Deep Dive Session – Construction Methodology Series

"PIPELINE PROTECTION THEORY AND SCHEMES

Subsea Pipeline Protection Philosophy and Typical Protection Designs"

By

Ng Eng Bin

Proprietor, Submarine Pipeline Consulting Engineers (SP*i*CE)

INTRODUCTION

– The purpose of this session is to explain the behaviour of a dropped/dragging anchor during an emergency.

– Conventional pipeline protection is based on covering the pipeline with a berm comprising one or more layers of sand, gravel and/or rock.

– This session also explains how a conventional rock berm affects the behaviour of a dragging anchor and subsequently providing the necessary protection.

Anchor Drop and Drag Mechanics

ANCHOR DRAG BEHAVIOUR

- The basis of the pipeline protection design is that anchor drop/drag will occur during an emergency.
- Anchors dropped onto the seabed may first penetrate a certain distance into the seabed depending upon the weight and shape of the anchor and the soil characteristics encountered.
- As the ship continues drifting, the anchor chain tightens and pulls the anchor over along the seabed.
- The pull exerted by the chain will cause the anchor to penetrate into the surrounding undisturbed soil.

ANCHOR DRAG BEHAVIOUR (cont'd)

- Anchor drag will occur as a result of shear failure along the shear plane.
- The pull exerted by the chain will cause the anchor to penetrate into the undisturbed soil.
- The holding power of the anchor is determined by the shear strength of the soil through which it is being dragged.
- Anchor drag will continue as the soil fails under the dragging anchor.
- Eventually, the resistance of the anchors on the soil will eventually slow down the vessel and cause it to stop.

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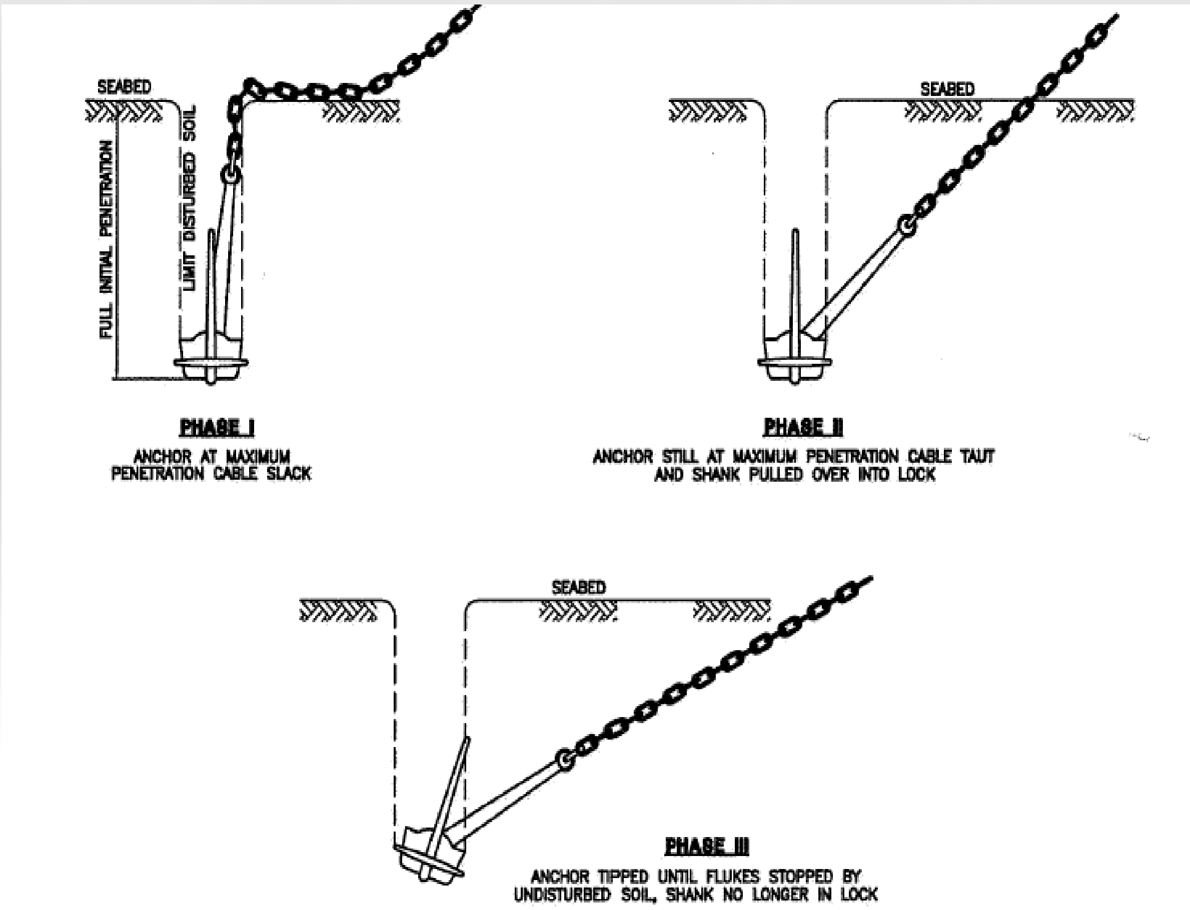
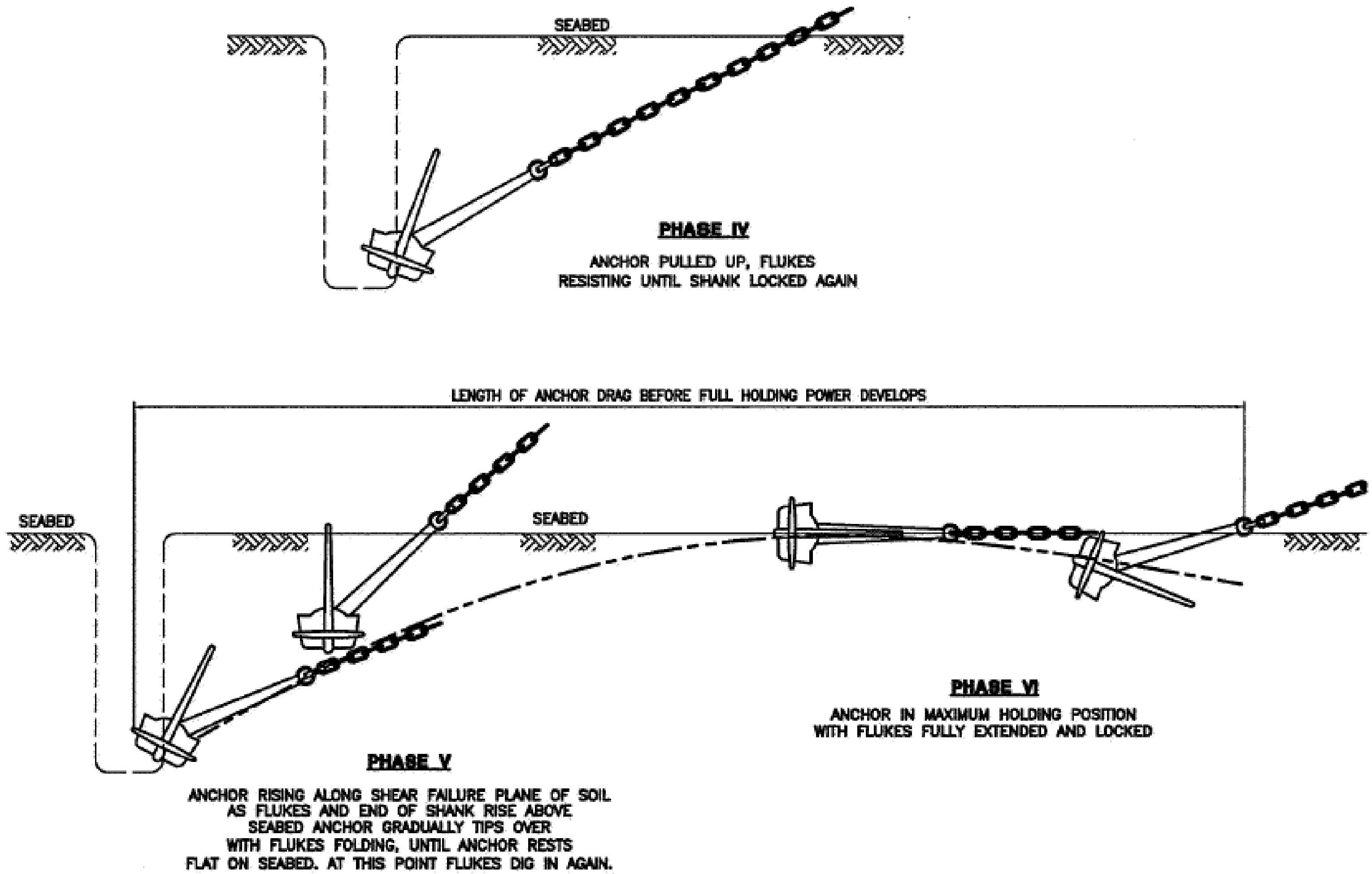
ANCHOR DRAG BEHAVIOUR (cont'd)

