# TYNE IMMERSED TUBE TUNNEL
# SEDIMENT RELEASE FROM DREDGING OPERATIONS

## 1 GENERAL REVIEW OF SEDIMENT RELEASE FROM DREDGING OPERATIONS

### 1.1 INTRODUCTION

Although considerable effort has been expended on the measurement of release from dredging operations, notably in the Netherlands, USA and Japan, very little of the resulting data can be used to predict accurately the rates of sediment release. There are several reasons for this:

- there are a limited number of data sets for each type of dredger;
- almost all of the data sets which are available have been obtained in a unique manner, there is no uniformity in the approach to the measurements and the results cannot therefore be sensibly compared;
- many of the data sets are incomplete, particularly those from the USA and Japan where important information relating to the dredging processes and the soil conditions have not been documented;
- all sets of measurements have been obtained on a one-off basis, i.e. none of the measurements have been undertaken in uniform soil and hydrodynamic conditions in a manner which permits the analysis of the effects of changing certain parts of the dredging process;
- many of the measurements have been affected by sediment put into suspension by passing ships etc. adding to the uncertainty of interpretation and analysis;
- almost all of the measurements have, due to limitations of measurement technique, produced data from which the rate of release of sediment from the dredging plant has had to be calculated (or sometimes inferred) on the basis of often doubtful assumptions; none have involved the direct measurement of total sediment loss.

However, taken as a whole, the available field data can be used to derive indicative estimates of sediment release for different types of dredger but the accuracy of the estimates is poor.

The latest work in this field has been commissioned by VBKO (Vereniging van Waterbouwers in Bagger- kust en Oeverwerken) in The Netherlands and is being undertaken by Dredging Research Ltd and HR Wallingford Ltd of the UK. The objective of this work is to derive a suite of empirical models of sediment release based largely on an intuitive analysis of the dredging processes. These are to be calibrated, and refined if necessary, during a programme of field calibration which is likely to take at least five years to complete. Initial predictive models were developed in 1999 for the following types of dredger:

- trailing suction hopper dredgers;
- cutter suction dredgers;
- bucket dredgers;
- grab dredgers;
- backhoes.

## 1.2 Types of Measurement

There are three different measures of sediment release which have been developed and which can be used to estimate, at an indicative level, the potential impacts of dredging operations.

The first measure simply comprises observations of sediment concentrations in the vicinity of dredging operations. These were the earliest measurements which were undertaken and very few were accurately related to the dredger, its manner of operation and the soil and hydrodynamic conditions at the measurements sites.

The second measure is the S-parameter which was developed in The Netherlands. It was the first attempt at systematic and scientific measurement of sediment release. The approach involves repeated measurements of solids concentration profiles on a grid pattern around a working dredger. These are used to estimate the volume of water in which excess solids concentrations exist and the total mass of sediment which is in suspension. On the assumption that a 'steady state' has been reached in which the release of sediment from the dredger is balanced by settling to the bed, the release is computed as the mass of sediment released per cubic metre of material dredged during the operations (kg $m^{-3}$). This can be converted into a rate per unit time (kg $s^{-1}$) by applying the known rate of production of the dredger. There are two flaws in this approach:

1) it is difficult to ensure that the full extent of the sediment plume has been measured at a sufficient intensity to fully quantify the sediment load, particularly when there is a water current;

2) the computation of losses depends on a rather crude field assessment of settling velocity which is subject to a degree of inaccuracy.

Despite these problems, the Dutch S-parameter measurements represent by far the best data concerning sediment release, especially from mechanical dredgers such as grabs and backhoes.

The latest approach, which is being adopted in the DRL studies for VBKO, is to measure directly, using a combination of acoustic and conventional techniques, the flux of sediment away from the dredging site. This can only be done at sites where there is a current. However, as long as it is possible to undertake the measurements close to the dredger and there is a reasonably fast current, this approach ensures that almost all of the released sediment is observed The loss computation does not depend on any assumptions concerning 'steady state' dredging or the settling velocity of the released sediment.

A broadly similar approach has been used by DRL in Hong Kong to measure sediment release during disposal operations from trailer dredgers in the East Tung Lung Chau Marine Borrow Area and from barges at the East Sha Chau Contaminated Mud Pits (DRL, 1996). It has only been used on one occasion to measure losses from a working dredger. The measurements were carried our around a self-propelled grab dredgers on the River Tees in May 2000 as part of DRL's work for VBKO. The data are still being analysed and are therefore not available to be included here.

