Qualitative Foundation Rock Block Stability Evaluation Performed for Green Peter Dam

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USACE Risk Management Center

Association of Engineering Geologists

Pittsburg, PA, September, 2015

US Army Corps of Engineers

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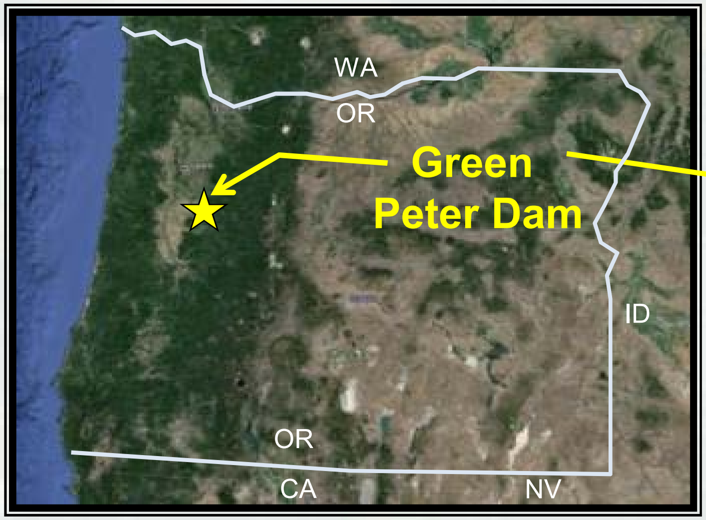
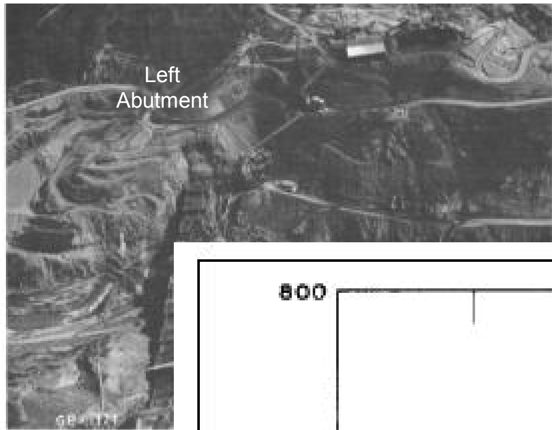
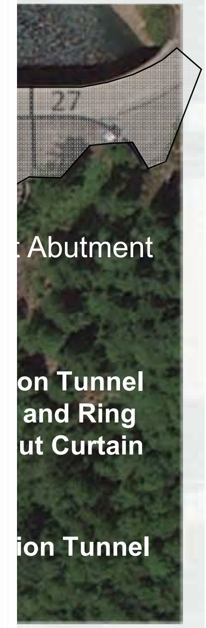
Site Location
Willamette River Basin



- Design: 1956-1963
- Construction: 1963-1967
- This was the era of active USACE dam building in the Pacific Northwest
  - Project geologists and engineers were experienced
  - Active District, Division and HQ involvement and support

Project Features





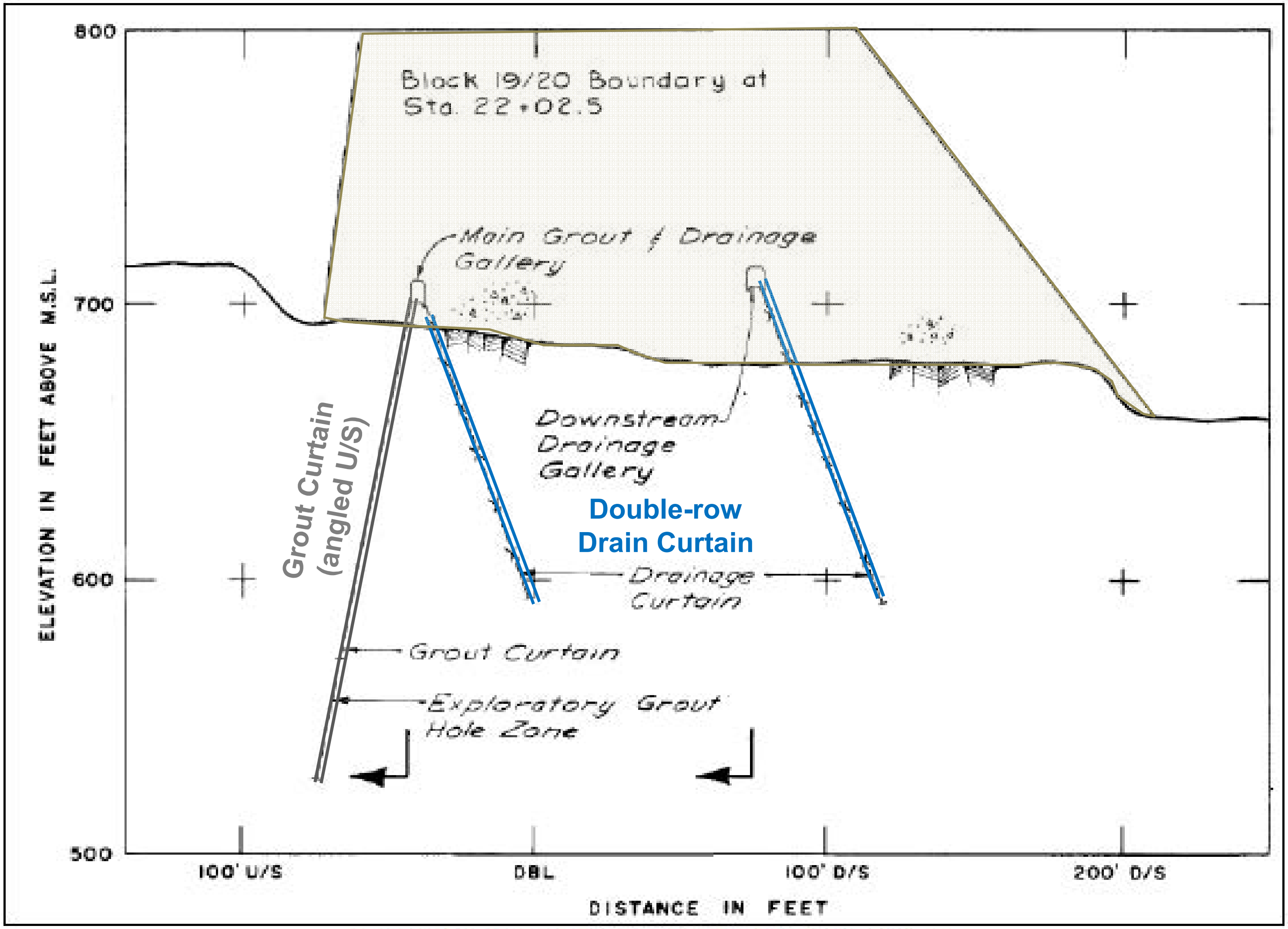
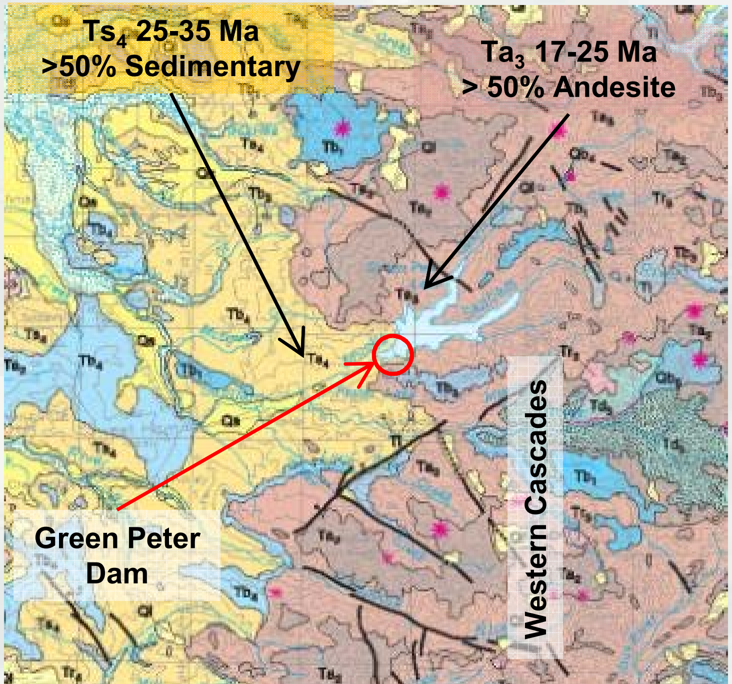


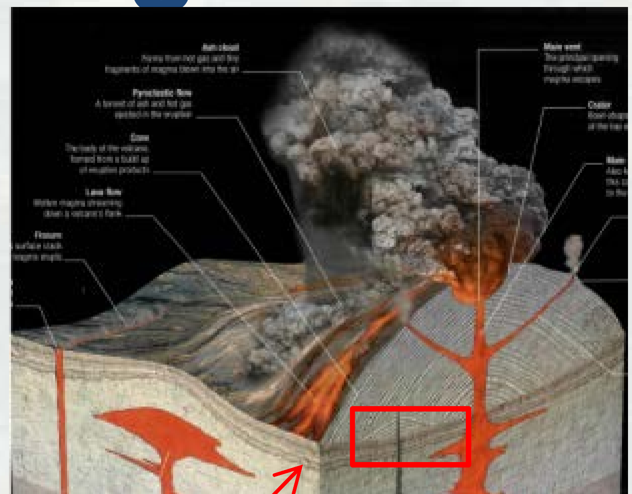
Figure 2.16 - Drainage and Grout Curtains

