 12.1 |
| Others | - | - | 0.0 | 1.9 | 52.1 | 31.6 | 85.6 |
| Total in Sieve Fraction | - | - | 0.3 | 3.3 | 62.0 | 32.0 | 97.7 |

**Total Mica Content:12.1%**

Countersigned by: [signature]

Test Performed by: [signature]

ড: মো: [illegible] হোসেন
সহকারী অধ্যাপক
পুরকৌশল বিভাগ
বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়, ঢাকা

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**APPENDIX C/3**

CHEMICAL COMPOSITION OF SAND

বাংলাদেশ বিজ্ঞান ও শিল্প গবেষণাগার ঢাকা

**BCSIR LABORATORIES DACCA**

Telegram : BSEARCH
Telephones :
Director Office : 315534
Res : 316069
Registrar : 318029
PABX : 315763, 31556?, 315528

Mirpur Road, Dhanmondi
P. O. Box No. 5010
( New Market )
Dacca-5


Ref. No......................

Dacca, the 25-4-91. ......197

## ANALYSIS REPORT

Supplied by Haskoning - DH-Bets Ltd.

Meghna River Bank Protection Study

| Sl.No. | | Sample No-1 MG -1 in% | Sample No-2 MN - 1 in% |
|---|---|---|---|
| 1. | Moisture at 110$^{0c}$ ( Volatite Matter) | 0.35 | 0.26 |
| 2. | Loss on ignition | 1.30 | 0.60 |
| 3. | $SiO_2$ | 74.49 | 80.53 |
| 4. | $Al_2O_3$ | 13.30 | 1Q54 |
| 5. | $Fe_2O_3$ | 1.22 | 0.58 |
| 6. | $CaO$ | 5.09 | 4.48 |
| 7. | $MgO$ | 3.80 | 2.78 |
| 8. | Cl | Trace | Trace |
| 9. | $SO_3$ | Nil | Nil |
| 10. | $CO_2$ | Nil | Nil |

N.B. Ref.H.Bennett and W.G Hawley,''Methods of silicate Analysis'',
London and Newyork,Academic Press,1965.

''Classical Method''

F-Majid
25.4.91.

(Dr. F.S.Majid)
Director .

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# বাংলাদেশ বিজ্ঞান ও শিল্প গবেষণাগার ঢাকা

## BCSIR LABORATORIES DACCA


Telegram : BSEARCH
Telephones :
Director's Office : 315534
Res : 258182
Registrar : 318029
PABX : 315763, 315563, 315528

Mirpur Road, Dhanmondi,
P. O. Box No. 5010
(New Market)
Dacca-5


Ref. No.......................

Dated Dacca, the...............198

Analysis report on soil sample : Meghna River protection short Term study. Supplied by HASKONING-DH-BETS LTD.

| | | |
|---|---|---|
| % | Moisture | 0,10 |
| % | Loss on ignition (Organic matter) | 1,20 |
| % | $SiO_2$ | 78,01 |
| % | $Al_2O_3$ | 13,95 |
| % | $Fe_2O_3$ | 0,75 |
| % | CaO | 2,51 |
| % | MgO | 2,20 |
| % | $Cl^-$ | 0,50 |
| % | $SO_3$ | 0.00 |
| % | $CO_2$ | 0,00 |
| | Total : | 99,22 |

Note : $SiO_2$, $Al_2O_3$, $Fe_2O_3$, CaO, MgO, were determined gravimetrically by titration after fusion of the sample by $Na_2CO_3$. $Cl^-$ determined as AgCl and $SO_3$ as $BaSO_4$. $CO_2$ by lime-water turbidity.

F. Majid 29/8?

(Dr. F.Z.Majid)
Director.

**APPENDIX C/4**

PARAMETRIC EVALUATION
TRIAXIAL (CU) AND CRITICAL DENSITY

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CONTENTS



TABLE

## C/4.1. GENERAL

Subsequent parametric evaluation, with emphasis on shear strength and density, mainly serves to extract simple design parameters enabling coverage of the numerous cases of slope failures. Such an approach, however, does not necessarily introduce very conservative data. Consistency in layering and composition, established a governing feature of the area, are both reflected in the laboratory test results and the derived design parameters.

## C/4.2. SHEAR STRENGTH

### C/4.2.1 Test Results per Sample

**TABLE C/4.2.1 - SHEAR STRENGTH PARAMETERS FROM TRIAXIAL TESTING (CU)**

| Boring/sample | Depth [m - g.l.] | Density [kN/m³] | | Shear parameter | |
|---|---|---|---|---|---|
| | | dry | saturated | ø' (°) | c'(kN/m²] |
| Layer I - FINE SAND, with silt | | | | | |
| MN1/U4 | 14,0 | 15.1 | 19.5 | 27,5 | 1.5 |
| BR1/U3 | 6.5 | 13.7 | 16.6 | 25 | 5 |
| BR1/U5 | 12.5 | 15.2 | 19.0 | 32.5 | 5.5 |
| BR2/U2 | 10.5 | 16.6 | 20.1 | 29 | 5.5 |
| BR2/U4 | 18.5 | 14.5 | 18.1 | 28 | 15 |
| Layer II - SILT, with sand & some clay | | | | | |
| MG1/U1 | 2 | 14.7 | 19.3 | 26 | 9 |
| MG1/U2 | 3 | 14.5 | 18.7 | 24 | 4 |
| MG2/U2 | 2 | 14.6 | 19.4 | 23.5 | 20 |
| MG2/U3 | 4.5 | 14.7 | 19.6 | 24.5 | 4 |
| MN2/U4 | 10 | 13.8 | 18.2 | 25 | 30 |
| CH1/U5 | 6 | 13.8 | 17.5 | 25 | 3.5 |
| CH2/U2 | 1.8 | 14.5 | 18.3 | 15 | 13 |
| Layer III - SILT, with some sand and clay | | | | | |
| MN2/U2 | 3 | 14.6 | 17.9 | 21.5 | 31 |
| MN2/U3 | 9 | 12.2 | 16.8 | 19.5 | 21.5 |
| CH1/U3 | 2.4 | 14.7 | 19.6 | 19 | 4022 |

The accuracy of the average design parameter must be balanced by its sensivity in a slope stability analysis. All test results, divided into three groups, have been assessed for their density and shear strength properties. Only one test result, from sample CH2/U2, appeared to be out of tune with the general trend. Its results were neglected.

## C/4.2.2 Design parameters

The Annex C elaborates on the effect of negative pore water pressures developed in saturated fine grained material (Section 4.2.4 & 7.3.7). They are reflected as an effective stress part, defined via a cohesion intercept. The physical process of dissipation will annihilate this effect in time, resulting in a transformation from a cohesive into a practically cohesionless assembly. Cohesion will disappear and the angle of internal friction will slightly increase. A weighing of the test results resulted in the design parameters per layer type. The results are summarized in Table C/4.2.2

**Table C/4.2.2 - GEOTECHNICAL DESIGN PARAMETERS FOR SLOPE STABILITY ANALYSIS**

| Layer | Description | Short term stability | | Density [kN/m³] | | Long term stability | |
|---|---|---|---|---|---|---|---|
| | | ø'(°) | c'[kN/m²] | dry* | saturat. | ø'(°) | c'[kNm/m²] |
| I | FINE SAND, with silt | 25 | 5 | 15.50 | 19 | 27 | - |
| II | SILT, with sand & some clay | 24 | 5 | 14.4 | 19 | 25 | - |
| III | SILT, with clay * some sand | 19 | 20 | 15.2 | 18 | 20 | 10 |

When backfilling with coarse material, e.g. for the containment bunds, the angle of internal friction can be chosen at ø' = 30°. The accretion of fines on a profiled natural underwater slope will require a friction angle of 25° to be introduced when analysing interface behaviour.

Note: (*) The use of a dry density above ground water applies to completely dry conditions. However, in the fine top layers, with water practically kept in place by negative pore water pressures, saturated conditions will persist. Consequently a saturated density has also been introduced to define the weight of layers above the ground water table.

## C/4.3. IN-SITU & CRITICAL DENSITY

Reconstituted samples, at varying densities, were tested for their volumetric strain under induced shear loading. A density exhibiting zero volume change is supposed to reflect a critical density. When an in-situ density is less than the critical density collapse phenomena may accompany induced shear. When additionally saturated conditions prevail a failure mechanism with flow properties, developed as a result of excess pore water pressures, is denoted as "liquefaction". The results of the critical density tests and their comparison with in-situ densities are summarized in table B.3

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TABLE C/4.3.1 - CRITICAL DENSITY PER SAMPLE

| Boring/sample | Depth [m- g.l.] | Dry density [kN/m$^2$] |
|---|---|---|
| Layer I - FINE SAND, with silt | | |
| MG1/6D | 9 | 14.4 |
| MN1/U5 | 18.5 | 16.3 |
| Layer II - SILT, with sand & some clay | | |
| MN1/U2 | 3.3 | 14.6 |
| MG/U1 | 1 | 14.7 |
| MG2/U3 | 4.5 | 13.9 |
| MN2/U3 | 9 | 14.3 |
| BR2/U2 | 1.2 | 13.6 |
| Layer III - SILT, with some sand and clay | | |
| MN2/U2 | 3 | 15.3 |
| MN2/U5 | 30 | 15.1 |

The mean of above results is compared with the mean of in-situ densities reported in conjunction with triaxial testing (table B.4).

Table C/4.3.2 - MEAN IN-SITU VERSUS CRITICAL DENSITY

| Layer | Description | Density [kN/m$^3$] | |
|---|---|---|---|
| | | in-situ | critical |
| I | FINE SAND, with silt | 15.0 | 15.3 |
| II | SILT, with sand & some clay | 14.4 | 14.4 |
| III | SILT, with clay & some sand | 15.2 | 15.2 |

It can be concluded that apparently the predominantly fine sand layers can exhibit an in-situ density below the critical density. It could well be that this phenomenon can be attributed to the presence of mica. Any induced shear strain will introduce some crushing and, consequently, create ample room for repositioning and densification.

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**APPENDIX C/5**

MACRO SLOPE STABILITY ANALYSIS
DETAILED DATA

## CONTENTS



## LIST OF TABLES



## LIST OF FIGURES

## C/5.1. GENERAL

Subsequent numerical slope stability (macro) analyses, as presented below using equilibrium principles defined in accordance with the so-called Bishop-method, serves the following pourposes:

- to give insight in the present conditions. Steep natural slope sections must signal just equilibrium, showing up in a safety factor of appr. 1 when taking into account the effect of ground water flow of falling water levels as well. Such a critical state of stress should develop without the effect of earthquake loading being taken into account.
- to check the reliability of the used computer program and soil parameters being used. When yielding a safety factor of appr. n = 1 the previous analysis can be regarded as satisfactory.
- to design slopes reflecting safety conditions appropriate for the specific loading conditions.

## C/5.2. SLOPE DESIGN PARAMETERS

### C/5.2.1 Safety factors

Slope stability analyses will have to satisfy different safety factors, with:

(a) n = 1.5 for permanent loading (incl. effects of ground water flow), governing macro- and micro-stability

(b) n = 1.1 when allowing for the effect of earthquake loading as well, for macro-stability only

### C/5.2.2 Piezometric head differences

Piezometric head differences governing worst loading conditions, different for various sites, are indicated on the relevant cross section of the computer input data for the slope stability analysis.

### C/5.2.3 Shear parameters

The geotechnical design parameters for natural soil, adopted for the above mentioned analysis, are summarized in table 8.1.

**Table C/5.2.1 - GEOTECHNICAL DESIGN PARAMETERS FOR SLOPE STABILITY ANALYSIS**

| Layer | Description | Density [kN/m³] | | Long term stability | |
|---|---|---|---|---|---|
| | | dry* | saturat. | ø'(°) | c'[kNm/m²] |
| I | FINE SAND, with silt | 15.50 | 19 | 27 | - |
| II | SILT, with sand & some clay | 14.4 | 19 | 25 | - |
| III | SILT, with clay * some sand | 15.2 | 18 | 20 | 10 |

When backfilling with coarse material, e.g. for the containment bunds, the angle of internal friction can be chosen at ø' = 30°.

Note: (*) The use of a dry density above ground water applies to completely dry conditions. However, in the fine top layers, with water practically kept in place by negative pore water pressures, saturated conditions will persist. Consequently a saturated density has also been introduced to define the weight of layers above the ground water table.

### C/5.2.4 Seismicity and ground water gradient

The horizontal acceleration, to introduce earthquake loading, is selected at 0.05g.
The effect of ground water head differences forms part of the slope stability analysis applied. A gradient of i = 0.04 is introduced to quantify the effect on the stability of an infinite slope. This evaluation, however, deals with micro-stability. This aspect has been dealt with in the relevant chapters of Annex C.

## C/5.3. SLOPE STABILITY EVALUATION

### C/5.3.1 Critical slope sections

Some typical cross sections in the near vicinty of the bore holes, established during recent bathymetric and/or topographic surveys, are presented in Fig.'s C/5.3.1 to 3.6. Some of the cross sections showed critical conditions and were numerically evaluated for their stability. Some other sections, however, in the near vicinity of a bore hole, did not indicate critical conditions. A more critical, i.e. steeper cross section, at some distance was then chosen.

**Table C/5.3.1 - PARTICULARS OF SLOPE STABILITY ANALYSIS**

| Figure | Site | Boring | Cross section | Analyzed |
|---|---|---|---|---|
| 3.1 | Bhairab Bazar | BR-1 | No. 5 | yes |
| 3.2 | Bhairab Bazar | BR-2 | No. 22 | no |
| 3.3 | R&H Bridge | MG-1 | from contours | no |
| 3.4 | Munshiganj | MN-1 | No. 40 | no |
| 3.5 | Munshiganj | MN-2 | No. 22 | yes |
| 3.6 | Chandpur | CH-1 | No. 21 | yes |

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C/5.3.1.1 Bhairab Bazar

The cross section in Fig. C/5.3.1, close to bore hole BR-1, was carried out to identify the soil layering at the location of the slide. At this moment, however, slope angles do not indicate critical conditions in this cross section. Such conditions, with a water depth up to 20m, are prevalent at some distance (cross section nr. 5, in calculation). The maximum existing slope angles approximate here the critical conditions defined by $\phi' = 27°$.

Taking into account the specific layering, with a less pervious layer below the slope toe, more critical loading conditions can be expected at this location. Consequently this situation will be evaluated only.

C.5.3.1.2 R&H Bridge

Available cross sections at some distance from the bore hole, derived from contour lines, did not signal the critical conditions that must govern the eroded area. In general, however, sub soil conditions must be expected to sustain erosion phenomena similar to those encountered elsewhere.

C/5.3.1.3 Munshiganj

When analyzing existing conditions preference was given to a cross section with the steepest slope sections, up to 1:1.8.

C/5.3.1.4 Chandpur

For the analysis of the existing stability preference is given to the predominantly cohesionless soil composition prevailing near bore hole CH-1. In addition the river has developed a very deep flow channel at this location.

## C/5.3.2 Discussion of results

C/5.3.2.1 General

The numerical test results, presented at the end of this Appendix, comprise:

(a) a sheet with the computer input data:

- (i) geometry points
- (ii) soil layering
- (iii) piezometric levels
- (iv) soil properties
- (v) slip circle boundaries
- (vi) seismic factor

(b) a summary of calculated slip circles with minimum safety factors

(c) typical slip circles representing a minimum safety factor

C/5.3.2.2 Summary of results

**Table C/5.3.2 SAFETY VALUES, FOR CRITICAL AND 1:3 & 1:3.5 SLOPE ANGLES**

| Site | Critical slope | | slope 1 : 3 | | slope 1 : 3.5 | |
|---|---|---|---|---|---|---|
| | section | whole | n > 1.5 | n > 1 | n > 1.5 | n > 1 |
| Bhairab Bazar | 1.0 & 1.2 | 1.2 | 1.40 | 1.10 | 1.55 | 1.14 |
| Munshiganj | 1.1 | 0.8 | - | - | 1.59 | 1.14 |
| Chandpur | - | 1.0 | - | - | 1.85<br>1.76<br>1.68 | 1.33<br>1.27<br>1.22 |

The above results indeed show that the existing steepest slope angles do develop a safety factor of practically n = 1, hence confirming the apparent critical state and the effectiveness of the applied computer program.

Only in one instance it was felt necessary to investigate a design slope angle of 1 : 3. Similarity in soil parameters and stratification did not warrant further analysis. The developed safety factors do not match the design criterium!

The derived safety factors for a slope at Chandpur represent slip circle radii of 264m, 335m and 429m respectively! A further increase of the radius of the slip circle will also reduce the safety factor. The development of such long radii, however, does nothing else but mean that its actual behaviour will approximate that of an infinite slope. Consequently an analysis according to straight failure planes will provide the governing design slope.

A slope angle of 1 : 3.5 does just match the design criteria. This slope angle does also match the design requirements when evaluating micro-stability, i.e. the stability of an infinite slope in which either the internal friction angle amounts to $\phi' = 25°$ or the interface friction angle between soil and geotextile amounts to $\beta = 25°$.

The latter friction angle will practically govern slope stability when geotextile does not prove to have a higher friction angle than 25°.
When geotextile would prove to have a higher friction angle it will be the macro-stability that governs the slope angle. This will also result in an angle of 1 : 3.5.

In general the conclusion emerges that, when applying geotextiles, no higher interface friction angle will be required than 25° in conjunction with a slope angle of 1 : 3.5. When steeper slope angles are pursued material as well as base properties should have proven higher friction angles.
In addition it is noticed that such an angle does well match the construction requirements emanating from the methods of underwater profiling.

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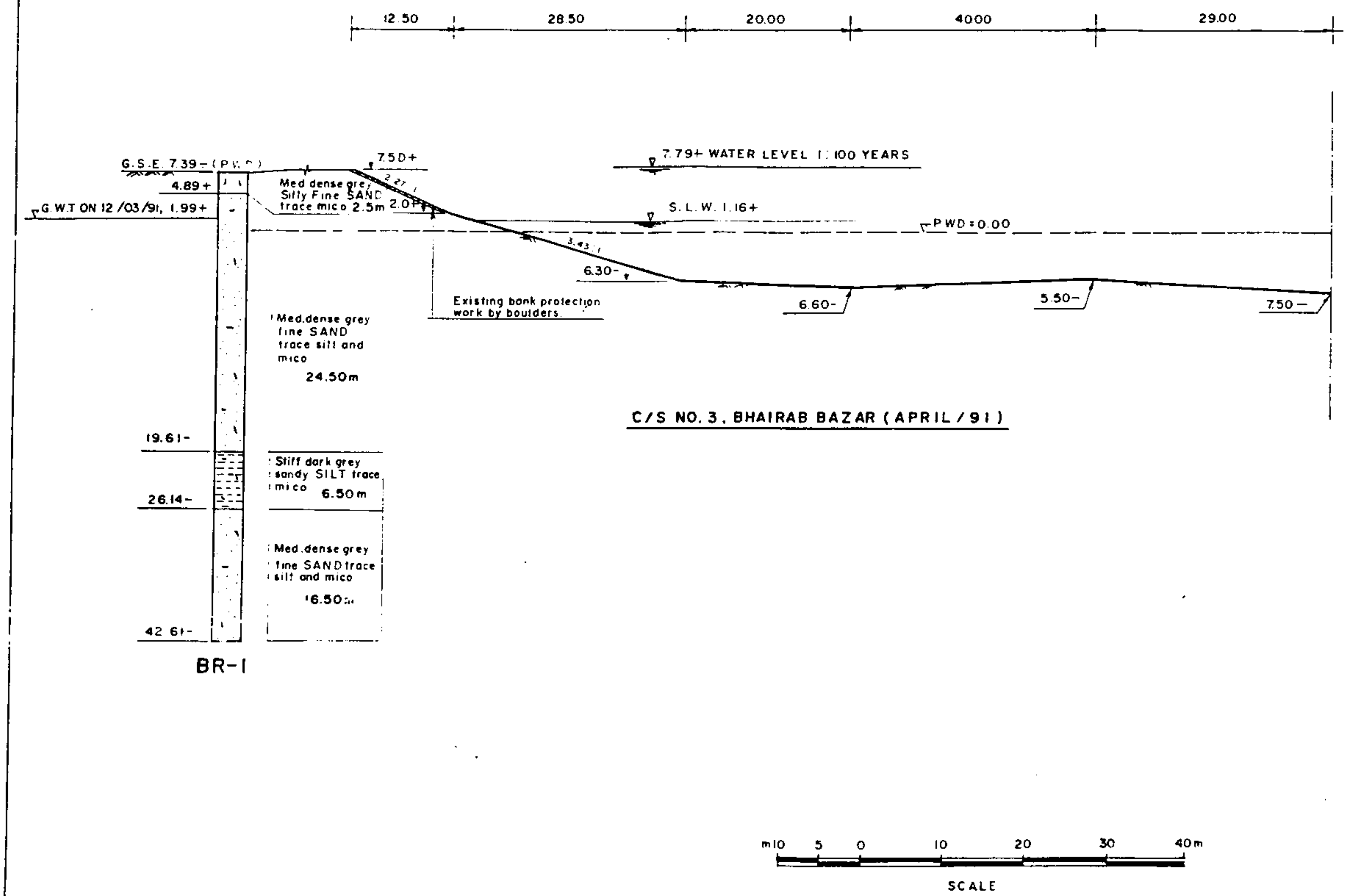
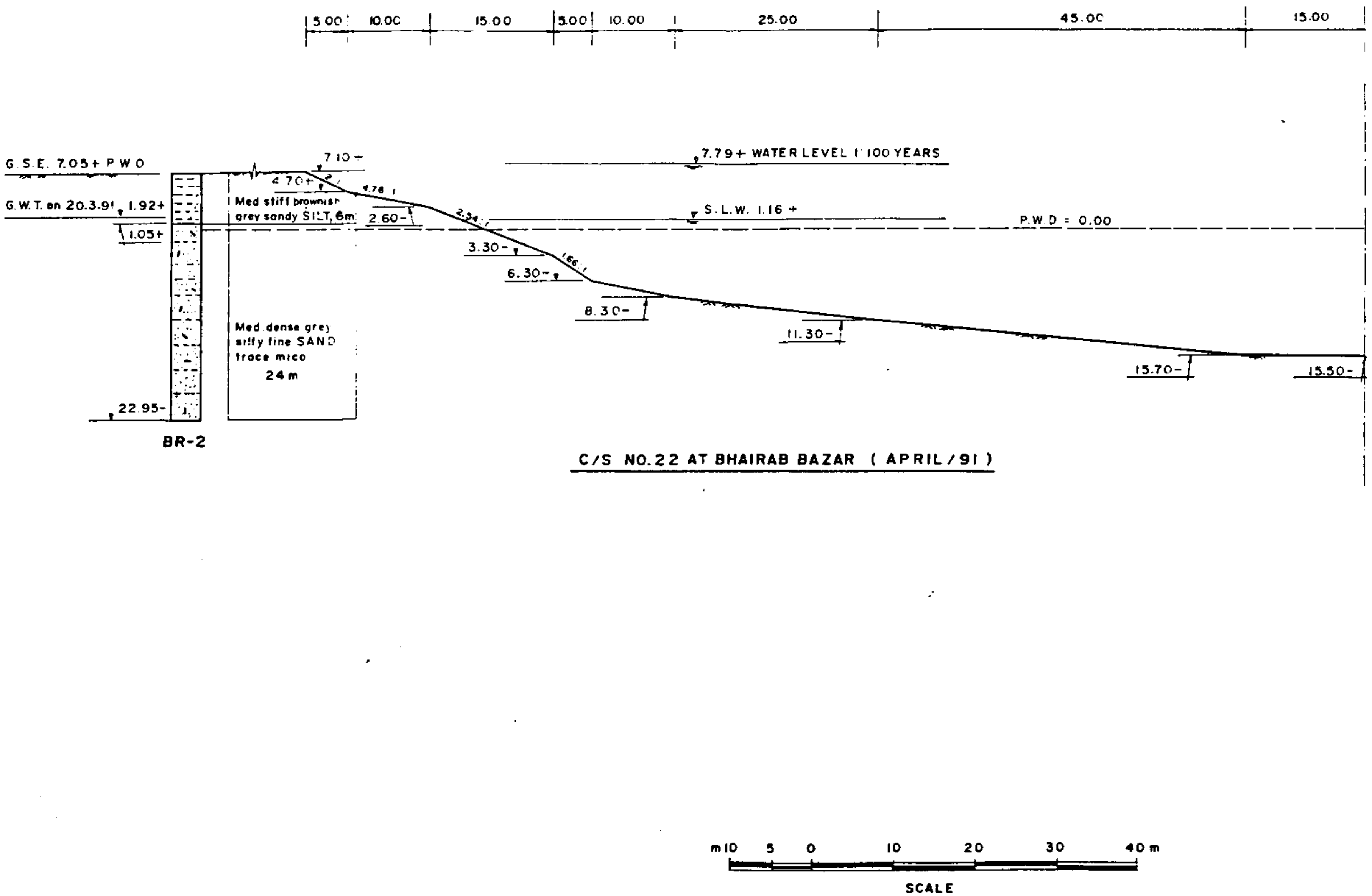
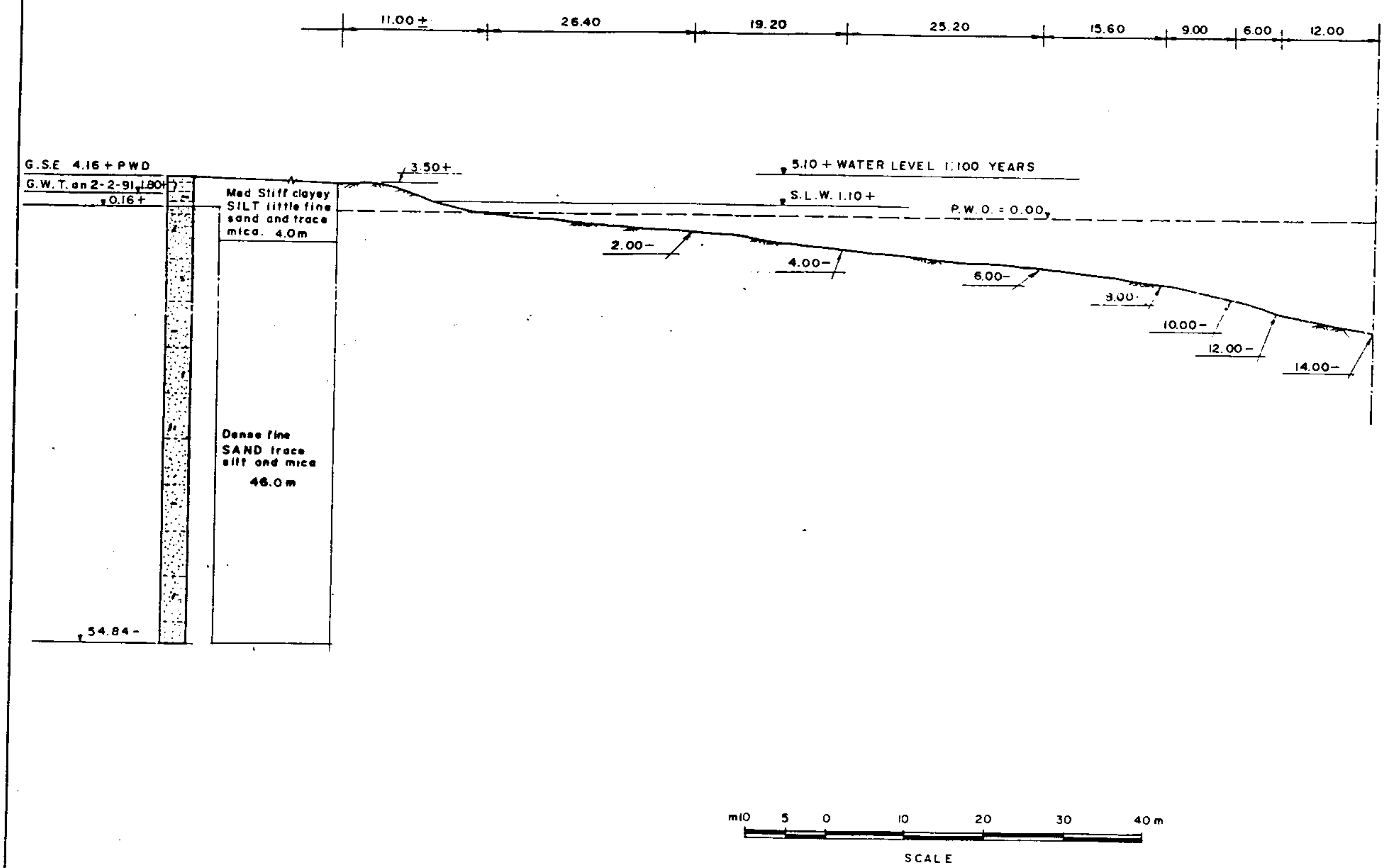



