COMPRESSION OF RESIDUAL SOIL FILL

Lecture presented to:

ACEM SARAWAK

20th October 2004

By:

C.T.Toh and Chee Sai Kim

Introduction

Thick fills common because of:

- Natural rolling terrain.
- Housing development. Large flat areas required for higher densities.
- Highways. High embankments cheaper than viaducts.

Lecture is about:

- Compression / settlement of fills derived from different weathering grades of different geological formations compacted in different ways.

Geological Formations

- Sedimentary and meta-sedimentary.
- Igneous.
- Sub volcanics and Volcanics.

Sedimentary and Meta Sedimentary Formations

- Kenny Hill (KL)
- Kajang(Selangor)
- Bukit Resam Clastic (Johor)
- Gua Musang (kelantan)
- Rajang (Sarawak)
- Tuang (Sarawak)
- Belaga(Sarawak)
- Crocker (Sabah)

Sedimentary and meta sedimentary formations

- 40 % of peninsular and most of Sarawak and Sabah.
- Inter bedded shales, sandstones, mudstones,siltstones,phyllites.
- Often highly folded and fractured

Igneous Formations

- Outcrops over 40 % of Peninsular.
- High mountain ranges.
- Includes granites, granodiorites, adamalites
- Gabbros (basic igneous)

Volcanics and sub volcanics

- Volcanic breccia
- Tuffs

Weathering

Necessary to understand:

- Weathering process.
- Weathering profiles.

to comprehend materials for filling.

Weathering Scheme

- Several schemes available. All variations of BS 5930 and IAEG (1981).
- All schemes adopt 6 zones classification. Grades I, II, III, IV, V and VI (residual soils).

Weathering process

- Slow breakdown of rock exposed on earth’s surface.
- Ultimately leads to formation of fully weathered rock (soil).
- Soil is in-situ or residual and not transported and deposited.
- Chemical weathering main agent in tropical regions. Breakdown rock. New minerals developed. Results in thick layers of residual soils.

Rock mass weathering scheme

Fresh	**No visible signs of rock material weathering; perhaps a slight discoloration on major discontinuity surfaces**	I
Slightly weathered	**Discoloration indicates weathering of rock material and discontinuity surfaces. All rock material may be discolored by weathering**	II
Moderately weathered	**Less than 50% rock decomposed into soil. Fresh or discolored rock is present either as a continuous framework or as core stones.**	III
Highly weathered	**More than 50% rock decomposed into soil. Fresh or discolored rock is present either as discontinuous framework or as core stones.**	IV
Completely weathered	**All rock material is decomposed or disintegrated to soil.The original mass structure is still largely intact.**	V
Residual soil	**All rock converted to soil. Mass structure and material fabric destroyed.**	VI

Rock material decomposition grades

Residual soil	Grade VI	**Original soil texture completely destroyed.Can be crumbled by finger pressure.**
Completely decomposed	Grade V	**Original rock texture preserved.** **Crumbled by hand.Indented by geol. pick.** **Slakes in water.** **Completely discolored.**

Rock mass decomposition grades

Highly decomposed	Grade IV	**Broken by hand. Dull sound by geol hammer.Not easily indented by geol pick.Does not slake in water.Completely discolored.**
Moderately decomposed	Grade III	**Cannot easily broken by hand.easily broken by geol hammer. Dull or slight ringing sound by geol hammer.Completely stained thru out.**

Rock mass decomposition grades

Slightly decomposed	Grade II	**Not easily broken by geol hammer.Makes a ringing sound when struck by geol hammer.** **Fresh rock color remains but stained near joint surface.**
Fresh	Grade I	**Not easily broken by geol hammer.Makes a ringing sound when struck by geol hammer.** **No signs of decomposition(i.e. no discoloration)**

Tropical Weathering Profiles

- <u>Igneous</u>
- Grade VI, V and IV. Considerably thick > 30 m.
- Grade III and II. Relatively thin. Few metres.

- **<u>Sedimentary</u>**
- **Grade VI. Only a few metres. Often iron rich.**
- **Grade V and IV. Not distinguishable. Often 0 to 15 m.**
- **Grade III. Often 20 m to 40 m.**
- **Grade II relatively thin.**

Granite weathering profile. Paya Terupong

Grade III granite. > 50 % rock.

Granite weathering profile. Paya Terupong

Grade IV (< 50 % rock). LHS.

Grade III (> 50 % rock) RHS.

Granite weathering profile. Paya Terupong.

Grade IV.

< 50% rock.

Discontinuous framework.

Core stones.

Granite weathering profile. Paya Terupong

Grade IV.

< 50 % rock.

Discontinuous

Framework.

Core stones.

Sedimentary weathering profile

Far more complicated than granite weathering profile because of:

- In homogeneity, layering,folding
- Textural variations (very fine to very coarse grain).
- Weathering classification based on rock mass decomposition.

Sedimentary. Gua Musang mudstone.Grades IV - V

Sedimentary Gua Musang Grade IV mudstone fragment

Sedimentary Gua Musang Grade IV. Excavated material

Sedimentary Gua Musang. Grades IV and V mudstones

Natural materials

- Firm to hard clayey / sandy silt.
- Foliation, relict joints, beds can be seen.
- SPT = 20 to 50.
- UCS < 1 MPa.
- Extremely weak and very weak rock.

Sedimentary. Gua Musang mudstones. Grade IV - V

Excavated materials

- 70 % soil size. 30 % grade IV rock fragments of up to 300 mm size.
- Rock fragments can be crushed by dozers to between 100 mm and 150 mm and then to less than 50 mm by vibrating rollers.

Sedimentary Gua Musang. Grade III mudstone

Sedimentary Gua Musang. Grade III mudstone.

<u>Natural material</u>

- Highly jointed
- Moderately weathered.
- SPT = 100 to 200.
- UCS = 1.5 to 2 MPa (Weak rock).

Sedimentary Gua Musang. Grade III mudstone.

<u>Excavated material</u>

- 40 % soil size and 60 % weak rock fragments.
- Size of fragments depends on joint spacing. Generally > 500 mm.
- Extraneous effort by dozers and vibrating rollers to crush to 150 to 200 mm size.
- Fragments slake. Deteriorate on wetting.

Sedimentary. Gua Musang. Grades I and II mudstones.

Sedimentary Gua Musang. Grade I and II mudstone

<u>Natural material</u>

- Slightly weathered and fresh.
- Highly fractured.
- No discoloration.
- UCS = 2 to 5 MPa (Weak rock).
- Does not slake.

Sedimentary. Gua Musang. Grade I and II mudstone.

<u>Excavated material</u>

- 90 % rock fragments.
- 10 % soil size.
- Sizes of rock fragments depend on joint spacing.

Sedimentary Gua Musang. Grade IV and V sandstone.

Sedimentary. Gua Musang. Grade IV and V sandstone.

Excavated
IV
&
V
sandstone

Sedimentary. Gua Musang. Grade IV and V sandstone.

Natural material

Dense and fine gravelly sand.

SPT = 20 to 50.

UCS < 1 MPa

Foliation, relict jts, fault planes observed.

Sedimentary. Gua Musang. Grade IV and V sandstone.

<u>Excavated material.</u>

- 40 % soil size and 60 % Grade IV rock fragments.
- 300 mm to 500 mm rock fragments.
- Extraneous effort required to crush rock fragments to 100 mm to 150 mm with dozers.
- Extraneous effort required to crush rock fragments to 50 mm size with vibrating rollers.

Sedimentary. Gua Musang. Grade III sandstone.

Sedimentary Gua Musang. Grade III sandstone.

Exc.
Grade
III
Sand
stone

Sedimentary. Gua Musang. Grade III sandstone.

Natural material

- Moderately weathered.
- Highly jointed.
- SPT hammer rebound.
- Require NLMC.
- UCS = 2 to 5 MPa (Weak rock).
- Joints iron stained.
- Does not slake.

Sedimentary. Gua Musang. Grade III sandstone.

<u>Excavated material</u>

- 20 % soil size.
- 80 % rock fragments.
- Size of rock fragments depends on joint spacing. Generally 50% > 500 mm.
- Mostly cannot be crushed to smaller by dozers and compacters.

Sedimentary Gua Musang. Sandstone. Grade I and II

Sedimentary. Gua Musang. Grade I and II sandstone.

Exc.
Sand
Stone.

Sedimentary. Gua Musang. Sandstone. Grade I and II.

Natural material.

- Fresh to slightly weathered.
- Highly fractured.
- SPT hammer rebound.
- UCS = 10 to 20 MPa (moderately strong)
- Blasting required.

Sedimentary. Gua Musang. Sandstone. Grade I and II.

<u>Excavated material.</u>

- 5 % soil size. 95 % rock size.
- Rock fill material.

Sed. Sepangar bay. Sandstone / mudstone. Grade V

Sed. Sepangar Bay.Sandstone / mudstone. Grade IV

Sed. Sepangar bay. Sandstone / mudstone. Grades V and VI.

Natural materials

- Dense silty sand and gravelly sand.
- Foliation, relict jts.,bedding,fault planes.
- SPT = 20 to 50.
- UCS sandstone < 1 MPa(Ext. weak).
- UCS mudstone< 0.5 MPa (Ext. weak).

Sed. Sepangar Bay. Sandstone / mudstone. Grade V and IV.

<u>Excavated materials.</u>

- 70 % soil size.
- 30 % rock fragments.
- Most rock fragments about 300 mm size.
- Can be crushed to 100 mm to 150 mm size by dozers.
- Can be crushed to 50 mm size by vibrating rollers.

Sed. Sepangar bay. Sandstone / mudstone. Grade III

Sed. Sepangar Bay. Sandstone / mudstone. Grade III

<u>Natural materials.</u>

- Moderately weathered.
- Sandstone and highly friable mudstone.
- SPT hammer rebound on sandstone.
- Casing can ream thru mudstone.
- UCS sandstone. 2 to 5 MPa. (weak)
- UCS mudstone. $<$ 1 MPa.(very weak)
- Joints iron oxide stains.

Sed. Sepangar Bay. Sandstone / mudstone. Grade III.

Excavated material.

- Mixture of soil and rock. Percentage of each type depends on ratio of sand stone to mudstone beds.
- Rock fragment sizes depend on joint spacing. Can be about 500 mm.
- Sandstone cannot be crushed by dozers and vibrating rollers.

Sed. Sepangar bay.Sandstone /mudstone. Grade II and I

Sed. Sepangar Bay. Friable mudstone.

Sed. Sepangar Bay. Fill from sandstone / mudstone mix.

Sed.
Sepangar Bay

Excavated Sandstone (Grades I & II) fragments

Sed. Sepangar Bay. Sandstone / mudstone. Grades II and I.

Natural materials

- Slightly weathered and fresh, highly fractured sandstone and highly friable mudstone.
- Intact joints and beds.
- UCS sandstone = 10 to 20 MPa (mod. Strong).
- UCS mudstone < 1 MPa (very weak).
- Blasting required.

Sed. Sepangar Bay. Sandstone / mudstone. Grades II and I.

<u>Excavated material.</u>

- Mixture of soil (from mudstone) and rock fragments (mainly from sandstone).
- Ratio of soil to rock fragments depends on ratio of the mudstone to sandstone beds.
- Sandstone fragments cannot be crushed by dozers and vibrating rollers.

TATAU MUDSTONES

TATAU MUDSTONES

TATAU

Volcanics

The main characteristics of volcanic formations such as volcanic tuffs are:

- Deep seated weathering.
- High moisture contents which are significantly higher than OMC.
- High shrinkage characteristics.

BASIC IGNEOUS

Gabbros

Deep seated weathering. > 30 m.

Wet fills with high moisture contents appreciably higher than OMC

Purposes for compacting fill

- Increase strength of fill materials at least to a level that the embankment is stable- slope can hold itself up.
- Increase strength to level suitable for traffic loads.
- Increase strength to level where bearing capacity adequate for structures.

Purposes for compacting fill.

- Increase stiffness of fill to minimize settlements under applied loads.
- Minimize the compression of the fill under its own self weight and to ensure that self weight compression will be completed soon after end of filling.
- Minimize/negate possibility of long term settlements due to ground water rise and water infiltration into fill.

Engineered fills.

- Engineered fills requires engineering.
- Engineering requires design of the filling and compaction process to ensure the correct outcome in terms of strength and settlement.
- Design requires understanding of the behavior and characteristics of materials to be used.
- Design requires knowledge of equipment and processes.

EARTHWORKS SPECIFICATIONS

Two main general specifications in current use are:

- JKR Standard specifications for road works.
- PLUS – North South Highway earthworks specifications.

Earthworks specifications.

Both earthworks specs. are essentially :

- Meant for soil size particles.
- Or pure rock.
- Or where rock and soil can be separated.
- Does not address the issue of weak rock or mixture of soil and rock that <u>cannot</u> be separated.
- Assumes that all will be well when compaction is carried out o 90 % MDD.
- British inheritance.

JKR definition of suitable materials.

<u>Suitable</u> if it is not unsuitable.