- The various stages of anchor dragging including the anchor configuration are shown schematically below.



ANCHOR DRAG BEHAVIOUR (cont'd)



Schematic Presentation of Initial Anchor Penetration and Drag

Considerations for Pipeline Protection Schemes against Emergency Anchor Drop and Drag

DRAGGING OF ANCHOR DROPPED IN AN EMERGENCY

- A ship under emergency conditions would drop the anchor and pay out at the most 2 to 3 "shots" of chains (1 shot = 27.5 m) and then lock the chain in the prevailing water depths.

- Under these circumstances, the anchor will penetrate into the seabed if the vessel is not moving so fast, but it will be pulled up rapidly to the surface due to the shortness of the chain paid out.

- Thereafter, the anchor will "bite" along the seabed and act as a brake to slow down the vessel.

DRAGGING OF ANCHOR DROPPED IN AN EMERGENCY (cont'd)

- On the other hand, if the vessel is moving more rapidly, the anchor will not be able to penetrate fully into the seabed, but may just penetrate slightly and then be pulled up rapidly and will 'bite' along the seabed and act as a kind of brake to slow down the motion of the vessel.

- Due to the force exerted by the vessel, the chain would be very taut and the anchor will be dragging and hopping intermittently along the seabed.

- Based on the above, the anchor in this mode would basically drag with the shank either on the seabed or just below it and the flukes will be at its maximum to the horizontal (35º – 45º depending on make of anchor).

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Design against Anchor Related Damage

The causes of anchor damage may result from either one of the three following scenarios:

- **Scenario 1 - Anchor Drop**
- **Scenario 2 - Initial Anchor Drag**
- **Scenario 3 - Continued Anchor Drag**

Design against Anchor Related Damage – Scenario 1

Scenario 1 - Anchor Drop:

- Anchor is dropped directly on top of the pipeline i.e. direct impact.

PRINCIPLE OF PIPE PROTECTION AGAINST DIRECT ANCHOR IMPACT

- Protection against direct impact of a falling anchor or other object is provided by covering the pipeline with a layer of materials (e.g. rock berm, concrete mattress, etc.) to insulate the pipe from direct impact and to absorb and spread the impact energy.
- Protection against dropped object is governed by two criteria. First, the expected penetration of the object into the protective material and secondly, the pressure force resulting from the impact.
- The penetration depth depends on the shape of the dropped object and the relative density of the protective material. In general, a larger anchor requires a deeper and coarser backfill than a smaller anchor.
- For an anchor that falls on a densely packed rock berm, the penetration depth would be small, resulting in a small time interval and high pressure forces. If, on the other hand, the anchor falls on a loosely packed berm, then the penetration depth would be larger and the pressure forces smaller.

PRINCIPLE OF PIPE PROTECTION AGAINST DIRECT ANCHOR IMPACT (cont'd)

- Therefore, to protect the pipeline from falling object (e.g. anchor), the pipeline protective layer should have sufficient thickness to provide against penetration and an additional thickness must be added to provide sufficient spread of the impact forces so that only acceptable pressure forces are exerted on the pipeline.
- Past tests have shown that the thickness of pipeline protection cover designed against anchor drag using a conventional rock berm almost always protect the pipeline from direct impact of that design anchor size. Hence, where a conventional rock berm protection design is utilised, design for direct impact becomes a secondary issue.
- For protection design using other means, such as concrete mattresses, detailed finite element simulation may be required, followed by factory tests.

Design against Anchor Related Damage (cont'd)

Scenario 2 - Initial Anchor Drag:

Anchor is dropped in the vicinity of the pipeline route and thereafter dragged across the route.

However, due to the shortness and tautness of the anchor chain (2-3 "shots" released in practice), the anchor will be dragged into the soil very rapidly and rise to the surface; it will then be dragged for most of the way along the top of the seabed strata. Thus, the anchor will ride over and above the pipelines provided that they are buried with sufficient clearance.

Design against Anchor Related Damage (cont'd)

- **Scenario 3 - Continued Anchor Drag:**

Anchor is dropped at a distance from the pipeline route and dragged over the route after its maximum holding power is exceeded. The anchor will have risen from its initial penetration into the seabed and be dragged for some distance before it stops.

If the anchor does not stop before the pipeline, the pipeline may be get damaged if not properly protected.