## 1.3 Summary of Field Measurements

The following summary of loss measurement is concerned only with grab dredgers, backhoes and cutter suction dredgers which are the types of plant likely to be used for the Tyne Tunnel works.

The Dutch S-parameter measurements involved 'mapping' excess solids concentrations around the working dredgers. These data were analysed to establish a 'characteristic' increase of concentration over background concentrations. The characteristic increases relates to the area within 50 metres of the working dredger. The settling time is defined as the time after dredging stopped to the point at which the sediment plume was no longer detectable at a height of 0.5 metre above the bed. These data are included in the relevant tables below. In all cases, the loss rates (in terms of kg $s^{-1}$) shown in Tables 1-3 have been inferred by us; they are not included in the original reports on the field measurements.

### 1.3.1 Grab dredgers

The results of the Dutch S-parameter measurements are summarised in Table 1.

*Table 1* ***Summary of sediment release measurements around grab dredgers***

| Grab volume, $m^3$ | Production rate, $m^3$ $hr^{-1}$ | S-parameter, kg $m^{-3}$ | Loss rate, kg $s^{-1}$ | Concentration increase, mg $L^{-1}$ | Settling time, hr | Data Source |
|---|---|---|---|---|---|---|
| 2.5 (1) (3) | 204 | 11 | 0.623 | 105 | 1 | Pennekamp and Bosland, 1990 |
| 1.3 (1) (2) | 220 | 11 | 0.672 | 90 | 1 | A/A |
| 3 (3) | 102 | 3 | 0.085 | 20 | 1 | WL, 1989 |
| 2.5 (3) | 84 | 9 | 0.210 | 35 | 1 | A/A |
| 3 | 166 | 19 | 0.876 | 100 | 1 | A/A |
| 1.1 | 90 | 3 | 0.075 | 35 | 1 | Pennekamp and Quaak, (1990 and 1996) |
| ? (2) | 121 | 13 | 0.437 | 80 | 1 | Pennekamp et al., 1996 |

*(1) debris prevented proper grab closure*
*(2) nominally watertight grab*
*(3) working within silt screen*

An attempt was made to estimate rates of release at three grab-dredging sites in the USA at Black Rock Harbour, Calumet River and St. John's River (Collins, 1995). The estimates were based on a complex mathematical analysis of the dredging process and were based on a limited number of point measurements down-current of the dredgers. In all cases, very poor records of dredging process and soil type were presented and the data must therefore be viewed with considerable caution. The grabs were open and varied between 7.65 and 9.2 $m^3$ capacity and worked in water depths of 5.5 - 8.25 metres. Silt curtains were not used and sediment release rates of 0.243 - 1.684 kg $sec^{-1}$ were estimated.

### 1.3.2 Backhoes

There has been only one case of loss measurement around a backhoe dredger (Pennekamp et al, 1996; WL, 1993). The results are summarised in Table 2.

*Table 2* ***Summary of sediment release measurements around backhoes***

| Bucket type | S-parameter, kg $m^{-3}$ | Production rate, $m^3$ $hr^{-1}$ | Loss rate, kg $s^{-1}$ | Concentration increase, mg $L^{-1}$ | Settling time, hr | Data Source |
|---|---|---|---|---|---|---|
| Open | 54 | 208 | 3.12 | 530 | 0.5 | Pennekamp et al, 1996; WL, 1993 |
| Closed | 21 | 199 | 1.161 | 170 | 0.5 | A/A |

### *1.3.3 Cutter Suction Dredgers*

There has been only one attempt at measuring the S-parameter for a cutter suction dredger (WL, 1996). These measurements around the CSD 'Seine' in Emden yielded no observed loss. However, we consider this to be mainly a reflection of the limitations of the observational methodology.

In Japan, Kaneko and Watari (1983)measured losses around a CSD working at about 600 $m^3$ hr-1 in soil with a fines content of 87%. The loss was estimated to be about 8 kg $m^{-3}$ which suggests a release rate of about 1.33 kg $s^{-1}$.

Collins (1995) analysed USACE data from three sites to derive loss rates. The site records were very poor which, in combination with little or no soils data, make the loss estimates of doubtful accuracy. The main details are summarised in Table 3. The cut height of 5.85 metres reported for site 3 is extremely high and probably explains the high estimated sediment release rate.

