C0	31/10/08	Emissione per approvazione	DV	DL	YE
REVISIONE		DESCRIZIONE	EL.	CON.	APP.

MINISTERO DELLE INFRASTRUTTURE E DEI TRASPORTI

MAGISTRATO ALLE ACQUE

NUOVI INTERVENTI PER LA SALVAGUARDIA DI VENEZIA

LEGGE N.798 DEL 29-11-1984

CONVENZIONE REP. 7191 DEL 04-10-1991

ATTO ATTUATIVO REP. 8249 DEL 28-12-2007 (PROGETTAZIONE)

INTERVENTI ALLE BOCCHE LAGUNARI PER LA REGOLAZIONE DEI FLUSSI DI MAREA

CUP: D51B02000050001

PROGETTO ESECUTIVO

WBS:LN.L1.50

BOCCA DI LIDO: SAN NICOLO' - TREPORTI

IMPIANTI

MEZZI PER LA RIMOZIONE DEI SEDIMENTI

RELAZIONE TECNICA SUL MODELLO FISICO DELLA CASSA DI ASPIRAZIONE

ELABORATO	CONTROLLATO	APPROVATO
D. Varisco	D. Lesina	Y. Eprim
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CONSORZIO "VENEZIA NUOVA"

COORDINAMENTO PROGETTAZIONE

VERIFICATO: S. Pastore

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CONSORZIO VENEZIA NUOVA

PROGETTAZIONE TECHNITAL

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ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI MILANO — DOTT. ING. ALBERTO SCOTTI — Sez. A Settori: a) civile e ambientale b) industriale c) dell'informazione — A 9782

PROGETTAZIONE SPECIALISTICA TECON

INDICE

1. SCOPO DEL DOCUMENTO

Il presente documento riporta la descrizione delle prove su modello fisico di un compartimento della cassa di aspirazione, realizzate presso il laboratorio BHR di Cranfield, Regno Unito, al fine di verificare il funzionamento del sistema di messa in sospensione e rimozione dei sedimenti e di dimensionare tutte le componenti idrauliche del sistema stesso.

Per una completa trattazione delle prove su modello si rimanda alla relazione CR8074 emessa dal BHR ed ai relativi disegni del modello presenti in Allegato.

2. RIFERIMENTI

2.1 Elaborati del Progetto Esecutivo

Quanto sopra è stato eseguito con riferimento ai seguenti elaborati:

SPECIFICHE	
MV146P-PE-GNS-2001	MEZZI PER LA RIMOZIONE DEI SEDIMENTI - SPECIFICA TECNICA GENERALE
MV146P-PE-GMS-2001	MEZZI PER LA RIMOZIONE DEI SEDIMENTI - SPECIFICA TECNICA SISTEMA DI ESTRAZIONE, STOCCAGGIO E SCARICO SEDIMENTI
RELAZIONI	
MV146P-PE-GER-2031	MEZZI PER LA RIMOZIONE DEI SEDIMENTI – SISTEMA DI RIMOZIONE DEI SEDIMENTI - RELAZIONE TECNICA PROGETTAZIONE IDRAULICA
MV146P-PE-GER-2032	MEZZI PER LA RIMOZIONE DEI SEDIMENTI - SISTEMA DI RIMOZIONE DEI SEDIMENTI - RELAZIONE TECNICA PROGETTAZIONE STRUTTURALE
DISEGNI	
MV146P-PE-GND-2001	MEZZI PER LA RIMOZIONE DEI SEDIMENTI - PIANO GENERALE - VISTE ESTERNE
MV146P-PE-GND-2002	MEZZI PER LA RIMOZIONE DEI SEDIMENTI - PIANO GENERALE - SEZIONI
MV146P-PE-GMD-2030	MEZZI PER LA RIMOZIONE DEI SEDIMENTI – SISTEMA DI ESTRAZIONE E STOCCAGGIO SEDIMENTI – CASSA DI ESTRAZIONE SEDIMENTI

3. SOMMARIO E CONCLUSIONI

Lo studio aveva lo scopo di verificare la fattibilità del sistema proposto per rimuovere i sedimenti dai recessi di alloggiamento delle paratoie alle quattro bocche di porto.

Il progetto a cui fanno riferimento le prove prevede una cassa di aspirazione sedimenti suddivisa in due metà, ciascuna servita da un circuito di estrazione acqua servito da una pompa sommersa. Ciascuna mezza cassa è ulteriormente suddivisa in cinque compartimenti. Il progetto sottoposto a prova prevede 8 tubi di adduzione acqua DN 150 mm in ciascun compartimento con la funzione di mettere in sospensione i sedimenti.

La portata massima di solidi in ciascuna metà cassa è di 300 m^3/ora per la bocca di Malamocco. Inizialmente si è assunto un rapporto sedimenti/acqua di 1/3 per cui la portata di acqua entrante in ciascuna metà cassa è di 900 m^3/ora attraverso un totale di 40 tubi.

Nello studio teorico iniziale (preliminare alla costruzione del modello) si è assunto che non ci fosse nessun ingresso d'acqua da sotto i bordi della cassa.

I risultati della studio teorico iniziale hanno evidenziato la necessità di aumentare la velocità di iniezione dell'acqua per mettere in sospensione i sedimenti e si sono quindi adottati ugelli di diametro ridotto alle estremità dei tubi di adduzione acqua all'interno del compartimento.

Lo studio teorico ha anche considerato altri parametri, compresa la velocità di sedimentazione delle particelle solide paragonata alla velocità del flusso verso l'alto dell'acqua nella parte bassa della cassa, la velocità media del flusso di acqua e sedimenti necessaria per evitare deposito di sedimenti nelle tubazioni inclinate lungo il braccio di manovra e in quelle orizzontali a bordo del mezzo navale e le condizioni di aspirazione della pompa di estrazione.

Infine nello studio teorico si è potuto confermare la scala geometrica del modello inizialmente indicata come 1:7 per motivi pratici di dimensioni del compartimento da modellare e delle tubazioni di adduzione ed estrazione dell'acqua.

La conclusione principale delle prime prove su modello fisico è stata quella di evidenziare che il sistema così come inizialmente pensato non era sufficiente a fornire sufficiente energia all'acqua immessa nella cassa per mettere in sospensione i sedimenti e mantenerli all'interno del flusso ascendente nella cassa e da qui nelle tubazioni inclinate lungo il braccio.

Questa scarsità di energia nel flusso entrante si è manifestata nelle prove evidenziando la creazione di vie preferenziali per l'ingresso dell'acqua nella cassa attraverso i tubi meno infissi nei sedimenti e soprattutto al di sotto dei bordi della cassa.

Quando la pompa di aspirazione acqua viene azionata, l'acqua è immessa all'interno della cassa attraverso i tubi e al di sotto dei bordi in funzione della resistenza offerta dalla presenza di sedimenti e questo fenomeno si amplifica in quanto i sedimenti vengono rimossi dalle le zone con maggior flusso d'acqua diminuendo ulteriormente la resistenza in confronto ai tubi di immissione più immersi nei sedimenti che quindi risultano praticamente inutilizzati con nessun flusso d'acqua attraverso loro.

Nelle prove si è visto che la presenza di ugelli di piccolo diametro migliorava l'efficacia del sistema con tubi a sezione piena DN 150. Gli ugelli più piccoli (diametro 5 mm nel modello corrispondenti a 35 mm prototipo) sono apparsi i più efficaci nel mettere in sospensione i sedimenti, ma non sono state rilevate differenze apprezzabili nel quantitativo totale di sedimenti rimossi utilizzando ugelli da 5, 7 o 9 mm di diametro nel modello (35, 49, 63 mm prototipo). Infatti, sebbene gli ugelli di diametro minore sembrino dare un risultato migliore nel creare turbolenza all'interno del compartimento, c'è sempre un equilibrio fra la resistenza negli ugelli e quella al di sotto del compartimento per cui non è vero che gli ugelli più piccoli diano un risultato migliore.

I risultati di queste prime prove hanno suggerito di modificare il modello introducendo una seconda pompa con la funzione di forzare l'ingresso dell'acqua nel compartimento attraverso i tubi di adduzione con l'intento di ottenere il doppio risultato di aumentare l'energia immessa nel sistema e di eliminare il flusso d'acqua al di sotto dei bordi del compartimento.

L'immissione forzata di acqua attraverso gli ugelli ha effettivamente superato il problema delle "vie preferenziali" sotto il bordo del compartimento e ha consentito di ottenere risultati migliori in termini di percentuale di sedimenti rimossi nel tempo, arrivando a rimuove oltre il 70% dei sedimenti dopo poco più di due minuti totali di attività (corrispondenti a circa 7 minuti nel prototipo).

Il sistema necessita di affinamenti per ottimizzarne il funzionamento che dovranno essere studiati attraverso ulteriori prove su modello fisico tendenti a definire i valori finali di dimensioni e geometria della cassa di aspirazione e dei singoli compartimenti, diametri dei tubi e degli ugelli, caratteristiche delle pompe e conseguenti tempi di operazione, ma i risultati delle prove sin qui eseguite hanno dimostrato la sua efficacia ed hanno consentito di sviluppare la progettazione del mezzo di rimozione sedimenti.

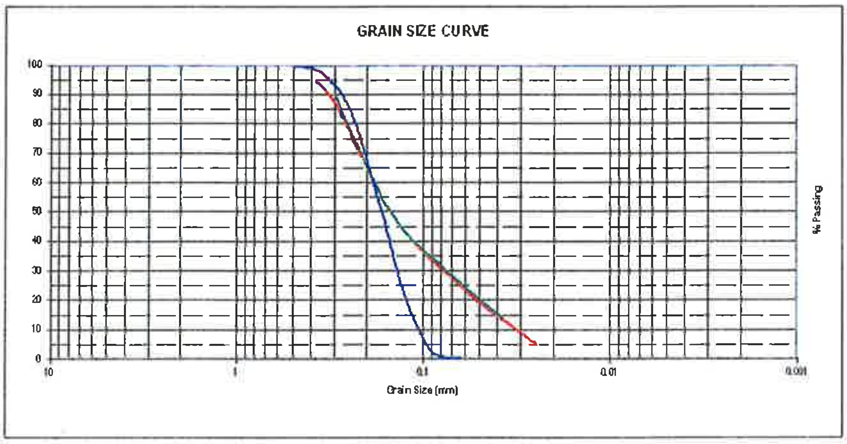
4. DATI E CARATTERISTICHE DEL MODELLO

Numero di compartimenti serviti da una pompa	5
Lunghezza del compartimento	5 m
Larghezza del compartimento	1.88 m
Altezza del compartimento	1.45 m
Numero di ugelli di iniezione per compartimento	8
Lunghezza dei tubi di iniezione	1.35 m
Diametro interno dei tubi di iniezione	0.15 m
Distanza dagli ugelli al piano di base del compartimento	0.10 m
Altezza del collettore di aspirazione	1.45 m

Proprietà fisiche dei sedimenti

Densità dei sedimenti	2.700 kg/m^3
Dimensioni dei sedimenti	d_{50} = 250 microns
	d_{95} = 380 micron

La distribuzione delle dimensioni dei sedimenti è indicata nella seguente figura.



Input TCH (red)	
Size	%
0.024	5
0.031	10
0.051	20
0.077	30
0.114	40
0.15	50
0.18	60
0.22	70
0.26	80
0.32	90
0.38	95

BHR Initial (green)	
Size	%
0.0375	14
0.075	30
0.15	50
0.3	90

DA30F (Blue)	
Size	%
0.5	99.8
0.355	97.5
0.25	85.5
0.18	57.4
0.15	39.2
0.125	21.3
0.09	2.9
0.063	0.3

FIG. 4.1 - CURVE GRANULOMETRICHE DEI SEDIMENTI

Dati della pompa e delle tubazioni

Diametro del tubo di aspirazione	0.45 m
Diametro del tubo di mandata	0.35 m
Elevazione dell'aspirazione della pompa	2.15 m

Condizioni operative

Portata solidi totale attraverso le due pompe	600 m^3/h
Portata acqua totale attraverso le due pompe	1.800 m^3/h
Portata miscela totale attraverso le due pompe	2400 m^3/h

Condizioni operative

Concentrazione media della miscela in aspirazione	25.0 % volume solidi
	46.5 % peso solidi
Altezza media dei sedimenti nel compartimento	0.50 m
Altezza massima dei sedimenti nel compartimento	0.80 m

5. IDRODINAMICA ALL'INTERNO DI UN COMPARTIMENTO

5.1 Velocità del getto richiesta per metter in sospensione i sedimenti

La stima della velocità del getto necessaria per raggiungere la condizione di sospensione iniziale dei sedimenti, V_j si basa su una correlazione empirica sviluppata dal BHR per la messa in sospensione di solidi sul fondo di un miscelatore circolare con l'utilizzo di un getto libero. Questa correlazione empirica considera le due grandezze geometriche legate al diametro di influenza del getto, H e T, l'altezza a cui vengono portate le particelle messe in sospensione, la misura della frazione più grande di particelle (d_{43} o d_{95}), le densità della fase solida e di quella liquida e il diametro interno dell'ugello, d_j. Adottando i dati disponibili o assunzioni ragionevoli per tutti questi parametri BHR è arrivato a stimare la velocità del getto necessaria come 2.79 m/s.

La formulazione di dettaglio di questa correlazione empirica è confidenziale e riservata ai membri di un consorzio di ricerca industriale coordinato dal BHR (Processi di miscelazione dei fluidi, o FMP), tuttavia è possibile dare un'indicazione della correlazione empirica usata:

$$V_j = K\left[\frac{H}{T}\right]^a g^b X^c D_p^d T^e \left[\frac{\rho_s - \rho_l}{\rho_l}\right]^f / d_j$$

Dove:

V_j = velocità minima del getto

K = Costante che dipende dalla forma della base del miscelatore e dall'altezza a cui l'acqua è prelevata per essere reiniettata attraverso i getti.

H = Altezza del fluido nel miscelatore (si è adottata l'altezza del singolo compartimento)

T = Diametro del miscelatore (si è calcolato considerando l'area di un compartimento divisa per il numero di getti)

X = concentrazione dei solidi completamente messi in sospensione in un compartimento, definita come il rapporto in peso fra solidi e liquidi moltiplicato per 100% (assunto uguale a 20%)

D_p = dimensione dei sedimenti d_{43} e d_{95} (assunta pari a 380 micron)

ρ_s = densità della fase solida (2700 kg/m^3)

ρ_l = densità del liquido (1035 kg/m^3)

d_j = diametro interno dell'ugello

Va sottolineato che l'applicazione della precedente equazione al caso in esame può solo dare un'indicazione della minima velocità dei getti necessaria a mettere in sospensione i sedimenti (da verificarsi poi in via sperimentale) per le seguenti ragioni:

(1) l'equazione è stata sviluppata per analizzare la messa in sospensione di solidi in un recipiente circolare chiuso in cui il liquido senza solidi è prelevato dalla parte alta o bassa del recipiente ed è reiniettato usando un circuito esterno che alimenta gli ugelli.

(2) Il getto è orientato verticalmente, mentre nel compartimento questi sono inclinati.

5.2 Portata specifica ascendente nella parte bassa del compartimento verso velocità di sedimentazione delle particelle

La portata specifica (definita come portata per unità di superficie da cui vengono rimossi i sedimenti) ascendente nella parte bassa del compartimento è un parametro importante e può essere calcolato come segue.

La portata totale in volume da una metà della cassa di aspirazione (5 compartimenti) è 0.33 m^3/s corrispondente a rimuovere 300 m^3/h di solidi insieme a 900 m^3/h di acqua. La superficie in pianta di metà cassa è 47 m^2, quindi la portata specifica è 0.33/47 = 0.0071 m^3/m^2/s = 7 l/m^2/s.

Questa velocità è in effetti una velocità media verso l'alto nella parte inferiore della cassa e può essere comparata con la velocità terminale libera di sedimentazione delle particelle di sedimenti. Quest'ultima può essere calcolata assumendo condizioni di calma senza turbolenze, e può rappresentare un'indicazione del valore fino a cui la velocità ascensionale è sufficiente a contrastare la tendenza delle particele a depositarsi all'interno della cassa di aspirazione.

La velocità terminale libera di sedimentazione è calcolata conoscendo il coefficiente di drag delle particelle C_D ed il loro numero di Reynolds Re_p definiti rispettivamente come:

$$C_D = \frac{4dg(\rho_s - \rho_l)}{3V_{t\infty}^{\ 2}\rho_l}$$

Dove:

ρ_s = densità dei solidi

ρ_l = densità dell'acqua

d = dimensione delle particelle

$V_{t\infty}$ = velocità terminale libera di sedimentazione della singola particella.

e:

$$Re_p = \frac{dV_{t\infty}\rho_l}{\eta_l}$$

Dove:

η_l = viscosità dell'acqua

Il coefficiente di drag delle particelle ed il loro numero di Reynolds sono legati come indicato nella figura seguente ed espresso nell'equazione ivi contenuta.

