Restoration of the Salton Sea

Volume 2: Embankment Designs and Optimization Study

Appendix 2D: Risk Analysis

Attachment D: Risk Assessment Brainstorm Session Notes

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Failure Modes Sand Dam Mid sea (1)

Static

A. Embankment Only

- Type A → S.C.B → Type ~~A~~ B → ~~topple~~ B → grou
  - → Need defect in SCB wall
  - → Need unfiltered exit into Type B
  - → Need velocity sufficient to carry Type A
  - → Need segregation to create erodible layer
  - → Need overlying material to form roof
- → need to remove >5' from top of SCB wall
- → Need to not detect
- → Additional erosion needed to topple wall

B. ~~Foundation~~ Emb to Fnd

- → Full reservoir head in Stiff Lacustrian Inclusion d.s. From SCB
- → high gradients push fines into Stone Column
- → Plug 1st S.C. → high grad to next SC →
- → pipe through Stiff Lacustrian enlarge
- → Type B does not filter type A
- → SCB undermined

Failure Modes ~~[illegible]~~ Rock notches (2)

Static

A Embankment only

Type C → SCB → Type C → Type D → coarse rock

→ Defect in SCB wall

→ Type C / type D not compatible

→ ~~Fine rock / coarse rock not compatible~~

→ Type C upstream stopes, travels through to coarse rockfill

→ Type D upstream chokes ⇒ No Fail

→ Filter into Rockfill ~~leaving to notch~~

→ Soft lacustrian ~~[illegible]~~ also moves into Rockfill

→ Type C & Type D collapse into >5' void

→ cone forms in Type C/D exposes downstream edge of wall

→ Top of SCB wall topples (50 psi weakness needed)

→ ~~cone forms~~

→ Unsuccessful intervention

→ Rockfill has to be carried away

(3)

Rock Notch

B. Emb to Fnd

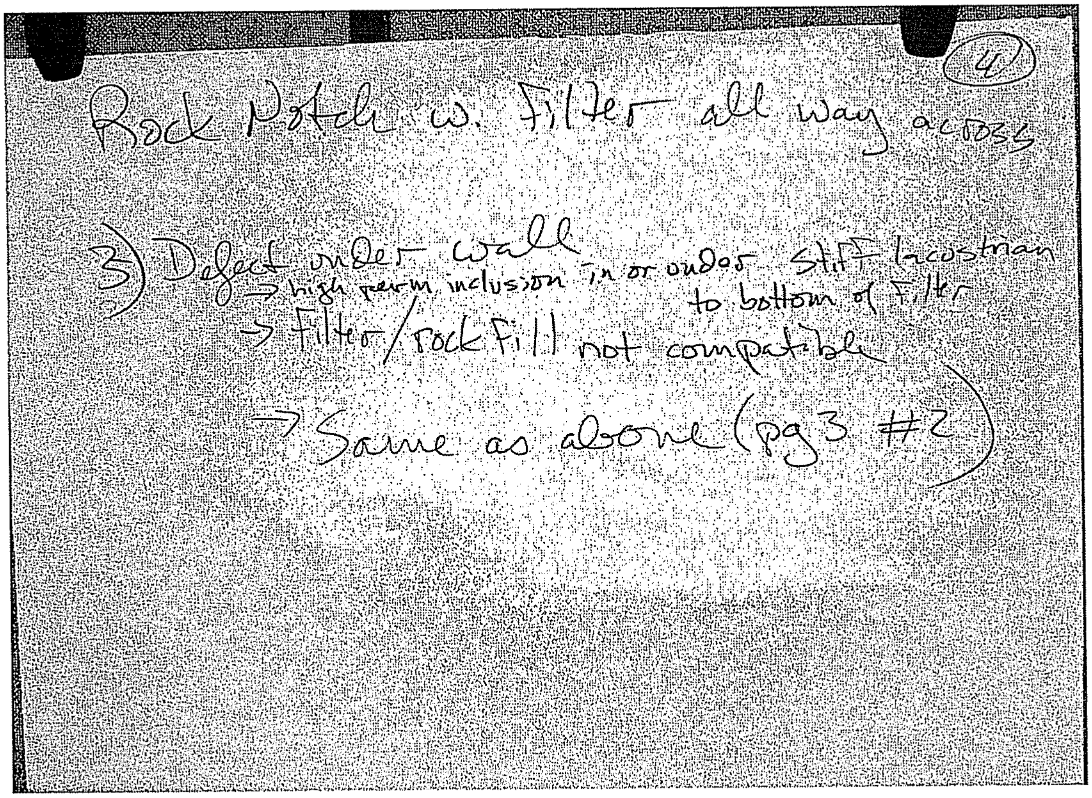
1) → defect in wall
- high perm inclusion in or under stiff lacustrian
- defect in SCB wall

→ throat control on SCB wall stops void expansion before rockfill collapses.