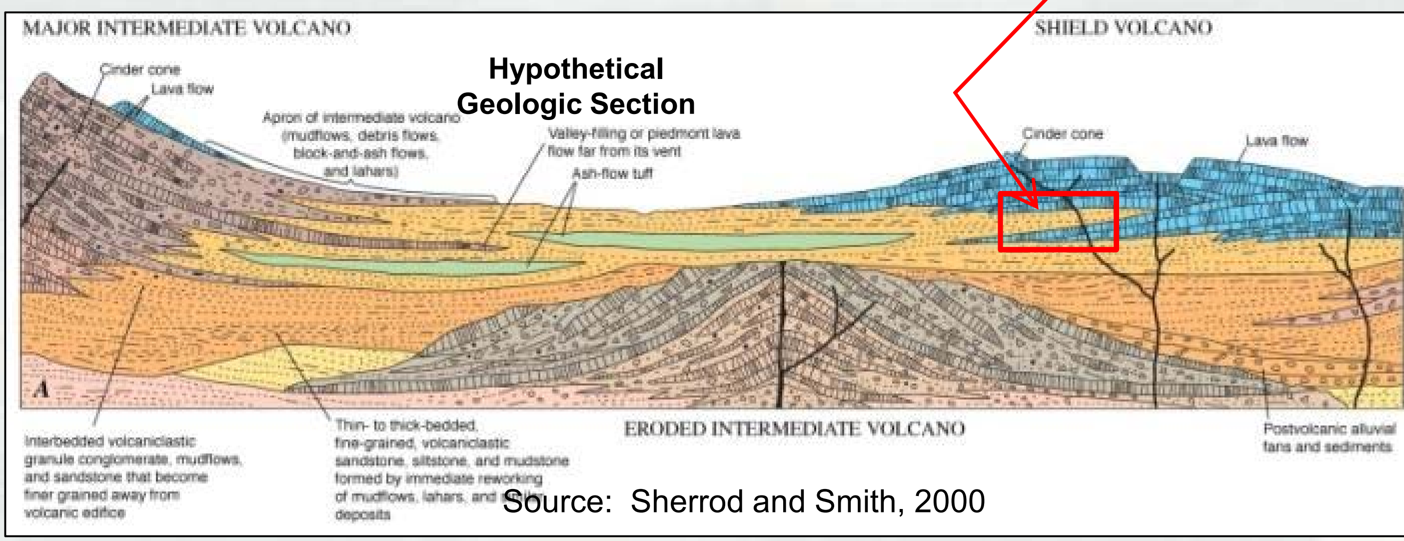
Maxim
Lengtl
Numbe
Crest V
Powerl
Numbe

Regional Geologic Setting



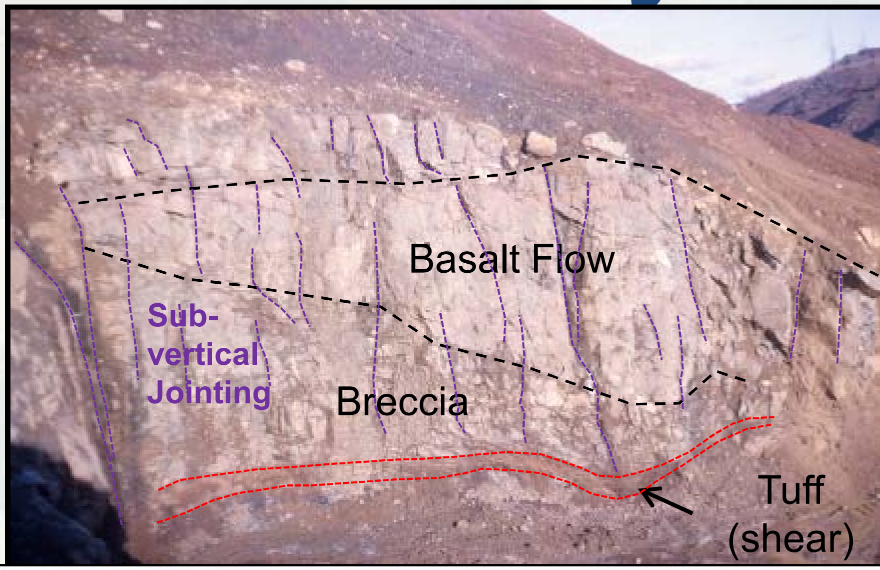
USGS generalized mapping does not agree Corps site-specific mapping (scale issue)





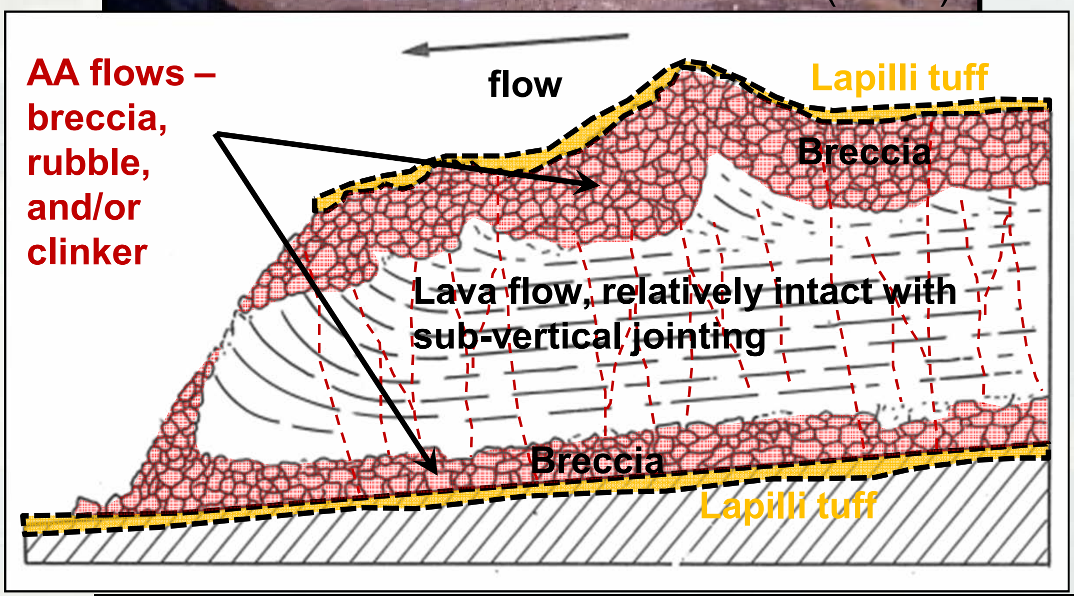
Source: Sherrod and Smith, 2000

Anatomy of a Lava Flow



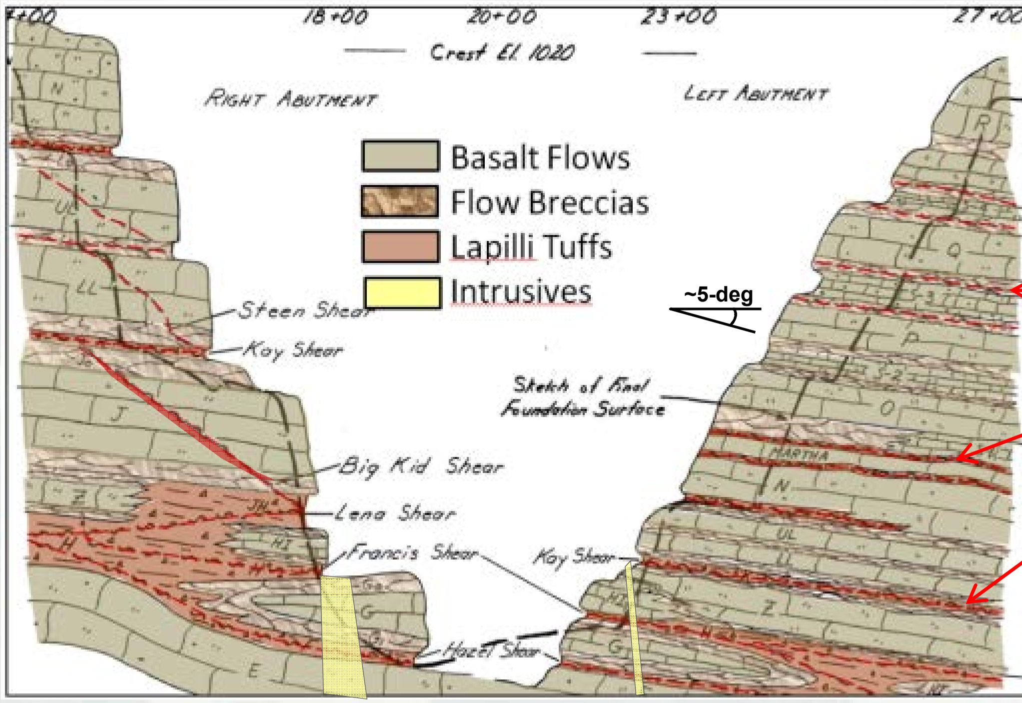
Note irregular top surface of rubbly rock fragments.

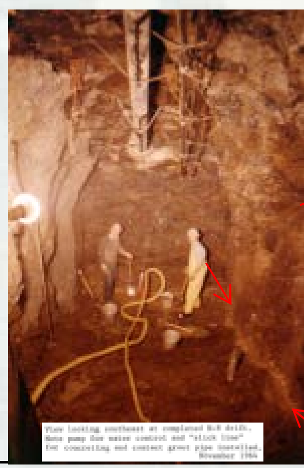
Typical basalt flow with sub-vertical jointing



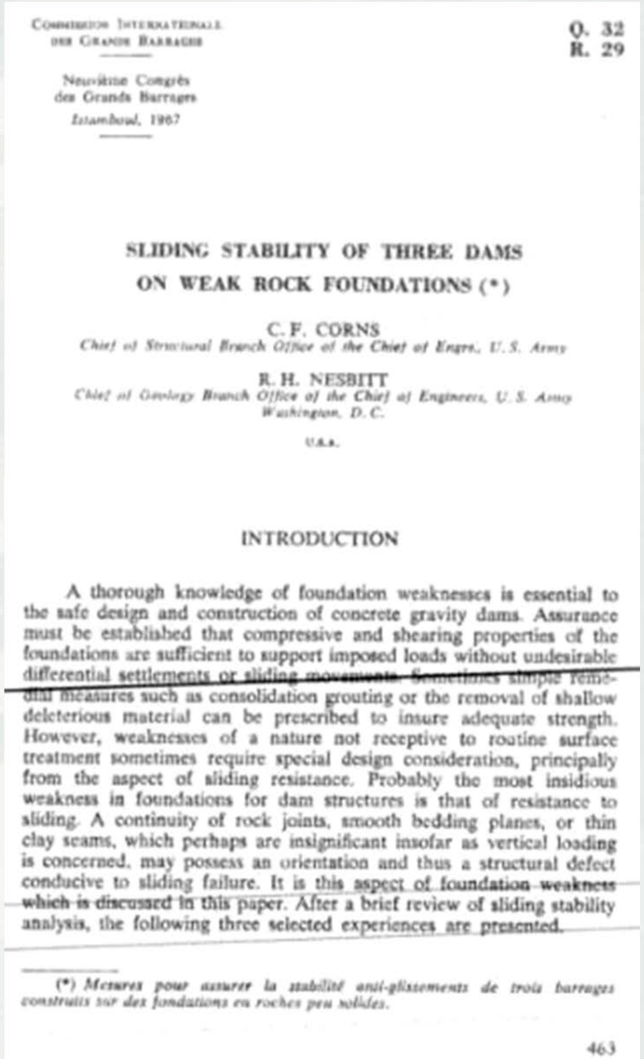
Lapilli tuff (typ.) readily alters to clays, zeolites and consolidates.

Generalized Geologic Section





USACE Geologic / Geotechnical Perspective



Commission Internationale des Grands Barrages

Neuvième Congrès des Grands Barrages

Istamboul, 1967

Q. 32
R. 29

SLIDING STABILITY OF THREE DAMS ON WEAK ROCK FOUNDATIONS (*)

C. F. CORNS
Chief of Structural Branch Office of the Chief of Engrs., U.S. Army

R. H. NESBITT
Chief of Geology Branch Office of the Chief of Engineers, U.S. Army
Washington, D.C.

U.S.A.