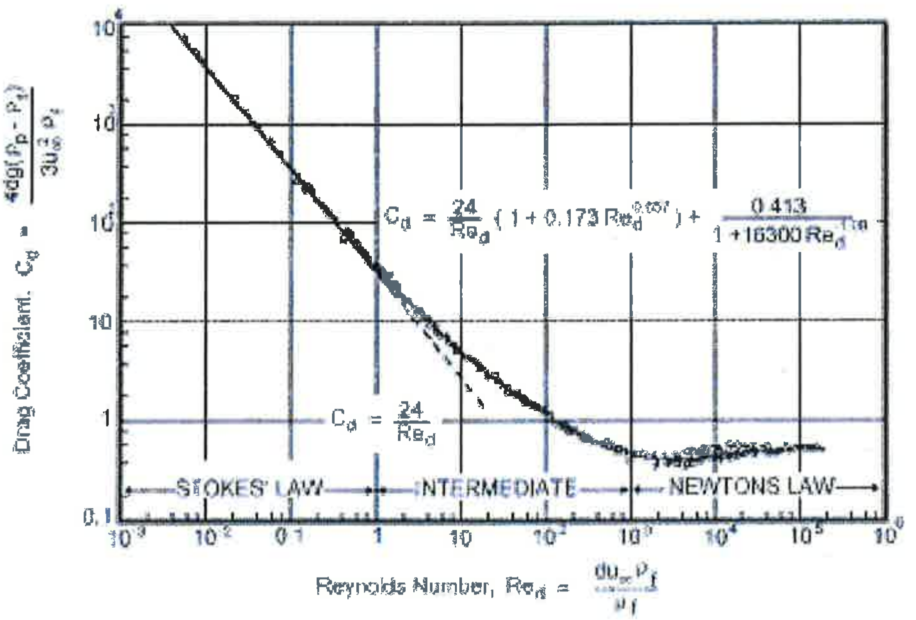


FIG. 5.1 - RELAZIONE FRA COEFFICIENTE DI DRAG DELLE PARTICELLE E LORO NUMERO DI REYNOLDS

La velocità terminale libera di sedimentazione di una particella può essere calcolata da queste informazioni e la tabella seguente riassume le caratteristiche gravitazionali di sedimentazione di particelle aventi d_{50} e d_{95} come da figura 4.1. La viscosità dell'acqua di mare è stata assunta pari a 0.001 Pa s.

Dimensione delle particelle di sedimenti [μm]	Re_p = Numero di Reynolds delle particelle di sedimenti	C_D = Coefficiente di drag delle particelle	$V_{t\infty}$ = Velocità terminale libera di sedimentazione [m/s]	V_t = Velocità terminale ostacolata di sedimentazione [m/s]
d_{50} = 150	11.7	3.77	0.029	0.011
d_{95} = 380	84.1	1.19	0.082	0.036

TAB. 5.1 –SEDIMENTAZIONE PER GRAVITÀ DELLE PARTICELLE

La tabella precedente mostra che, per le due dimensioni di particelle considerate, la velocità terminale libera di sedimentazione è circa da 3 a 12 volte la velocità del flusso ascendente nella cassa. Questo suggerirebbe che quest'ultima velocità avrebbe potuto essere troppo bassa e questa potrebbe essere un'ulteriore ragione per incrementare la portata di aspirazione dalla cassa stessa.

Un raffinamento dell'analisi è stato fatto tenendo conto della presenza delle altre particelle e quindi considerando la velocità terminale ostacolata di sedimentazione Vt che può essere calcolata con l'equazione di Richardson-Zaki:

$$V_t = V_{t\infty}(1-C_v)^z$$

Dove:

C_v = 0.25 frazione di solidi presenti nella miscela

E l'esponente z può essere stimato per un range di numero di Reynolds delle particelle da 1 a 200 secondo l'equazione:

$$z = \frac{4.45}{Re_p^{0.1}}$$

6. IL MODELLO FISICO

6.1 Estensione del modello fisico

Il modello fisico copre un compartimento della cassa di aspirazione ed i relativi otto tubi di iniezione acqua.
Il modello del compartimento è stato realizzato in perspex ed è mostrato nella figura seguente.

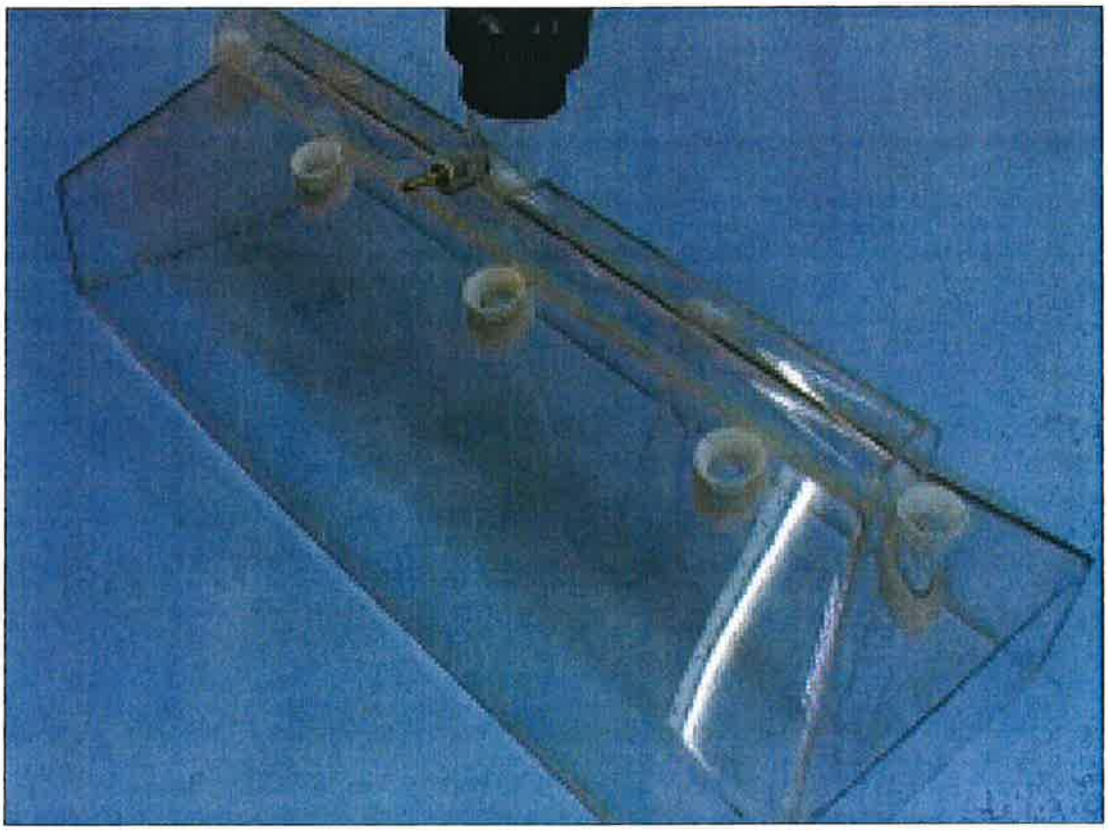


FIG. 6.1 - MODELLO FISICO - COMPARTIMENTO

La superficie del recesso è stata modellata con una scatola aperta in legno di dimensioni in pianta maggiori di quelle del compartimento in modo da eliminare effetti bordo e di avere la possibilità di investigare l'instaurarsi di flusso al di sotto delle pareti laterali del modello in perspex, e con pareti verticali di altezza molto limitata con il solo scopo di contenere lateralmente i sedimenti, al di fuori comunque dall'area di interesse.
Il modello del compartimento e quello del recesso sono stati alloggiati all'interno di una cassa realizzata in legno e pareti di plastica trasparenti che veniva riempita

d'acqua per le prove.

6.2 Scale del modello

Il modello fisico è stato realizzato in una scala geometrica lineare di 1:7.
La scelta della legge di similitudine da applicare ai modelli per lo studio della messa in sospensione e trasporto di solidi in correnti di liquido è molto complessa e dipende essenzialmente dall'obbiettivo dello studio. In questo caso l'obbiettivo era stabilire se i sedimenti potessero essere messi in sospensione dai getti ed aspirati nel circuito di evacuazione. Per ottenere questo risultato si sono usati gli stessi sedimenti previsti nella realtà e si sono scalate le portate in modo da ottenere lo stesso input di potenza per unità di volume del prototipo.
Imporre la costanza della potenza introdotta per unità di volume è la legge di similitudine usata normalmente per lo studio di solidi in sospensione in sistemi geometricamente simili.
Questo criterio è stato confermato sperimentalmente al BHR nel corso di molte ricerche ed è stato usato in molti studi analoghi.
La potenza immessa nel sistema dai getti è definita come $\frac{1}{2}\rho Q v^2$ dove ρ è la densità dell'acqua, Q è la portata e v la velocità.
Con questo criterio, dalla scala lineare di 1:7 si ricavano i seguenti fattori di scala per le altre variabili di interesse:

Parametro	Relazione di scala	Fattore di scala
Lunghezza	$\frac{h_m}{h_p}$	1:7
Velocità	$\left(\frac{h_m}{h_p}\right)^{\frac{1}{3}}$	1:2
Portata	$\left(\frac{h_m}{h_p}\right)^{\frac{7}{3}}$	1:94
Tempi	$\left(\frac{h_m}{h_p}\right)^{\frac{2}{3}}$	1:3.7
Numero di Reynolds	$\left(\frac{h_m}{h_p}\right)^{\frac{4}{3}}$	1:13.4

In questa scala il numero di Reynolds anche alla minima velocità del getto è 5442 e quindi il flusso è in regime turbolento.

6.3 Manovra del modello

Il modello è stato sempre usato in condizioni di flusso stazionario. Una pompa da laboratorio è stata usata per pompare l'acqua dal cassone contenete il modello a una cassa di sedimentazione. La portata attraverso la pompa era controllata da una valvola e misurata con un misuratore di portata magnetico.

Le traiettorie del flusso nel modello sono state osservate con l'aiuto di coloranti rossi. In alcune prove si sono ricavati campioni della miscela asportata dal compartimento dal tubo di mandata, si sono filtrati i solidi e se ne è calcolata la concentrazione dal volume totale e dal peso a secco. Il quantitativo di sedimenti asportati dal compartimento di aspirazione è stato misurato al termine delle singole prove raccogliendo il materiale dalla cassa di decantazione.

7. RISULTATI DELLE PROVE

7.1 Configurazione iniziale

Le prove iniziali sono state effettuate considerando diverse composizioni di sedimenti e diverse condizioni di "sigillatura" dei bordi inferiori del compartimento di aspirazione rispetto ai sedimenti ed al fondo della scatola in cui questi erano raccolti.
Sono state altresì provate diverse dimensioni degli ugelli dei getti e la presenza di un diffusore all'uscita di questi che ne deviava il flusso da verticale a orizzontale.

Tutti questi parametri si sono dimostrati di importanza secondaria rispetto al problema principale rappresentato dall'insufficienza della portata e della velocità del flusso attraverso i getti. Tali portata e velocità erano in grado di mantenere i sedimenti in sospensione e di convogliarli all'interno del manifold di aspirazione situato al colmo del compartimento solo all'inizio della prova, quando il livello di sedimenti era sufficientemente alto.

In tutte le prove eseguite con le sole pompe aspiranti dal compartimento l'efficienza del sistema decadeva con il diminuire della quantità di sedimenti da asportare fino a quando questi venivano messi in sospensione, ma il flusso non aveva energia sufficiente a portarli fino alla sommità del compartimento e quindi a farli aspirare dalla portata uscente.
Raggiunta questa situazione, i sedimenti rimanevano in circolazione all'interno del compartimento e l'acqua che ne usciva era praticamente priva di sedimenti.
In tutte le prove eseguite con questa configurazione la quantità massima di sedimenti rimossa dal compartimento di aspirazione non ha superato il 40% del valore iniziale.
Le seguenti fotografie mostrano a titolo di esempio come si presentavano i sedimenti sul fondo del compartimento di aspirazione al termine di varie prove eseguite con le sole pompe aspiranti.

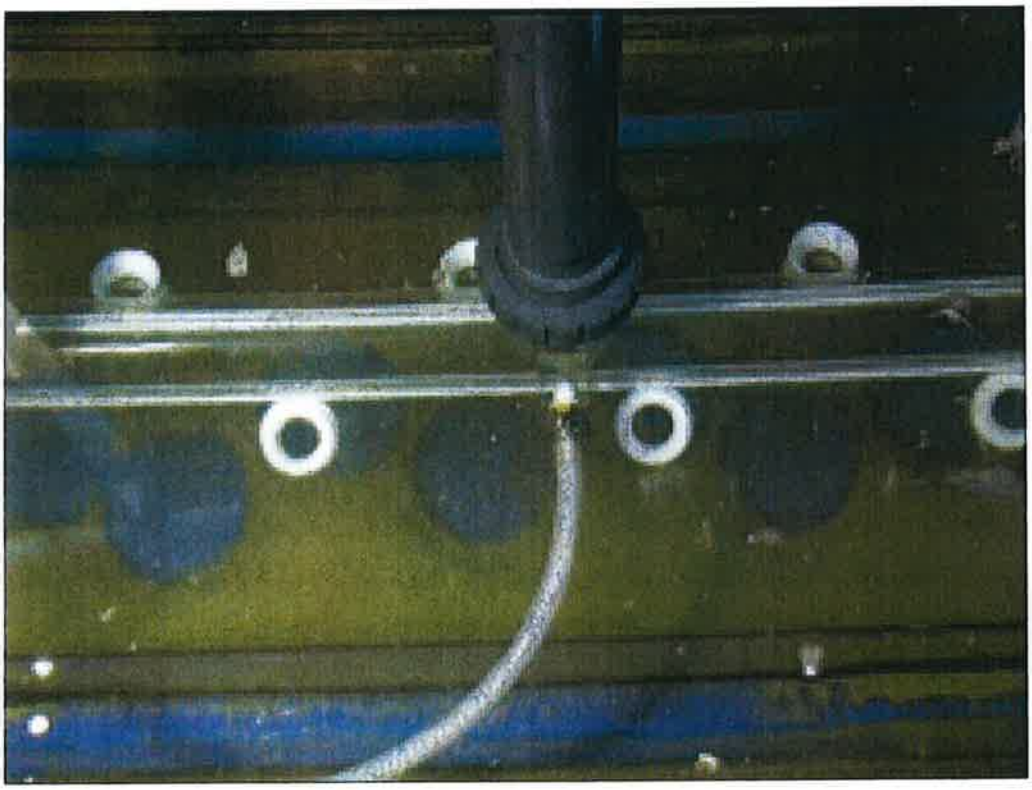


FIG. 7.1 - MODELLO FISICO – RISULTATO PROVA CON VELOCITÀ DEI GETTI 0.25 m/s

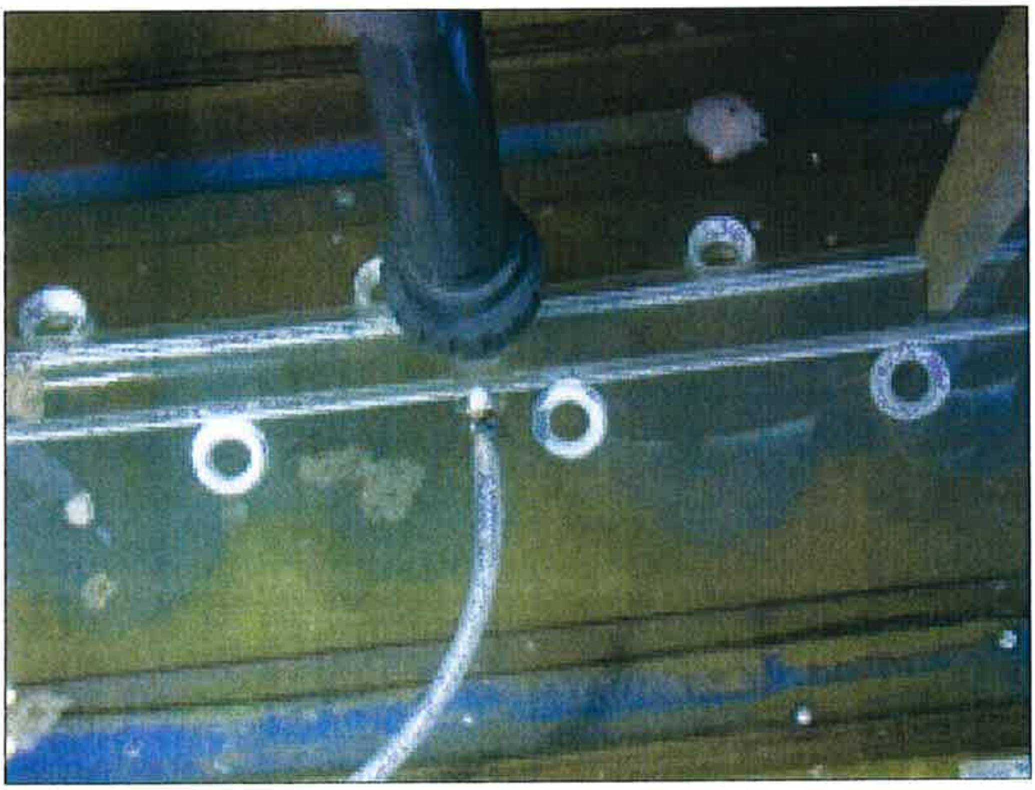


FIG. 7.2 - MODELLO FISICO – RISULTATO PROVA CON VELOCITÀ DEI GETTI 0.50 m/s

7.2 Configurazione finale con pompe di iniezione

Basandosi sui risultati degli studi teorici e delle prove su modello nella prima configurazione, si è giunti alla conclusione che era necessario adottare un sistema attivo di iniezione acqua attraverso gli ugelli al fine di aumentare la velocità dei getti ed introdurre nel sistema sufficiente energia per ottenere il risultato voluto, aumentando anche la portata del circuito di aspirazione ed espulsione sedimenti.