Unsuitable includes:

- Running silts,logs,perishable,toxic,slurry,mud.
- Highly organic clays and silts.
- Clay with LL>80 % . PI>55 %.
- Susceptible to combustion.
- Large amts of roots,grass,vegetation matter.

JKR. Earth embankment materials and compaction.

- Fill materials for embankments shall be suitable materials from excavation….
- Fill shall be deposited in layers.
- Compaction shall be…by plant approved by SO
- Compaction to 90 % MDD (for cohesive soils) or 95 % (for cohesionless soils). BS 1377 (4.5 kg hammer).

JKR specs. Rock fill embankment.

- Maximum size 400 mm.
- Well graded.
- Large voids filled with broken fragments.
- Spread by 15 tonne crawler tractor.
- Each layer compacted by at least 12 passes of a vibrating roller or grid roller.

Comments on JKR Specs.

- Allows all suitable materials from cuttings (except unsuitable materials) for forming embankments.
- No statement on mixed soil – rock.
- No statement on crushing weak rock.
- Does not limit quantum of boulders or rock (weak or strong) in fill.
- Gabbros and volcanics cannot be used.
- Specs require modification for sedimentary formation.

PLUS N.S. Highway specs.

- Suitable material shall comprise all that is acceptable in accordance with Contract for use in the Works, and which is capable of being compacted …specified in Clause 608.
- Compacted in layers < 250 mm loose depth… with appropriate equipment.
- Compaction moisture within 3 % OMC.
- For clayey, silty, sandy or gravelly materials… compaction to 90 % maximum dry density. BS 1377. Test 13.

PLUS N.S. Highway specs.

- Unsuitable material comprises material from swamp, marshes, bog;peat, logs,stumps…;susceptible to combustion; clays of LL > 80 %, PI> 55 %.
- Rock fill shall be clean, hard, durable,well graded from approved rock.

PLUS N S Highway specs.

- When materials of widely divergent characteristics are used in embankments and fill areas they shall be spread and compacted in separate clearly defined areas in such a manner as to comply with the compaction requirements of this specifications.

PLUS N.S. Highway specs.

- Isolated boulders 0.02 cu.m. to 0.1 cu.m. in size may be allowed in earth embankments.

Comments on PLUS Specs.

- Does not adequately cover soil – rock mix from excavation in sedimentary formation.
- Requires materials of divergent properties to be separated. This is not possible in sedimentary formation.
- Limits boulders in earth embankments and therefore mixed soil- rock cannot be used for forming fills.
- By defn. of suitable soils, excludes volcanics and gabbros for fill.
- Modification needed in Gabbro & sedimentary formations.

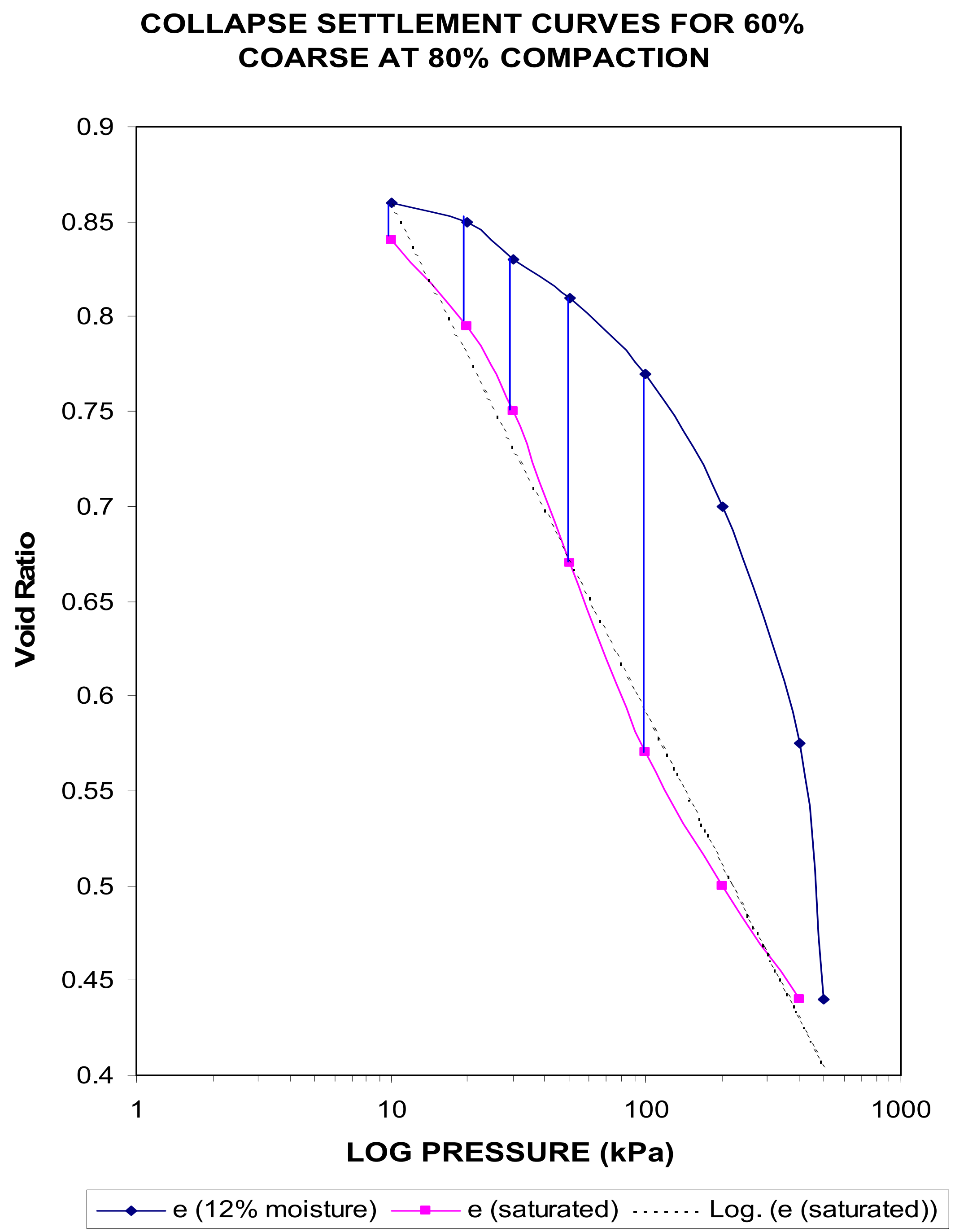
Fills from Igneous (granite) formations

- Separation of soil from boulders required.
- Separation easily achieved.
- Deep weathering profile implies significant portion of cut will result in soil size fill.
- Generally compaction in layers (< 300 mm lifts) to 90 % MDD (modified proctor) will result in negligible fill compression.
- Collapse settlement on soaking if compaction < 90 % MDD

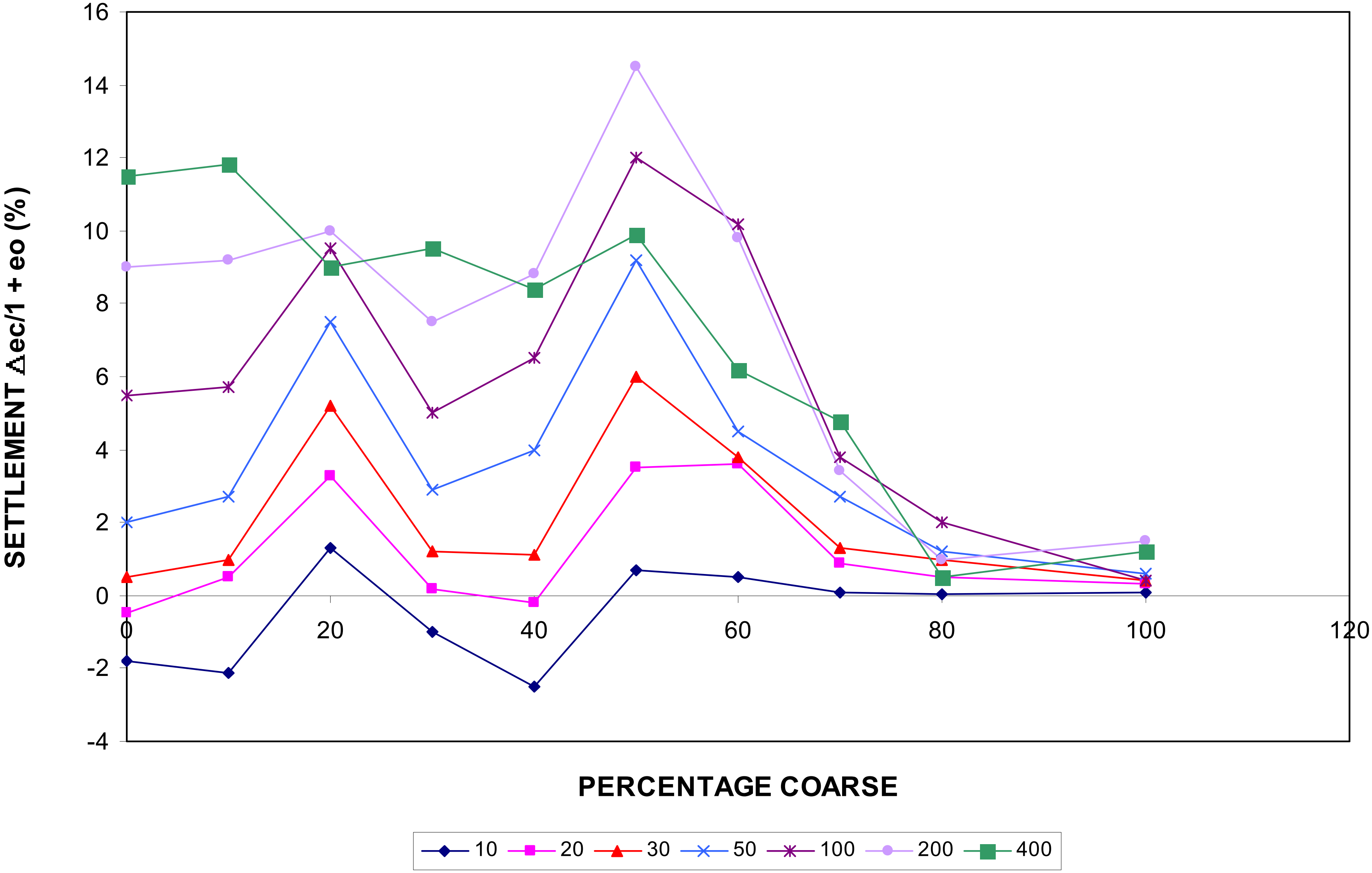
Fills from igneous (granite) formations.

- Oedometer tests on soils compacted to 80 % MDD show collapse settlement of up to 10 % of fill thickness on soaking.
  Example. 1000 mm for 10 m of saturated fill.
- Maximum collapse is when coarse content about 20 %.
- Collapse settlement significantly lesser when coarse content > 70 %.

OEDOMETER TESTS ON COMPACTED GRANITE SOILS


COLLAPSE SETTLEMENT CURVES FOR 60% COARSE AT 80% COMPACTION
Void Ratio
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
1
10
100
1000
LOG PRESSURE (kPa)
e (12% moisture)
e (saturated)
Log. (e (saturated))