INTRODUCTION

A thorough knowledge of foundation weaknesses is essential to the safe design and construction of concrete gravity dams. Assurance must be established that compressive and shearing properties of the foundations are sufficient to support imposed loads without undesirable differential settlements or sliding movements. Sometimes simple remedial measures such as consolidation grouting or the removal of shallow deleterious material can be prescribed to insure adequate strength. However, weaknesses of a nature not receptive to routine surface treatment sometimes require special design consideration, principally from the aspect of sliding resistance. Probably the most insidious weakness in foundations for dam structures is that of resistance to sliding. A continuity of rock joints, smooth bedding planes, or thin clay seams, which perhaps are insignificant insofar as vertical loading is concerned, may possess an orientation and thus a structural defect conducive to sliding failure. It is this aspect of foundation weakness which is discussed in this paper. After a brief review of sliding stability analysis, the following three selected experiences are presented.

(*) *Mesures pour assurer la stabilité anti-glissements de trois barrages construits sur des fondations en roches peu solides.*

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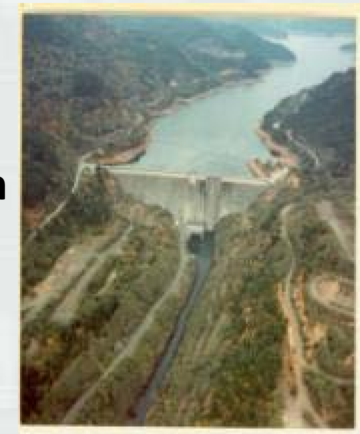
"Sliding Stability of Three Dams on Weak Rock Foundations" **presented at the Ninth Congress on Large Dams, Istanbul, 1967.**



C.F. Corns (Ch. Structural Branch Office, USACE HQ)
R.H. Nesbitt (Ch. of Geology Branch Office, USACE HQ)

"Within the experience of the Corps of Engineers, probably no other high concrete gravity dam site has presented the designer and builder with a <u>greater number of foundation tailoring requirements</u> **[topographic and geologic]** ***than this project*** **[i.e. Green Peter Dam]."**

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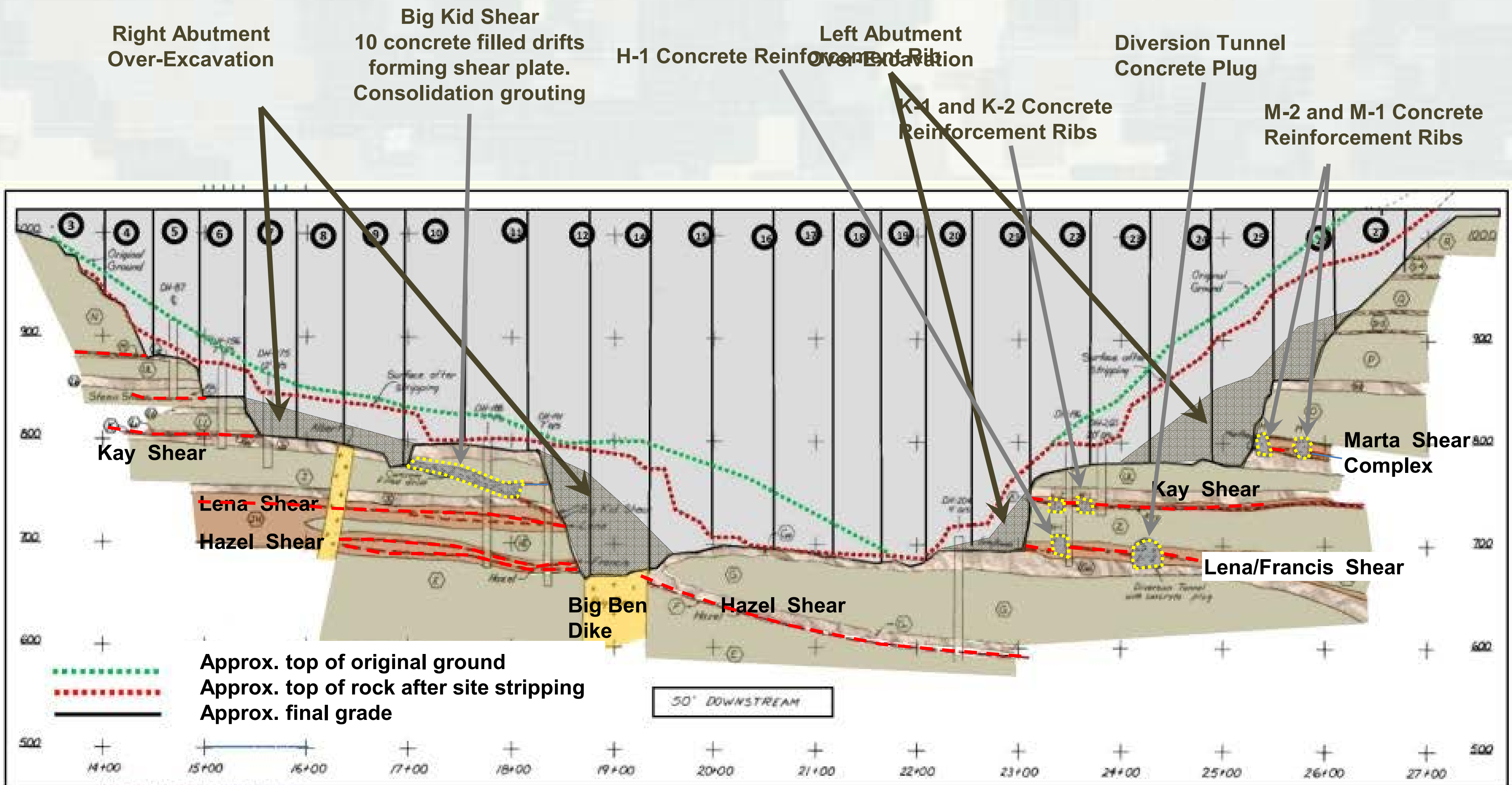
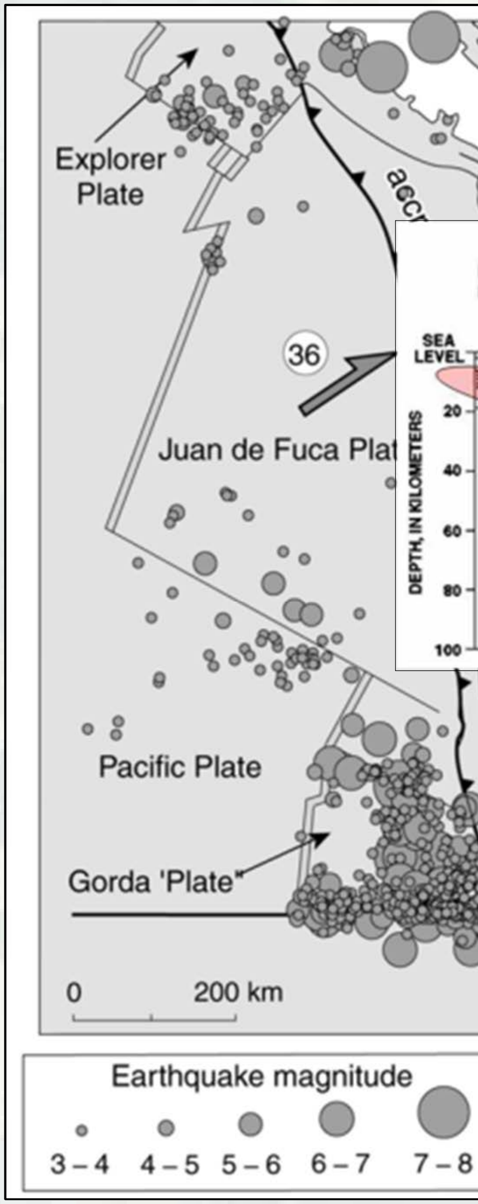
Foundation Modifications



Regional Seismic Setting



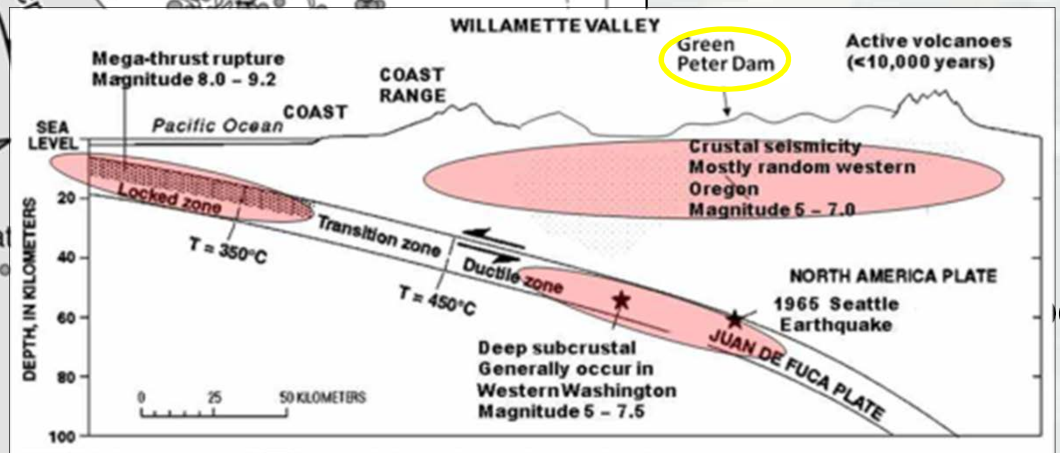


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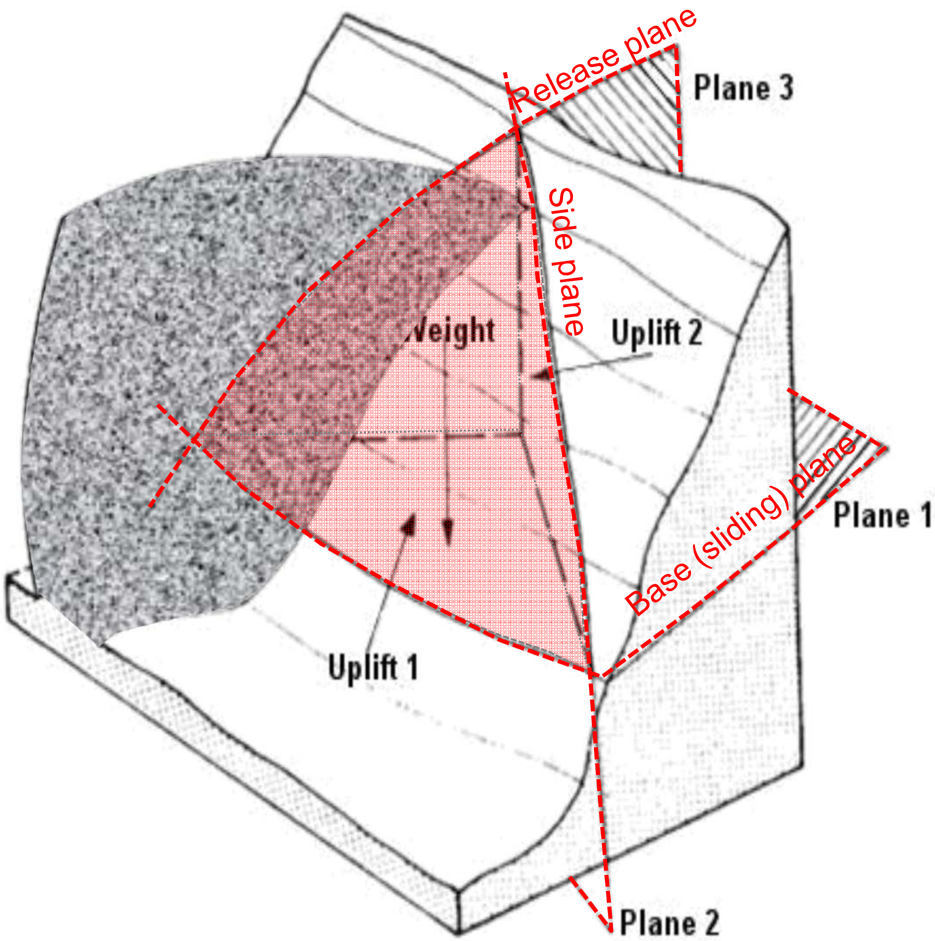
Table 5-11. Ground Motion Spectra for Green Peter Dam

