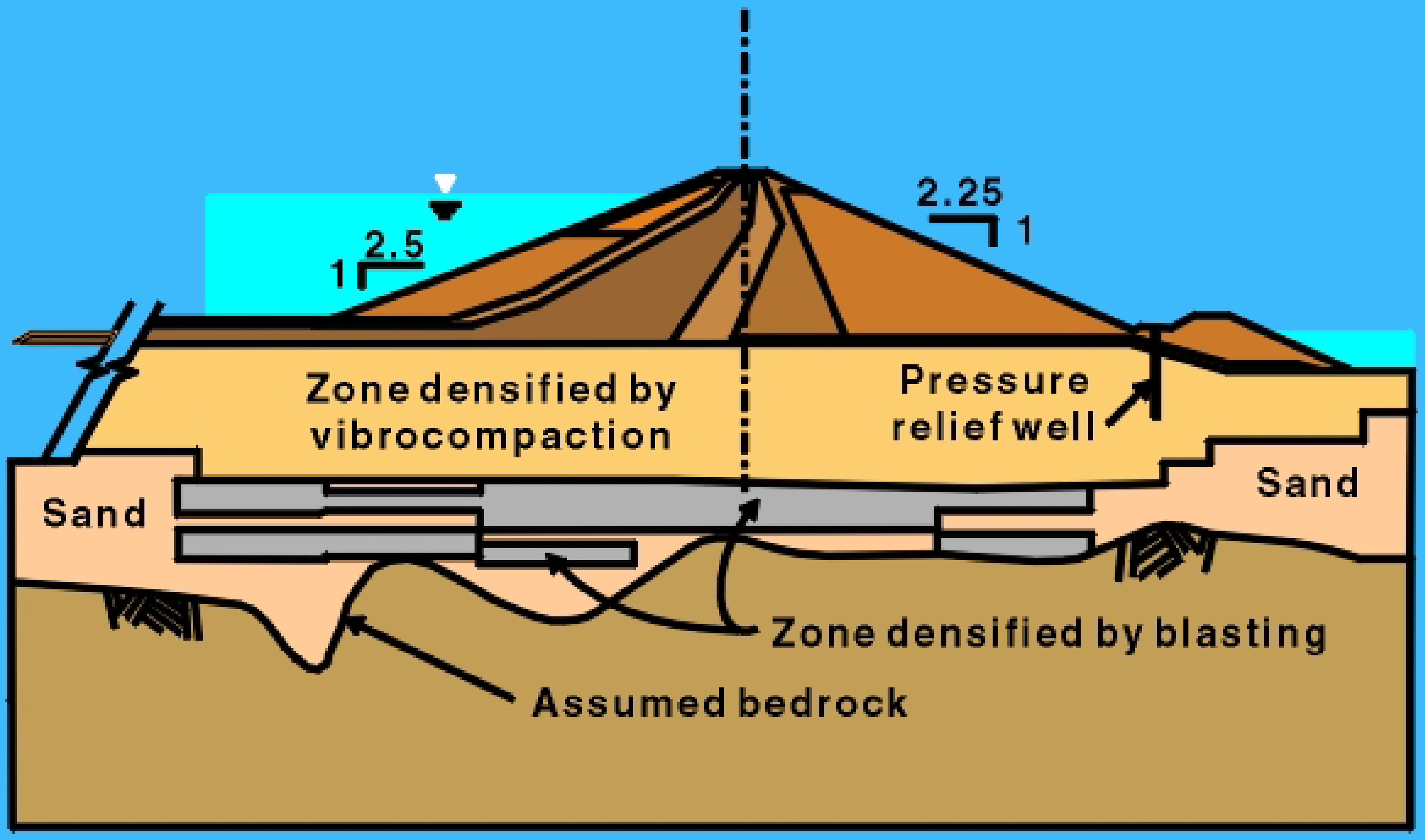
Problems in Improvement Evaluation, QA and QC

- Specifying test types, locations, and frequency
- Representativeness of samples
- Variability in treatment and uncertainty about acceptable amount of variability
- Accounting for time-dependency of properties after treatment
- Correlations to relevant properties
- Failure to meet specs
- Differing soil conditions – real and perceived

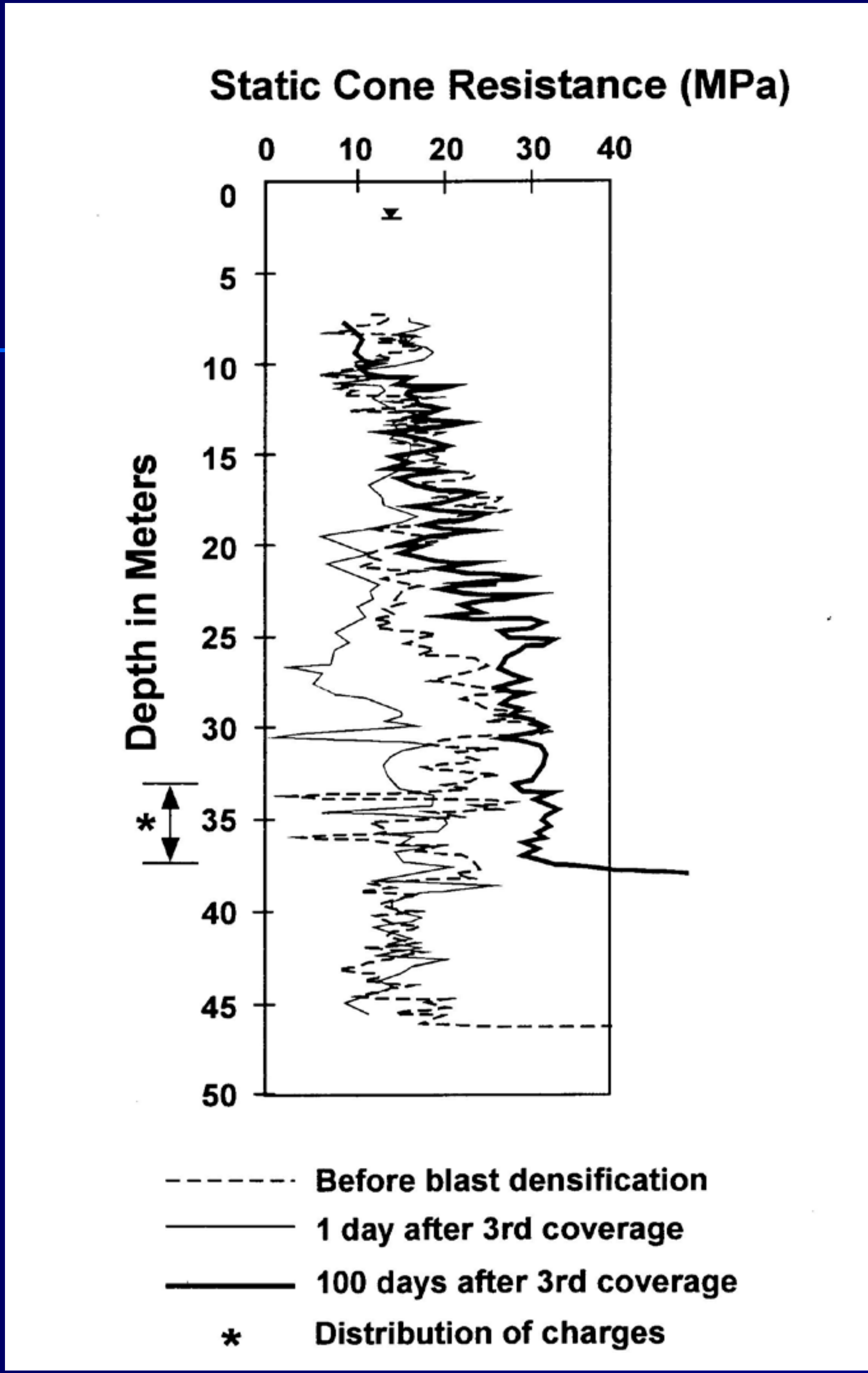
Time Effects In Ground Improvement

- Pore pressure dissipation
- Compression and secondary compression
- Stress redistribution and structural adjustment
- Curing of admixtures
- "Aging" (property changes – usually improvements - take place with time after treatment)

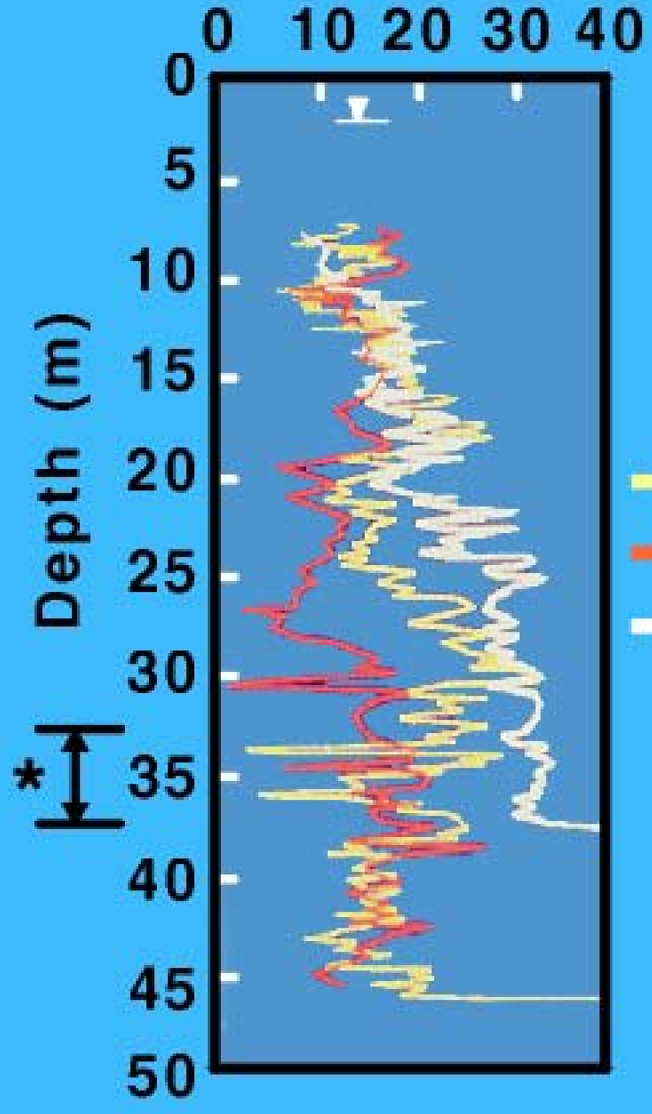

Jebba Hydroelectric Development, Nigeria
Time-dependent strength gain after densification of the clean sand foundation was a major factor in the acceptance of treatment.



Treated foundation at Jebba Dam



Strength loss at early times after blasting was a big surprise – but large increase in CPT resistance over time confirmed that the blasting improved the ground.

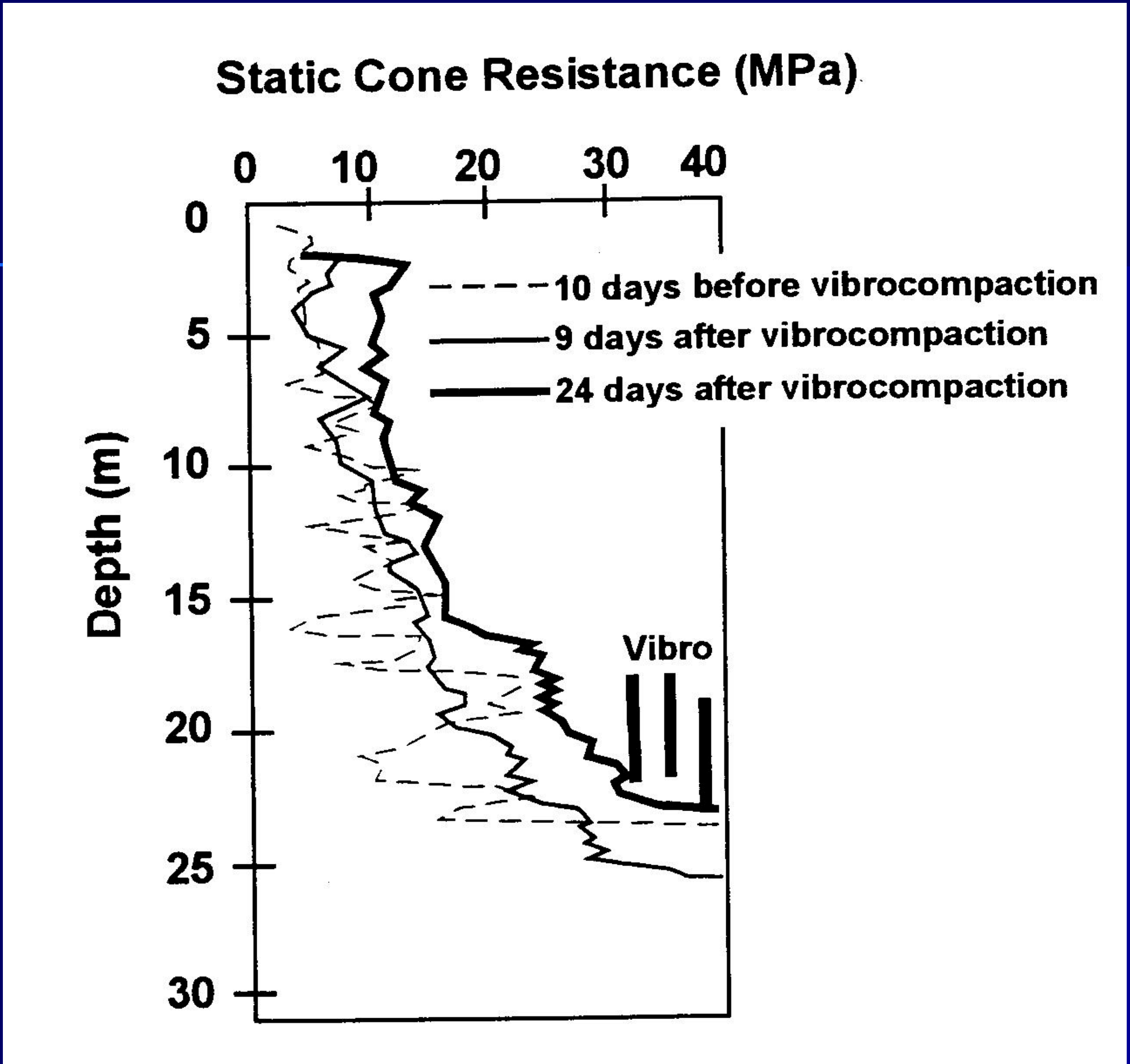


Static Cone Resistance (MPa)