2) Defect under SCB
→ high perm inclusion in or under stiff lacustrian

~~[illegible]~~
→ move fines from St. L, into Rockfill
→ pipe expands until ~~rock~~ U.S. rockfill collapses into void
→ Erosion expected to expand laterally along the ℄
→ intervention unsuccessful

Failure by release of reservoir, but no breach


4
Rock Notch w. Filter all way across
3) Defect under wall
→ high perm inclusion in or under stiff lacostrian
to bottom of filter
→ Filter / rock fill not compatible
→ Same as above (pg 3 #2)

What is the likelihood a panel-sized non-detected/repaired flaw exists after the SCB wall is constructed? (5)

Assume Relation b/twn size of defect & flow necessary to detect

→ Side wall caves
→ cement/bentonite mix wrong
→ movement ~~[illegible]~~ slope before cement sets
→ loss of trench fluid
→ contractor doesn't install deep enough
→ contractor stops overnight/over weekend

assumes poor quality QC { .01 / .001 Unlikely	assumes high quality QC { .001 / .0001 likely (Unlikely)
– depth well known at all locations ~~[illegible]~~ – set within 24 hrs 70% strength in 7 days → Stone columns in place reduce likelihood of slope instability → Fresh water used to mix SCB → salt water ~~[illegible]~~ cements exist * Construction practice include well established QC → loss of trench fluid easily detected → construction w/ equal head hydro on both sides → low prob of fracturing * panel size is constraining length of defect	* construction must take place over 8 miles (~7,000 panels) * non-uniform foundation conditions – salt water may interfer with cement set – M5 ~~eq~~ earthquake fairly likely @ some point in the 400+ days required to build wall → Earthquake is very likely to

(6)

What is the likelihood the Type B material will not Filter the Type A material ~~in the~~ From the AB interface to ~~vicinity of the SCB Flaw~~ the downstream Face?

Unlikely	likely
	.02 .005 .01 to .04 eq
* Types A & B will be similar gradations w. B slightly coaser	- With earthquake some B will move away (distance where filter incompatibility will change)
→ stratification in B not likely to occur over inter-connected layer 100 to 200' distant	- pluviation process will segregate B, materials that readily can segregate
→ Type A < 15% Fines (high grad., velocity needed to move) (permeability high, head drops off quickly)	* not controlled placement, Quality control in stockpile & handling not in placement
~~→ unlikely flaw in SCB would be in vicinity in filter incompatibility area~~	
→ Distance from SCB wall to A/B contact Elevation is far (water spreads)	
* → Flaw in B not likely to continue to daylight	

what is the likelihood A root will form in Type A material? (7)

assume no change for eq.

Unlikely	likely .001 <
* Fines content < 15% * non plastic Fines → ~~compacted~~ → saturated (no apparent cohesion) → region of high gradient & partial satur/apparant cohesion not extensive	→ zone of partial saturation ~~adhesion~~ can have some apparent cohesion

Progression not limited (8)

Unlikely	Likely .1 .01 ~~.001~~ loads range 4 ↑ .15 .02
* → SCB not erodible (- if not rubble, would change erodibility) → Type B upstream of A (crack stopper) → Stone Column	- if remove enough material SCB wall will Buckle → rubble-ized wall increases likelihood of erodibility.

Intervention Doesn't work .1 ?? 0.9 load range 4; neg. .4 .6 range 3; .4 .6 range 2

- have to replace wall - regrade crest } takes longer than it takes to sink(?) → progressing slump or stoping will be easily observed & will take long time → material may be observed being deposited d.s. if water is down * → Fix is pretty simple	→ if monitoring is infrequent then sinkhole/slump won't be detected

What is the likelihood that a 2-order mag diff (or more) material exist under St. Lac [undetected & untreated], exposed to full res head U.S. & constrained D.S. of the Sand dam?

without cutoff wall .05 to .50 (.25)

