TECHNICAL MEMORANDUM

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Geotechnical & Earthquake Engineering Consultants

TO: Mr. Dennis Gathard, River Resources

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SUBJECT: **PRELIMINARY ASSESSMENT OF SLOPE STABILITY, IRON GATE AND COPCO DAMS AND RESERVOIRS, UNDER RAPID DRAWDOWN**

PROJECT NO.: 06-201

DATE: November 27, 2006

PanGEO, Inc. (PanGEO) prepared this technical memorandum in support of preliminary design studies for the removal of the Iron Gate and Copco Dams and other associated smaller structures, on the Klamath River in northern California. The purpose of this study was to review existing documents related to the dams and the reservoir areas, and to assess the potential for slope instability under conditions of rapid drawdown of the reservoir levels. The study concentrates on the stability of the upstream slope of the rock and earth fill Iron Gate Dam, and the stability of the reservoir slopes in both the Iron Gate and Copco reservoirs.

As discussed in detail below, we analyzed the upstream slope of the Iron Gate Dam for conditions of rapid drawdown where the pool is lowered from about elevation 2330 to 2165. Because the upstream shell of the dam is constructed of compacted, pervious fill, we assumed that the hydrostatic pressures in the shell would dissipate quickly and reach equilibrium with a water surface located at the contact of the shell material and the overlying rip rap. Two analyses were performed: one using soil properties for the dam that were used in the 1960 stability evaluation conducted by the State of California and another analysis was performed using somewhat higher soil strengths in the upstream shell.

Both sets of analyses provided stability factors of safety of 1.2 or greater for the rapid drawdown condition. The computed factors of safety are within or greater than the range of 1.1 to 1.3 established by the US Army Corps of Engineers (EM-1110-2-1902) for the rapid drawdown analyses of the upstream shell of dams. The 5 foot thick rip rap blanket also provides an additional measure of safety in that it is well drained and provides confinement to the underlying shell as drainage occurs. Consequently, we believe that a drawdown rate of 3 feet per day is appropriate for maintaining structural integrity and will not result in significant risk of failure for the dam.

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Because of the lack of data for the upstream reservoir slopes, we are not able to provide definitive conclusions regarding the stability of these slopes under rapid drawdown conditions. However, based on the general geology of the area and assuming that rock is generally present at a shallow depth, the upstream reservoir slopes may be stable under a reservoir draw down rate of 3 feet per day. However, to provide a more definitive assessment, we will need to conduct a geological reconnaissance of the slopes and review any available well logs or geotechnical borings in the area of the upstream slopes. In the absence of any existing data, we may need to conduct a limited exploration program to confirm the underlying subsurface conditions.

Available Data

Rather limited geotechnical data was available for our review of the dams, with most data pertaining to the Iron Gate Dam. Such records include summary reports of borrow source investigations, design drawings, State of California stability analyses and construction inspection memorandums. These records do not appear to be complete, as the memoranda contain gaps of several weeks to several months and the memos reference other documents that were not available to us. Additionally, the lack of discussion of important events in the available records, such as the topping out of the dam, further suggest the incomplete nature of the records that were available for our review.

The only site specific subsurface data available for our review were summary borehole logs and a subsurface profile for the Iron Gate dam that is presented in design sheets AA-87051 and AA-87053. However, it appears that geotechnical and geologic data for the Iron Gate Dam is contained in the September, 1931 report by a Mr. Ira Williams (referred to in the Application for Approval of the Plans and Specifications for the Construction or Enlargement of a Dam, Application Number 91-3, which was dated March 23, 1961). We anticipate similar data should be available for Copco Dam.

Geological mapping in the project area by public agencies is also limited. The only readily available map that covers the project area is the Geologic Map of the Weed Quadrangle, California, 1:250,000 (Wagner, D.L. and Saucedo, G.J., 1987, California Division of Mines and Geology, Regional Geologic Map 4A). Some other GIS based publications may have useful data but are compiled at a scale of 1:500,000, which does not provide sufficient detail for our review.

Area Geology and Topography

The project area lies generally within the Cascade and Basin and Range physiographic provinces. According to the Klamath River Dam and Sediment Investigation (Draft 11/15/06), the two dams lie within the southern Cascades and Modoc Plateau (part of the Basin Range) provinces. The rocks in project area are dominated by interbedded Basalt flows and Andesitic tuffs. Based on available drawings (Sheet AA-87053, Section B-B’), these strata generally appear to be gently dipping to flat-lying. This observation tends to be confirmed by available photographs of the area. The construction photos also show that the basalt rock, while strong and resistant, is intensely fractured. The fine-grained tuff material tends to be soft and erodible.