JEBBA DAM, NIGERIA

Before blast densification
1 day after 3rd coverage
100 days after 3rd coverage
* Distribution of change

Penetration Resistance Increase with Time After Blasting

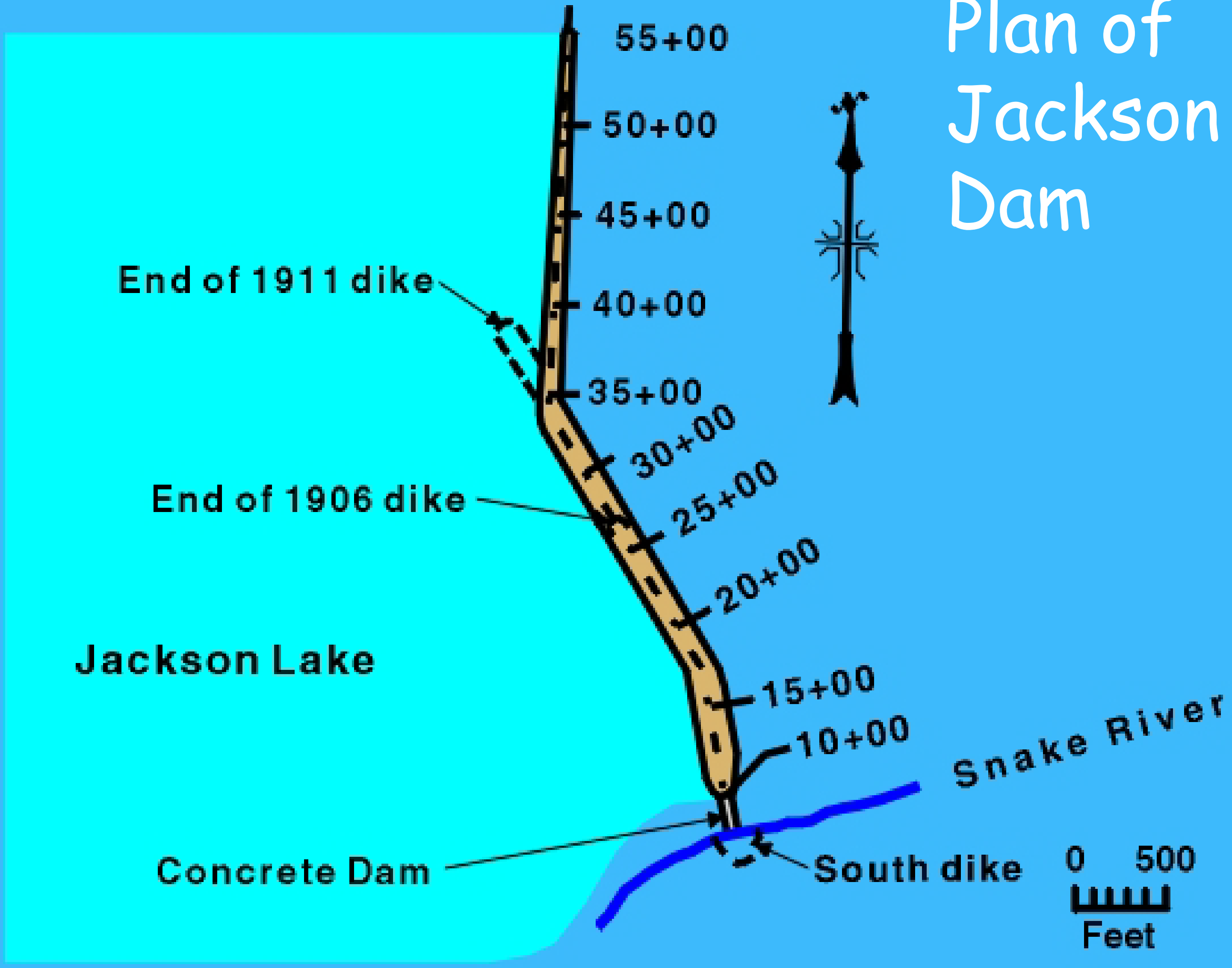

Static Cone Resistance (MPa)
0
10
20
30
40
Depth (m)
0
5
10
15
20
25
30
10 days before vibrocompaction
9 days after vibrocompaction
24 days after vibrocompaction
Vibro

SOME CASE HISTORIES AND SOME LESSONS

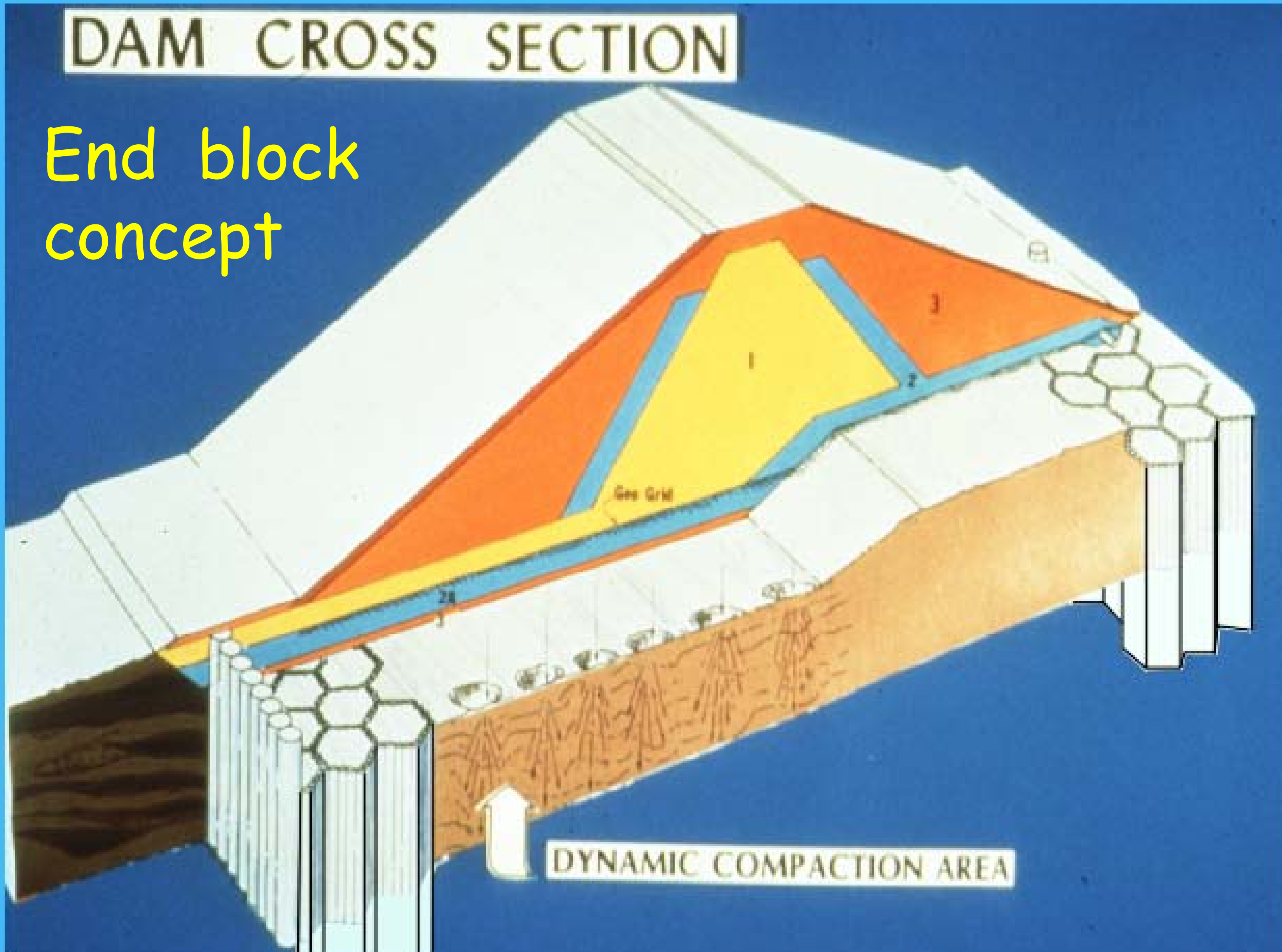
JACKSON LAKE DAM, WYOMING

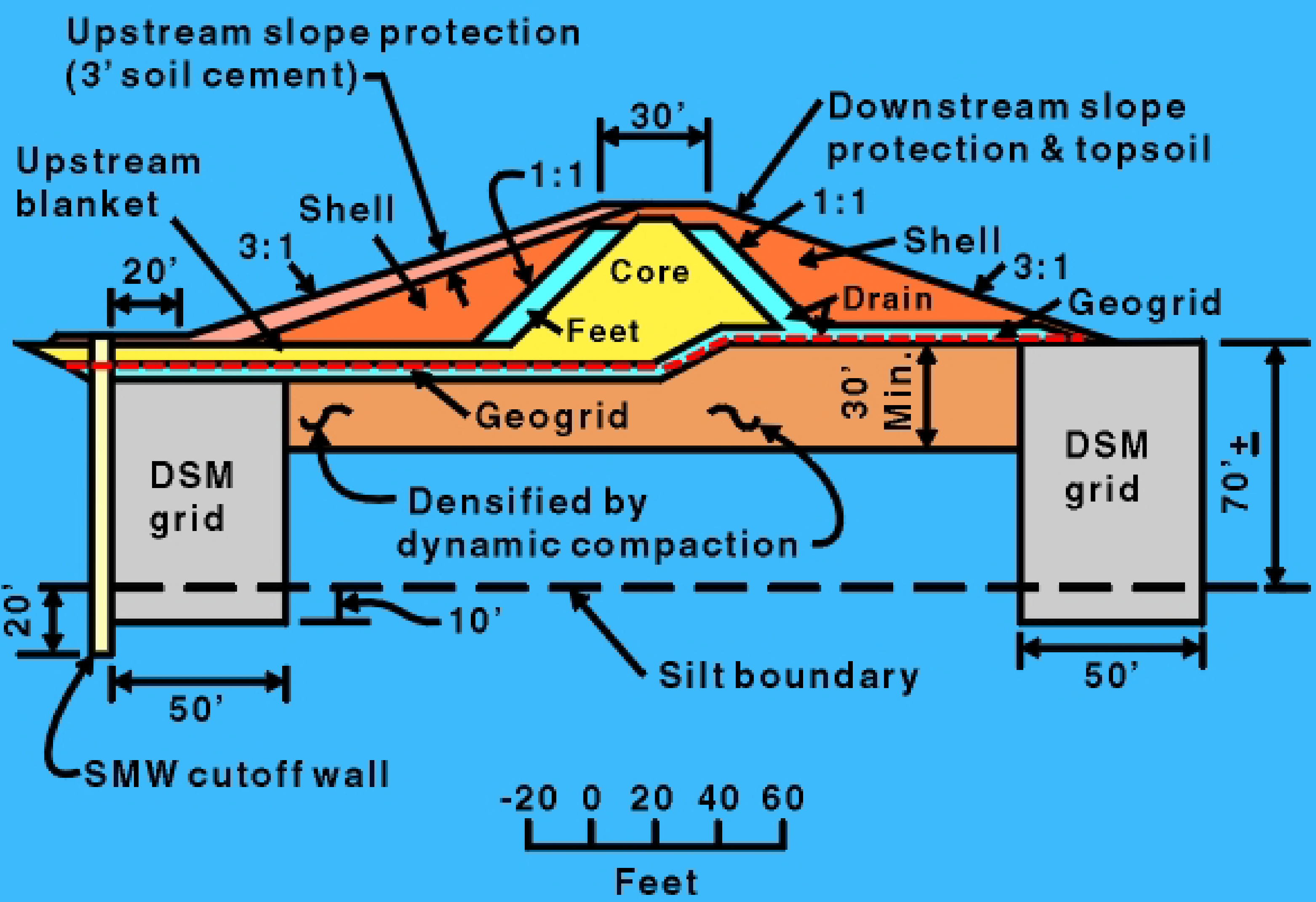
- Remediation done in 1980's
- Required draining the lake, strengthening the liquefiable foundation materials and rebuilding the embankment.
- The first large-scale Cement Deep Soil Mixing in the U.S.
- Both upstream and downstream foundation improvement