COLLAPSE SETTLEMENT AS A FUNCTION OF COARSE CONTENT AND APPLIED PRESSURE



Raft foundation on fill

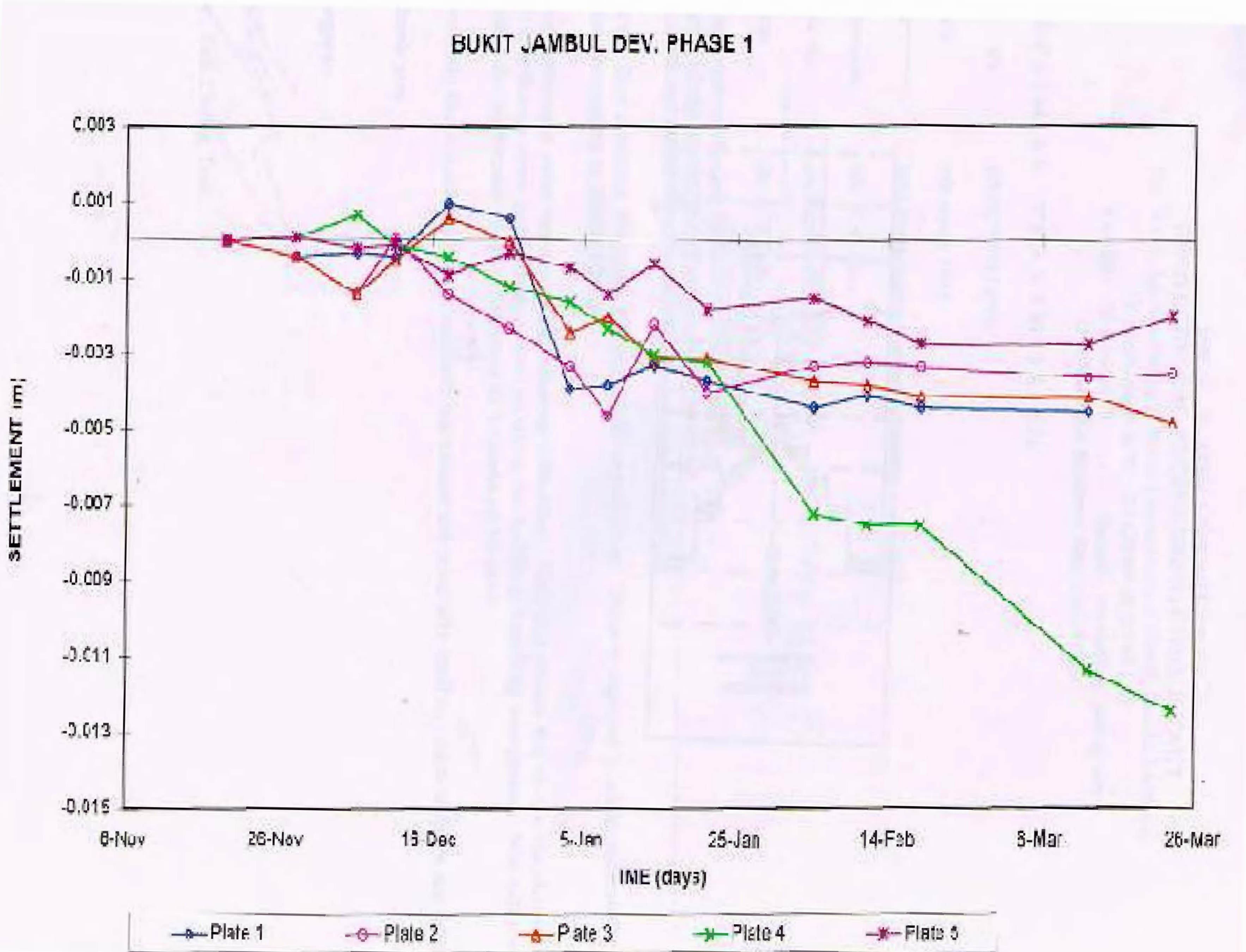
EXAMPLE OF 7 STOREY RAFT OVER 10 M GRANITE RESIDUAL SOIL FILL

Fills from Igneous (granite) formations.

- Example of 7 storey building on raft foundation over about 10 m of fill.
- Fill about 2 to 3 years old.
- Predicted maximum settlement of raft = 30 mm.
- Measured settlement < 15 mm.

RAFT ON GRANITE FILL.

- Fill thickness = 10 m over 2 m residual soils over rock.
- Plate load tests show ultimate bearing capacity > 700 kPa.
- Back calculated Cu > 120 kPa (N>24. Very stiff).
- Back calculated E = 35 kPa.



BUKIT JAMBUL DEV. PHASE 1
SETTLEMENT (m)
0.003
0.001
-0.001
-0.003
-0.005
-0.007
-0.009
-0.011
-0.013
-0.015
6-Nov
26-Nov
16-Dec
5-Jan
25-Jan
14-Feb
6-Mar
26-Mar
IME (days)
Plate 1
Plate 2
Pate 3
Plate 4
Plate 5

Fills from sedimentary formations.

<u>SOIL SIZE PARTICLES</u>

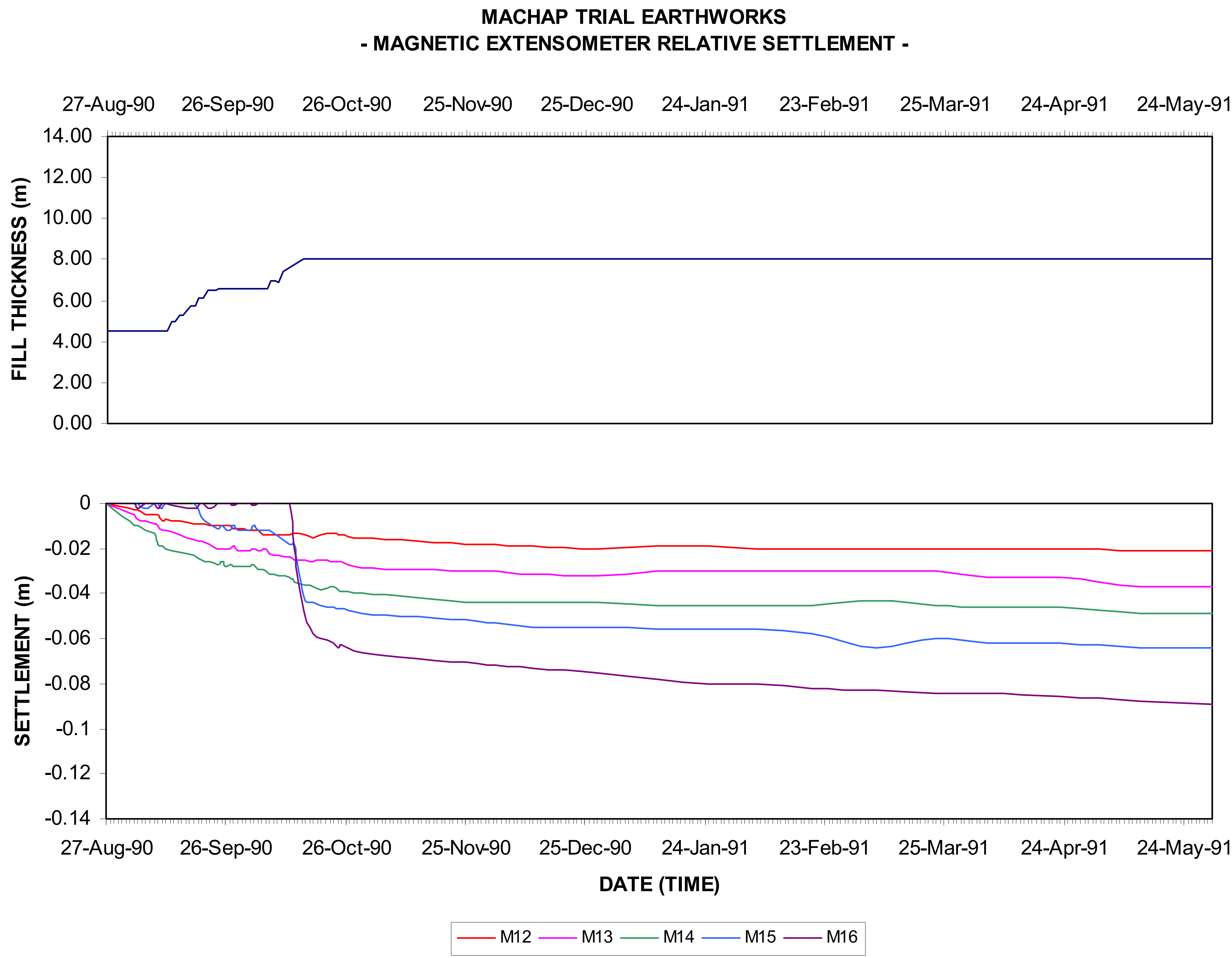
- Example 1: Machap peat replacement.
  6 to 12 m fill compacted by
  vibrating rollers in layers
  to 90 % MDD.
- Example 2: Putrajaya LK3 dam clay core.
  Total 18 m thick fill compacted by
  vibrating rollers in layers to 90 %
  MDD.

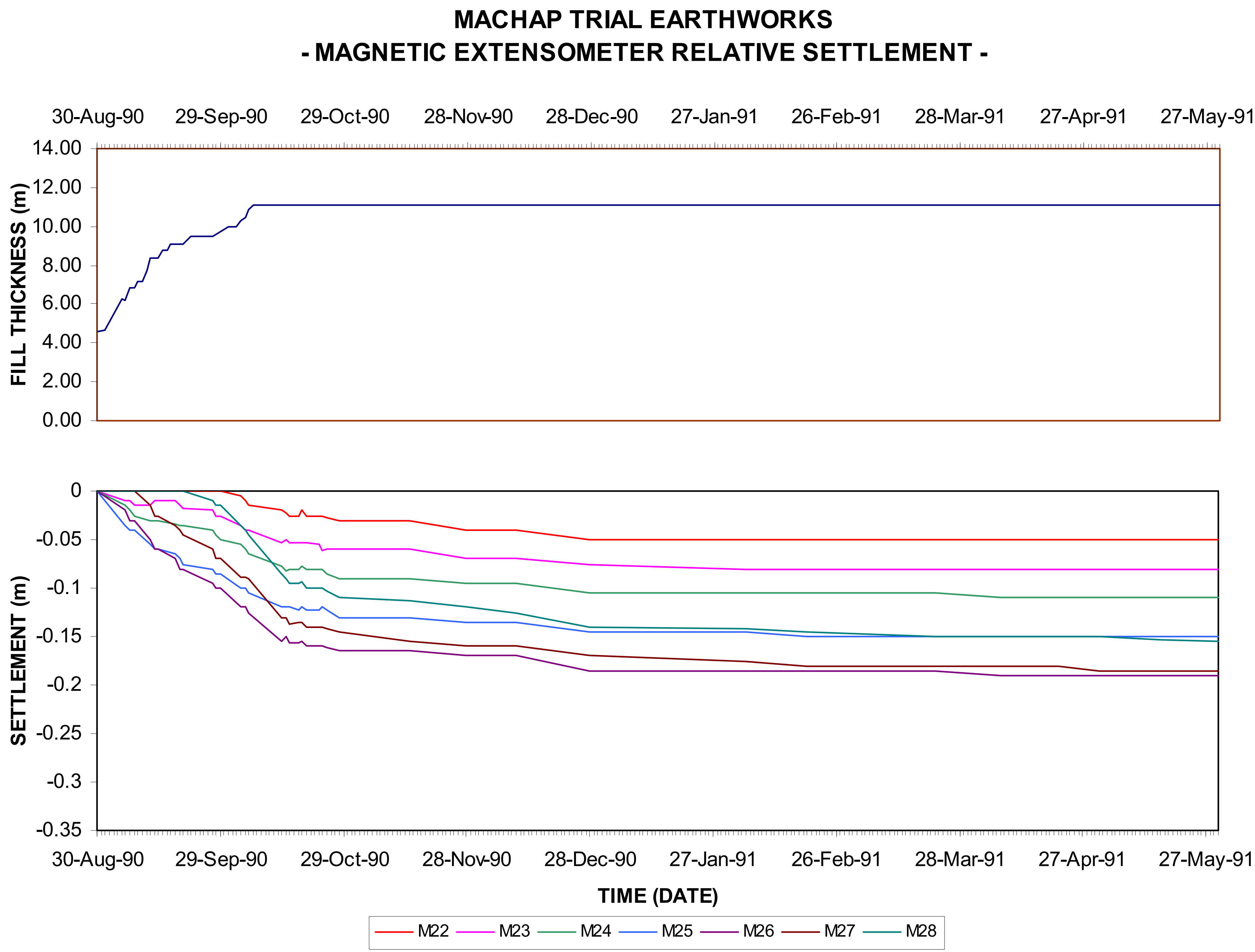
MACHAP TRIAL EARTHWORKS FOR PLUS

Machap Trial earthworks.

- For removal of peat for N.S. Highway.
- Remove peat, dewater and compact fill in layers.
- Top of fill at RL 11.7 m.
- Base of fill at deepest parts at RL + 1 to -2 m.
- Ground water will rise up to RL +8 m.
- Most of the fill fully saturated and beneath permanent ground water table.