with deeper cutoff wall .0001 to .005

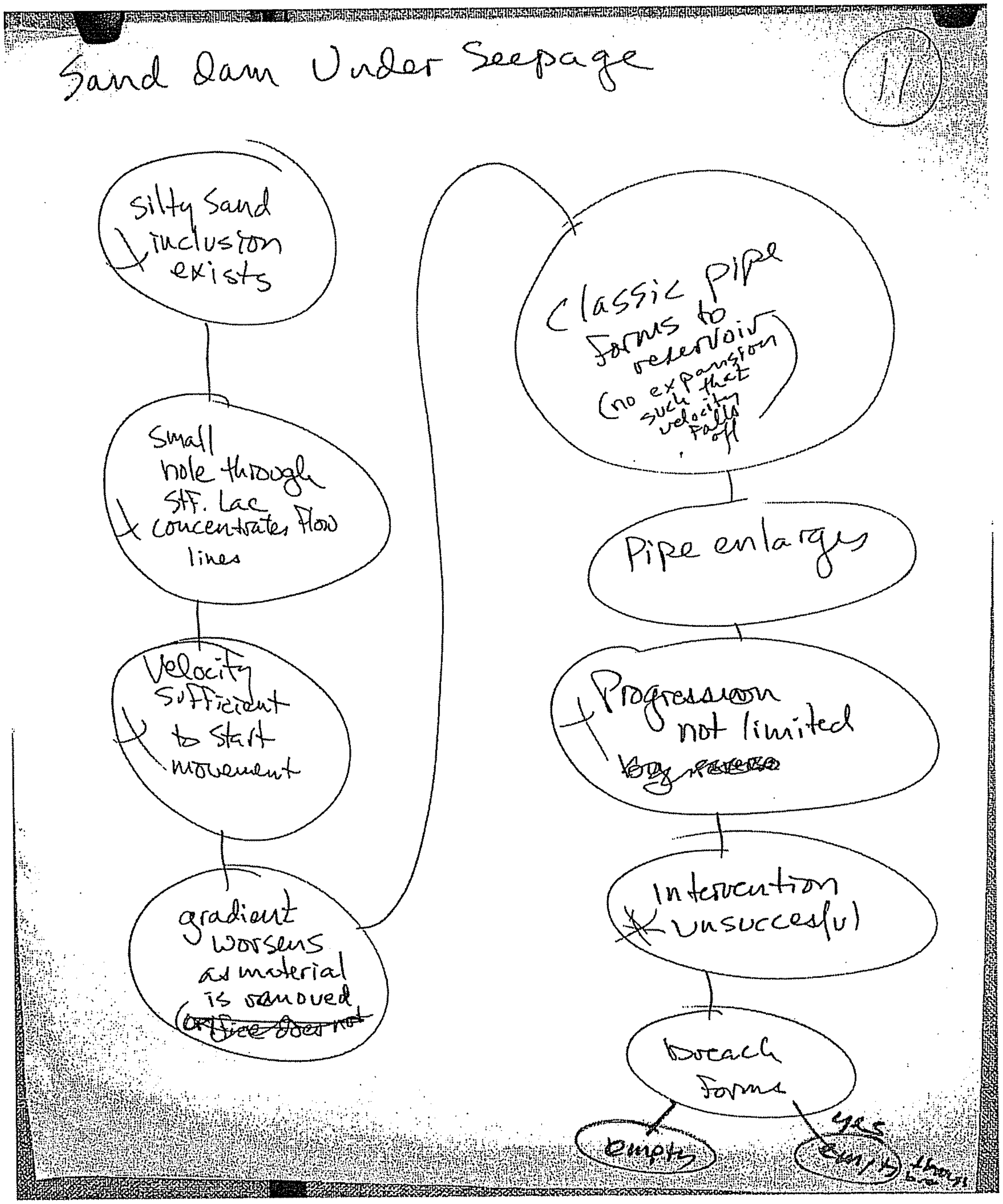
.001 [illegible] no change

Unlikely	Likely
explorations for seismic fix would decrease liklihood D.S. toe would be constrained	explorations for seismic fix would increase likelihood of connection w/ reservoir
– exploration will be on 'close' centers & will identify likely bad acting situations	– 8 miles of dam
– Fat clay in exploration so far shows thick & continuous	– several mechanisms for cracking U.S. – desiccation – lateral spreading – erosion channels – dunes existed on west side
– depositional environment implies fat clay placed continuously for long time periods	– erosion channels can fit between exploration spacing (when clay deposited)
→ if cracks are likely upstream, they are also likely downstream	– Silty-fine-sand lenses discovered in fat clay
	→ coarser-grained inclusions evident within fat clay in all CPT's to date.

(10)

What is the likelihood the ~~[illegible]~~ ~~[illegible]~~ allowing ~~[illegible]~~ constraint will be breached & into a single small isolated defect in the d.s. blanket that will maintain high head & concentrate flow p & create high exit velocities?

Unlikely	likely
	rock nodules w deep SCB & likely .001 to .01
	sand dam w shallow SCB with deep SCB & sand dam .0001 to .001
→ ~~[illegible]~~ upper stiff Lac measured 4 to 31.5' thick (if 31.5 then unlikely)	→ SCB only extends 5' into stiff Lac. (if the inclusion is 5' down, will does not cut it off.) Not true
→ material surrounding defect is likely to erode.	→ Pre-Sea human activity left penetrations less likely w deeper SCB wall
→ stiff ~~Clay~~ Lac likely to be dispersive	→ natural penetrations → burrows less likely → roots → sand boils from liquefaction eg induced pressure relief
→ got to have a single hole → has to stay small	→ Fluid flowing through hole likely to be highly saline (won't disperse clay) ↑ Florida may
↓ .00	earthquake can → damage grout in exploration holes → build up pressure in silty sand layer that might blow out


Sand Dam Under Seepage
11
Silty Sand inclusion exists
Small hole through Stf. Lac concentrates flow lines
Velocity sufficient to start movement
gradient worsens as material is removed
Classic pipe forms to reservoir (no expansion such that velocity falls off
Pipe enlarges
Progression not limited
Intervention unsuccesful
breach forms
empty
yes
empty

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Progression not limited
→ Collapse of Stf. Lac.
→ ~~Type B~~ material type may grade coarser towards sea
→ Outlet hole expands quickly - velocity drops off
→ Type B ~~might act as crack stopper~~

.001 to .01

~~un~~ unlikely	~~un~~ likely + ~~points~~
- very unlikely to have perfectly erodible material for 1200'	* - depositional environment such that layer of silty sand can be uniformly graded over ~~wide~~ extensive distance.
* → layers within Stf Lac. not likely to be greater than ~~1ft~~ thick (Few inches to couple feet)	- Stiff Lac. has higher resistance than fine sand (hole will not expand larger than necessary to handle the available ~~required~~ flow)
- ~~As erosion~~ as eroded area enlarges, overlying Stf Lac will collapse into void (progressive)	* → ~~Dust~~ unlimited reservoir supply

~~reasons to change~~ better ~~for rock notch~~

- rockfill not sand	worse - shorter path

Wash

what is likelihood intervention is unsuccessful? (14)

~~un~~likely leads to failure	unlikely leads to stop ~~.1 to .7~~ .1 to .7 Transported material more likely to be hidden Rock notch option .2 to .9 .5 to .9
* → if water is d.s., wouldn't it be easy to detect visually (& during 1st filling is when this would happen)	– if water is evaporated downstream, easy to detect
* – magnitude of subsidence on order of typical settlement (if layer is few inches to 1 or 2 feet)	* – slow development time to construct (modifications is more likely to make intervention successful)
– slow load (decreased vigalence)	– multiple instrumentation ways to detect
– reliable prediction from instrumentation of seepage not well established	* → if silty-sand layer is thick, a large volume of material must be eroded (slow development & easy to detect)
– distracted / infrastructure damage	– heightened awareness