Plan of Jackson Lake Dam



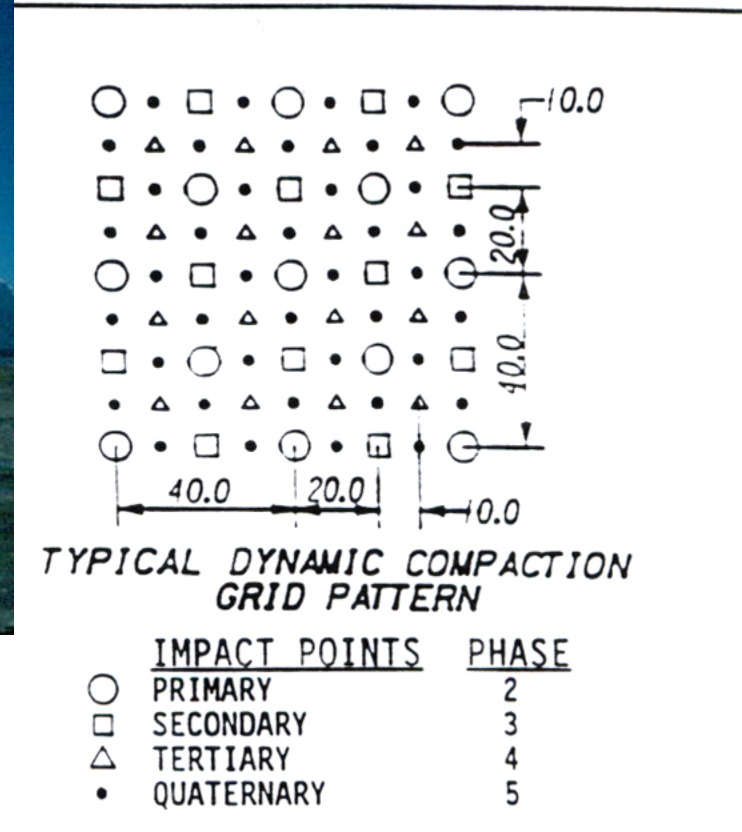
End block concept





Treatment Plan


DDC in progress at Jackson Lake Dam



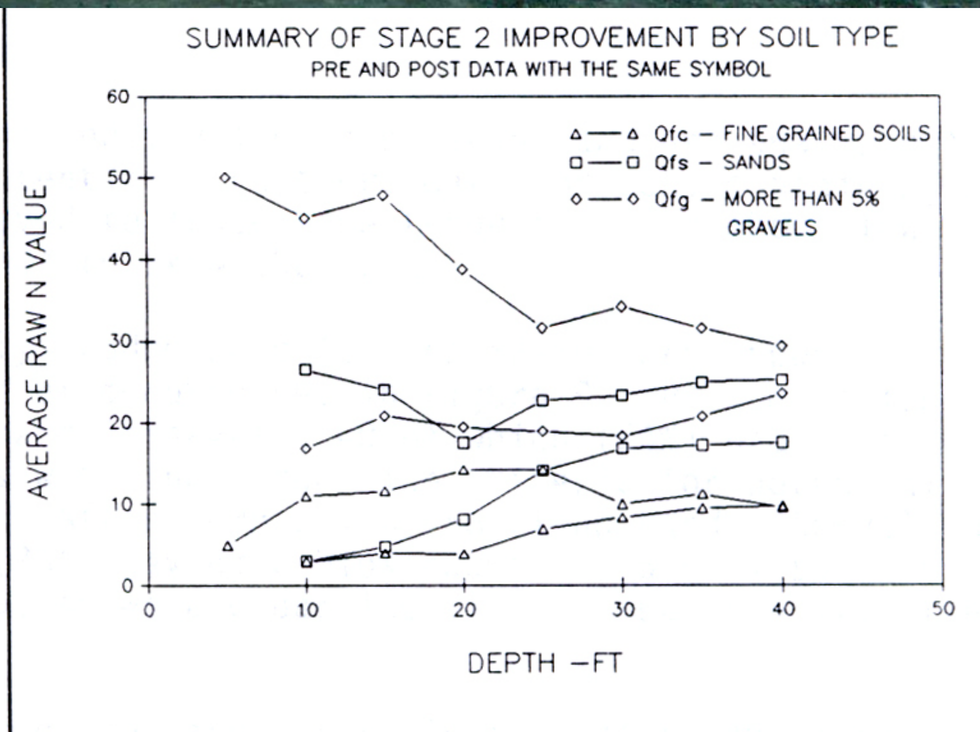


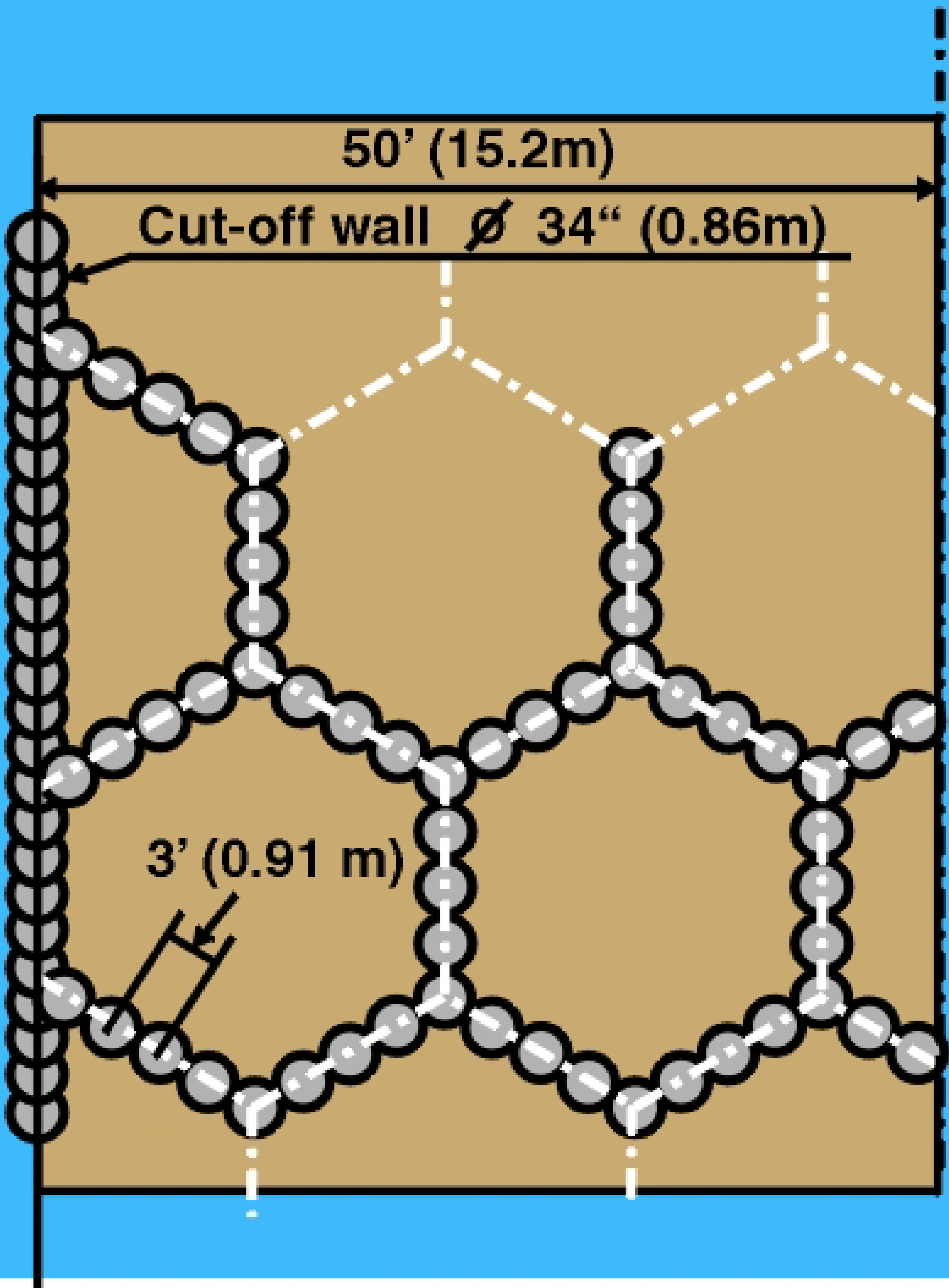
Figure 8 Stage II - Improvement by Soil Type

Improvement in SPT Blowcount by Deep Dynamic Compaction

Soil Type	Number of Tests	Δ N (Blows per Ft)
GP and SP	80	14.0
SM	53	10.4
ML	70	5.8
SM - ML	6	10.4
ALL	209	10.3

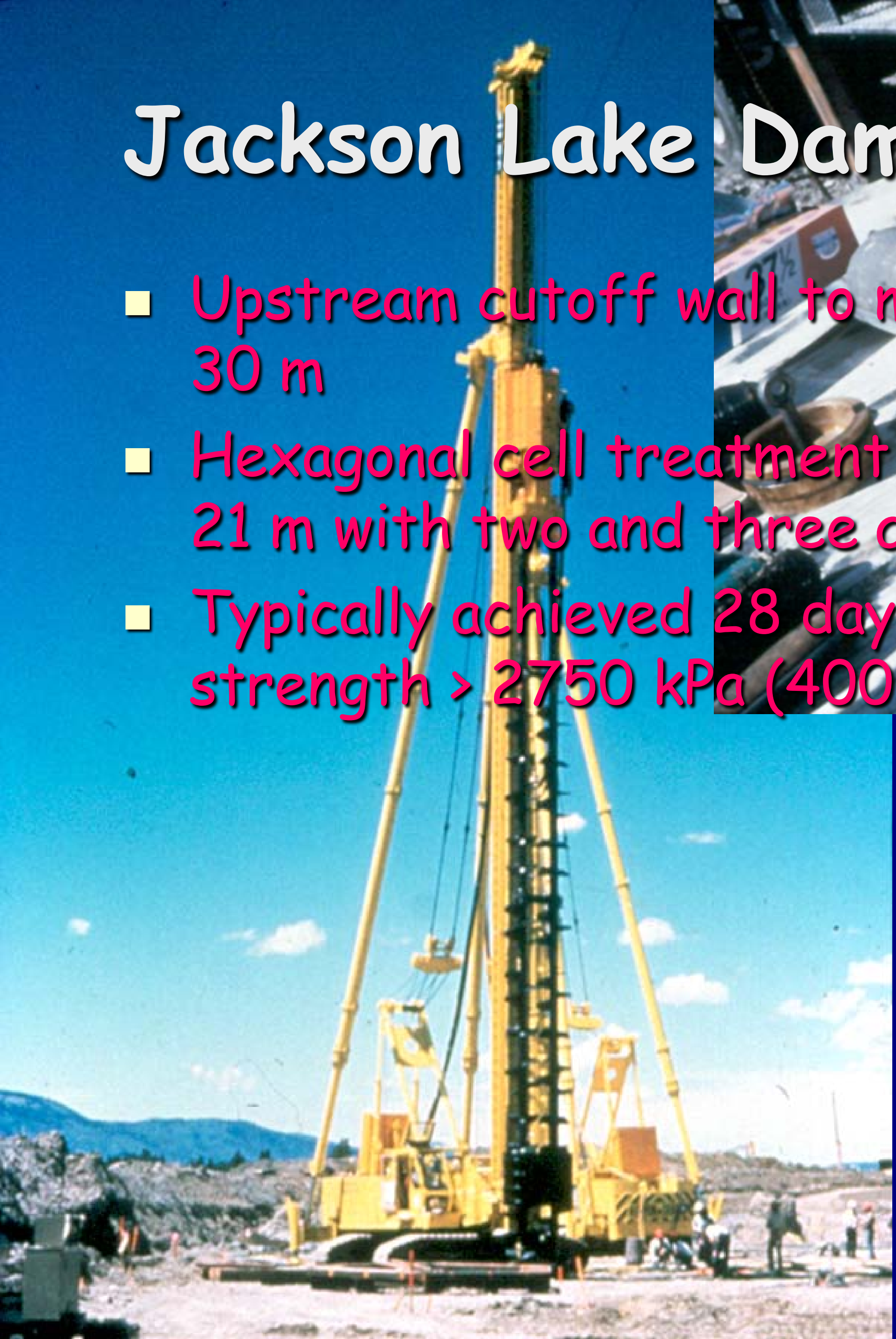
Increase in penetration resistance decreases as fines content increases

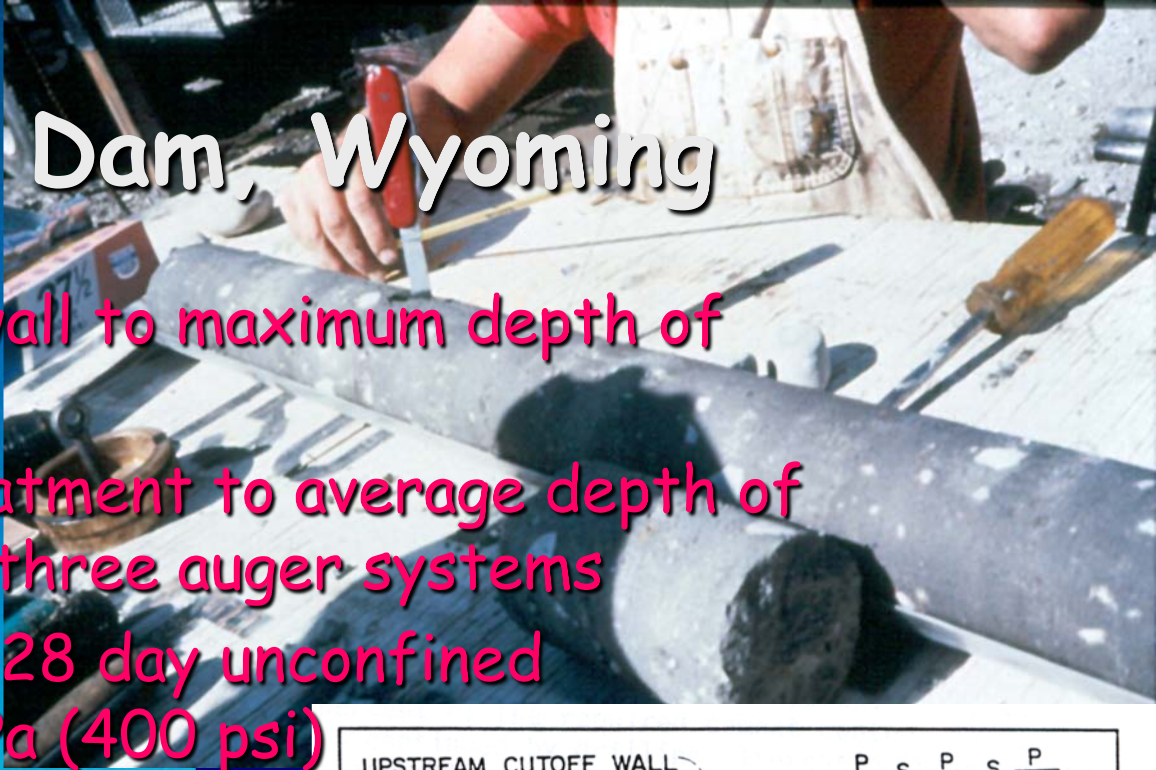
Pattern for DSM columns

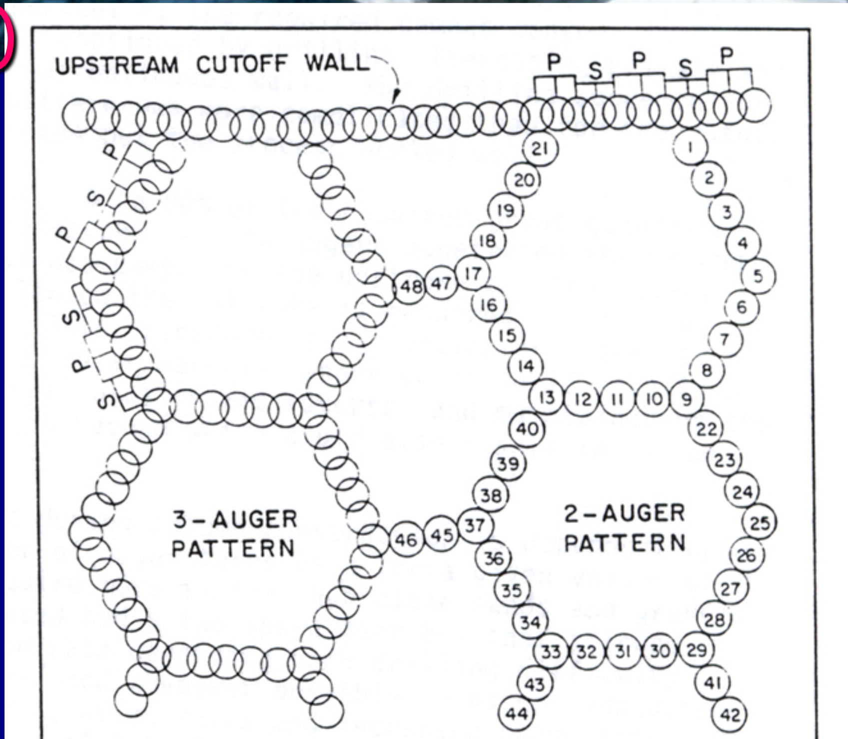


Jackson Lake Dam, Wyoming

- Upstream cutoff wall to maximum depth of 30 m
- Hexagonal cell treatment to average depth of 21 m with two and three auger systems
- Typically achieved 28 day unconfined strength > 2750 kPa (400 psi)








CDSM at Jackson
Lake Dam


CDSM column
construction

Rebuilt Jackson Lake Dam, Wyoming

RYE PATCH DAM

- 78 ft high homogeneous earth fill; 700 ft crest length
- 30-38 ft thick liquefiable alluvial foundation
- Lower 20-30 ft of embankment had low residual strength
- Dynamic deformation analyses gave unacceptably high deformations in both the US and DS directions and low stability FS (1.02) in US direction.