PRINCIPLE OF PIPE PROTECTION AGAINST DRAGGING ANCHOR

- Penetration by the anchor can be countered by changing the soil type and contour in which the anchor is dragging. This can be accomplished by an engineered backfill (e.g. rock berm) to influence the behaviour of the dragging anchor.

- The behaviour of an anchor approaching and/or penetrating into a rock berm is influenced by following two mechanisms:
  1. changing of angle of the anchor chain resulting in a vertical uplift force
  2. instability of the anchor due to uneven loads on anchor flukes (after penetration into the rock berm)

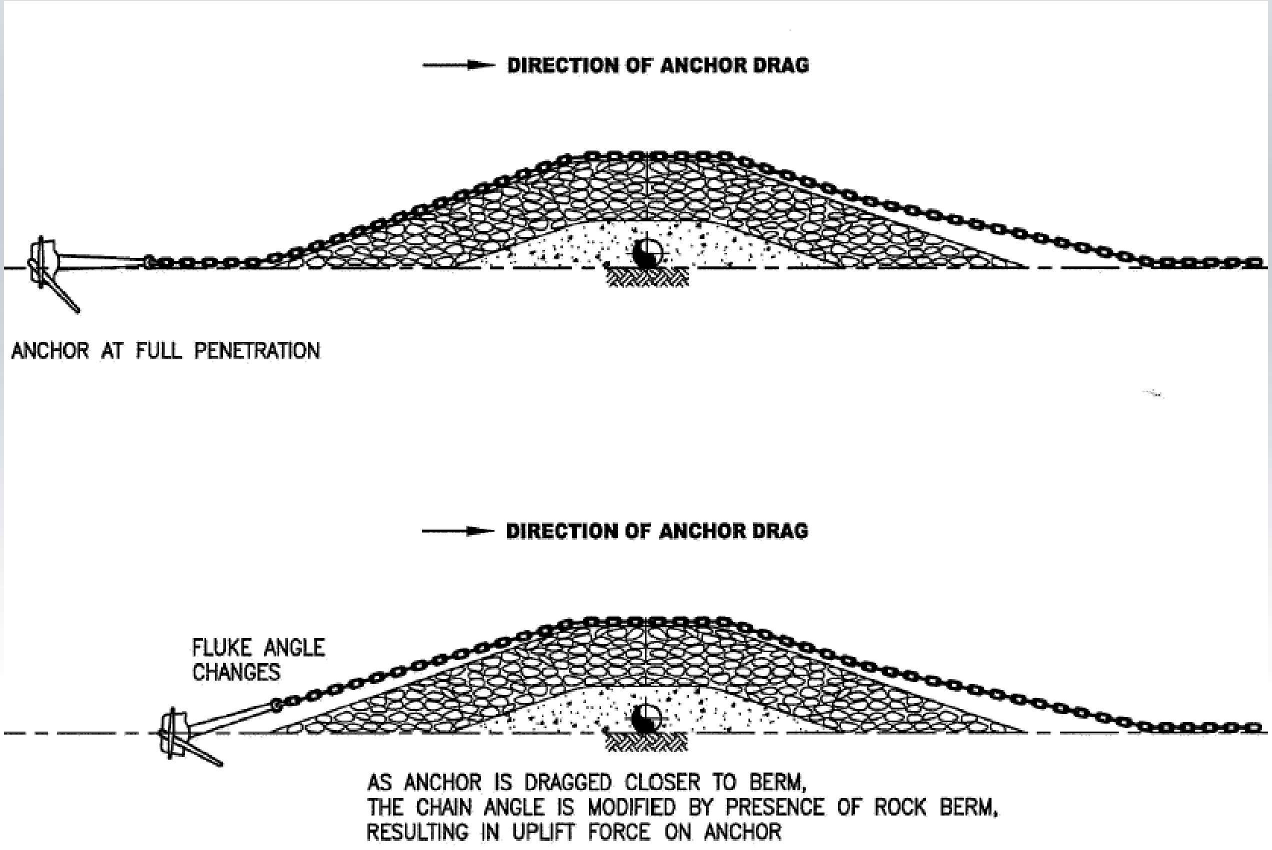
PRINCIPLE OF PIPE PROTECTION AGAINST DRAGGING ANCHOR (cont'd)

These two mechanisms can be demonstrated with two types of pipeline protection:

1. a rock berm on a pipeline lying on the original seabed (see Illustration A) ; and
2. a rock berm on a pipeline lying in a trench, as is the case with this project (see Illustration B).

BEHAVIOUR OF DRAGGING ANCHOR AND IMPACT OF ROCK BERM ON ITS BEHAVIOUR (Illustration A)

- Figure below shows the behaviour of an anchor as it approaches and crosses a rock berm sitting on the original seabed. A similar behaviour is expected for an anchor crossing a berm in a trench.



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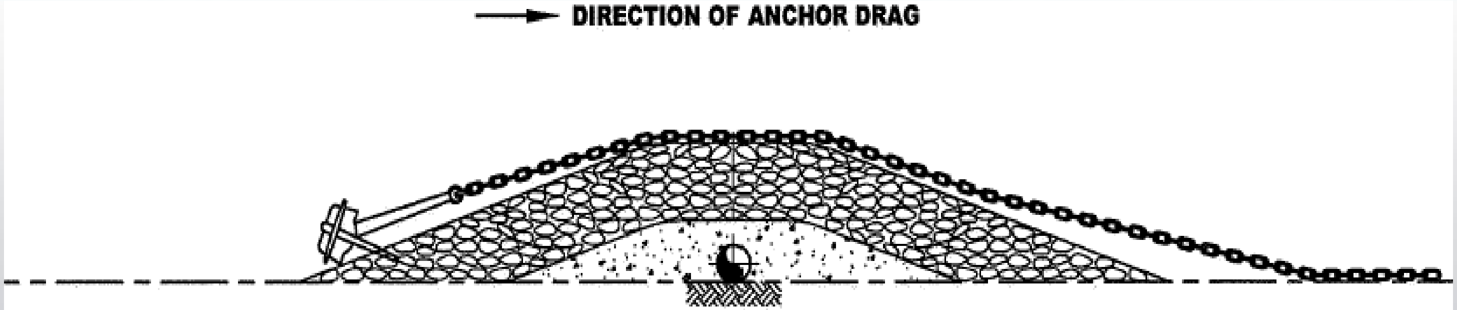
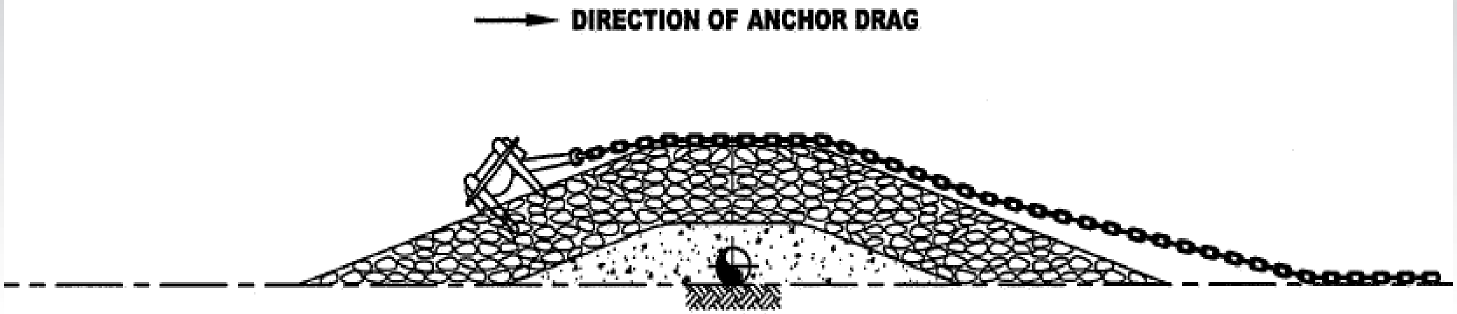
BEHAVIOUR OF DRAGGING ANCHOR AND IMPACT OF ROCK BERM ON ITS BEHAVIOUR (Cont'd)