Il modello iniziale è stato modificato collegando gli ugelli ad un collettore a sua volta collegato ad una seconda pompa da laboratorio.

Il modello modificato è illustrato nelle seguenti due figure.

FIG. 7.3 - MODELLO FISICO – ASSIEME MODELLO CON POMPA DI INIEZIONE

FIG. 7.4 - MODELLO FISICO – CONFIGURAZIONE MODELLO CON POMPA DI INIEZIONE

Azionando le pompe in modo da quasi bilanciare la portata in entrata e quella in uscita dal compartimento, ma lasciando un piccolo eccesso di portata uscente in modo da avere un piccolo flusso al di sotto dei bordi del compartimento si è ottenuta un'ottima sospensione dei sedimenti che si è mantenuta inalterata anche al diminuire della quantità di sedimenti rimasti nel compartimento.

La figura seguente mostra il modello in operazione e ben evidenzia l'entità dei sedimenti in sospensione.

FIG. 7.5 - MODELLO FISICO – MODELLO CON POMPE DI INIEZIONE ED ESTRAZIONE IN FUNZIONE CONTEMPORANEAMENTE

Il risultato delle prove eseguite con le pompe di iniezione in funzione è stato migliore rispetto ai precedenti in termini di percentuale di sedimenti rimossi.

In particolare, nel tempo inizialmente indicato di 1.4 minuti corrispondenti a 5 minuti prototipo, si è giunti al 57% con ugelli da 7 mm (49 mm prototipo) e portata di circa 5 m/s (10 m/s prototipo).

Ulteriori prove hanno dimostrato che lasciando in funzione le pompe il sistema continua ad avere una buona efficienza e rimuove oltre il 70% dei sedimenti dopo poco più di due minuti totali di attività (corrispondenti a circa 7 minuti nel prototipo).

La seguente figura mostra il grado di pulizia dell'interno del compartimento di aspirazione alla fine di una di queste prove prolungate e indica come l'eccesso di portata uscente abbia causato un flusso dall'esterno del compartimento sotto il bordo dello stesso asportando sedimenti anche dalla zona immediatamente esterna.

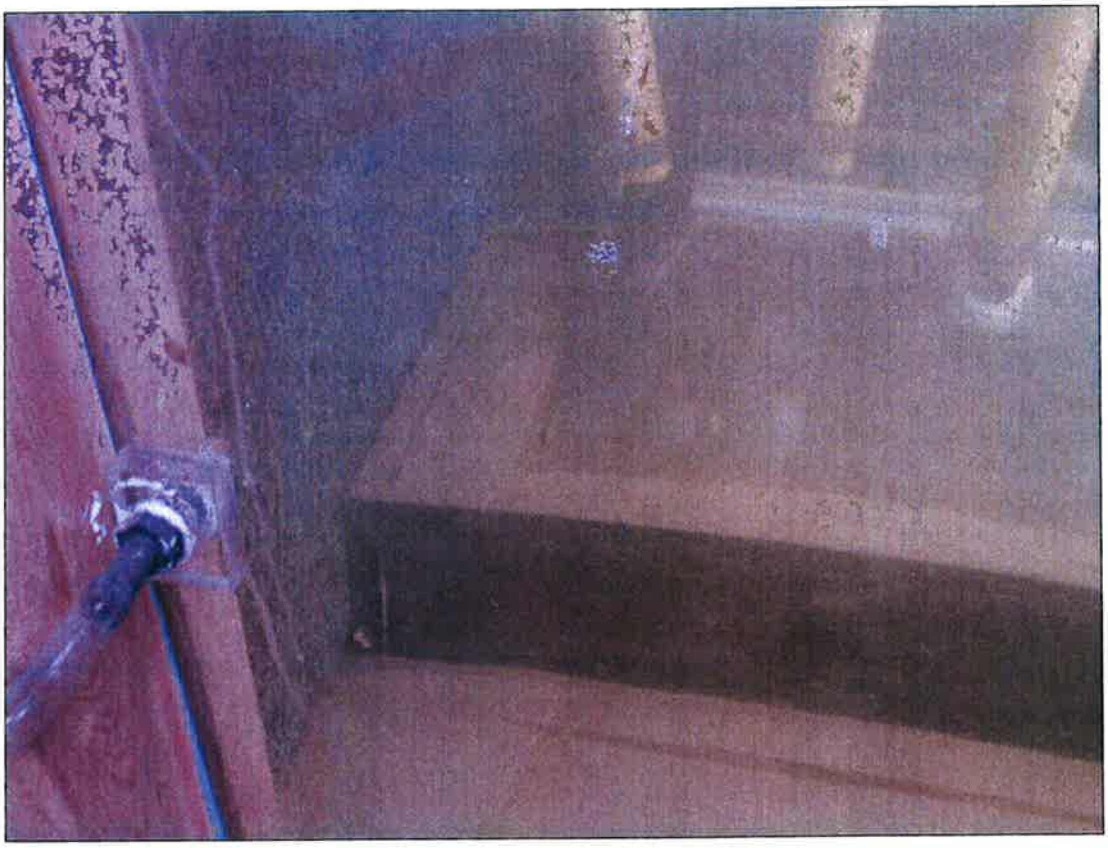


FIG. 7.6 - MODELLO FISICO – RISULTATO DI UNA PROVA CON POMPE DI INIEZIONE ED ESTRAZIONE IN FUNZIONE CONTEMPORANEAMENTE

8. ALLEGATO

Documentazione BHR

- Report CR 8074 – Venice Flood Barriers – Sedimental Removal System – Desk Study and Physical Model Study
- Drawing 2883/001 – Caisson model
- Drawing 2883/002 – Model layout
- Drawing 2883/003 – Model layout with positive pumping

8. References

1. Etchells, A W & Newlands, C. (2006) "Jet Solid Suspension Design Guide", FMP Consortium Report No. FMP 064, BHR Group Ltd, Cranfield, UK.
2. Brown, N P & Heywood, N I (1991) "Slurry Handling: Design of Solid-Liquid Systems", publ. by Springer. Chapter 2: "The Settling Behaviour of Particles in Fluids".
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WORLD CLASS IN FLUID ENGINEERING

CR 8074

Venice Flood Barriers Sediment Removal System Desk Study and Physical Model Study

October 2008

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BHR Group Project No: 131-2937

Executive Summary

This study considers the feasibility of the proposed design to raise sediment from gate storage recesses in the four inlets to the Venice lagoon. The proposed design incorporates 2 half-caissons, each of which contains five "extract caisson compartments". The current design proposes that one compartment includes 8 jet tubes, each having an internal diameter of 150mm. Total flows from each of the two half-caissons has been initially set at 300 m^3/h of sediment solids and 900 m^3/h of seawater. There is, therefore, an inflow of seawater into a half-caisson of 1200 m^3/h through a total of 40 jet tubes (8 in each of the 5 extract caisson compartments). Throughout the initial desk study it has been assumed that there is no leakage of water under the walls of the caisson, and that all seawater passes though the jet tubes.

An initial study suggests that while the upflow rate of solids and water in the lower part of the extract caisson compartment is possibly adequate at 0.007 $l/m^2/s$, the jet velocity impinging on the settled sediment may be much too low, and a substantial increase in this velocity may be required. This can be achieved by increasing the water flowrate through the tubes, and/or decreasing the number of tubes, and/or decreasing the internal diameter of the tubes. A study has been done to see how varying these three parameters can augment the required jet velocity to a level considered necessary. To undertake this study, a detailed spreadsheet has been developed.

There are several alternative designs to the outlet of each jet tube. In particular, a base plate can be added at the tube base such that the water flow is diverted from an axial flow to a near horizontal flow. The jet velocity can be varied for a given flowrate by altering the clearance between the end of the jet outlet and the base plate. However, it should be noted that while this is a useful option to examine in the physical modelling study, there are no known empirical or theoretical correlations for determination of the minimum jet velocity required to mobilise and suspend the coarsest silt particles. In view of this, the desk review examines only the option when a jet tube is not fitted with a base plate, and where a free co-axial jet emerges from the jet tube above the interface between the settled sediment and the seawater contained in an extract compartment.

The desk study has also considered other parameters including the terminal settling velocity of sediment particles compared with the upflow rate in the lower part of an extract caisson compartment, the required mean slurry velocities through horizontal and inclined pipework linking the caissons to the barge, and centrifugal pump suction conditions.

A 1:7 scale model of a caisson compartment was constructed and tested under a range of operating conditions. The tests showed that the proposed design cannot remove sufficient material operating on a suction basis, even at flowrates up to three times the design figure.

Sealing of the caisson compartment to the sand bed or concrete base is critical to performance. When suction is applied, water is drawn into the caisson compartment preferentially underneath the walls rather than through the jet tubes. It was also clear that if there was any difference at all in the flow resistance for the different jets, for example a slight variation in the initial sand surface, then compensating flow would be greater through those jets seeing less resistance. Sand would clear faster around these jets, increasing the differential further and the 'deeper' jets would remain buried.

The small jets can suspend and remove the solids better than the 21mm open tube (150mm full scale). The smallest jet tested, 5mm (36mm) appeared to create the best suspension but no difference in actual removal was found comparing this with the 9mm (61mm) and 7mm (46mm) jets. No improvement in performance was found with baffle plates underneath the jets. Although the smallest jet appears to give the best performance, there is always a trade-off between the resistance through the jet (jet diameter) and the resistance to flow beneath the side walls, which means the smallest jets may not achieve the best performance in reality.

Positive pumping into the jet tubes, rather than relying on the pump suction to draw flow in, appeared to overcome the problem of breakthrough beneath the caisson compartment walls. Improved removal rates were obtained, at 57%, with 5.24m/s (10.02m/s) through the 7mm (46mm) nozzles. A removal rate of around 70% was achieved by increasing the running time to approximately double the original figure. This indicates that the design can be optimised to produce an arrangement that will give acceptable performance when operated in this manner. The flowrate and operating time required are likely to be higher than those originally envisaged, but should be within a feasible range.

Contents

1. Introduction

TECON s.r.l. is proposing to design a new sediment removal system to extract sediment from the gate recesses of Venice Flood Barriers. BHR Group has been asked to assist in the evaluation of the system through an initial desk study and through the development of the design and testing by using a scaled physical model.

A mobile sediment extraction system was designed last year. The proposed silt extraction system will be installed on board a ship/barge. Silt will be extracted from recesses of the gates through mobile folding pipework and stored in tanks. Two submerged pumps will be used to extract silt through ten paratactic extraction caisson compartments via mobile folding pipework to tanks on the ship. The arrangement of caisson compartments will need to move 4 or 5 times intermittently along the recess during the extraction process (which should take about 30 minutes).

A discharge pipework is also included to discharge silt from tanks to other places. It is not necessary to remove all the silt in an installation like the concrete caisson. The removal ratio of about 80% is considered to be the minimum acceptable value.

This report covers the desk study and physical model study carried out on the initial design of the sediment extraction system. The desk study considers the design and its efficacy in relation to sediment mobilisation and transport from the caissons through the pipework using two centrifugal slurry pumps.

Physical model testing of the silt extraction system was required to identify whether satisfactory conditions can be established within the proposed design. This report describes the observations and measurements made and presents the results of the tests carried out.

In this report, the following terminology has been adopted:

- an <u>extract caisson compartment</u>: a single 5m x 1.88m unit
- a <u>half caisson</u>: five extract caisson compartments joined together
- a <u>gate storage recess</u>: the concrete caisson containing the sediment to be extracted.

When describing parameters and results of the model study, model scale dimensions are used unless otherwise specified.

2. Objectives of the Project

The initial desk study prior to the development of the detailed physical modelling scope comprised the following activities:

- The jet velocity required to mobilise and suspend particles of the specified particle size distribution will be estimated. The total flowrate requirement for each of the five caissons will then be determined and this will be compared with the available total flowrate.

- If the total flowrate required is more than that specified by the client, a number of options will be explored, including:
  - Recommendation to increase the total flowrate to meet or exceed that required
  - Reduce the diameter of the jets to increase the jet velocity, while retaining the initially specified total flowrate
  - Reduce the number of jets in a caisson
  - Some combination of the above two options

- A check will be made in all cases to ensure that the flowrate in any pipework exceeds by a sufficient margin the deposit velocity, or "mean transport velocity", and how this may vary with the solids recovery concentration in the pipework. Recommendations will be made with regard to alteration of the proposed design should this not occur in some scenarios.

- The consequences of inadequate sealing between the bottom of a steel caisson and the surface of the sediment will be considered, if possible quantitatively, otherwise qualitatively. Design changes, such as the inclusion of a sawtooth edge to the base of the caisson, will be considered.

The following was excluded from the desk study:

- Consideration of the effects of any change in total flowrate delivered by the pump as a result of:
  - Changes in suction pressure due to changes in resistances on the pump suction
  - Changes in friction and static head across the pipework on pump discharge.

The objective of the model study was to construct and test a scale model of the Venice sediment extraction system.

3. Initial Data Set

The study was initially focused on the following data set:

Extract Caisson Compartment Arrangement

Number of extract caisson compartments per pump:	5
Caisson compartment length:	5m
Caisson compartment width:	1.88m
Caisson compartment height:	1.45m
Jet number per caisson compartment:	8
Jet tube length:	1.35m
Jet tube internal diameter:	0.15m
Jet tube clearance from surface of sediment	0.10m
Jet inlet elevation:	1.45m

Physical Properties of Silt

Density of sediment particles:	2700 kg/m^3
Density of sea water:	1035 kg/m^3
Sediment particle sizes:	
	d_{50} = 150 microns
	d_{95} = 380 microns

The full particle size distribution of the sediment is given in Figure 1.

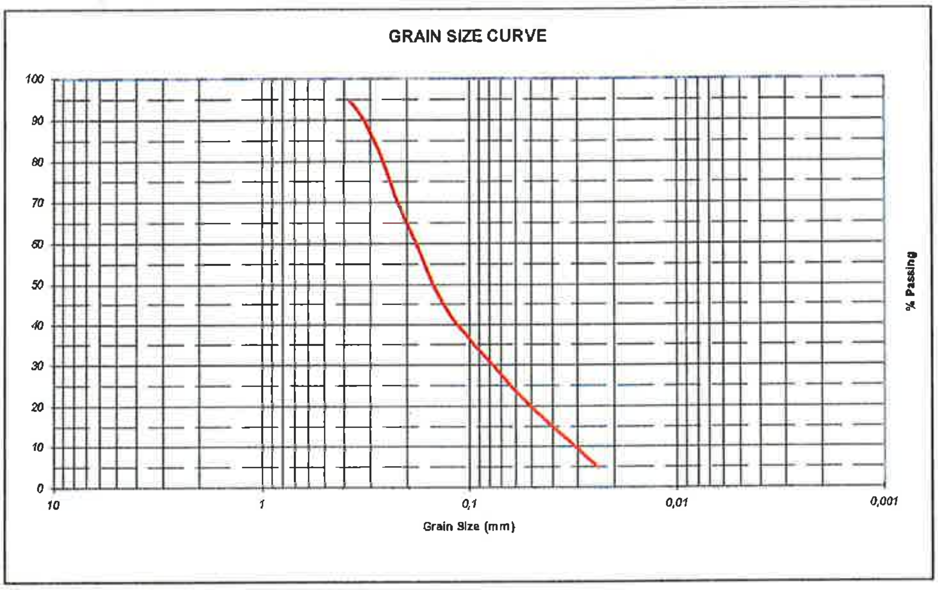

Figure 1 Particle Size Distribution of Sediment

Pump/pipeline Data

Suction pipe diameter:	0.45m
Discharge pipe diameter:	0.35m
Pump suction elevation:	2.15m

Operating Conditions

Total flow of solids through two pumps:	600 m^3/h
Total flow of seawater through two pumps:	1800 m^3/h
Total flow of seawater through jet tubes in 2 "half-caissons"	2400 m^3/h
Average feed slurry concentration:	
	25% by volume solids
	46.5% by weight solids
Average silt height in caisson:	0.50m
Maximum silt height in caisson:	0.80m

4. Assessment of Initially Proposed Design and Operating Conditions

4.1 Assessment of Hydrodynamics in a Single Extract Caisson Compartment

4.1.1 Jet velocity required to mobilise sediment

As a first approximation, it is assumed that the jet velocity in each of the 8 jet tubes and in each of the 10 extract caisson compartments is the same throughout. There may be minor differences owing to the location of the jets in a single caisson compartment, and how far the caisson is from the pump suction, but this is sufficiently accurate as a first scoping design assessment.

This jet velocity is calculated knowing the total flowrate of 2400 m^3/h (600 m^3/h solids and 1800 m^3/h) split equally between the two pumping units, each unit comprising of 5 extract caisson compartments. With 8 jet tubes per caisson and an initial jet tube internal diameter of 0.15m, **the jet velocity is calculated at 0.472 m/s**. This should be viewed as the maximum jet velocity achievable under the given set of operating conditions, as it is assumed that there is no leakage of water under the walls of the caisson.

An estimate of the required jet velocity to achieve "just suspension" condition of the sediment, V_j, can be based on an empirical correlation that has been developed for the suspension of solids on the base of a circular mixing vessel using a free jet (Ref. 1). This empirical correlation involves the two geometric quantities related to the diameter of influence of the jet, H and T, the height that the particles are suspended to, a measure of the coarser end of the particle size (d_{43} or d_{95}), the solids concentration of well-mixed solids in the caisson, X, the densities of the solids and liquid phases, and the jet tube internal diameter, d_j. Actual values or alternatively, estimates for all these parameters have been made, and **the predicted jet velocity is 2.79 m/s**.