BORE LOG BR-1 AND CROSS SECTION
C/S NO. 3 OF MEGHNA RIVER AT BHAIRAB BAZAR

APPENDIX - 5
FIGURE NO. C/5.1

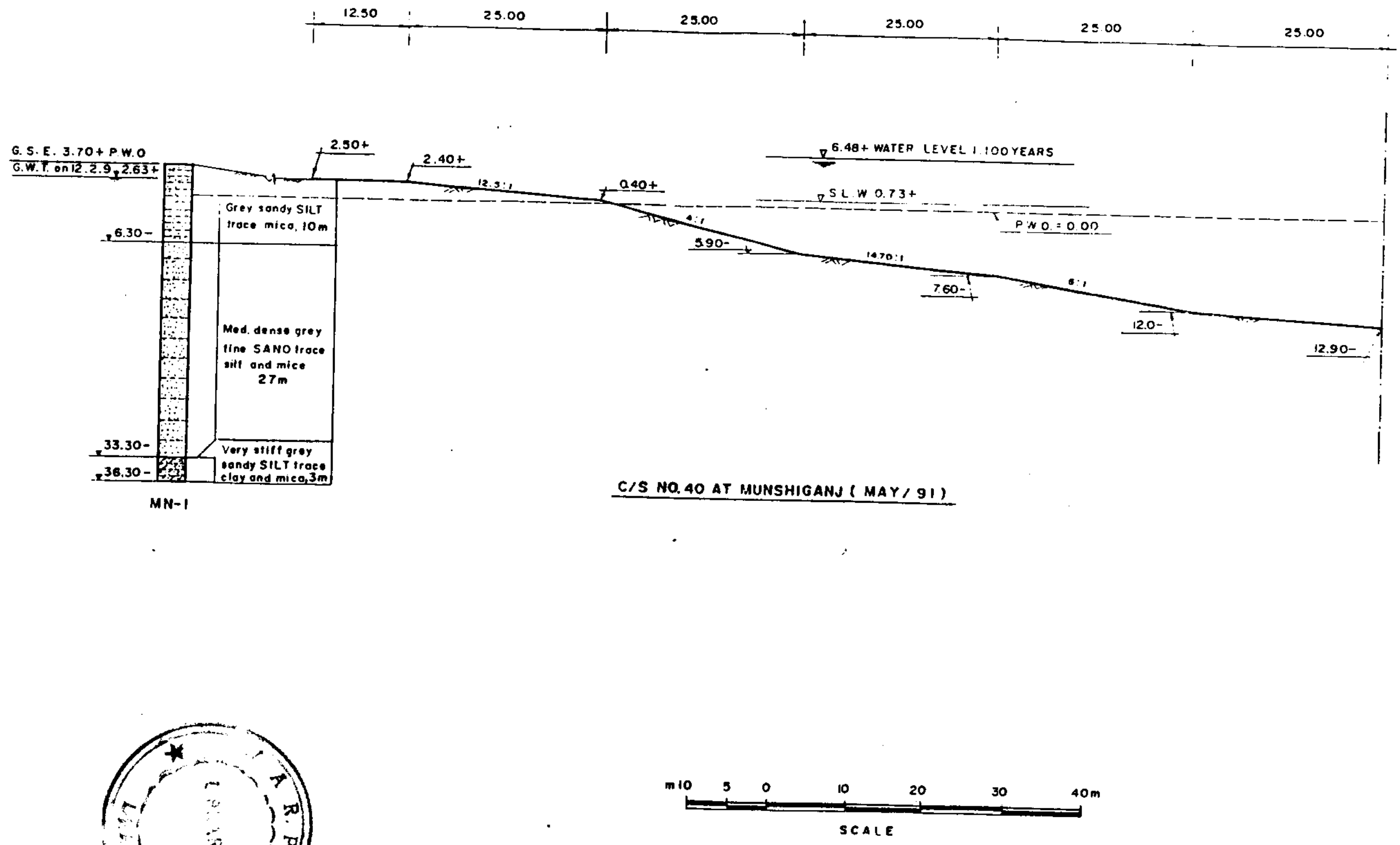



| | |
|---|---|
| BORE LOG BR-2 AND CROSS SECTIDN C/S NO. 22 OF MEGHNA RIVER AT BHAIRAB BAZAR | APPENDIX – 5<br>FIGURE NO. C/5.2 |




BORE LOG MG – I AND RIVER CROSS SECTION NEAR R & H BRIDGE ON MEGHNA

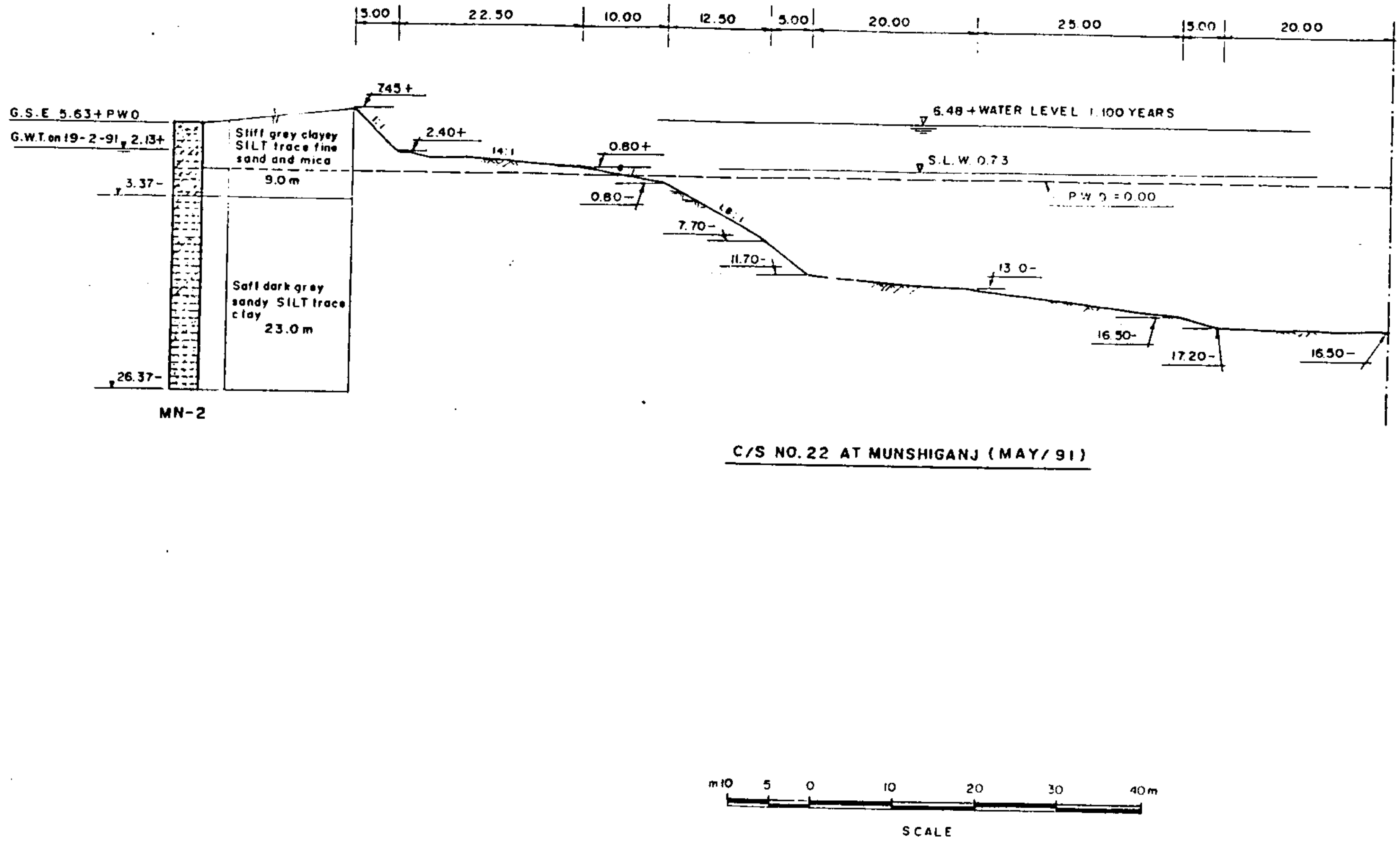
APPENDIX – 5
FIGURE NO.– C/5.3






BORE LOG MN-1 AND CROSS SECTION C/S NO. 40 OF DHALESWARI RIVER AT MUNSHIGANJ

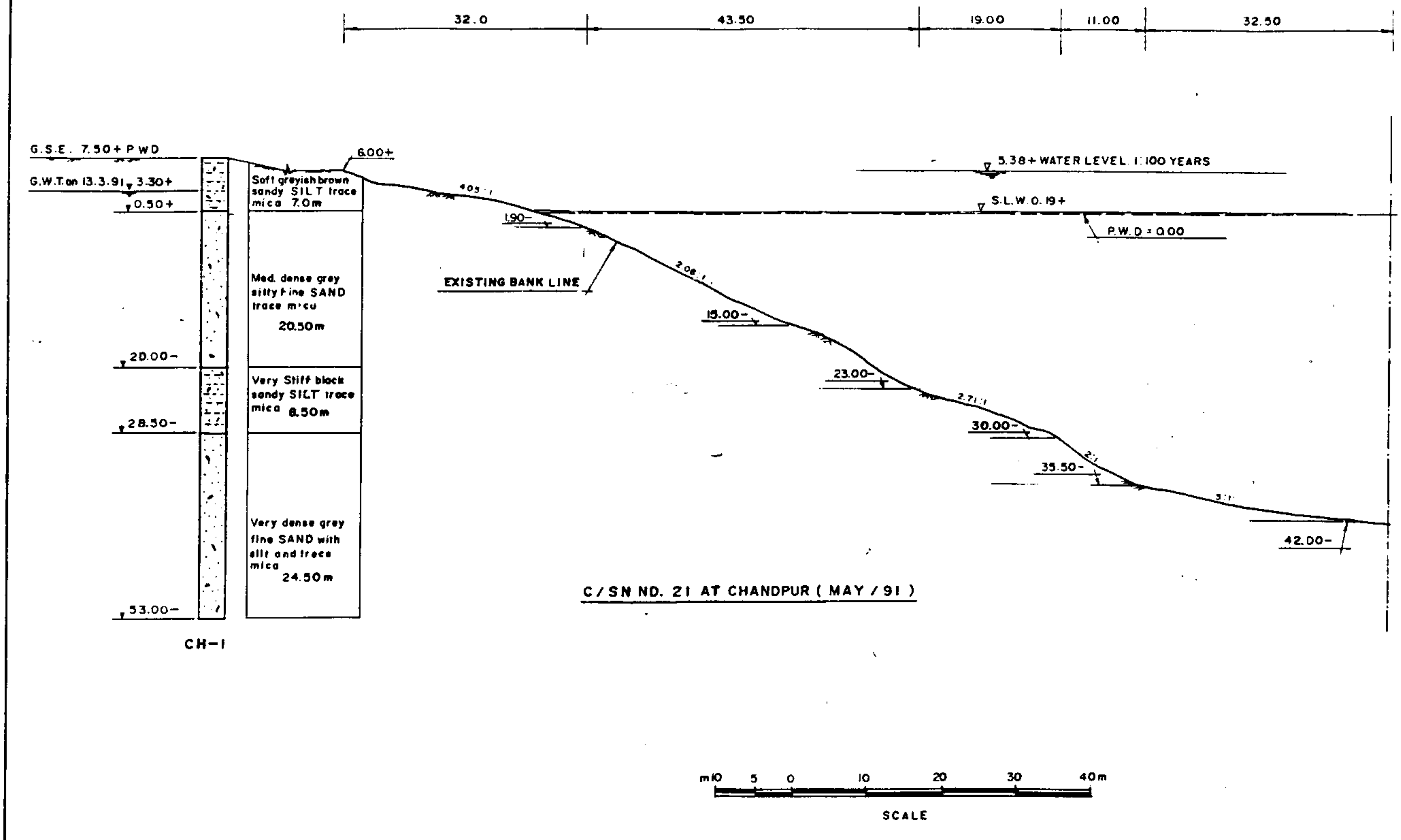
APPENDIX — 5
FIGURE NO. C/5.4




BORE LOG MN-2 AND CROSS SECTION C/S NO. 22 OF DHALESWARI RIVER AT MUNSHIGANJ

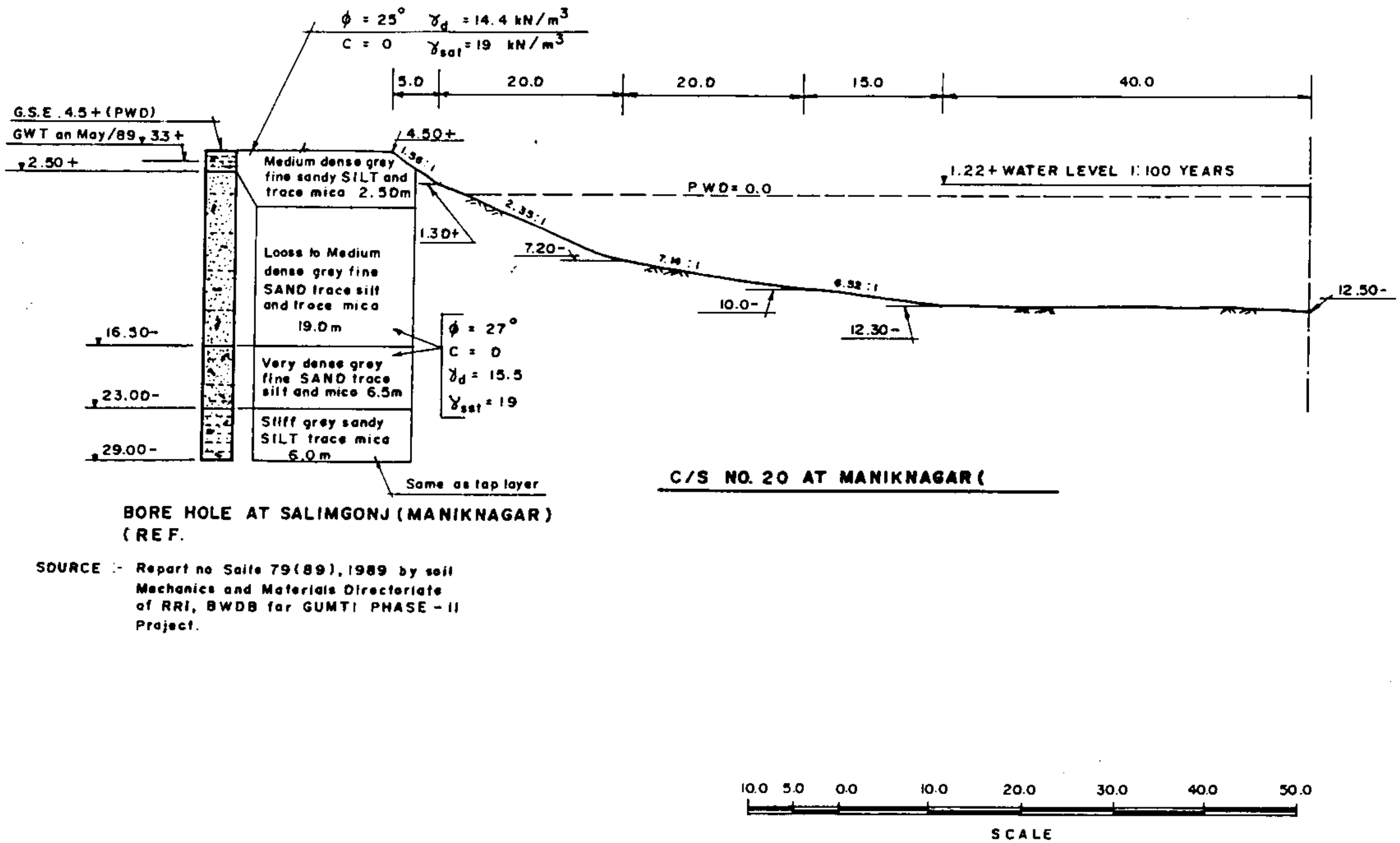
APPENDIX - 5

FIGURE NO. C/5.5



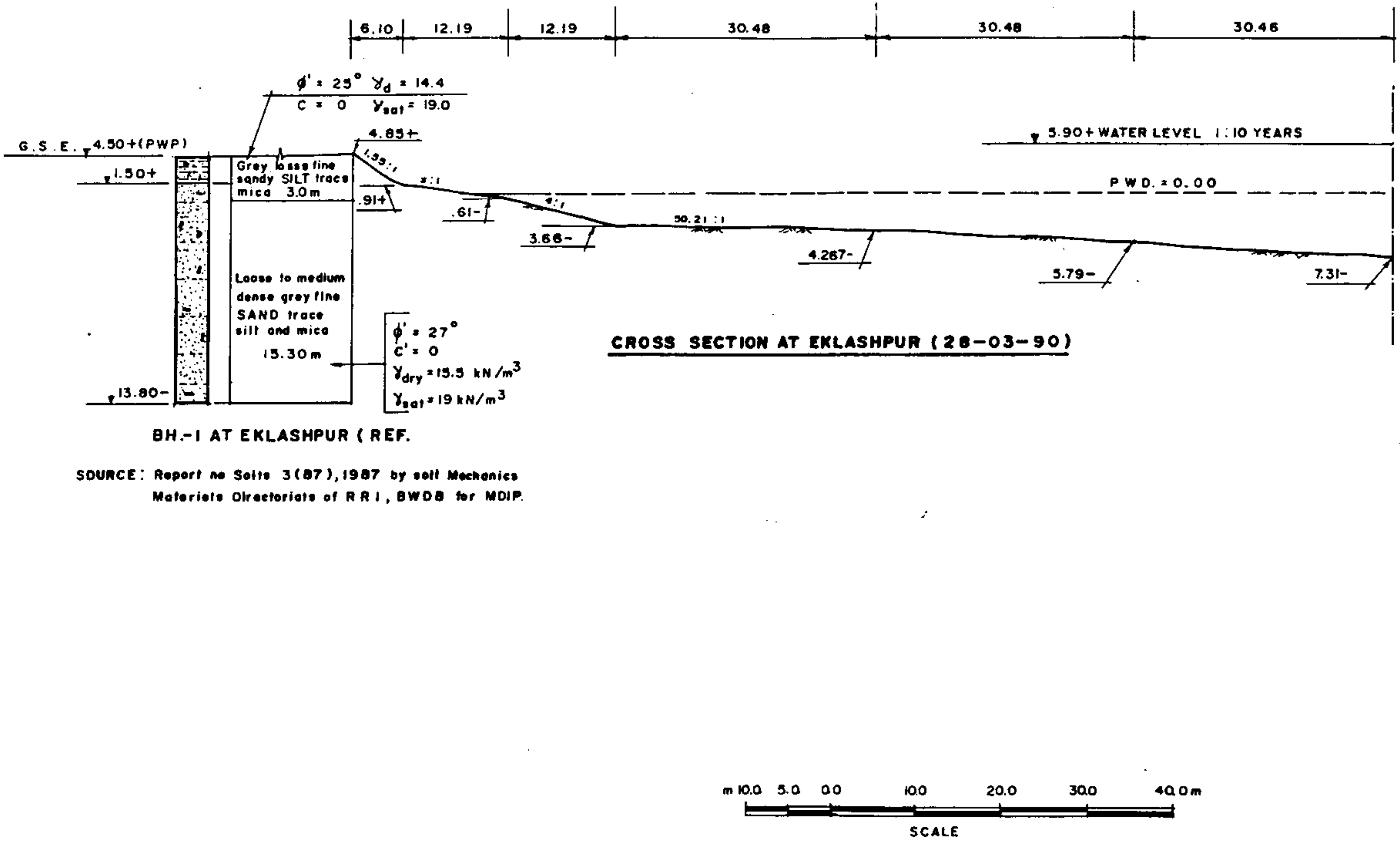

BORE LOG CH-1 AND CROSS SECTION C/SN NO.21 OF MEGHNA RIVER AT CHANDPUR

APPENDIX – 5
FIGURE NO. C/5.6



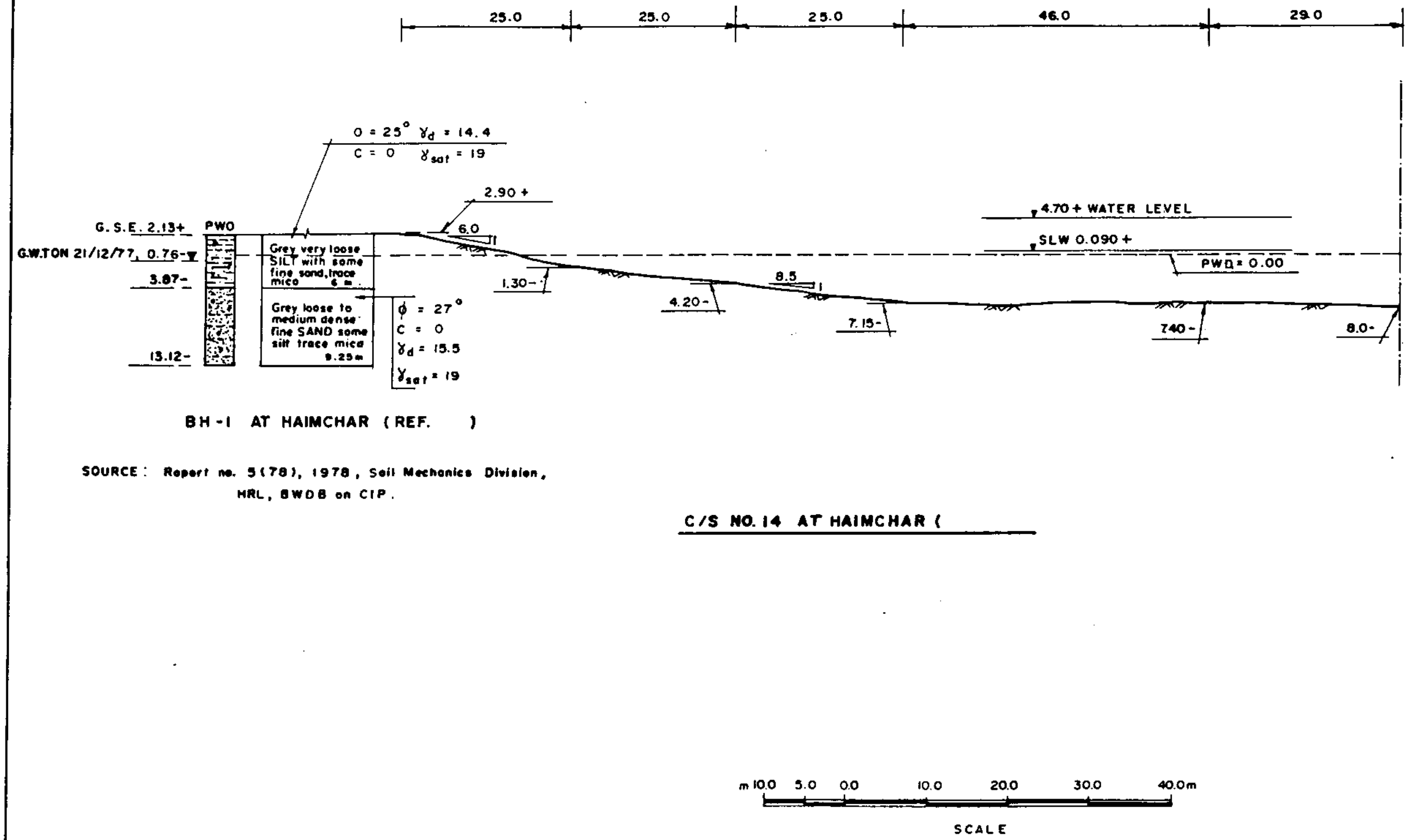

BORE HOLE AT SALIMGANJ (MANIKNAGAR) AND CROSS SECTION ON C/S NO. 20 OF MEGHNA RIVER AT MANIKNAGAR

FIGURE NO. C/5.7




BORE LOG AT EKLASHPUR AND CROSS SECTION OF MEGHNA RIVER AT EKLASHPUR

FIGURE NO. C/5.8




BORE LOG AT HAIMCHAR AND CROSS SECTION ON C/S NO. 14 AT HAIMCHAR

FIGURE NO. C/5.9

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# ***** SLOPE STABILITY *****

PROJECT : MRBPSTS - BHAIRAB BAZAR
PROJECT No. : HASKONING - BANGLADESH
CASE (No.) : 08-Typical Cross Section (1:3.5)
DATE : 91-08-25