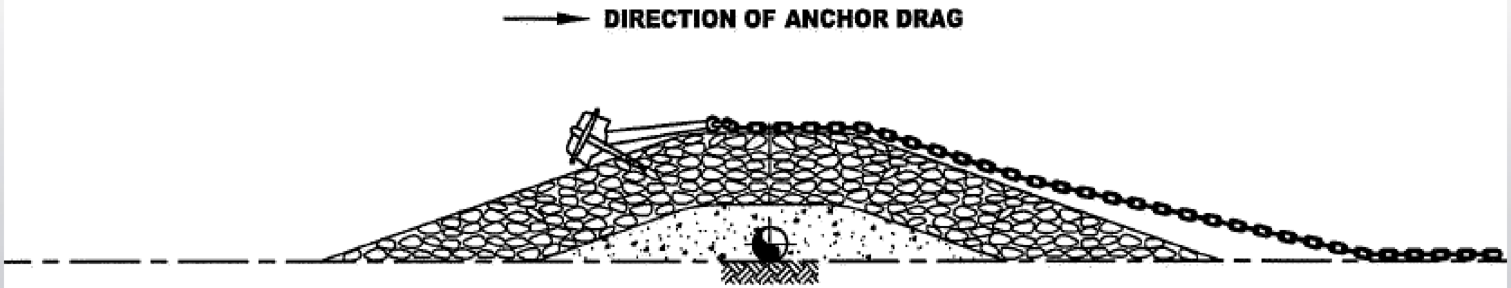


ANCHOR FLUKES PENETRATE ROCK BERM AND
EXPERIENCES UNEVEN LOADING CAUSING ANCHOR INSTABILITY

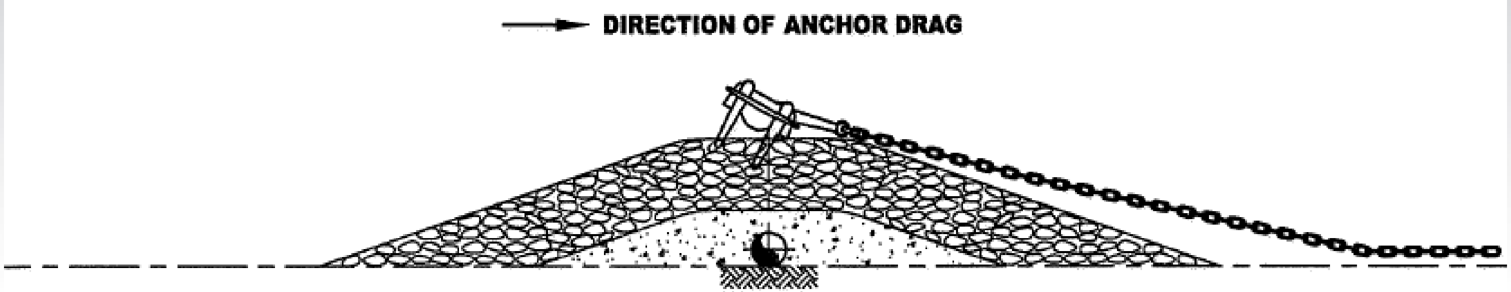


ANCHOR BREAKS OUT OF BERM
DUE TO INSTABILITY CAUSED BY UNEVEN LOADING

BEHAVIOUR OF DRAGGING ANCHOR AND IMPACT OF ROCK BERM ON ITS BEHAVIOUR (Cont’d)