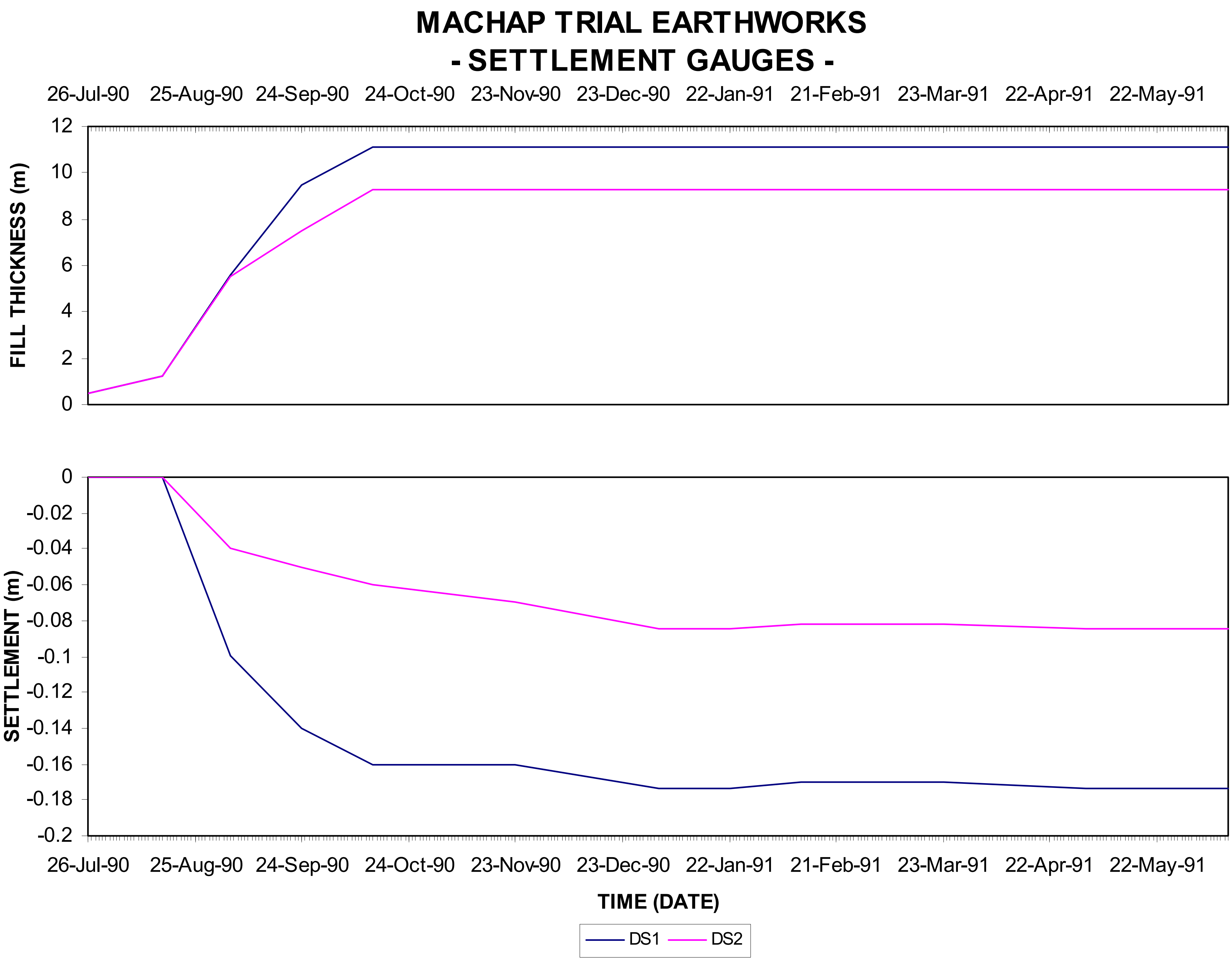
MACHAP TRIAL EARTHWORKS -MAGNETIC EXTENSOMETER- (SD1 & SD2)


MACHAP TRIAL EARTHWORKS
- MAGNETIC EXTENSOMETER RELATIVE SETTLEMENT -
27-Aug-90
26-Sep-90
26-Oct-90
25-Nov-90
25-Dec-90
24-Jan-91
23-Feb-91
25-Mar-91
24-Apr-91
24-May-91
FILL THICKNESS (m)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
SETTLEMENT (m)
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
DATE (TIME)
M12
M13
M14
M15
M16

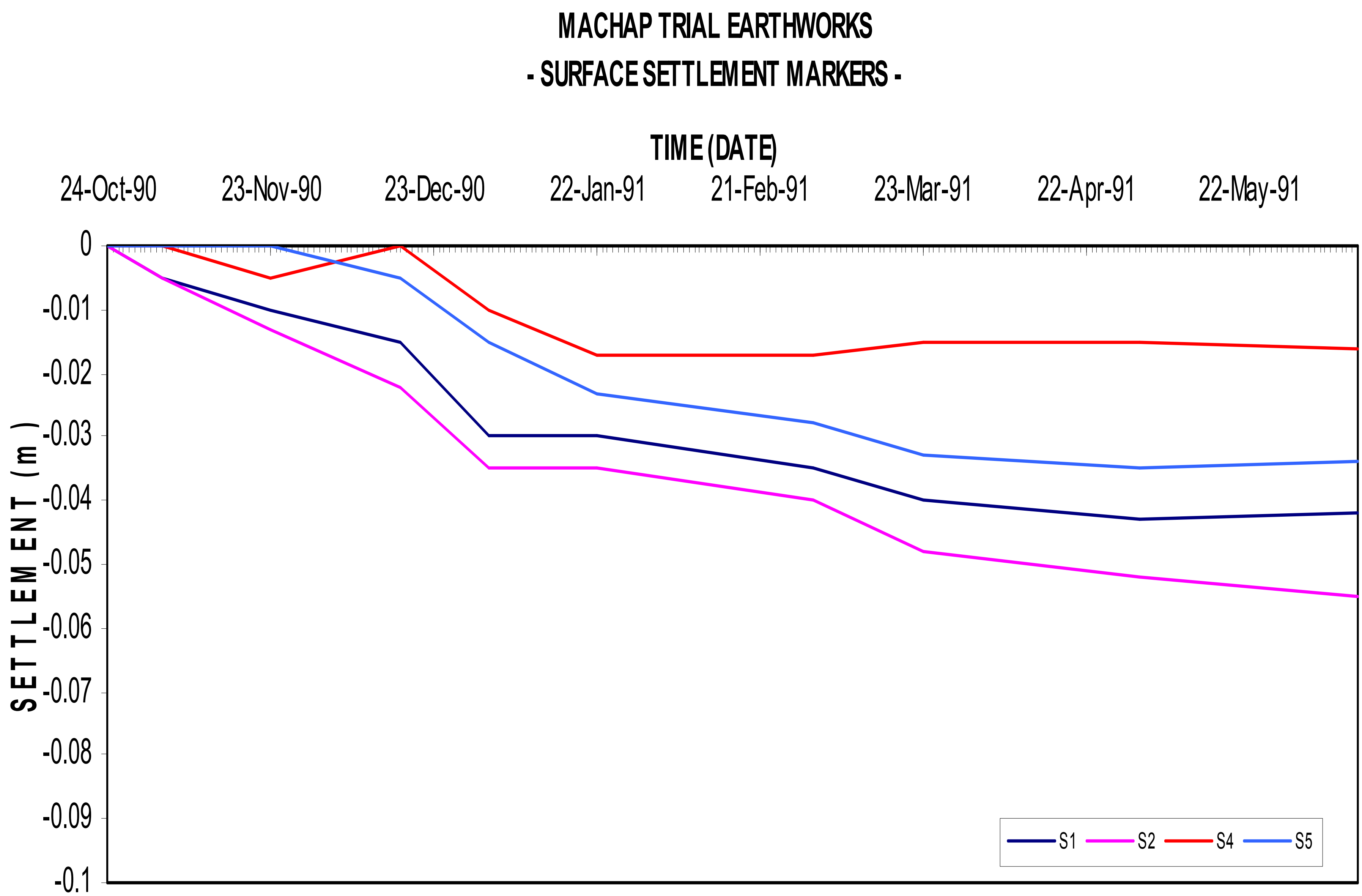


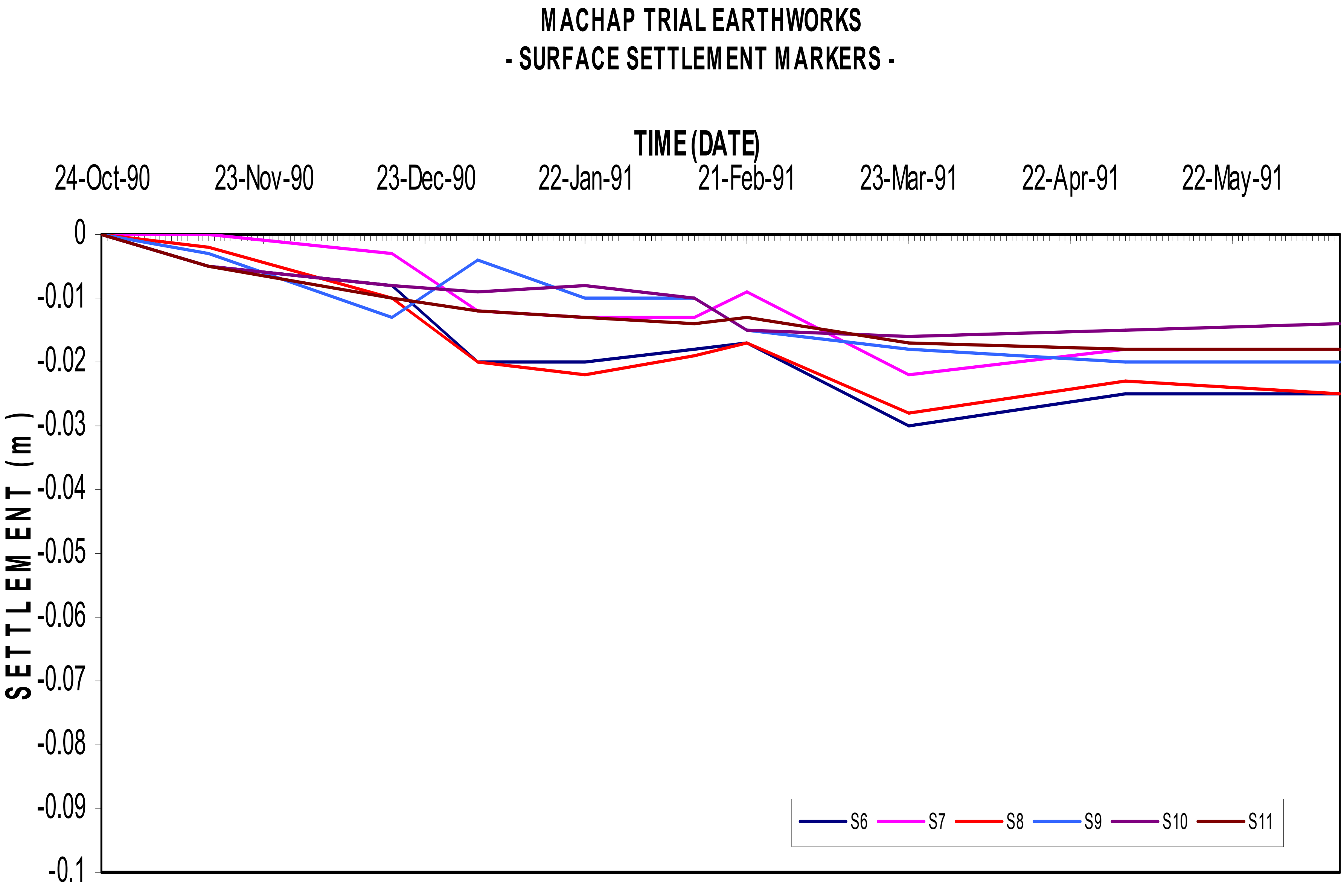
MACHAP TRIAL EARTHWORKS
- MAGNETIC EXTENSOMETER RELATIVE SETTLEMENT -
30-Aug-90
29-Sep-90
29-Oct-90
28-Nov-90
28-Dec-90
27-Jan-91
26-Feb-91
28-Mar-91
27-Apr-91
27-May-91
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
FILL THICKNESS (m)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
SETTLEMENT (m)
TIME (DATE)
M22
M23
M24
M25
M26
M27
M28