Spectral Period (sec)	Pseudo-Spectral Acceleration (g), 5% Damping, for: UHRS for Return Period of: 144 years	500 years	1,000 years	2,500 years	5,000 years	10,000 years	Deterministic Motions from Cascadia Interface M 8.7 to M 9.1: Median	84th Percentile
PGA	0.0299	0.1020	0.1564	0.2506	0.3325	0.4258	0.1363	0.2734
0.075	0.0464	0.1537	0.2530	0.4148	0.5610	0.7426	0.2017	0.4377
0.1	0.0543	0.1807	0.2955	0.4805	0.6534	0.8662	0.2303	0.5020
0.2	0.0663	0.2283	0.3701	0.6018	0.8111	1.0499	0.3110	0.6611
0.3	0.0601	0.2136	0.3501	0.5700	0.7668	0.9850	0.3042	0.6422
0.5	0.0419	0.1738	0.3056	0.5007	0.6624	0.8531	0.2676	0.5621
1.0	0.0208	0.1065	0.1985	0.3405	0.4712	0.6176	0.1731	0.3887
2.0	0.0078	0.0478	0.1045	0.1954	0.2834	0.3920	0.0870	0.2249
4.0	0.0022	0.0149	0.0336	0.0679	0.1096	0.1527	0.0243	0.0837

Source: AMEC, Quest, 2009

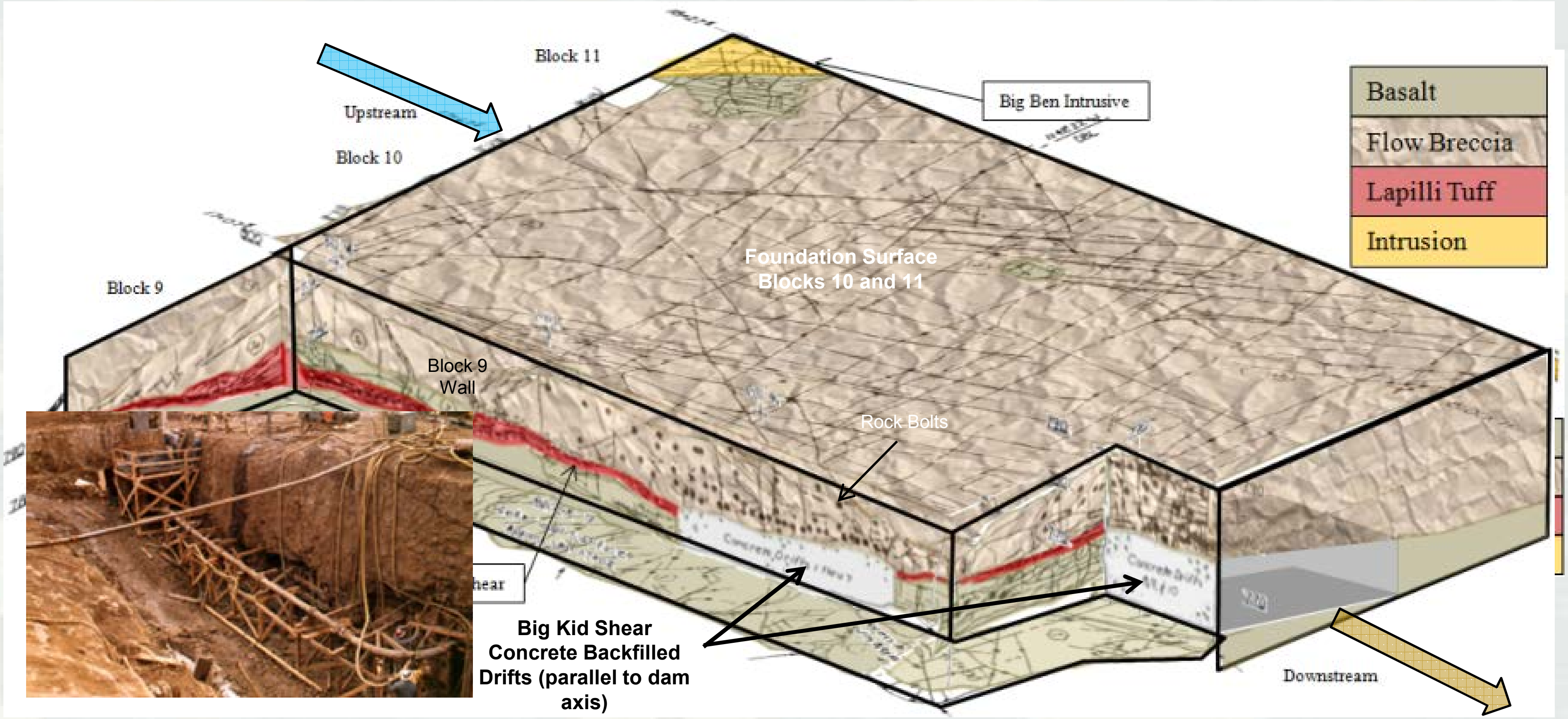
Foundation Rock Block



The geometry of sliding (i.e. "*kinematic removability*") of a foundation rock block/wedge depends on:

2. loading vectors (static, hydraulic, seismic)
3. shear strength of base & side plane must be overcome by the loading
4. configuration of the foundation excavation
5. downstream TOR topography

Rectified Mapping into 3-D Graphical Sections



Compiled all foundation mapping in 3-D graphical sections for visualization (not a 3-D CAD model).