As the precise form the equation used for the minimum jet velocity is confidential to member of an industrial research consortium managed by BHR Group ("Fluid Mixing Processes", or FMP), it is possible only to give an indication of the empirically-based correlation used:

$$V_j = K\left[\frac{H}{T}\right]^a g^b X^c D_p^d T^e \left[\frac{\rho_s - \rho_l}{\rho_l}\right]^f / d_j \qquad \text{Eqn 4.1}$$

in which

V_j = the minimum co-axial jet velocity

K = constant which varies depending on the shape of the base of the mixing vessel, and how the position in a mixing vessel at which liquid is withdrawn for reintroduction through jets

H = height of fluid in the tank (estimated as the height of a single extract caisson compartment)

T = diameter of the tank (estimated by calculating the area of a single extract caisson compartment divided by the number of jets used)

X = concentration of fully suspended solids in a single extract compartment, defined as the ratio of mass of solids to mass of liquid times 100% (taken as 20%)

D_p = d_{43} or d_{95} particle size (taken as 380 microns)

ρ_s = solids density (2700 kg/m^3)

ρ_l = liquid density (1035 kg/m^3)

d_j = internal diameter of jet tube

It must be stressed here that the use of Eqn 1 in the current application can only ever be a guide to the magnitude of jet velocity that is required to mobilise and suspend the coarsest silt particles for the following reasons:

(1) it has been developed for suspending solids in a closed batch circular mixing vessel where particle-free or low concentration liquid is taken from either the lower or upper part of the vessel and re-introduced using an external recirculation loop to jets;

(2) the jet tube is assumed vertical whereas in the proposed design for the extract caisson compartment the jet tubes are positioned in an inclined position.

Thus, part of the role of the physical modelling work will be to determine the minimum jet velocity required under different operating conditions.

The results of the comparison of the calculated and predicted jet velocity indicates that a much larger jet velocity is required in order to mobilise the coarsest sediment particles. Increasing the jet velocity can be done by:

- Reducing the jet tube diameter (or fitting the jet tube with a nozzle at its outlet to accelerate the flow)
- Reducing the number of jets in a single caisson
- Increasing the flowrate of seawater through the caissons
- Or, a combination of two or three of the above options.

There would appear to be no other options for increasing the jet velocity. These options are explored in detail in Section 5.

4.1.2 Silt extraction rates

A measure of the silt extraction rate can be made by assuming that the solids feed concentration is 25% v/v (i.e., 600 m^3/h solids and 1800 m^3/h sea water), and that the worst case (i.e., longest extraction time) is when a single concrete caisson contains the maximum expected height of sediment of 0.8m (average 0.5m).

A maximum silt volume at that height is estimated to be 7.52m^3. If solid particle packing fraction is estimated at 0.70 (reasonable for fairly narrowly-sized but angular particles), the total solids volume for a 80% removal ratio is 4.21 m^3 per caisson. Assuming a total solids removal rate of 600 m^3/h, this translates to a solids removal rate of 0.017 m^3/s. Thus the average time required to remove the solids from one caisson is 4.21/0.017/60 = 4.21 minutes. As there is a total time allocated of 30 minutes to remove solids from one gate, and the caissons must be deployed between 4 to 6 times per gate, this average extraction time seems reasonable.

4.1.3 Upflow rate in lower part of extract caisson versus particle terminal settling velocities

The upflow rate in the lower part of an extract caisson is an important parameter. This can be calculated as follows. The total volume flowrate through a half-caisson is 0.33 m^3/s, when 300 m^3/h of solids are being removed with 900 m^3/h of water, and 300 m^3/h water remains and takes the place of the solids removed. The total area of the "footprint" of the half-caisson is 47 m^2. Therefore, the upflow rate is 0.33/47 = 0.0071 m^3/m^2/s, or 7 l/m^2/s.

This upflow rate is effectively an average upward velocity in the lower part of an extract caisson compartment, and can be compared with the terminal settling velocity of the sediment particles. The latter can be calculated assuming quiescent, non-turbulent conditions but may represent a guide regarding the extent to which the upflow rate is overcoming the tendency for particles to settle back into the extract caisson compartment.

The terminal settling velocity is calculated from a knowledge of the particle drag coefficient, C_D, and particle Reynolds number, Re_p, as defined by

$$C_D = \frac{4dg(\rho_s - \rho_l)}{3V_{t\infty}^2 \rho_l} \qquad \text{Eqn. 4.2}$$

where

ρ_s is the density of the solids

ρ_l is the seawater density

d is the particle size

$V_{t\infty}$ is the terminal settling velocity of a single particle

And

$$Re_p = \frac{dV_{t\infty}\rho_l}{\eta_l} \qquad \text{Eqn. 4.3}$$

The particle drag coefficient C_D, and the particle Reynolds number, Re_p, are related according to Figure 2 and the equation it contains (Ref. 2).

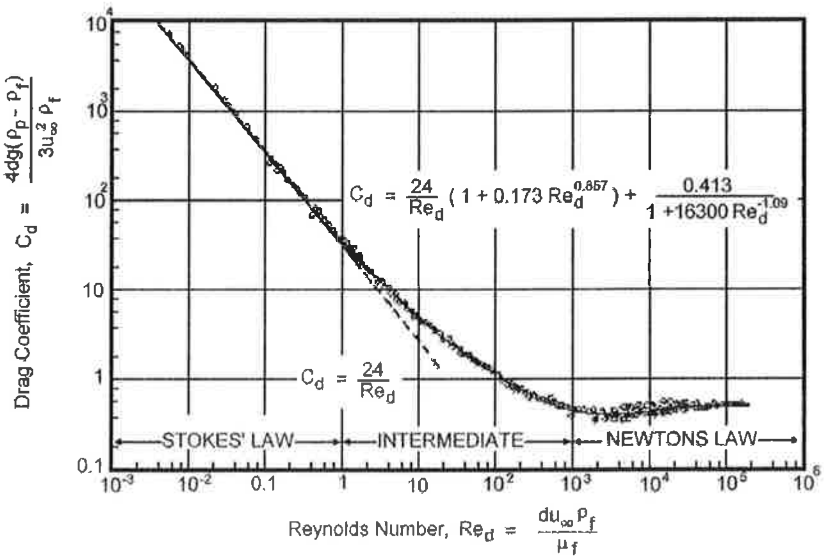

Figure 2 Relationship between Particle Drag Coefficient and Particle Reynolds number

The terminal settling velocity of a single particle of sediment can be calculate from this information, and Table 1 summarises the gravitational settling characteristics of the d_{50} and d_{95} particles in the particle size distribution given in Figure 1. The viscosity of the seawater is assumed to be 0.001 Pa s.

Table 1. Gravitational Settling of Sediment Particles

Sediment Particle Size, microns	Particle Reynolds number, Re_p	Particle Drag Coefficient, C_D	Particle Terminal Settling Velocity, m/s	Hindered Particle Terminal Settling Velocity, m/s (C_v = 0.25)
d_{50} = 150	11.7	3.77	0.029	0.011
d_{95} = 380	84.1	1.19	0.082	0.036

Table 1 shows that for the two sediment particle sizes considered, the terminal settling velocity of a single 380-micron sediment particle is approximately 3 to 12 times the upflow rate. This would suggest that the upflow rate may be too low, and provides an additional reason for raising the water flowrate into the caissons, if this is possible.

A further refinement to this analysis is to account for the presence of surrounding particles on the terminal settling velocity. This can be assessed by calculating the hindered settling velocity, V_t, according to the Richardson-Zaki equation (Ref. 3):

$$V_t = V_{t\infty}(1 - C_v)^z \quad \text{Eqn. 4.4}$$

where the exponent, z, can be estimated for a particle Reynolds number range of 1 to 200 from

$$z = \frac{4.45}{Re_p^{0.1}} \quad \text{Eqn. 4.5}$$

Table 1 shows that at a total solids volume fraction of 0.25, the terminal settling velocity of the 150-micron sediment particle reduces from 0.029 m/s to 0.011 m/s in the presence of other particles, and for the 380-micron particles from 0.082 to 0.036 m/s. Thus, inclusion of hindered particle settling effects indicates that the range of the ratio of the hindered settling velocity to the average upflow velocity is reduced to 1.5 to 5.

4.1.4 Consideration of the geometry of a half-caisson

Sealing between base of caissons and silt/water interface

The estimates of jet velocity as a function of total seawater flowrate through the jets, number of jets and internal jet diameter assume that there is a complete seal between the base of all the extract caisson compartments. This may occur for silt which is laid down fairly uniformly within a gate storage recess, but, in general, it may be difficult to form this seal for silt profiles which are undulating. One option to improve the sealing is to impose some oscillating lateral movement to the caissons as they are moved downwards into the gate recesses. This will then probably have the effect of moving the top layers of the silt laterally, and so facilitate a deeper penetration of the caisson vertical walls into the silt. The extent of caisson penetration into the silt will be governed by the normal stress on the unit and the level of consolidation of the silt, and therefore its strength development, during up to a 5-year period.

The process of caisson penetration into the silt may also be improved by using a "saw-tooth" profile to the bottom of each caisson, instead of a flat surface to the bottom of each wall. This will then facilitate a cutting action into the silt.

However, there is currently no on-line instrumentation envisaged in the vicinity of the caissons during normal full-scale operations. It will be very difficult to determine the extent of the sealing for each extract caisson compartment and resulting efficiency of not only all the jet tubes contained in one extract caisson compartment, but also whether one or more jet tubes are partially or wholly blocked by silt ingress as the caissons are lowered onto the silt interface.

Jet tube design

Throughout this desk review, jets emerging axially from jet tubes have been assumed. However, a base plate could be incorporated at the end of a jet tube which would cause an essentially horizontally-directed jet across the silt interface rather than vertically downwards. This is shown in Figure 3. The mechanism and forces responsible for silt mobilisation and suspension are likely to be quite different from those applicable to an axially-emerging jet.

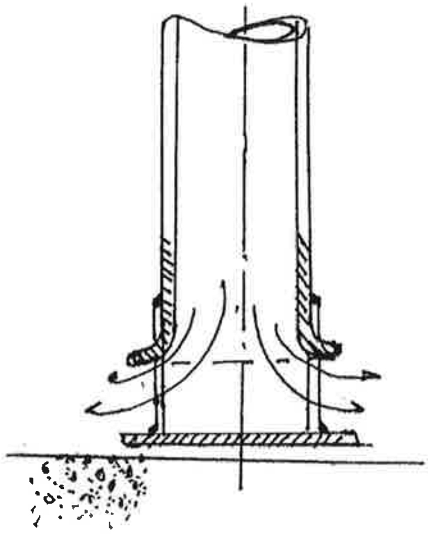

Figure 3 A Jet Tube incorporating a Base-Plate

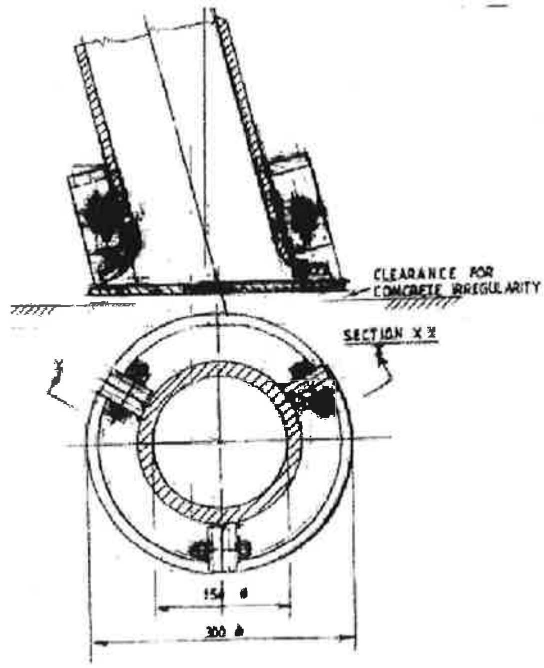

Figure 4 An Inclined Jet Tube incorporating an Adjustable Base-Plate

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Figure 4 shows a similar design but modified to allow for an adjustable base-plate during physical modelling testwork. It also takes account of the inclination of the jet tube in the extract caisson compartment.

Jet tube orientation

The current preliminary design indicates a total of eight jet tubes in a single extract caisson compartment:- one vertical tube at each end of the caisson and six inclined and equally-spaced along the caisson length. Owing to the requirement for a horizontal manifold pipe on the top of each extract caisson compartment which collects the silt slurry and feeds it to the pump suction, these six jet tubes need to be inclined. At present, all six are inclined in the same direction, and this is likely to result in preferential mobilisation and suspension of silt on one side of the bank of six jet tubes with a corresponding accumulation of silt on the other side.

In an attempt to counteract this tendency, it is recommended that the six tubes are inclined alternately within any one extract caisson compartment.

Number of extract caisson compartments per half-caisson

It is currently envisaged that there be 5 extract caissons for each of the two half-caissons. Another parameter that could be investigated is this number, and a case could be made for increasing this number form 5 to possibly 10, with an appropriate adjustment to the number of jet tubes placed in each extract caisson. This could result in more efficient silt mobilisation and suspension, and could be explored further as part of the scaling up process of experimental data from the physical modelling test work.

4.2 Considerations for Connecting Pipework and Pumping

4.2.1 Prediction of silt particle deposit velocities in horizontal or inclined pipework

The minimum transport velocity (deposit velocity), V_L, required to maintain the coarsest silt particles in suspension in horizontal and low inclination pipework can be calculated using the Durand equation:

$$V_L = F_L(2gD(s-1))^{0.5} \qquad \text{Eqn 4.6}$$

where F_L is the Durand factor which typically varies between 0.7 and 1.5, D is the pipe internal diameter, and s is the ratio of the densities of the silt particles and the seawater. As the "s" parameter is fixed at 2.61, Eqn 4.6 reduces to

$$V_L = 5.62 F_L D^{0.5} \quad \text{Eqn 4.6a}$$

Estimates for F_L can be obtained by calculating the particle Archimedes number,

$$Ar = \frac{4 g d_{95}^3 \rho_f (\rho_s - \rho_f)}{3 \eta_f^2} \quad \text{Eqn 4.7}$$

in which ρ_f is the density of the silt slurry containing sub-75 micron material only. The fraction of the solids distribution that is sub-75 micron has been estimated from the supplied particle size distribution to be 0.28. From this, and assuming a solids concentration of 25% v/v, the "fines", slurry density is 1152 kg/m^3. Taking the d_{95} particle size as 380 microns, and making the assumption that the viscosity of the "fines" slurry is approximately 0.004 Pa s, the particle Archimedes number is 80.0.

The Durand factor can now be estimated from the empirical expression (Ref. 4):

$$F_L = 0.139 Ar^{0.4} \quad \text{Eqn 4.8}$$

from which an estimate of the Durand factor is 0.80. Using Eqn 4.6a provides estimates for the deposit velocity in differently-sized pipe.

For the 0.45m diameter inlet (suction) pipe to the pump, the deposit velocity is estimated to be 2.76 m/s, compared with an operating velocity of 2.10 m/s. Thus, the coarsest sediment particles are predicted to settle out in transfer pipework that is either horizontal or slightly inclined. However, these particles may still be transported as a sliding bed. Further analysis is required to confirm this.

For the 0.35m diameter outlet (discharge) pipe to the pump, the deposit velocity is estimated to be 2.44 m/s, compared with an operating velocity of 3.46 m/s. Thus, the coarsest sediment particles are predicted to be conveyed in the heterogeneous flow pattern (fully suspended) in transfer pipework that is either horizontal or slightly inclined.

4.2.2 Frictional pressure loss estimation through straight pipework

Using the Two-Layer Model (Ref. 4) approach to modelling the pipeflow of coarse particle solids, it is possible to make estimates of the frictional gradient in differently-sized pipe which may be horizontal or inclined.

For the 0.45m inlet pipe to the pump having an operating velocity of 2.10 m/s, the model predicts the presence of the <u>sliding bed flow pattern</u> and a corresponding frictional pressure gradient for horizontal flow of 226 Pa/m and an *in situ* solids concentration of 26.8% v/v instead of the feed solids concentration of 25% v/v. The *in situ* concentration is important because it determines the frictional pressure loss.

For the 0.35m inlet pipe to the pump having an operating velocity of 2.10 m/s, the model predicts the presence of the <u>heterogeneous flow pattern</u> and a corresponding frictional pressure gradient for horizontal flow of 396 Pa/m and an *in situ* solids concentration of 25.5% v/v instead of the feed solids concentration of 25% v/v.

Analyses can be undertaken using the Two-Layer Model approach for any combination of internal pipe diameter, pipe inclination, mean slurry velocity, feed solids concentration, etc. The model can therefore be used to assist in the prediction of the pump suction pressure under different conditions. However, the model assumes steady state flow through constant cross-section ducts, and this is generally not the case in the manifold structure above the caissons.

4.2.3 Centrifugal pump suction conditions

While making changes to the operating conditions in order to establish an appropriate jet velocity for sediment mobilisation, it is important to monitor the effects these changes have on the pump suction pressure. The pump type and size has yet to be selected but once done the manufacturer can provide information for water flow for the NPSHR (the net positive suction head required) as a function of pump impeller speed, diameter, etc. This NPSHR needs to be adjusted appropriately for the effect of the presence of the solids and then compared with the NPSHA (net positive suction head available). Typically, NPSHA = 1.5 times NPSHR in order to minimise the chances of pump cavitation especially when solids are present. NPSHA = NPSHR for liquids not containing solids.