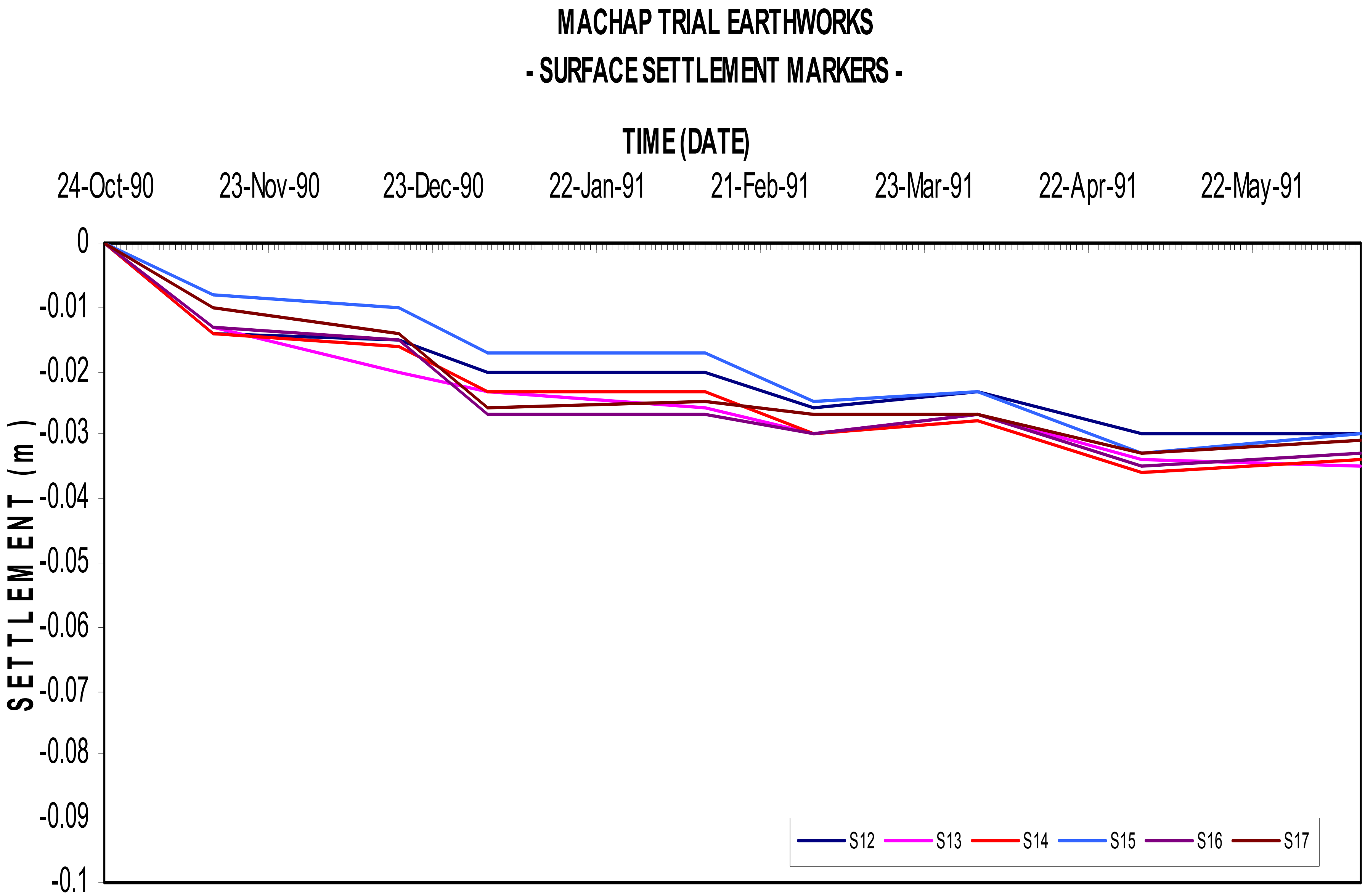
MACHAP TRIAL EARTHWORKS -SETTLEMENT GAUGES-


MACHAP TRIAL EARTHWORKS
- SETTLEMENT GAUGES -
26-Jul-90
25-Aug-90
24-Sep-90
24-Oct-90
23-Nov-90
23-Dec-90
22-Jan-91
21-Feb-91
23-Mar-91
22-Apr-91
22-May-91
FILL THICKNESS (m)
12
10
8
6
4
2
0
SETTLEMENT (m)
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.2
TIME (DATE)
DS1
DS2

MACHAP TRIAL EARTHWORKS -SURFACE SETTLEMENT MARKERS-


MACHAP TRIAL EARTHWORKS
- SURFACE SETTLEMENT MARKERS -
TIME (DATE)
24-Oct-90
23-Nov-90
23-Dec-90
22-Jan-91
21-Feb-91
23-Mar-91
22-Apr-91
22-May-91
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
SETTLEMENT (m)
S1
S2
S4
S5


MACHAP TRIAL EARTHWORKS
- SURFACE SETTLEMENT MARKERS -
TIME (DATE)
24-Oct-90
23-Nov-90
23-Dec-90
22-Jan-91
21-Feb-91
23-Mar-91
22-Apr-91
22-May-91
SETTLEMENT (m)
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
S6
S7
S8
S9
S10
S11



MACHAP TRIAL EARTHWORKS
- SURFACE SETTLEMENT MARKERS -
TIME (DATE)
24-Oct-90
23-Nov-90
23-Dec-90
22-Jan-91
21-Feb-91
23-Mar-91
22-Apr-91
22-May-91
SETTLEMENT (m)
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
S12
S13
S14
S15
S16
S17

Machap Trial Earthworks.

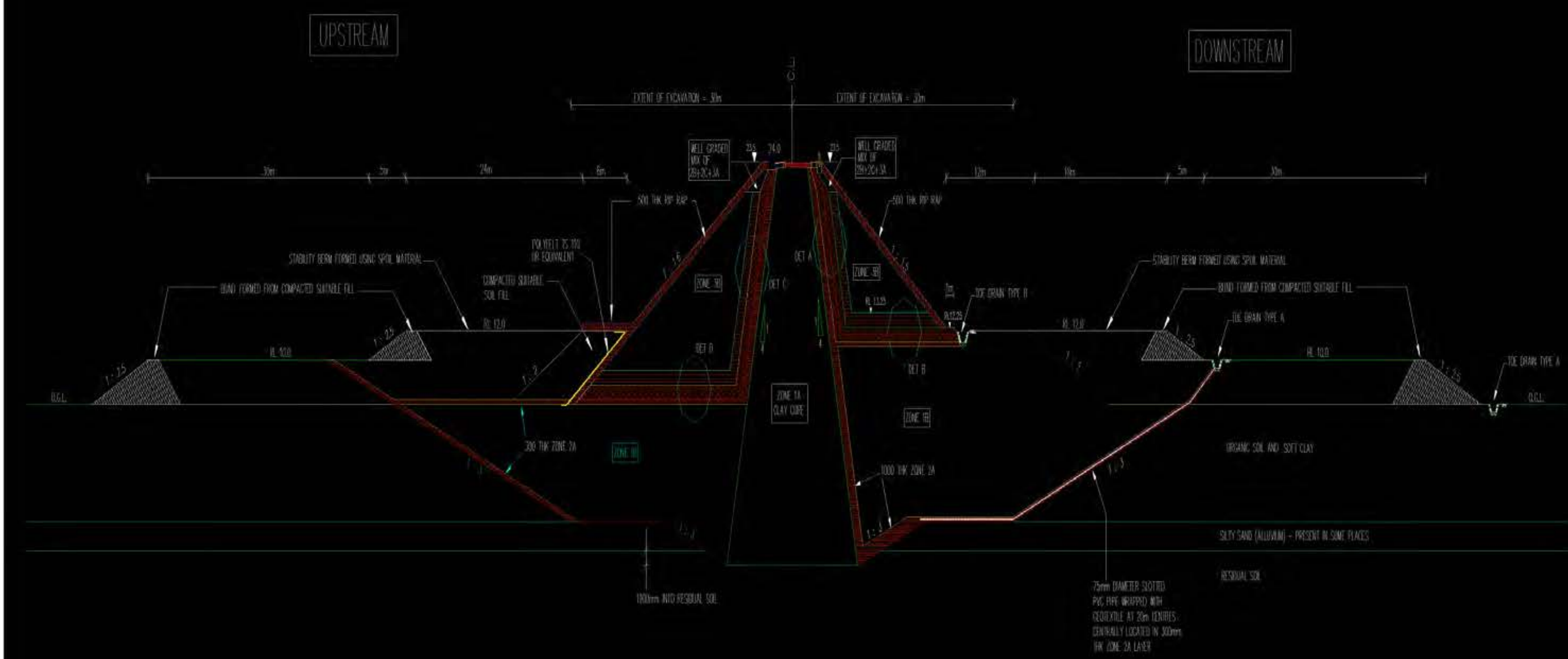
- MDD = 1.7Mg/cu.m. OMC = 22%.
- Average fill thickness where settlement markers installed = 11 m.
- Measured total post construction settlement. Mostly 15 to 25 mm . Some locations 35 mm.
- Compression / thickness ratio = Mostly 0.14 % but up to 0.35 %.
- Settlement complete within 5 months.

Machap Trial Earthworks

- Sondex SD1. Total post construction settlement = 10 mm. Fill thickness = 8 m. Ratio settlement / fill thickness = 0.13 %.
- Sondex SD2. Total post construction settlement = 10 mm. Fill thickness = 11 m. Ratio settlement / fill thickness =0.09 %.

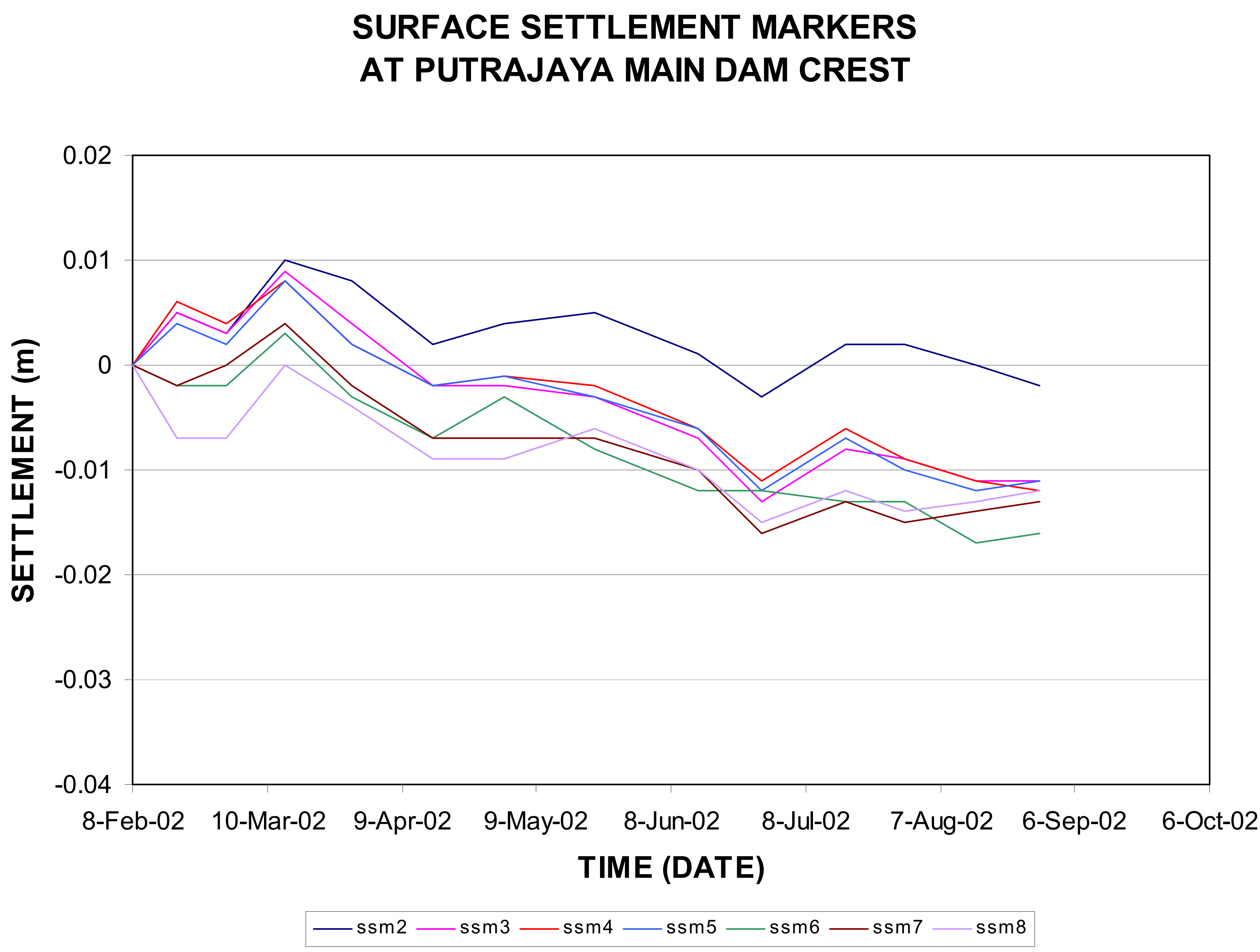
Putrajaya LK 3 Dam

- Clay core rock fill dam.
- Ht. Above natural ground level = 16 m.
- Depth of excavation of peat and organic clay with dewatering and compacting fill in layers = 11 m.
- Total fill thickness = 27 m.
- Clay core. PI>10 %. LL< 60 %.
- Compaction moisture –2 to +3 % of OMC



TYPICAL CROSS-SECTION OF MAIN DAM ACROSS FLOOD PLAIN

SCALE :- 1 : 300



SURFACE SETTLEMENT MARKERS
AT PUTRAJAYA MAIN DAM CREST
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
SETTLEMENT (m)
8-Feb-02
10-Mar-02
9-Apr-02
9-May-02
8-Jun-02
8-Jul-02
7-Aug-02
6-Sep-02
6-Oct-02
TIME (DATE)
ssm2
ssm3
ssm4
ssm5
ssm6
ssm7
ssm8

Putrajaya LK3 Permanent Dam

- Total height of clay core = 27 m.
- Height above Natural ground level =16m
- Depth of replacement of organic soils and peat with clay core = 11 m.
- Maximum post construction settlement = 15 mm.
- Settlement / fill thickness ratio =0.06 %.
- Settlement complete within 7 months.

Fills from sedimentary formations.

FILLS OF SOIL SIZE PARTICLES

- Measurements show settlements totally complete within 5 to 7 months after completion of filling.
- Post construction compression less than 40 mm.
- Post construction settlements average about 0.15 % of fill thickness. Range from 0.05 to 0.35 %.

Shallow foundations on sed. soil fill.

Putrajaya Hospital.

- New fill of up to 5 m thick.
- Raft constructed immediately after completion of fill.
- Fill compacted in layers to 90 to 95 % MDD.