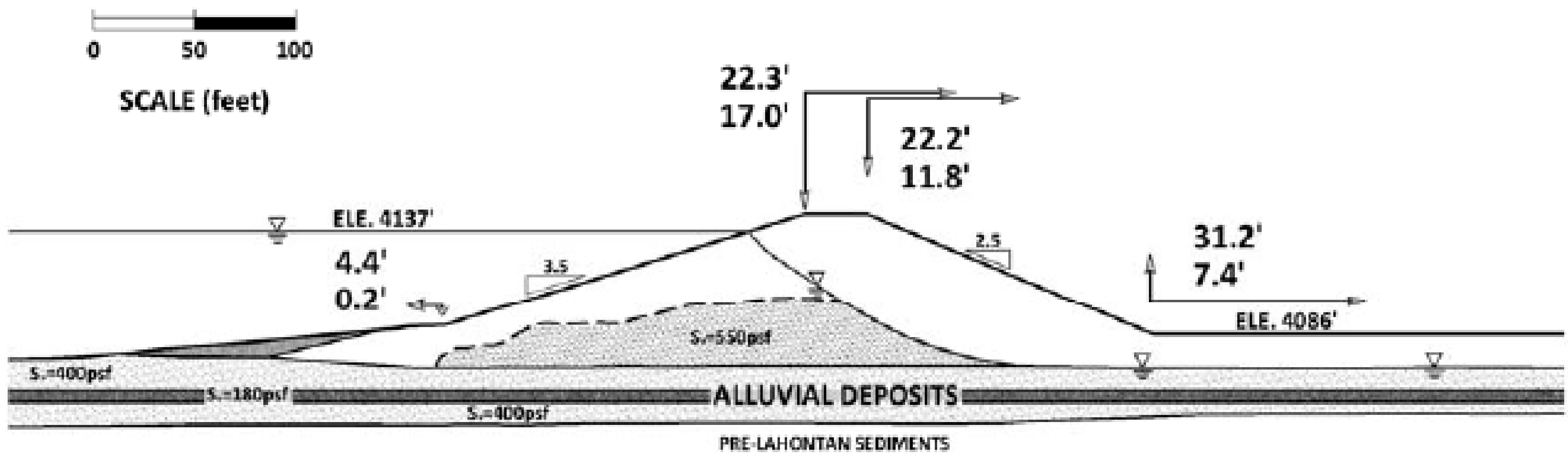


Fig. 8. Computed dynamic vertical and horizontal displacements for the existing conditions at Rye Patch Dam (modified from Woodward-Clyde Consultants - URS Corporation)

RYE PATCH DAM – a new strategy for dam remediation

- Could not design an upstream improved ground restraining block to limit deformations sufficiently to prevent overtopping
- Constructed a DS combination shear key and buttress fill that would limit crest settlements enough to prevent overtopping

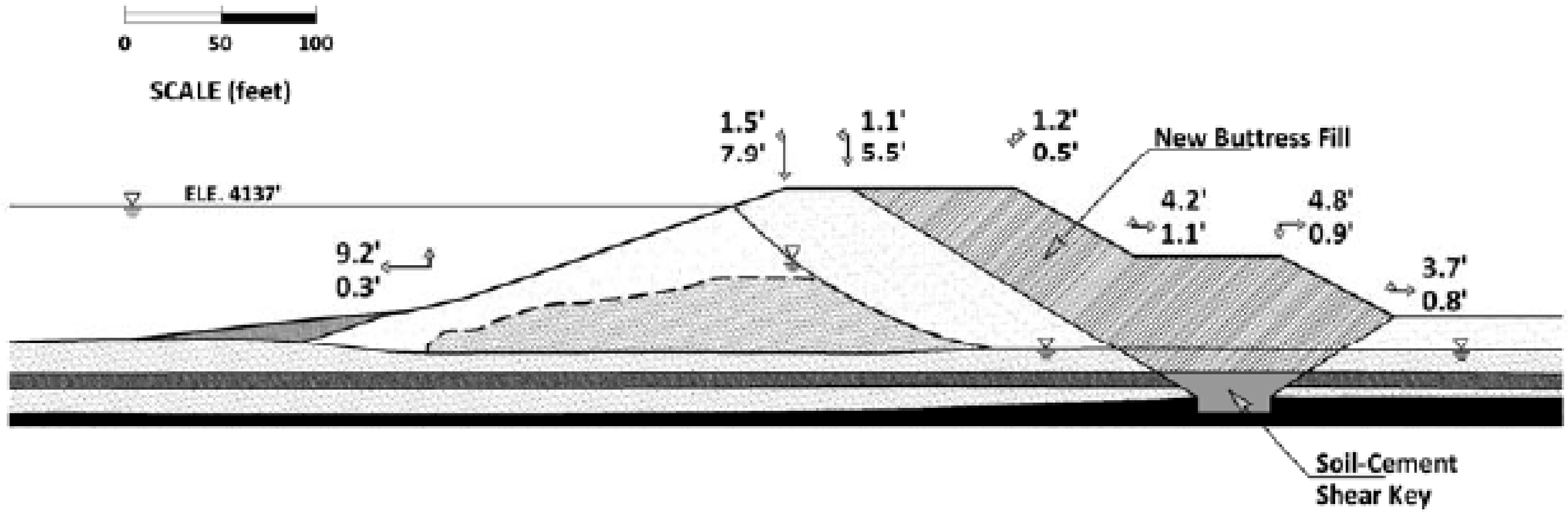


Fig. 9. Computed dynamic vertical and horizontal displacements for the remediated Rye Patch Dam (modified from Woodward-Clyde Consultants - URS Corporation)

RYE PATCH DAM (USBR), Nevada after remediation.

Confining the foundation improvement, buttress fills, and key trenches to the downstream side of the dam is often the preferred strategy now.

Rye Patch Dam, NV: Remediated in late 1980's using a Soil-Cement Key-block and Downstream Overlay Buttress Fill

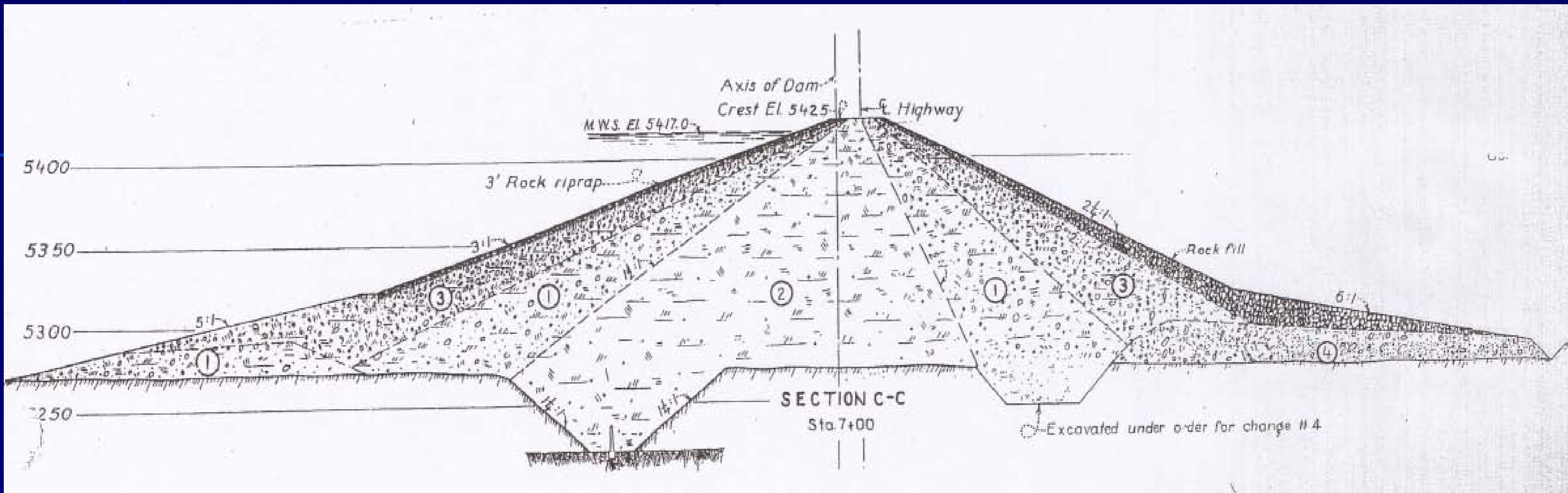
DEER CREEK DAM

Near Provo, Utah

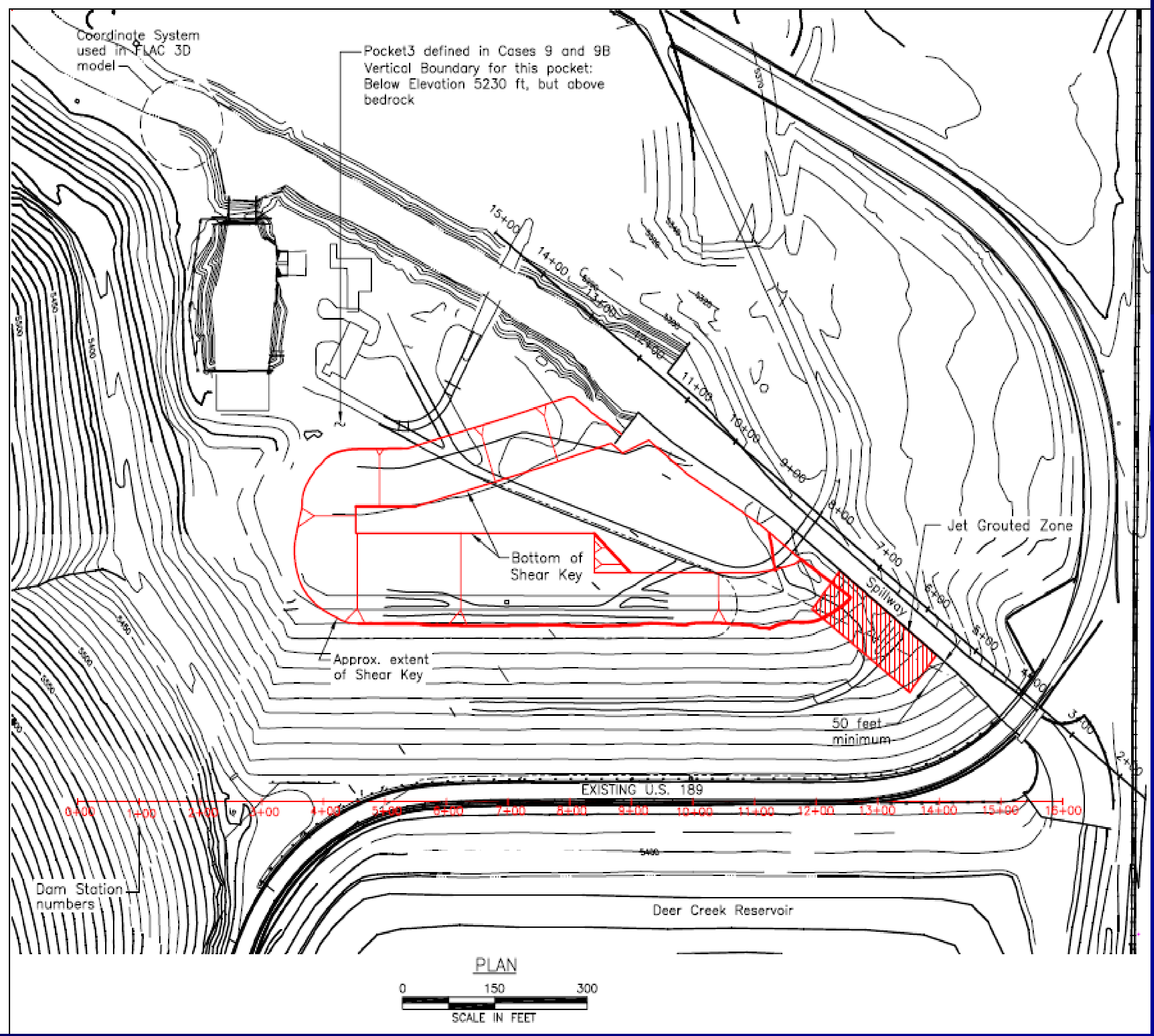
Seismic upgrade completed in November 2008

Deer Creek Dam on the Provo River, Utah (1941)

Five-year safety upgrade completed a year ahead of schedule, November 2008. Retrofitted to resist a M7 EQ. Crest raised 6 feet. Large excavation beneath embankment toe to replace potentially liquefiable material with shear key of recompacted dense material. Highway 189 moved from dam crest to an overpass on DS slope of embankment.