## INPUT DATA

### GEOMETRY POINTS:

| Point No. | Co-ordinates X | Y |
|---|---|---|
| 1 | 0.00 | -19.50 |
| 2 | 58.00 | -18.50 |
| 3 | 68.00 | -20.50 |
| 4 | 98.00 | -21.70 |
| 5 | 164.00 | 0.00 |
| 6 | 168.20 | 1.16 |
| 7 | 191.00 | 7.40 |
| 8 | 235.00 | 7.40 |
| 9 | 235.00 | -34.40 |
| 10 | 235.00 | -40.90 |
| 11 | 0.00 | -40.90 |
| 12 | 0.00 | -34.40 |
| 13 | 0.00 | 1.16 |
| 14 | 179.80 | 4.50 |
| 15 | 235.00 | 4.50 |

### SOIL LAYER BOUNDARIES:

| Boundary No. | Geometry points: | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 2 | 12 | 9 | | | | | | |

### PIEZOMETRIC LEVEL LINES:

| Line No. | Geometry points: | | | |
|---|---|---|---|---|
| 1 | 13 | 6 | 14 | 15 |

### SOIL PROPERTIES:

| Layer No. | Rho(dry) kN/m3 | Rho(wet) kN/m3 | Phi deg. | Cohesion kN/m2 | PL-line Nos top | bottom |
|---|---|---|---|---|---|---|
| 1 | 19.00 | 19.00 | 27.0 | 0.00 | 1 | 1 |
| 2 | 19.00 | 19.00 | 20.0 | 10.00 | 1 | |

### SLIPCIRCLES:

| | | Min. | Step | Max. |
|---|---|---|---|---|
| - Grid of centre points: | X | 98.00 | 4.00 | 114.00 |
| | Y | 12.00 | 4.00 | 32.00 |
| - Lower tangent lines: | Y | -34.00 | 2.00 | -20.00 |

### SEISMIC FACTORS:

Horizontal seismic factor on soil is 0.050

PROJECT : MRBPSTS - BHAIRAB BAZAR
CASE (No.) : 08-Typical Cross Section (1:3.5)

# RESULTS OF CALCULATION

| <------ SLIP-CIRCLES -----> | | | <---------- MOMENTS ---------> | | | <---------- SAFETY COEFFICIENTS ----------> | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRE POINT CO-ORDINATES | | RADIUS | COUNTER-ACTING | DRIVING | WATER ON SLOPE | EXCL.SEISMIC EFFECTS | | | INCL.SEISMIC EFFECTS | | |
| X | Y | m | kNm | kNm | kNm | BEFORE ITER. | No of ITER. | AFTER ITER. | BEFORE ITER. | No of ITER. | AFTER ITER. |
| 98.00 | 12.00 | 46.00 | 174953 | 94740 | 49165 | 3.839 | 3 | 3.967 | | | |
| | | | 174953 | 120849 | 49165 | | | | 2.441 | 3 | 2.495 |
| | | 44.00 | 129046 | 74977 | 38875 | 3.574 | 3 | 3.705 | | | |
| | | | 129046 | 95001 | 38875 | | | | 2.299 | 3 | 2.355 |
| | | 42.00 | 90933 | 56947 | 29507 | 3.314 | 4 | 3.449 | | | |
| | | | 90933 | 71659 | 29507 | | | | 2.157 | 3 | 2.214 |
| | | 40.00 | 59747 | 41025 | 21243 | 3.020 | 4 | 3.159 | | | |
| | | | 59747 | 51159 | 21243 | | | | 1.997 | 4 | 2.059 |
| | | 38.00 | 35172 | 27211 | 14076 | 2.678 | 4 | 2.817 | | | |
| | | | 35172 | 33500 | 14076 | | | | 1.811 | 4 | 1.874 |
| | | 36.00 | 16828 | 15441 | 7983 | 2.256 | 4 | 2.388 | | | |
| | | | 16828 | 18633 | 7983 | | | | 1.580 | 4 | 1.638 |
| | | 34.00 | 4621 | 5833 | 3013 | 1.639 | 4 | 1.735 | | | |
| | | | 4621 | 6771 | 3013 | | | | 1.230 | 4 | 1.264 |
| | | 32.00 | Circle doesn't intersect slope | | | | | | | | |
| 98.00 | 16.00 | 50.00 | 202503 | 113274 | 58762 | 3.715 | 3 | 3.844 | | | |
| | | | 202503 | 144206 | 58762 | | | | 2.370 | 3 | 2.425 |
| | | 48.00 | 150398 | 90710 | 47023 | 3.443 | 3 | 3.573 | | | |
| | | | 150398 | 114564 | 47023 | | | | 2.227 | 3 | 2.283 |
| | | 46.00 | 106911 | 69556 | 36030 | 3.189 | 4 | 3.326 | | | |
| | | | 106911 | 87206 | 36030 | | | | 2.089 | 3 | 2.147 |
| | | 44.00 | 71160 | 50640 | 26216 | 2.914 | 4 | 3.053 | | | |
| | | | 71160 | 62915 | 26216 | | | | 1.939 | 4 | 2.001 |
| | | 42.00 | 42636 | 34082 | 17628 | 2.591 | 4 | 2.730 | | | |
| | | | 42636 | 41803 | 17628 | | | | 1.764 | 4 | 1.826 |
| | | 40.00 | 21012 | 19829 | 10249 | 2.193 | 4 | 2.322 | | | |
| | | | 21012 | 23846 | 10249 | | | | 1.545 | 4 | 1.602 |
| | | 38.00 | 6277 | 7979 | 4122 | 1.627 | 4 | 1.722 | | | |
| | | | 6277 | 9255 | 4122 | | | | 1.223 | 4 | 1.256 |
| | | 36.00 | 133 | 187 | 96 | 1.477 | 4 | 1.556 | | | |
| | | | 133 | 215 | 96 | | | | 1.124 | 4 | 1.144 |
| 98.00 | 20.00 | 54.00 | 232289 | 133358 | 69140 | 3.617 | 3 | 3.745 | | | |
| | | | 232289 | 169524 | 69140 | | | | 2.314 | 3 | 2.368 |
| | | 52.00 | 173373 | 107849 | 55879 | 3.336 | 3 | 3.468 | | | |
| | | | 173373 | 135864 | 55879 | | | | 2.168 | 3 | 2.225 |
| | | 50.00 | 124216 | 83565 | 43276 | 3.083 | 4 | 3.221 | | | |
| | | | 124216 | 104424 | 43276 | | | | 2.031 | 4 | 2.093 |
| | | 48.00 | 83627 | 61418 | 31791 | 2.823 | 4 | 2.962 | | | |
| | | | 83627 | 76050 | 31791 | | | | 1.889 | 4 | 1.952 |
| | | 46.00 | 50917 | 41882 | 21660 | 2.518 | 4 | 2.656 | | | |
| | | | 50917 | 51202 | 21660 | | | | 1.724 | 4 | 1.786 |
| | | 44.00 | 25772 | 24904 | 12872 | 2.142 | 4 | 2.269 | | | |
| | | | 25772 | 29862 | 12872 | | | | 1.517 | 4 | 1.572 |
| | | 42.00 | 8287 | 10594 | 5473 | 1.618 | 4 | 1.712 | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 8287 | 12280 | 5473 | | | | 1.217 | 4 | 1.250 |
| | | 40.00 | 475 | 663 | 342 | 1.483 | 4 | 1.562 | | | |
| | | | 475 | 763 | 342 | | | | 1.128 | 4 | 1.149 |
| 98.00 | 24.00 | 58.00 | 264104 | 154912 | 80303 | 3.540 | 3 | 3.669 | | | |
| | | | 264104 | 196729 | 80303 | | | | 2.268 | 3 | 2.324 |
| | | 56.00 | 198324 | 126310 | 65440 | 3.258 | 4 | 3.394 | | | |
| | | | 198324 | 158854 | 65440 | | | | 2.123 | 3 | 2.181 |
| | | 54.00 | 142922 | 98989 | 51257 | 2.994 | 4 | 3.133 | | | |
| | | | 142922 | 123335 | 51257 | | | | 1.983 | 4 | 2.045 |
| | | 52.00 | 97203 | 73480 | 38012 | 2.741 | 4 | 2.880 | | | |
| | | | 97203 | 90693 | 38012 | | | | 1.845 | 4 | 1.908 |
| | | 50.00 | 60046 | 50658 | 26197 | 2.455 | 4 | 2.591 | | | |
| | | | 60046 | 61747 | 26197 | | | | 1.689 | 4 | 1.750 |
| | | 48.00 | 31140 | 30723 | 15879 | 2.098 | 4 | 2.223 | | | |
| | | | 31140 | 36748 | 15879 | | | | 1.492 | 4 | 1.547 |
| | | 46.00 | 10685 | 13724 | 7090 | 1.610 | 4 | 1.704 | | | |
| | | | 10685 | 15898 | 7090 | | | | 1.213 | 4 | 1.245 |
| | | 44.00 | 1031 | 1433 | 740 | 1.487 | 4 | 1.567 | | | |
| | | | 1031 | 1651 | 740 | | | | 1.132 | 4 | 1.153 |
| 98.00 | 28.00 | 62.00 | 298207 | 178148 | 92332 | 3.475 | 3 | 3.604 | | | |
| | | | 298207 | 226043 | 92332 | | | | 2.230 | 3 | 2.285 |
| | | 60.00 | 225045 | 146258 | 75747 | 3.192 | 4 | 3.328 | | | |
| | | | 225045 | 183673 | 75747 | | | | 2.085 | 3 | 2.143 |
| | | 58.00 | 163076 | 115730 | 59913 | 2.922 | 4 | 3.061 | | | |
| | | | 163076 | 143851 | 59913 | | | | 1.943 | 4 | 2.005 |
| | | 56.00 | 111897 | 86731 | 44863 | 2.673 | 4 | 2.812 | | | |
| | | | 111897 | 106751 | 44863 | | | | 1.808 | 4 | 1.871 |
| | | 54.00 | 70052 | 60454 | 31261 | 2.400 | 4 | 2.535 | | | |
| | | | 70052 | 73491 | 31261 | | | | 1.659 | 4 | 1.719 |
| | | 52.00 | 37151 | 37333 | 19295 | 2.060 | 4 | 2.183 | | | |
| | | | 37151 | 44551 | 19295 | | | | 1.471 | 4 | 1.524 |
| | | 50.00 | 13505 | 17414 | 8996 | 1.604 | 4 | 1.697 | | | |
| | | | 13505 | 20164 | 8996 | | | | 1.209 | 4 | 1.241 |
| | | 48.00 | 1830 | 2537 | 1310 | 1.491 | 4 | 1.572 | | | |
| | | | 1830 | 2923 | 1310 | | | | 1.134 | 4 | 1.156 |
| 98.00 | 32.00 | 66.00 | 334218 | 203450 | 105428 | 3.410 | 3 | 3.539 | | | |
| | | | 334218 | 257829 | 105428 | | | | 2.193 | 3 | 2.248 |
| | | 64.00 | 253712 | 167664 | 86809 | 3.138 | 4 | 3.274 | | | |
| | | | 253712 | 210324 | 86809 | | | | 2.054 | 3 | 2.112 |
| | | 62.00 | 184885 | 133754 | 69239 | 2.866 | 4 | 3.005 | | | |
| | | | 184885 | 165963 | 69239 | | | | 1.911 | 4 | 1.974 |
| | | 60.00 | 127746 | 101280 | 52385 | 2.613 | 4 | 2.752 | | | |
| | | | 127746 | 124342 | 52385 | | | | 1.775 | 4 | 1.838 |
| | | 58.00 | 80968 | 71317 | 36876 | 2.351 | 4 | 2.485 | | | |
| | | | 80968 | 86485 | 36876 | | | | 1.632 | 4 | 1.692 |
| | | 56.00 | 43838 | 44780 | 23143 | 2.026 | 4 | 2.148 | | | |
| | | | 43838 | 53330 | 23143 | | | | 1.452 | 4 | 1.504 |
| | | 54.00 | 16783 | 21723 | 11221 | 1.598 | 4 | 1.690 | | | |
| | | | 16783 | 25142 | 11221 | | | | 1.206 | 4 | 1.237 |
| | | 52.00 | 2904 | 4018 | 2075 | 1.495 | 4 | 1.576 | | | |
| | | | 2904 | 4629 | 2075 | | | | 1.137 | 4 | 1.159 |
| 102.00 | 12.00 | 46.00 | 184790 | 118233 | 61378 | 3.250 | 4 | 3.388 | | | |
| | | | 184790 | 145602 | 61378 | | | | 2.194 | 3 | 2.255 |
| | | 44.00 | 138194 | 95130 | 49350 | 3.019 | 4 | 3.157 | | | |
| | | | 138194 | 116391 | 49350 | | | | 2.061 | 4 | 2.126 |
| | | 42.00 | 99124 | 74241 | 38488 | 2.772 | 4 | 2.909 | | | |
| | | | 99124 | 90136 | 38488 | | | | 1.919 | 4 | 1.983 |
| | | 40.00 | 67031 | 55573 | 28775 | 2.501 | 4 | 2.636 | | | |
| | | | 67031 | 66830 | 28775 | | | | 1.761 | 4 | 1.824 |
| | | 38.00 | 41549 | 38972 | 20161 | 2.209 | 4 | 2.338 | | | |
| | | | 41549 | 46312 | 20161 | | | | 1.589 | 4 | 1.648 |
| | | 36.00 | 22307 | 24428 | 12630 | 1.891 | 4 | 2.006 | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 22307 | 28591 | 12630 | | | | 1.398 | 4 | 1.447 |
| | | 34.00 | 9217 | 11938 | 6168 | 1.597 | 4 | 1.690 | | | |
| | | | 9217 | 13755 | 6168 | | | | 1.215 | 4 | 1.248 |
| | | 32.00 | 1970 | 2681 | 1385 | 1.520 | 4 | 1.604 | | | |
| | | | 1970 | 3089 | 1385 | | | | 1.156 | 4 | 1.181 |
| 102.00 | 16.00 | 50.00 | 213417 | 140917 | 73110 | 3.147 | 4 | 3.285 | | | |
| | | | 213417 | 173344 | 73110 | | | | 2.129 | 4 | 2.193 |
| | | 48.00 | 160962 | 114054 | 59136 | 2.931 | 4 | 3.068 | | | |
| | | | 160962 | 139400 | 59136 | | | | 2.005 | 4 | 2.069 |
| | | 46.00 | 116559 | 89622 | 46442 | 2.699 | 4 | 2.836 | | | |
| | | | 116559 | 108709 | 46442 | | | | 1.872 | 4 | 1.935 |
| | | 44.00 | 79798 | 67647 | 35017 | 2.446 | 4 | 2.579 | | | |
| | | | 79798 | 81288 | 35017 | | | | 1.725 | 4 | 1.787 |
| | | 42.00 | 50268 | 47966 | 24810 | 2.171 | 4 | 2.299 | | | |
| | | | 50268 | 56971 | 24810 | | | | 1.563 | 4 | 1.621 |
| | | 40.00 | 27637 | 30580 | 15809 | 1.871 | 4 | 1.985 | | | |
| | | | 27637 | 35785 | 15809 | | | | 1.383 | 4 | 1.432 |
| | | 38.00 | 11917 | 15493 | 8004 | 1.591 | 4 | 1.684 | | | |
| | | | 11917 | 17852 | 8004 | | | | 1.210 | 4 | 1.242 |
| | | 36.00 | 2947 | 4006 | 2069 | 1.521 | 4 | 1.606 | | | |
| | | | 2947 | 4615 | 2069 | | | | 1.157 | 4 | 1.182 |
| 102.00 | 20.00 | 54.00 | 244312 | 165422 | 85794 | 3.068 | 4 | 3.205 | | | |
| | | | 244312 | 203330 | 85794 | | | | 2.079 | 4 | 2.141 |
| | | 52.00 | 185453 | 134778 | 69854 | 2.856 | 4 | 2.993 | | | |
| | | | 185453 | 164558 | 69854 | | | | 1.958 | 4 | 2.021 |
| | | 50.00 | 135429 | 106559 | 55200 | 2.637 | 4 | 2.773 | | | |
| | | | 135429 | 129131 | 55200 | | | | 1.832 | 4 | 1.895 |
| | | 48.00 | 93733 | 81036 | 41939 | 2.397 | 4 | 2.531 | | | |
| | | | 93733 | 97300 | 41939 | | | | 1.693 | 4 | 1.755 |
| | | 46.00 | 59910 | 58038 | 30016 | 2.138 | 4 | 2.265 | | | |
| | | | 59910 | 68894 | 30016 | | | | 1.541 | 4 | 1.598 |
| | | 44.00 | 33649 | 37575 | 19423 | 1.854 | 4 | 1.967 | | | |
| | | | 33649 | 43960 | 19423 | | | | 1.371 | 4 | 1.419 |
| | | 42.00 | 15076 | 19659 | 10156 | 1.586 | 4 | 1.678 | | | |
| | | | 15076 | 22653 | 10156 | | | | 1.206 | 4 | 1.238 |
| | | 40.00 | 4200 | 5704 | 2946 | 1.523 | 4 | 1.607 | | | |
| | | | 4200 | 6571 | 2946 | | | | 1.158 | 4 | 1.184 |
| 102.00 | 24.00 | 58.00 | 277187 | 191747 | 99386 | 3.001 | 4 | 3.138 | | | |
| | | | 277187 | 235549 | 99386 | | | | 2.036 | 4 | 2.099 |
| | | 56.00 | 211582 | 157343 | 81523 | 2.791 | 4 | 2.927 | | | |
| | | | 211582 | 191908 | 81523 | | | | 1.917 | 4 | 1.980 |
| | | 54.00 | 155790 | 125221 | 64816 | 2.579 | 4 | 2.715 | | | |
| | | | 155790 | 151579 | 64816 | | | | 1.796 | 4 | 1.858 |
| | | 52.00 | 108872 | 95785 | 49563 | 2.355 | 4 | 2.488 | | | |
| | | | 108872 | 114914 | 49563 | | | | 1.666 | 4 | 1.727 |
| | | 50.00 | 70504 | 69233 | 35802 | 2.109 | 4 | 2.235 | | | |
| | | | 70504 | 82132 | 35802 | | | | 1.522 | 4 | 1.578 |
| | | 48.00 | 40374 | 45458 | 23497 | 1.838 | 4 | 1.950 | | | |
| | | | 40374 | 53168 | 23497 | | | | 1.361 | 4 | 1.407 |
| | | 46.00 | 18728 | 24481 | 12647 | 1.583 | 4 | 1.674 | | | |
| | | | 18728 | 28211 | 12647 | | | | 1.203 | 4 | 1.235 |
| | | 44.00 | 5764 | 7822 | 4040 | 1.524 | 4 | 1.608 | | | |
| | | | 5764 | 9012 | 4040 | | | | 1.159 | 4 | 1.185 |
| 102.00 | 28.00 | 62.00 | 312627 | 219723 | 113875 | 2.954 | 4 | 3.089 | | | |
| | | | 312627 | 269882 | 113875 | | | | 2.004 | 4 | 2.066 |
| | | 60.00 | 239560 | 181663 | 94099 | 2.736 | 4 | 2.872 | | | |
| | | | 239560 | 221372 | 94099 | | | | 1.882 | 4 | 1.945 |
| | | 58.00 | 177806 | 145411 | 75254 | 2.532 | 4 | 2.667 | | | |
| | | | 177606 | 175853 | 75254 | | | | 1.765 | 4 | 1.828 |
| | | 56.00 | 125244 | 111936 | 57913 | 2.318 | 4 | 2.450 | | | |
| | | | 125244 | 134181 | 57913 | | | | 1.642 | 4 | 1.703 |
| | | 54.00 | 82083 | 81596 | 42191 | 2.083 | 4 | 2.208 | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 82083 | 96737 | 42191 | | | | 1.505 | 4 | 1.560 |
| | | 52.00 | 47846 | 54276 | 28053 | 1.825 | 4 | 1.935 | | | |
| | | | 47846 | 63461 | 28053 | | | | 1.351 | 4 | 1.397 |
| | | 50.00 | 22905 | 29996 | 15496 | 1.580 | 4 | 1.671 | | | |
| | | | 22905 | 34568 | 15496 | | | | 1.201 | 4 | 1.232 |
| | | 48.00 | 7675 | 10410 | 5376 | 1.525 | 4 | 1.609 | | | |
| | | | 7675 | 11993 | 5376 | | | | 1.160 | 4 | 1.185 |
| 102.00 | 32.00 | 66.00 | 350189 | 249584 | 129308 | 2.912 | 4 | 3.048 | | | |
| | | | 350189 | 306535 | 129308 | | | | 1.976 | 4 | 2.038 |
| | | 64.00 | 269528 | 207634 | 107528 | 2.692 | 4 | 2.829 | | | |
| | | | 269528 | 252878 | 107528 | | | | 1.854 | 4 | 1.917 |
| | | 62.00 | 200927 | 167286 | 86564 | 2.489 | 4 | 2.624 | | | |
| | | | 200927 | 202120 | 86564 | | | | 1.739 | 4 | 1.801 |
| | | 60.00 | 142877 | 129535 | 67010 | 2.285 | 4 | 2.416 | | | |
| | | | 142877 | 155150 | 67010 | | | | 1.621 | 4 | 1.681 |
| | | 58.00 | 94676 | 95172 | 49207 | 2.060 | 4 | 2.183 | | | |
| | | | 94676 | 112760 | 49207 | | | | 1.490 | 4 | 1.545 |
| | | 56.00 | 56099 | 64074 | 33116 | 1.812 | 4 | 1.922 | | | |
| | | | 56099 | 74892 | 33116 | | | | 1.343 | 4 | 1.388 |
| | | 54.00 | 27647 | 36268 | 18736 | 1.577 | 4 | 1.668 | | | |
| | | | 27647 | 41797 | 18736 | | | | 1.199 | 4 | 1.230 |
| | | 52.00 | 9964 | 13508 | 6976 | 1.525 | 4 | 1.610 | | | |
| | | | 9964 | 15562 | 6976 | | | | 1.160 | 4 | 1.186 |
| 106.00 | 12.00 | 46.00 | 196476 | 141524 | 73510 | 2.889 | 4 | 3.030 | | | |
| | | | 196476 | 170309 | 73510 | | | | 2.030 | 4 | 2.098 |
| | | 44.00 | 148862 | 115550 | 59977 | 2.679 | 4 | 2.818 | | | |
| | | | 148862 | 138185 | 59977 | | | | 1.903 | 4 | 1.971 |
| | | 42.00 | 108814 | 91967 | 47669 | 2.456 | 4 | 2.591 | | | |
| | | | 108814 | 109192 | 47669 | | | | 1.769 | 4 | 1.834 |
| | | 40.00 | 75755 | 70471 | 36508 | 2.230 | 4 | 2.361 | | | |
| | | | 75755 | 83003 | 36508 | | | | 1.629 | 4 | 1.692 |
| | | 38.00 | 49345 | 51188 | 26494 | 1.998 | 4 | 2.121 | | | |
| | | | 49345 | 59748 | 26494 | | | | 1.484 | 4 | 1.540 |
| | | 36.00 | 29200 | 34004 | 17584 | 1.778 | 4 | 1.888 | | | |
| | | | 29200 | 39324 | 17584 | | | | 1.343 | 4 | 1.390 |
| | | 34.00 | 15097 | 18933 | 9784 | 1.650 | 4 | 1.749 | | | |
| | | | 15097 | 21814 | 9784 | | | | 1.255 | 4 | 1.293 |
| | | 32.00 | 5651 | 7435 | 3841 | 1.572 | 4 | 1.662 | | | |
| | | | 5651 | 8566 | 3841 | | | | 1.196 | 4 | 1.226 |
| 106.00 | 16.00 | 50.00 | 226894 | 167747 | 87061 | 2.812 | 4 | 2.952 | | | |
| | | | 226894 | 201885 | 87061 | | | | 1.976 | 4 | 2.043 |
| | | 48.00 | 173330 | 137697 | 71424 | 2.615 | 4 | 2.753 | | | |
| | | | 173330 | 164705 | 71424 | | | | 1.858 | 4 | 1.924 |
| | | 46.00 | 127857 | 110270 | 57128 | 2.406 | 4 | 2.540 | | | |
| | | | 127857 | 130966 | 57128 | | | | 1.732 | 4 | 1.796 |
| | | 44.00 | 90032 | 85138 | 44089 | 2.193 | 4 | 2.322 | | | |
| | | | 90032 | 100323 | 44089 | | | | 1.601 | 4 | 1.662 |
| | | 42.00 | 59479 | 62452 | 32315 | 1.974 | 4 | 2.095 | | | |
| | | | 59479 | 72933 | 32315 | | | | 1.464 | 4 | 1.519 |
| | | 40.00 | 35844 | 42094 | 21764 | 1.763 | 4 | 1.871 | | | |
| | | | 35844 | 48700 | 21764 | | | | 1.331 | 4 | 1.376 |
| | | 38.00 | 19032 | 24054 | 12429 | 1.637 | 4 | 1.734 | | | |
| | | | 19032 | 27713 | 12429 | | | | 1.245 | 4 | 1.282 |
| | | 36.00 | 7575 | 9994 | 5162 | 1.568 | 4 | 1.658 | | | |
| | | | 7575 | 11514 | 5162 | | | | 1.193 | 4 | 1.223 |
| 106.00 | 20.00 | 54.00 | 259431 | 196179 | 101757 | 2.748 | 4 | 2.886 | | | |
| | | | 259431 | 236100 | 101757 | | | | 1.931 | 4 | 1.997 |
| | | 52.00 | 199631 | 161805 | 83886 | 2.562 | 4 | 2.698 | | | |
| | | | 199631 | 193557 | 83886 | | | | 1.820 | 4 | 1.885 |
| | | 50.00 | 148456 | 130288 | 67475 | 2.363 | 4 | 2.496 | | | |
| | | | 148456 | 154770 | 67475 | | | | 1.701 | 4 | 1.764 |
| | | 48.00 | 105590 | 101275 | 52430 | 2.162 | 4 | 2.290 | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 105590 | 119372 | 52430 | | | | 1.577 | 4 | 1.637 |
| | | 46.00 | 70642 | 74944 | 38771 | 1.953 | 4 | 2.073 | | | |
| | | | 70642 | 87554 | 38771 | | | | 1.448 | 4 | 1.502 |
| | | 44.00 | 43275 | 51173 | 26455 | 1.751 | 4 | 1.858 | | | |
| | | | 43275 | 59226 | 26455 | | | | 1.321 | 4 | 1.365 |
| | | 42.00 | 23534 | 29929 | 15464 | 1.627 | 4 | 1.723 | | | |
| | | | 23534 | 34483 | 15464 | | | | 1.237 | 4 | 1.273 |
| | | 40.00 | 9882 | 13065 | 6748 | 1.564 | 4 | 1.654 | | | |
| | | | 9882 | 15052 | 6748 | | | | 1.190 | 4 | 1.220 |
| 106.00 | 24.00 | 58.00 | 294104 | 226858 | 117616 | 2.692 | 4 | 2.829 | | | |
| | | | 294104 | 272995 | 117616 | | | | 1.893 | 4 | 1.958 |
| | | 56.00 | 227683 | 187912 | 97382 | 2.515 | 4 | 2.650 | | | |
| | | | 227683 | 224783 | 97382 | | | | 1.787 | 4 | 1.851 |
| | | 54.00 | 170633 | 152060 | 78729 | 2.327 | 4 | 2.459 | | | |
| | | | 170633 | 180648 | 78729 | | | | 1.674 | 4 | 1.736 |
| | | 52.00 | 122460 | 118923 | 61552 | 2.135 | 4 | 2.262 | | | |
| | | | 122460 | 140199 | 61552 | | | | 1.557 | 4 | 1.616 |
| | | 50.00 | 82866 | 88708 | 45885 | 1.935 | 4 | 2.054 | | | |
| | | | 82866 | 103662 | 45885 | | | | 1.434 | 4 | 1.487 |
| | | 48.00 | 51527 | 61287 | 31681 | 1.740 | 4 | 1.846 | | | |
| | | | 51527 | 70953 | 31681 | | | | 1.312 | 4 | 1.356 |
| | | 46.00 | 28630 | 36595 | 18909 | 1.619 | 4 | 1.714 | | | |
| | | | 28630 | 42162 | 18909 | | | | 1.231 | 4 | 1.266 |
| | | 44.00 | 12607 | 16696 | 8624 | 1.562 | 4 | 1.651 | | | |
| | | | 12607 | 19236 | 8624 | | | | 1.188 | 4 | 1.217 |
| 106.00 | 28.00 | 62.00 | 330895 | 259776 | 134640 | 2.644 | 4 | 2.780 | | | |
| | | | 330895 | 312570 | 134640 | | | | 1.860 | 4 | 1.924 |
| | | 60.00 | 257604 | 216058 | 111933 | 2.474 | 4 | 2.608 | | | |
| | | | 257604 | 258427 | 111933 | | | | 1.758 | 4 | 1.822 |
| | | 58.00 | 194379 | 175629 | 90911 | 2.294 | 4 | 2.426 | | | |
| | | | 194379 | 208647 | 90911 | | | | 1.651 | 4 | 1.713 |
| | | 56.00 | 140670 | 138126 | 71478 | 2.111 | 4 | 2.237 | | | |
| | | | 140670 | 162851 | 71478 | | | | 1.540 | 4 | 1.598 |
| | | 54.00 | 96180 | 103787 | 53678 | 1.919 | 4 | 2.037 | | | |
| | | | 96180 | 121305 | 53678 | | | | 1.422 | 4 | 1.474 |
| | | 52.00 | 60632 | 72481 | 37465 | 1.732 | 4 | 1.837 | | | |
| | | | 60632 | 83931 | 37465 | | | | 1.305 | 4 | 1.347 |
| | | 50.00 | 34366 | 44115 | 22793 | 1.612 | 4 | 1.706 | | | |
| | | | 34366 | 50826 | 22793 | | | | 1.226 | 4 | 1.260 |
| | | 48.00 | 15781 | 20929 | 10811 | 1.560 | 4 | 1.648 | | | |
| | | | 15781 | 24113 | 10811 | | | | 1.186 | 4 | 1.215 |
| 106.00 | 32.00 | 66.00 | 370010 | 294745 | 152726 | 2.605 | 4 | 2.741 | | | |
| | | | 370010 | 354656 | 152726 | | | | 1.832 | 4 | 1.896 |
| | | 64.00 | 289418 | 246284 | 127560 | 2.438 | 4 | 2.572 | | | |
| | | | 289418 | 294534 | 127560 | | | | 1.733 | 4 | 1.796 |
| | | 62.00 | 219748 | 201037 | 104044 | 2.266 | 4 | 2.396 | | | |
| | | | 219748 | 238812 | 104044 | | | | 1.631 | 4 | 1.692 |
| | | 60.00 | 160249 | 158927 | 82229 | 2.089 | 4 | 2.215 | | | |
| | | | 160249 | 187378 | 82229 | | | | 1.524 | 4 | 1.581 |
| | | 58.00 | 110616 | 120228 | 62174 | 1.905 | 4 | 2.022 | | | |
| | | | 110616 | 140536 | 62174 | | | | 1.412 | 4 | 1.463 |
| | | 56.00 | 70615 | 84760 | 43815 | 1.725 | 4 | 1.829 | | | |
| | | | 70615 | 98172 | 43815 | | | | 1.299 | 4 | 1.341 |
| | | 54.00 | 40781 | 52543 | 27145 | 1.606 | 4 | 1.700 | | | |
| | | | 40781 | 60536 | 27145 | | | | 1.221 | 4 | 1.255 |
| | | 52.00 | 19444 | 25819 | 13337 | 1.558 | 4 | 1.646 | | | |
| | | | 19444 | 29747 | 13337 | | | | 1.185 | 4 | 1.214 |
| 110.00 | 12.00 | 46.00 | 209794 | 164509 | 85504 | 2.655 | 4 | 2.799 | | | |
| | | | 209794 | 194828 | 85504 | | | | 1.919 | 4 | 1.991 |
| | | 44.00 | 161143 | 135883 | 70513 | 2.465 | 4 | 2.604 | | | |
| | | | 161143 | 160020 | 70513 | | | | 1.800 | 4 | 1.870 |
| | | 42.00 | 120044 | 109400 | 56740 | 2.280 | 4 | 2.414 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 120044 | 128084 | 56740 | | | | 1.683 | 4 | 1.749 |
| | | 40.00 | 86007 | 85298 | 44192 | 2.092 | 4 | 2.221 | | | |
| | | | 86007 | 99250 | 44192 | | | | 1.562 | 4 | 1.624 |
| | | 38.00 | 58631 | 63375 | 32808 | 1.918 | 4 | 2.039 | | | |
| | | | 58631 | 73308 | 32808 | | | | 1.448 | 4 | 1.504 |
| | | 36.00 | 37554 | 43605 | 22555 | 1.784 | 4 | 1.896 | | | |
| | | | 37554 | 50247 | 22555 | | | | 1.356 | 4 | 1.405 |
| | | 34.00 | 21904 | 26568 | 13734 | 1.707 | 4 | 1.811 | | | |
| | | | 21904 | 30611 | 13734 | | | | 1.298 | 4 | 1.340 |
| | | 32.00 | 10456 | 13293 | 6868 | 1.627 | 4 | 1.724 | | | |
| | | | 10456 | 15315 | 6868 | | | | 1.238 | 4 | 1.274 |
| 110.00 | 16.00 | 50.00 | 242149 | 194391 | 100935 | 2.591 | 4 | 2.732 | | | |
| | | | 242149 | 230382 | 100935 | | | | 1.871 | 4 | 1.941 |
| | | 48.00 | 187503 | 181397 | 83690 | 2.413 | 4 | 2.549 | | | |
| | | | 187503 | 190217 | 63690 | | | | 1.760 | 4 | 1.827 |
| | | 46.00 | 140843 | 130747 | 67768 | 2.236 | 4 | 2.369 | | | |
| | | | 140843 | 153205 | 67768 | | | | 1.649 | 4 | 1.713 |
| | | 44.00 | 101943 | 102705 | 53186 | 2.059 | 4 | 2.185 | | | |
| | | | 101943 | 119602 | 53186 | | | | 1.535 | 4 | 1.595 |
| | | 42.00 | 70331 | 77058 | 39878 | 1.892 | 4 | 2.010 | | | |
| | | | 70331 | 89194 | 39878 | | | | 1.426 | 4 | 1.480 |
| | | 40.00 | 45669 | 53785 | 27814 | 1.758 | 4 | 1.868 | | | |
| | | | 45669 | 61986 | 27814 | | | | 1.336 | 4 | 1.383 |
| | | 38.00 | 27218 | 33394 | 17260 | 1.687 | 4 | 1.789 | | | |
| | | | 27218 | 38475 | 17260 | | | | 1.283 | 4 | 1.324 |
| | | 36.00 | 13482 | 17252 | 8914 | 1.617 | 4 | 1.712 | | | |
| | | | 13482 | 19877 | 8914 | | | | 1.230 | 4 | 1.265 |
| 110.00 | 20.00 | 54.00 | 276744 | 226648 | 117598 | 2.538 | 4 | 2.676 | | | |
| | | | 276744 | 268765 | 117598 | | | | 1.831 | 4 | 1.899 |
| | | 52.00 | 215686 | 188837 | 97933 | 2.373 | 4 | 2.507 | | | |
| | | | 215686 | 222731 | 97933 | | | | 1.728 | 4 | 1.794 |
| | | 50.00 | 163311 | 153989 | 79787 | 2.201 | 4 | 2.331 | | | |
| | | | 163311 | 180537 | 79767 | | | | 1.621 | 4 | 1.684 |
| | | 48.00 | 119276 | 121740 | 63021 | 2.031 | 4 | 2.156 | | | |
| | | | 119276 | 141864 | 63021 | | | | 1.513 | 4 | 1.572 |
| | | 46.00 | 83172 | 92124 | 47662 | 1.871 | 4 | 1.987 | | | |
| | | | 83172 | 106693 | 47662 | | | | 1.409 | 4 | 1.461 |
| | | 44.00 | 54681 | 65105 | 33662 | 1.739 | 4 | 1.846 | | | |
| | | | 54681 | 75046 | 33662 | | | | 1.321 | 4 | 1.367 |
| | | 42.00 | 33204 | 41110 | 21248 | 1.672 | 4 | 1.773 | | | |
| | | | 33204 | 47365 | 21248 | | | | 1.271 | 4 | 1.311 |
| | | 40.00 | 17004 | 21873 | 11301 | 1.608 | 4 | 1.703 | | | |
| | | | 17004 | 25200 | 11301 | | | | 1.223 | 4 | 1.257 |
| 110.00 | 24.00 | 58.00 | 313594 | 261315 | 135511 | 2.493 | 4 | 2.629 | | | |
| | | | 313594 | 310013 | 135511 | | | | 1.797 | 4 | 1.864 |
| | | 56.00 | 245816 | 218622 | 113325 | 2.335 | 4 | 2.468 | | | |
| | | | 245816 | 257992 | 113325 | | | | 1.699 | 4 | 1.764 |
| | | 54.00 | 187465 | 179105 | 92756 | 2.171 | 4 | 2.300 | | | |
| | | | 187465 | 210125 | 92756 | | | | 1.597 | 4 | 1.659 |
| | | 52.00 | 138032 | 142443 | 73719 | 2.008 | 4 | 2.132 | | | |
| | | | 138032 | 166082 | 73719 | | | | 1.494 | 4 | 1.552 |
| | | 50.00 | 97182 | 108614 | 56182 | 1.853 | 4 | 1.969 | | | |
| | | | 97182 | 125852 | 56182 | | | | 1.395 | 4 | 1.446 |
| | | 48.00 | 64612 | 77576 | 40111 | 1.725 | 4 | 1.830 | | | |
| | | | 64612 | 89442 | 40111 | | | | 1.310 | 4 | 1.354 |
| | | 46.00 | 39918 | 49801 | 25736 | 1.659 | 4 | 1.758 | | | |
| | | | 39918 | 57378 | 25736 | | | | 1.262 | 4 | 1.300 |
| | | 44.00 | 21051 | 27196 | 14051 | 1.601 | 4 | 1.695 | | | |
| | | | 21051 | 31333 | 14051 | | | | 1.218 | 4 | 1.251 |
| 110.00 | 28.00 | 62.00 | 352728 | 298752 | 154684 | 2.446 | 4 | 2.583 | | | |
| | | | 352728 | 354511 | 154684 | | | | 1.765 | 4 | 1.830 |
| | | 60.00 | 277927 | 250605 | 129855 | 2.302 | 4 | 2.434 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 277927 | 295852 | 129855 | | | | 1.674 | 4 | 1.738 |
| | | 58.00 | 213302 | 206193 | 106755 | 2.145 | 4 | 2.273 | | | |
| | | | 213302 | 242013 | 106755 | | | | 1.577 | 4 | 1.638 |
| | | 56.00 | 158215 | 164742 | 85270 | 1.991 | 4 | 2.113 | | | |
| | | | 158215 | 192185 | 85270 | | | | 1.480 | 4 | 1.536 |
| | | 54.00 | 112376 | 126500 | 65439 | 1.840 | 4 | 1.954 | | | |
| | | | 112376 | 146648 | 65439 | | | | 1.384 | 4 | 1.434 |
| | | 52.00 | 75515 | 91301 | 47202 | 1.712 | 4 | 1.817 | | | |
| | | | 75515 | 105289 | 47202 | | | | 1.300 | 4 | 1.343 |
| | | 50.00 | 47370 | 59471 | 30732 | 1.648 | 4 | 1.747 | | | |
| | | | 47370 | 68520 | 30732 | | | | 1.254 | 4 | 1.291 |
| | | 48.00 | 25660 | 33267 | 17187 | 1.596 | 4 | 1.689 | | | |
| | | | 25660 | 38327 | 17187 | | | | 1.214 | 4 | 1.246 |
| 110.00 | 32.00 | 66.00 | 393738 | 337678 | 174875 | 2.418 | 4 | 2.552 | | | |
| | | | 393738 | 400912 | 174875 | | | | 1.742 | 4 | 1.806 |
| | | 64.00 | 312130 | 285061 | 147531 | 2.270 | 4 | 2.400 | | | |
| | | | 312130 | 336610 | 147531 | | | | 1.651 | 4 | 1.713 |
| | | 62.00 | 240873 | 235277 | 121785 | 2.122 | 4 | 2.249 | | | |
| | | | 240873 | 276246 | 121785 | | | | 1.559 | 4 | 1.619 |
| | | 60.00 | 179898 | 188894 | 97752 | 1.974 | 4 | 2.095 | | | |
| | | | 179898 | 220444 | 97752 | | | | 1.466 | 4 | 1.522 |
| | | 58.00 | 128816 | 145959 | 75495 | 1.828 | 4 | 1.941 | | | |
| | | | 128816 | 169267 | 75495 | | | | 1.374 | 4 | 1.423 |
| | | 56.00 | 87412 | 106298 | 54951 | 1.702 | 4 | 1.806 | | | |
| | | | 87412 | 122609 | 54951 | | | | 1.292 | 4 | 1.334 |
| | | 54.00 | 55587 | 70157 | 36255 | 1.640 | 4 | 1.737 | | | |
| | | | 55587 | 80831 | 36255 | | | | 1.247 | 4 | 1.284 |
| | | 52.00 | 30870 | 40144 | 20738 | 1.591 | 4 | 1.683 | | | |
| | | | 30870 | 46250 | 20738 | | | | 1.210 | 4 | 1.242 |
| 114.00 | 12.00 | 46.00 | 224838 | 186664 | 97094 | 2.510 | 4 | 2.655 | | | |
| | | | 224838 | 218625 | 97094 | | | | 1.850 | 4 | 1.924 |
| | | 44.00 | 175081 | 155284 | 80640 | 2.346 | 4 | 2.486 | | | |
| | | | 175081 | 181035 | 80640 | | | | 1.744 | 4 | 1.815 |
| | | 42.00 | 132922 | 126226 | 65469 | 2.188 | 4 | 2.323 | | | |
| | | | 132922 | 146495 | 65469 | | | | 1.640 | 4 | 1.708 |
| | | 40.00 | 97847 | 99388 | 51526 | 2.044 | 4 | 2.174 | | | |
| | | | 97847 | 114887 | 51526 | | | | 1.544 | 4 | 1.608 |
| | | 38.00 | 69499 | 74960 | 38815 | 1.923 | 4 | 2.046 | | | |
| | | | 69499 | 86404 | 38815 | | | | 1.460 | 4 | 1.519 |
| | | 36.00 | 47157 | 52991 | 27424 | 1.844 | 4 | 1.961 | | | |
| | | | 47157 | 61062 | 27424 | | | | 1.402 | 4 | 1.455 |
| | | 34.00 | 29543 | 34632 | 17909 | 1.767 | 4 | 1.877 | | | |
| | | | 29543 | 39904 | 17909 | | | | 1.343 | 4 | 1.391 |
| | | 32.00 | 16178 | 19855 | 10264 | 1.687 | 4 | 1.789 | | | |
| | | | 16178 | 22877 | 10264 | | | | 1.283 | 4 | 1.324 |
| 114.00 | 16.00 | 50.00 | 259264 | 220333 | 114467 | 2.449 | 4 | 2.591 | | | |
| | | | 259264 | 258307 | 114467 | | | | 1.802 | 4 | 1.874 |
| | | 48.00 | 203425 | 184280 | 95607 | 2.294 | 4 | 2.430 | | | |
| | | | 203425 | 215046 | 95607 | | | | 1.703 | 4 | 1.772 |
| | | 46.00 | 155609 | 150625 | 78112 | 2.146 | 4 | 2.278 | | | |
| | | | 155609 | 174986 | 78112 | | | | 1.606 | 4 | 1.672 |
| | | 44.00 | 115588 | 119661 | 61997 | 2.005 | 4 | 2.131 | | | |
| | | | 115588 | 138419 | 61997 | | | | 1.512 | 4 | 1.573 |
| | | 42.00 | 82905 | 91202 | 47204 | 1.884 | 4 | 2.004 | | | |
| | | | 82905 | 105155 | 47204 | | | | 1.431 | 4 | 1.486 |
| | | 40.00 | 56980 | 65270 | 33768 | 1.809 | 4 | 1.923 | | | |
| | | | 56980 | 75208 | 33768 | | | | 1.375 | 4 | 1.426 |
| | | 38.00 | 36356 | 43270 | 22375 | 1.740 | 4 | 1.847 | | | |
| | | | 36356 | 49856 | 22375 | | | | 1.323 | 4 | 1.368 |
| | | 36.00 | 20459 | 25379 | 13117 | 1.669 | 4 | 1.769 | | | |
| | | | 20459 | 29240 | 13117 | | | | 1.269 | 4 | 1.308 |
| 114.00 | 20.00 | 54.00 | 296080 | 256624 | 133163 | 2.398 | 4 | 2.537 | | | |