Putrajaya hosp. Plate load tests

Plate	Cut/fill	Cu (kPa)	E (MPa)	N = Cu/5.0	Description
PLT1	5 m fill	70	70	14	stiff
PLT2	2 m fill	97	59	19	Very stiff
PLT3	5 m fill	88	41	18	Very stiff
PLT4	5 m cut	76	67	15	stiff
PLT5	7 m cut	70	61	14	stiff

Putrajaya hospital

Plate load tests show that strength and stiffness of compacted fill – stiff to very stiff.

Comparable to cut ground.

Foundations performed satisfactorily.

Fills from sedimentary formations.

<u>SOIL – WEAK ROCK MIX.</u>

SIGNIFICANT POST CONSTRUCTION COLLAPSE SETTLEMENT IF METHOD OF FILLING AND COMPACTION PROCEDURE INAPPROPRIATE.

Fills from sedimentary formation

Soil – weak rock mix. Consequences of in appropriate compaction.

- Example 1. Expressway in Kajang Formation.
- Example 2. Bkt. Bandaraya KL. Kenny Hill Formation.
- Example 3. Nilai area. Kajang Formation.
- Example 4. Selangor. Kenny Hill.
- Example 5. Pulai Interchange, Johor.
- Example 6. Lembah Beringin.

Fills from sedimentary formations.

Soil – weak rock mix.

COLLAPSE SETTLEMENT

Contributory factors.

- % shales & mudstones of poorer durability. Rising ground water and infiltration into fill causes deterioration of shales and weaker mudstones and siltstones especially and initially at contact points.

Fills from sedimentary formations.

<u>Soil-weak rock mix.</u>

COLLAPSE SETTLEMENT.

Contributory factors:

- Proportion of voids. Voids found between boulder clusters. Over time water infiltration will cause soil size particles to be washed into voids.

Fills from sedimentary formation.

Soil – weak rock mix.

COLLAPSE SETTLEMENT.

Contributory factors

- Piping of fines and formation of sub surface channels and linking voids.
- Collapse of any loose silty soils on saturation.
- Whether there had been significant rainfall during earthworks inducing some of the total settlement earlier.

Exp. 1. Expressway Kajang sed. Formation.

Exp.1. Expressway. Kajang sed. Formation.

Exp. 1. Expressway. Kajang Sed. Formation.

Exp. 1. Expressway. Kajang Sed. Formation

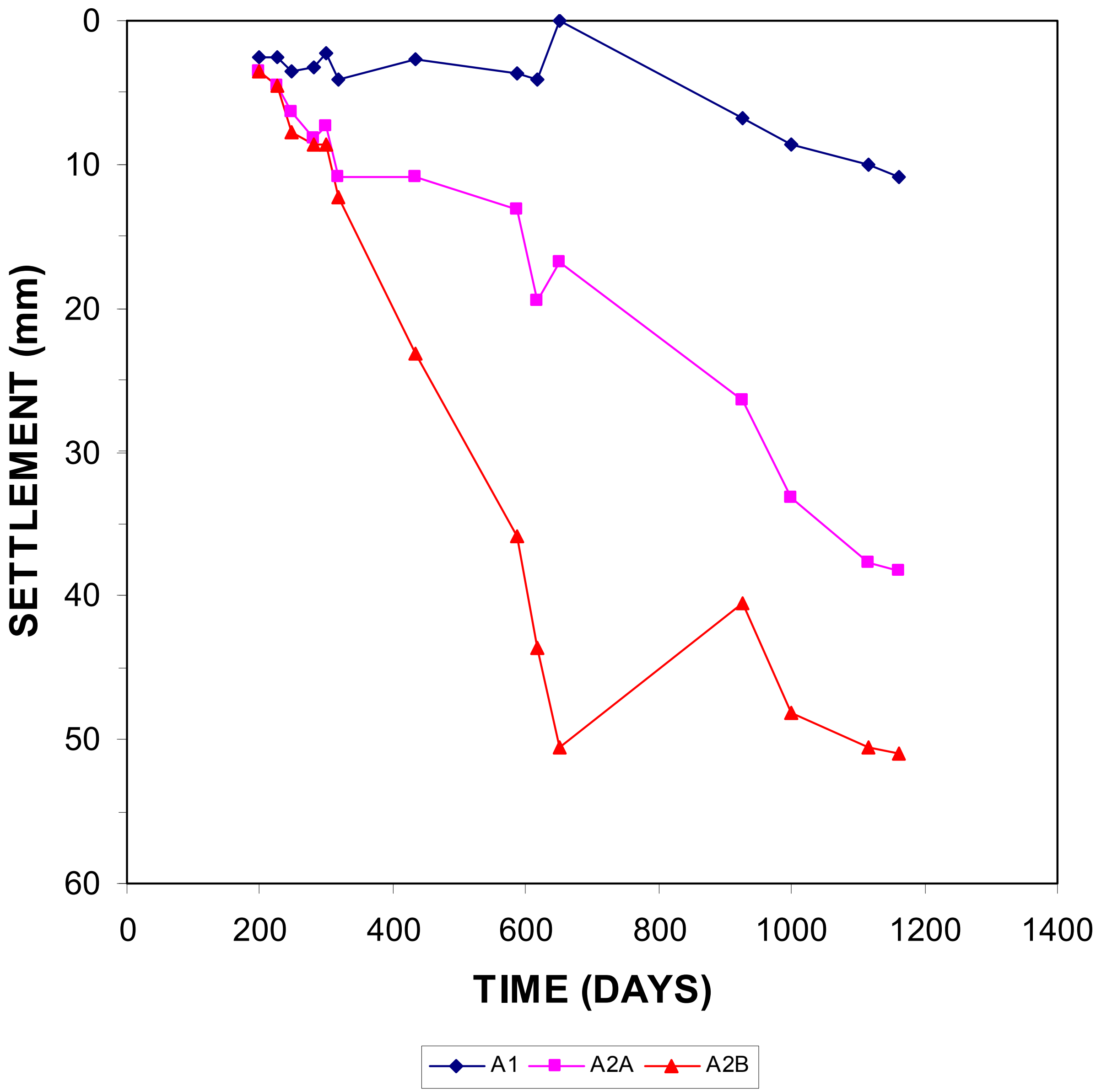
Exp. 1. Expressway. Kajang Sed. Formation.

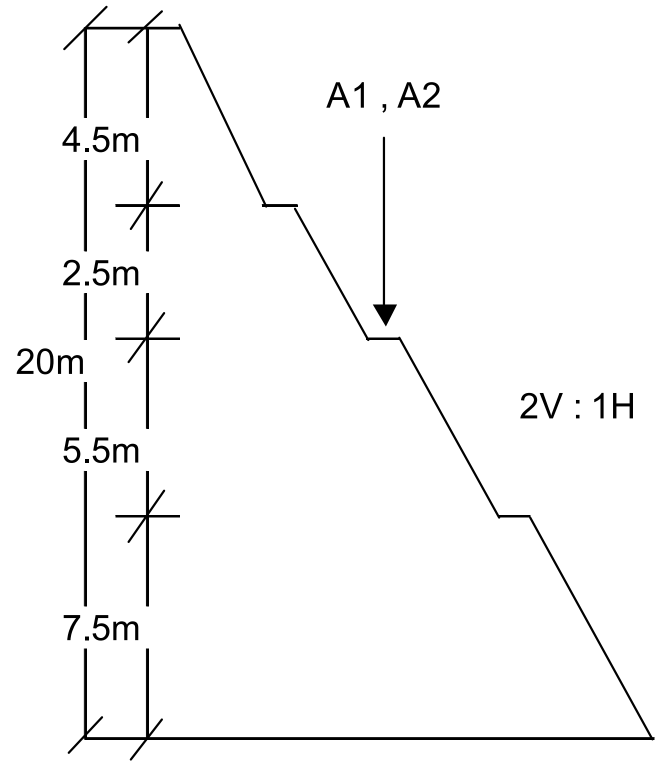
Ex. 1. Expressway. Kajang Sed. Formation.

- Approximate embankment ht. = 10 m.
- Undulations on pavement noticeable when settlements about 300 to 500 mm.
- Therefore approximate settlement / fill thickness ratio about 3 to 5 %. (Compare with average of 0.15 % for compacted sed. soil fill)

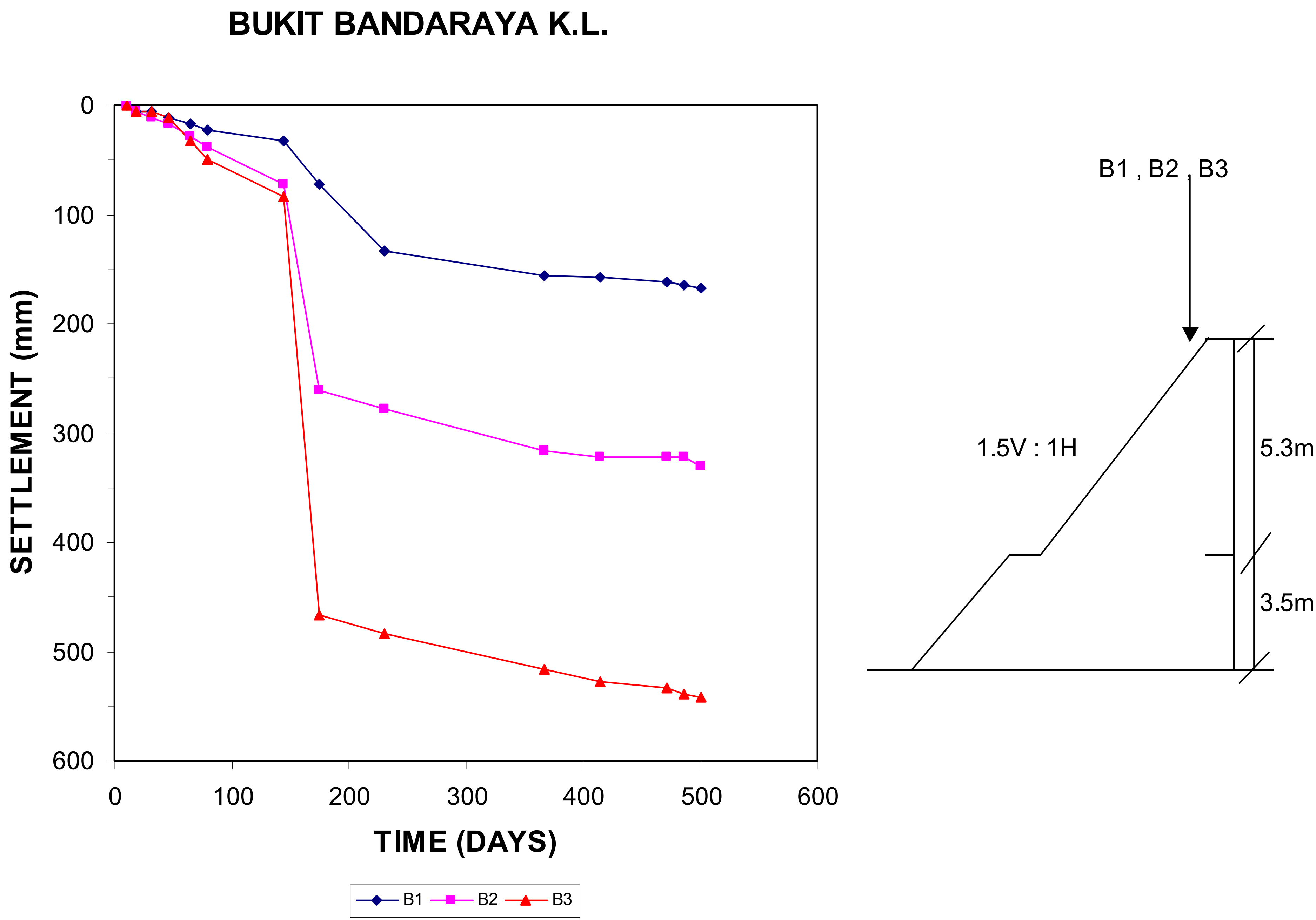
Ex. 2. Bukit Bandaraya (SITE A)

BUKIT BANDARAYA K.L.