Cross Section of Deer Creek Dam



Excavation plan for shear key at toe of Deer Creek Dam


Shear key excavation at downstream toe
of Deer Creek Dam

Pier construction for relocated Hwy 189 on DS face of remediated Deer Creek Dam

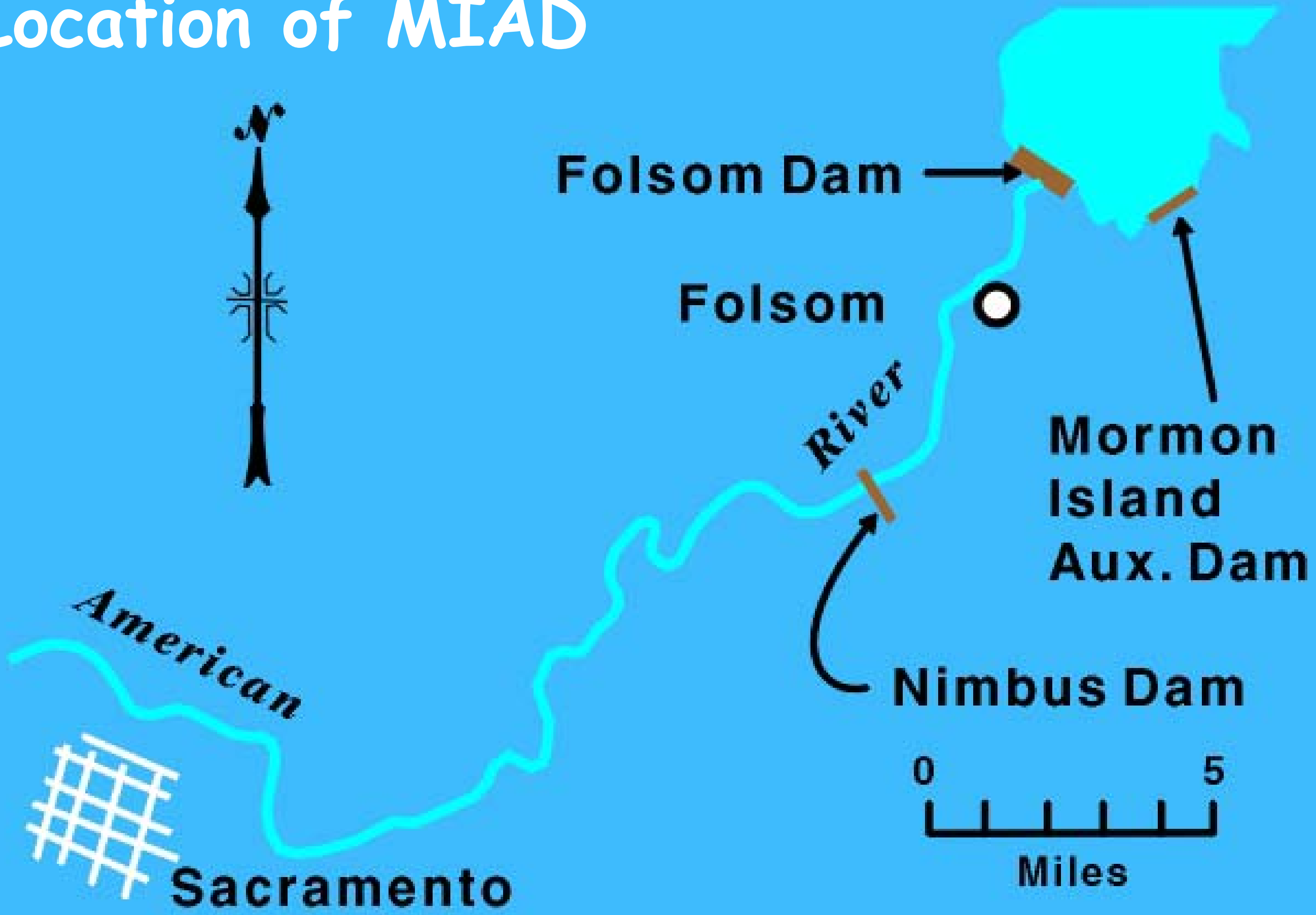
Remediated Deer Creek Dam with realigned state highway across downstream slope
(U.S. Bureau of Reclamation photo)

DEER CREEK DAM, Utah: Remediated using Downstream Shear Key and Berm; State Highway relocated over Downstream Embankment Slope

Mormon Island Auxiliary Dam (MIAD)

A Work in Progress

Location of MIAD



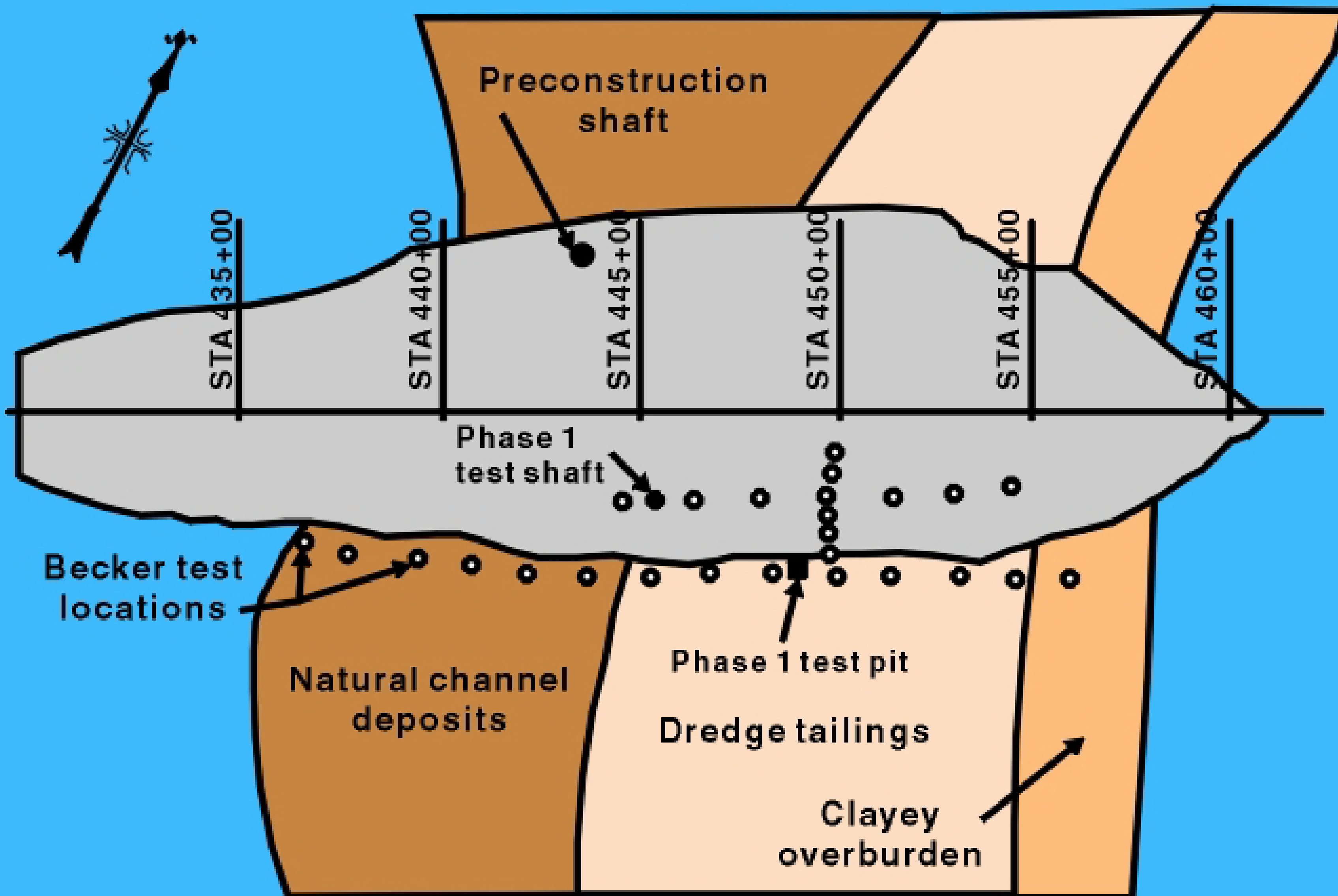

North Fork
American
River
South Fork
American River
Mormon Island
Auxiliary Dam
Dike 1
Dike 2
Dike 3
Dike 4
Dike 5
Dike 6
Dike7
Dike 8
Left wing
dam
Right wing
dam
Concrete
Gravity
Dam
Folsom Dam
General Plan
To Sacramento
0
1
Miles

FOLSOM PROJECT: Concrete Main Dam with Embankment Wing Dams, Mormon Island Auxiliary Dam and 8 Dikes

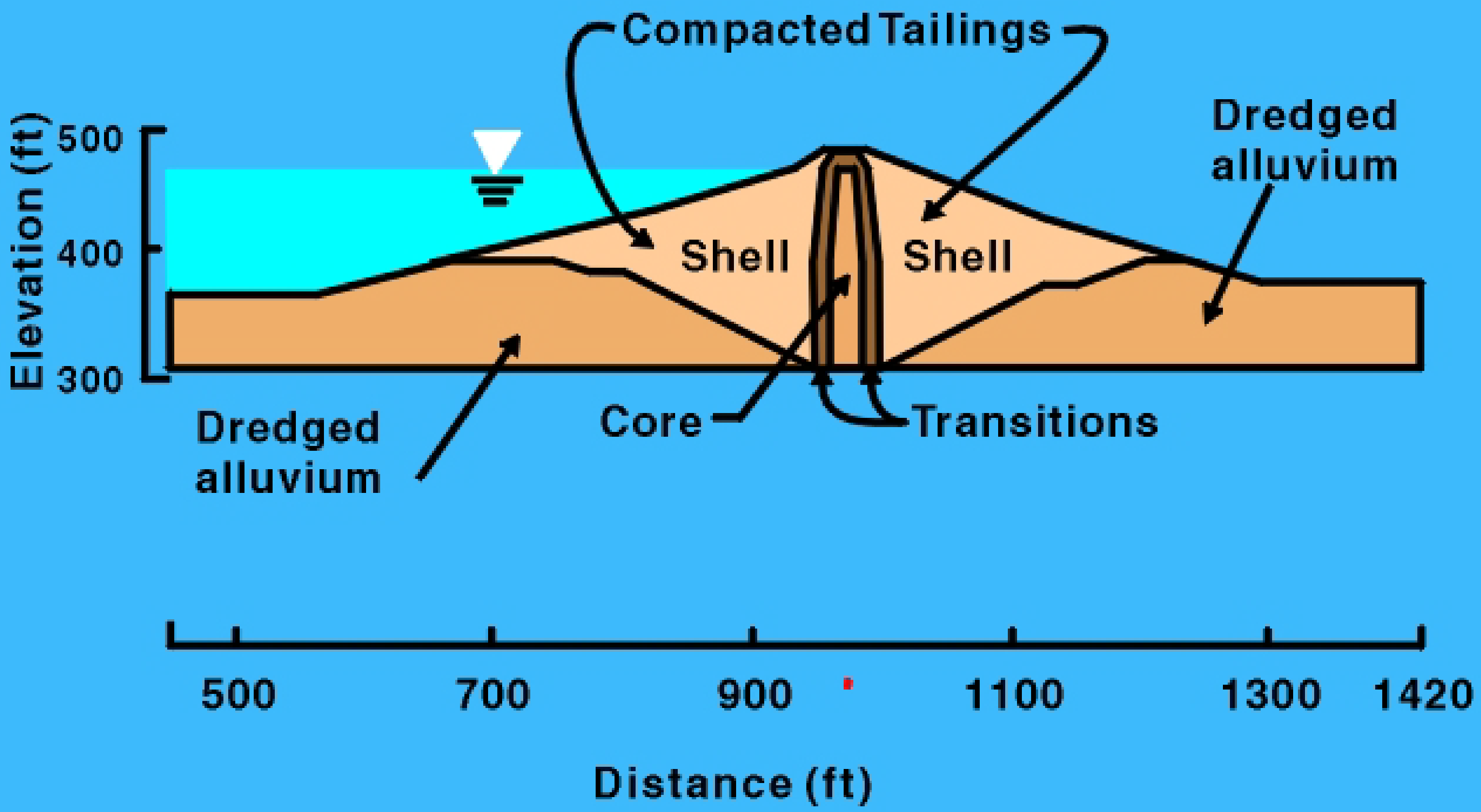
Mormon Island Auxiliary Dam
Central Valley Project, California