Rectified Mapping into 3-D Graphical Sections

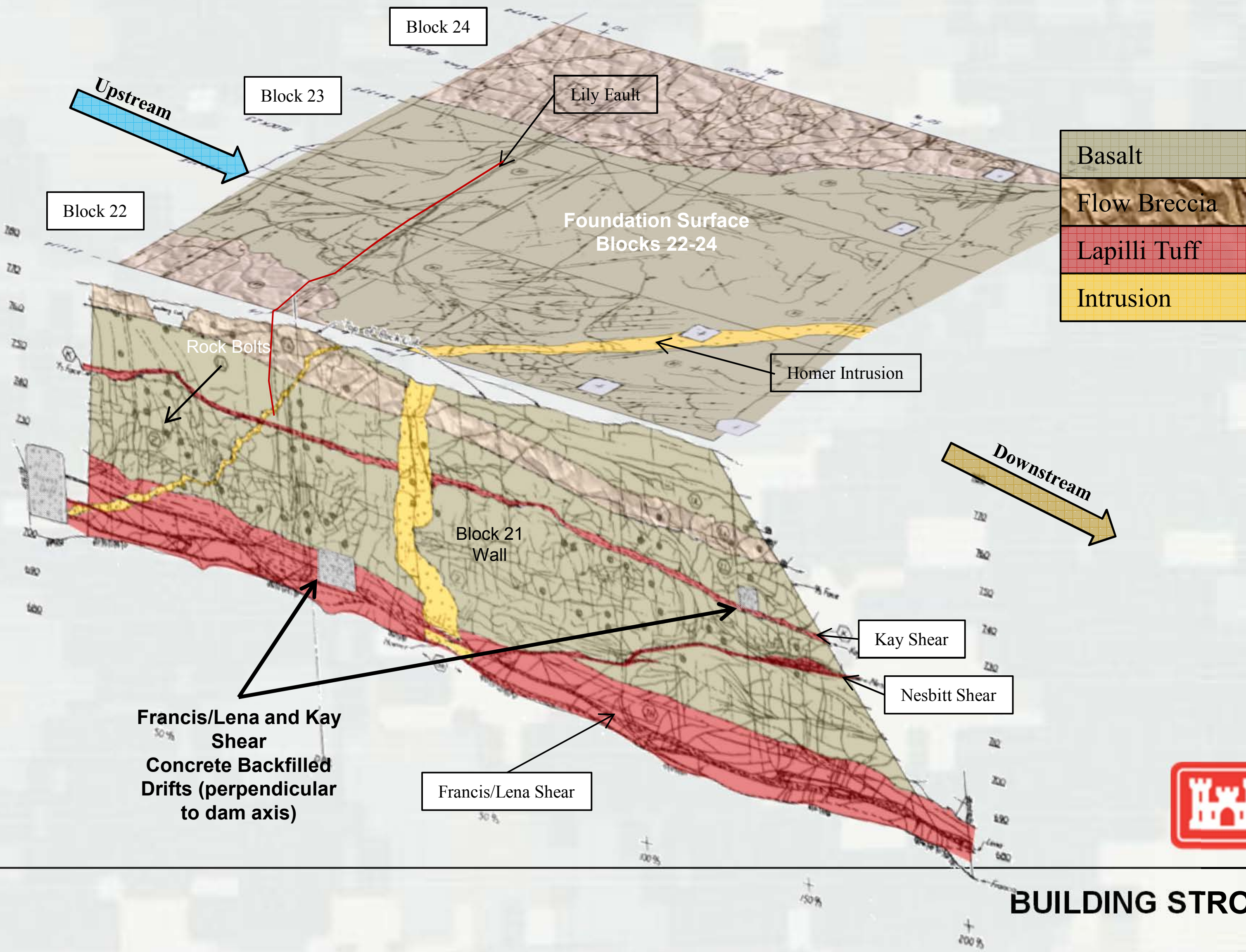
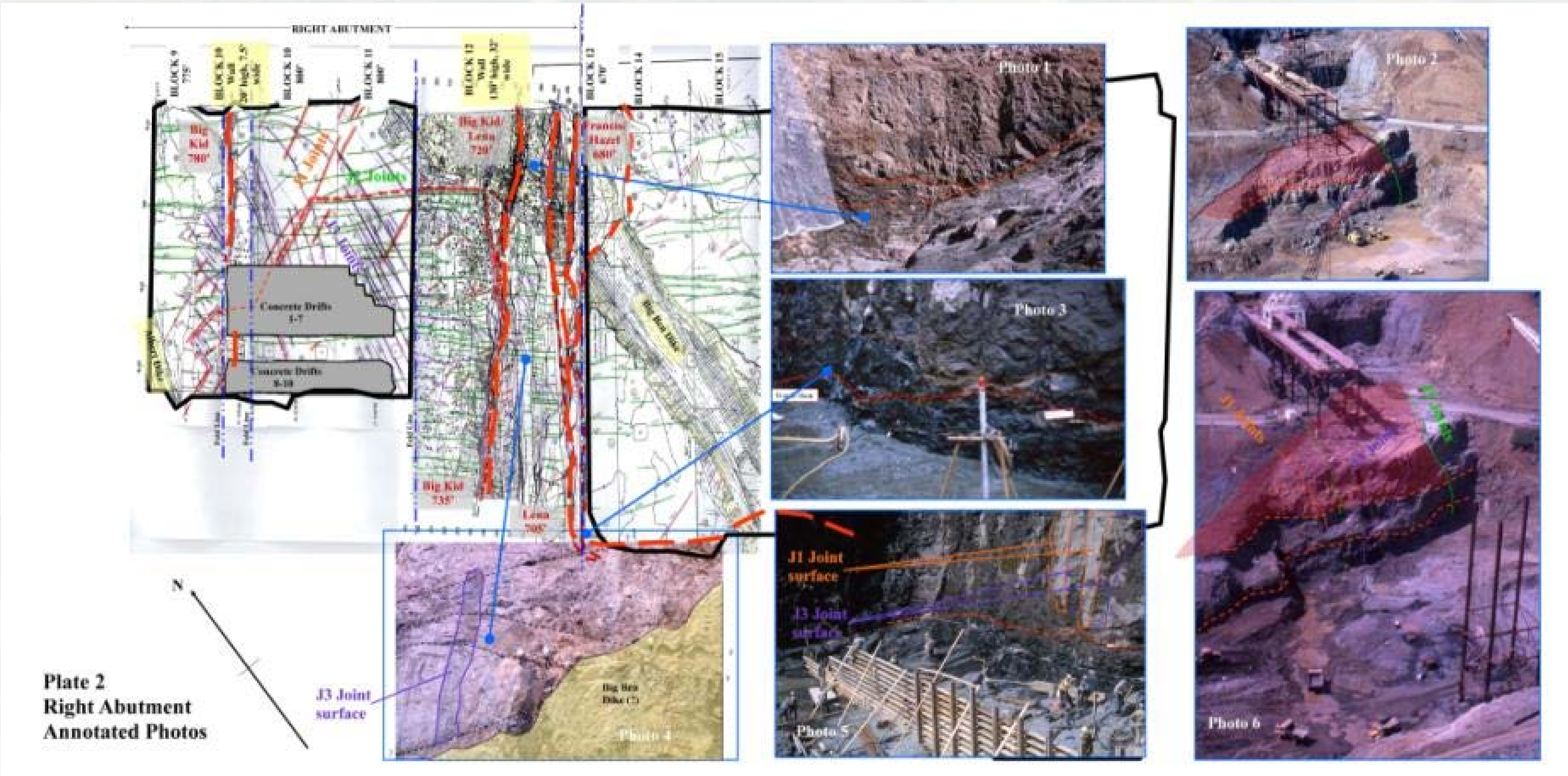
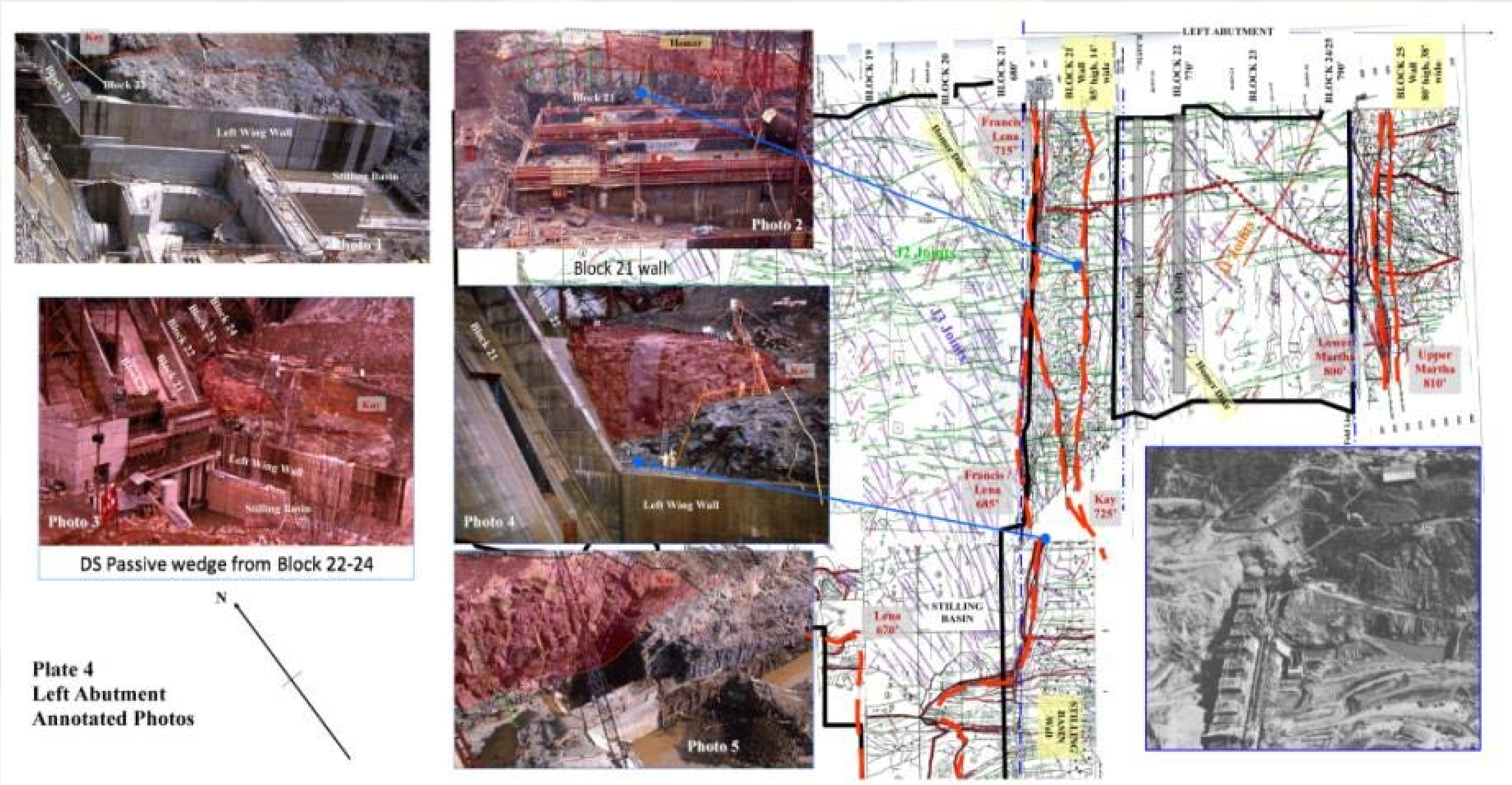