Ex. 2 BUKIT BANDARAYA (SITE B)


BUKIT BANDARAYA K.L.
SETTLEMENT (mm)
0
100
200
300
400
500
600
TIME (DAYS)
0
100
200
300
400
500
600
B1
B2
B3
B1 , B2 , B3
1.5V : 1H
5.3m
3.5m

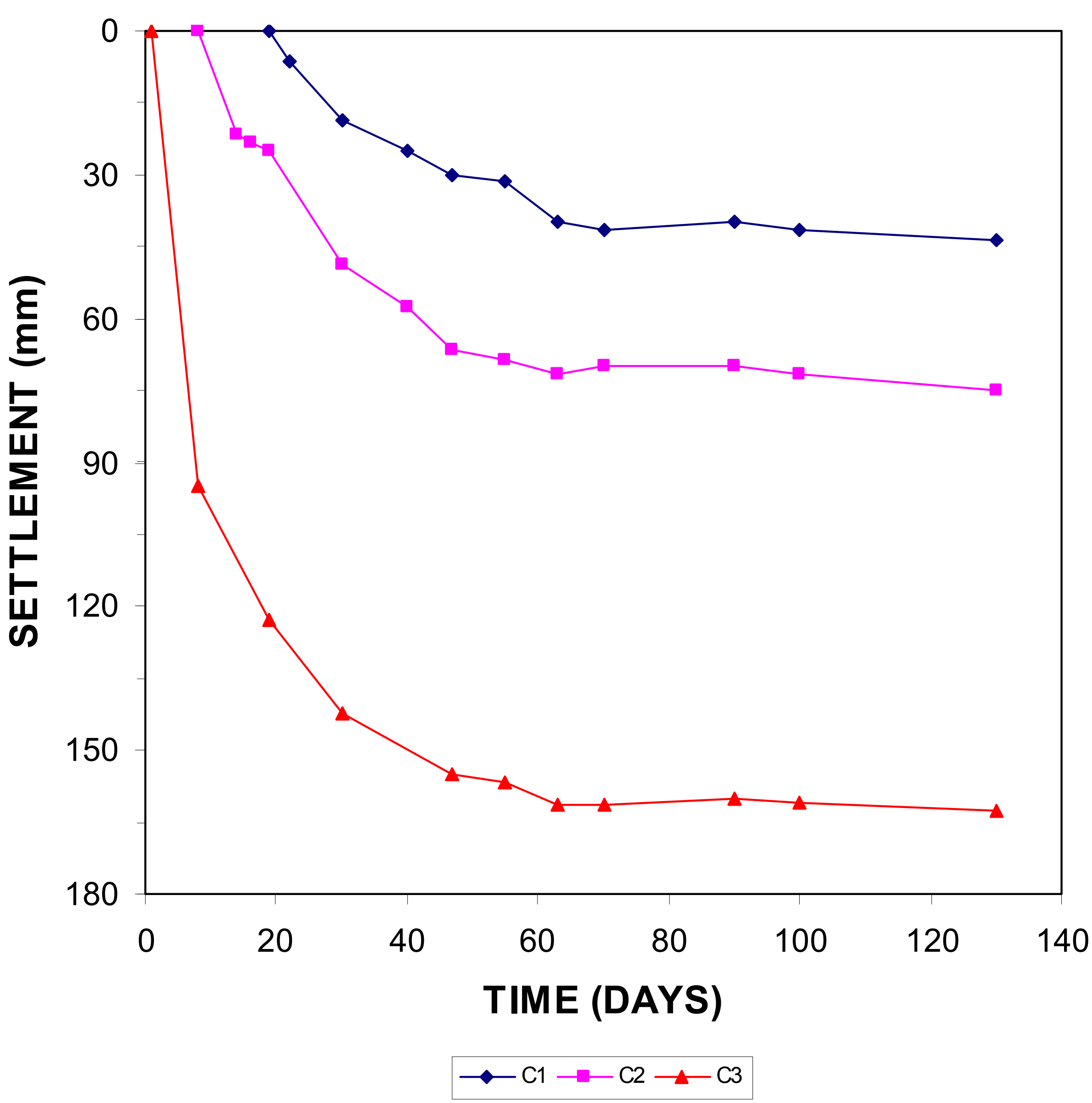
Bukit Bandaraya . Site B

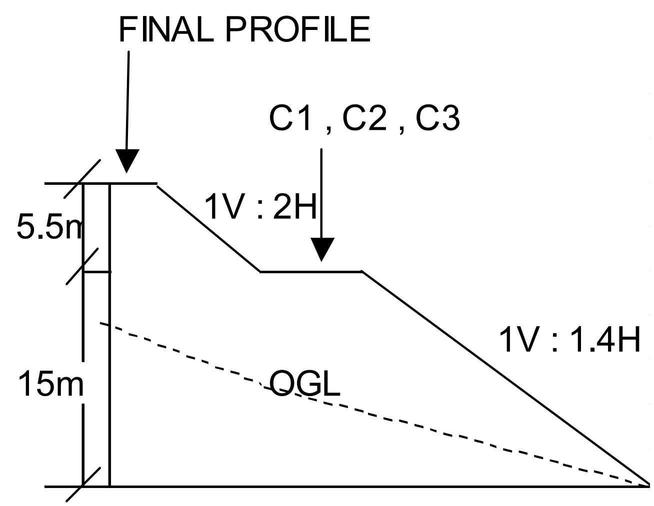
- Collapse settlement approximately 500 mm.
- Thickness of fill about 8 m.
- Fill compression / fill thickness ratio of about 6 %.
- Fill placed in layers (maybe 500 mm) and compacted with rollers.

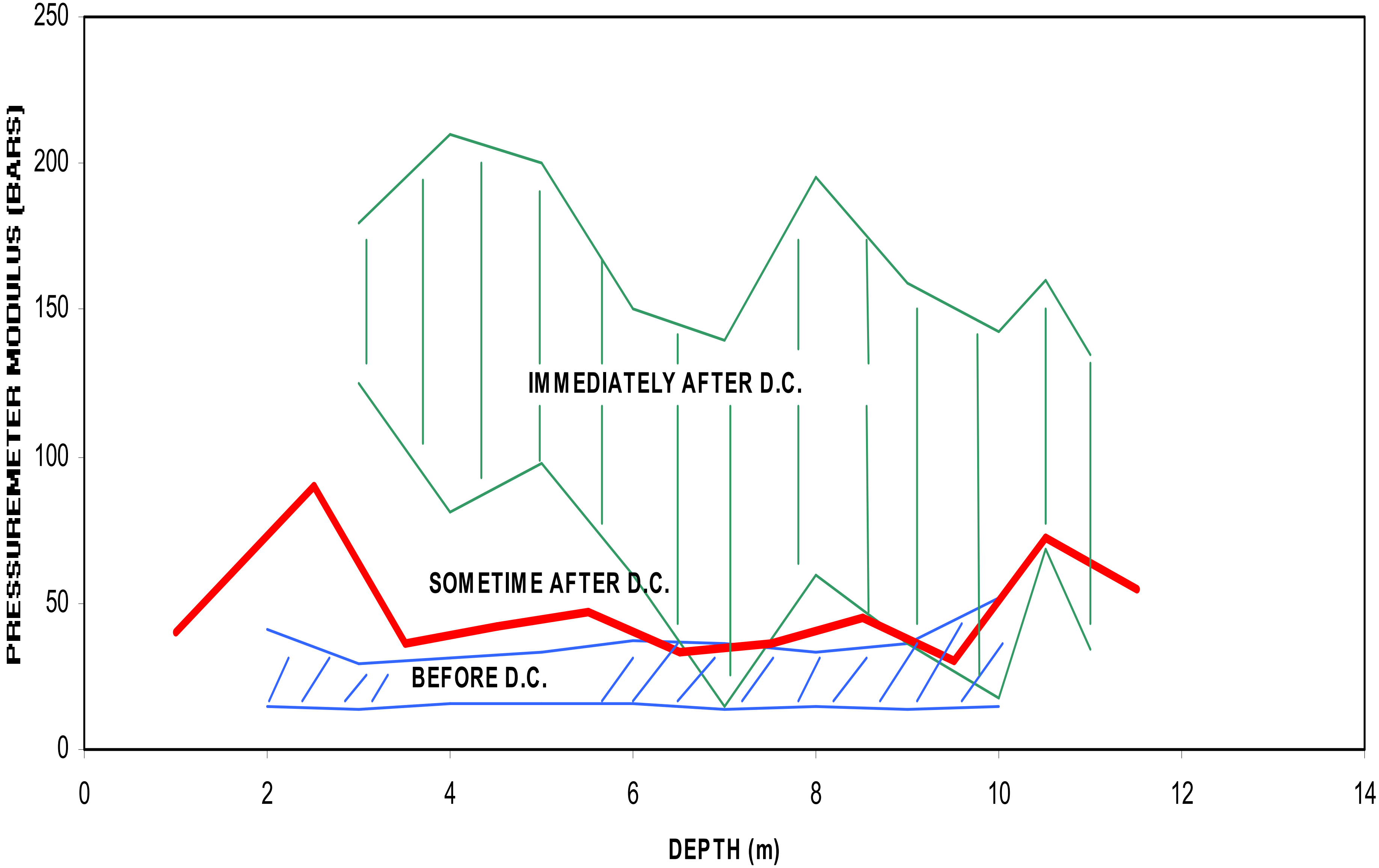
Ex. 2. BUKIT BANDARAYA (SITE C)

Fill placed in 3 layers of about 6 m lifts and each layer compacted using Dynamic compaction.

BUKIT BANDARAYA K.L.







PRESSUREMETER MODULUS (BARS)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
DEPTH (m)
IMMEDIATELY AFTER D.C.
SOMETIME AFTER D.C.
BEFORE D.C.

Bkt. Bandaraya Site C

- Total settlement exceeded that measured. Measurements started when settlement noticeable.
- Settlement occurred over about 2 to 3 months of heavy rainfall.
- Advantages gained by Dynamic Compaction virtually lost on soaking by rainfall infiltration.
- Settlement / fill thickness ratio > 1 %. Possibly 2 to 3 %.

EX. 3 Nilai area. Kajang Formation.

Ex.3 Nilai

- Filling between 1995 and 1997.
- Fill thickness range up to 15 m.
- Soil – weak rock mix material placed in layers.
- Building on shallow foundations started at end Nov. 1997.
- Heavy rainfall in October & Nov. 1997.

Ex. 3 Nilai

- Settlement monitoring in July / August 1998 showed settlement rates of up to 0.6 mm per day.
- Settlements between November 1997 and July 1998 (8 months) estimated to be up to 150 mm.
- Total compression of fills from end of filling up to July 1998 expected to be appreciably higher.

Ex. 3 Nilai

- Collapse settlement significantly in excess of 1 %. Possibly higher than 2 to 3 %.
- Part completed structures demolished and buildings reconstructed on piles driven thru the fill and down graded for negative skin friction.

Ex. 4 Selangor. Kenny Hill Formation.

Ex.4 Selangor. Kenny Hill

- 15m to 18 m thick fill.
- Large no. of buildings (> 150 units) in distress due to excessive settlement and subsequently demolished.
- Estimated collapse settlement = 400 mm.
- Settlement / fill thickness ratio about 2.5 %.

Ex. 4 Selangor. Kenny Hill.

- Fill characterized by soil size particles and abundant weak shale fragments / boulders. A lot of the shale fragments / boulders were up to 500 mm. The shales of low and medium durability. Slake durability index range from 56 to 95 %.
- Field density checks on the soil show dry densities ranging mostly between 85 % and 100 %.
- More than 50 % samples > 90 % MDD.
- 17 % samples with MDD between 85 and 90 %.

Ex. 4. Selangor.

Pit	Relative compaction compared to MDD inside pit. (%)
A	92, 91, 85. 80
B	77, 96, 99, 95
C	94, 98, 90
D	83, 99, 92
E	97, 84, 88

Ex. 4 Selangor.

- The field density tests indicate that efforts had been made at compacting the fill. However the resulting degree of compaction varied considerably.
- Within one location, compaction varied from 80 to 92 % over a distance of less than 2 m. This is likely because the energy imparted by the roller compacter may have been spent in breaking up some of the weak boulders rather than densifying the soil.

Ex. 4. Selangor.Slake Durability Index of shales (%).

Location	1st cycle	2nd cycle
1	76.0	56.7
2	92.8	87.0
2	84.6	75.6
3	69.7	51.3
3	82.5	67.8
4	91.4	88.2
4	94.2	89.1

Ex. 4 Selangor. Slake durability Index of shales (%).

Location	Cycle 1	Cycle 2
5	90.4	87.2
5	92.9	84.9
6	70.0	65.6
6	96.0	93.6

Gamble's Slake Durability Classification.

Group name	1st cycle (%)	2nd cycle (%)
V. high dura.	> 99	>98
High dura.	98 - 99	95 to 98
Med high dura	95 – 98	85 to 95
Med dura.	85 to 95	60 to 85
Low dura.	60 to 85	30 to 60
V. Low dura.	< 60	< 30

Ex. 4 Selangor

- Most of the shales are of Medium durability and worse.
- Likely major cause of the significant compression of fill is deterioration of the shale boulders.
- Infiltration substantial as surface dries rapidly after rainfall.

Ex. 5 Pulai Interchange

PULAI INTERCHANGE APPROACH EMBANKMENTS.

Bukit Resam Clastic Formation

Ex. 5. Pulai interchange

- Mix of soil and sandstone deposited in layers of about 500 mm to 1000 mm. Sandstone boulders up to 300 to 800 mm dimensions.
- No settlement measurements but observations of road levels indicate minimal differential settlements between pile abutment and embankment (SURPRISE!)

Ex. 5 Pulai Interchange.

- Excavation pits to uncover actual sizes and types of materials must be carried out by hand assisted with excavator.
- Photos show the mix and sizes of materials.
- Photos show presence of voids between larger sandstone pieces.
- Photos show potential piping holes at the surface.