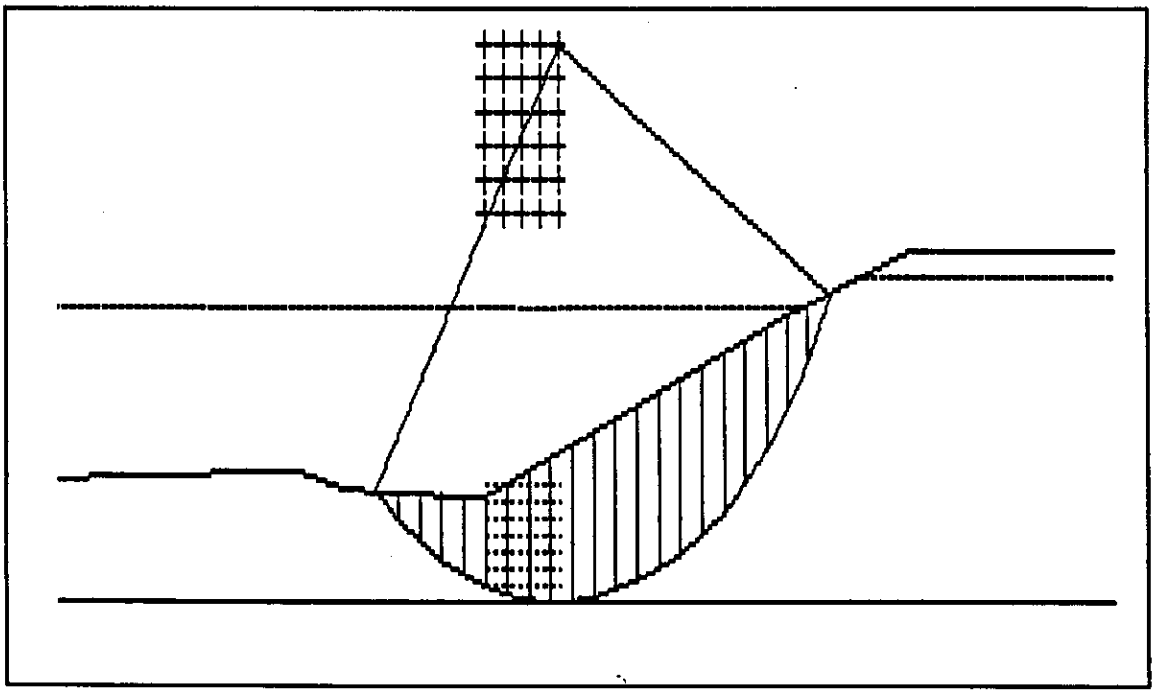
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 296080 | 301090 | 133163 | | | | 1.763 | 4 | 1.833 |
| | | 52.00 | 233709 | 215565 | 111762 | 2.251 | 4 | 2.386 | | | |
| | | | 233709 | 251765 | 111762 | | | | 1.669 | 4 | 1.736 |
| | | 50.00 | 180087 | 177184 | 91830 | 2.110 | 4 | 2.240 | | | |
| | | | 180087 | 206004 | 91830 | | | | 1.577 | 4 | 1.841 |
| | | 48.00 | 134840 | 141721 | 73393 | 1.973 | 4 | 2.097 | | | |
| | | | 134840 | 164044 | 73393 | | | | 1.487 | 4 | 1.546 |
| | | 46.00 | 97553 | 108925 | 56374 | 1.856 | 4 | 1.974 | | | |
| | | | 97553 | 125637 | 56374 | | | | 1.408 | 4 | 1.462 |
| | | 44.00 | 67813 | 78905 | 40807 | 1.780 | 4 | 1.891 | | | |
| | | | 67813 | 90916 | 40807 | | | | 1.353 | 4 | 1.402 |
| | | 42.00 | 43971 | 52979 | 27392 | 1.718 | 4 | 1.824 | | | |
| | | | 43971 | 61043 | 27392 | | | | 1.307 | 4 | 1.350 |
| | | 40.00 | 25344 | 31705 | 16386 | 1.654 | 4 | 1.753 | | | |
| | | | 25344 | 36529 | 16386 | | | | 1.258 | 4 | 1.296 |
| 114.00 | 24.00 | 58.00 | 335218 | 295373 | 153049 | 2.355 | 4 | 2.491 | | | |
| | | | 335218 | 346810 | 153049 | | | | 1.730 | 4 | 1.797 |
| | | 56.00 | 266111 | 249125 | 129083 | 2.217 | 4 | 2.349 | | | |
| | | | 266111 | 291184 | 129083 | | | | 1.642 | 4 | 1.706 |
| | | 54.00 | 206363 | 205817 | 106623 | 2.080 | 4 | 2.208 | | | |
| | | | 206363 | 239460 | 106623 | | | | 1.553 | 4 | 1.615 |
| | | 52.00 | 155628 | 165607 | 85733 | 1.948 | 4 | 2.071 | | | |
| | | | 155628 | 191806 | 85733 | | | | 1.467 | 4 | 1.524 |
| | | 50.00 | 113500 | 128278 | 66373 | 1.833 | 4 | 1.949 | | | |
| | | | 113500 | 148011 | 66373 | | | | 1.390 | 4 | 1.442 |
| | | 48.00 | 79653 | 93875 | 48541 | 1.757 | 4 | 1.866 | | | |
| | | | 79653 | 108163 | 48541 | | | | 1.336 | 4 | 1.383 |
| | | 46.00 | 52413 | 63789 | 32977 | 1.701 | 4 | 1.805 | | | |
| | | | 52413 | 73497 | 32977 | | | | 1.294 | 4 | 1.336 |
| | | 44.00 | 30873 | 38892 | 20097 | 1.643 | 4 | 1.740 | | | |
| | | | 30873 | 44809 | 20097 | | | | 1.249 | 4 | 1.286 |
| 114.00 | 28.00 | 62.00 | 376410 | 336086 | 173761 | 2.319 | 4 | 2.452 | | | |
| | | | 376410 | 394954 | 173761 | | | | 1.702 | 4 | 1.767 |
| | | 60.00 | 300444 | 284741 | 147479 | 2.189 | 4 | 2.320 | | | |
| | | | 300444 | 333070 | 147479 | | | | 1.619 | 4 | 1.682 |
| | | 58.00 | 234489 | 236703 | 122509 | 2.053 | 4 | 2.179 | | | |
| | | | 234489 | 275547 | 122509 | | | | 1.532 | 4 | 1.592 |
| | | 56.00 | 177977 | 191359 | 99038 | 1.928 | 4 | 2.048 | | | |
| | | | 177977 | 221750 | 99038 | | | | 1.450 | 4 | 1.506 |
| | | 54.00 | 130758 | 149251 | 77208 | 1.815 | 4 | 1.929 | | | |
| | | | 130758 | 172270 | 77208 | | | | 1.376 | 4 | 1.426 |
| | | 52.00 | 92546 | 110247 | 57000 | 1.738 | 4 | 1.845 | | | |
| | | | 92546 | 127026 | 57000 | | | | 1.322 | 4 | 1.367 |
| | | 50.00 | 61730 | 75768 | 39161 | 1.686 | 4 | 1.789 | | | |
| | | | 61730 | 87297 | 39161 | | | | 1.282 | 4 | 1.323 |
| | | 48.00 | 37066 | 46962 | 24266 | 1.633 | 4 | 1.730 | | | |
| | | | 37066 | 54107 | 24266 | | | | 1.242 | 4 | 1.278 |
| 114.00 | 32.00 | 66.00 | 419736 | 378505 | 194521 | 2.281 | 4 | 2.412 | | | |
| | | | 419736 | 445267 | 194521 | | | | 1.674 | 4 | 1.738 |
| | | 64.00 | 336879 | 322568 | 166597 | 2.160 | 4 | 2.288 | | | |
| | | | 336879 | 377603 | 166597 | | | | 1.597 | 4 | 1.658 |
| | | 62.00 | 264276 | 269177 | 139318 | 2.035 | 4 | 2.160 | | | |
| | | | 264276 | 313570 | 139318 | | | | 1.517 | 4 | 1.576 |
| | | 60.00 | 201885 | 218991 | 113296 | 1.910 | 4 | 2.029 | | | |
| | | | 201885 | 253888 | 113296 | | | | 1.436 | 4 | 1.490 |
| | | 58.00 | 149355 | 171887 | 88903 | 1.800 | 4 | 1.912 | | | |
| | | | 149355 | 198461 | 88903 | | | | 1.363 | 4 | 1.412 |
| | | 56.00 | 106523 | 128063 | 66205 | 1.722 | 4 | 1.828 | | | |
| | | | 106523 | 147552 | 66205 | | | | 1.309 | 4 | 1.353 |
| | | 54.00 | 71907 | 88882 | 45941 | 1.675 | 4 | 1.776 | | | |
| | | | 71907 | 102406 | 45941 | | | | 1.273 | 4 | 1.313 |
| | | 52.00 | 43964 | 55971 | 28919 | 1.625 | 4 | 1.721 | | | |
| | | | 43964 | 64486 | 28919 | | | | 1.236 | 4 | 1.272 |