The topography of the area consists of northwest to southeast running ridges or trends, with an abundance of rounded volcanic cinder cones. Upstream of Copco, the wide valley floors were occupied by large pluvial lakes during the Pleistocene. One such lake, glacial Lake Modoc, covered 1,096 sq. miles and was up to 75 miles long. The lake occupied the entire upper reach of the Klamath River, including the area encompassed by Klamath Lakes, Tule Lake, and other lake areas such as Butte Valley. Lake Modoc may have reached into the area surrounding Copco Reservoir, but likely not into the Iron Gate area. The Klamath River drained glacial Lake Modoc, and likely carried much greater flows during glacial times. It is also likely that much of the down-cutting in the present river valley occurred during these times of higher flow.

The available photos of the Iron Gate site and valley show a generally rounded and subdued topography. Slopes are generally moderate with some steep areas. Rounded debris fans have formed at the base of the various dry tributary ravines distributed along the valley. There is abundant basalt outcrop, but even the outcrop is usually broken and sloped in appearance. Most of the steeper slopes are underlain by talus or scree material. Investigations for Iron Gate Dam (memorandum of Inspection, March 23, 1960) found that the hill slopes in the reservoir area consisted of a thin veneer of talus over extremely weathered, rocky soil. The alluvial fans may be expected to be underlain by rock and soil material, similar to the valley slopes; however, the depth to bedrock is likely deeper.

There are several terraces along the river banks and at higher levels, which likely have multiple modes of origin. They may reflect erosion along the top of resistant basalt beds, they may be alluvial terraces, or (particularly in the area of the Copco Reservoir) they may be deposits left by glacial Lake Modoc. They may also have been the result of deposition in temporary lakes formed locally when the river was dammed by volcanic flows and/or landslides.

Some of these terraces (especially in the Iron Gate reservoir area) are clearly alluvial in origin. One terrace upstream of the Iron Gate dam site, which was used as a borrow source for the impervious core of the dam, was found to be underlain by a layer of plastic clay and silt, overlying alluvial sand, gravel and cobbles. This material classification varies from silty sand with gravel (SM) to sandy fat clay (CH). Based on the available data, the thickness of this fine alluvial layer appears to be between 4 and 9 feet.

River terraces in the Iron Gate reservoir tend to be narrow and discontinuous, while the Copco reservoir has wide, well developed terraces. Many of the terrace surfaces in the Copco reservoir are above the lake level and have been developed with houses. Since these terraces are larger, they are likely different in origin from those in the Iron Gate reservoir area. The Geologic Map of the Weed Quadrangle (Wagner and Saucedo, 1987) maps these terraces as lacustrine in origin. The Geologic Map shows that the Copco Dam was sited in a narrow valley through a lava flow, between two cinder cones. The Klamath River Dam and Sediment Investigation draft report suggests these lava flows dammed the river, resulting in the development of the terraces. Because the terraces are likely lacustrine in origin, they are probably fine grained and relatively deep. There presently appears to be no available studies regarding the nature or thickness of these deposits.

The nature and thickness of unconsolidated material on the upland terraces is likewise not currently available. One upland area above the left abutment of the Iron Gate Dam was apparently used as a borrow source for impervious core material.

Iron Gate Dam

Iron Gate Dam is a zoned, engineered earth and rock fill dam built in 1961. The dam was designed with 5 zones of fill, an upstream pervious shell (zone 1), an impervious core (zone 3), a down stream granular filter (zone 4), a downstream chimney and blanket drain (zone 5) and a down stream pervious shell (zone 2) (Specifications for the Construction of the Iron Gate Earth Fill Re-Regulating Dam, The California Power Company, 1960). In response to the quality of the fill materials found during construction, this design was eventually expanded to include a zone 1A, of “dirty talus”, adjacent to the upstream face of the core, and a second, finer filter zone (zone 4A) on the downstream side of the core.

Dam Construction and Materials

The shell material was designed to consist of locally borrowed, pervious talus rock material containing not more than 10% passing the #100 sieve, and not more than 20% passing the #4 sieve. The material was to be placed in three foot lifts, water was to be added, and the rock compacted with 4 passes of a 72-inch vibratory roller.