Rock Notch Dam

What is the likelihood a silty sand inclusion exists close to the bottom of the D.S. rock notch that has a connection to the upstream Rock notch. (15)

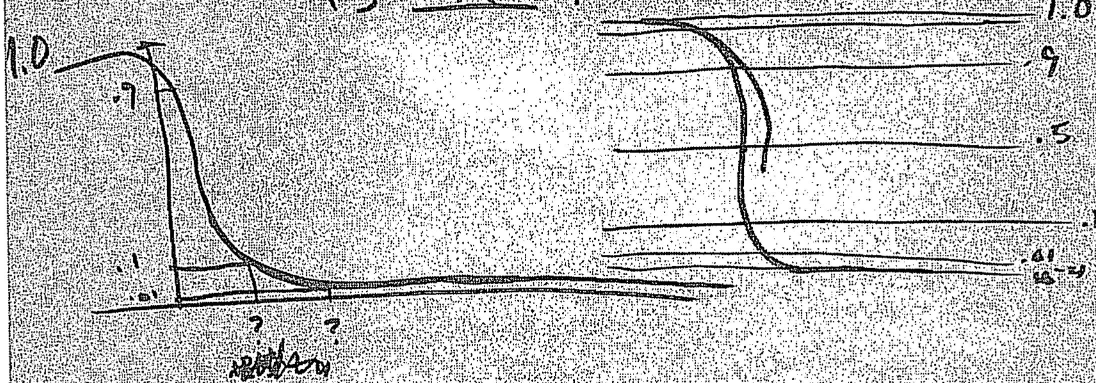
.0005 – .01

Unlikely	likely
– exploration 'close' spacing makes likely to detect inclusion	– 8 mile long dam
– dep. environment suggests	– silty-sand layers described in Stf. Lac.
– cracks U.S. & D.S. equally likely	– CPT's show inclusions in each bore hole
– Stf Lac (Fat clay) so far exploration shows thick & continuous	– Seepage path length of inclusion from U.S. to D.S. ≈ 400+ feet (instead of 1200' w. sand dam)
– vertical distance from bottom of U.S. rock notch to pervious inclusion @ bottom of D.S. rock notch is ≈ 40' (difficult to imagine wave)	

Sand dam

16

What is the probability the dam will continue to breach if the post-earthquake freeboard is __X__?