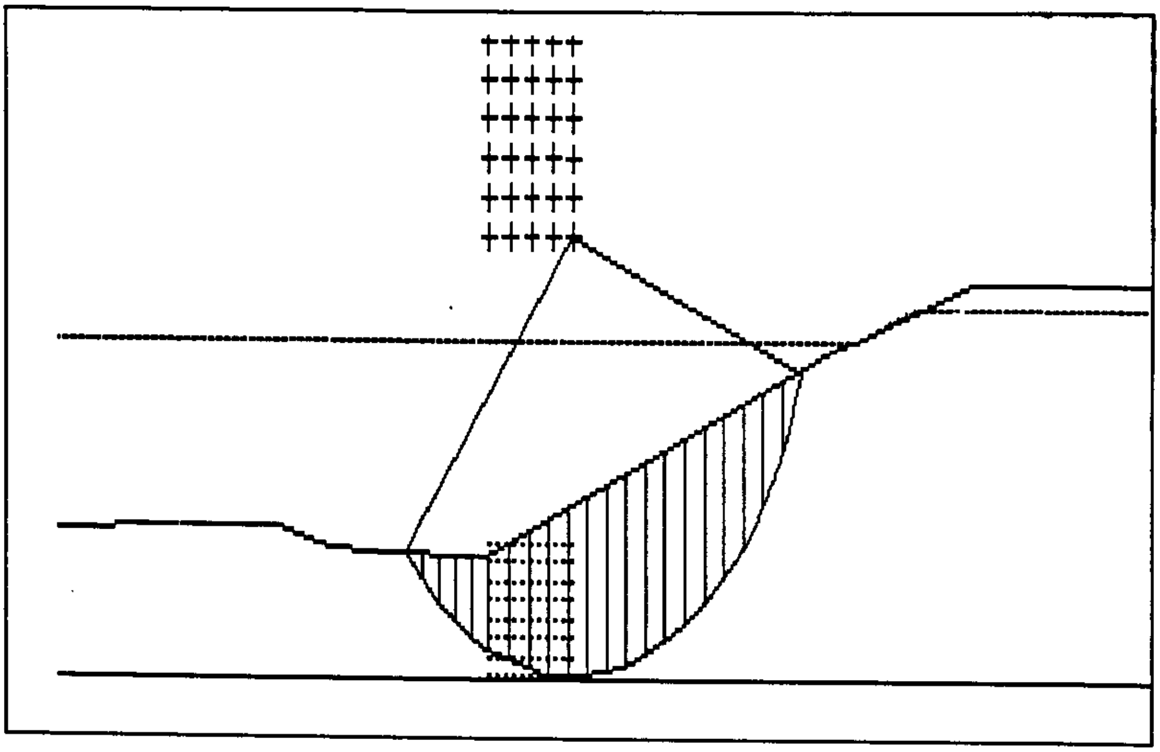
PROJECT : MRBPSTS - BHAIRAB BAZAR
CASE (No.) : 08-Typical Cross Section (1:3.5)

## MINIMUM SAFETY COEFFICIENTS

| CENTRE POINT CO-ORDINATES | | EXCL. SEISMIC EFFECTS | | INCL. SEISMIC EFFECTS | |
|---|---|---|---|---|---|
| X | Y | RADIUS m | SAFETY COEFF. | RADIUS m | SAFETY COEFF. |
| 98.00 | 12.00 | 34.00 | 1.735 | 34.00 | 1.264 |
| 98.00 | 16.00 | 36.00 | 1.556 | 36.00 | 1.144 |
| 98.00 | 20.00 | 40.00 | 1.562 | 40.00 | 1.149 |
| 98.00 | 24.00 | 44.00 | 1.567 | 44.00 | 1.153 |
| 98.00 | 28.00 | 48.00 | 1.572 | 48.00 | 1.156 |
| 98.00 | 32.00 | 52.00 | 1.576 | 52.00 | 1.159 |
| 102.00 | 12.00 | 32.00 | 1.604 | 32.00 | 1.181 |
| 102.00 | 16.00 | 36.00 | 1.606 | 36.00 | 1.182 |
| 102.00 | 20.00 | 40.00 | 1.607 | 40.00 | 1.184 |
| 102.00 | 24.00 | 44.00 | 1.608 | 44.00 | 1.185 |
| 102.00 | 28.00 | 48.00 | 1.609 | 48.00 | 1.185 |
| 102.00 | 32.00 | 52.00 | 1.610 | 52.00 | 1.186 |
| 106.00 | 12.00 | 32.00 | 1.662 | 32.00 | 1.226 |
| 106.00 | 16.00 | 36.00 | 1.658 | 36.00 | 1.223 |
| 106.00 | 20.00 | 40.00 | 1.654 | 40.00 | 1.220 |
| 106.00 | 24.00 | 44.00 | 1.651 | 44.00 | 1.217 |
| 106.00 | 28.00 | 48.00 | 1.648 | 48.00 | 1.215 |
| 106.00 | 32.00 | 52.00 | 1.646 | 52.00 | 1.214 |
| 110.00 | 12.00 | 32.00 | 1.724 | 32.00 | 1.274 |
| 110.00 | 16.00 | 36.00 | 1.712 | 36.00 | 1.265 |
| 110.00 | 20.00 | 40.00 | 1.703 | 40.00 | 1.257 |
| 110.00 | 24.00 | 44.00 | 1.695 | 44.00 | 1.251 |
| 110.00 | 28.00 | 48.00 | 1.689 | 48.00 | 1.246 |
| 110.00 | 32.00 | 52.00 | 1.683 | 52.00 | 1.242 |
| 114.00 | 12.00 | 32.00 | 1.789 | 32.00 | 1.324 |
| 114.00 | 16.00 | 36.00 | 1.769 | 36.00 | 1.308 |
| 114.00 | 20.00 | 40.00 | 1.753 | 40.00 | 1.296 |
| 114.00 | 24.00 | 44.00 | 1.740 | 44.00 | 1.286 |
| 114.00 | 28.00 | 48.00 | 1.730 | 48.00 | 1.278 |
| 114.00 | 32.00 | 52.00 | 1.721 | 52.00 | 1.272 |

| | | EXCL. SEISMIC EFFECTS | INCL. SEISMIC EFFECTS |
|---|---|---|---|
| MINIMUM SAFETY COEFFICIENT | F : | 1.56 | 1.14 |
| AT CIRCLE CENTRE POINT | X : | 98.00 | 98.00 |
| | Y : | 16.00 | 16.00 |
| RADIUS | R : | 36.00 | 36.00 |





# ***** SLOPE STABILITY *****

PROJECT : MRBPSTS - MUNSHIGANJ
PROJECT No. : HASKONING/BANGLADESH (5146.22)
CASE (No.) : 06-Slope 1:3.5
DATE : 91-08-31

## INPUT DATA

### GEOMETRY POINTS:

| Point No. | X | Y | Point No. | X | Y |
|---|---|---|---|---|---|
| 1 | 0.00 | -16.50 | 9 | 123.30 | 5.63 |
| 2 | 20.00 | -17.50 | 10 | 150.00 | 5.60 |
| 3 | 25.00 | -16.50 | 11 | 150.00 | -3.40 |
| 4 | 50.00 | -13.00 | 12 | 150.00 | -26.40 |
| 5 | 70.00 | -11.70 | 13 | 0.00 | -26.40 |
| 6 | 98.30 | -3.40 | 14 | 0.00 | 0.00 |
| 7 | 110.30 | 0.00 | 15 | 150.00 | 2.40 |
| 8 | 120.00 | 2.40 | | | |

### SOIL LAYER BOUNDARIES:

| Boundary No. | Geometry points: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2 | 1 | 2 | 3 | 4 | 5 | 6 | 11 | | | |

### PIEZOMETRIC LEVEL LINES:

| Line No. | Geometry points: | | | |
|---|---|---|---|---|
| 1 | 14 | 7 | 8 | 15 |

### SOIL PROPERTIES:

| Layer No. | Rho(dry) kN/m3 | Rho(wet) kN/m3 | Phi deg. | Cohesion kN/m2 | PL-line Nos top | PL-line Nos bottom |
|---|---|---|---|---|---|---|
| 1 | 18.00 | 18.00 | 20.0 | 10.00 | 1 | 1 |
| 2 | 19.00 | 19.00 | 25.0 | 0.00 | 1 | |

### SLIPCIRCLES:

| | | Min. | Step | Max. |
|---|---|---|---|---|
| - Grid of centre points: | X | 66.00 | 2.00 | 70.00 |
| | Y | 54.00 | 2.00 | 60.00 |
| - Lower tangent lines: | Y | -16.00 | 1.00 | -11.00 |

### SEISMIC FACTORS:

Horizontal seismic factor on soil is 0.050

PROJECT : MRBPSTS - MUNSHIGANJ
CASE (No.) : 06-Slope 1:3.5

# RESULTS OF CALCULATION

| <------ SLIP-CIRCLES -----> | | | <---------- MOMENTS ---------> | | | <---------- SAFETY COEFFICIENTS ----------> | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRE POINT CO-ORDINATES | | RADIUS | COUNTER-ACTING | DRIVING | WATER ON SLOPE | EXCL.SEISMIC EFFECTS | | | INCL.SEISMIC EFFECTS | | |
| | | | | | | BEFORE ITER. | No of ITER. | AFTER ITER. | BEFORE ITER. | No of ITER. | AFTER ITER. |
| X | Y | m | kNm | kNm | kNm | | | | | | |
| 66.00 | 54.00 | 70.00 | 74091 | 70924 | 36929 | 2.179 | 4 | 2.299 | | | |
| | | | 74091 | 86342 | 36929 | | | | 1.499 | 4 | 1.549 |
| | | 69.00 | 55623 | 54089 | 28112 | 2.141 | 4 | 2.265 | | | |
| | | | 55623 | 65505 | 28112 | | | | 1.488 | 4 | 1.539 |
| | | 68.00 | 37058 | 38777 | 20112 | 1.985 | 4 | 2.097 | | | |
| | | | 37058 | 46607 | 20112 | | | | 1.399 | 4 | 1.443 |
| | | 67.00 | 22478 | 25017 | 12944 | 1.862 | 4 | 1.968 | | | |
| | | | 22478 | 29752 | 12944 | | | | 1.337 | 4 | 1.379 |
| | | 66.00 | 9909 | 13033 | 6731 | 1.572 | 4 | 1.648 | | | |
| | | | 9909 | 15280 | 6731 | | | | 1.159 | 4 | 1.180 |
| | | 65.00 | 2909 | 3918 | 2023 | 1.535 | 4 | 1.607 | | | |
| | | | 2909 | 4586 | 2023 | | | | 1.135 | 4 | 1.153 |
| 66.00 | 56.00 | 72.00 | 79081 | 75704 | 39373 | 2.177 | 4 | 2.297 | | | |
| | | | 79081 | 92075 | 39373 | | | | 1.501 | 4 | 1.551 |
| | | 71.00 | 59401 | 57944 | 30146 | 2.137 | 4 | 2.261 | | | |
| | | | 59401 | 70112 | 30146 | | | | 1.486 | 4 | 1.538 |
| | | 70.00 | 40709 | 41807 | 21701 | 2.025 | 4 | 2.144 | | | |
| | | | 40709 | 50207 | 21701 | | | | 1.428 | 4 | 1.477 |
| | | 69.00 | 24082 | 27246 | 14111 | 1.833 | 4 | 1.936 | | | |
| | | | 24082 | 32383 | 14111 | | | | 1.318 | 4 | 1.357 |
| | | 68.00 | 12051 | 14525 | 7507 | 1.717 | 4 | 1.816 | | | |
| | | | 12051 | 17028 | 7507 | | | | 1.266 | 4 | 1.302 |
| | | 67.00 | 3502 | 4714 | 2434 | 1.536 | 4 | 1.609 | | | |
| | | | 3502 | 5517 | 2434 | | | | 1.136 | 4 | 1.154 |
| 66.00 | 58.00 | 74.00 | 84201 | 80614 | 41819 | 2.170 | 4 | 2.292 | | | |
| | | | 84201 | 97968 | 41819 | | | | 1.500 | 4 | 1.550 |
| | | 73.00 | 63326 | 61960 | 32268 | 2.133 | 4 | 2.257 | | | |
| | | | 63326 | 74910 | 32268 | | | | 1.485 | 4 | 1.537 |
| | | 72.00 | 43751 | 44960 | 23361 | 2.026 | 4 | 2.145 | | | |
| | | | 43751 | 53954 | 23361 | | | | 1.430 | 4 | 1.480 |
| | | 71.00 | 26208 | 29585 | 15338 | 1.840 | 4 | 1.944 | | | |
| | | | 26208 | 35145 | 15338 | | | | 1.323 | 4 | 1.363 |
| | | 70.00 | 13121 | 16121 | 8333 | 1.685 | 4 | 1.778 | | | |
| | | | 13121 | 18899 | 8333 | | | | 1.242 | 4 | 1.275 |
| | | 69.00 | 4160 | 5595 | 2889 | 1.537 | 4 | 1.610 | | | |
| | | | 4160 | 6549 | 2889 | | | | 1.137 | 4 | 1.155 |
| 66.00 | 60.00 | 76.00 | 89454 | 85682 | 44265 | 2.160 | 4 | 2.281 | | | |
| | | | 89454 | 104050 | 44265 | | | | 1.496 | 4 | 1.547 |
| | | 75.00 | 65808 | 66145 | 34438 | 2.075 | 4 | 2.192 | | | |
| | | | 65808 | 79909 | 34438 | | | | 1.447 | 4 | 1.495 |
| | | 74.00 | 46916 | 48255 | 25098 | 2.026 | 4 | 2.146 | | | |
| | | | 46916 | 57866 | 25098 | | | | 1.432 | 4 | 1.482 |
| | | 73.00 | 29234 | 32054 | 16629 | 1.895 | 4 | 2.008 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 29234 | 38057 | 16629 | | | | 1.364 | 4 | 1.410 |
| | | 72.00 | 15186 | 17814 | 9217 | 1.766 | 4 | 1.873 | | | |
| | | | 15186 | 20885 | 9217 | | | | 1.302 | 4 | 1.343 |
| | | 71.00 | 4888 | 6570 | 3392 | 1.538 | 4 | 1.611 | | | |
| | | | 4888 | 7690 | 3392 | | | | 1.137 | 4 | 1.156 |
| 68.00 | 54.00 | 70.00 | 83288 | 81027 | 41924 | 2.130 | 4 | 2.250 | | | |
| | | | 83288 | 98001 | 41924 | | | | 1.485 | 4 | 1.535 |
| | | 69.00 | 61945 | 63445 | 33041 | 2.037 | 4 | 2.152 | | | |
| | | | 61945 | 76314 | 33041 | | | | 1.432 | 4 | 1.478 |
| | | 68.00 | 45025 | 47170 | 24543 | 1.990 | 4 | 2.108 | | | |
| | | | 45025 | 56350 | 24543 | | | | 1.416 | 4 | 1.464 |
| | | 67.00 | 29158 | 32389 | 16811 | 1.872 | 4 | 1.983 | | | |
| | | | 29158 | 38358 | 16811 | | | | 1.353 | 4 | 1.398 |
| | | 66.00 | 15637 | 19256 | 9969 | 1.684 | 4 | 1.777 | | | |
| | | | 15637 | 22578 | 9969 | | | | 1.240 | 4 | 1.272 |
| | | 65.00 | 6597 | 8485 | 4382 | 1.608 | 4 | 1.690 | | | |
| | | | 6597 | 9932 | 4382 | | | | 1.189 | 4 | 1.214 |
| 68.00 | 56.00 | 72.00 | 88607 | 86190 | 44359 | 2.118 | 4 | 2.237 | | | |
| | | | 88607 | 104198 | 44359 | | | | 1.481 | 4 | 1.531 |
| | | 71.00 | 66358 | 67751 | 35205 | 2.039 | 4 | 2.155 | | | |
| | | | 66358 | 81453 | 35205 | | | | 1.435 | 4 | 1.482 |
| | | 70.00 | 47647 | 50650 | 26372 | 1.963 | 4 | 2.077 | | | |
| | | | 47647 | 60478 | 26372 | | | | 1.397 | 4 | 1.444 |
| | | 69.00 | 31628 | 35002 | 18187 | 1.881 | 4 | 1.994 | | | |
| | | | 31628 | 41441 | 18187 | | | | 1.360 | 4 | 1.406 |
| | | 68.00 | 17302 | 21108 | 10941 | 1.702 | 4 | 1.797 | | | |
| | | | 17302 | 24752 | 10941 | | | | 1.253 | 4 | 1.287 |
| | | 67.00 | 7690 | 9653 | 4987 | 1.648 | 4 | 1.737 | | | |
| | | | 7690 | 11299 | 4987 | | | | 1.218 | 4 | 1.248 |
| 68.00 | 58.00 | 74.00 | 92368 | 91501 | 46792 | 2.066 | 4 | 2.179 | | | |
| | | | 92368 | 110569 | 46792 | | | | 1.448 | 4 | 1.495 |
| | | 73.00 | 70895 | 72177 | 37370 | 2.037 | 4 | 2.153 | | | |
| | | | 70895 | 86739 | 37370 | | | | 1.436 | 4 | 1.484 |
| | | 72.00 | 51159 | 54254 | 28266 | 1.969 | 4 | 2.084 | | | |
| | | | 51159 | 64754 | 28266 | | | | 1.402 | 4 | 1.449 |
| | | 71.00 | 34220 | 37755 | 19639 | 1.889 | 4 | 2.003 | | | |
| | | | 34220 | 44690 | 19639 | | | | 1.366 | 4 | 1.413 |
| | | 70.00 | 19754 | 23089 | 11977 | 1.778 | 4 | 1.885 | | | |
| | | | 19754 | 27078 | 11977 | | | | 1.308 | 4 | 1.350 |
| | | 69.00 | 8991 | 10908 | 5639 | 1.707 | 4 | 1.805 | | | |
| | | | 8991 | 12770 | 5639 | | | | 1.261 | 4 | 1.297 |
| 68.00 | 60.00 | 76.00 | 98015 | 96974 | 49230 | 2.053 | 4 | 2.165 | | | |
| | | | 98015 | 117139 | 49230 | | | | 1.443 | 4 | 1.489 |
| | | 75.00 | 75557 | 76738 | 39521 | 2.030 | 4 | 2.146 | | | |
| | | | 75557 | 92190 | 39521 | | | | 1.435 | 4 | 1.483 |
| | | 74.00 | 54932 | 57966 | 30161 | 1.976 | 4 | 2.093 | | | |
| | | | 54932 | 69162 | 30161 | | | | 1.408 | 4 | 1.457 |
| | | 73.00 | 36271 | 40657 | 21169 | 1.861 | 4 | 1.972 | | | |
| | | | 36271 | 48114 | 21169 | | | | 1.346 | 4 | 1.390 |
| | | 72.00 | 21742 | 25169 | 13071 | 1.797 | 4 | 1.907 | | | |
| | | | 21742 | 29521 | 13071 | | | | 1.322 | 4 | 1.366 |
| | | 71.00 | 10765 | 12250 | 6340 | 1.821 | 4 | 1.937 | | | |
| | | | 10765 | 14344 | 6340 | | | | 1.345 | 4 | 1.393 |
| 70.00 | 54.00 | 70.00 | 90979 | 91364 | 46472 | 2.027 | 4 | 2.137 | | | |
| | | | 90979 | 109936 | 46472 | | | | 1.434 | 4 | 1.479 |
| | | 69.00 | 70788 | 73085 | 37680 | 1.999 | 4 | 2.114 | | | |
| | | | 70788 | 87469 | 37680 | | | | 1.422 | 4 | 1.469 |
| | | 68.00 | 52316 | 56027 | 29162 | 1.947 | 4 | 2.063 | | | |
| | | | 52316 | 66636 | 29162 | | | | 1.396 | 4 | 1.443 |
| | | 67.00 | 35548 | 40249 | 20963 | 1.843 | 4 | 1.952 | | | |
| | | | 35548 | 47532 | 20963 | | | | 1.338 | 4 | 1.381 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 66.00 | 21991 | 26052 | 13537 | 1.757 | 4 | 1.861 | | | |
| | | | 21991 | 30551 | 13537 | | | | 1.293 | 4 | 1.332 |
| | | 65.00 | 12302 | 13939 | 7222 | 1.832 | 4 | 1.949 | | | |
| | | | 12302 | 16324 | 7222 | | | | 1.352 | 4 | 1.401 |
| 70.00 | 56.00 | 72.00 | 96666 | 96949 | 48893 | 2.012 | 4 | 2.121 | | | |
| | | | 96666 | 116634 | 48893 | | | | 1.427 | 4 | 1.472 |
| | | 71.00 | 73852 | 77750 | 39839 | 1.948 | 4 | 2.056 | | | |
| | | | 73852 | 93040 | 39839 | | | | 1.388 | 4 | 1.431 |
| | | 70.00 | 54823 | 59855 | 31054 | 1.904 | 4 | 2.013 | | | |
| | | | 54823 | 71180 | 31054 | | | | 1.366 | 4 | 1.410 |
| | | 69.00 | 38303 | 43292 | 22573 | 1.849 | 4 | 1.959 | | | |
| | | | 38303 | 51121 | 22573 | | | | 1.342 | 4 | 1.385 |
| | | 68.00 | 24026 | 28289 | 14717 | 1.770 | 4 | 1.876 | | | |
| | | | 24026 | 33179 | 14717 | | | | 1.301 | 4 | 1.342 |
| | | 67.00 | 13381 | 15459 | 8017 | 1.798 | 4 | 1.910 | | | |
| | | | 13381 | 18107 | 8017 | | | | 1.326 | 4 | 1.372 |
| 70.00 | 58.00 | 74.00 | 102508 | 102661 | 51319 | 1.997 | 4 | 2.104 | | | |
| | | | 102508 | 123493 | 51319 | | | | 1.420 | 4 | 1.465 |
| | | 73.00 | 78737 | 82564 | 41985 | 1.940 | 4 | 2.047 | | | |
| | | | 78737 | 98790 | 41985 | | | | 1.386 | 4 | 1.429 |
| | | 72.00 | 58835 | 63858 | 32957 | 1.904 | 4 | 2.013 | | | |
| | | | 58835 | 75933 | 32957 | | | | 1.369 | 4 | 1.413 |
| | | 71.00 | 41501 | 46476 | 24226 | 1.865 | 4 | 1.977 | | | |
| | | | 41501 | 54880 | 24226 | | | | 1.354 | 4 | 1.399 |
| | | 70.00 | 26171 | 30651 | 15966 | 1.782 | 4 | 1.889 | | | |
| | | | 26171 | 35955 | 15966 | | | | 1.309 | 4 | 1.351 |
| | | 69.00 | 15383 | 17069 | 8864 | 1.875 | 4 | 1.998 | | | |
| | | | 15383 | 19997 | 8864 | | | | 1.382 | 4 | 1.435 |
| 70.00 | 60.00 | 76.00 | 106817 | 108533 | 53746 | 1.950 | 4 | 2.052 | | | |
| | | | 106817 | 130546 | 53746 | | | | 1.391 | 4 | 1.432 |
| | | 75.00 | 83795 | 87580 | 44146 | 1.929 | 4 | 2.035 | | | |
| | | | 83795 | 104782 | 44146 | | | | 1.382 | 4 | 1.425 |
| | | 74.00 | 62965 | 67970 | 34859 | 1.902 | 4 | 2.011 | | | |
| | | | 62965 | 80820 | 34859 | | | | 1.370 | 4 | 1.414 |
| | | 73.00 | 44798 | 49751 | 25871 | 1.876 | 4 | 1.989 | | | |
| | | | 44798 | 58749 | 25871 | | | | 1.363 | 4 | 1.409 |
| | | 72.00 | 29113 | 33152 | 17286 | 1.835 | 4 | 1.950 | | | |
| | | | 29113 | 38894 | 17286 | | | | 1.347 | 4 | 1.395 |
| | | 71.00 | 17151 | 18783 | 9767 | 1.902 | 4 | 2.029 | | | |
| | | | 17151 | 22009 | 9767 | | | | 1.401 | 4 | 1.457 |

PROJECT : MRBPSTS - MUNSHIGANJ
CASE (No.) : 06-Slope 1:3.5

## MINIMUM SAFETY COEFFICIENTS

| CENTRE POINT CO-ORDINATES | | EXCL. SEISMIC EFFECTS | | INCL. SEISMIC EFFECTS | |
|---|---|---|---|---|---|
| X | Y | RADIUS m | SAFETY COEFF. | RADIUS m | SAFETY COEFF. |
| 66.00 | 54.00 | 65.00 | 1.607 | 65.00 | 1.153 |
| 66.00 | 56.00 | 67.00 | 1.609 | 67.00 | 1.154 |
| 66.00 | 58.00 | 69.00 | 1.610 | 69.00 | 1.155 |
| 66.00 | 60.00 | 71.00 | 1.611 | 71.00 | 1.156 |
| 68.00 | 54.00 | 65.00 | 1.690 | 65.00 | 1.214 |
| 68.00 | 56.00 | 67.00 | 1.737 | 67.00 | 1.248 |
| 68.00 | 58.00 | 69.00 | 1.805 | 69.00 | 1.297 |
| 68.00 | 60.00 | 72.00 | 1.907 | 72.00 | 1.366 |
| 70.00 | 54.00 | 66.00 | 1.861 | 66.00 | 1.332 |
| 70.00 | 56.00 | 68.00 | 1.876 | 68.00 | 1.342 |
| 70.00 | 58.00 | 70.00 | 1.889 | 70.00 | 1.351 |
| 70.00 | 60.00 | 72.00 | 1.950 | 72.00 | 1.395 |

| | | EXCL. SEISMIC EFFECTS | INCL. SEISMIC EFFECTS |
|---|---|---|---|
| MINIMUM SAFETY COEFFICIENT | F : | 1.61 | 1.15 |
| AT CIRCLE CENTRE POINT | X : | 66.00 | 66.00 |
| | Y : | 54.00 | 54.00 |
| RADIUS | R : | 65.00 | 65.00 |