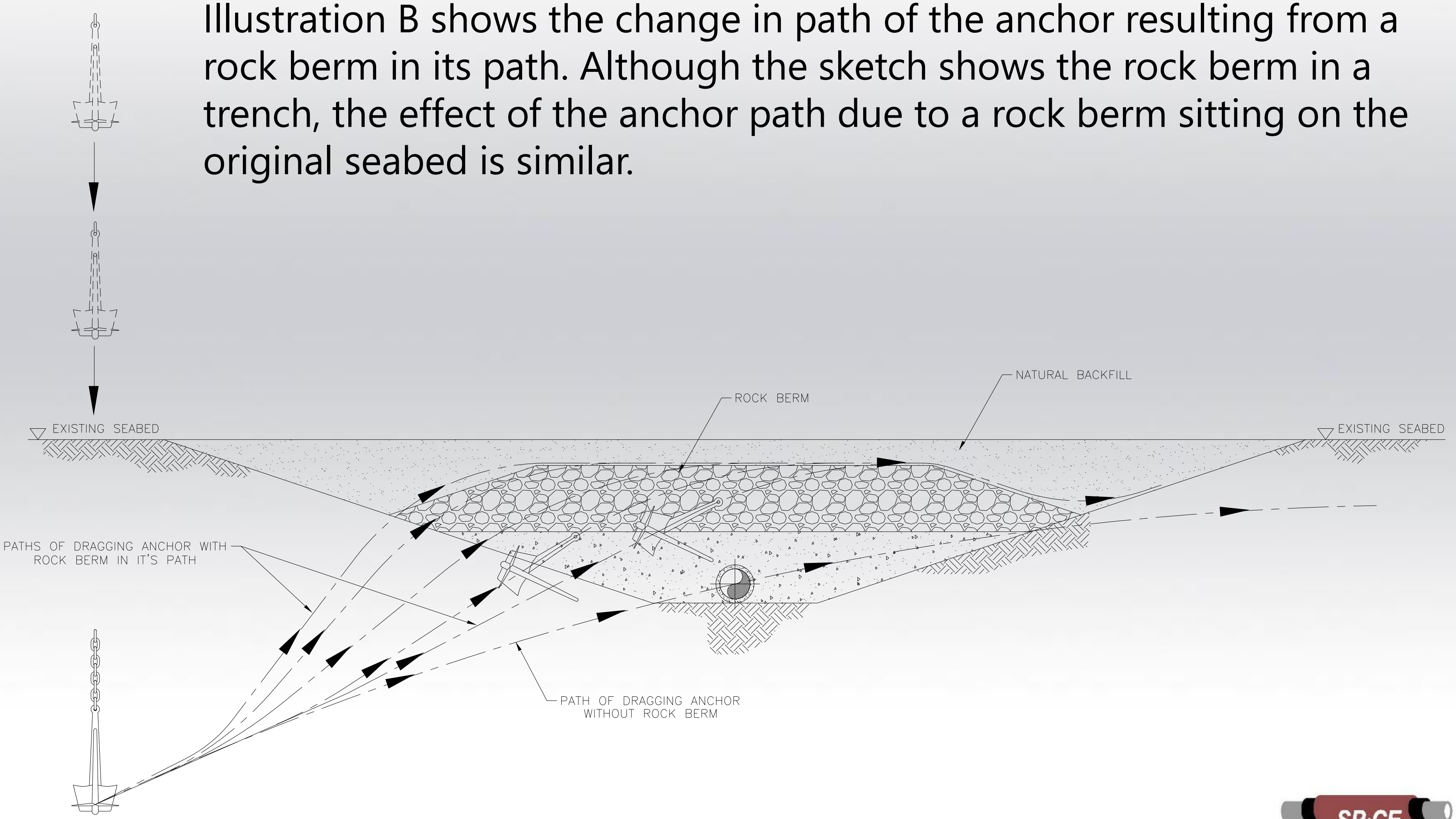
ANCHOR "WALKS" ON BACKFILL CAUSING LIMITED DAMAGE



ANCHOR "WALKS" ON BACKFILL CAUSING LIMITED DAMAGE

Schematic Showing Effect of Rock Berm (In Trench) on Anchor Path

Illustration B shows the change in path of the anchor resulting from a rock berm in its path. Although the sketch shows the rock berm in a trench, the effect of the anchor path due to a rock berm sitting on the original seabed is similar.



PRINCIPLE OF PIPE PROTECTION AGAINST DRAGGING ANCHOR (cont'd)

A series of model tests from past projects have shown that:

- both mechanism work in combination to protect the pipeline. However, mechanism (i), i.e. changing of anchor chain angle due to presence of the berm, is less important for the design when the berm is in the trench unless the anchor has penetrated very deeply into the soil;

PRINCIPLE OF PIPE PROTECTION AGAINST DRAGGING ANCHOR (cont'd)

- anchors dropped a distance from the berm would have broken out before reaching the berm, and the anchor would be pulled through the toe of the berm before finally breaking out due to uneven loads on the anchor flukes;

- after breaking out of the berm, anchors dragged across the berm would cause limited damage;

- the larger is the anchor, the deeper is the berm and the larger is the rock required for the berm.

EFFECT OF TRENCH SLOPE ON PIPE PROTECTION

- In terms of pipeline protection provided by the trench and backfill, it is desirable to have gentle trench side slopes. Elaborate tests performed in the past have shown that for sandy soil, a trench slope of about 1:3 is desired, although trench slopes of 1:2 could also yield acceptable results.

- A gentle slope and the correct berm depth will ensure that the berm deflects the anchor out before it cuts into the pipe. When the slope is too steep and the surrounding soil is soft, the possibility of anchor cutting into the berm and pipe is very high.

Pipeline Protection Schemes against Anchor Drop and Drag

PROTECTION SCHEME OPTIONS

Typically two alternative protection schemes are used for considerations. These are:

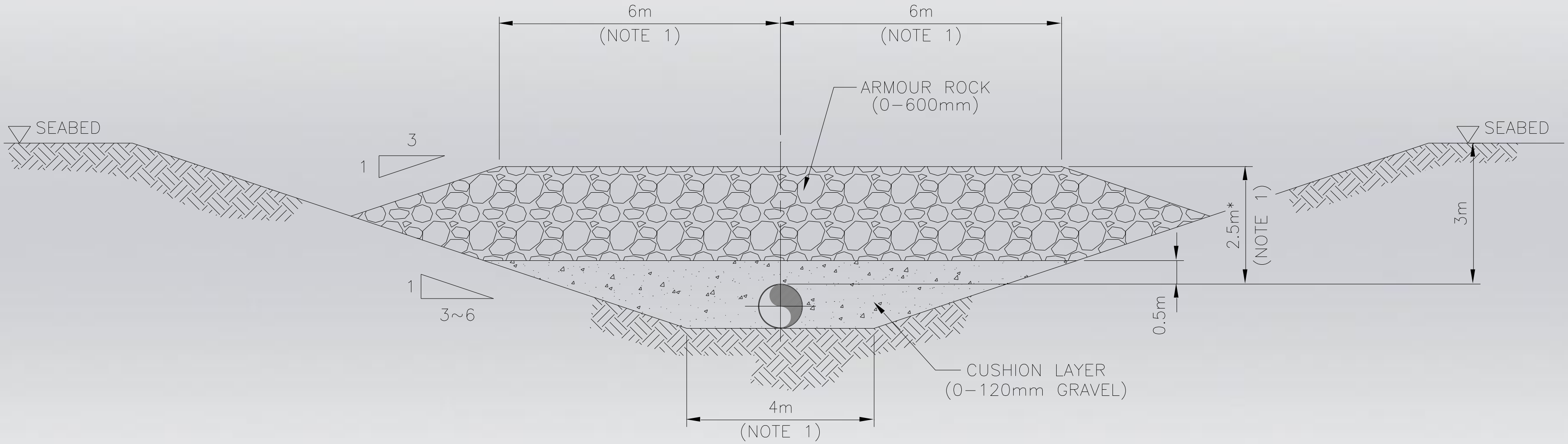
Scheme No.	Description
1	Conventional Armour Rock Protection with Two layer Rock
2	Conventional Armour Rock Protection with Single layer Rock

PROTECTION SCHEME OPTIONS

Briefly, the key features of the various schemes are described below:

- Scheme No. 1 - Conventional Armour Rock Protection with Two layer Rock (Figure A)
- This is a well tested and well used conventional design.
- The first layer of gravel/rock mixture acts to cushion impact of anchor and armour rocks on pipeline and on trench substrate.
- The cushion layer also provides additional separation between anchor fluke and pipeline.
- The top armour layer provides the required protection against a dropped and dragging anchor.