U.S. Department of the Interior
Bureau of Reclamation

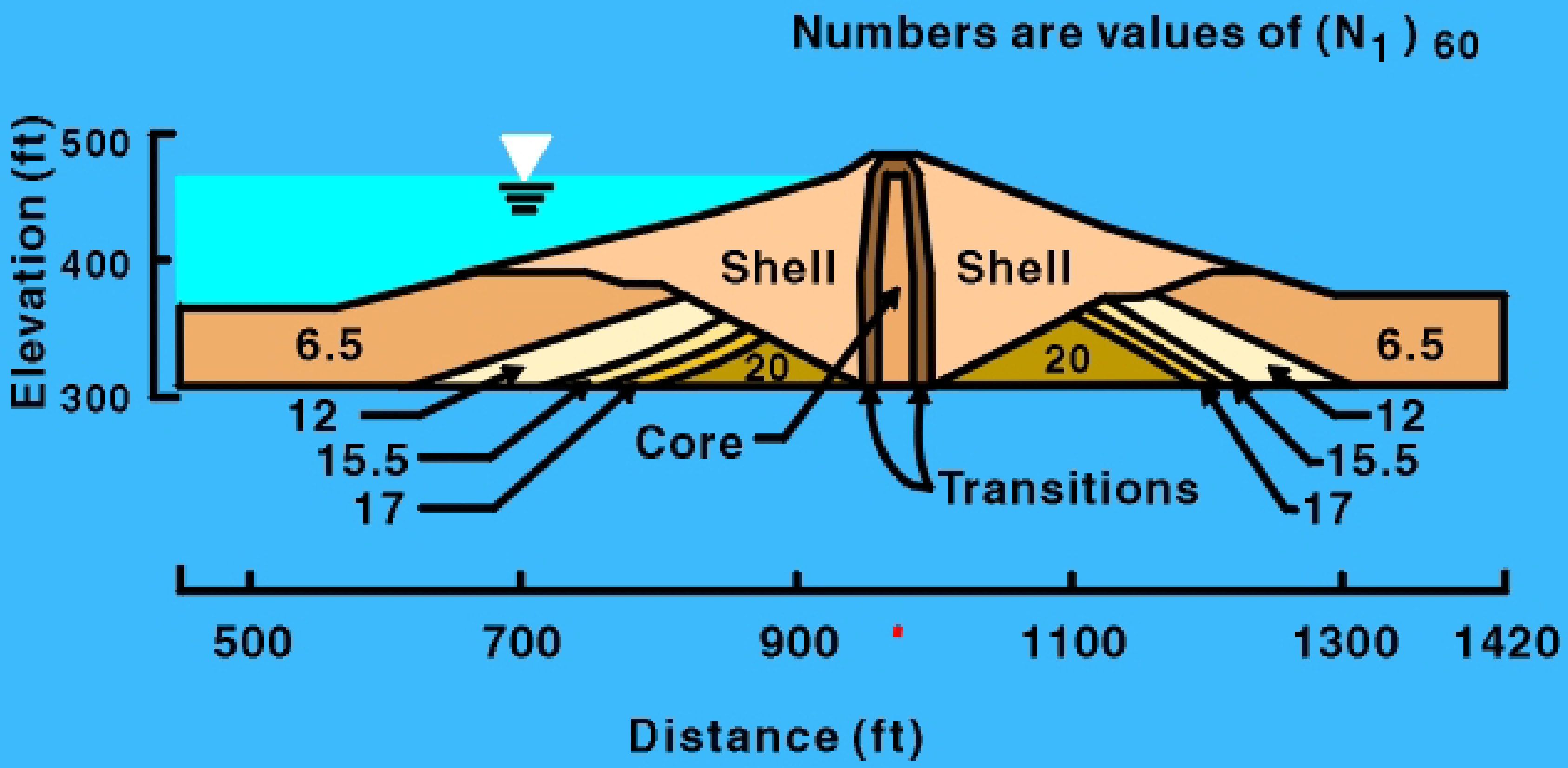
Upstream and downstream improvements done from late 1980s to 1994



Foundation Exploration Plan

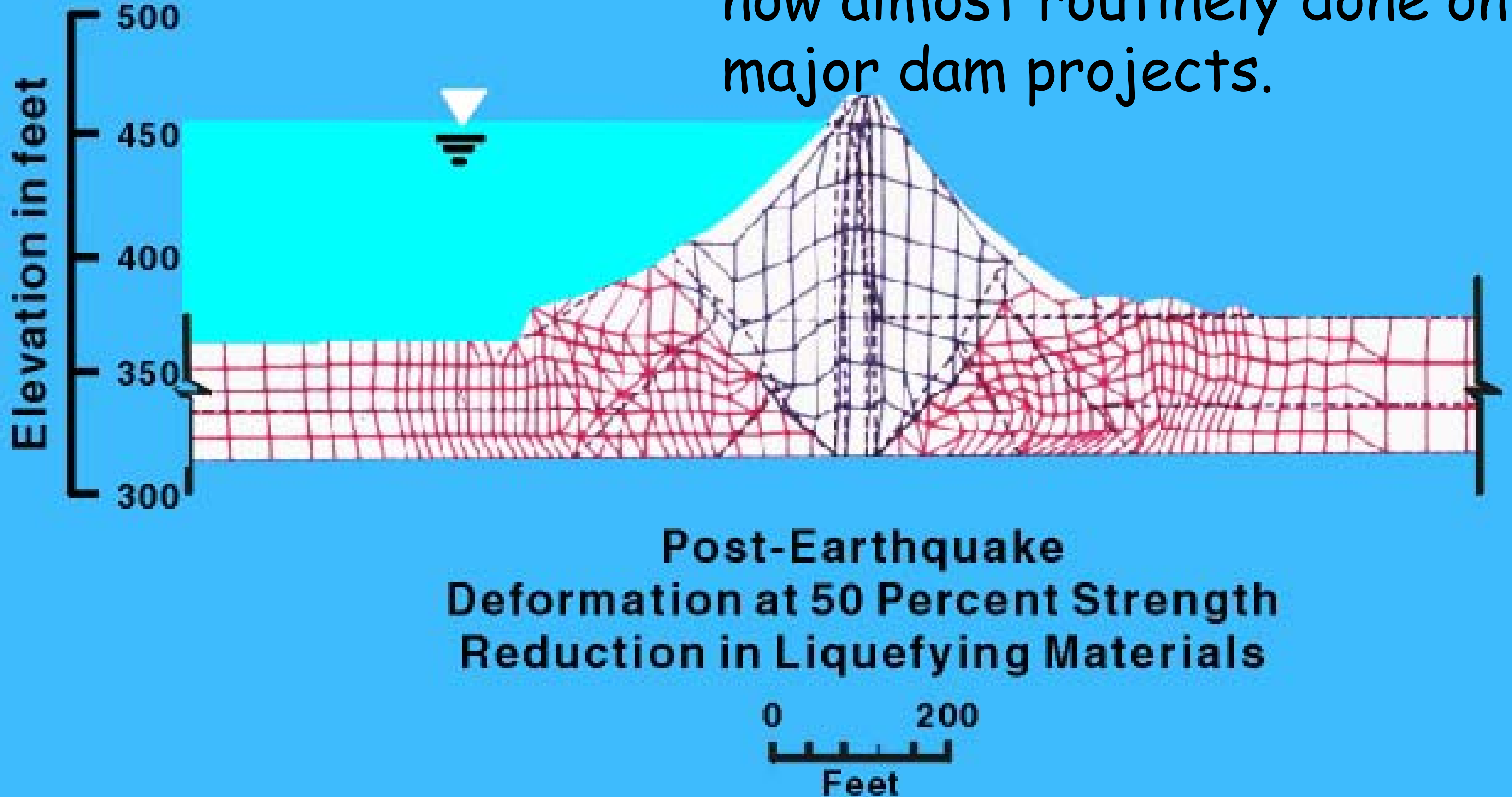


Cross section of Mormon Island Dam



Penetration Resistance of Foundation – re-deposited dredged alluvium

This was an early project in which dynamic deformation analyses were made. They are now almost routinely done on major dam projects.



Deformation Pattern in the Absence of Foundation Improvement

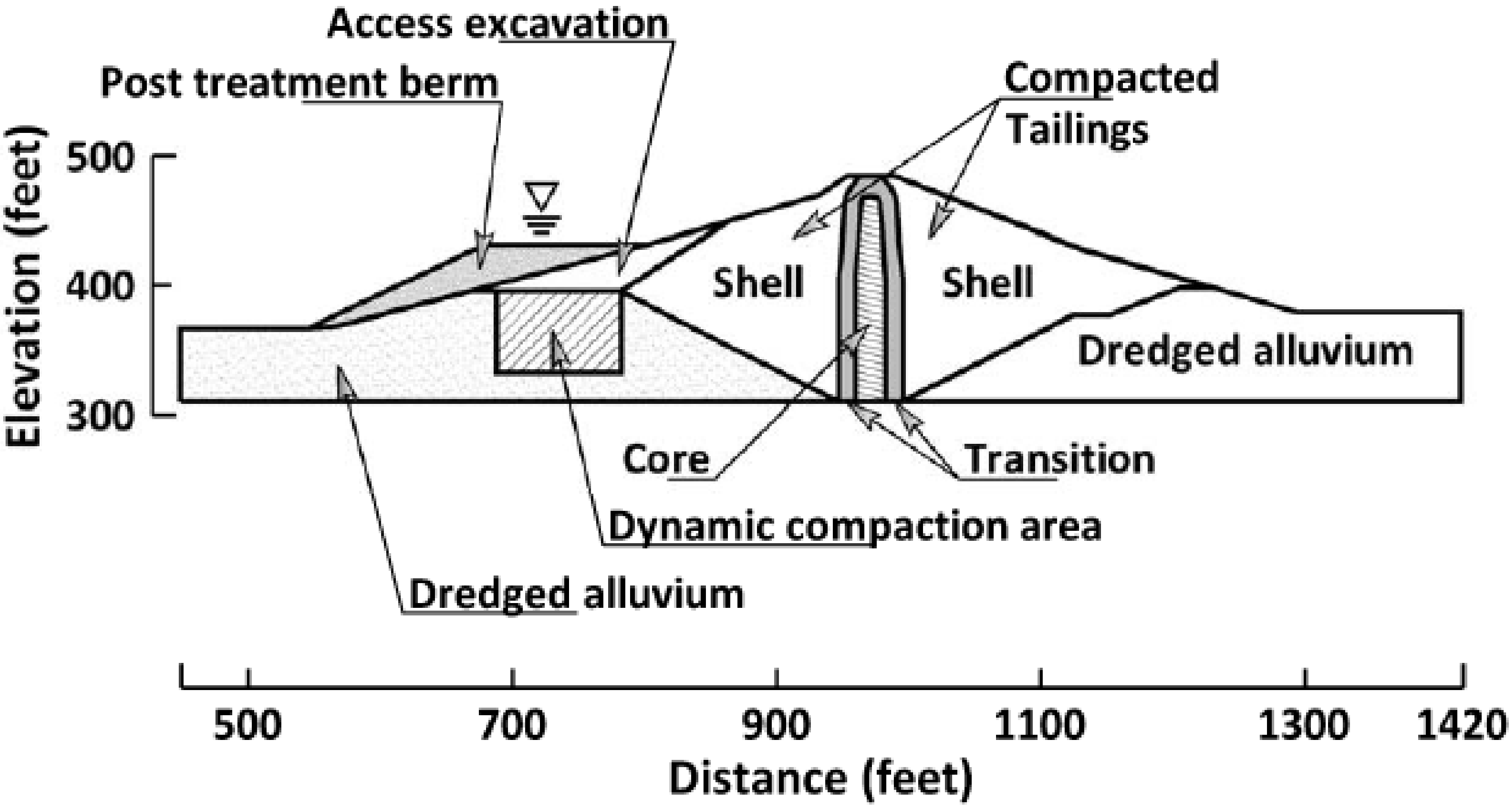
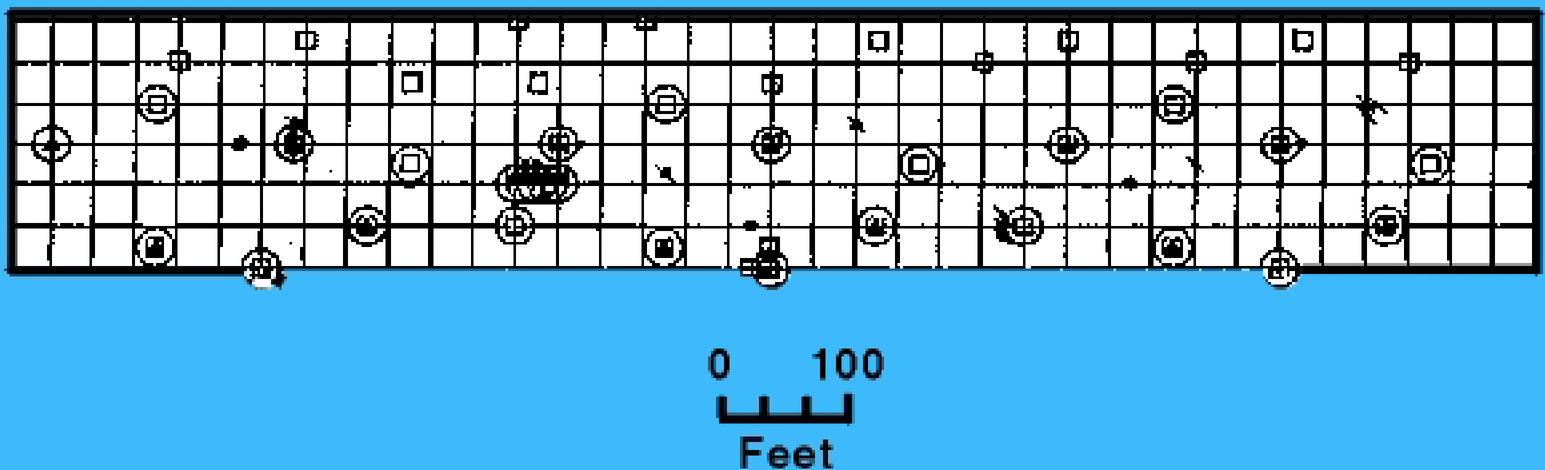


Fig. 6. Ground improvement design for stabilization of the upstream embankment of Mormon Island Auxiliary Dam done in 1990.