Photo Review - Right Abutment



Review of available construction photos
relative to mapped features

Photo Review - Left Abutment



Review of available construction photos relative to mapped features

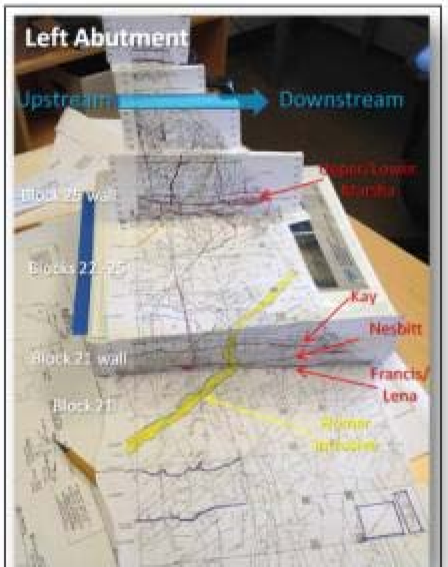


Photo of left abutment 3-D physical paper model

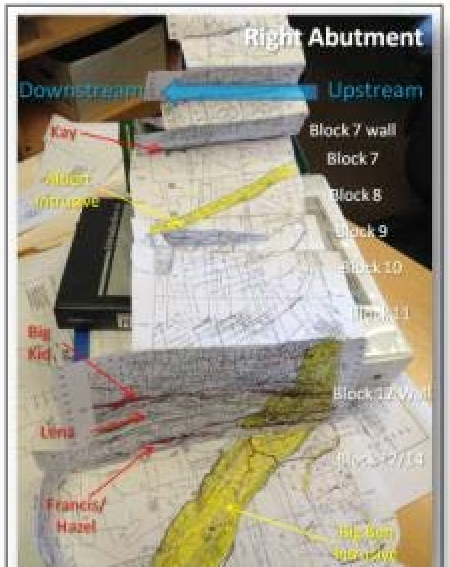
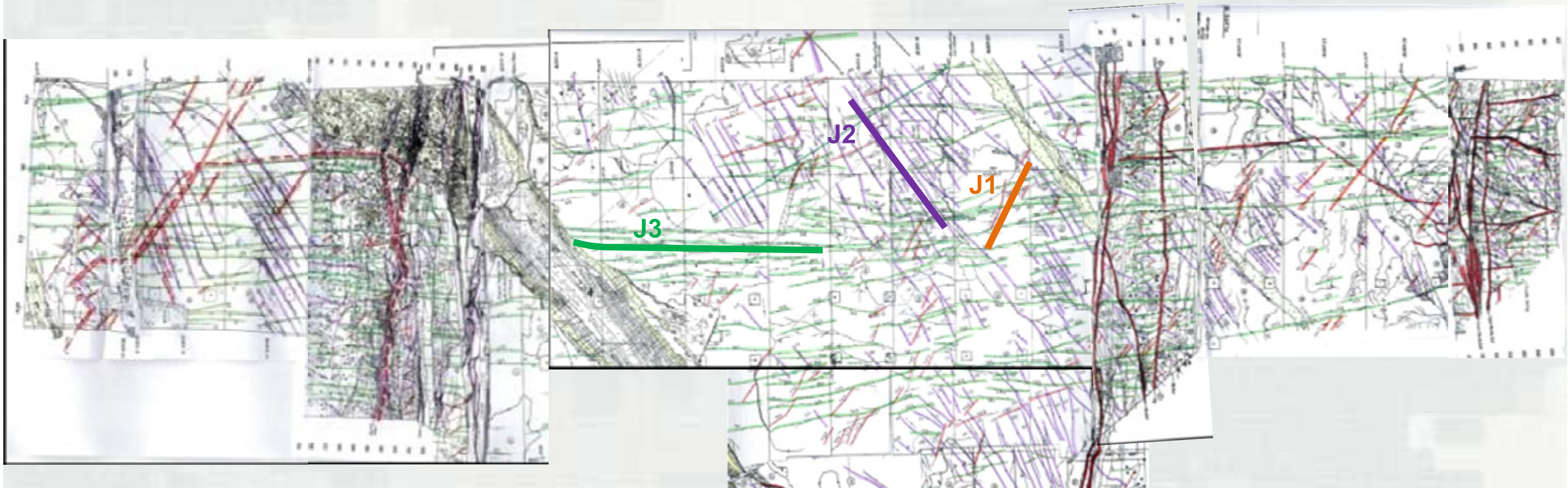
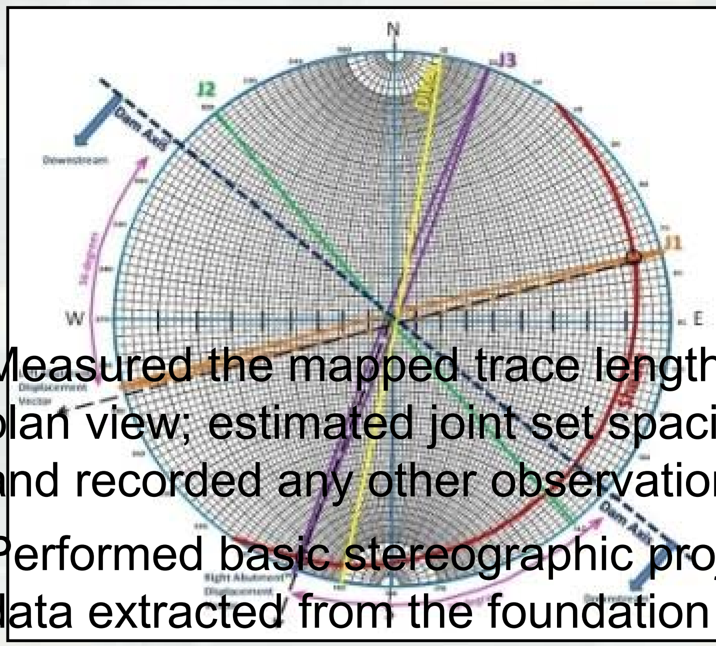
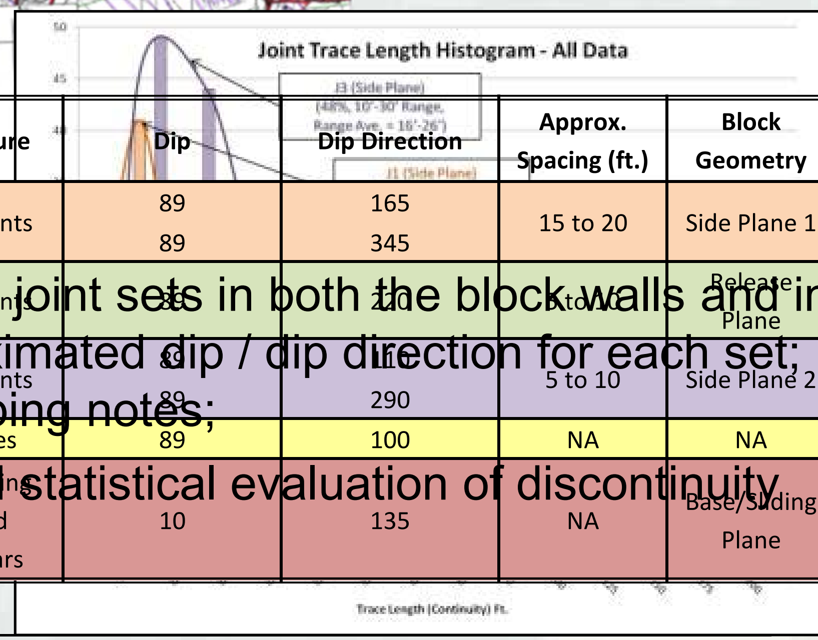


Photo of right abutment 3-D physical paper model

Constructed a 3-D physical paper model of the foundation mapping and delineated/measured three different discontinuity sets (in addition to shears and dikes).

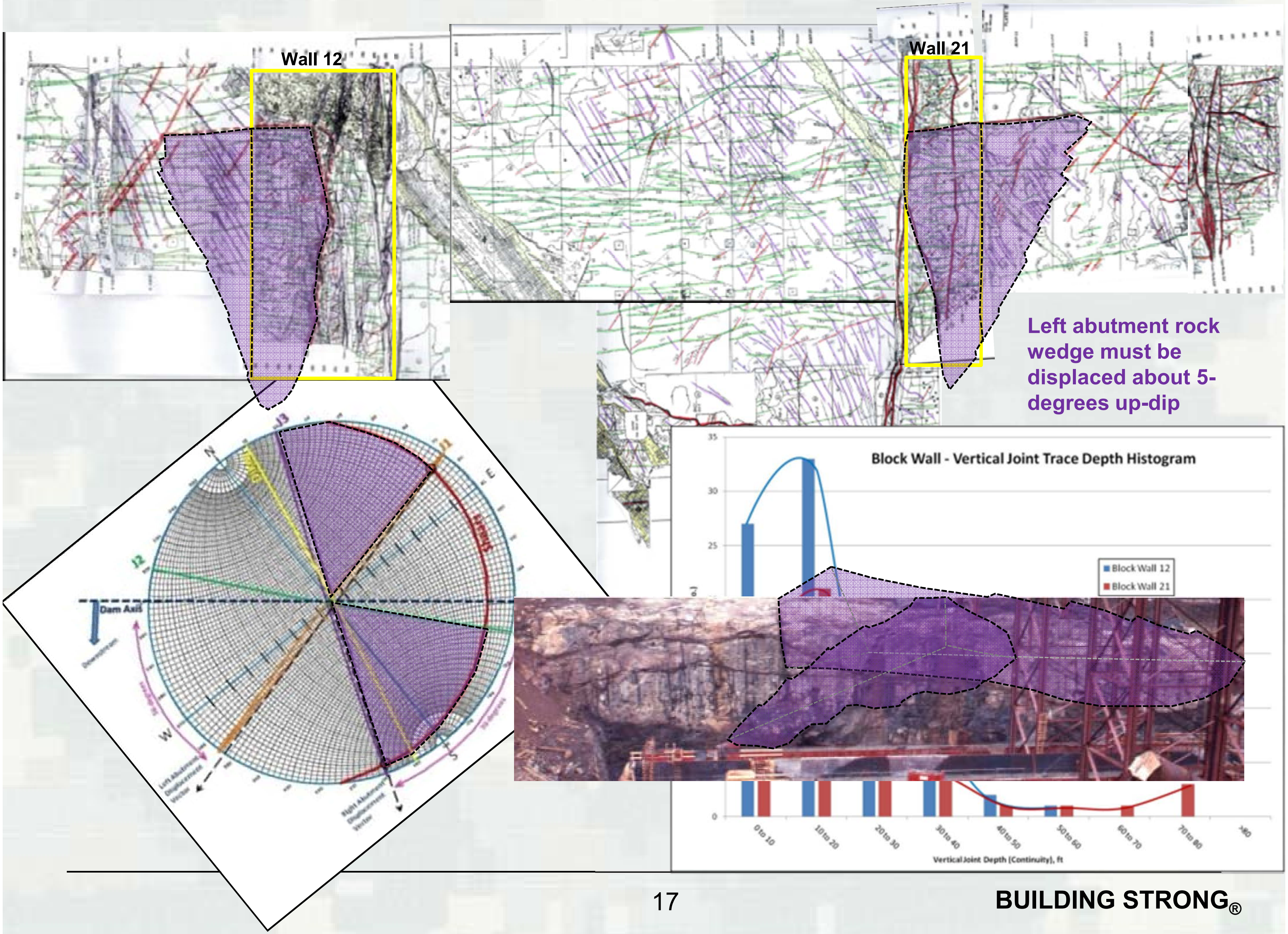






Feature	Dip	Dip Direction	Approx. Spacing (ft.)	Block Geometry
J1 Joints	89 89	165 345	15 to 20	Side Plane 1
J2 Joints	89	220	5 to 10	Release Plane
J3 Joints	89 89	110 290	5 to 10	Side Plane 2
Dikes	89	100	NA	NA
Bedding and Shears	10	135	NA	Base/Sliding Plane

- Measured the mapped trace lengths of all the joint sets in both the block walls and in plan view; estimated joint set spacing; approximated dip / dip direction for each set; and recorded any other observations or mapping notes;
- Performed basic stereographic projection and statistical evaluation of discontinuity data extracted from the foundation mapping



Left abutment rock wedge must be displaced about 5-degrees up-dip

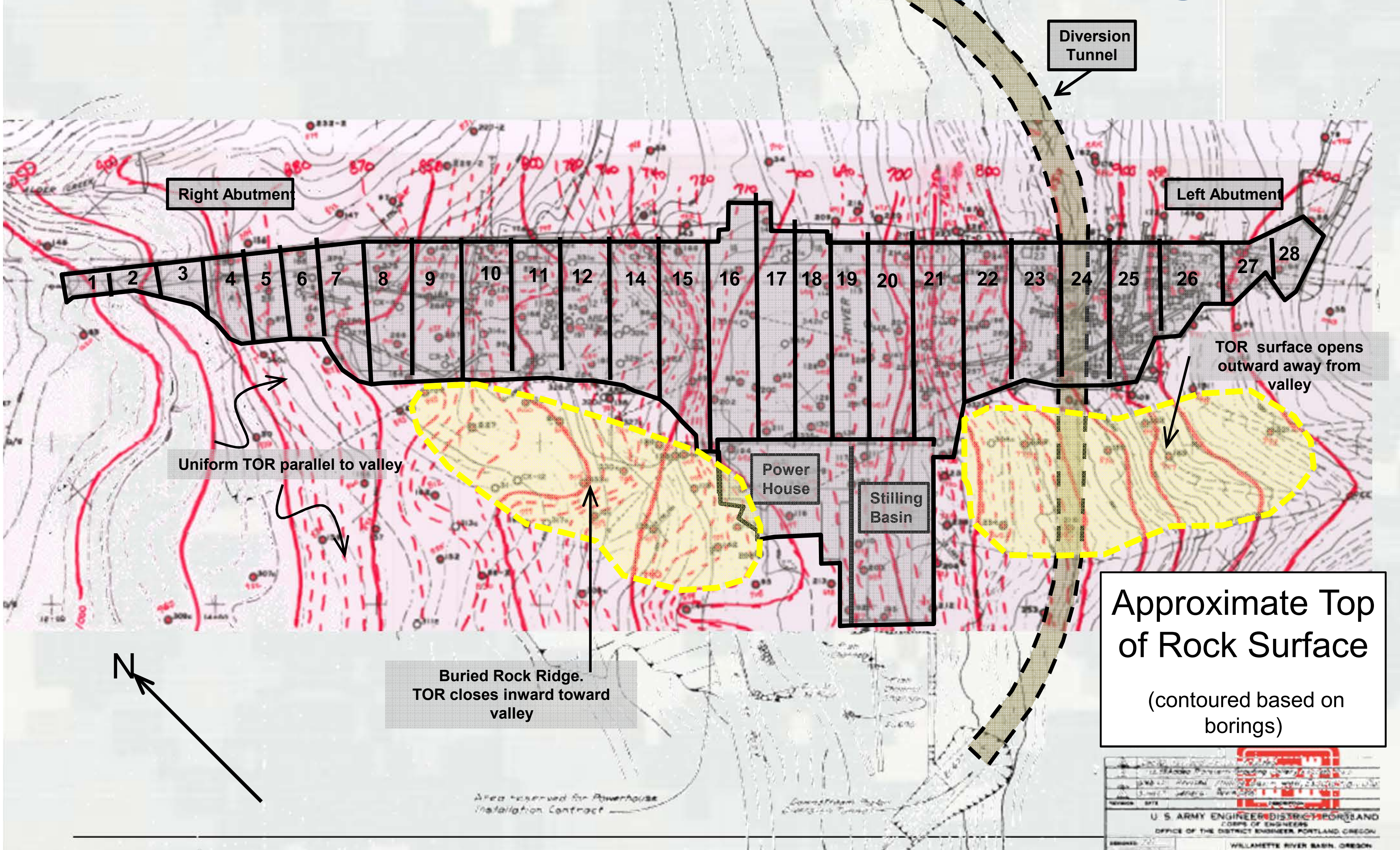
Joint Continuity & Side Plane

- Limited horizontal and vertical continuity and spatial distribution of the J1 and J3 discontinuities and therefore the side plane must be composed of multiple joints or joint sets.
- Orientation of side planes results in an outward-stepping, very rough, blocky side surface, and would require deformation through portions of intact rock and the high quality rock mass of the lava sequence.