Zone 3 impervious core material was to consist of material borrowed locally from pit areas designated borrow areas A and 5 (Specifications for the Construction of the Iron Gate Earth Fill Re-Regulating Dam, The California Power Company, 1960). The material was to be placed in 8-inch lifts and compacted to 98% of the maximum dry density as determined by ASTM D-698-587 Method A. The maximum dry density reported from testing of samples from the borrow sites was 107 pcf.

The specifications also required the placement of rip-rap over both the upstream and downstream faces of the dam. The rip-rap blanket was to consist of not less than 5 feet of rock material “generally in excess of eight inches in diameter” (Specifications for the Construction of the Iron Gate Earth Fill Re-Regulating Dam, The California Power Company, 1960).

According to the design plans, the upstream face of the dam was to be sloped at a pitch of 3H:1V from the toe of the dam to elevation 2300. In addition, there was to be a 29-foot wide bench at elevation 2275. Above elevation 2300, the face of the dam was sloped at 2½H:1V to the crest elevation of 2338. The crest was to be 30 feet wide. The zone 3 impervious core was to be constructed in a wedge, with an upstream face sloped at ¾H:1V, to a core width of 20 feet at the top.

A “Preliminary Report on the Investigation of Locally Available Materials for Construction of the Impervious Core of the Iron Gate Reregulating Dam” (March 7, 1960) details the results of a sampling program in a borrow area located one mile north of the dam site, on the north side (right bank) of the Klamath River. The samples for the area had an average dry density of 110.1 pcf. This location is presumed to be borrow site A. Based on the description of soil horizons found in the borings, the material appears to consist of fine grained and/or weathered alluvial terrace flood deposits, overlying river alluvium.

The Memorandum of Inspection dated March 23, 1960, indicates that it was difficult to find suitable material for the pervious shell zones. The Report indicates that talus deposits downstream of the dam site and alluvial deposits upstream were the most likely sources. The report also described the impervious borrow soil as “red plastic clay”, suggesting that the floodplain deposit was weathered and to some degree residual.

By February, 1961, construction of the embankment had begun. The Memorandum of Construction Inspections, dated February 23, 24 & 25, 1961, indicated that the diversion cofferdam consisted of “clean rock” sealed with a clay blanket on both the upstream and downstream faces. By March 16, about 6 feet of upstream shell material had been placed. This material appears to consist of rock derived from the excavation for the powerhouse.

By April 20-21, the upstream shell had reached elevation 2195. The fill was rock consisting of “exceptionally clean and hard” rock. In this memorandum it is also mentioned that a “transition zone” of “dirty talus” (zone 1A) was being placed. At this level the shell material was coming from quarry “upstream of the dam on the left abutment”.

As of the Memorandum of May 9, the upstream shell had reached 2210. Material in use came from the power house excavation, and was reported to be “smaller and dirtier” than the material from the left abutment, but still in specification. This memorandum also first mentions impervious borrow 5, located “downstream of the trammel on the left side of the river”. Material properties are reported to be similar to the “main borrow pit”, which is also referred to as borrow area 1. This is presumably the same pit as borrow pit A.

After the May 9 memorandum there is no further discussion of the upstream shell in the reference material currently available. We assume that the placement of fill in the upstream shell reached maximum elevation shortly after May 9, and no further zone 1 fill was placed except as needed next to the core material as it was brought up.

In 1965 the crest of the dam was raised 5 feet. The upstream face of the dam was sloped at 2H:1V above elevation 2338 (Geotechnical Evaluation Iron Gate Dam Crest Materials Siskiyou County, California, May 14, 2002).

In summary, the upstream side of the dam appears to consist of 4 zones of material: the riprap shell, zone 1 (consisting of relatively clean rock talus from the powerhouse excavation and the left abutment), zone 1A (consisting of “dirty talus” from the powerhouse excavation and possibly other, unknown borrow sources), and zone 3 impervious core, derived from a borrow pit located on the left bank, one mile upstream of the dam site, a second borrow pit above the left abutment and possibly some smaller borrow areas.

Dam Stability Analysis

PanGEO conducted a slope stability analysis of the upstream slope of the Iron Gate dam conditions of a rapid drawdown of the reservoir. Based on the information available to us regarding dam geometry, we developed the generalized dam cross section as shown in Figures 1 and 2. To simulate the worst-case rapid drawdown condition, we modeled an instantaneous drawdown in which the riprap blanket would drain immediately, but all other materials would remain saturated (i.e. water surface at the contact of the rip rap and the underlying upstream shell material).