Ex. 5. Pulai I/C. Thick lifts. All sizes. All types.

Ex. 5. PULAI I/C. Sandstone boulders of variable sizes.

EX. 5. Pulai. Weak sandstone boulders up to 800 mm.

Ex. 5. Pulai. Surface conditions after each thick lift.

Ex. 5. Pulai. Surface conditions after each thick lift.

Ex. 5. Pulai. Excavating fill. 800 mm size boulders.

Ex. 5. Pulai I/C. Deep voids.

Ex. 5. Pulai I/C. Piping hole

Ex. 5. Pulai I/C. Boulders, voids, piping hole

Ex. 5. Pulai I/C. Materials hand excavated from trial pits.

Ex. 5. Pulai I/C. Fragments and sandstone boulders

Ex. 5. Pulai I/C. Weak sandstone boulder broken on exposure.

Ex. 5. Pulai I/C. Piping holes and voids.

Ex. 5. Pulai I/C. Voids, fragments and piping holes.

Ex. 5. Pulai I/C. Voids beneath flat boulder

Ex. 5. Pulai I/C. Piping holes and voids

Ex. 5. Pulai I/C. Piping holes / voids

Ex. 5. Pulai I/C. Piping hole appearing at surface.

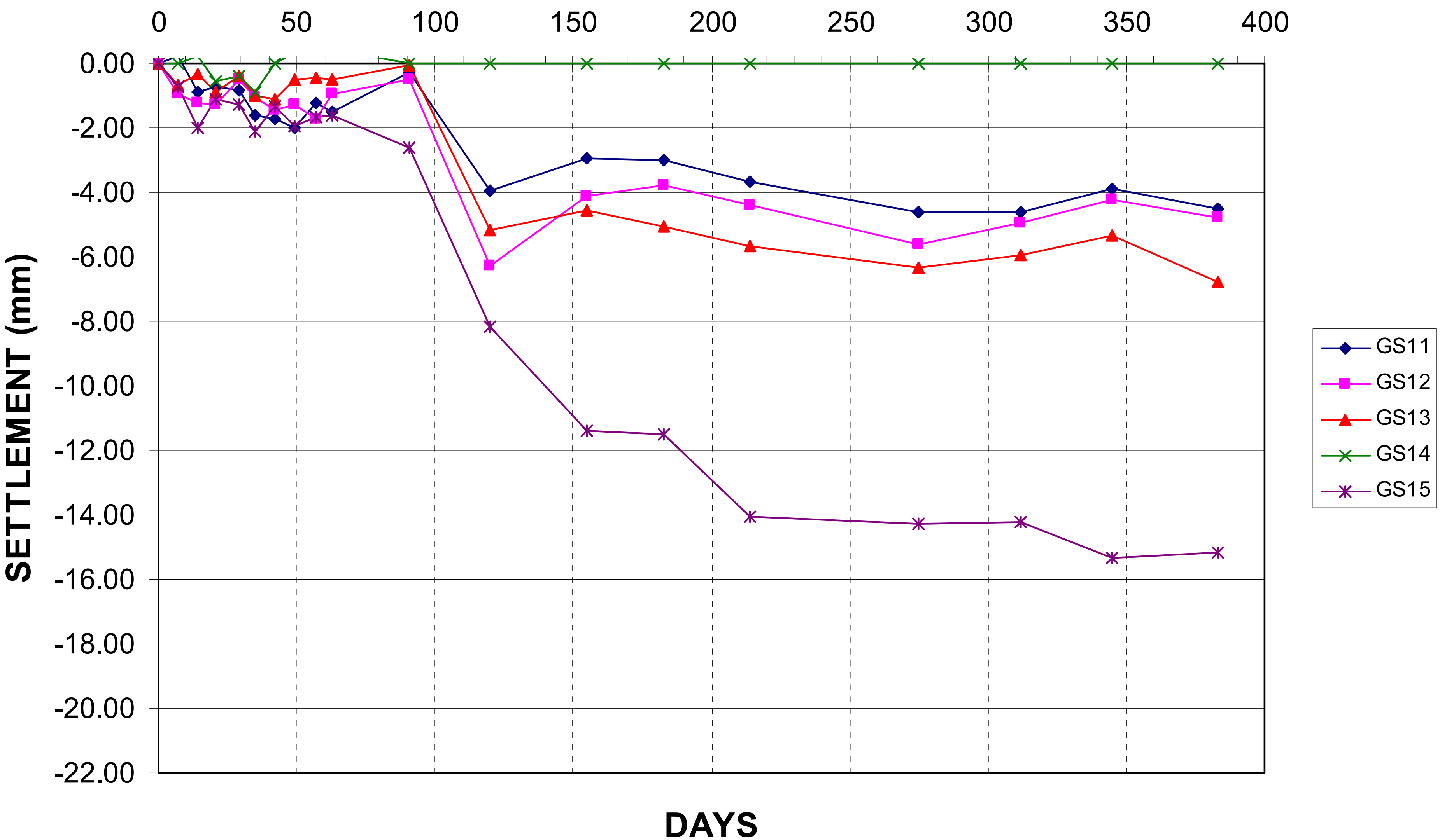
Ex. 5. Pulai I/C. Piping hole appearing at surface after rain.

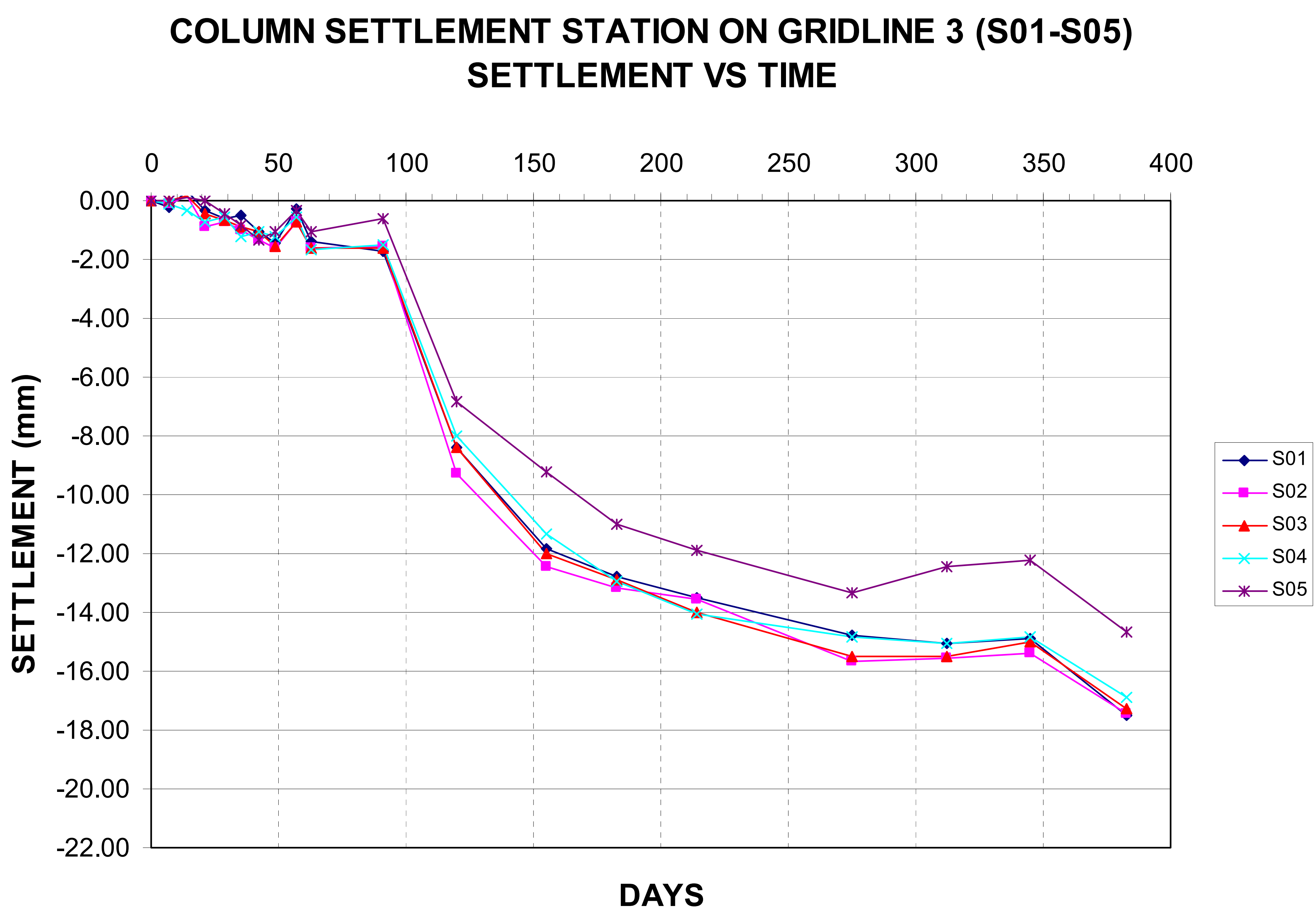
Ex. 6. LEMBAH BERINGIN

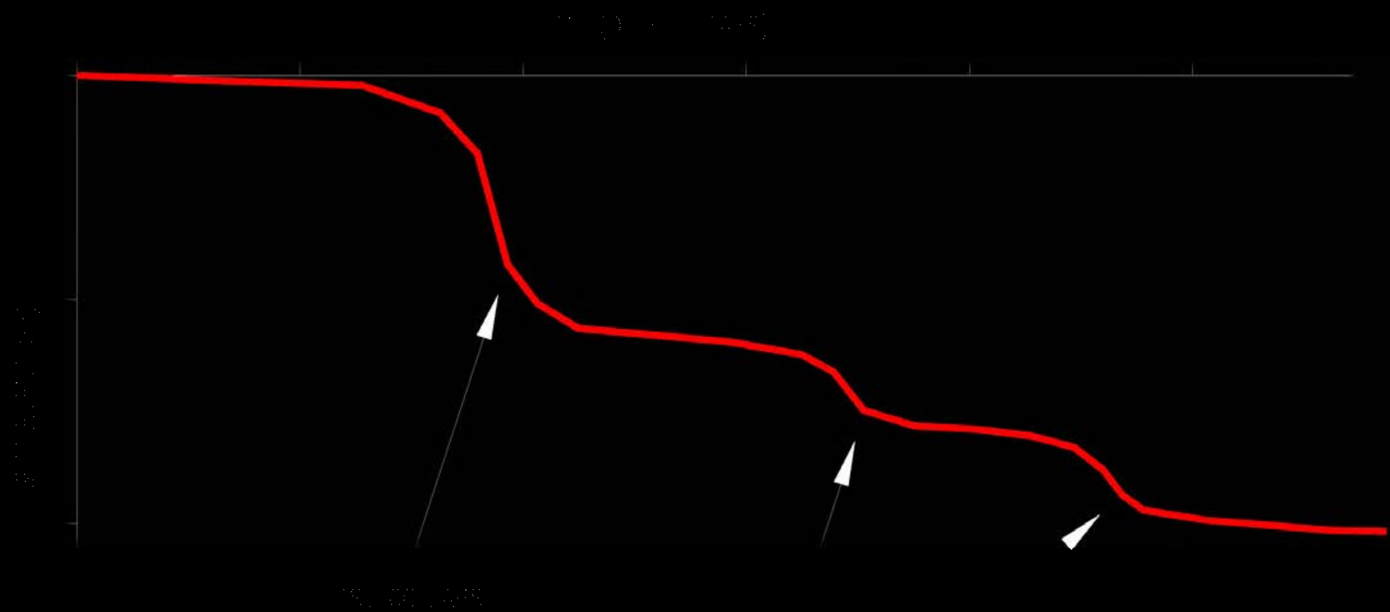
- LONG TERM COMPRESSION CAUSING DISTRESS TO PILE FOUNDATIONS.

- CRACKS TO BUILDINGS.

(GOUND SETTLEMENT STATION 11-15)
SETTLEMENT VS TIME




COLUMN SETTLEMENT STATION ON GRIDLINE 3 (S01-S05)
SETTLEMENT VS TIME
0
50
100
150
200
250
300
350
400
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
-22.00
SETTLEMENT (mm)
DAYS
S01
S02
S03
S04
S05



MORE EXAMPLES OF POORLY COMPACTED SOIL – WEAK ROCK

POORLY COMPACTED MUDSTONES

Poorly compacted Grade III mudstones. Not mixed with soil. Not crushed.

Fragments of mudstones not crushed. Inadequate soil.

Mudstone
too
hard.
Lift too thick.

Poorly compacted mudstones. Blocky pieces not crushed.

Poorly compacted and soaked mudstones. 100 mm sizes.

Poorly compacted mudstones. Loose soils, fragments and boulders.

Poorly compacted sandstone, shale,mudstone,etc.

Grade II sandstone mixed with mudstones. 500 mm lifts.

Large sandstone pieces. Poor compaction. Voids.