When there is no flow through the system, the pump suction pressure is equal to the hydrostatic head provided by the sea level in the lagoon. This sea level is lowest for the Treporti gate at 11.55m and so this inlet represents the worst case in providing the lowest pump suction pressure, all other conditions being the same. For no flow, and If the caisson walls are assumed to be touching the bottom of the concrete caissons, and for the Treporti gate at low tide (water depth 10.55m) the pump suction pressure is (10.55-2.15)*9.807*1035 Pa g = 0.853 bar g.

With seawater flow through the jet tubes, and slurry flow through the pump suction manifold and caisson manifolds, this suction pressure will reduce owing to the frictional pressure loss in the system. The higher the jet velocities that are required, the greater the frictional pressure loss across the jet tubes and therefore the lower the pump suction pressure.

With such a low current jet velocity of just 0.354 m/s, the frictional pressure loss across a jet tube is very small at around 12 Pa, so the pump suction pressure is largely unaffected. However, jet velocities of around 8 to 10 m/s are considered likely to be appropriate, and this would reduce the pump suction pressure to around 0.80 bar g at a jet velocity of 10 m/s.

However, at this stage the additional frictional pressure losses caused by the flow of slurry through the seven orifices in the caisson manifold, along the manifold to the pump manifold, and through the pump manifold have not yet been taken into account.

5. Alternative Operating Conditions to meet Required Predicted Jet Velocity for Silt Mobilisation

A study has been conducted to determine the necessary jet number / diameter and total flow rate to give a sufficient jet velocity to suspend the silt in the main bulk of water. Through this study the ratio of actual jet velocity to required jet velocity has been calculated and used to determine the required parameter. This ratio has been used to judge whether the achieved jet velocity is sufficient. Ratios greater than 1.2 are considered as acceptable (green region in Figures 5 to 9), between 0.8 and 1.2 is borderline acceptable (yellow region in Figures 5 to 9) and less than 0.8 is insufficient (red region in Figures 5 to 9) to suspend the silt.

A number of key findings have been found (Figure 4) on varying the total water flow rate through all jet tubes between 2400 m^3/h (current design) and 6000 m^3/h, whilst maintaining the originally specified internal jet diameter (0.15m) and jet number (8 jets). It has been found that for 8 jets of 0.15m internal diameter the actual to required velocity ratio never exceeds 0.42 even for the high, perhaps impractical, 6000m^3/h flow rate. However, it has been seen that by increasing the flow rate from 2400 to 3000m^3/h can increase the ratio by just under 25%. This increase in flow rate is therefore an important factor that should not be neglected when recommending an 'improved' set of specifications.

Other variables that have been found to influence the actual velocity to required velocity ratio are the jet number and internal jet diameter. The influence of 5, 6, 7 and 8 jets have been investigated, and the results for 5 jets and 8 jets are shown in Figure 6 and 7 respectively. From these figures it can be seen that the jet number must be at the lower end of the scale to give usable velocities, but these must be accompanied with high flow rates to achieve the required velocity to suspend the particles.

In addition it has been found that by reducing the jet diameter from 0.075m to 0.07m (as shown in Figure 8 and 9) improvements in the achieved velocities can be seen, these are more evident when the diameter is reduced to 0.07m (Figure 9). However, the necessity for higher flow rates are once again evident in these results.

From each of these findings it can be seen that jet diameter influence and jet number can have large influences on the final achieved jet velocities. However, the combination of one of these factors with increased flow rates can allow the jet velocities to be sufficient to allow the silt to be suspended.