The stability of the upstream face of the dam was first evaluated utilizing the soil properties defined in the original stability analysis conducted by the State of California (September 16, 1960). While the materials in zone 1 and zone 1A are expected to differ somewhat, we used the California zone 1 soil properties for both zones in this analysis. This was based on the inference that the zone 1A materials, while dirtier than the zone 1 material, still met specification. Differing slightly from the 1960 analyses which did not include rip rap in the stability evaluation, our model included rip rap with an assumed friction angle of 42 degrees and a unit weight of 125 pcf.

A second stability analysis was then conducted utilizing revised (stronger) soil properties for the upstream shell (i.e. Zones 1 and 1A) as based on our understanding of the actual materials used to construct the shell. Figure 2 presents the soils parameters used for this analysis.

The computer program XSTABL (Interactive Software Designs, 2001) was utilized to perform the stability analysis. Search routines were used to identify the potential failure surface having the lowest static factor of safety using the Spencer method of analysis.

As seen in Figures 1 and 2, the lowest factor of safety was found to correspond to a circular failure surface near the top of the slope, where the slope face is steepest. Factors of safety of 1.20 and 1.38 were calculated for the upper slope utilizing the original soil properties and revised soil properties, respectively. A circular failure surface through the toe of the slope was also analyzed. As shown on Figures 1 and 2, the lower circular surface had computed factors of safety of 1.25 and 1.45 utilizing the original soil properties and revised soil properties, respectively.

The computed factors of safety from our stability analyses are within or exceed factors of safety of 1.1 to 1.3 established by the US Army Corps of Engineers (EM-1110-2-1902) as being acceptable for the rapid drawdown conditions of the upstream shell of dams. Consequently, we believe that the existing upstream dam face will be globally stable during reservoir drawdown.

Iron Gate Reservoir Slope Stability Assessment

As described above, the data regarding the nature and stability of the rock and unconsolidated materials within the reservoir area are sparse. The Geologic Map of the Weed Quadrangle does show at least one landslide deposit in the area of Copco, but no mapping of landslides in the valley has yet been done. A brief review of available air photos in the valley did not reveal obvious signs of instability. In general, we expect that the slopes directly underlain by basalt and talus have achieved an angle of repose. Slopes above the reservoir level should remain undisturbed unless affected by events on the slopes below the water level. Some minor slope movement, such as rock fall and perhaps slippage of talus cones that have their toes inundated, might be expected.

A series of profiles of the reservoir bottom was taken in 2003. These profiles show that the subsurface slopes of the reservoir are on the order of level to moderately sloped. The steepest underwater slopes are approximately 18^o. This is well below the expected angle of repose for the talus and for the alluvial materials.

The profiles, however, also show that up to about 15 feet of sediment has accumulated along the floor of the reservoir. Some of this material may be rockfall from adjacent subarial slopes, but in the absence of sample data, we assume it is mainly the soft to medium stiff silt, clay and sand that was found in the test borings in the bottom of the channel. We anticipate that these materials will slump during the reservoir drawdown.

While the gently sloping structure of the surrounding strata and the topography suggest that the reservoir area is stable, we recommend that geological mapping and landslide inventory studies should be undertaken. These studies would be to confirm the nature of the geologic materials and their condition. We recommend also that samples of the sediment that have accumulated on subaquious slopes, especially steeper areas, be taken to assess the stability of these deposits.