View of Block Wall 12.

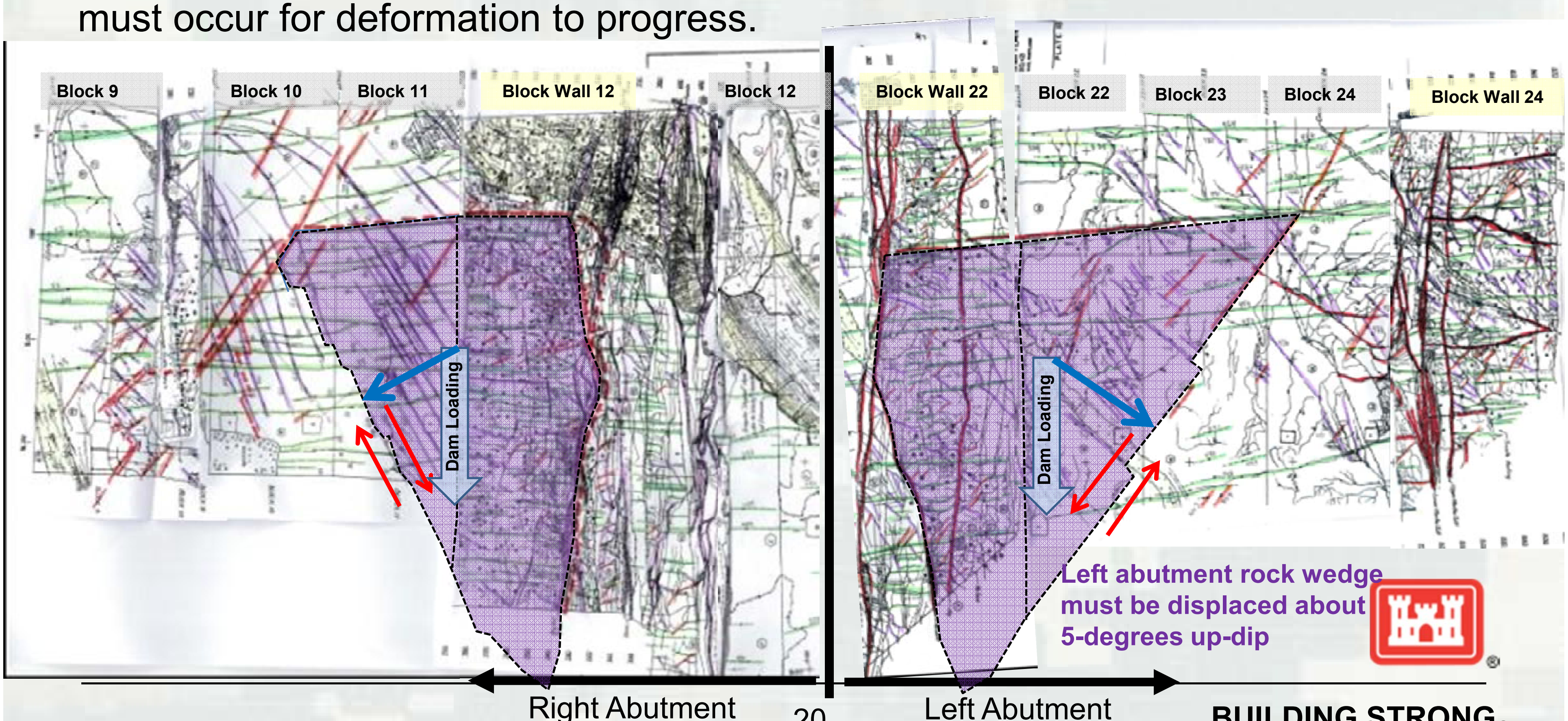
View upstream of Block Wall 21.

Top or Rock Topography

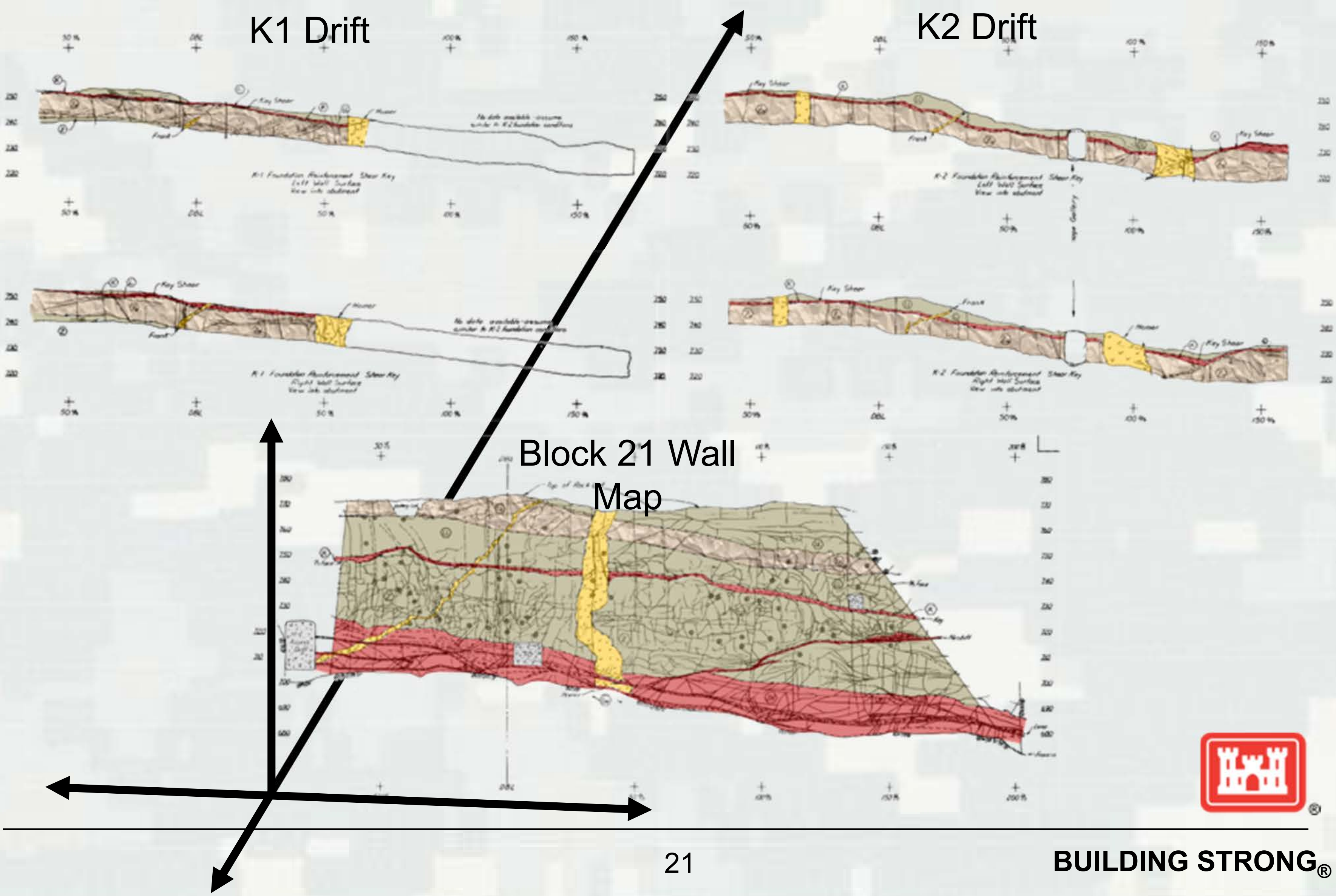


Direction of Sliding & Side Plane

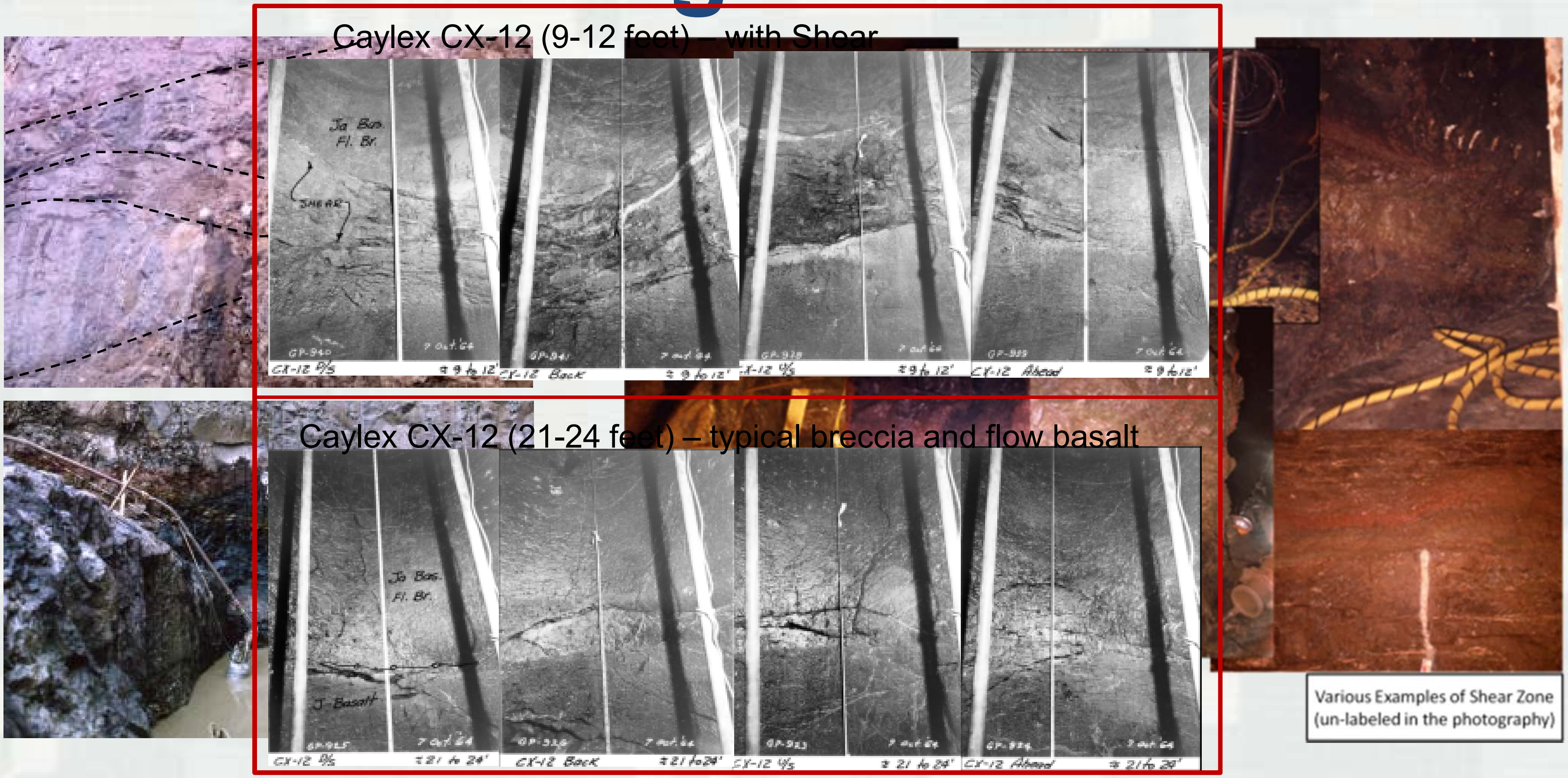
- A normal force of 34% and 55% of the driving force from dam would be imparted on the side surface for the right and left abutments, respectively.
- Rock wedge movement would be oriented into the valley and orthogonal (20 to 34-deg) to the direction of dam loading.
- Some amount of dilation and breaking through intact rock along both sliding surfaces must occur for deformation to progress.