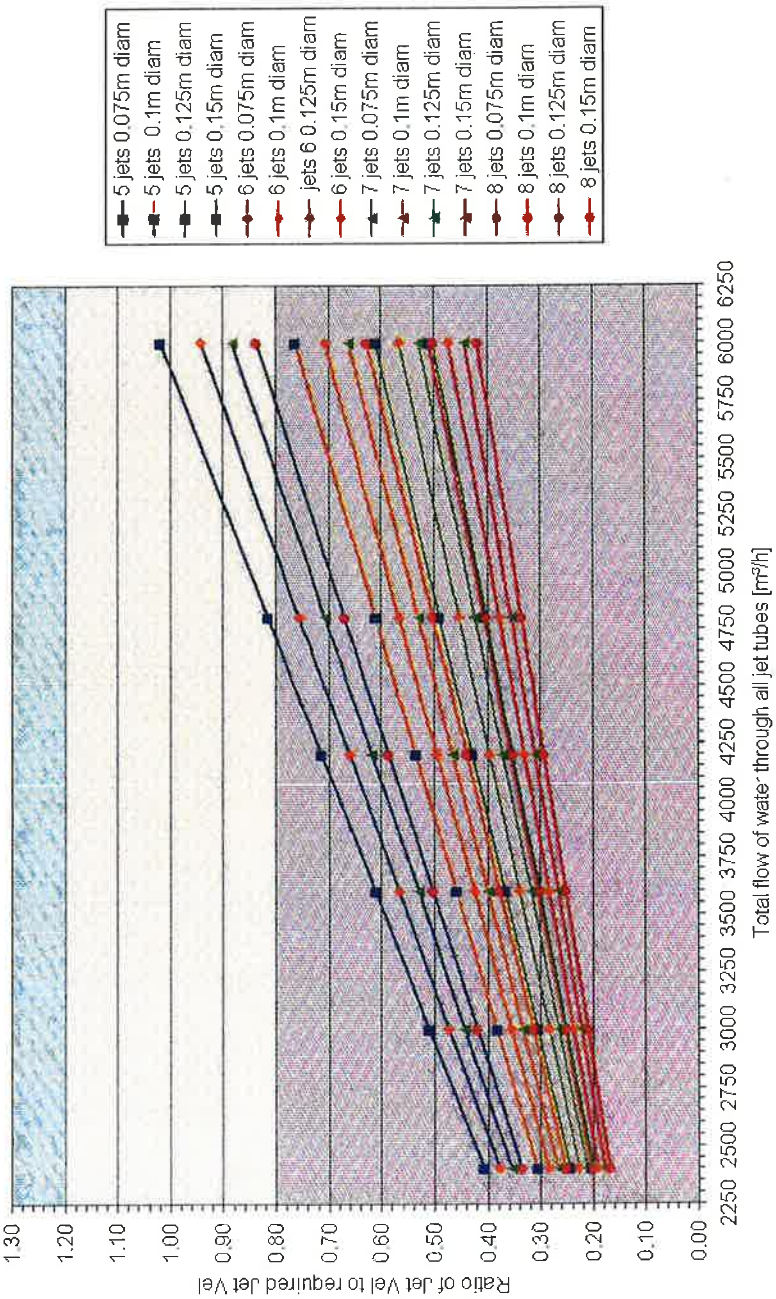


Figure 5: Influence of changing the total flow rate between 2400 and 6000 m^3/h

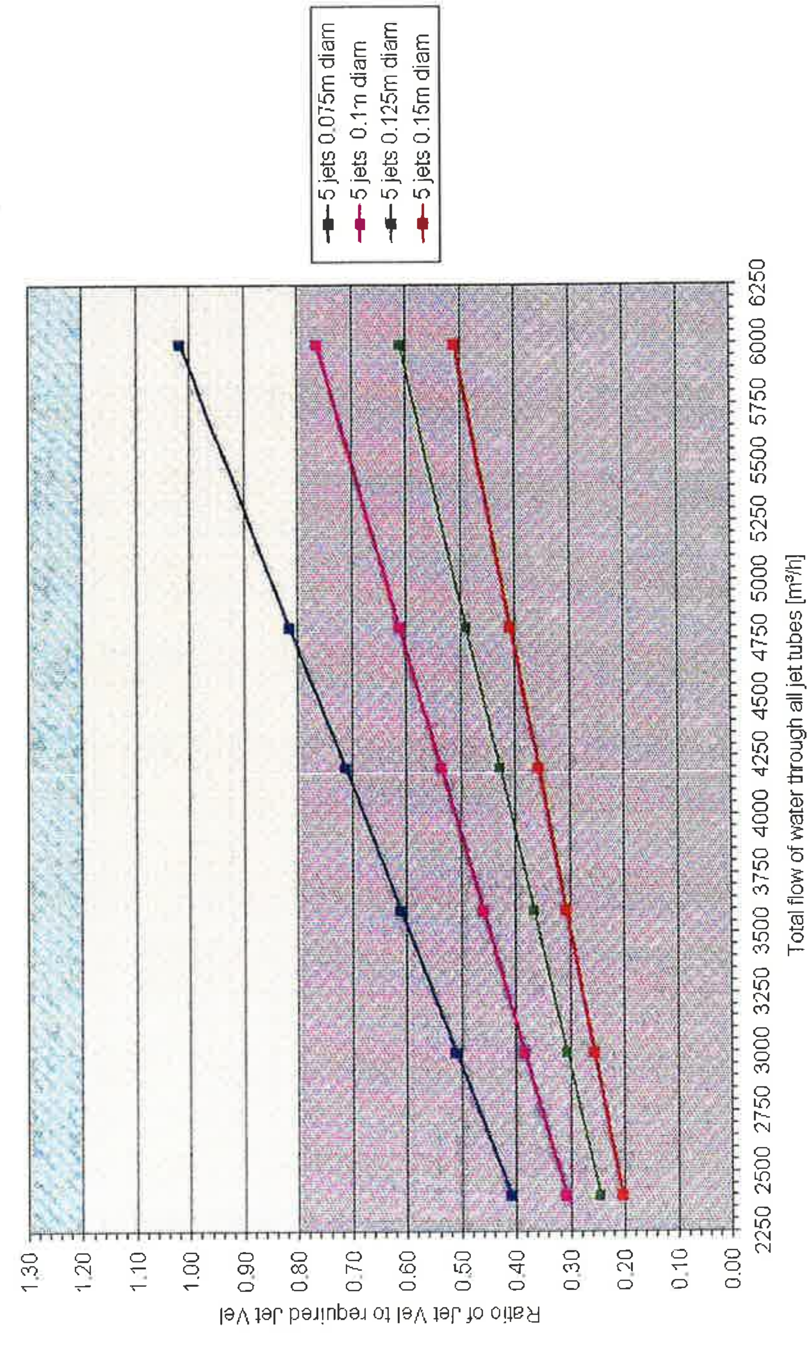


Figure 6: Influence of changing the jet diameter for 5 jets

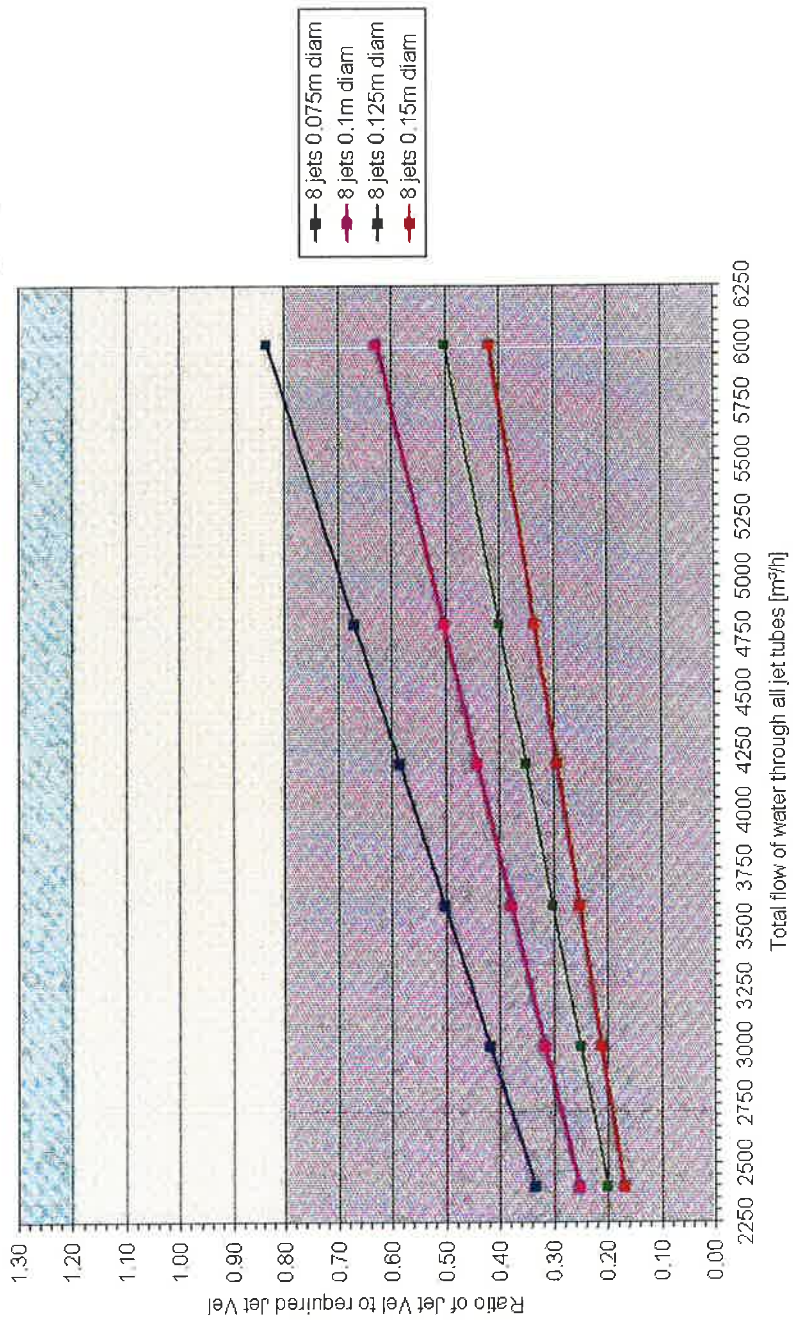


Figure 7: Influence of changing the jet diameter for 8 jets

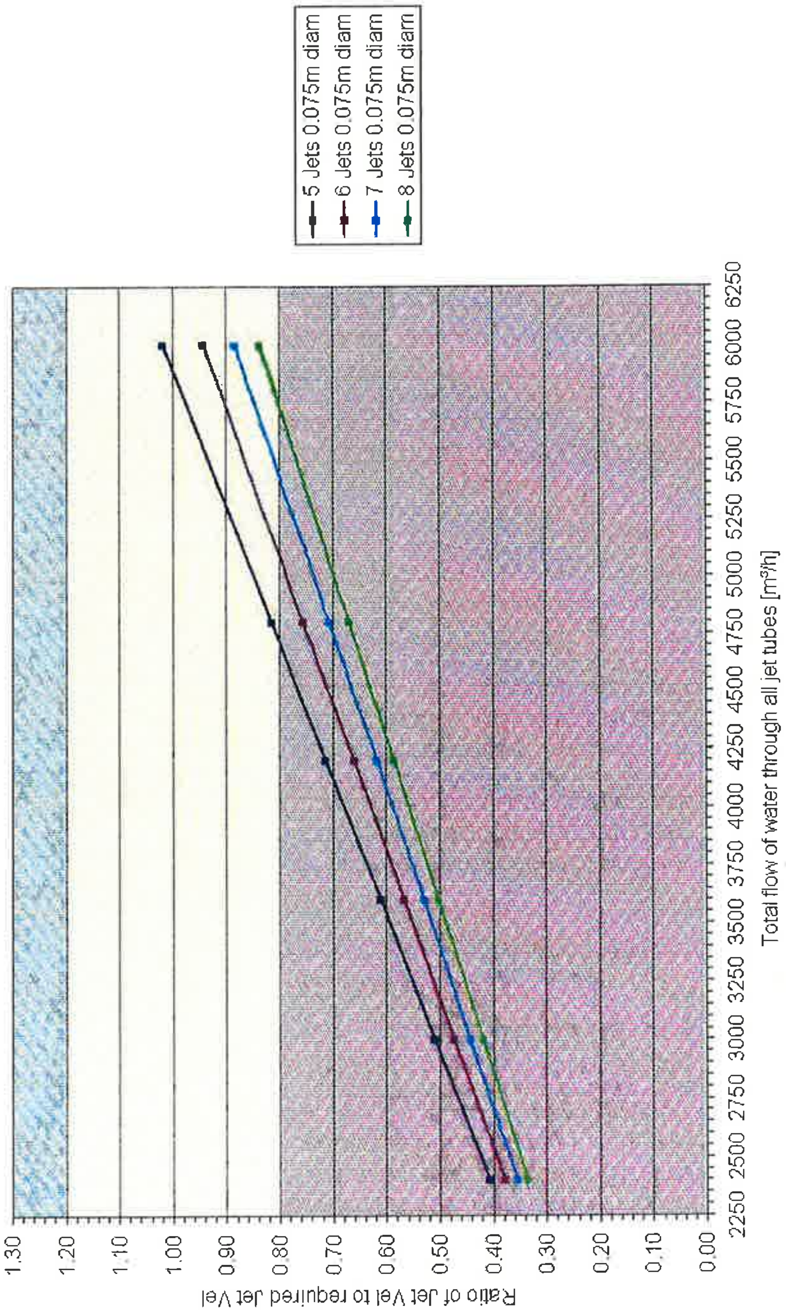


Figure 8: Influence of changing the jet number for a jet diameter of 0.075m

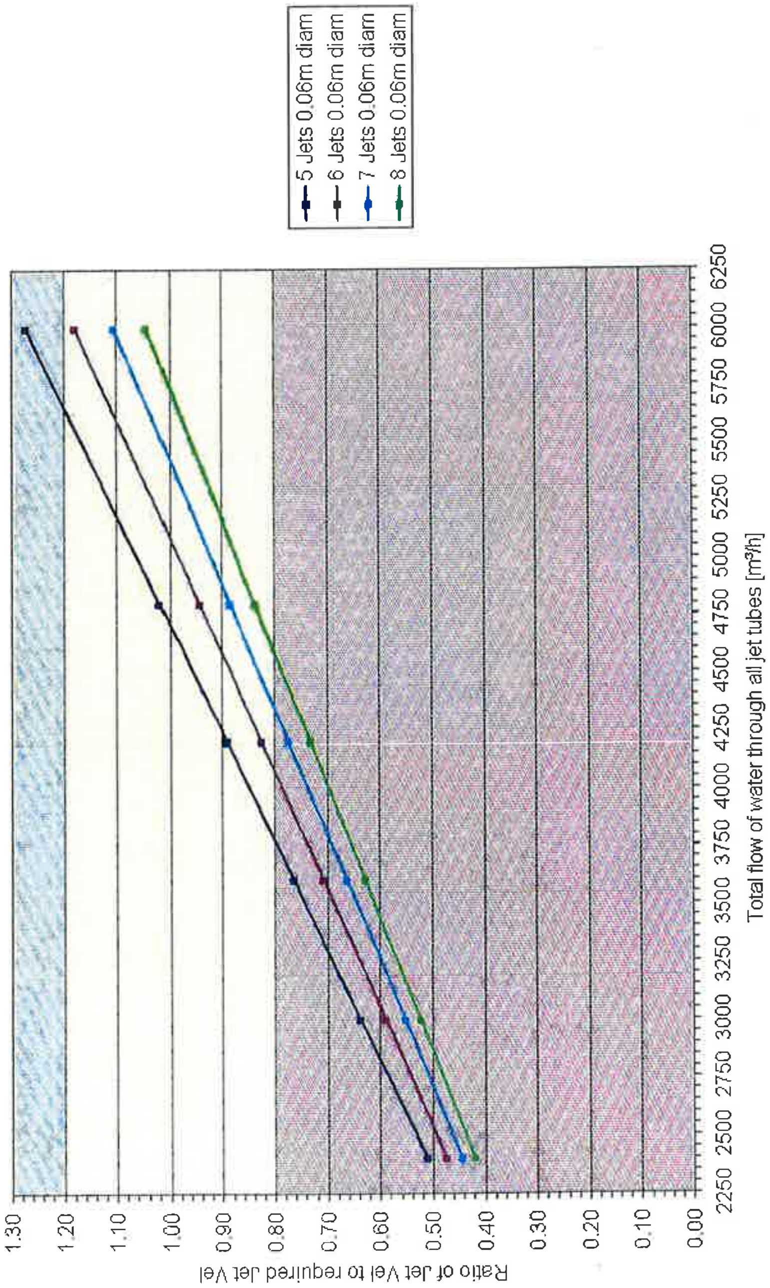


Figure 9: Influence of changing the jet number for a jet diameter of 0.06m

6. Conclusions and Recommendations from Desk Study

This desk study review suggests that the preliminary design may result in jet velocities that are too low to suspend the coarsest silt particles. The analysis has assumed complete sealing of the base of all extract caissons, so any leakage of seawater through here can only lower the jet velocities further. Using an empirical correlation for the minimum jet velocity required to suspend 380-micron silt particles of SG 2.7, ratios of the actual jet velocity to that required have indicated the range of jet velocity that should be included as part of the physical modelling test work.

It has been possible to only estimate required jet velocities using an empirical correlation that was developed for quite different operating conditions. Nevertheless, there is currently such a large difference between the actual and required jet velocities that this needs to be explored further in some detail during physical modelling test work. A substantial increase in the jet velocity for each jet tube should be investigated during physical modelling test work. Typical range of jet velocity should be about 2 to 8 m/s, compared with the "base case" value of only about 0.5 m/s.

The inclined jet tubes should be alternated such that adjacent jet tubes are inclined in the opposite direction. This is then likely to lead to a more uniform recovery of silt from the gate storage recess.

This review has been undertaken of the initial design, assuming only suction from the caisson. In this case the sealing of the base of all extract caissons is crucial to achieving adequate jet velocities, and further thought and test work is required to try to ensure that adequate sealing can always be relied upon. Consideration should be given to a "sawtooth" bottom edge to all extract caisson compartments to assist in the penetration of the caisson walls into the sediment. It is considered crucial that the great effort is directed towards attempting to provide good sealing between caisson walls and the silt interface under a wide variety of operational conditions. The seal should also be checked during operations using suitably chosen instrumentation. Making recommendations for this instrumentation is outside the scope of the current desk review, but there is a wide range of commercially-available on-line instrumentation options, and these should be reviewed to see which, if any, should be incorporated into the design. If flow could be positively pumped into the jet tubes the seal would be less critical to performance.

Seawater jets that emerge axially from the jet tubes have been assumed throughout this study, but one option is to provide a base-plate. The base-plate, at least for physical modelling studies, could be fabricated to allow adjustment of the clearance between the end of the jet tube and base plate, so facilitating the use of a range of jet velocities for a given flowrate through the jet tube. With this addition, the jet direction would be essentially horizontal, rather than vertical, and, as there is currently little guidance on the required minimum jet velocity, this could be examined in some detail in physical modelling test work.

A representative particle size distribution for the silt has been supplied, and some numerical analysis has been carried out using this. However, for the purposes of the physical modelling test work, it would seem to be important that real silt samples from the Venice Lagoon be used, if this is at all feasible.

Silt slurry flow velocities in all pipework and manifolds need to be at least 25% to 50% above the estimated deposit velocity. Thus, volume flowrates and internal pipe diameters need to be selected accordingly.

The net positive suction head available (NPSHA) for the centrifugal pumps need to at least match, and preferably exceed by up to 50%, the net positive suction head required (NPSHR) and all possible operating conditions. The latter can be obtained from the pump supplier. This criterion is likely to be met under most circumstances, unless high jet velocities need to be induced using relatively small jet tubes when the frictional pressure loss across the jet tubes reduces the NPSHA substantially and possibly below the NPSHR. If this should happen, pump cavitation will occur, leading to inadequate flow through the jet tubes, and poor recovery of the silt slurry.

The system characteristics should be established for the pump discharge to determine the likely range of pump duty points in order to confirm that the minimum seawater replacement flowrate can be met. This can be done only once a pump type has been selected and sized. The latter should allow for head deration arising from the presence of slurry of concentrations averaging 25% v/v, but sometimes exceeding this value.

7. The Physical Model

7.1 Extent of the Model

One caisson compartment (5m x 1.88m) was constructed from perspex, along with eight jet tubes. These modelled an internal diameter of 0.15m, and end nozzles were inserted in some tests to reduce the diameter and increase the velocity onto the bed. Further tests were undertaken with jet tubes incorporating baffle plates. The model caisson and end nozzles are shown in Figures 10 and 11.

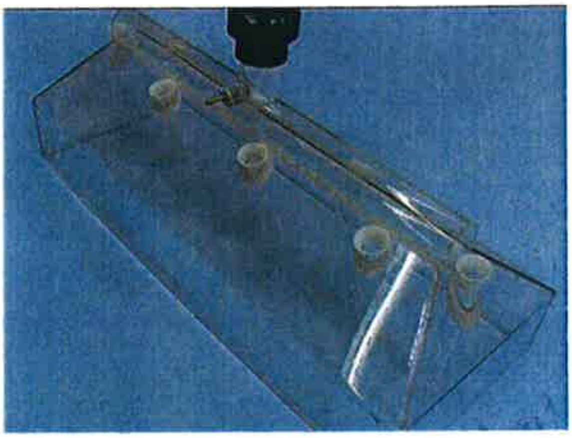


Figure 10 Model Overview

Figure 11 Different sizes of nozzles and plates

A 400mm x 900mm (model scale) timber box was used to model the sand bed underneath the suction caisson. When it was fully filled with sand, the sand depth was 115mm (model scale) which simulated 800mm prototype sand depth. The cross-section of the timber box was larger than the area covered by caisson in order to eliminate any boundary effect and to investigate any suction / breakthrough from the sidewalls of caisson.

7.2 Scale Effects

The model was constructed to a geometric scale of 1:7. At this scale the Reynolds numbers in the suction pipes are in excess of the minimum required to avoid scale effects, while flow rates and depths are large enough to ensure accurate measurement.

In practice the scale physical modelling of systems containing solids material is extremely difficult, and consideration must be given to the objective, in this case whether the solids could be suspended by the jets. In order to achieve this, the solids in the scale model were kept the same size as those in the real system and the flow rates were scaled to maintain a constant power input per unit volume with the full scale.

Constant jet power input is the scale-down rule used to investigate solids suspension in geometrically similar systems. This criterion has been confirmed experimentally at BHR Group and has been used on a number of model studies, for example, studying jet suspension systems for sand removal from large storm tanks and for mixing in sludge digesters. It has shown to be more representative than maintaining full scale velocities, which tends to over predicts performance.

The mixing power supplied by jets can be calculated from the kinetic energy of the jets. Therefore, the jet power input is defined as $\frac{1}{2}\rho Q v^2$

where ρ is the water density, Q the flowrate and v the jet velocity. From this criterion the different scale ratios for a 1:7 geometric scale model can be derived:

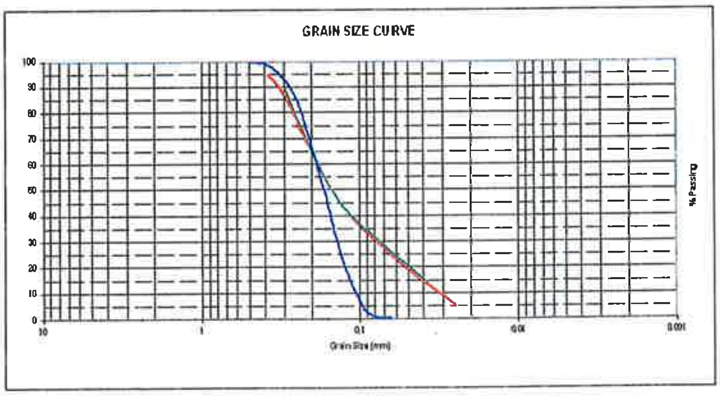
Parameter	Scale Relation	Scale Ratio
Length	$\frac{h_m}{h_p}$	1:7
Velocity	$\left(\frac{h_m}{h_p}\right)^{\frac{1}{3}}$	1:2
Flowrate	$\left(\frac{h_m}{h_p}\right)^{\frac{7}{3}}$	1:94

Time	$\left(\frac{h_m}{h_p}\right)^{\frac{2}{3}}$	1:3.7
Reynolds No.	$\left(\frac{h_m}{h_p}\right)^{\frac{4}{3}}$	1:13.4

At this scale the Reynolds Number at the minimum jet velocity is 5442, thus the flow is in the turbulent regime.

In order to examine the suspension of the solids within the caisson, the aim was to match the settling velocity of the solids in the model to that of the full-scale system. Using tap water as the working fluid in the model, this implies matching the full scale properties of the solids.

The silt has been shown to have a density of 2700 kg/m3 and a particle size distribution as given in Figure 12, with d50 = 150 microns and d95 = 380 microns. During the model commissioning, the silt was modelled with sand selected to approximate the full scale particle size distribution. This was achieved with a mix of four commercially available sands as given in the table below:



Input TCH (red)	
Size	%
0.024	5
0.038	10
0.051	20
0.077	30
0.114	40
0.15	50
0.18	60
0.22	70
0.28	80
0.32	90
0.38	95

BHR Initial (green)	
Size	%
0.0375	14
0.075	30
0.15	50
0.3	90

DAMF (Blue)	
Size	%
0.5	99.8
0.355	97.5
0.25	85.5
0.18	57.4
0.15	39.2
0.125	21.3
0.09	2.9
0.063	0.3

Figure 12 Solid Particle Size Distribution

Sand Name	% solids	Typical Size Range
DA80F	33	0.2-0.4mm
RH110	31	0.1-0.2mm
HPF5	19	0.05-0.1mm
HPF3	17	0.025-0.05mm

Very poor flow visualisation was observed due to the fines in the mix of sand, which was selected to accurately represent the particle size distribution provided (Figure 14). It was therefore decided to undertake subsequent tests with only one kind of sand (DA80F) giving the almost correct D50 and D90 but with fewer of the small grain sizes. This will be a conservative approximation of the full scale. The particle size distribution of DA80F sand is also shown in Figure 12.

7.3 Model Operation

The model was operated under steady state conditions. A laboratory pump was used to pump water from the caisson to a settling tank. The flow through the model pump was controlled by a valve and measured by a magnetic flowmeter.

Flow patterns in the model were observed with the aid of a red dye tracer. For some tests, outflow samples were taken from the outlet pipe, solids collected by filtering and the concentration calculated from the total volume and the dry weight.

To measure the pressure drop over the caisson compartment, a static tapping was installed at the pump suction pipe just above the location of the suction manifold. A pressure transducer was connected to the static tapping to measure the internal pressure when the system is operating. A computer based data acquisition system was set up to collect the data from the flowmeter and the pressure tapping.

8. Test Programme

The review identified that the jet velocity would have an impact on the performance and that for a given total flow rate this could be changed by altering the number of jets or the jet diameter. In the model study the number of jets was kept constant at eight and the nozzle inserts used to change the internal diameter.

The model was set up with each of the five jet arrangements given in the table below and a test run for a period of 1.4 minutes. The majority of tests were undertaken at the nominal total flowrate of 1200m³/hr through a half caisson (giving the velocities calculated in the table below). Some tests were undertaken at higher flowrates.

Full scale		Model	
Nozzle diameter (mm)	Velocity (m/s)	Nozzle diameter (mm)	Velocity (m/s)
150	0.47	21	0.25
61	2.85	9	1.49
46	5.01	7	2.62
36	8.19	5	4.28
Running Time: 4.21 min, Maximum 5 min		Running Time: 1.15 min, Maximum 1.4 min	

Four series of tests were undertaken:

Series 1	caisson compartment sitting on the silt bed	Silt bed 800mm	Commissioning tests
Series 2	caisson compartment sitting on a rubber seal and held down	Silt bed 70mm	
Series 3	caisson compartment sitting on a rubber seal and held down	Silt bed 800mm	
Series 4	caisson compartment sitting on the silt bed	Silt bed 800mm	Equal flow pumped in through the 8 jet tubes

8.1 Test Series 1

At the beginning of the initial tests (series 1), red dye was used to examine the flow pattern through the caisson compartment with no solids present. Dye was injected at the top of the eight inlet jets and the bottom of side walls when the pump was operating. Flow was seen to be drawn preferentially through the bottom of the side wall rather than coming through the jets (Figure 13).

Figure 13 Flow passing below the side wall reduces the inlet flow through the jets

Figure 14 Poor visualisation using mixed sand

One test was carried out using the sand selected to approximate the full scale particle size distribution (see section 3). This produced very poor visibility due to the constant suspension of the fines as shown in Figure 14 and all further tests were carried out using DA80F sand only in order to improve the visualisation.

Two tests were carried out using an 800mm thick layer of DA80F sand. The caisson compartment was placed on the surface of the sand where it sank slightly under its own weight. The pump was operated after the caisson compartment was set in position. Water flow tended to break through underneath the side wall, entraining sand with it (Figure 15). Once this mechanism had started this area quickly became the path of least resistance and minimal flow entered through the jets. As the pump continued operating, more sand was entrained into the caisson compartment and a larger gap was formed at the break through point. In addition, sand entrained from outside was seen to build up within the caisson compartment and bury the jets, totally eliminating flow through these jets and worsening the operating condition (Figure 16).

A further test was undertaken with the jet clearance increased to 45mm (model scale) in order to avoid burying the jets. Observations showed similar performance to the previous tests.

The differential pressure was recorded throughout the tests. However there was negligible difference between the readings for the system operating and non-operating due to the breakthrough at the bottom of the side walls.

Figure 15 sand entrained into the caisson compartment under the side wall (Series 1)

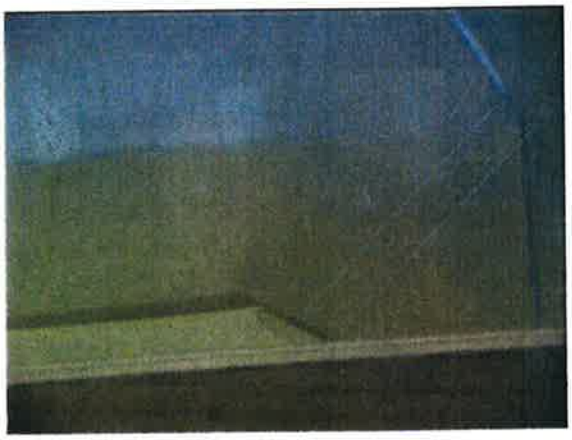


Figure 16 jets become buried in the sand (Series 1)

8.2 Test Series 2

Further to the first series of tests, the bottom of the caisson compartment was sealed onto rubber and the caisson compartment held down in order to alleviate the problem of sealing (see Figures 17 and 18). General flow patterns were again observed with the aid of visible tracers (red dye). Good sealing (but not 100%) and a reasonable jet velocity were achieved.