→ SCB wall blocks transverse, open, deep U.S/D.S cracks

→ SCB wall does not deform

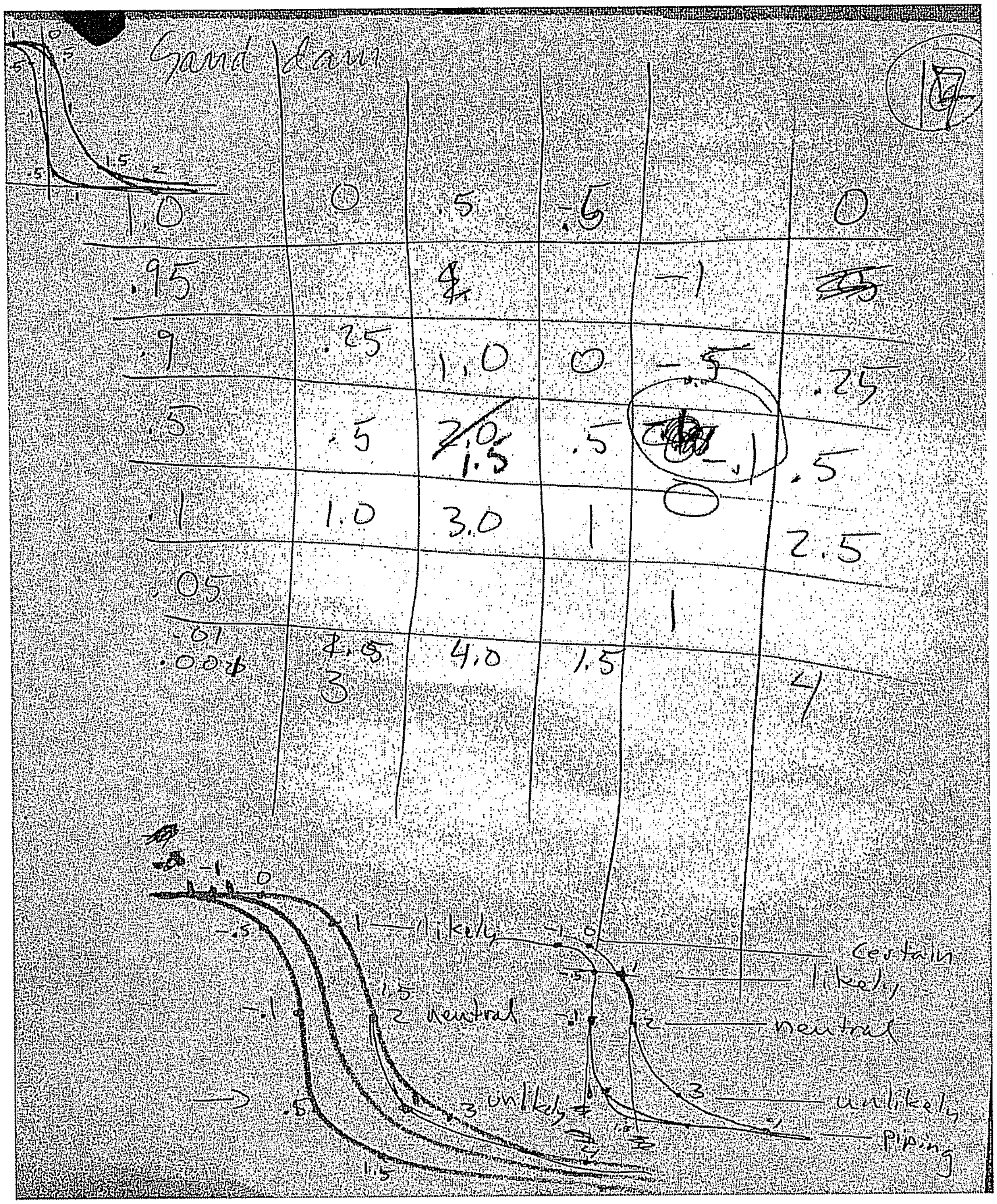
→ Wave action can be several feet

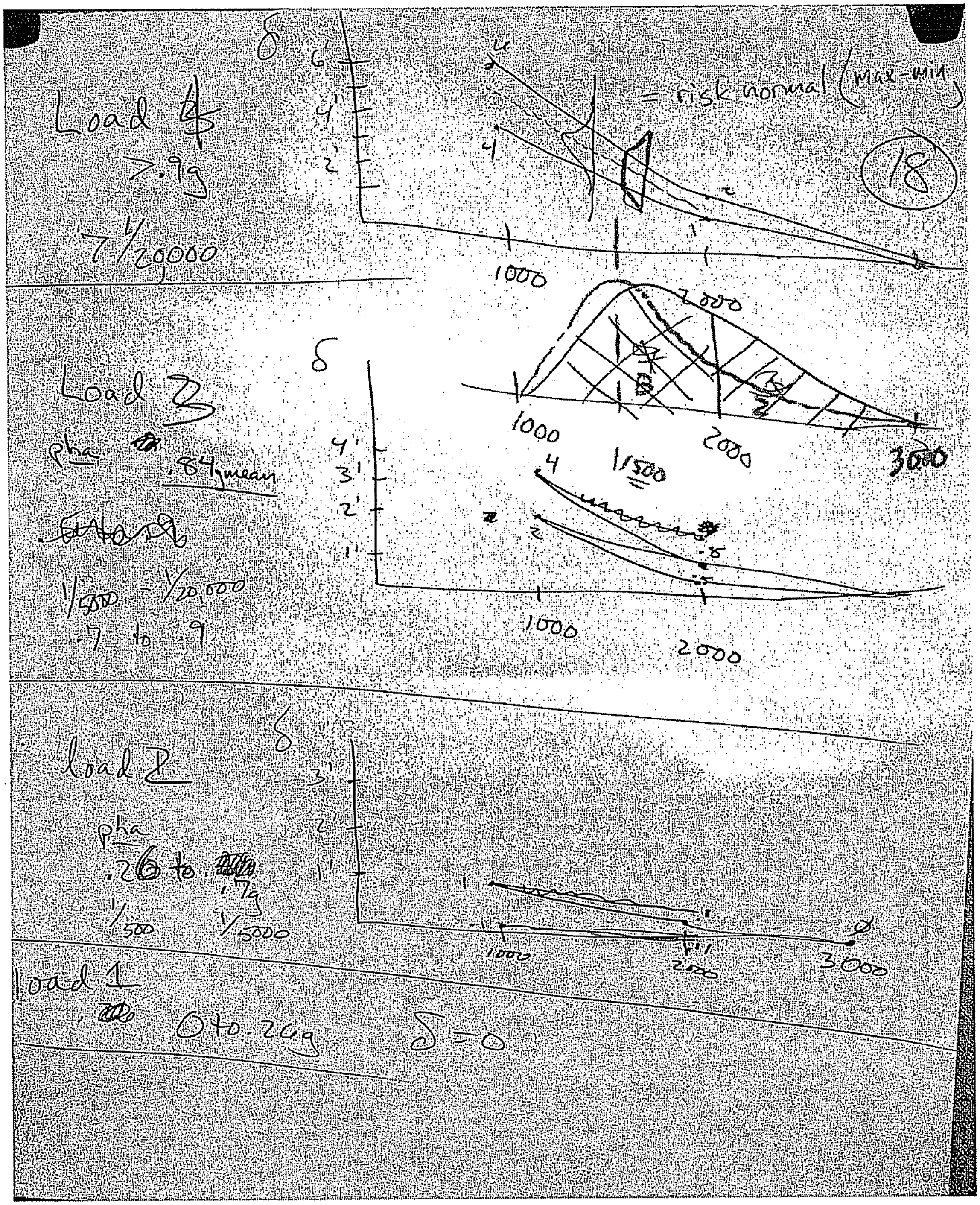
→ Sand on either side of SCB wall

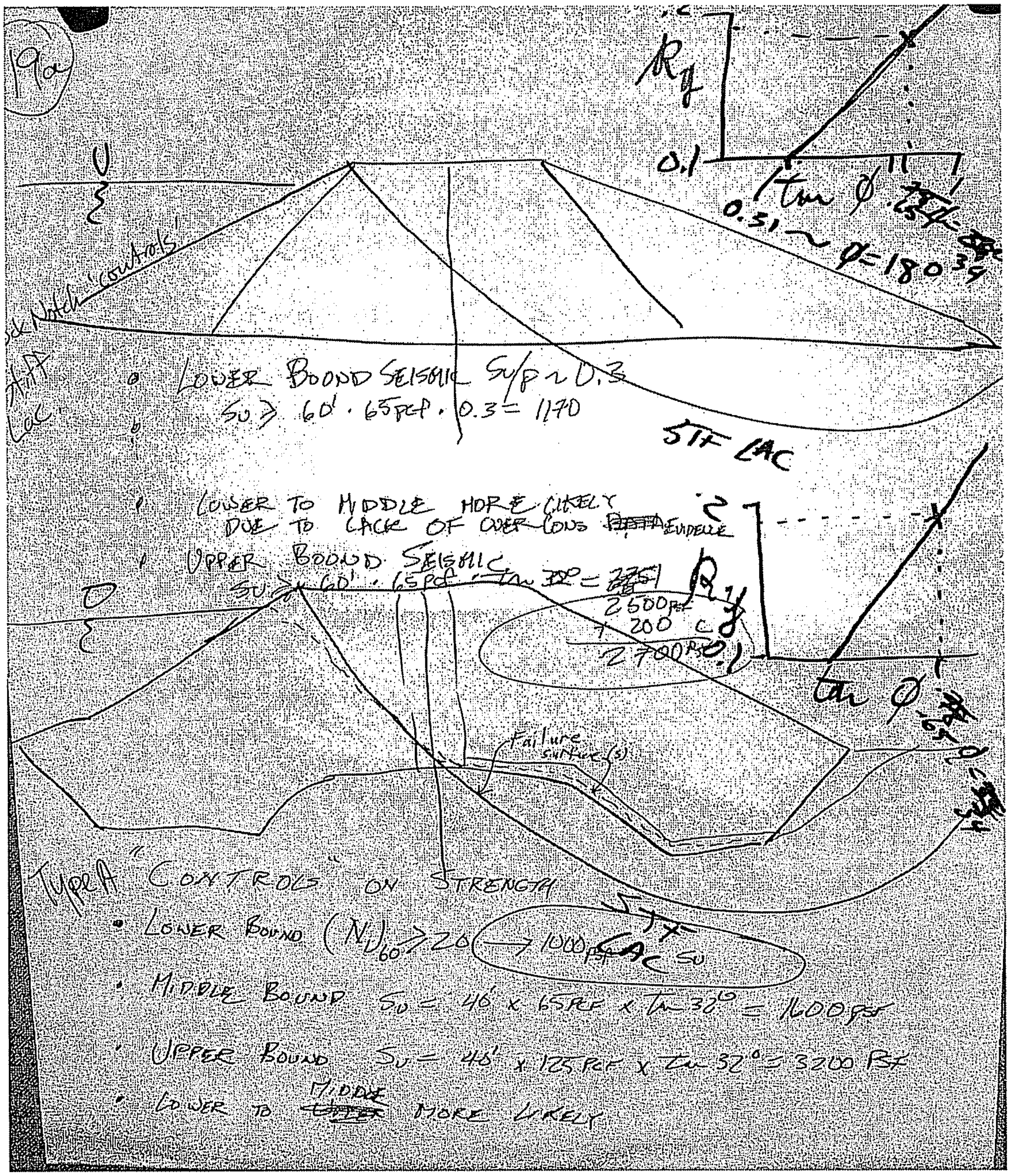
→ sand bag/intervention is accounted for

→ 30% of time, surrounding area has wind generating capability.

→ very long dam, large fetch

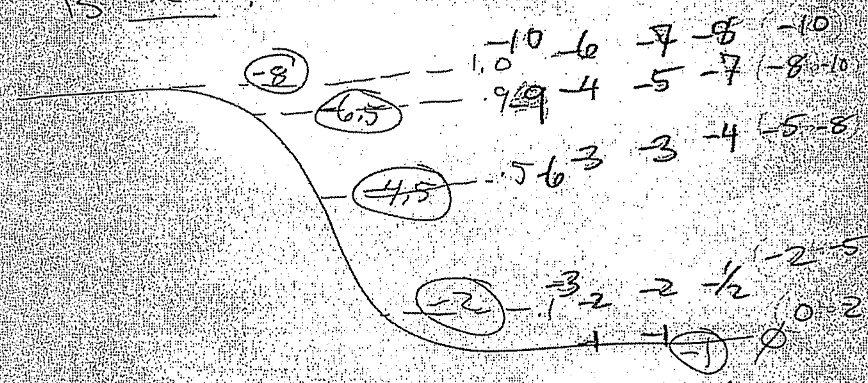

Sand dam
1.0
.95
.9
.5
.1
.05
likely
neutral
unlikely
Certain
likely
neutral
unlikely
piping


Load 4
>.9g
1/20000
risk normal (max-min)
18
1000
2000
Load 3
pha .84 mean
1/500 - 1/20,000
.7 to .9
1/500
1000
2000
3000
load 2
pha
.26 to .7g
1/500 1/5000
1000
2000
3000
load 1
0 to .26g
δ = 0


19a
Rf
0.1
tan Ø
0.31 ~ Ø=18°
• LOWER BOUND SEISMIC Su/p ~ 0.3
Su ≥ 60' · 65pcf · 0.3 = 1170
STIF LAC
• LOWER TO MIDDLE MORE LIKELY DUE TO LACK OF OVER CONS EVIDENCE
• UPPER BOUND SEISMIC
2500 psf
+ 200
2700 psf
Rf
0.1
tan Ø
Failure surface(s)
TYPE A "CONTROLS" ON STRENGTH
• LOWER BOUND (N1)60 ≥ 20 → 1000 psf
STIF LAC Su
• MIDDLE BOUND Su = 40' x 65pcf x Tan 32° = 1600 psf
• UPPER BOUND Su = 40' x 125 pcf x Tan 32° = 3200 psf
• LOWER TO MIDDLE MORE LIKELY

Rock Notches (19b)

What is the probability the dam will continue to breach if the post-earthquake freeboard is x ?