***Table 3. CSD sediment release data for three USA sites (some parameters estimated/guessed)***

| *Parameter* | *Site 1* | *Site 2* | *Site 3* |
|---|---|---|---|
| Soil type | 'Silty loam' | 'V. soft silty clay' | 'Soft clay/silt' |
| $D_{50}$, microns | 43 | 15 | 23 |
| Cutterhead diameter, m | 0.92 | 1.53 | 1.83 |
| Cut height | 0.9 | 1.5 | 5.85 (!) |
| Estimated release rate, kg $sec^{-1}$ | 0.013 | 2.858 | 4.413 |

DRL (during the Hong Kong Conmud Study, Mott MacDonald, 1991) made crude estimates of loss rates (using many assumptions) based on data reported by Koba (1982). The known details and estimated S-parameters and release rates are summarised in Table 4.

***Table 4. CSD sediment release data for three Japanese measurements (some parameters estimated/guessed)***

| *Parameter* | *1* | *2* | *3* |
|---|---|---|---|
| Soil | Silty clay | Clay | ? |
| Cut height, m | 1 - 2 | 1.7 - 2.6 | 0.5 - 2.0 |
| Swing speed, m $min^{-1}$ | 8 - 18 | 4.4 - 6.1 | 4 - 21 |
| Rotation speed, rpm | 12 | 17.6 | 16 |
| Estimated S parameter, kg $m^{-3}$ | 3.2 | 1.8 | 5.8 |
| Estimated loss rate, kg $s^{-1}$ | 1.06 | 0.935 | 1.59 |

## 1.4 Kirby and Land (1991)

The Kirby/Land table of losses (reproduced in Environment Canada, 1994 without any of the original qualifying statements) was developed during the Contaminated Spoil Management Study in Hong Kong (Mott MacDonald Hong Kong Ltd 1991). It was based on a largely intuitive assessment of the data which were available at the time which included only a proportion of the Dutch data summarised above. It was mainly intended to provide some guidance as to the order of magnitude differences between dredgers working in muddy soils under broadly similar conditions. The indicated release rates were noted to be subject to considerable variation depending on site specific factors such as soil and hydrodynamic conditions and the details of the dredger and its manner of operation. The indicative losses from grab, backhoe and cutter suction dredgers working in soft muddy sediments are set out in Table 5 below.

*Table 5* *Indicative S-parameters (after Kirby and Land, 1991)*

| *Dredger* | *Approximate Dredger Capacity* | | |
|---|---|---|---|
| | *Large* | *Medium* | *Small* |
| | *Sediment loss, kg $m^{-3}$ dredged* | | |
| Grab (open) | 12 | 17 | 25 |
| Grab (closed) | 11 | 14 | 20 |
| | | | |
| Backhoe (no silt screen) | 12 | 17 | 25 |
| Backhoe (with silt screen) | 5 | 7 | 10 |
| | | | |
| Cutter suction | Approximately 6 | | |
| Cutter suction (reduced swing and rotation speeds) | Approximately 3 | | |

## 2 DISCUSSION

The data presented above were all obtained from dredgers working in fine muddy sediments. The grab dredger data indicate that sediment release rates are almost invariably less than 1 kg $s^{-1}$ and usually significantly less than this amount. These are lower than the loss rates which would be derived from Kirby and Land's table. The solids concentration increases in the area within 50 metres of the dredgers were observed to be typically in the range 20 – 100 mg/L.

For backhoes, the only measured data indicate losses of about twice those suggested by Kirby and Land. The high concentrations of up to 530 mg/L observed around the backhoe dredger probably represent the maximum likely to be encountered with mechanical dredging plant. The recent DRL work for VBKO includes backhoes and a theoretical consideration of the manner in which backhoes work has led to the conclusion that they probably give rise to the highest sediment losses of all types of mechanical plant and that operator care and experience plays a significant role in determining the actual losses.

The data for cutter suction dredgers are subject to extreme uncertainty, largely due to the paucity of data on which loss estimates have been based. Conventional wisdom holds that losses from cutter suction dredgers are lower than those from most other types of dredger. The losses of 1.8 to 5.8 kg $m^{-3}$ estimated by DRL from the data provided by Koba, and the 8 kg $m^{-3}$ derived from Kaneko and Watari's data suggest that this is indeed the case.