Tests were undertaken with a thin layer of sand to investigate the performance with a well sealed system. Four tests were carried out using thin layer of DA80F sand. A perspex plate was installed below the caisson compartment and strips of rubber were fitted on this plate, shaped to seal the bottom of the side walls. Sand was put in the perspex plate with the same height as the rubber strip (10mm) and the caisson compartment was fixed and held down for the test duration.

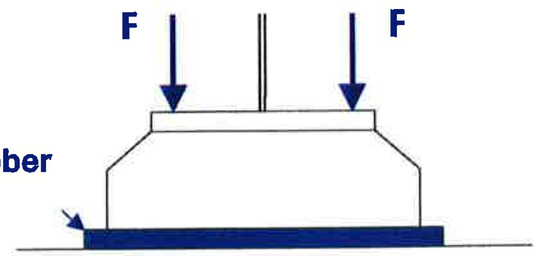


Figure 17 Seal arrangement sketch (Series 2)

Figure 18 Sealed caisson compartment arrangement (Series 2)

Sand concentration measurement was carried out 30 seconds after the pump start as an indication of the system performance. A 500ml sample was taken from the outlet and filtered. The collected sand was dried for one day and the weight of sand was measured. The results are listed below (Model scale). As this is a snapshot in time, the result does not reflect the real operation but gives an indication of the performance of different sizes of jets.

Nozzle size	21mm	9mm	7mm	5mm
Sand weight (g)	1.0147	1.8945	1.857	1.862
C% (kg/m^3)	2.0294	3.789	3.714	3.724
Removal (g/s)	0.012	0.023	0.022	0.022

This result shows the removal efficiency of the caisson compartment with a thin layer of sand. The caisson compartment with the largest jet gave the worst result. The smaller jets performed better but no significant difference in the removal rate was found between the 9mm, 7mm and 5mm jets.

Test observation showed that with the large nozzle, the solids cannot be fully suspended within the caisson compartment. Circles below the bottom of the jets showed that the flow pushes the sand aside and very little is actually removed. With smaller jet nozzles, the solids appeared to be fully suspended within the caisson compartment. Sand removal appeared to be very effective at the beginning of the test but then the sand did not effectively go into the manifold. No clear circle was found below the smallest jets because the sand was fully suspended and settled across the full area of the caisson compartment when the pump was turned off (see Figures 19, 21, 23, 25 and 26).

After each test, a further test was carried out with double the design flowrate in order to investigate any improvement in performance. The tests showed that double the flowrate can suspend the solids better within the caisson compartment but it was still not high enough to get the solid out of the caisson compartment effectively (see Figures 20, 22 and 24).

In addition, the pressure differential across the caisson compartment for each test was investigated. During each test, negative pressure was formed within the caisson compartment. For the large diameter jets, the pressure difference was found to be only about 15mb. The large diameter jets gave a low resistance to the compensation flow thus a small negative pressure was generated. For the smaller diameter jets (9mm, 7mm and 5mm), the differential pressure readings are listed below. Larger negative pressures may cause breakthrough under the bottom of the caisson compartment much easier.

Nozzle size	21mm	9mm	7mm	5mm
Average Pressure Difference when operating (mb)	15	32	35	42

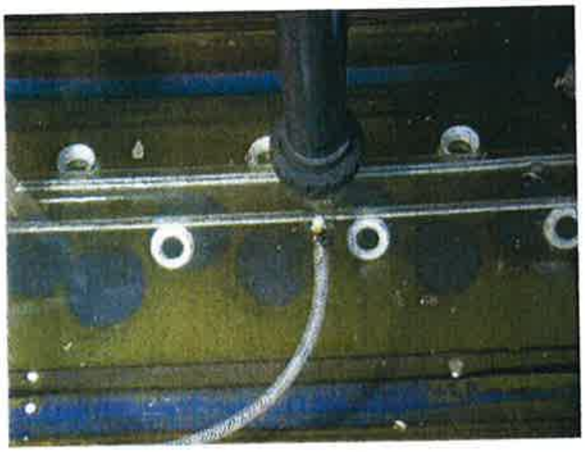


Figure 19 21mm jets (0.25 m/s)

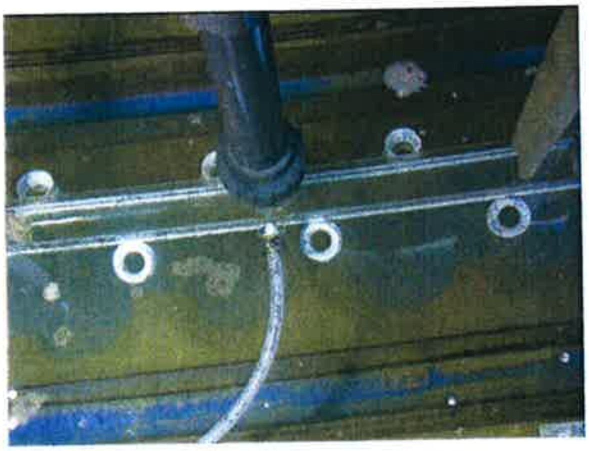


Figure 20 21mm jets (0.50 m/s)

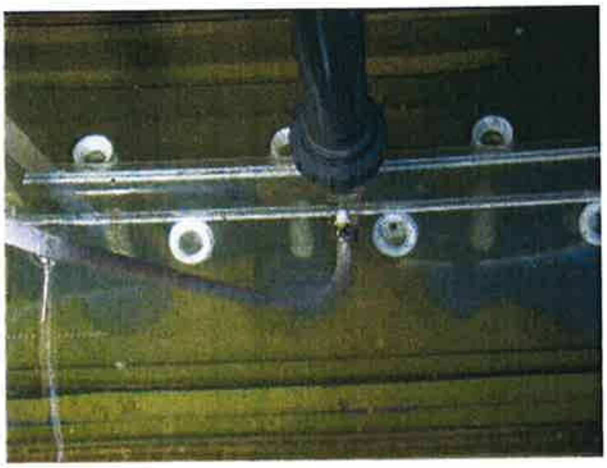


Figure 21 9mm jets (1.49 m/s)

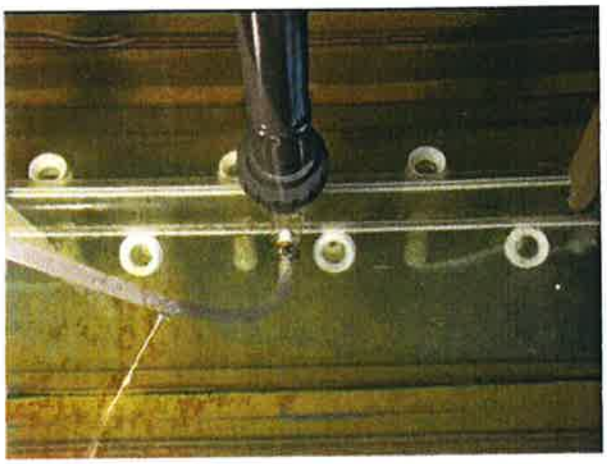


Figure 22 9mm jets (2.98 m/s)

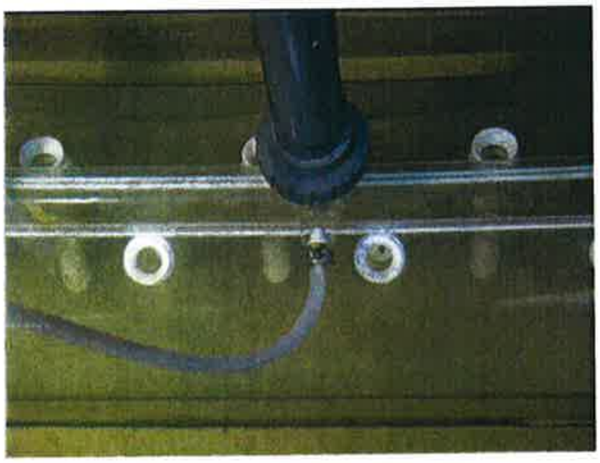


Figure 23 7mm jets (2.62 m/s)

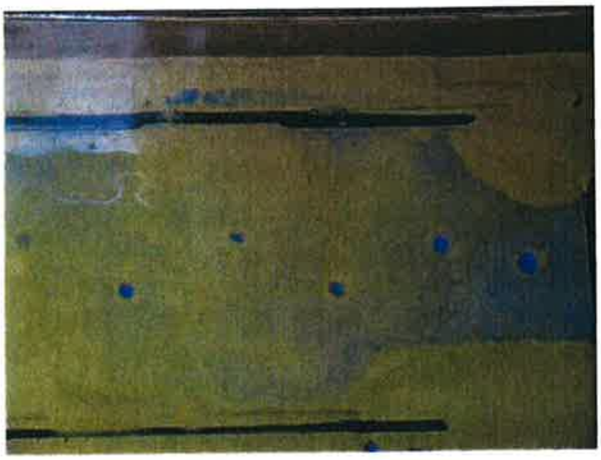


Figure 24 7mm jets (5.24 m/s)

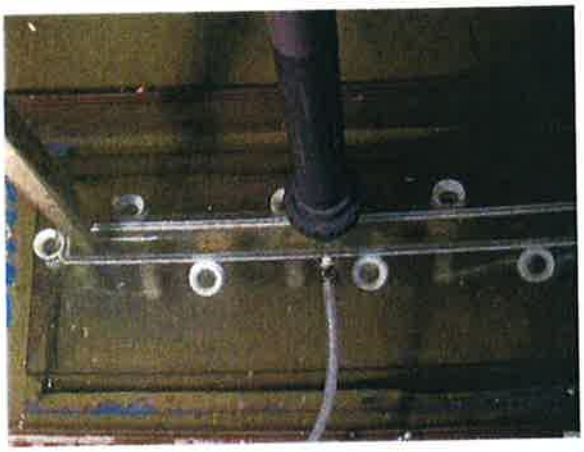


Figure 25 5mm jets (4.28 m/s)

Figure 26 5mm jets operating (8.56 m/s)

8.3 Test Series 3

For test series 3, a thick layer of DA80F sand was used to simulate the condition where the caisson compartment cuts through the bed and sits on the concrete base with good sealing around the bottom of the side walls. Sand was built up on the perspex plate as much as possible and caisson compartment was fixed on the rubber and held down. More sand was then put into the timber case around the outside of the caisson compartment. Finally, more sand was put into the caisson compartment through the outlet manifold in order to create a thick layer of sand outside/inside of the caisson compartment. As some sand had to be put into the caisson compartment through the manifold after the caisson compartment been sealed, a flat surface could not be created within the caisson compartment (it was slightly deeper in the middle and shallower near the far sides).

Due to the large variation of sand concentration with time, sand removal efficiency was investigated by measuring the average sand depth change after the each test.

Four tests were carried out at this stage and are listed below. The flowrate was based on 2400m^3/hr (full scale) through a half- caisson for all cases.

No.	Test 1	Test 2	Test 3 & Test 4
Jet diameter (mm)	21mm	5mm	5mm with plate underneath
Breakthrough	No	Yes	Yes
Removal	approx. 20%	approx. 40%	Not available (Large breakthrough occurred and reached the boundary of the timber box)

During test 1 and 2, jets in each side operated well and large quantity of sand was removed (approximately 20% and 40% of the total sand in the timber sand box, respectively). Jets in the middle section of the caisson compartment were blocked due to the uneven initial surface and further sand movement. No breakthrough from the bottom was found for test 1. Breakthrough was found in test 2 indicating a much higher resistance through the jet than through the bottom of the caisson compartment (see Figures 27 to 30).

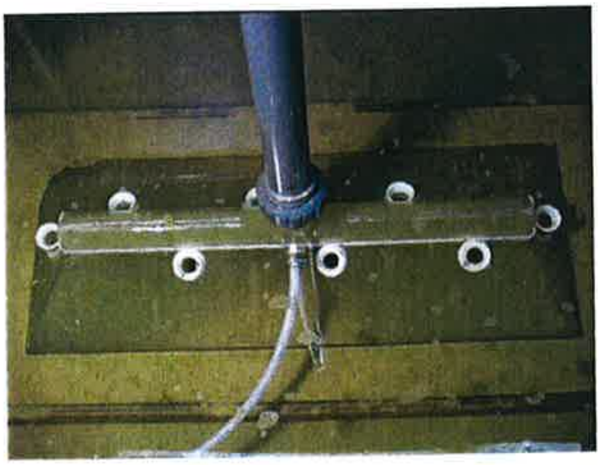


Figure 27 Series 3 test 1 overview

Figure 28 Series 3 test 1 operating

Figure 29 Series 3 test 1 result

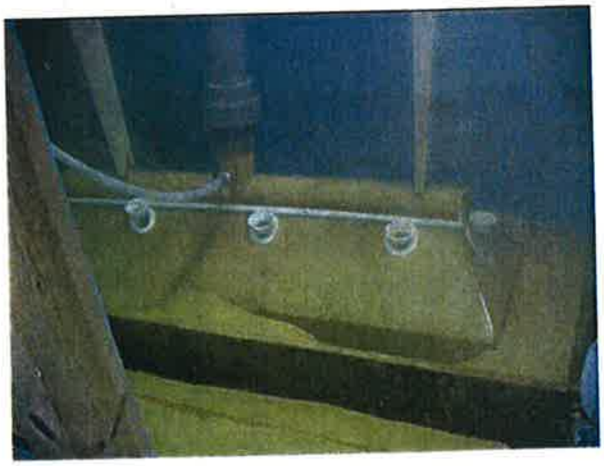


Figure 30 Series 3 test 2 Operating

Tests 3 and 4 were carried out with baffle plates installed underneath all of the jets. The baffle plates were installed to prevent the jets blocking with sand as the caisson compartment was lowered into the bed. Cones were installed under all the plates in order to make the caisson compartment easier to sink down into the sand. With the baffle plates in place the compensation flow jets out horizontally into the bed material. The stand-off of each baffle plate from the end of the jet was reduced to 3mm in order to maintain a relatively high velocity.

Water was seen to break through the seal entraining sand from the outside. The sand removal rate is quite high at the start of the test. Although the suspension appeared to be good within the caisson compartment, it was unclear whether the suspension is created by the breakthrough flow or the jets (see Figures 31 to 34).

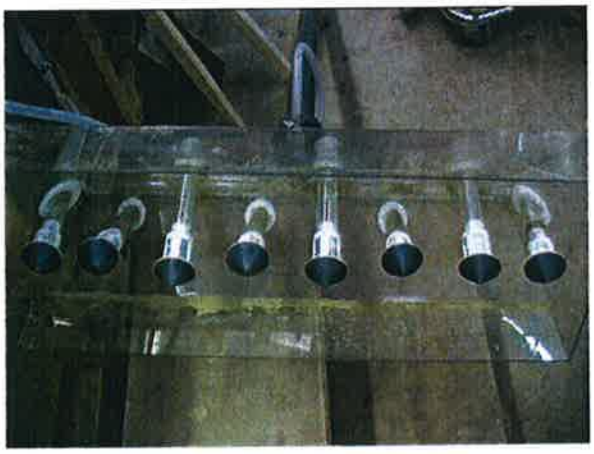


Figure 31 Series 3 Baffle Plate Arrangement

Figure 32 Series 3 Baffle Plate

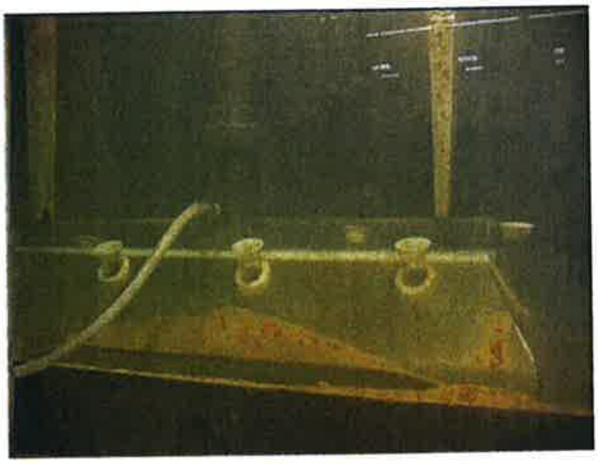


Figure 33 Series 3 Test 3 Result

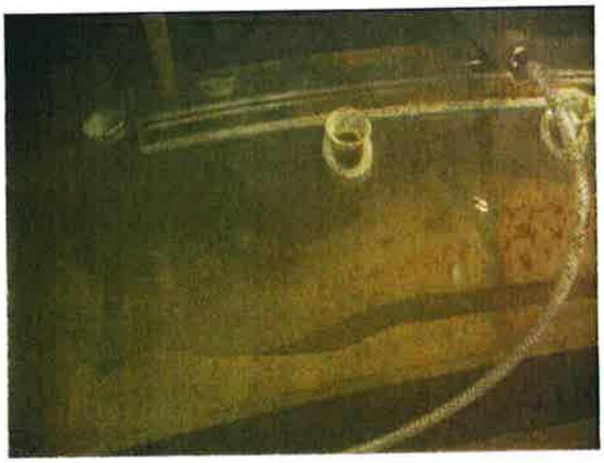


Figure 34 Series 3 Test 4 Result

Three times the nominal flow rate (equating to 3600m^3/hr through a half-caisson, full scale) was investigated with baffle plates installed and no significant improvement of sand removal was found (suspension but not removal).