PROJECT : MRBPSTS - MUNSHIGANJ
CASE (No.) : 06-Slope 1:3.5

## SLICE DATA

CIRCLE CENTRE POINT X : 70.00
Y : 60.00
RADIUS R : 76.00
SAFETY COEFFICIENT F : 1.43
(including seismic effects)

| Slice No | Co-ord. of centre of slice boundary X | Y | Slice width m | Arc length m | Groundwater pressures hydro-static | over-pressure | total pressure | <----- Soil normal stress | effect. stress | shear stress -----> |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.62 | -13.21 | 0.76 | 0.79 | 129.61 | 0.00 | 129.61 | 131.06 | 1.46 | 0.52 |
| 2 | 51.67 | -13.73 | 3.33 | 3.43 | 134.71 | 0.00 | 134.71 | 142.42 | 7.72 | 2.73 |
| 3 | 55.00 | -14.48 | 3.33 | 3.40 | 142.06 | 0.00 | 142.06 | 158.67 | 16.60 | 5.79 |
| 4 | 58.33 | -15.08 | 3.33 | 3.37 | 147.90 | 0.00 | 147.90 | 171.96 | 24.06 | 8.25 |
| 5 | 61.67 | -15.52 | 3.33 | 3.35 | 152.24 | 0.00 | 152.24 | 182.36 | 30.12 | 10.17 |
| 6 | 65.00 | -15.81 | 3.33 | 3.34 | 155.13 | 0.00 | 155.13 | 189.94 | 34.81 | 11.58 |
| 7 | 68.33 | -15.96 | 3.33 | 3.33 | 156.56 | 0.00 | 156.56 | 194.71 | 38.15 | 12.51 |
| 8 | 71.57 | -15.96 | 3.14 | 3.15 | 156.60 | 0.00 | 156.60 | 200.02 | 43.42 | 14.04 |
| 9 | 74.72 | -15.83 | 3.14 | 3.15 | 155.32 | 0.00 | 155.32 | 206.02 | 50.70 | 16.18 |
| 10 | 77.86 | -15.57 | 3.14 | 3.16 | 152.76 | 0.00 | 152.76 | 209.53 | 56.77 | 17.88 |
| 11 | 81.01 | -15.18 | 3.14 | 3.18 | 148.90 | 0.00 | 148.90 | 210.52 | 61.63 | 19.15 |
| 12 | 84.15 | -14.65 | 3.14 | 3.20 | 143.72 | 0.00 | 143.72 | 208.96 | 65.25 | 20.01 |
| 13 | 87.29 | -13.98 | 3.14 | 3.23 | 137.19 | 0.00 | 137.19 | 204.79 | 67.61 | 20.46 |
| 14 | 90.44 | -13.18 | 3.14 | 3.26 | 129.27 | 0.00 | 129.27 | 197.94 | 68.67 | 20.50 |
| 15 | 93.58 | -12.23 | 3.14 | 3.31 | 119.93 | 0.00 | 119.93 | 188.32 | 68.39 | 20.13 |
| 16 | 96.73 | -11.12 | 3.14 | 3.36 | 109.10 | 0.00 | 109.10 | 175.82 | 66.72 | 19.36 |
| 17 | 99.80 | -9.89 | 3.00 | 3.26 | 97.03 | 0.00 | 97.03 | 160.16 | 63.13 | 16.05 |
| 18 | 102.80 | -8.53 | 3.00 | 3.33 | 83.71 | 0.00 | 83.71 | 141.33 | 57.62 | 16.23 |
| 19 | 105.80 | -7.01 | 3.00 | 3.40 | 68.81 | 0.00 | 68.81 | 119.42 | 50.62 | 14.04 |
| 20 | 108.80 | -5.32 | 3.00 | 3.49 | 52.20 | 0.00 | 52.20 | 94.23 | 42.02 | 11.47 |
| 21 | 111.82 | -3.43 | 3.03 | 3.63 | 37.34 | 0.00 | 37.34 | 68.54 | 31.20 | 8.36 |
| 22 | 114.85 | -1.32 | 3.03 | 3.76 | 24.00 | 0.00 | 24.00 | 44.04 | 20.04 | 10.18 |
| 23 | 117.89 | 1.02 | 3.03 | 3.91 | 8.40 | 0.00 | 8.40 | 15.41 | 7.01 | 7.27 |

DRIVING MOMENT : 130546
COUNTER-ACTING MOMENT : 106817
MOMENT WATER ON SLOPE : 53746

(Units: m and kNm/m)

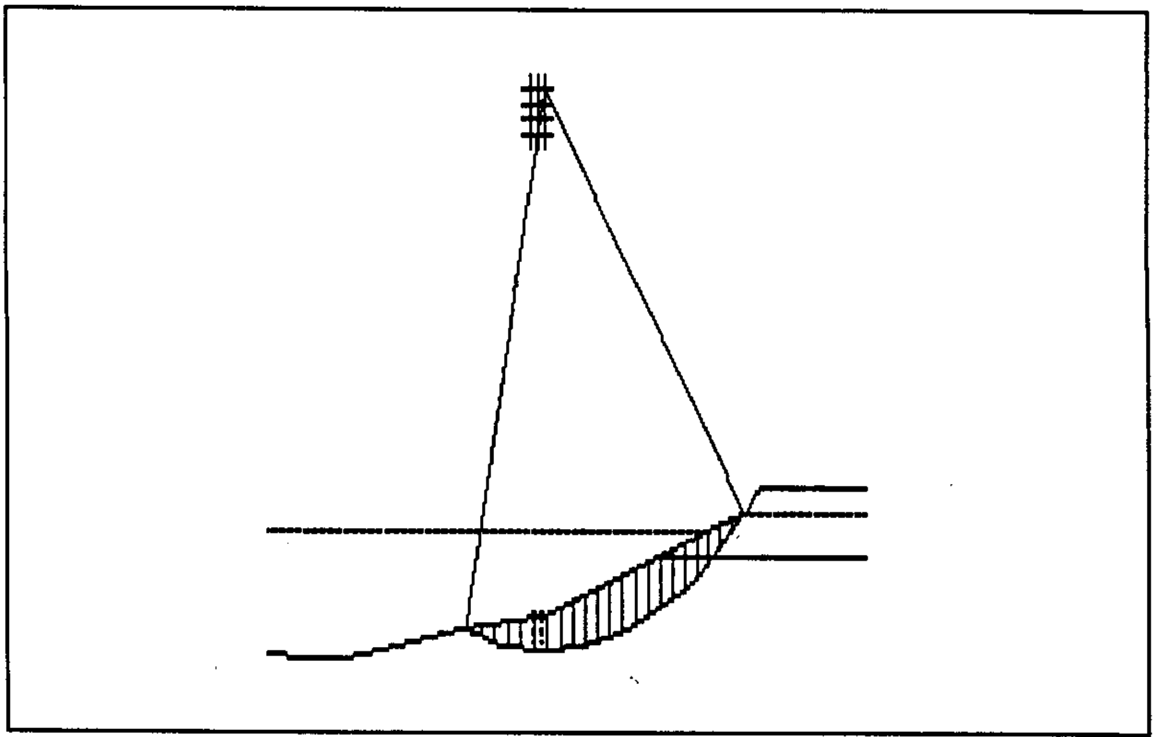


FIGURE 1. Slope Stability Analysis. Munshiganj Town. Slope 1 to 3.5
Calculation with HASKONING/BISEIS Model.

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# ***** SLOPE STABILITY *****

PROJECT : MRBPSTS - MUNSHIGANJ
PROJECT No. : HASKONING/BANGLADESH (5146.22)
CASE (No.) : 01-Present Situation Cross Section 22
DATE : 91-08-31

## INPUT DATA

### GEOMETRY POINTS:

| Point No. | X | Y | Point No. | X | Y |
|---|---|---|---|---|---|
| 1 | 0.00 | -16.50 | 10 | 97.50 | 0.80 |
| 2 | 20.00 | -17.50 | 11 | 120.00 | 2.40 |
| 3 | 25.00 | -16.50 | 12 | 123.30 | 5.63 |
| 4 | 50.00 | -13.00 | 13 | 150.00 | 5.60 |
| 5 | 70.00 | -11.70 | 14 | 150.00 | -3.40 |
| 6 | 75.00 | -7.70 | 15 | 150.00 | -26.40 |
| 7 | 79.50 | -3.40 | 16 | 0.00 | -26.40 |
| 8 | 87.50 | -0.80 | 17 | 0.00 | 0.00 |
| 9 | 90.00 | 0.00 | 18 | 150.00 | 2.40 |

### SOIL LAYER BOUNDARIES:

| Boundary No. | Geometry points: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | 11 | 12 | 13 | | | | | | | |
| 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 14 | | |

### PIEZOMETRIC LEVEL LINES:

| Line No. | Geometry points: | | | | |
|---|---|---|---|---|---|
| 1 | 17 | 8 | 10 | 11 | 18 |

### SOIL PROPERTIES:

| Layer No. | Rho(dry) kN/m3 | Rho(wet) kN/m3 | Phi deg. | Cohesion kN/m2 | PL-line Nos top | PL-line Nos bottom |
|---|---|---|---|---|---|---|
| 1 | 18.00 | 18.00 | 20.0 | 10.00 | 1 | 1 |
| 2 | 19.00 | 19.00 | 25.0 | 0.00 | 1 | |

### SLIPCIRCLES:

| | | Min. | Step | Max. |
|---|---|---|---|---|
| - Grid of centre points: | X | 60.00 | 2.00 | 70.00 |
| | Y | 12.00 | 2.00 | 24.00 |
| - Lower tangent lines: | Y | -20.00 | 2.00 | -12.00 |

### SEISMIC FACTORS:

Horizontal seismic factor on soil is 0.050

PROJECT : MRBPSTS - MUNSHIGANJ
CASE (No.) : 01-Present Situation Cross Section 22

## MINIMUM SAFETY COEFFICIENTS

| CENTRE POINT CO-ORDINATES | | EXCL. SEISMIC EFFECTS | | INCL. SEISMIC EFFECTS | |
|---|---|---|---|---|---|
| X | Y | RADIUS m | SAFETY COEFF. | RADIUS m | SAFETY COEFF. |
| 60.00 | 12.00 | 26.00 | 1.669 | 26.00 | 1.233 |
| 60.00 | 14.00 | 28.00 | 1.575 | 28.00 | 1.194 |
| 60.00 | 16.00 | 28.00 | 0.825 | 30.00 | 1.139 |
| 60.00 | 18.00 | 30.00 | 0.937 | 30.00 | 0.784 |
| 60.00 | 20.00 | 32.00 | 1.000 | 32.00 | 0.834 |
| 60.00 | 22.00 | 34.00 | 0.998 | 34.00 | 0.823 |
| 60.00 | 24.00 | 36.00 | 1.078 | 36.00 | 0.887 |
| 62.00 | 12.00 | 26.00 | 1.389 | 26.00 | 1.083 |
| 62.00 | 14.00 | 26.00 | 0.846 | 26.00 | 0.704 |
| 62.00 | 16.00 | 28.00 | 0.869 | 28.00 | 0.718 |
| 62.00 | 18.00 | 30.00 | 0.892 | 30.00 | 0.732 |
| 62.00 | 20.00 | 32.00 | 0.985 | 32.00 | 0.808 |
| 62.00 | 22.00 | 34.00 | 1.000 | 34.00 | 0.816 |
| 62.00 | 24.00 | 36.00 | 1.072 | 36.00 | 0.872 |
| 64.00 | 12.00 | 24.00 | 0.837 | 24.00 | 0.692 |
| 64.00 | 14.00 | 26.00 | 0.870 | 26.00 | 0.715 |
| 64.00 | 16.00 | 28.00 | 0.959 | 28.00 | 0.787 |
| 64.00 | 18.00 | 30.00 | 0.984 | 30.00 | 0.802 |
| 64.00 | 20.00 | 32.00 | 1.023 | 32.00 | 0.833 |
| 64.00 | 22.00 | 34.00 | 1.044 | 34.00 | 0.847 |
| 64.00 | 24.00 | 36.00 | 1.045 | 36.00 | 0.846 |
| 66.00 | 12.00 | 24.00 | 0.898 | 24.00 | 0.736 |
| 66.00 | 14.00 | 26.00 | 0.978 | 26.00 | 0.799 |
| 66.00 | 16.00 | 28.00 | 0.997 | 28.00 | 0.810 |
| 66.00 | 18.00 | 30.00 | 1.011 | 30.00 | 0.820 |
| 66.00 | 20.00 | 32.00 | 1.054 | 32.00 | 0.854 |
| 66.00 | 22.00 | 34.00 | 1.049 | 34.00 | 0.848 |
| 66.00 | 24.00 | 36.00 | 1.084 | 36.00 | 0.876 |
| 68.00 | 12.00 | 24.00 | 1.000 | 24.00 | 0.816 |
| 68.00 | 14.00 | 26.00 | 1.025 | 26.00 | 0.834 |
| 68.00 | 16.00 | 28.00 | 1.041 | 28.00 | 0.844 |
| 68.00 | 18.00 | 30.00 | 1.067 | 30.00 | 0.864 |
| 68.00 | 20.00 | 32.00 | 1.070 | 32.00 | 0.863 |
| 68.00 | 22.00 | 34.00 | 1.078 | 34.00 | 0.868 |
| 68.00 | 24.00 | 36.00 | 1.106 | 36.00 | 0.888 |
| 70.00 | 12.00 | 24.00 | 1.065 | 24.00 | 0.866 |
| 70.00 | 14.00 | 26.00 | 1.080 | 26.00 | 0.877 |
| 70.00 | 16.00 | 28.00 | 1.095 | 28.00 | 0.886 |
| 70.00 | 18.00 | 30.00 | 1.104 | 30.00 | 0.891 |
| 70.00 | 20.00 | 32.00 | 1.131 | 32.00 | 0.909 |
| 70.00 | 22.00 | 34.00 | 1.137 | 34.00 | 0.911 |
| 70.00 | 24.00 | 36.00 | 1.158 | 36.00 | 0.925 |

| | | | EXCL. SEISMIC EFFECTS | INCL. SEISMIC EFFECTS |
|---|---|---|---|---|
| MINIMUM SAFETY COEFFICIENT | F | : | 0.82 | 0.69 |
| AT CIRCLE CENTRE POINT | X | : | 60.00 | 64.00 |
| | Y | : | 16.00 | 12.00 |
| RADIUS | R | : | 28.00 | 24.00 |

PROJECT : MRBPSTS - MUNSHIGANJ
CASE (No.) : 01-Present Situation Cross Section 22

## SLICE DATA

CIRCLE CENTRE POINT X : 70.00
Y : 24.00
RADIUS R : 36.00
SAFETY COEFFICIENT F : 0.92
(including seismic effects)

| Slice No | Co-ord. of centre of slice boundary X | Y | Slice width m | Arc length m | Groundwater pressures hydro-static | over-pressure | total pressure | <----- Soil stresses -----> normal stress | effect. stress | shear stress |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 67.87 | -11.93 | 1.42 | 1.42 | 110.91 | 0.00 | 110.91 | 111.72 | 0.81 | 0.42 |
| 2 | 69.29 | -11.98 | 1.42 | 1.42 | 111.33 | 0.00 | 111.33 | 113.50 | 2.17 | 1.10 |
| 3 | 70.63 | -11.99 | 1.25 | 1.25 | 111.24 | 0.00 | 111.24 | 118.46 | 7.22 | 3.61 |
| 4 | 71.88 | -11.94 | 1.25 | 1.25 | 110.70 | 0.00 | 110.70 | 126.71 | 16.01 | 7.86 |
| 5 | 73.13 | -11.85 | 1.25 | 1.25 | 109.74 | 0.00 | 109.74 | 134.13 | 24.40 | 11.78 |
| 6 | 74.38 | -11.72 | 1.25 | 1.26 | 108.34 | 0.00 | 108.34 | 140.72 | 32.38 | 15.38 |
| 7 | 75.75 | -11.53 | 1.50 | 1.52 | 106.27 | 0.00 | 106.27 | 148.02 | 41.74 | 19.46 |
| 8 | 77.25 | -11.25 | 1.50 | 1.53 | 103.43 | 0.00 | 103.43 | 155.82 | 52.38 | 23.93 |
| 9 | 78.75 | -10.91 | 1.50 | 1.55 | 99.94 | 0.00 | 99.94 | 162.35 | 62.41 | 27.94 |
| 10 | 80.17 | -10.52 | 1.33 | 1.39 | 96.04 | 0.00 | 96.04 | 163.28 | 67.24 | 29.52 |
| 11 | 81.50 | -10.10 | 1.33 | 1.41 | 91.79 | 0.00 | 91.79 | 158.71 | 66.92 | 28.84 |
| 12 | 82.83 | -9.62 | 1.33 | 1.43 | 86.97 | 0.00 | 86.97 | 153.03 | 66.06 | 27.94 |
| 13 | 84.17 | -9.08 | 1.33 | 1.45 | 81.56 | 0.00 | 81.56 | 146.21 | 64.65 | 26.81 |
| 14 | 85.50 | -8.48 | 1.33 | 1.48 | 75.52 | 0.00 | 75.52 | 138.17 | 62.65 | 25.46 |
| 15 | 86.83 | -7.81 | 1.33 | 1.51 | 68.81 | 0.00 | 68.81 | 128.85 | 60.03 | 23.90 |
| 16 | 88.13 | -7.09 | 1.25 | 1.45 | 62.70 | 0.00 | 62.70 | 120.54 | 57.84 | 22.54 |
| 17 | 89.38 | -6.33 | 1.25 | 1.48 | 57.17 | 0.00 | 57.17 | 113.23 | 56.06 | 21.38 |
| 18 | 90.75 | -5.40 | 1.50 | 1.84 | 50.22 | 0.00 | 50.22 | 100.62 | 50.40 | 18.75 |
| 19 | 92.25 | -4.28 | 1.50 | 1.91 | 41.59 | 0.00 | 41.59 | 82.23 | 40.64 | 14.67 |
| 20 | 93.75 | -3.03 | 1.50 | 2.00 | 31.69 | 0.00 | 31.69 | 61.75 | 30.06 | 16.83 |
| 21 | 95.25 | -1.63 | 1.50 | 2.11 | 20.33 | 0.00 | 20.33 | 39.47 | 19.14 | 13.22 |
| 22 | 96.75 | -0.06 | 1.50 | 2.24 | 7.26 | -0.00 | 7.26 | 14.04 | 6.78 | 9.38 |
| 23 | 97.51 | 0.79 | 0.02 | 0.04 | 0.13 | 0.00 | 0.13 | 0.24 | 0.11 | 7.40 |

DRIVING MOMENT : 38102
COUNTER-ACTING MOMENT : 20365
MOMENT WATER ON SLOPE : 16367

(Units: m and kNm/m)

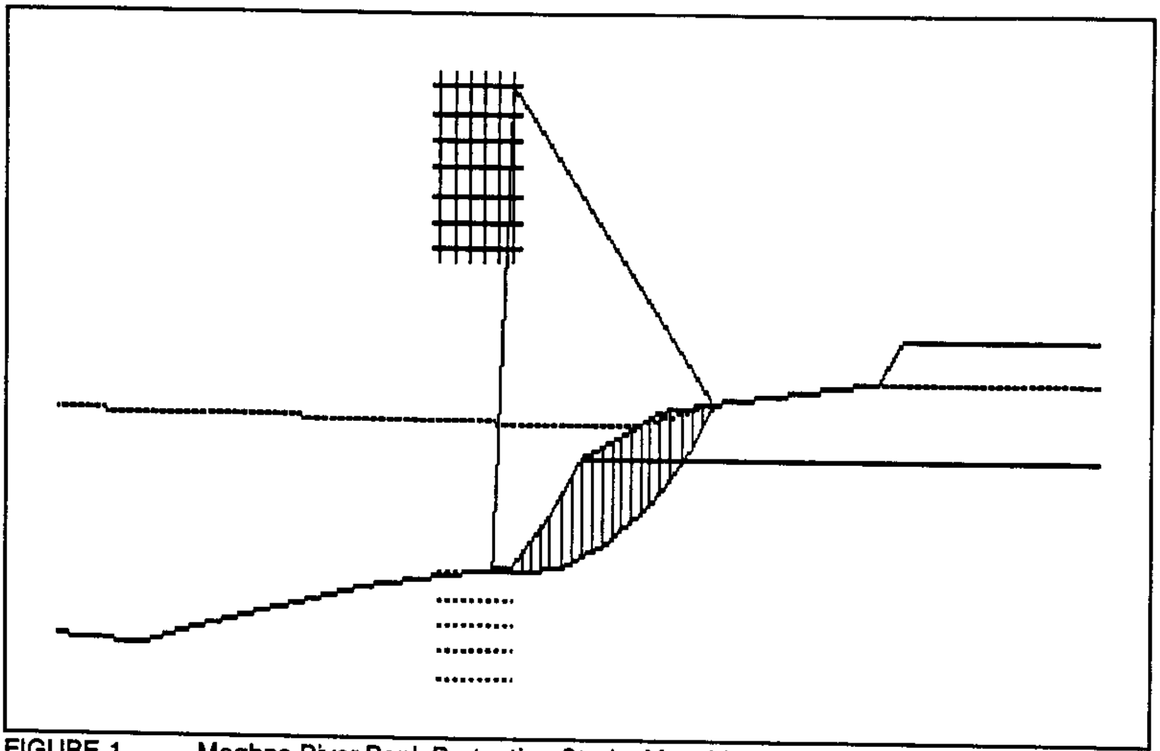

FIGURE 1. Meghna River Bank Protection Study. Munshiganj Town. Slope Stability Analyisis. Present Situation Cross Section 22.

# ***** SLOPE STABILITY *****

PROJECT : MRBPSTS - CHANDPUR
PROJECT No. : HASKONING/BANGLADESH
CASE (No.) : 01-Stability Analysis. Slope 1:3.5 (C/S-21)
DATE : 91-03-09

## INPUT DATA

### GEOMETRY POINTS:

| Point No. | Co-ordinates X | Co-ordinates Y | Point No. | Co-ordinates X | Co-ordinates Y |
|---|---|---|---|---|---|
| 1 | 0.00 | -50.00 | 7 | 280.00 | 6.00 |
| 2 | 33.00 | -50.00 | 8 | 280.00 | -20.00 |
| 3 | 103.00 | -30.00 | 9 | 280.00 | -30.00 |
| 4 | 138.00 | -20.00 | 10 | 0.00 | 0.00 |
| 5 | 208.00 | 0.00 | 11 | 221.50 | 4.50 |
| 6 | 228.00 | 6.00 | 12 | 280.00 | 4.50 |

### SOIL LAYER BOUNDARIES:

| Boundary No. | Geometry points: | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 | 1 | 2 | 3 | 4 | 8 | | |
| 3 | 1 | 2 | 3 | 9 | | | |

### PIEZOMETRIC LEVEL LINES:

| Line No. | Geometry points: | | | |
|---|---|---|---|---|
| 1 | 10 | 5 | 6 | 12 |

### SOIL PROPERTIES:

| Layer No. | Rho(dry) kN/m3 | Rho(wet) kN/m3 | Phi deg. | Cohesion kN/m2 | PL-line Nos top | PL-line Nos bottom |
|---|---|---|---|---|---|---|
| 1 | 19.00 | 19.00 | 27.0 | 0.00 | 1 | 1 |
| 2 | 19.00 | 19.00 | 25.0 | 0.00 | 1 | 1 |
| 3 | 19.00 | 19.00 | 27.0 | 0.00 | 1 | |

### SLIPCIRCLES:

| | | Min. | Step | Max. |
|---|---|---|---|---|
| - Grid of centre points: | X | 33.00 | 5.00 | 43.00 |
| | Y | 350.00 | 5.00 | 385.00 |
| - Lower tangent lines: | Y | -50.00 | 1.00 | -49.00 |

### SEISMIC FACTORS:

Horizontal seismic factor on soil is 0.050

PROJECT : MRBPSTS - CHANDPUR
CASE (No.) : 01-Stability Analysis. Slope 1:3.5 (C/S-21)