Irregular Shear Surface



Shear Strength of Slide Plane



- The sliding shear surfaces tend to have **rock and gravel fragments embedded within the material, large-scale undulations on the order of 5-10 feet, and are composed of anastomosing shear surfaces** that can provide some additional 3-dimentional resistance to deformation potentially increasing the strength of the sliding surface at the scale of the rock wedge.

Low Uplift Pressures

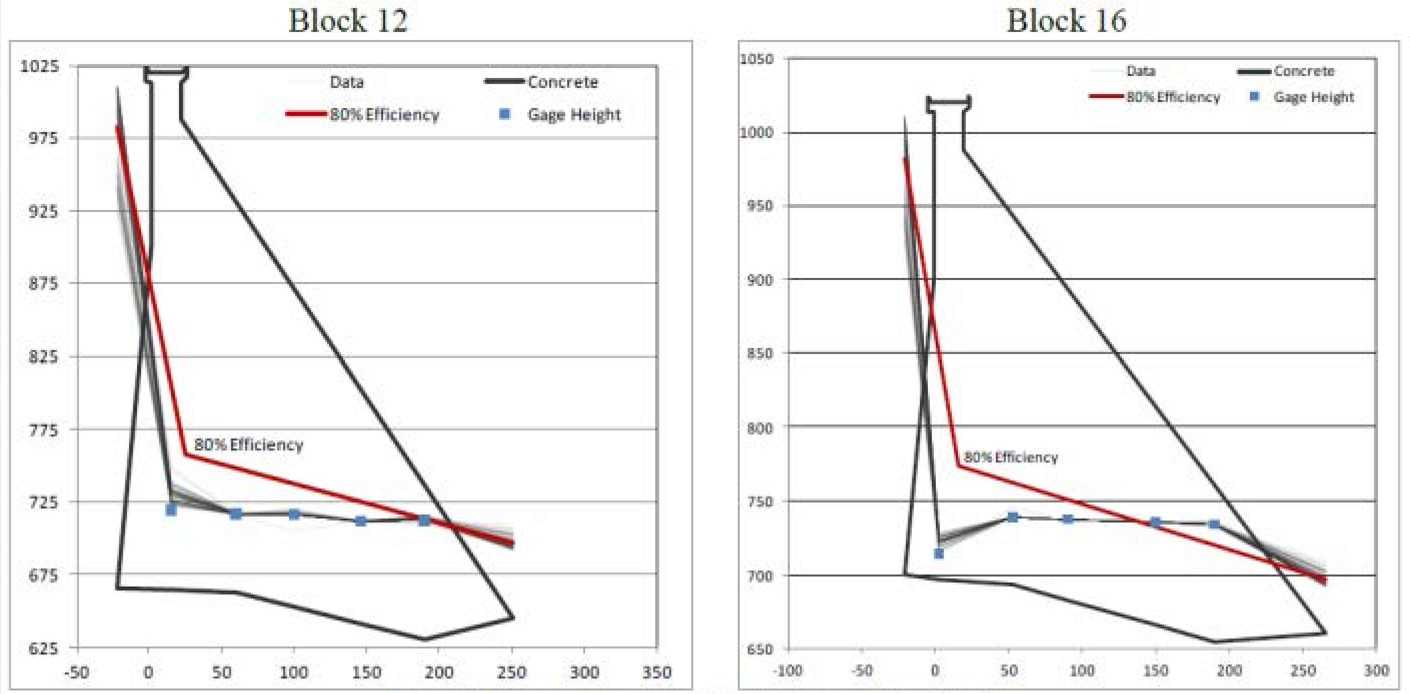
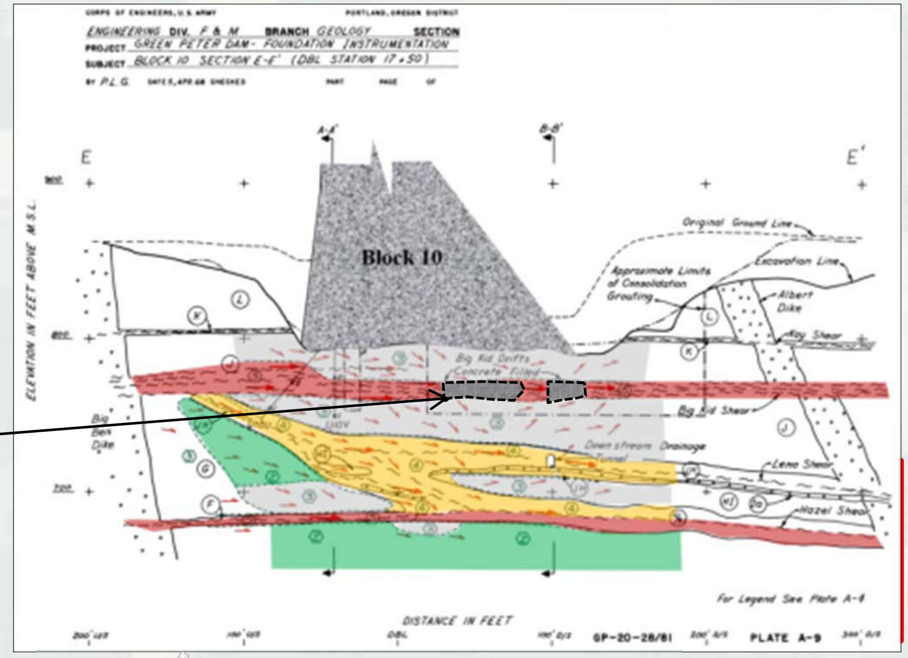


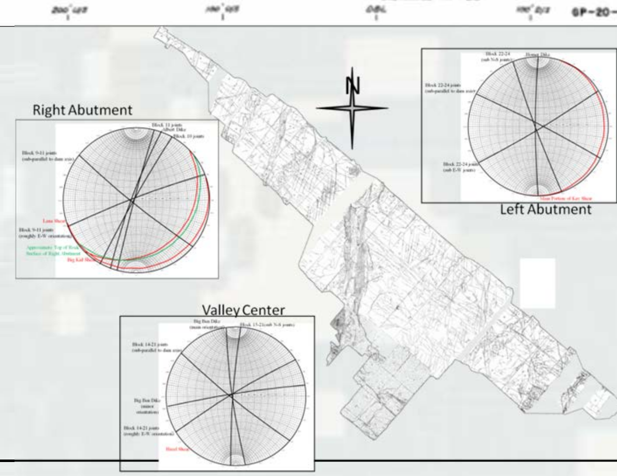
Figure 9.32 – Assumed Drain Efficiency vs. Uplift Data

- Generally low uplift pressure are acting on the foundation rock as the grout curtain and **drain efficiency is approximately 80%,** and the potentiometric surface is below the evaluated shears during normal dam operations.

Foundation Treatment

- **<u>Construction Modifications</u>:**
  - The designers were very <u>experienced</u> and concerned about potential foundation sliding.
  - Concrete backfilled drift reinforcement strengthened foundation. Approx. 15-30% of the sliding shears were removed making them <u>discontinuous</u> under the dam.
  - <u>High quality geologic mapping</u> - provides an equivalent level of confidence in evaluating the site geology and geomechanical conditions.

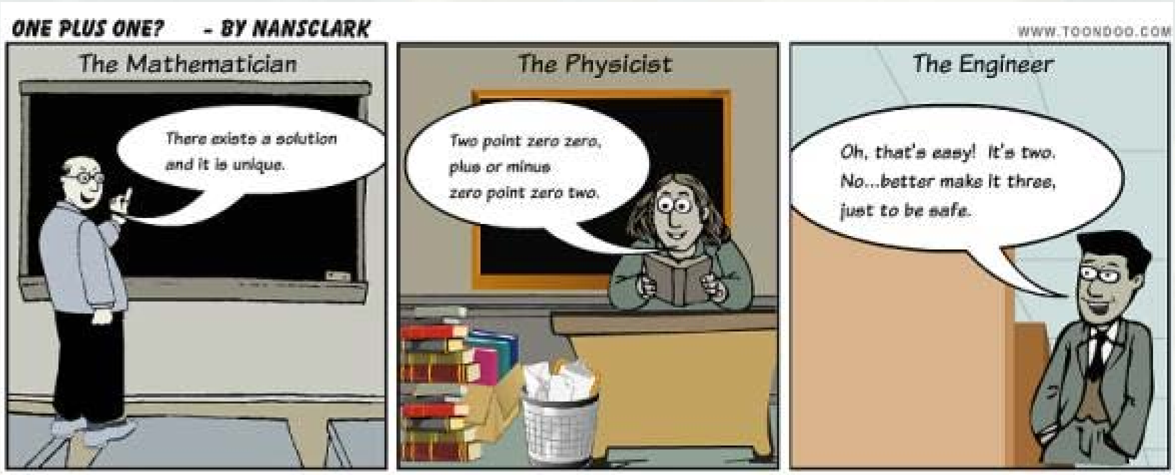




Dam–Rock Wedge 3-D Geometry

- GPD has thick dam sections and the concrete monoliths will develop some magnitude of inter-locking and 3-D strength across the foundation wedges.
- Foundation rock wedges are buttressed by the concrete dam leading to increased stability due to the kinematics required for displacement.

Thank You



Engineers

Geologists

Risk Analysis