As an example, the SEPL Bundled Pipelines/Cables Project from Bukom to Seraya in Singapore adopted this scheme.



NOTE

1. DIMENSIONS SHOWN ARE TYPICAL. TO BE FINALISED DURING DETAILED DESIGN

Figure A - Conventional Armour Rock Protection with Two Layer Rock

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PROTECTION SCHEME OPTIONS (cont'd)

Scheme 2 - Conventional Armour Rock
Protection with Single layer Rock (Figure B)

- This is another tested and used conventional design.
- The armour berm provides the required protection against a dropped and dragging anchor.
- The simplicity in design minimises logistics and installation requirements.
- Careful selection of rock grading is required.

PROTECTION SCHEME OPTIONS (cont'd)

- As an example, the West Natuna Gas Pipeline Project in Indonesia adopted this scheme.

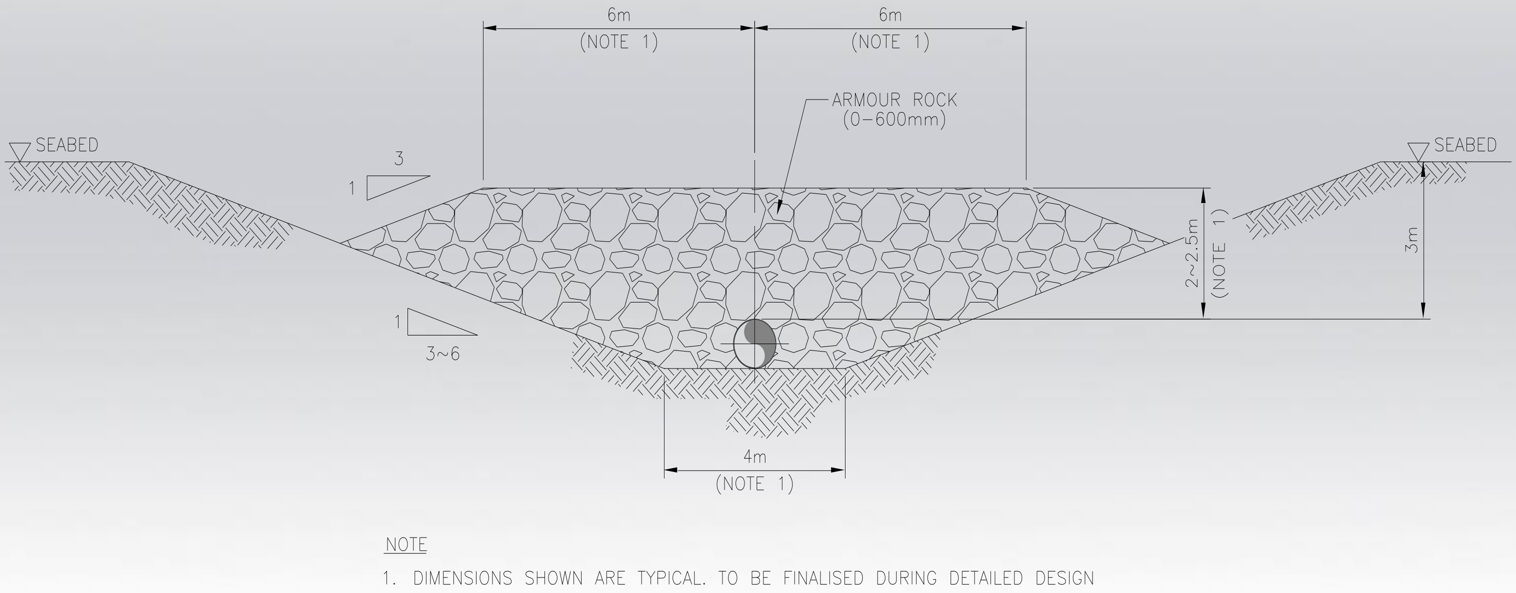
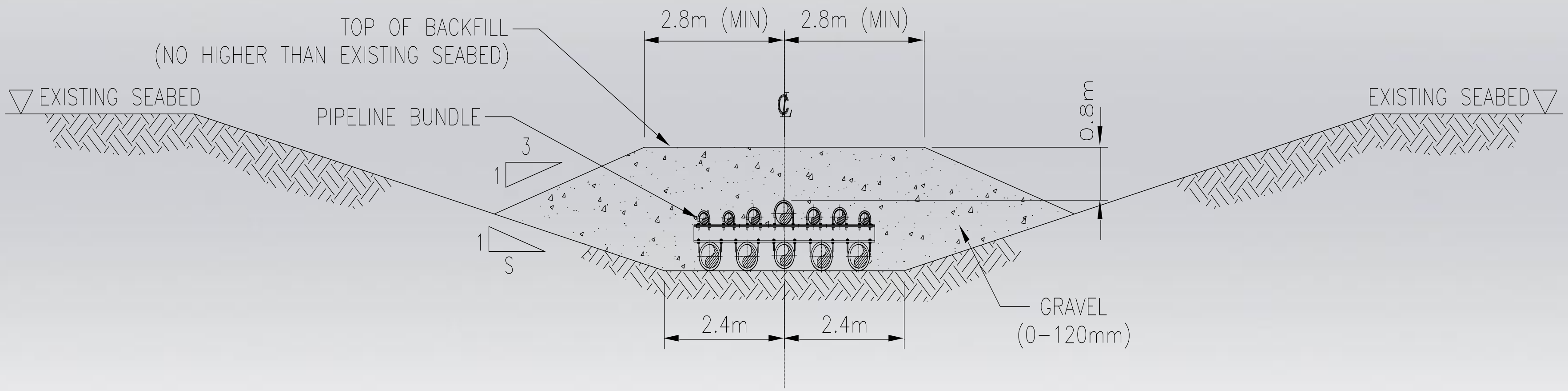