Dynamic Compaction Grid



- Precompaction BPTs
- Intermediate BPTs (Following phase 2 dynamic compaction)
- Post compaction BPTs (Oct. 1990)
- Post BPTs (Mar. 1991)
- Cased and uncased BPTs (Sept. 1991)
- SPT Locations all

BPT = Becker Penetration Test

(used in soils with gravel and cobbles)

Deep Dynamic Compaction

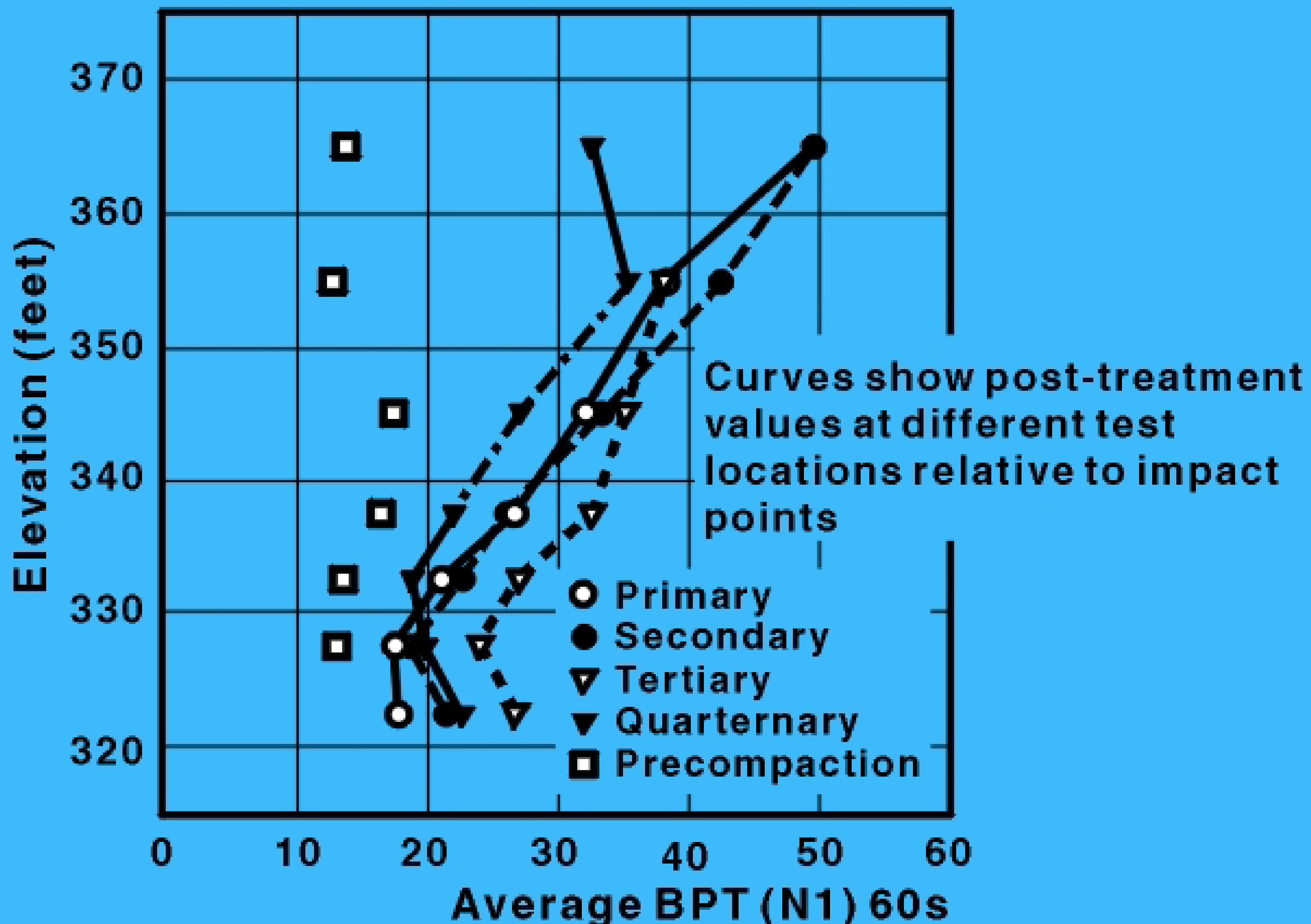
Treatment zone	800 x 150 ft
Steel drop weight	35 tons (6.5 ft Ø)
Drop height	108 ft ⟹ 98.4 ft free fall

Dynamic Compaction Program

Coverage	Spacing	Number of Drops
Primary	50 ft c-c	30
Secondary	Split primary	30
Tertiary	Split secondary	15
Ironing	Edge to edge	2 @ 30 ft drop

Upstream Ground Improvement in Progress (1990)

Mormon Island Auxiliary Dam



Effect of Location on BPT Resistance

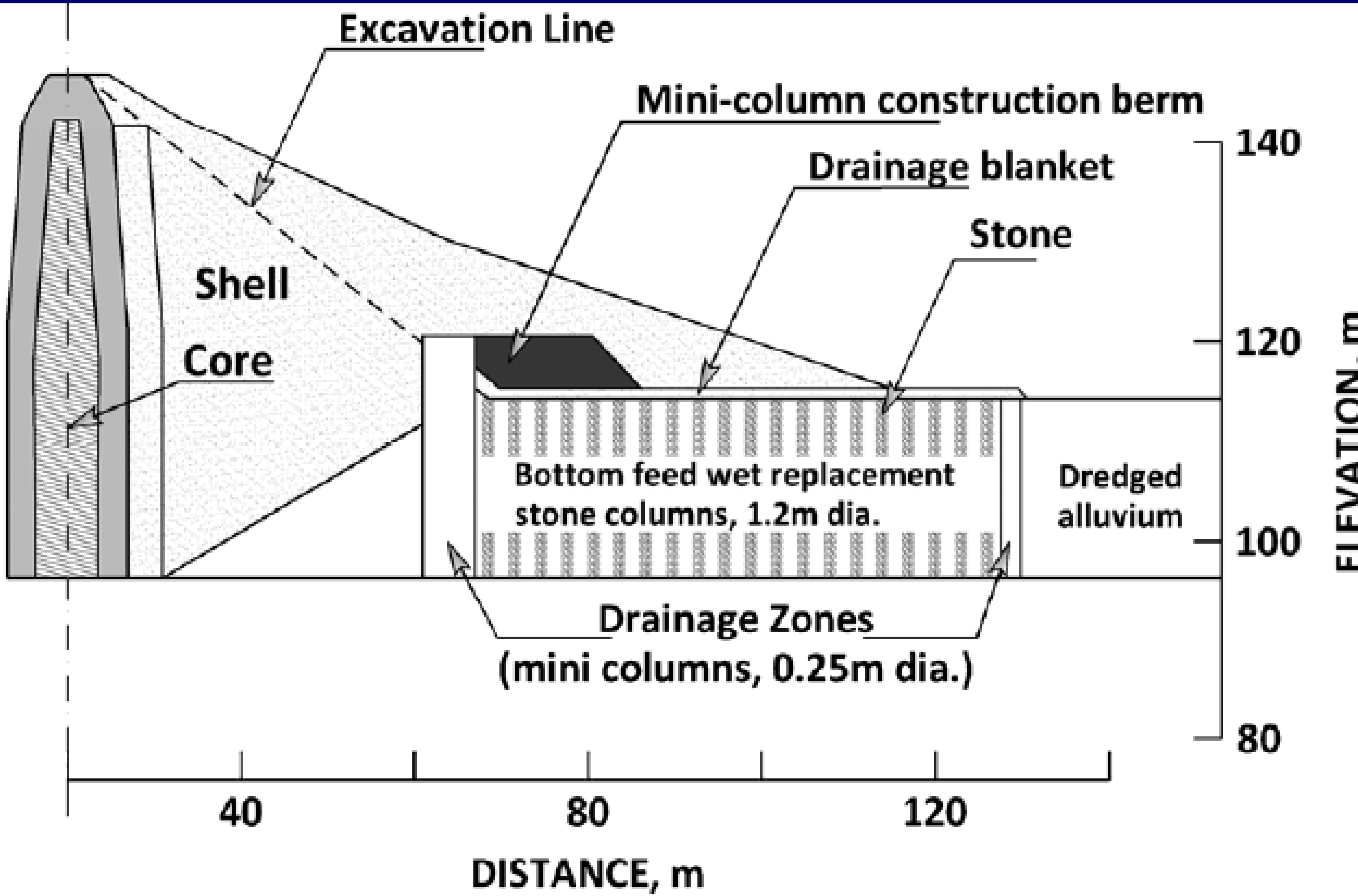
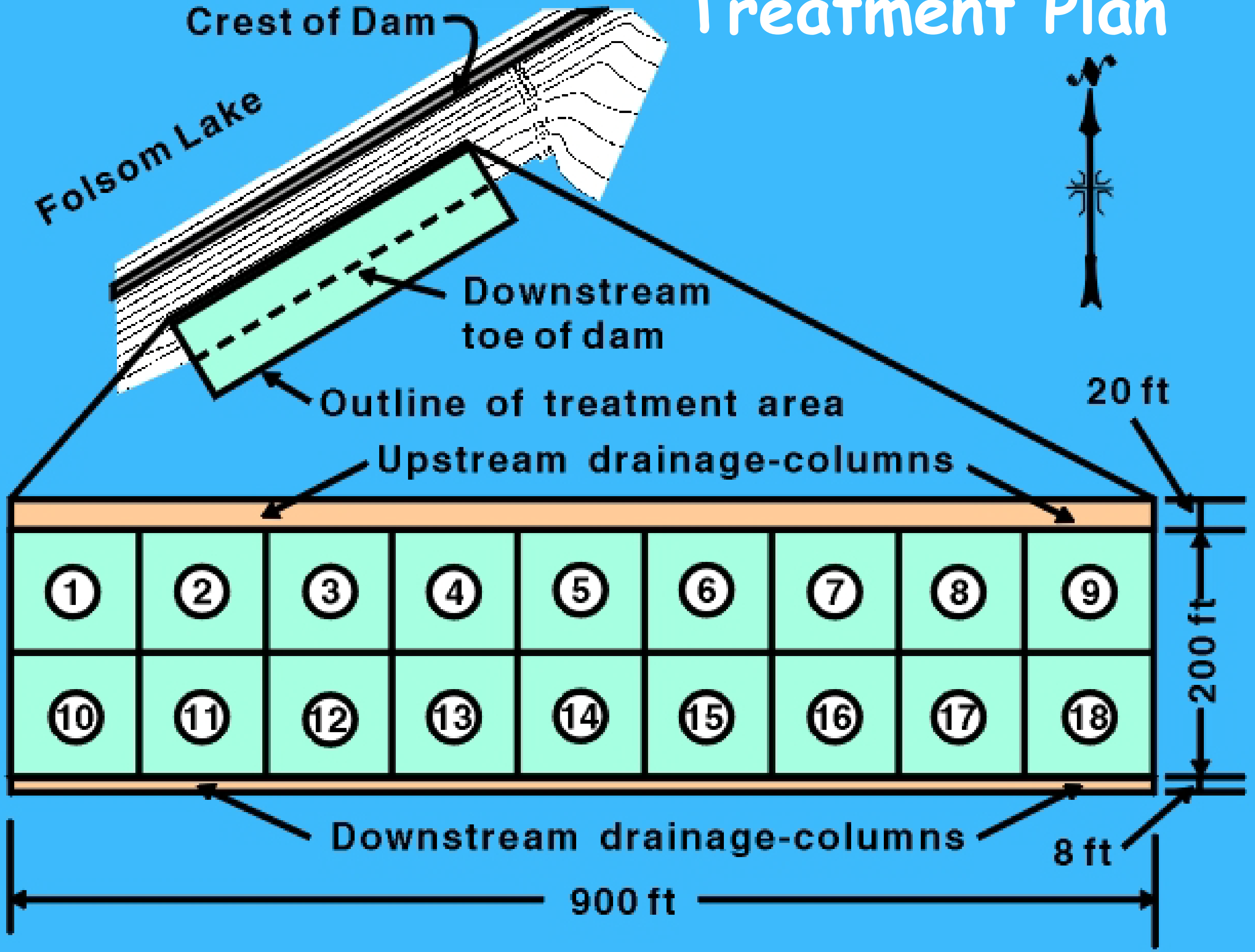


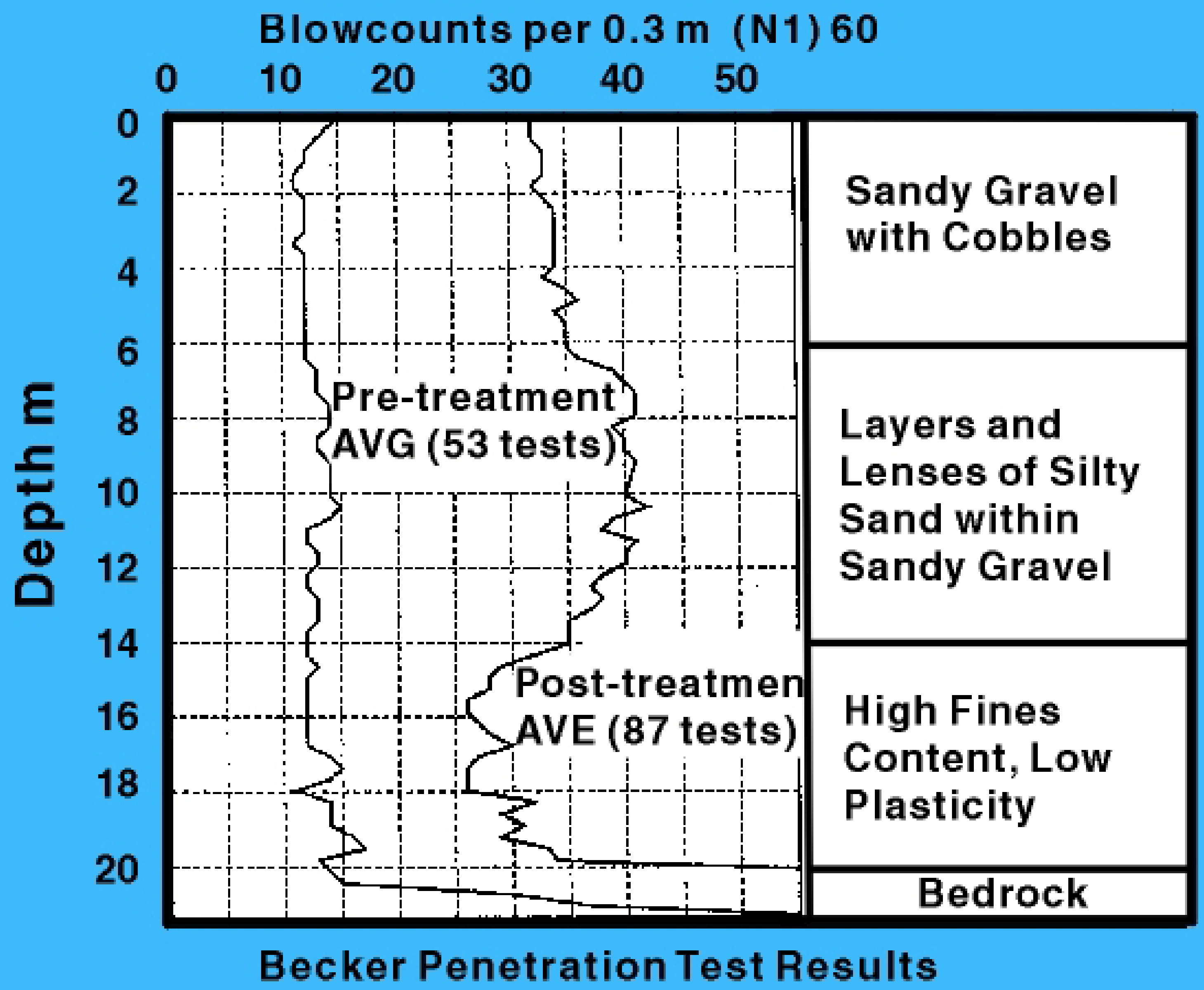
Fig. 7. Ground improvement design for stabilization of the downstream embankment of Mormon Island Auxiliary Dam done in 1993-94.