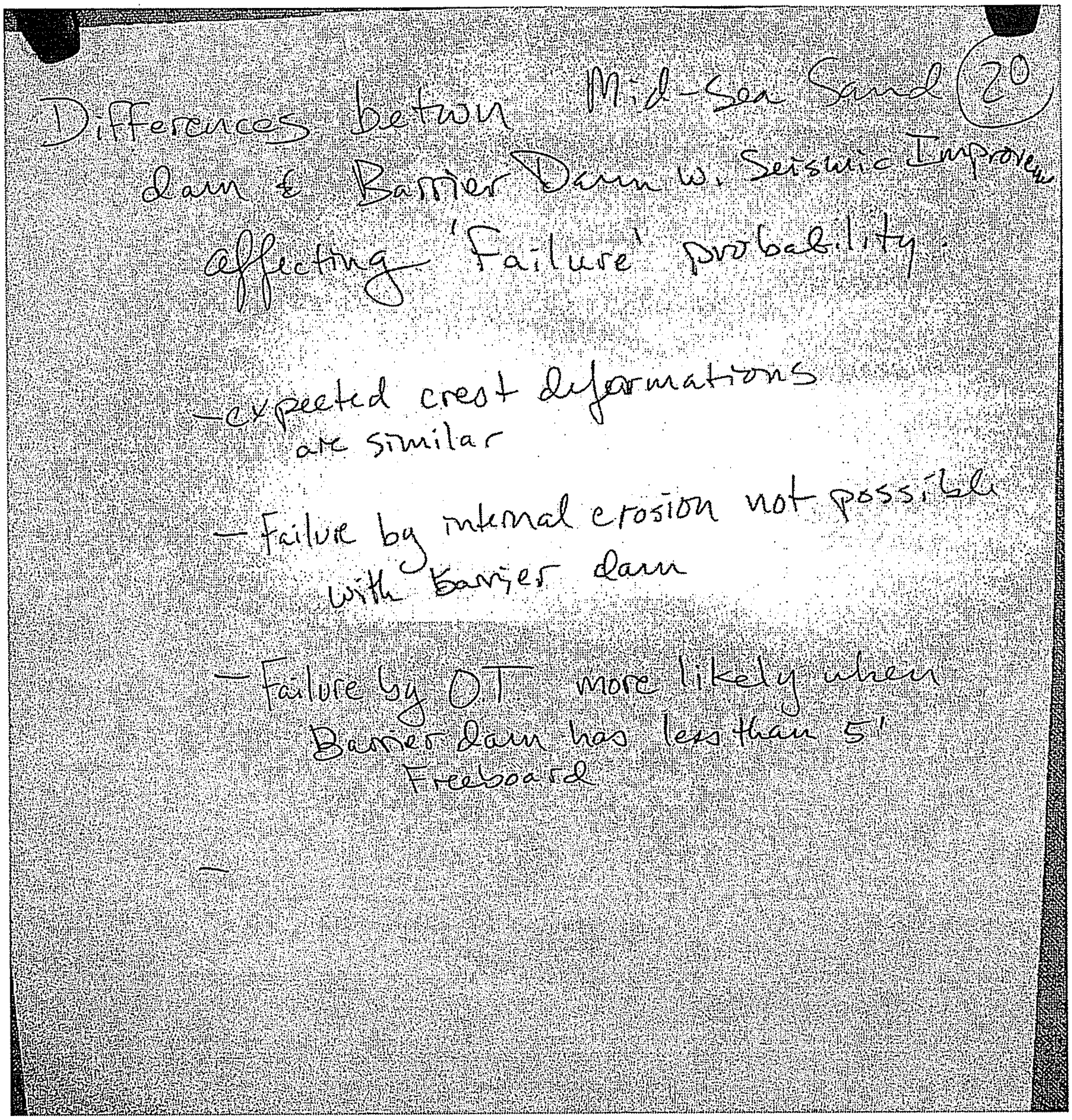
→ SCB will blocks transverse cracks

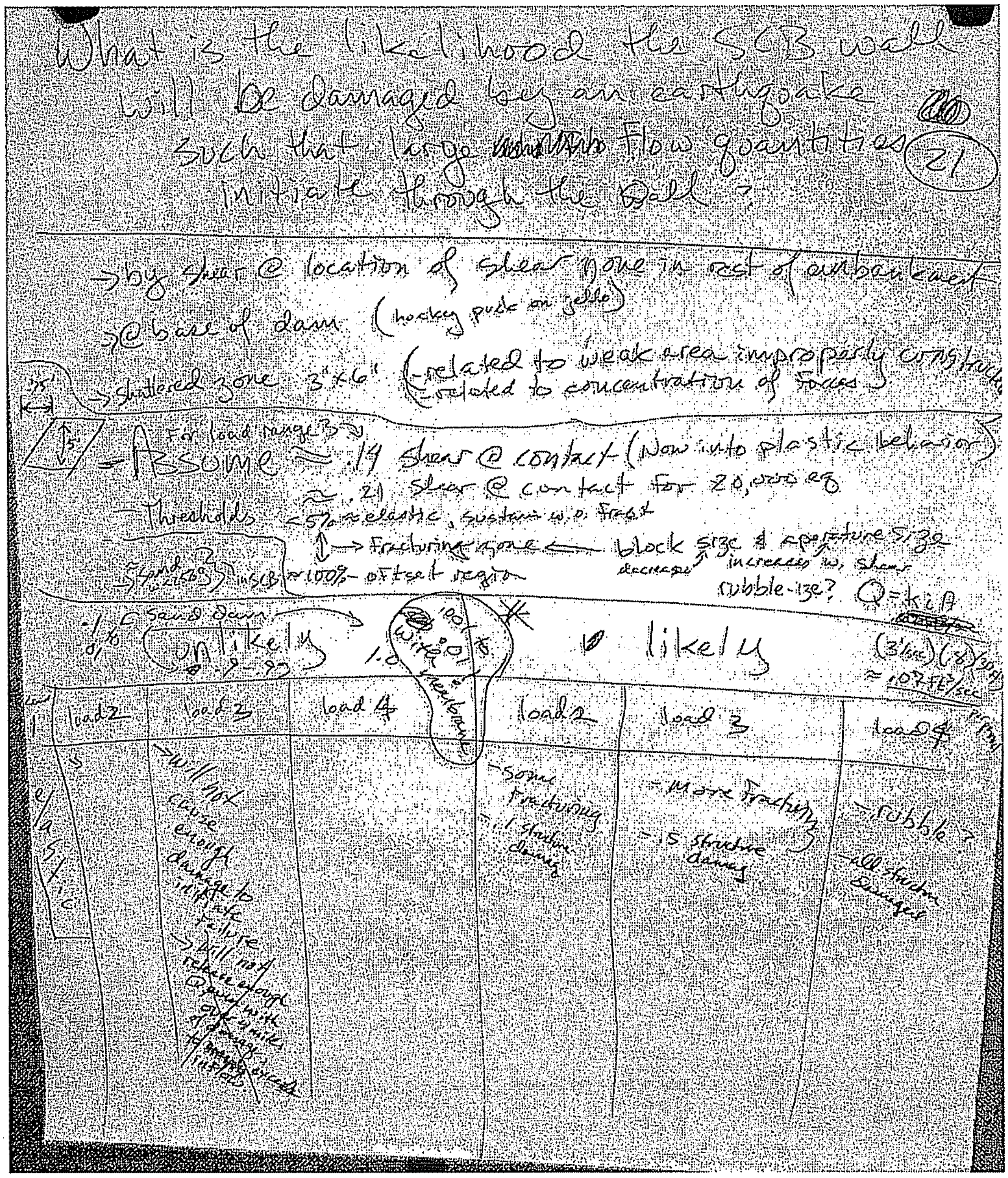
→ Rock shell portions not erodible

→ Flowthrough capacity of RockFill w. 1' to 4' size is very large

→ Hell Hole Dam overtopped by up to 20' before failure ? (may not have failed)

→ Wave action NOT likely to lead to breach


20
Differences betwn Mid-Sea Sand dam & Barrier Dam w. Seismic Improvem affecting 'Failure' probability:
– expected crest deformations are similar
– Failure by internal erosion not possible with barrier dam
– Failure by O.T. more likely when Barrier dam has less than 5' Freeboard
–


What is the likelihood the SCB wall will be damaged by an earthquake such that large flow quantities initiate through the wall?
21
→ by shear @ location of shear zone in rest of embankment
→ @ base of dam (hockey puck on jello)
→ shattered zone 3"x6" (related to weak area improperly construct
related to concentration of forces)
For load range 3
Assume ≈ .14 shear @ contact (Now into plastic behavior)
≈ .21 shear @ contact for 20,000 eq
Thresholds <5% ≈ elastic, system w.o. fract
→ Fracturing zone ← block size & aperture size
decrease increase w. shear
rubble-ize?
≈100% - offset region
Q = kiA
sand dam
unlikely
likely
1.0
(3'/sec)(.8)(30')
≈ 107 ft³/sec
load 2
load 3
load 4
load 2
load 3
load 4
→ will not cause enough damage to initiate failure