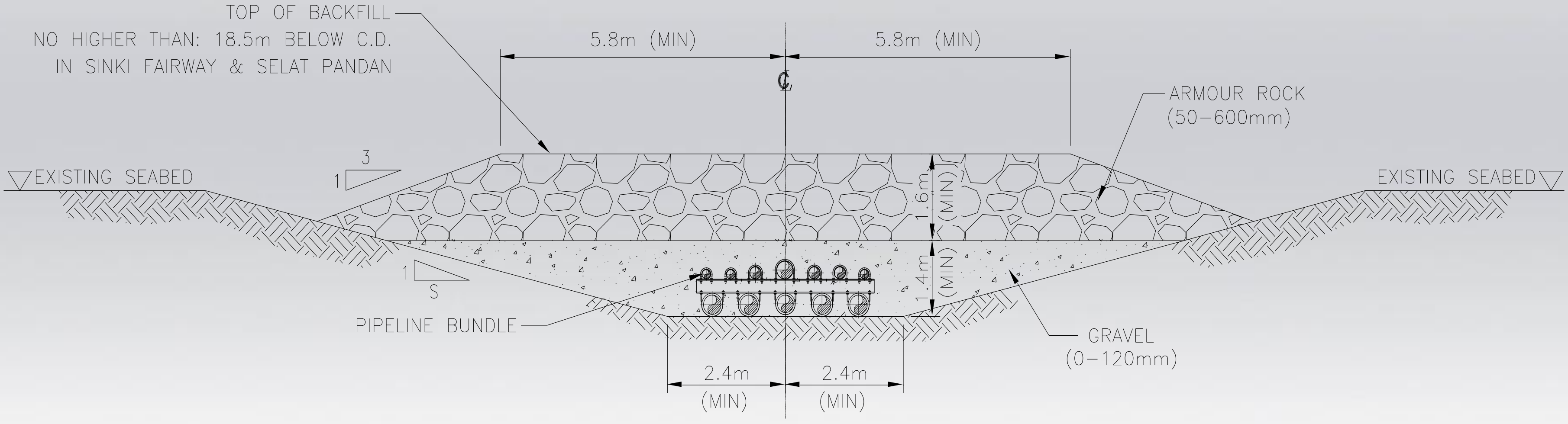
Figure B - Conventional Armour Rock Protection with Single Layer Rock

Examples of applications in Singapore



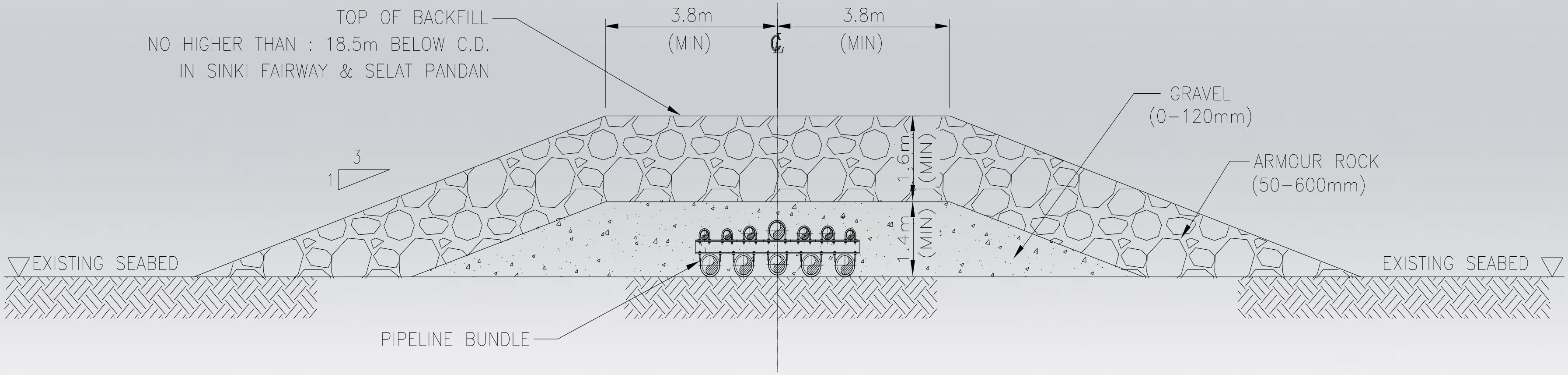
TYPE I - LANDFALL APPROACHES AND AREAS OUTSIDE FAIRWAYS

Examples of applications in Singapore (cont'd)



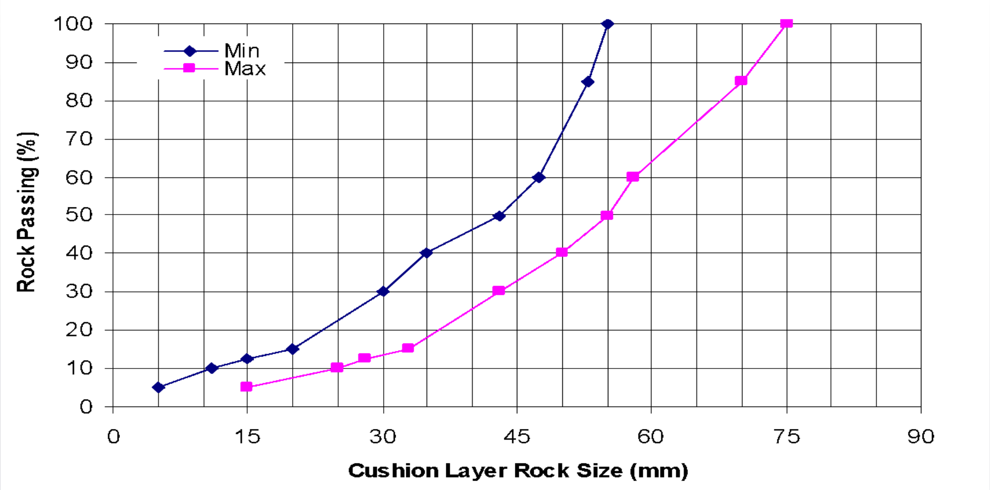
TYPE II - WATER DEPTH <21.5m MIN. IN SINKI FAIRWAY & SELAT PANDAN

Examples of applications in Singapore (cont'd)