There is, as may be expected, a relationship between the rate of production and the rate of sediment release. High rates of production tend to result in relatively high release rates and high concentrations. Thus, for any particular soil type, a dredger which has a low S-parameter (in kg $m^{-3}$) but a high rate of production could result in higher temporal rates of release (kg $s^{-1}$) than one which has a high S-parameter but a low rate of production.

The soil type clearly has a significant bearing on rates of release. In addition to there being a tendency for soft muddy soils to release more sediment during dredging than firm clayey soils and granular soils, the nature of the material which is released needs to be taken into consideration when estimating input data for modelling purposes. For example, if a sandy soil were being dredged and the rate of release was very high, this may have little or no impact because the released particles would likely settle within or very close to the dredging site. Working in muddy soils, but at a slower rate of release, may have a greater impact due to the very fine nature of the released material and its tendency to remain in suspension for a relatively long period.

In the case of the Tyne Tunnel, the materials to be dredged range from soft alluvial clays and silts, through dense sands and stiff clays, to rock. These will have different characteristics in terms of sediment release and they will probably be dredged using different types of plant. This, in combination of the scant knowledge concerning sediment release from dredging plant, makes it impossible to predict with confidence the likely rates of sediment loss during the dredging works.

Under the circumstances, the rational approach must be to adopt upper-bound figures based on the available observational data.

## 3 ESTIMATED RATES OF SEDIMENT RELEASE

The estimation of release rates is based on conservative S-parameters applied to the dredging of the alluvial silts and clays. In the case of the grab dredger, the 20 kg $m^{-3}$ for small closed grabs is adopted. This is in line with Kirby and Land's figure and slightly higher than the maximum S-parameter which has been measured for grabs (19 kg $m^{-3}$, refer to Table 1). This measurement was undertaken on a 3 $m^3$ grab which is slightly smaller that the 4-5 $m^3$ grab which we would expect to be used for the Tyne Tunnel. The larger grab would be expected to have a slightly lower S-parameter.

For backhoes, a figure of 55 kg $m^{-3}$ is used, in line with the measurements set out in Table 2. Kirby and Land's indicative figure of 6 kg $m^{-3}$ for cutter suction dredgers is raised to 8 kg $m^{-3}$, in line with the observations of Kaneko and Watari.

The alluvial clays and sands are likely to represent the worst case in terms of S-parameters. S-parameters for all other soil types are expected to be significantly lower because the soils are either stronger (and thus less likely to disaggregate during dredging) or comprise relatively coarse materials. For the granular materials, the S-parameters have been adjusted in line with the average fines contents, relative to an assumed fines content of 95% for the alluvial silts. The average fines content of the alluvial sands and gravels is 10% compared with 95% for the silts and clays. The S-parameters for the sands and gravels have therefore been reduced to 10/95, or 11% of those for the silts and clays. In a similar manner, the S-parameters have been reduced to 20% for the glacial sands and gravels which have a much higher and very variable fines content.

For the stiff cohesive glacial soils, the release rates are expected to be very low compared with the alluvial silts and clays. Although the tendency of these soils to disaggregate will be very low due to their high cohesion and plasticity, it is not possible at this stage to estimate this with a high degree of confidence. An arbitrary, but intuitively conservative, reduction of 75% has been applied for these soils. Similarly, the release rates for rock dredging are expected to be very low. An 80% reduction has been applied to the S-parameter for rock.

The assumed S-parameters are summarised in Table 6. In all cases, values have been rounded up to the nearest whole number.

***Table 6. S-parameters assumed for estimation of sediment losses during dredging***

| *Dredger* | *Assumed S-parameter* | | | | |
|---|---|---|---|---|---|
| | *Alluvial clay and silt* | *Alluvial sand and gravel* | *Cohesive glacial soils* | *Granular glacial soils* | *Rock* |
| Grab (closed) | 20 | N/A | N/A | N/A | N/A |
| Backhoe | 55 (N/A) | 6 | 14 | 11 | 11 |
| Cutter suction | 8 (N/A) | 1 | 2 | 2 | 1 |

*N/A indicates that the dredger would not be used in the relevant material type.*

## 3.2 Grab dredger

The grab dredger is envisaged only to be used for the very soft alluvial silts and clays. The rate of production is estimated to be 13,500 $m^3$ per 105 working hour week. This rate of production includes an allowance for delays and inefficiencies. For the purposes of estimating the likely maximum rate of sediment release when working at maximum efficiency, it is assumed that all production is actually achieved in 70 hours. A similar approach is adopted for the backhoe and cutter suction dredger discussed below.