# RESULTS OF CALCULATION

| <------ SLIP-CIRCLES -----> | | | <---------- MOMENTS ---------> | | | <---------- SAFETY COEFFICIENTS ----------> | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRE POINT CO-ORDINATES | | RADIUS | COUNTER-ACTING | DRIVING | WATER ON SLOPE | EXCL.SEISMIC EFFECTS | | | INCL.SEISMIC EFFECTS | | |
| | | | | | | BEFORE ITER. | No of ITER. | AFTER ITER. | BEFORE ITER. | No of ITER. | AFTER ITER. |
| X | Y | m | kNm | kNm | kNm | | | | | | |
| 33.00 | 350.00 | 400.00 | 3799765 | 4547426 | 2192034 | 1.613 | 4 | 1.697 | | | |
| | | | 3799765 | 5348632 | 2192034 | | | | 1.204 | 4 | 1.231 |
| | | 399.00 | 3435666 | 4128468 | 1998747 | 1.613 | 4 | 1.697 | | | |
| | | | 3435666 | 4853655 | 1998747 | | | | 1.203 | 4 | 1.231 |
| 33.00 | 355.00 | 405.00 | 3934654 | 4696559 | 2253337 | 1.610 | 4 | 1.693 | | | |
| | | | 3934654 | 5526245 | 2253337 | | | | 1.202 | 4 | 1.229 |
| | | 404.00 | 3563243 | 4272099 | 2057622 | 1.609 | 4 | 1.692 | | | |
| | | | 3563243 | 5024199 | 2057622 | | | | 1.201 | 4 | 1.228 |
| 33.00 | 360.00 | 410.00 | 4070984 | 4845512 | 2314639 | 1.609 | 4 | 1.691 | | | |
| | | | 4070984 | 5703969 | 2314639 | | | | 1.201 | 4 | 1.228 |
| | | 409.00 | 3686037 | 4414069 | 2116083 | 1.604 | 4 | 1.686 | | | |
| | | | 3686037 | 5193156 | 2116083 | | | | 1.198 | 4 | 1.225 |
| 33.00 | 365.00 | 415.00 | 4209043 | 4994456 | 2375943 | 1.607 | 4 | 1.690 | | | |
| | | | 4209043 | 5882041 | 2375943 | | | | 1.200 | 4 | 1.227 |
| | | 414.00 | 3817170 | 4557953 | 2174958 | 1.602 | 4 | 1.684 | | | |
| | | | 3817170 | 5364757 | 2174958 | | | | 1.197 | 4 | 1.223 |
| 33.00 | 370.00 | 420.00 | 4348825 | 5143391 | 2437245 | 1.607 | 4 | 1.689 | | | |
| | | | 4348825 | 6060457 | 2437245 | | | | 1.200 | 4 | 1.227 |
| | | 419.00 | 3949611 | 4701628 | 2233832 | 1.600 | 4 | 1.682 | | | |
| | | | 3949611 | 5536412 | 2233832 | | | | 1.196 | 4 | 1.222 |
| 33.00 | 375.00 | 425.00 | 4490324 | 5292317 | 2498549 | 1.607 | 4 | 1.689 | | | |
| | | | 4490324 | 6239215 | 2498549 | | | | 1.200 | 4 | 1.227 |
| | | 424.00 | 4083723 | 4845295 | 2292708 | 1.600 | 4 | 1.681 | | | |
| | | | 4083723 | 5708401 | 2292708 | | | | 1.196 | 4 | 1.222 |
| 33.00 | 380.00 | 430.00 | 4633531 | 5441235 | 2559851 | 1.608 | 4 | 1.690 | | | |
| | | | 4633531 | 6418314 | 2559851 | | | | 1.201 | 4 | 1.228 |
| | | 429.00 | 4219498 | 4988955 | 2351582 | 1.600 | 4 | 1.681 | | | |
| | | | 4219498 | 5880723 | 2351582 | | | | 1.196 | 4 | 1.222 |
| 33.00 | 385.00 | 435.00 | 4801903 | 5590144 | 2621154 | 1.617 | 4 | 1.700 | | | |
| | | | 4801903 | 6597751 | 2621154 | | | | 1.208 | 4 | 1.235 |
| | | 434.00 | 4356929 | 5132606 | 2410457 | 1.601 | 4 | 1.681 | | | |
| | | | 4356929 | 6053374 | 2410457 | | | | 1.196 | 4 | 1.222 |
| 38.00 | 350.00 | 400.00 | 4281070 | 5055374 | 2400505 | 1.613 | 4 | 1.695 | | | |
| | | | 4281070 | 5955532 | 2400505 | | | | 1.204 | 4 | 1.231 |
| | | 399.00 | 3899983 | 4634745 | 2206826 | 1.606 | 4 | 1.688 | | | |
| | | | 3899983 | 5456705 | 2206826 | | | | 1.200 | 4 | 1.227 |
| 38.00 | 355.00 | 405.00 | 4444099 | 5204301 | 2461807 | 1.620 | 4 | 1.704 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 4444099 | 6134187 | 2461807 | | | | 1.210 | 4 | 1.238 |
| | | 404.00 | 4033847 | 4778415 | 2265701 | 1.605 | 4 | 1.687 | | | |
| | | | 4033847 | 5628606 | 2265701 | | | | 1.200 | 4 | 1.226 |
| 38.00 | 360.00 | 410.00 | 4587677 | 5353218 | 2523110 | 1.621 | 4 | 1.705 | | | |
| | | | 4587677 | 6313189 | 2523110 | | | | 1.210 | 4 | 1.238 |
| | | 409.00 | 4169408 | 4922075 | 2324576 | 1.605 | 4 | 1.687 | | | |
| | | | 4169408 | 5800846 | 2324576 | | | | 1.199 | 4 | 1.226 |
| 38.00 | 365.00 | 415.00 | 4732994 | 5502126 | 2584412 | 1.622 | 4 | 1.706 | | | |
| | | | 4732994 | 6492537 | 2584412 | | | | 1.211 | 4 | 1.239 |
| | | 414.00 | 4306663 | 5065726 | 2383450 | 1.606 | 4 | 1.687 | | | |
| | | | 4306663 | 5973423 | 2383450 | | | | 1.200 | 4 | 1.226 |
| 38.00 | 370.00 | 420.00 | 4859856 | 5651024 | 2645715 | 1.617 | 4 | 1.699 | | | |
| | | | 4859858 | 6672229 | 2645715 | | | | 1.207 | 4 | 1.234 |
| | | 419.00 | 4445601 | 5209368 | 2442325 | 1.607 | 4 | 1.688 | | | |
| | | | 4445601 | 6146334 | 2442325 | | | | 1.200 | 4 | 1.227 |
| 38.00 | 375.00 | 425.00 | 5007856 | 5799914 | 2707018 | 1.619 | 4 | 1.701 | | | |
| | | | 5007856 | 6852261 | 2707018 | | | | 1.208 | 4 | 1.235 |
| | | 424.00 | 4609197 | 5353002 | 2501200 | 1.616 | 4 | 1.699 | | | |
| | | | 4609197 | 6319579 | 2501200 | | | | 1.207 | 4 | 1.235 |
| 38.00 | 380.00 | 430.00 | 5158333 | 5949151 | 2768321 | 1.622 | 4 | 1.704 | | | |
| | | | 5158333 | 7033160 | 2768321 | | | | 1.210 | 4 | 1.237 |
| | | 429.00 | 4752116 | 5496628 | 2560075 | 1.618 | 4 | 1.701 | | | |
| | | | 4752116 | 6493155 | 2560075 | | | | 1.208 | 4 | 1.236 |
| 36.00 | 385.00 | 435.00 | 5309893 | 6098077 | 2829622 | 1.625 | 4 | 1.707 | | | |
| | | | 5309893 | 7213952 | 2829622 | | | | 1.211 | 4 | 1.239 |
| | | 434.00 | 4676345 | 5640555 | 2618949 | 1.614 | 4 | 1.695 | | | |
| | | | 4676345 | 6667521 | 2618949 | | | | 1.204 | 4 | 1.231 |
| 43.00 | 350.00 | 400.00 | 4767944 | 5536482 | 2596758 | 1.622 | 4 | 1.704 | | | |
| | | | 4767944 | 6535359 | 2596758 | | | | 1.211 | 4 | 1.238 |
| | | 399.00 | 4394567 | 5116400 | 2403329 | 1.620 | 4 | 1.703 | | | |
| | | | 4394567 | 6035292 | 2403329 | | | | 1.210 | 4 | 1.238 |
| 43.00 | 355.00 | 405.00 | 4915615 | 5665368 | 2658060 | 1.624 | 4 | 1.706 | | | |
| | | | 4915615 | 6715282 | 2658060 | | | | 1.212 | 4 | 1.239 |
| | | 404.00 | 4516445 | 5260033 | 2462203 | 1.614 | 4 | 1.696 | | | |
| | | | 4516445 | 6208444 | 2462203 | | | | 1.206 | 4 | 1.233 |
| 43.00 | 360.00 | 410.00 | 5065778 | 5834615 | 2719362 | 1.626 | 4 | 1.708 | | | |
| | | | 5065778 | 6896088 | 2719362 | | | | 1.213 | 4 | 1.241 |
| | | 409.00 | 4658381 | 5403656 | 2521077 | 1.616 | 4 | 1.698 | | | |
| | | | 4658381 | 6381935 | 2521077 | | | | 1.207 | 4 | 1.234 |
| 43.00 | 365.00 | 415.00 | 5217086 | 5983540 | 2780665 | 1.629 | 4 | 1.711 | | | |
| | | | 5217086 | 7076792 | 2780665 | | | | 1.214 | 4 | 1.242 |
| | | 414.00 | 4802015 | 5547269 | 2579952 | 1.618 | 4 | 1.700 | | | |
| | | | 4802015 | 6555760 | 2579952 | | | | 1.208 | 4 | 1.235 |
| 43.00 | 370.00 | 420.00 | 5370145 | 6132460 | 2841966 | 1.632 | 4 | 1.714 | | | |
| | | | 5370145 | 7257847 | 2841966 | | | | 1.216 | 4 | 1.244 |
| | | 419.00 | 4948142 | 5691250 | 2638827 | 1.621 | 4 | 1.703 | | | |
| | | | 4948142 | 6730474 | 2638827 | | | | 1.209 | 4 | 1.237 |
| 43.00 | 375.00 | 425.00 | 5524949 | 6281375 | 2903269 | 1.636 | 4 | 1.718 | | | |
| | | | 5524949 | 7439246 | 2903269 | | | | 1.218 | 4 | 1.246 |
| | | 424.00 | 5095296 | 5834902 | 2697702 | 1.624 | 4 | 1.706 | | | |
| | | | 5095296 | 6905053 | 2697702 | | | | 1.211 | 4 | 1.238 |
| 43.00 | 380.00 | 430.00 | 5681489 | 6430285 | 2964570 | 1.639 | 4 | 1.722 | | | |
| | | | 5681489 | 7620995 | 2964570 | | | | 1.220 | 4 | 1.248 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 429.00 | 5244142 | 5978550 | 2756576 | 1.628 | 4 | 1.709 | | | |
| | | | 5244142 | 7079969 | 2756576 | | | | 1.213 | 4 | 1.240 |
| 43.00 | 385.00 | 435.00 | 5867121 | 6579191 | 3025873 | 1.651 | 4 | 1.736 | | | |
| | | | 5867121 | 7803085 | 3025873 | | | | 1.228 | 4 | 1.257 |
| | | 434.00 | 5394671 | 6122194 | 2815451 | 1.631 | 4 | 1.713 | | | |
| | | | 5394671 | 7255220 | 2815451 | | | | 1.215 | 4 | 1.243 |

PROJECT : MRBPSTS - CHANDPUR
CASE (No.) : 01-Stability Analysis. Slope 1:3.5 (C/S-21)

## MINIMUM SAFETY COEFFICIENTS

| CENTRE POINT CO-ORDINATES | | EXCL. SEISMIC EFFECTS | | INCL. SEISMIC EFFECTS | |
|---|---|---|---|---|---|
| X | Y | RADIUS m | SAFETY COEFF. | RADIUS m | SAFETY COEFF. |
| 33.00 | 350.00 | 400.00 | 1.697 | 399.00 | 1.231 |
| 33.00 | 355.00 | 404.00 | 1.692 | 404.00 | 1.228 |
| 33.00 | 360.00 | 409.00 | 1.686 | 409.00 | 1.225 |
| 33.00 | 365.00 | 414.00 | 1.684 | 414.00 | 1.223 |
| 33.00 | 370.00 | 419.00 | 1.682 | 419.00 | 1.222 |
| 33.00 | 375.00 | 424.00 | 1.681 | 424.00 | 1.222 |
| 33.00 | 380.00 | 429.00 | 1.681 | 429.00 | 1.222 |
| 33.00 | 385.00 | 434.00 | 1.681 | 434.00 | 1.222 |
| 38.00 | 350.00 | 399.00 | 1.688 | 399.00 | 1.227 |
| 38.00 | 355.00 | 404.00 | 1.687 | 404.00 | 1.226 |
| 38.00 | 360.00 | 409.00 | 1.687 | 409.00 | 1.226 |
| 38.00 | 365.00 | 414.00 | 1.687 | 414.00 | 1.226 |
| 38.00 | 370.00 | 419.00 | 1.688 | 419.00 | 1.227 |
| 38.00 | 375.00 | 424.00 | 1.699 | 424.00 | 1.235 |
| 38.00 | 380.00 | 429.00 | 1.701 | 429.00 | 1.236 |
| 38.00 | 385.00 | 434.00 | 1.695 | 434.00 | 1.231 |
| 43.00 | 350.00 | 399.00 | 1.703 | 399.00 | 1.238 |
| 43.00 | 355.00 | 404.00 | 1.696 | 404.00 | 1.233 |
| 43.00 | 360.00 | 409.00 | 1.698 | 409.00 | 1.234 |
| 43.00 | 365.00 | 414.00 | 1.700 | 414.00 | 1.235 |
| 43.00 | 370.00 | 419.00 | 1.703 | 419.00 | 1.237 |
| 43.00 | 375.00 | 424.00 | 1.706 | 424.00 | 1.238 |
| 43.00 | 380.00 | 429.00 | 1.709 | 429.00 | 1.240 |
| 43.00 | 385.00 | 434.00 | 1.713 | 434.00 | 1.243 |

| | | EXCL. SEISMIC EFFECTS | INCL. SEISMIC EFFECTS |
|---|---|---|---|
| MINIMUM SAFETY COEFFICIENT | F : | 1.68 | 1.22 |
| AT CIRCLE CENTRE POINT | X : | 33.00 | 33.00 |
| | Y : | 380.00 | 380.00 |
| RADIUS | R : | 429.00 | 429.00 |

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PROJECT : MRBPSTS - CHANDPUR
CASE (No.) : 01-Stability Analysis. Slope 1:3.5 (C/S-21)

## SLICE DATA

CIRCLE CENTRE POINT X : 33.00
Y : 380.00
RADIUS R : 429.00
SAFETY COEFFICIENT F : 1.22
(including seismic effects)

| Slice No | Co-ord. of centre of slice boundary X | Y | Slice width m | Arc length m | Groundwater pressures hydro-static | over-pressure | total pressure | <----- Soil stresses -----> normal stress | effect. stress | shear stress |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 41.31 | -48.89 | 9.49 | 9.49 | 479.60 | 0.00 | 479.60 | 491.22 | 11.61 | 4.81 |
| 2 | 50.80 | -48.60 | 9.49 | 9.50 | 476.77 | 0.00 | 476.77 | 510.65 | 33.88 | 13.89 |
| 3 | 60.29 | -48.10 | 9.49 | 9.51 | 471.87 | 0.00 | 471.87 | 526.07 | 54.21 | 22.02 |
| 4 | 69.78 | -47.39 | 9.49 | 9.53 | 464.89 | 0.00 | 464.89 | 537.48 | 72.59 | 29.23 |
| 5 | 79.27 | -46.47 | 9.49 | 9.55 | 455.83 | 0.00 | 455.83 | 544.86 | 89.03 | 35.52 |
| 6 | 88.76 | -45.33 | 9.49 | 9.57 | 444.68 | 0.00 | 444.68 | 548.18 | 103.50 | 40.93 |
| 7 | 98.25 | -43.98 | 9.49 | 9.60 | 431.41 | 0.00 | 431.41 | 547.40 | 115.99 | 45.46 |
| 8 | 107.38 | -42.48 | 8.75 | 8.88 | 416.69 | 0.00 | 416.69 | 542.84 | 126.14 | 49.01 |
| 9 | 116.13 | -40.84 | 8.75 | 8.92 | 400.66 | 0.00 | 400.66 | 534.76 | 134.10 | 51.67 |
| 10 | 124.88 | -39.02 | 8.75 | 8.96 | 382.77 | 0.00 | 382.77 | 523.09 | 140.32 | 53.62 |
| 11 | 133.63 | -37.00 | 8.75 | 9.00 | 363.00 | 0.00 | 363.00 | 507.78 | 144.77 | 54.86 |
| 12 | 143.00 | -34.62 | 10.00 | 10.35 | 339.63 | 0.00 | 339.63 | 487.13 | 147.50 | 55.39 |
| 13 | 153.00 | -31.84 | 10.00 | 10.42 | 312.33 | 0.00 | 312.33 | 460.51 | 148.18 | 55.10 |
| 14 | 163.00 | -28.79 | 10.00 | 10.49 | 282.44 | 0.00 | 282.44 | 428.87 | 146.43 | 49.84 |
| 15 | 173.00 | -25.47 | 10.00 | 10.58 | 249.91 | 0.00 | 249.91 | 392.12 | 142.21 | 47.96 |
| 16 | 183.00 | -21.88 | 10.00 | 10.67 | 214.66 | 0.00 | 214.66 | 350.11 | 135.45 | 45.25 |
| 17 | 193.00 | -18.01 | 10.00 | 10.78 | 176.64 | 0.00 | 176.64 | 302.72 | 126.09 | 45.03 |
| 18 | 203.00 | -13.84 | 10.00 | 10.89 | 135.75 | 0.00 | 135.75 | 249.78 | 114.04 | 40.30 |
| 19 | 213.00 | -9.37 | 10.00 | 11.02 | 106.61 | 0.00 | 106.61 | 206.49 | 99.87 | 34.92 |
| 20 | 223.00 | -4.59 | 10.00 | 11.15 | 89.13 | 0.00 | 89.13 | 172.64 | 83.50 | 28.88 |
| 21 | 231.79 | -0.14 | 7.57 | 8.55 | 59.12 | 0.00 | 59.12 | 116.58 | 57.46 | 19.67 |
| 22 | 239.36 | 3.92 | 7.57 | 8.64 | 17.17 | 0.00 | 17.17 | 39.48 | 22.31 | 7.57 |

DRIVING MOMENT : 5880723
COUNTER-ACTING MOMENT : 4219498
MOMENT WATER ON SLOPE : 2351582

(Units: m and kNm/m)

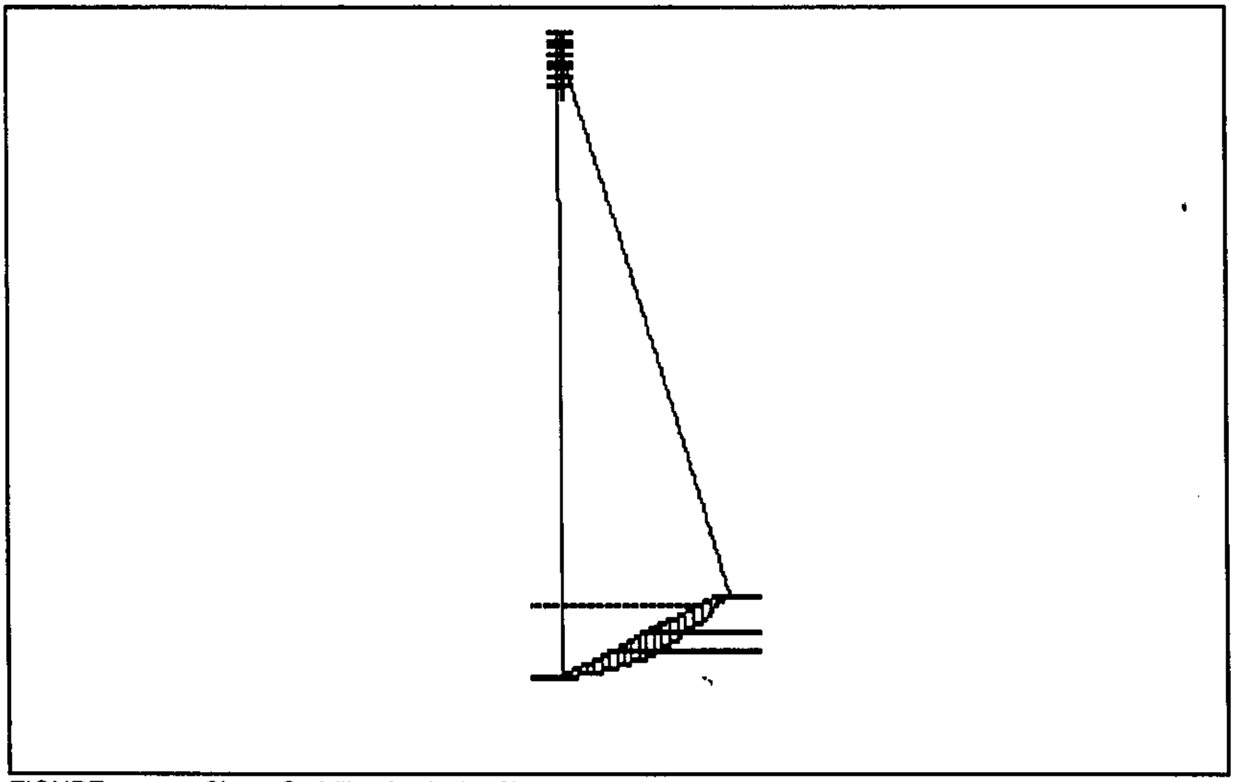

FIGURE . Slope Stability Analysis. Slope 1:3.5
Chandpur Town Protection.

***** SLOPE STABILITY *****

PROJECT : MRBPSTS - CHANDPUR
PROJECT No. : HASKONING/BANGLADESH
CASE (No.) : Present Situation/Cross Section 21 (alt3)
DATE : 91-09-02

## INPUT DATA

### GEOMETRY POINTS:

| Point No. | X | Y |
|---|---|---|
| 1 | 0.00 | -50.00 |
| 2 | 47.00 | -50.00 |
| 3 | 65.50 | -45.00 |
| 4 | 96.50 | -40.00 |
| 5 | 128.00 | -35.00 |
| 6 | 136.00 | -30.00 |
| 7 | 150.00 | -25.00 |
| 8 | 162.00 | -20.00 |
| 9 | 172.00 | -15.00 |
| 10 | 183.00 | -10.00 |
| 11 | 191.50 | -5.00 |
| 12 | 197.50 | 0.00 |
| 13 | 204.00 | 6.00 |
| 14 | 230.00 | 6.00 |
| 15 | 230.00 | -20.00 |
| 16 | 230.00 | -30.00 |
| 17 | 0.00 | 0.00 |
| 18 | 211.00 | 4.50 |
| 19 | 230.00 | 4.50 |

### SOIL LAYER BOUNDARIES:

| Boundary No. | Geometry points: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | 11 | 12 | 13 | 14 | | | | | | |
| 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 15 | |
| 3 | 1 | 2 | 3 | 4 | 5- | 6 | 16 | | | |

### PIEZOMETRIC LEVEL LINES:

| Line No. | Geometry points: | | | |
|---|---|---|---|---|
| 1 | 17 | 12 | 18 | 19 |

### SOIL PROPERTIES:

| Layer No. | Rho(dry) kN/m3 | Rho(wet) kN/m3 | Phi deg. | Cohesion kN/m2 | PL-line Nos top | PL-line Nos bottom |
|---|---|---|---|---|---|---|
| 1 | 19.00 | 19.00 | 27.0 | 0.00 | 1 | 1 |
| 2 | 19.00 | 19.00 | 25.0 | 0.00 | 1 | 1 |
| 3 | 19.00 | 19.00 | 27.0 | 0.00 | 1 | |

### SLIPCIRCLES:

| | | Min. | Step | Max. |
|---|---|---|---|---|
| - Grid of centre points: | X | 110.00 | 2.00 | 126.00 |
| | Y | 70.00 | 2.00 | 72.00 |
| - Lower tangent lines: | Y | -40.00 | 2.00 | -30.00 |

### SEISMIC FACTORS:

Horizontal seismic factor on soil is 0.050

PROJECT : MRBPSTS - CHANDPUR
CASE (No.) : Present Situation/Cross Section 21 (alt3)