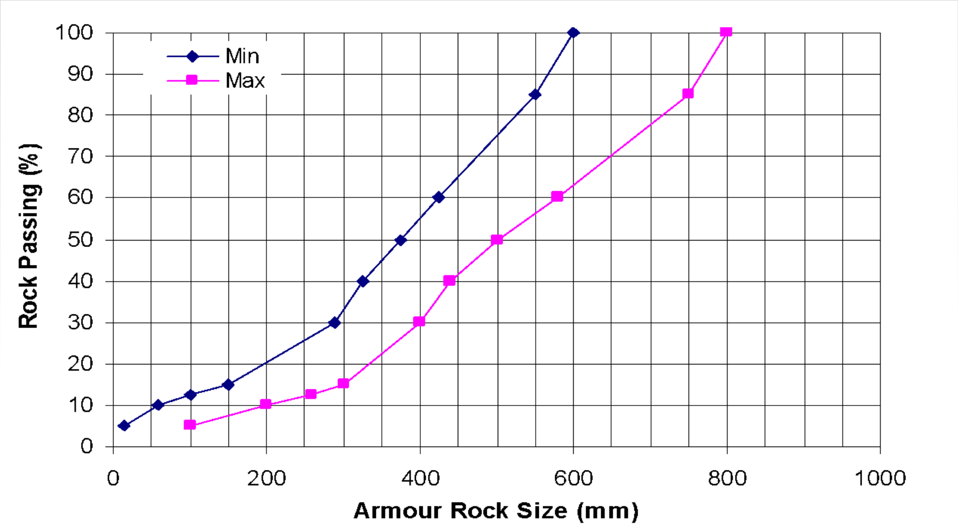


TYPE III - SHIPPING FAIRWAY : WATER DEPTH ≥ 21.5m MIN. IN SINKI FAIRWAY & SELAT PANDAN

Typical Examples of Grading Curves for Backfill



Typical Grading Distribution Curve for Cushion Layer Rocks



Typical Grading Distribution Curve for Armour Rocks

Verification of Pipeline Protection Design against Anchor Drag

'Conventional' Method of Testing Rock Berm Design – Scaled Model Tests

Preparation of prototype model for anchor drag test

Example of Drag Testing of Prototype Model

Actual anchor drag testing of prototype model

- ✓ extremely primitive
- ✓ doubt if we can get consistent result
- ✓ Modelling of the prototype rock berm is good, but way in which anchor is dragged is questionable on whether it reflects actual anchor behaviour

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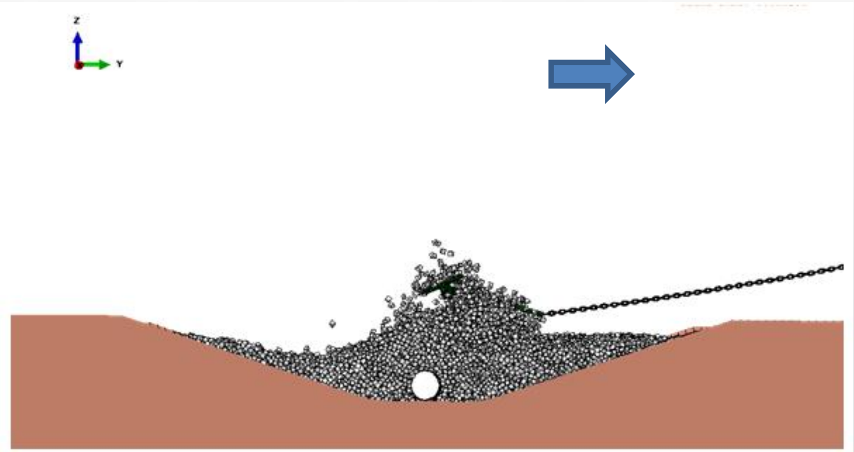
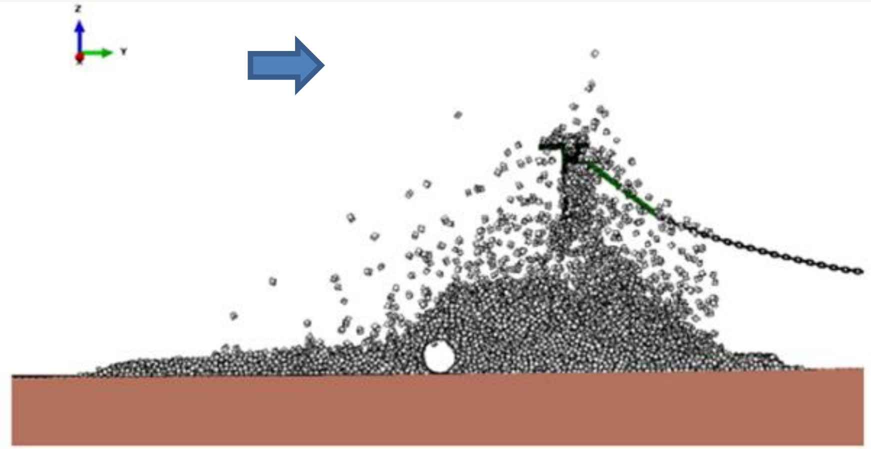
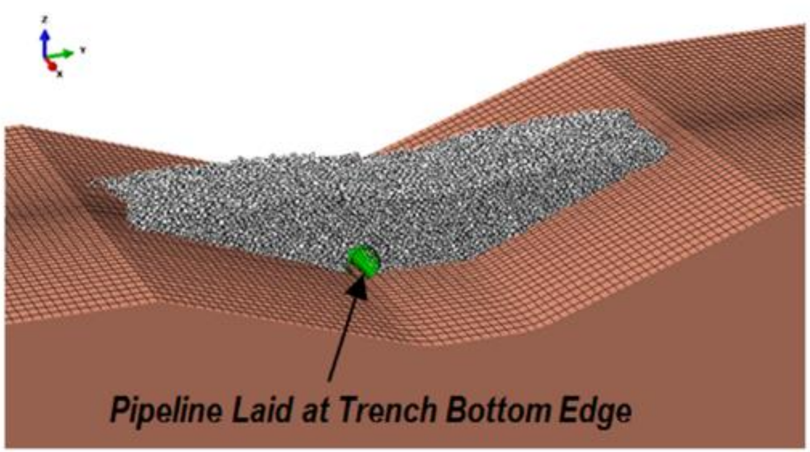
Modern Method of Anchor Protection Design Verification using Computer Simulations with High-end Finite Element Software, e.g. Abacus

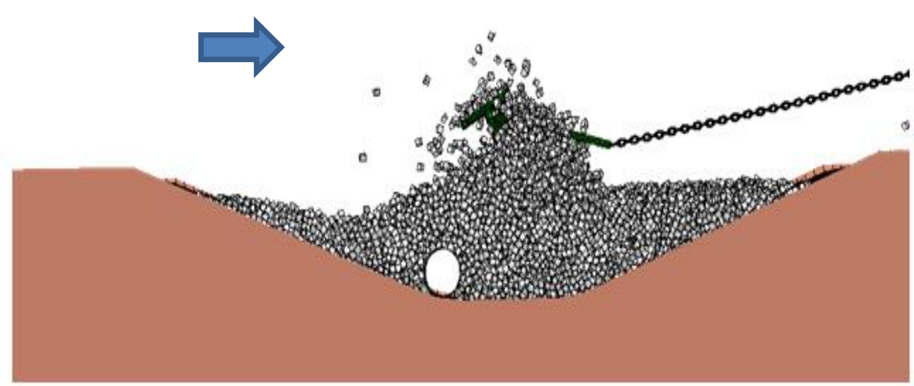


Anchor Passing Through Rock Berm and Deflected by Rocks



Anchor Passing Through Rock Berm and Deflected by Rocks





Anchor Passing Through Rock Berm and Deflected by Rocks

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Thank You!

Questions?