8.4 Test Series 4

In order to overcome the breakthrough problem and obtain the required flowrate though the inlet jets, the physical model was modified to allow water to be pumped into the eight jet tubes. An eight way manifold was fitted on the outlet of a second pump and eight flexible hoses were connected from the manifold to the jet bellmouths. The total inflow and outflow to the caisson compartment were both measured with magnetic flowmeters and were adjusted throughout the test to ensure that they were matched. The 7mm diameter jets with no baffle plates were used in the test, set at 14mm from the base of the caisson compartment (see Figure 35). The caisson compartment was set up on top of the sand bed before the test (see Figure 36).

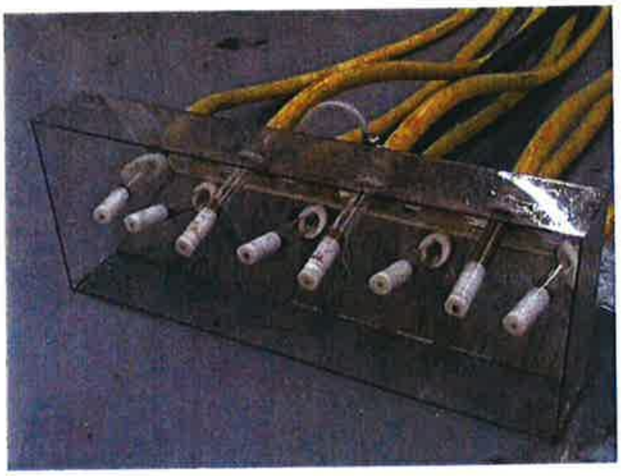


Figure 35 Series 4 Caisson Arrangement

Figure 36 Series 4 Model Overview

Figure 37 Series 4 Model Operating

The flow rates simulated 2400m^3/hr through a half-caisson. Good solid suspension and removal rate were observed throughout the test (removal rates had visibly reduced over the test period in all previous tests). Suspended solids can be seen throughout the caisson compartment and suction manifold in Figure 37. Due to equal outflow and inflow, no evidence of breakthrough flow was seen. In the 1.4 minute test, the total removal rate was measured about 57% within the caisson compartment area. A further test was undertaken with this arrangement running for around 5 minutes. A relatively high concentration of solids in the suction line was noted for 2.7 minutes and the total removal rate was about 70%. This final test is shown in Figures 38 and 39.

Figure 38 Series 4 Model Operating 5 min test showing some breakthrough

Figure 39 Series 4 Model Operating 5 min test

9. Conclusions from the Model Study

The tests have shown that the proposed caisson compartment design cannot remove sufficient material operating on a suction basis, even at three times the nominal flow rate (equating to 3600m^3/hr through a half-caisson, full scale).

Sealing of the caisson compartment to the sand bed or concrete base is critical to performance. When suction is applied, water is drawn into the caisson compartment preferentially underneath the walls rather than through the jet tubes. This was even the case with the perspex model sitting on a flat painted timber bed.

It was clear that if there was any difference at all in the flow resistance for the different jets, for example a slight variation in the initial sand surface, then compensating flow would be greater through those jets seeing less resistance. Sand would clear faster around these jets, increasing the differential further and the 'deeper' jets would remain buried.

The small jets can suspend and remove the solids better than the 21mm open tube (150mm full scale). The smallest jet tested, 5mm (36mm) appeared to create the best suspension but no difference in actual removal was found comparing this with the 9mm (61mm) and 7mm (46mm) jets.

The baffle plates underneath the jets had no improvement of the solid suspension and removal but can create more resist through the jet, which may lead to easier breakthrough.

Although the smallest jet appears to give the best performance, there is always a trade-off between the resistance through the jet (jet diameter) and the resistance to flow beneath the side walls, which means the smallest jets may not achieve the best performance in reality.

Positive pumping into the jet tubes, rather than relying on the pump suction to draw flow in, appeared to overcome the problem of breakthrough beneath the caisson compartment walls. Improved removal rates were obtained, at 57%, with 5.24m/s (10.02m/s) through the 7mm (46mm) nozzles - this equates to 2400m^3/hr through a half- caisson. The removal rate was increased to around 70% by doubling the duration of the test.

This last result is promising and indicates that with modifications, such as footprint and height of caisson department, stand-off and diameter of nozzle, the design can be optimised to produce an arrangement that will give acceptable performance. When the problems associated with operating on suction alone are eliminated, jet velocities in a similar range to that predicted in the desk study become realistic. The flowrate and operating time required are likely to be higher than those originally envisaged, but should be within a feasible range.

8. References

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3. Chhabra, R P & Richardson, J F (1999) "Non-Newtonian Flow in the Process Industries", publ. by Butterworth Heinemann, p. 222.
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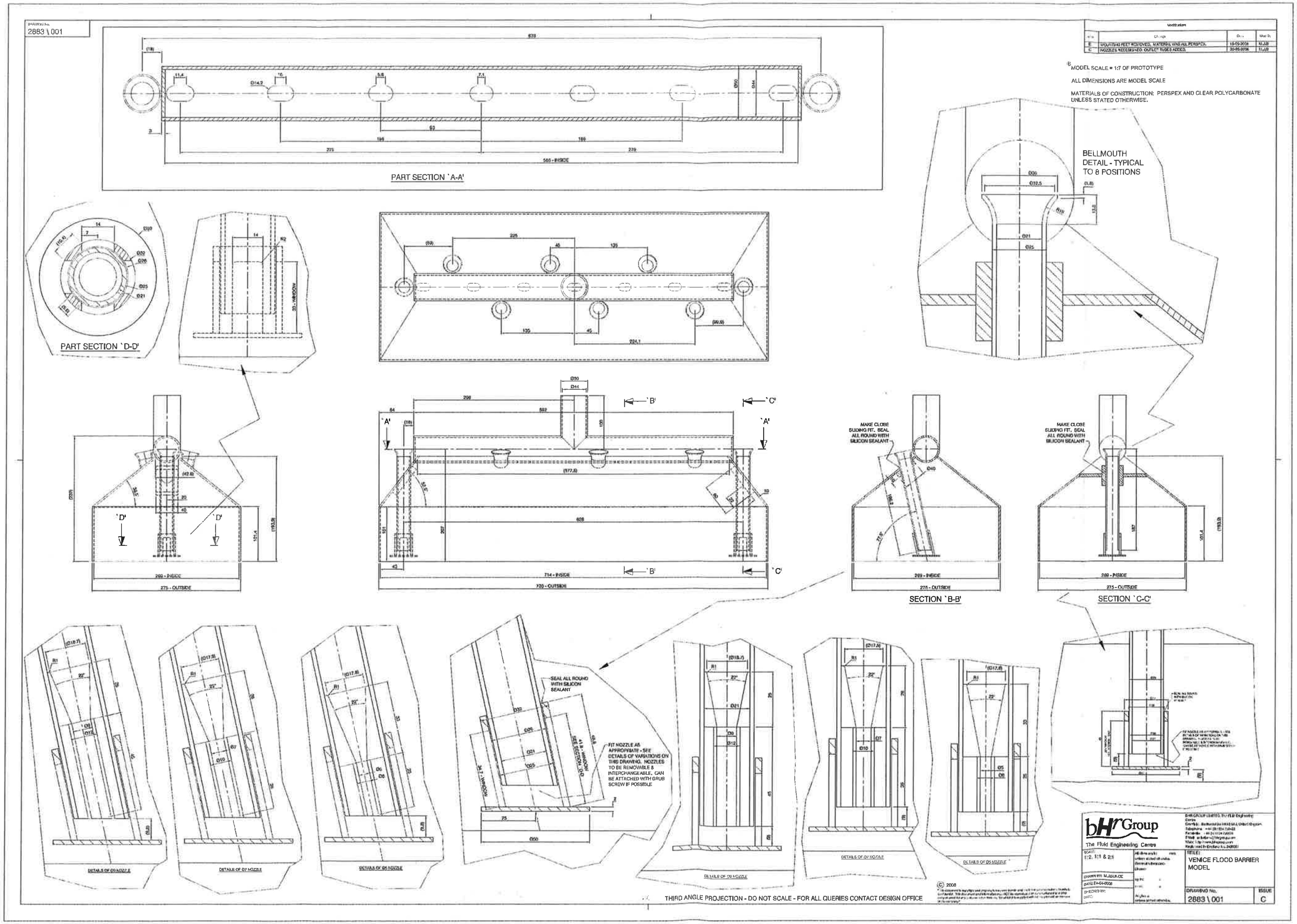

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MODEL SCALE = 1:7 OF PROTOTYPE
ALL DIMENSIONS ARE MODEL SCALE
MATERIALS OF CONSTRUCTION: PERSPEX AND CLEAR POLYCARBONATE UNLESS STATED OTHERWISE.
PART SECTION 'A-A'
566 - INSIDE
BELLMOUTH DETAIL - TYPICAL TO 8 POSITIONS
PART SECTION 'D-D'
269 - INSIDE
275 - OUTSIDE
714 - INSIDE
720 - OUTSIDE
MAKE CLOSE SLIDING FIT. SEAL ALL ROUND WITH SILICON SEALANT
SECTION 'B-B'
SECTION 'C-C'
SEAL ALL ROUND WITH SILICON SEALANT
FIT NOZZLE AS APPROPRIATE - SEE DETAILS OF VARIATIONS ON THIS DRAWING. NOZZLES TO BE REMOVABLE & INTERCHANGEABLE. CAN BE ATTACHED WITH GRUB SCREW IF POSSIBLE
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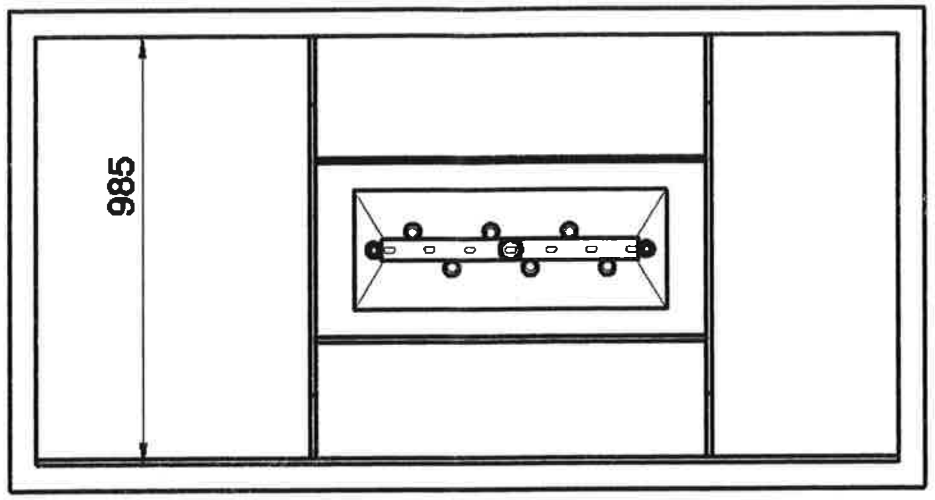

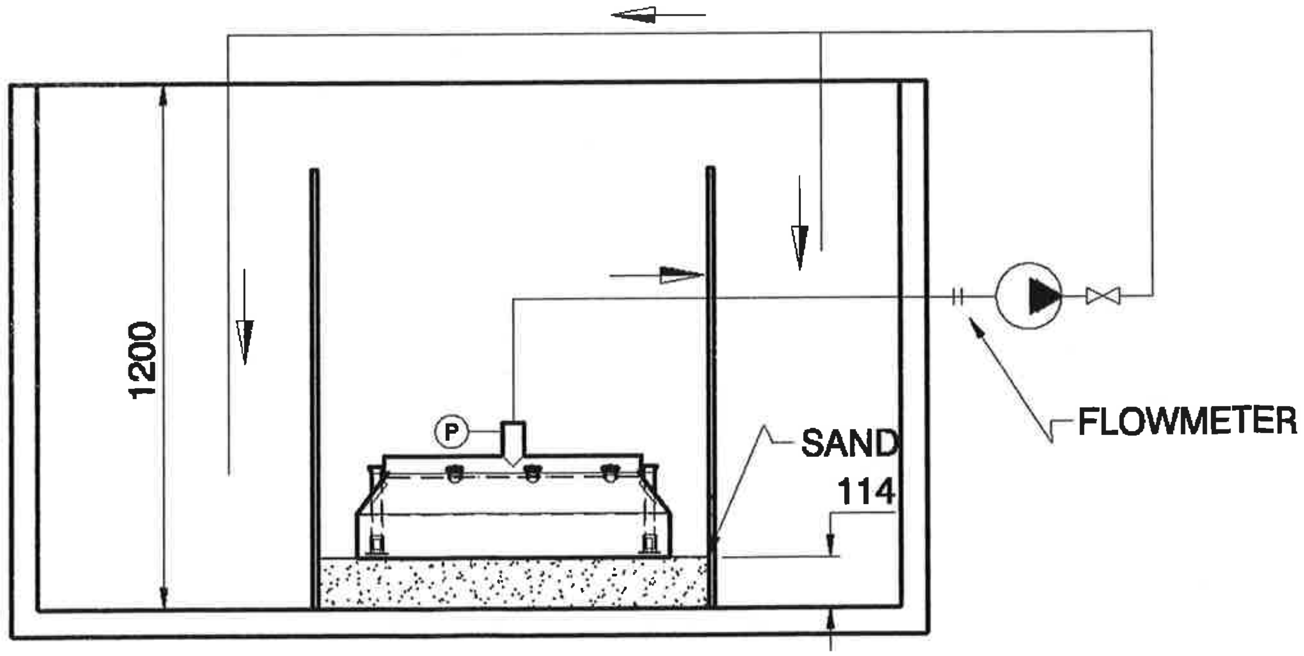

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			DRAWING No. 2883 \ 002		ISSUE C

Modifications

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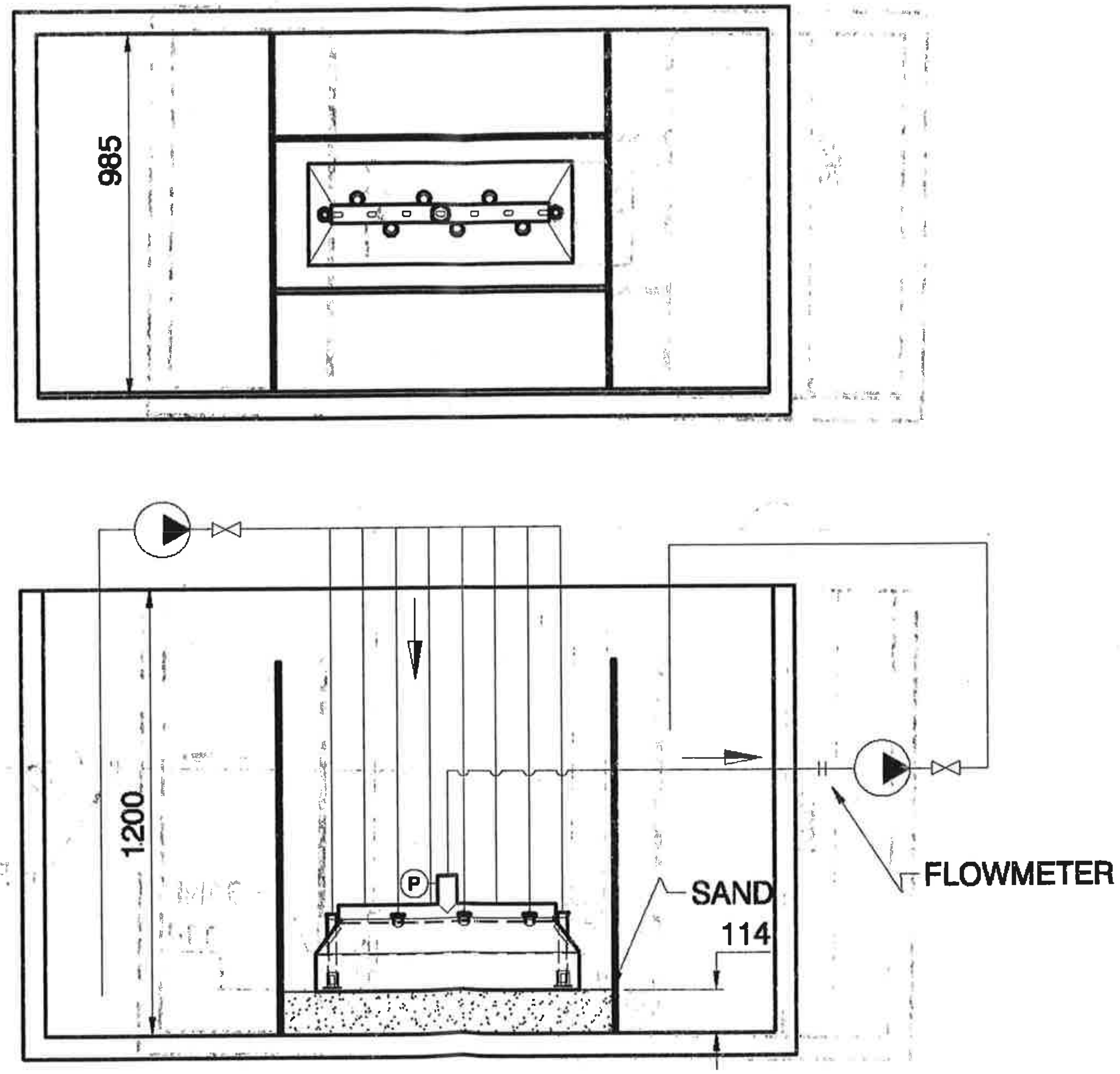

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