Copco Reservoir Slope Stability Assessment

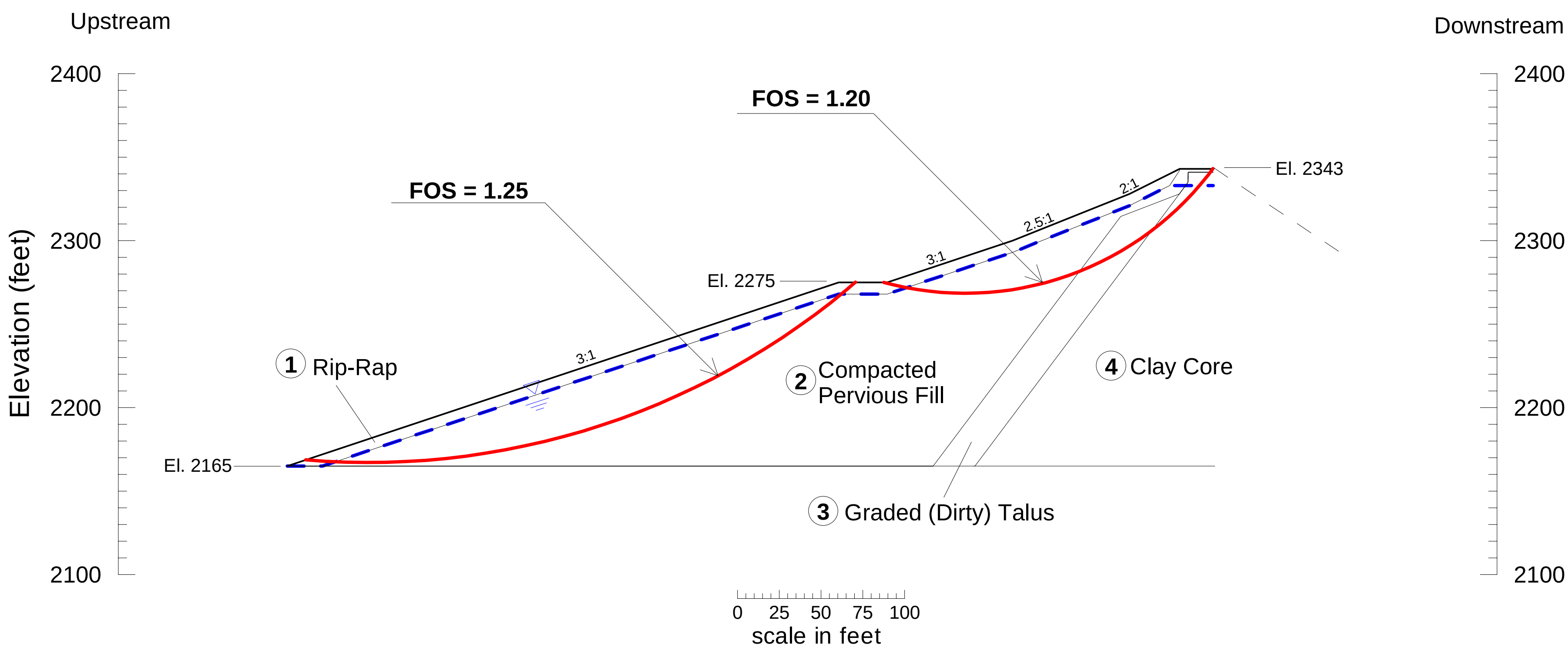
Since the geologic conditions at the Copco reservoir are similar to those at Iron Gate, we expect similar slope stability conditions to prevail. However, the bathymetric map of the reservoir area suggests that there are areas of very steep topography, especially approaching the dam site. As these appear to be cut slopes on the outside of former meander bends, we expected them to be underlain by stable rock. Talus deposits in theses areas may experience surficial slumping under rapid drawdown conditions. If any of these areas are underlain by tuffaceous beds, some instability could occur in the saturated tuffs. Block sliding of overlying basalt flow rocks along the contacts with tuffaceous material is a slight possibility, where the dip of the bedding is into the valley.

The bathymetric map and the available air photos of the reservoir area show several terrace surfaces. As described above, these terrace deposits were most likely laid down in a temporary lake when the river valley was dammed by volcanic flows. The nature and thickness of these lake beds are unknown. Shallow sliding of the terrace slopes throughout the reservoir area is possible. Since many of the subarial terraces have homes built upon them, such sliding could potential threaten structures. We recommend that a geotechnical exploration be undertaken to further assess the slope stability of these terrace areas.

If you have any questions, please do not hesitate to contact our office.

Encl: Figure 1 – Rapid Drawdown Stability Analysis – Soil Properties per State of California Analysis (1960)

Figure 2 – Rapid Drawdown Stability Analysis – Soil Properties used in Current Analysis