# RESULTS OF CALCULATION

| <------ SLIP-CIRCLES -----> | | | <---------- MOMENTS ---------> | | | <---------- SAFETY COEFFICIENTS ----------> | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRE POINT CO-ORDINATES | | RADIUS | COUNTER-ACTING | DRIVING | WATER ON SLOPE | EXCL.SEISMIC EFFECTS | | | INCL.SEISMIC EFFECTS | | |
| | | | | | | BEFORE ITER. | No of ITER. | AFTER ITER. | BEFORE ITER. | No of ITER. | AFTER ITER. |
| X | Y | m | kNm | kNm | kNm | | | | | | |
| 110.00 | 70.00 | 110.00 | 193024 | 308215 | 159202 | 1.295 | 4 | 1.349 | | | |
| | | | 193024 | 347093 | 159202 | | | | 1.027 | 3 | 1.032 |
| | | 108.00 | 106938 | 182781 | 94413 | 1.210 | 4 | 1.251 | | | |
| | | | 106938 | 204805 | 94413 | | | | 0.969 | 3 | 0.964 |
| | | 106.00 | 46455 | 83490 | 43109 | 1.150 | 4 | 1.180 | | | |
| | | | 46455 | 93319 | 43109 | | | | 0.925 | 4 | 0.911 |
| | | 104.00 | 9554 | 16443 | 8490 | 1.201 | 4 | 1.237 | | | |
| | | | 9554 | 18576 | 8490 | | | | 0.947 | 4 | 0.938 |
| | | 102.00 | Circle doesn't intersect slope | | | | | | | | |
| | | 100.00 | Circle doesn't intersect slope | | | | | | | | |
| 110.00 | 72.00 | 112.00 | 206278 | 330268 | 170620 | 1.292 | 4 | 1.346 | | | |
| | | | 206278 | 371564 | 170620 | | | | 1.027 | 3 | 1.031 |
| | | 110.00 | 115236 | 197620 | 102080 | 1.206 | 4 | 1.246 | | | |
| | | | 115236 | 221328 | 102080 | | | | 0.966 | 3 | 0.961 |
| | | 108.00 | 51700 | 93345 | 48197 | 1.145 | 4 | 1.174 | | | |
| | | | 51700 | 104277 | 48197 | | | | 0.922 | 4 | 0.907 |
| | | 106.00 | 11904 | 20673 | 10675 | 1.191 | 4 | 1.225 | | | |
| | | | 11904 | 23319 | 10675 | | | | 0.941 | 4 | 0.931 |
| | | 104.00 | Circle doesn't intersect slope | | | | | | | | |
| | | 102.00 | Circle doesn't intersect slope | | | | | | | | |
| 112.00 | 70.00 | 110.00 | 225546 | 365975 | 189089 | 1.275 | 4 | 1.327 | | | |
| | | | 225546 | 410903 | 189089 | | | | 1.017 | 3 | 1.019 |
| | | 108.00 | 133033 | 227991 | 117763 | 1.207 | 4 | 1.247 | | | |
| | | | 133033 | 255138 | 117763 | | | | 0.968 | 3 | 0.963 |
| | | 106.00 | 65684 | 118481 | 61179 | 1.146 | 4 | 1.176 | | | |
| | | | 65684 | 132212 | 61179 | | | | 0.925 | 4 | 0.910 |
| | | 104.00 | 21566 | 38231 | 19741 | 1.166 | 4 | 1.198 | | | |
| | | | 21566 | 42930 | 19741 | | | | 0.930 | 4 | 0.917 |
| | | 102.00 | Circle doesn't intersect slope | | | | | | | | |
| | | 100.00 | Circle doesn't intersect slope | | | | | | | | |
| 112.00 | 72.00 | 112.00 | 240933 | 395714 | 204292 | 1.259 | 4 | 1.308 | | | |
| | | | 240933 | 443549 | 204292 | | | | 1.007 | 3 | 1.008 |
| | | 110.00 | 142939 | 246228 | 127191 | 1.201 | 4 | 1.240 | | | |
| | | | 142939 | 275352 | 127191 | | | | 0.965 | 4 | 0.958 |
| | | 108.00 | 71837 | 130230 | 67249 | 1.141 | 4 | 1.169 | | | |
| | | | 71837 | 145272 | 67249 | | | | 0.921 | 4 | 0.905 |
| | | 106.00 | 25199 | 45180 | 23330 | 1.153 | 4 | 1.183 | | | |
| | | | 25199 | 50664 | 23330 | | | | 0.922 | 4 | 0.907 |
| | | 104.00 | Circle doesn't intersect slope | | | | | | | | |
| | | 102.00 | Circle doesn't intersect slope | | | | | | | | |
| 114.00 | 70.00 | 110.00 | 265520 | 439393 | 224587 | 1.236 | 4 | 1.283 | | | |
| | | | 265520 | 491152 | 224587 | | | | 0.996 | 2 | 0.996 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 108.00 | 162002 | 279318 | 144264 | 1.200 | 4 | 1.239 | | | |
| | | | 162002 | 312015 | 144264 | | | | 0.966 | 4 | 0.959 |
| | | 106.00 | 87171 | 157297 | 81230 | 1.146 | 4 | 1.176 | | | |
| | | | 87171 | 175337 | 81230 | | | | 0.926 | 4 | 0.912 |
| | | 104.00 | 36870 | 66592 | 34386 | 1.145 | 4 | 1.173 | | | |
| | | | 36870 | 74509 | 34386 | | | | 0.919 | 4 | 0.903 |
| | | 102.00 | 3102 | 5478 | 2829 | 1.171 | 4 | 1.201 | | | |
| | | | 3102 | 6180 | 2829 | | | | 0.925 | 4 | 0.912 |
| | | 100.00 | Circle doesn't intersect slope | | | | | | | | |
| 114.00 | 72.00 | 112.00 | 286803 | 479152 | 240275 | 1.201 | 4 | 1.242 | | | |
| | | | 286803 | 534374 | 240275 | | | | 0.975 | 3 | 0.971 |
| | | 110.00 | 173513 | 302938 | 156497 | 1.185 | 4 | 1.222 | | | |
| | | | 173513 | 337993 | 156497 | | | | 0.956 | 4 | 0.947 |
| | | 108.00 | 94923 | 171716 | 88675 | 1.143 | 4 | 1.172 | | | |
| | | | 94923 | 191322 | 88675 | | | | 0.925 | 4 | 0.910 |
| | | 106.00 | 41635 | 75443 | 38959 | 1.141 | 4 | 1.169 | | | |
| | | | 41635 | 84354 | 38959 | | | | 0.917 | 4 | 0.901 |
| | | 104.00 | 4833 | 8647 | 4465 | 1.156 | 4 | 1.184 | | | |
| | | | 4833 | 9732 | 4465 | | | | 0.918 | 4 | 0.903 |
| | | 102.00 | Circle doesn't intersect slope | | | | | | | | |
| 116.00 | 70.00 | 110.00 | 313294 | 525451 | 259136 | 1.176 | 4 | 1.214 | | | |
| | | | 313294 | 584638 | 259136 | | | | 0.962 | 4 | 0.955 |
| | | 108.00 | 196741 | 344066 | 176920 | 1.177 | 4 | 1.213 | | | |
| | | | 196741 | 383030 | 176920 | | | | 0.955 | 4 | 0.945 |
| | | 106.00 | 111538 | 202366 | 104510 | 1.140 | 4 | 1.168 | | | |
| | | | 111538 | 225284 | 104510 | | | | 0.924 | 4 | 0.908 |
| | | 104.00 | 54898 | 99156 | 51207 | 1.145 | 4 | 1.174 | | | |
| | | | 54898 | 110739 | 51207 | | | | 0.922 | 4 | 0.907 |
| | | 102.00 | 13494 | 24622 | 12714 | 1.133 | 4 | 1.159 | | | |
| | | | 13494 | 27589 | 12714 | | | | 0.907 | 4 | 0.890 |
| | | 100.00 | Circle doesn't intersect slope | | | | | | | | |
| 116.00 | 72.00 | 112.00 | 335108 | 565593 | 274792 | 1.152 | 4 | 1.185 | | | |
| | | | 335108 | 628411 | 274792 | | | | 0.948 | 4 | 0.937 |
| | | 110.00 | 214673 | 378075 | 191039 | 1.148 | 4 | 1.179 | | | |
| | | | 214673 | 419978 | 191039 | | | | 0.938 | 4 | 0.925 |
| | | 108.00 | 120951 | 220379 | 113818 | 1.135 | 4 | 1.163 | | | |
| | | | 120951 | 245167 | 113818 | | | | 0.921 | 4 | 0.905 |
| | | 106.00 | 60499 | 109921 | 56762 | 1.138 | 4 | 1.166 | | | |
| | | | 60499 | 122706 | 56762 | | | | 0.917 | 4 | 0.901 |
| | | 104.00 | 16706 | 30666 | 15835 | 1.126 | 4 | 1.151 | | | |
| | | | 16706 | 34314 | 15835 | | | | 0.904 | 4 | 0.885 |
| | | 102.00 | Circle doesn't intersect slope | | | | | | | | |
| 118.00 | 70.00 | 110.00 | 358686 | 608461 | 292163 | 1.134 | 4 | 1.163 | | | |
| | | | 358686 | 675035 | 292163 | | | | 0.937 | 4 | 0.923 |
| | | 108.00 | 240019 | 424926 | 210184 | 1.118 | 4 | 1.143 | | | |
| | | | 240019 | 470928 | 210184 | | | | 0.921 | 4 | 0.904 |
| | | 106.00 | 140392 | 257279 | 132883 | 1.129 | 4 | 1.155 | | | |
| | | | 140392 | 285727 | 132883 | | | | 0.919 | 4 | 0.902 |
| | | 104.00 | 75314 | 136635 | 70564 | 1.140 | 4 | 1.168 | | | |
| | | | 75314 | 152348 | 70564 | | | | 0.921 | 4 | 0.905 |
| | | 102.00 | 27489 | 50606 | 26132 | 1.123 | 4 | 1.148 | | | |
| | | | 27489 | 56552 | 26132 | | | | 0.904 | 4 | 0.885 |
| | | 100.00 | Circle doesn't intersect slope | | | | | | | | |
| 118.00 | 72.00 | 112.00 | 381928 | 648536 | 307845 | 1.121 | 4 | 1.148 | | | |
| | | | 381928 | 718921 | 307845 | | | | 0.929 | 4 | 0.914 |
| | | 110.00 | 260354 | 461732 | 224346 | 1.097 | 4 | 1.118 | | | |
| | | | 260354 | 510954 | 224346 | | | | 0.908 | 4 | 0.888 |
| | | 108.00 | 154678 | 285259 | 145594 | 1.107 | 4 | 1.131 | | | |
| | | | 154678 | 316167 | 145594 | | | | 0.907 | 4 | 0.887 |
| | | 106.00 | 82739 | 150779 | 77867 | 1.135 | 4 | 1.162 | | | |
| | | | 82739 | 167987 | 77867 | | | | 0.918 | 4 | 0.902 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 104.00 | 31711 | 58492 | 30206 | 1.121 | 4 | 1.145 | | | |
| | | | 31711 | 65321 | 30206 | | | | 0.903 | 4 | 0.884 |
| | | 102.00 | 477 | 902 | 466 | 1.093 | 4 | 1.111 | | | |
| | | | 477 | 1008 | 466 | | | | 0.878 | 4 | 0.855 |
| 120.00 | 70.00 | 110.00 | 406057 | 688330 | 323731 | 1.114 | 4 | 1.139 | | | |
| | | | 406057 | 762289 | 323731 | | | | 0.926 | 4 | 0.910 |
| | | 108.00 | 285843 | 505224 | 242024 | 1.086 | 4 | 1.106 | | | |
| | | | 285843 | 558354 | 242024 | | | | 0.904 | 4 | 0.882 |
| | | 106.00 | 179972 | 331184 | 164718 | 1.081 | 4 | 1.099 | | | |
| | | | 179972 | 366138 | 164718 | | | | 0.894 | 4 | 0.870 |
| | | 104.00 | 98978 | 181928 | 93960 | 1.125 | 4 | 1.151 | | | |
| | | | 98978 | 202367 | 93960 | | | | 0.913 | 4 | 0.895 |
| | | 102.00 | 43996 | 80961 | 41809 | 1.124 | 4 | 1.149 | | | |
| | | | 43996 | 90346 | 41809 | | | | 0.906 | 4 | 0.888 |
| | | 100.00 | 6900 | 13274 | 6854 | 1.075 | 4 | 1.091 | | | |
| | | | 6900 | 14761 | 6854 | | | | 0.873 | 5 | 0.845 |
| 120.00 | 72.00 | 112.00 | 429252 | 728466 | 339410 | 1.103 | 4 | 1.126 | | | |
| | | | 429252 | 806414 | 339410 | | | | 0.919 | 4 | 0.902 |
| | | 110.00 | 306394 | 541934 | 256185 | 1.072 | 4 | 1.089 | | | |
| | | | 306394 | 598444 | 256185 | | | | 0.895 | 4 | 0.872 |
| | | 108.00 | 198056 | 364728 | 177429 | 1.057 | 4 | 1.071 | | | |
| | | | 198056 | 402520 | 177429 | | | | 0.880 | 5 | 0.852 |
| | | 106.00 | 109733 | 203131 | 104738 | 1.115 | 4 | 1.140 | | | |
| | | | 109733 | 225529 | 104738 | | | | 0.908 | 4 | 0.889 |
| | | 104.00 | 49308 | 91269 | 47132 | 1.117 | 4 | 1.141 | | | |
| | | | 49308 | 101774 | 47132 | | | | 0.902 | 4 | 0.883 |
| | | 102.00 | 9511 | 18279 | 9438 | 1.076 | 4 | 1.092 | | | |
| | | | 9511 | 20317 | 9438 | | | | 0.874 | 5 | 0.847 |
| 122.00 | 70.00 | 110.00 | 449108 | 764736 | 353825 | 1.093 | 4 | 1.114 | | | |
| | | | 449108 | 846036 | 353825 | | | | 0.912 | 4 | 0.894 |
| | | 108.00 | 328518 | 582310 | 272406 | 1.060 | 4 | 1.074 | | | |
| | | | 328518 | 642552 | 272406 | | | | 0.888 | 5 | 0.861 |
| | | 106.00 | 222770 | 408475 | 195229 | 1.045 | 4 | 1.055 | | | |
| | | | 222770 | 450210 | 195229 | | | | 0.874 | 5 | 0.844 |
| | | 104.00 | 131911 | 245711 | 123557 | 1.080 | 4 | 1.098 | | | |
| | | | 131911 | 271900 | 123557 | | | | 0.889 | 4 | 0.865 |
| | | 102.00 | 63687 | 118004 | 60947 | 1.116 | 4 | 1.140 | | | |
| | | | 63687 | 131395 | 60947 | | | | 0.904 | 4 | 0.885 |
| | | 100.00 | 19010 | 36179 | 18682 | 1.086 | 4 | 1.105 | | | |
| | | | 19010 | 40240 | 18682 | | | | 0.882 | 4 | 0.857 |
| 122.00 | 72.00 | 112.00 | 471905 | 804951 | 369500 | 1.084 | 4 | 1.102 | | | |
| | | | 471905 | 890419 | 369500 | | | | 0.906 | 4 | 0.886 |
| | | 110.00 | 349156 | 619060 | 286566 | 1.050 | 4 | 1.062 | | | |
| | | | 349156 | 682853 | 286566 | | | | 0.881 | 5 | 0.853 |
| | | 108.00 | 240710 | 441807 | 207885 | 1.029 | 4 | 1.036 | | | |
| | | | 240710 | 486523 | 207885 | | | | 0.864 | 5 | 0.831 |
| | | 106.00 | 147714 | 276126 | 134893 | 1.046 | 4 | 1.056 | | | |
| | | | 147714 | 304616 | 134893 | | | | 0.869 | 5 | 0.839 |
| | | 104.00 | 70965 | 132444 | 68406 | 1.108 | 4 | 1.131 | | | |
| | | | 70965 | 147264 | 68406 | | | | 0.900 | 4 | 0.879 |
| | | 102.00 | 22627 | 43072 | 22243 | 1.086 | 4 | 1.105 | | | |
| | | | 22627 | 47894 | 22243 | | | | 0.882 | 4 | 0.858 |
| 124.00 | 70.00 | 110.00 | 494927 | 837949 | 382454 | 1.087 | 4 | 1.106 | | | |
| | | | 494927 | 926564 | 382454 | | | | 0.910 | 4 | 0.890 |
| | | 108.00 | 372697 | 655976 | 301337 | 1.051 | 4 | 1.063 | | | |
| | | | 372697 | 723293 | 301337 | | | | 0.883 | 5 | 0.856 |
| | | 106.00 | 264016 | 482463 | 224273 | 1.023 | 3 | 1.027 | | | |
| | | | 264016 | 530969 | 224273 | | | | 0.861 | 5 | 0.827 |
| | | 104.00 | 172509 | 319456 | 152467 | 1.033 | 4 | 1.041 | | | |
| | | | 172509 | 351983 | 152467 | | | | 0.865 | 5 | 0.832 |
| | | 102.00 | 89769 | 169275 | 86452 | 1.084 | 4 | 1.102 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 89769 | 187574 | 86452 | | | | 0.888 | 4 | 0.864 |
| | | 100.00 | 34111 | 64738 | 33433 | 1.090 | 4 | 1.109 | | | |
| | | | 34111 | 71972 | 33433 | | | | 0.885 | 4 | 0.861 |
| 124.00 | 72.00 | 112.00 | 518655 | 878066 | 398124 | 1.081 | 4 | 1.099 | | | |
| | | | 518655 | 971014 | 398124 | | | | 0.905 | 4 | 0.885 |
| | | 110.00 | 392819 | 692803 | 315496 | 1.041 | 4 | 1.051 | | | |
| | | | 392819 | 763842 | 315496 | | | | 0.876 | 5 | 0.847 |
| | | 108.00 | 282427 | 515962 | 236984 | 1.012 | 3 | 1.015 | | | |
| | | | 282427 | 567622 | 236984 | | | | 0.854 | 5 | 0.819 |
| | | 106.00 | 188375 | 349838 | 163805 | 1.013 | 3 | 1.015 | | | |
| | | | 188375 | 385013 | 163805 | | | | 0.852 | 5 | 0.815 |
| | | 104.00 | 103316 | 195523 | 96473 | 1.043 | 4 | 1.053 | | | |
| | | | 103316 | 215949 | 96473 | | | | 0.865 | 5 | 0.833 |
| | | 102.00 | 39355 | 74804 | 38631 | 1.088 | 4 | 1.107 | | | |
| | | | 39355 | 83087 | 38631 | | | | 0.885 | 4 | 0.861 |
| 126.00 | 70.00 | 110.00 | 538100 | 907625 | 409601 | 1.080 | 4 | 1.098 | | | |
| | | | 538100 | 1003489 | 409601 | | | | 0.906 | 4 | 0.886 |
| | | 108.00 | 412361 | 726513 | 328808 | 1.037 | 4 | 1.045 | | | |
| | | | 412361 | 800881 | 328808 | | | | 0.874 | 5 | 0.844 |
| | | 106.00 | 305066 | 553298 | 251963 | 1.012 | 3 | 1.015 | | | |
| | | | 305066 | 608570 | 251963 | | | | 0.855 | 5 | 0.820 |
| | | 104.00 | 210999 | 390217 | 180067 | 1.004 | 2 | 1.004 | | | |
| | | | 210999 | 429104 | 180067 | | | | 0.847 | 5 | 0.810 |
| | | 102.00 | 126165 | 238274 | 113742 | 1.013 | 3 | 1.016 | | | |
| | | | 126165 | 262445 | 113742 | | | | 0.848 | 5 | 0.811 |
| | | 100.00 | 53629 | 103147 | 53283 | 1.075 | 4 | 1.092 | | | |
| | | | 53629 | 114331 | 53283 | | | | 0.878 | 5 | 0.852 |
| 126.00 | 72.00 | 112.00 | 560889 | 947990 | 425266 | 1.073 | 4 | 1.089 | | | |
| | | | 560889 | 1048380 | 425266 | | | | 0.900 | 4 | 0.879 |
| | | 110.00 | 434400 | 763145 | 342895 | 1.034 | 4 | 1.041 | | | |
| | | | 434400 | 841384 | 342895 | | | | 0.871 | 5 | 0.842 |
| | | 108.00 | 323426 | 586811 | 264674 | 1.004 | 2 | 1.004 | | | |
| | | | 323426 | 645399 | 264674 | | | | 0.850 | 5 | 0.813 |
| | | 106.00 | 227382 | 420605 | 191405 | 0.992 | 3 | 0.990 | | | |
| | | | 227382 | 462295 | 191405 | | | | 0.839 | 5 | 0.800 |
| | | 104.00 | 141081 | 265707 | 123784 | 0.994 | 3 | 0.993 | | | |
| | | | 141081 | 292203 | 123784 | | | | 0.838 | 5 | 0.797 |
| | | 102.00 | 63529 | 122931 | 62047 | 1.043 | 4 | 1.053 | | | |
| | | | 63529 | 135774 | 62047 | | | | 0.862 | 5 | 0.829 |

PROJECT : MRBPSTS - CHANDPUR
CASE (No.) : Present Situation/Cross Section 21 (alt3)

## MINIMUM SAFETY COEFFICIENTS

| CENTRE POINT CO-ORDINATES | | EXCL. SEISMIC EFFECTS | | INCL. SEISMIC EFFECTS | |
|---|---|---|---|---|---|
| X | Y | RADIUS m | SAFETY COEFF. | RADIUS m | SAFETY COEFF. |
| 110.00 | 70.00 | 106.00 | 1.180 | 106.00 | 0.911 |
| 110.00 | 72.00 | 108.00 | 1.174 | 108.00 | 0.907 |
| 112.00 | 70.00 | 106.00 | 1.176 | 106.00 | 0.910 |
| 112.00 | 72.00 | 108.00 | 1.169 | 108.00 | 0.905 |
| 114.00 | 70.00 | 104.00 | 1.173 | 104.00 | 0.903 |
| 114.00 | 72.00 | 106.00 | 1.169 | 106.00 | 0.901 |
| 116.00 | 70.00 | 102.00 | 1.159 | 102.00 | 0.890 |
| 116.00 | 72.00 | 104.00 | 1.151 | 104.00 | 0.885 |
| 118.00 | 70.00 | 108.00 | 1.143 | 102.00 | 0.885 |
| 118.00 | 72.00 | 102.00 | 1.111 | 102.00 | 0.855 |
| 120.00 | 70.00 | 100.00 | 1.091 | 100.00 | 0.845 |
| 120.00 | 72.00 | 108.00 | 1.071 | 102.00 | 0.847 |
| 122.00 | 70.00 | 106.00 | 1.055 | 106.00 | 0.844 |
| 122.00 | 72.00 | 108.00 | 1.036 | 108.00 | 0.831 |
| 124.00 | 70.00 | 106.00 | 1.027 | 106.00 | 0.827 |
| 124.00 | 72.00 | 108.00 | 1.015 | 106.00 | 0.815 |
| 126.00 | 70.00 | 104.00 | 1.004 | 104.00 | 0.810 |
| 126.00 | 72.00 | 106.00 | 0.990 | 104.00 | 0.797 |

| | | EXCL. SEISMIC EFFECTS | INCL. SEISMIC EFFECTS |
|---|---|---|---|
| MINIMUM SAFETY COEFFICIENT | F : | 0.99 | 0.80 |
| AT CIRCLE CENTRE POINT | X : | 126.00 | 126.00 |
| | Y : | 72.00 | 72.00 |
| RADIUS | R : | 106.00 | 104.00 |

PROJECT : MRBPSTS - CHANDPUR
CASE (No.) : Present Situation/Cross Section 21 (alt3)

## SLICE DATA

CIRCLE CENTRE POINT X : 126.00
Y : 72.00
RADIUS R : 112.00
SAFETY COEFFICIENT F : 0.88
(including seismic effects)

| Slice No | Co-ord. of centre of slice boundary X | Y | Slice width m | Arc length m | Groundwater pressures hydro-static | over-pressure | total pressure | <----- Soil stresses -----> normal stress | effect. stress | shear stress |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 109.52 | -38.74 | 5.28 | 5.34 | 380.09 | 0.00 | 380.09 | 387.55 | 7.46 | 4.73 |
| 2 | 114.80 | -39.40 | 5.28 | 5.31 | 386.54 | 0.00 | 386.54 | 407.75 | 21.21 | 13.06 |
| 3 | 120.08 | -39.81 | 5.28 | 5.29 | 390.52 | 0.00 | 390.52 | 423.15 | 32.64 | 19.52 |
| 4 | 125.36 | -39.96 | 5.28 | 5.28 | 392.04 | 0.00 | 392.04 | 433.80 | 41.76 | 24.29 |
| 5 | 130.00 | -39.91 | 4.00 | 4.00 | 391.48 | 0.00 | 391.48 | 448.06 | 56.58 | 32.13 |
| 6 | 134.00 | -39.69 | 4.00 | 4.01 | 389.38 | 0.00 | 389.38 | 466.96 | 77.58 | 43.18 |
| 7 | 138.33 | -39.29 | 4.67 | 4.70 | 385.44 | 0.00 | 385.44 | 478.47 | 93.03 | 50.68 |
| 8 | 143.00 | -38.67 | 4.67 | 4.72 | 379.38 | 0.00 | 379.38 | 482.06 | 102.68 | 54.66 |
| 9 | 147.67 | -37.85 | 4.67 | 4.76 | 371.35 | 0.00 | 371.35 | 481.83 | 110.47 | 57.47 |
| 10 | 152.00 | -36.92 | 4.00 | 4.11 | 362.15 | 0.00 | 362.15 | 479.33 | 117.17 | 59.67 |
| 11 | 156.00 | -35.88 | 4.00 | 4.15 | 352.01 | 0.00 | 352.01 | 475.01 | 122.99 | 61.40 |
| 12 | 160.00 | -34.69 | 4.00 | 4.20 | 340.31 | 0.00 | 340.31 | 467.65 | 127.34 | 62.31 |
| 13 | 164.50 | -33.14 | 5.00 | 5.32 | 325.07 | 0.00 | 325.07 | 457.29 | 132.22 | 63.22 |
| 14 | 169.50 | -31.17 | 5.00 | 5.43 | 305.75 | 0.00 | 305.75 | 442.84 | 137.09 | 63.86 |
| 15 | 173.83 | -29.25 | 3.67 | 4.06 | 286.91 | 0.00 | 286.91 | 425.50 | 138.59 | 58.79 |
| 16 | 177.50 | -27.43 | 3.67 | 4.13 | 269.10 | 0.00 | 269.10 | 406.32 | 137.22 | 57.11 |
| 17 | 181.17 | -25.44 | 3.67 | 4.21 | 249.60 | 0.00 | 249.60 | 383.87 | 134.27 | 54.78 |
| 18 | 185.13 | -23.08 | 4.25 | 5.00 | 226.46 | 0.00 | 226.46 | 358.19 | 131.73 | 52.55 |
| 19 | 189.38 | -20.30 | 4.25 | 5.16 | 199.18 | 0.00 | 199.18 | 328.34 | 129.16 | 50.23 |
| 20 | 193.00 | -17.73 | 3.00 | 3.74 | 173.88 | 0.00 | 173.88 | 302.32 | 128.43 | 51.96 |
| 21 | 196.00 | -15.40 | 3.00 | 3.84 | 151.11 | 0.00 | 151.11 | 281.18 | 130.07 | 51.50 |
| 22 | 199.13 | -12.80 | 3.25 | 4.29 | 130.89 | -0.00 | 130.89 | 271.72 | 140.83 | 54.43 |
| 23 | 202.38 | -9.88 | 3.25 | 4.44 | 112.91 | 0.00 | 112.91 | 273.30 | 160.39 | 60.35 |
| 24 | 205.75 | -6.59 | 3.50 | 4.99 | 91.65 | 0.00 | 91.65 | 239.26 | 147.61 | 53.88 |
| 25 | 209.25 | -2.87 | 3.50 | 5.23 | 66.59 | -0.00 | 66.59 | 168.55 | 101.96 | 35.94 |
| 26 | 212.37 | 0.74 | 2.74 | 4.31 | 36.93 | 0.00 | 36.93 | 100.02 | 63.09 | 21.48 |
| 27 | 215.11 | 4.20 | 2.74 | 4.53 | 2.96 | 0.00 | 2.96 | 34.23 | 31.27 | 10.29 |

DRIVING MOMENT : 1048380
COUNTER-ACTING MOMENT : 560889
MOMENT WATER ON SLOPE : 425266

(Units: m and kNm/m)

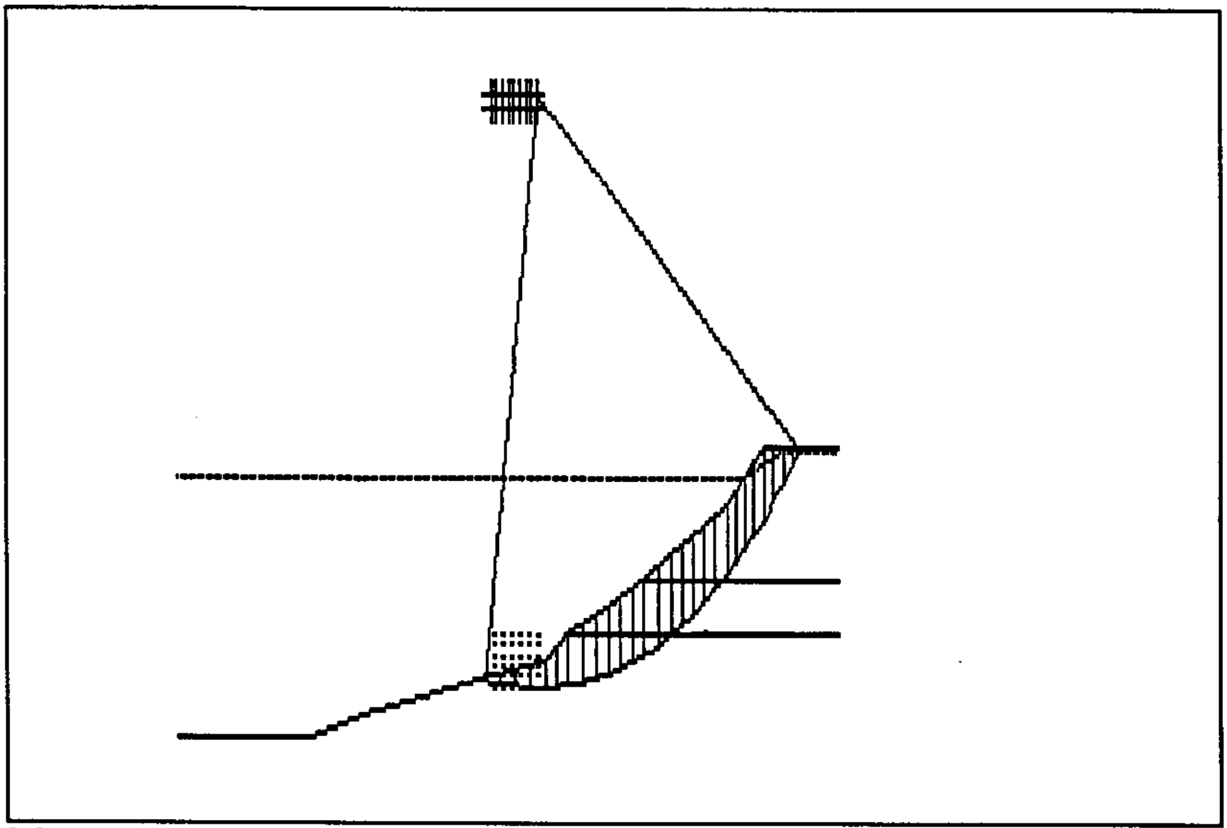

FIGURE . Slope Stability Analysis
Chandpur Town Protection. Cross Section 21 (Present Situation).