→ will not release enough @ joint with ...
elastic
- Some fracturing
- .1 structure damag
- more fracturing
- .5 structure damag
→ rubble?
- all structure damaged

(22)

If there is 2 to 5 meters of displacement on the Imperial San Andreas step-over transition what is the likelihood the ~~east~~ South Sea Dike will Fail?

.01 if ~~ZM~~ Imperial type even to 1.0 if ~~SAF~~ S.A. type event

Unlikely

→ velocities likely to start erosion @ d.s. end of Type A

→ Wall no longer there to limit progression

→ likely

→ intervention can't happen cause failure develops too quick

→ with this much displacement comes significant shaking → ~~TB~~ Type B likely to slide away from Typ A, removing filter

→ Shear zone might be 50' wide (meters distributed such that any 1 offset less than wall thickness)

→

Δ has to be > wall thickness

→ ~~[illegible]~~ Strike slip movement is oriented ~45° to dam meaning compressional ~~extensional~~ pull apart nature to wall failure

→ Channel flow velocities rather than Darcy flow

→ Settlement of 2 to 4 feet of the crest elevation

→ Strike slip has vertical component

What would an earthquake do to the emb/Fnd Failure modes?

→ if silty sand inclusion liquefies
- → pressure wants to relieve itself
- → easier to initiate Flow (resistance to flow
  & less velocity requi
  to start

→ if the stiff Lacustrian cracks
- by lateral spreading