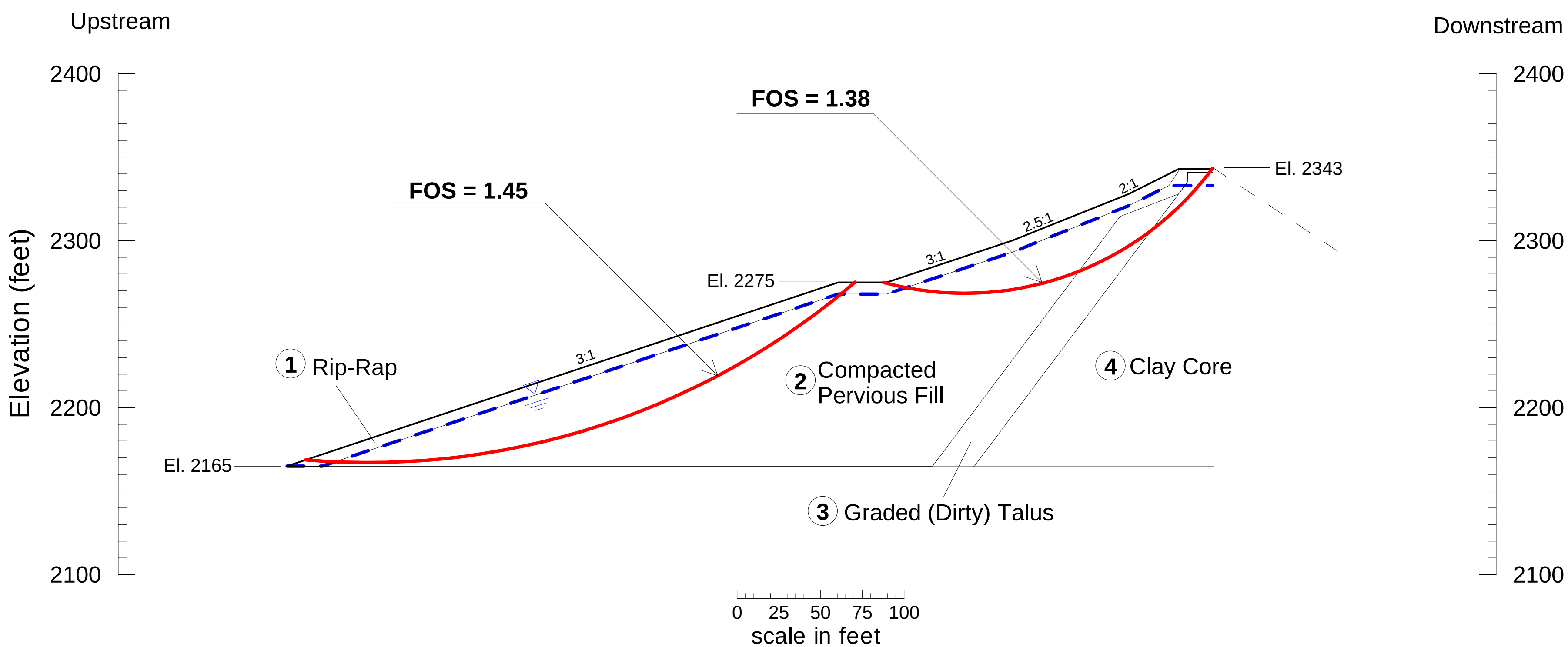


Material Properties				
	Unit Weight		ϕ	c
Material	Wet (pcf)	Saturated (pcf)	(deg)	(psf)
1	125	125	42	0
2	126	136	30	0
3	126	136	30	0
4	125	131	17	0

Note: Material 1 (Rip-Rap) was not included in the 1960 analysis.

Note:
Dam cross section based on 1) Earth Dam Stability Analysis sketch prepared by the State of California (1960), 2) Sketch of Iron Gate Dam "Topping Out" Scheme (8-31-61), and 3) Iron Gate Dam Cross Section (Figure 3) prepared by Cornforth Consultants, May 2002.

PanGEO INCORPORATED	**Iron Gate Dam Removal** **Preliminary Stability Analysis** **Klamath River, California**	**RAPID DRAWDOWN STABILITY ANALYSIS - SOIL PROPERTIES PER STATE OF CALIFORNIA ANALYSIS (1960)** Project No. **06-201** Figure No. **1**



Material Properties				
	Unit Weight		ϕ	c
Material	Wet (pcf)	Saturated (pcf)	(deg)	(psf)
1	125	125	42	0
2	126	136	34	0
3	126	136	34	0
4	125	131	17	0

Note:
Dam cross section based on 1) Earth Dam Stability Analysis sketch prepared by the State of California (1960), 2) Sketch of Iron Gate Dam "Topping Out" Scheme (8-31-61), and 3) Iron Gate Dam Cross Section (Figure 3) prepared by Cornforth Consultants, May 2002.

PanGEO INCORPORATED	Iron Gate Dam Removal Preliminary Stability Analysis Klamath River, California	RAPID DRAWDOWN STABILITY ANALYSIS - SOIL PROPERTIES USED IN CURRENT ANALYSIS	
		Project No. 06-201	Figure No. 2