The maximum hourly rate of production is thus estimated to be 193 $m^3$ which, in combination with an S-parameter of 20 kg $m^{-3}$, yields a sediment release rate of 1.07 kg $m^{-3}$.

## 3.3 Backhoe

A backhoe may be used for dredging all of the soils except the alluvial silts and clays. It might also be used for dredging very weak and weak rock but rates of production are expected to be very low. The estimated sediment release rates are set out in Table 7. In the case of the alluvial sands and gravels, the assumed rate of production is taken to be that which will be achieved when the dredger is working at the shallowest depths. Lower rates of production will be achieved when working in these deposits at greater depths. Similarly, in the case of rock, the highest rate of production has been adopted, ie. that which will be achieved in very weal rock at a depth of 12 metres.

***Table 7. Estimated sediment release rates - backhoe***

| *Material* | *S parameter, kg $m^{-3}$* | *Weekly production, $m^3$* | *Assumed maximum production, $m^3$ $hr^{-1}$* | *Estimated sediment release, kg $s^{-1}$* |
|---|---|---|---|---|
| Alluvial sand and gravel | 6 | 42,630 | 609 | 1.02 |
| Cohesive glacials | 14 | 13,500 | 193 | 0.75 |
| Granular glacials | 11 | 14,590 | 208 | 0.64 |
| Rock | 11 | 7,640 | 109 | 0.33 |

## 3.4 Cutter suction dredger

A cutter suction dredgers may be used for dredging the rock and all of the soils except the alluvial silts and clays. However, there is a significant risk attached to working in the granular alluvium and glacial materials due to the presence of boulders. Even a very small proportion of boulders could give rise to considerable difficulties. As was the case with backhoes, the production rate used in rock is that which is expected to be achieved in the weakest materials. The estimated sediment release rates are set out in Table 8.

***Table 8. Estimated sediment release rates - cutter suction dredger***

| *Material* | *S parameter, kg $m^{-3}$* | *Weekly production, $m^3$* | *Assumed maximum production, $m^3$ $hr^{-1}$* | *Estimated sediment release, kg $s^{-1}$* |
|---|---|---|---|---|
| Alluvial sand and gravel | 1 | 71,000 | 1014 | 0.28 |
| Cohesive glacials | 2 | 71,000 | 1014 | 0.56 |
| Granular glacials | 2 | 71,000 | 1014 | 0.56 |
| Rock | 1 | 33,000 | 471 | 0.13 |

## 4 SUMMARY OF CONCLUSIONS

Despite the efforts of researchers in Japan, USA and Netherlands, there exists no reliable means of predicting rates of sediment release from dredging plant. However, there is reasonable knowledge of the relative order of magnitude of losses from different types of dredger working in soft muddy soils, supported by some observational data. These have been used to derive S-parameters for the different types of dredger which may be used for the Tyne Tunnel. These S-parameters are, in relation to our current state of knowledge, conservative. These have been combined with the expected maximum instantaneous rates of production of the dredgers to derive estimates of sediment release.

The maximum estimated rate of release is 1.07 kg $s^{-1}$ which applies to the grab dredger working in the alluvial silts and clays. A slightly lower rate of release (1.02 kg $s^{-1}$) is estimated for a backhoe dredger working in alluvial sands and gravels. All other material and dredger combinations are expected to yield release rates of 0.75 kg $s^{-1}$ or less.

A conservative approach has been adopted at all stages of the estimating process which is likely to have resulted in pessimistic estimates of sediment release. For the purposes of modelling the potential impacts of the dredging operations, we recommend that a maximum rate of release of 1 kg $s^{-1}$ be adopted. This rate of release might be achieved for short periods by a grab dredger working in the soft alluvial soils. Over the course of a working day or week, the average rate is expected to be less. The released sediment may be assumed to be distributed evenly throughout the water column and the point where the dredger is working.

In the case of the cutter suction dredger, a maximum release rate of 1 kg $s^{-1}$ might also be achieved for short periods but, in this case, the release will take place at the cutterhead and the sediment should therefore be assumed to be initially distributed throughout the lowest 2.5 metres of the water column..

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