Treatment Plan

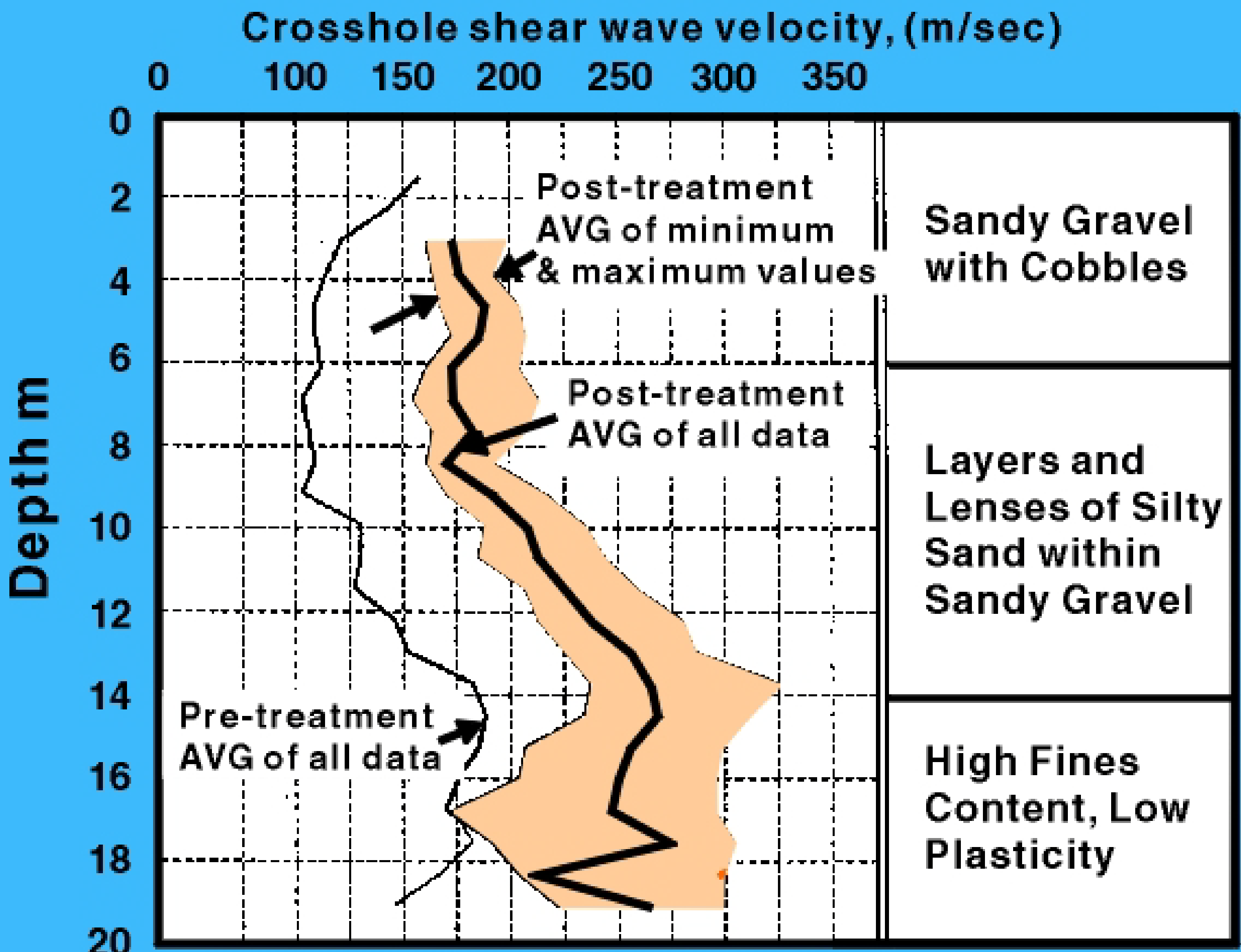



Downstream treatment in progress (1994)
at Mormon Island Auxiliary Dam

Stone column construction at MIAD



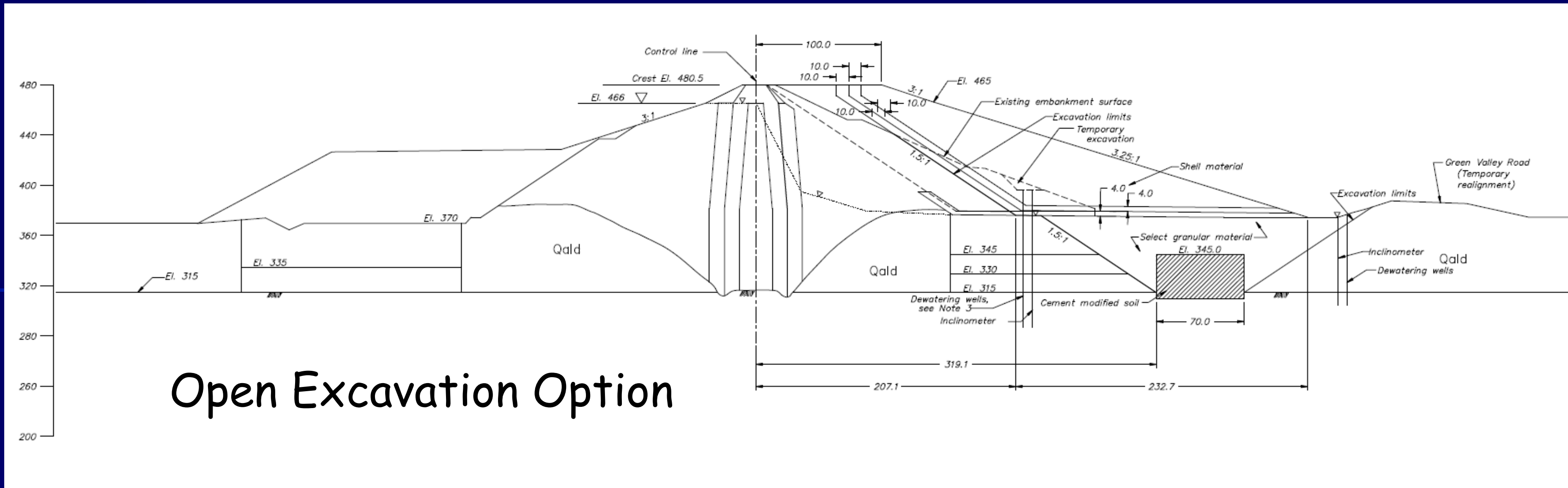
Blowcounts per 0.3 m (N1) 60
0
10
20
30
40
50
0
2
4
6
8
10
12
14
16
18
20
Depth m
Pre-treatment
AVG (53 tests)
Post-treatmen
AVE (87 tests)
Sandy Gravel
with Cobbles
Layers and
Lenses of Silty
Sand within
Sandy Gravel
High Fines
Content, Low
Plasticity
Bedrock
Becker Penetration Test Results

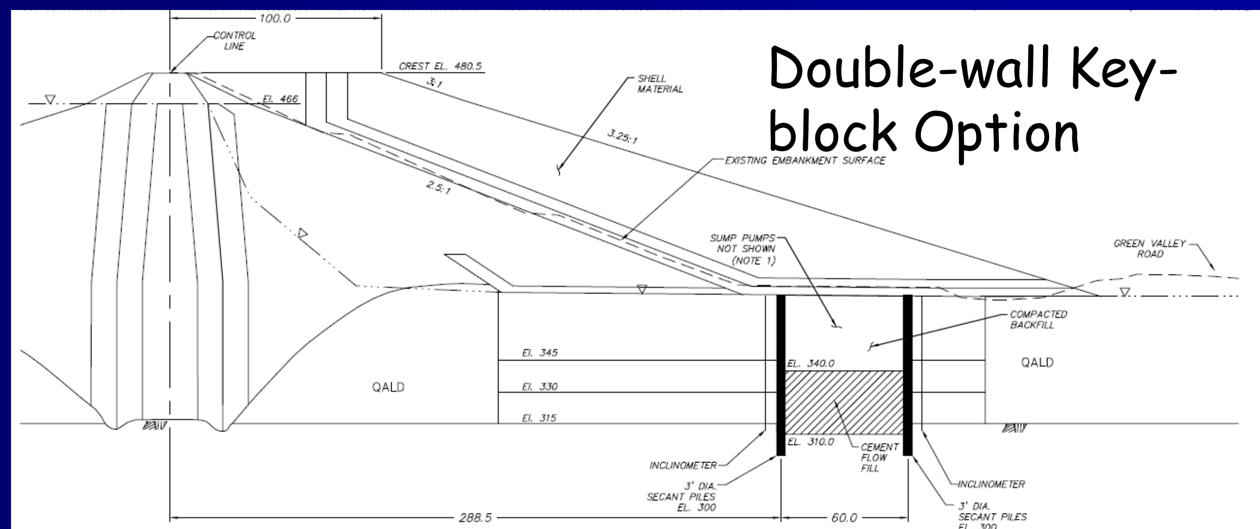


Crosshole shear wave velocity, (m/sec)
0
100
150
200
250
300
350
0
2
4
6
8
10
12
14
16
18
20
Depth m
Post-treatment
AVG of minimum
& maximum values
Post-treatment
AVG of all data
Pre-treatment
AVG of all data
Sandy Gravel
with Cobbles
Layers and
Lenses of Silty
Sand within
Sandy Gravel
High Fines
Content, Low
Plasticity

MIAD – The Continuing Story (since 2001)

- Reevaluations – greater seismic and hydrologic risk, larger population at risk
- Residual liquefaction risk beneath US DDC zone
- Adequacy of lower portion of vibro-replacement could not be demonstrated
- Risk analysis indicates a Take Action situation
- No further US treatment is planned
- Proposed DS treatment was Jet Grout (JG) block in foundation and filtered overlay on DS shell
- Test program indicated that JG treatment was unsatisfactory
- Corrective Alternative Action Studies completed





Two Alternatives for MIAD Remediation

Trends in Ground Improvement Methods and Application Strategies

- Simpler is better
- Formal risk analyses are being increasingly used as a basis for selection among alternative corrective actions, with probability of failure and annualized life loss being the major criteria
- Focus is downstream (upstream work requires reservoir drawdown and/or working over water)
- Excavate and replace plus a downstream overlay or buttress fill is simple and reliable – but may involve a high failure risk during construction
- Dynamic deformation analyses are now widely used
- 3-D analyses increasingly used
- Vibro-replacement use is decreasing
- Use of CDSM is increasing
- The promise of Jet Grouting is yet to be realized
- Can allow upstream failure if downstream buttressed to prevent excess loss of freeboard (and can demonstrate this by suitable analysis)

Some Unresolved Problems:

- Assessing liquefaction potential of soils containing gravel and cobbles
- Assessing liquefaction potential of silty soils
- Assessing residual strength
- Assessing compliance with specifications
- Interpreting the results of a risk analysis
- Deciding the acceptable level of risk
- Selecting and implementing the appropriate soil constitutive model for liquefaction and dynamic deformation analyses – UBCSand works well
- Assessing the reliability and accuracy of dynamic deformation analyses – "factor of 2 rule"
- Assessing and controlling conservatism
- Getting it right the first time

CONCLUDING COMMENTS:

- Basic approaches to ground improvement are old
- New ways to implement these approaches continue to be developed
- Success is largely dependent on accurate characterization of existing subsurface and embankment conditions
- Predicted deformations for evaluation of existing dam should be based on realistic (unfactored) loads and actual soil parameters. More conservative values should be used in the remediation design.
- Full-scale field tests yield the most reliable understanding and validation and should be a component of virtually all projects
- The QA/QC program should verify the most critical aspects of the work

CONCLUDING COMMENTS (cont.)

- Many methods and strategies exist for improving the ground at both new and existing dams.
- Different methods are most suitable for different soils, different purposes, and different site and project constraints.
- Combining methods may help optimize the solution.
- Evaluating the results may be challenging.
- Soil improvement will continue to play an important role in the mitigation of seismic risk to existing dams.
- **Dam safety is a critical life safety issue.**

A Few Relevant References

1. Mitchell, J.K. (2008) "Mitigation of Seismic Risk to Existing Dams," Keynote Paper, ASCE Geotechnical Special Publication 181, Geotechnical Earthquake Engineering and Soil Dynamics, 2008.
2. Mitchell, J.K. (2008) "Mitigation of Liquefaction Potential of Silty Sands," in From research to Practice in Geotechnical Engineering, ASCE Geotechnical Special Publication 180, J.E. Laier, D.K. Crapps, and M.H. Hussein, eds., pp.433-451, 2008.
3. Mitchell, J.K. (2008) "Aging of Sands – A Continuing Enigma?", Proc. 6th Int. Conf. on Case Histories in Geotechnical Engineering, Arlington, VA, Aug. 11-16, 2008.
4. "Engineering and Design Guidelines on Ground Improvement for Structures and Facilities," (James K. Mitchell and Patricia M. Gallagher) Publication No. ETL 1110-1-185, U.S. Army Corps of Engineers, Engineering Division, Directorate of Civil Works, Washington, DC, 1 February 1999. (http://www.usace.army.mil/inet/usace-docs/eng-tech-ltrs/etl1110-1-185/toc.htm)
5. Mitchell, J.K., Cooke, H.G. and Schaeffer, J.A. (1998) "Design Considerations in Ground Improvement for Seismic Risk Mitigation," Emerging Art Paper, Geotechnical Earthquake Engineering and Soil Dynamics III, ASCE Special Geotechnical Publication No. 75, (P. Dakoulas, M. Yegian, R.D. Holtz, eds.), Vol. 1, pp. 580-613.