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Generation

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May 25, 2021

Via Electronic Submittal (E-File)

Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street, N.E. Room 1A
Washington, DC 20426

Re: UPPER NORTH FORK FEATHER RIVER PROJECT, FERC NO. 2105-089
RESPONSE TO ADDITIONAL INFORMATION REQUEST

Dear Secretary Bose:

Pacific Gas and Electric Company (Licensee or PG&E) submits the enclosed response to the Federal Energy Regulatory Commission's (FERC or Commission) Additional Information Request (AIR) regarding the Licensee's Application for New License for PG&E's Upper North Fork Feather River Project (FERC No. 2105), originally submitted on October 23, 2002. The existing license expired on October 31, 2004, and the Project has been operating under annual licenses.

Response to item 10 in Schedule A of the Commission's January 29, 2021 AIR is included. PG&E performed the requested analysis on the Belden Forebay Dam and determined that the proposed change in the normal operation range for Belden Forebay from elevation 2,965.2 to 2,915.2 (USGS datum) will not adversely affect the safety of Belden Forebay Dam.

The other 17 items were addressed in PG&E's April 26, 2021 filing. This filing concludes PG&E's response to the Commission's January 29, 2021 AIR.

Please call me at (925) 357-7120 if you have any questions.

Sincerely,

Tony Gigliotti
Mail Code N11D
P.O. Box 770000
San Francisco, CA 94177

FERC Service List

List of Attachments
Attachment 1—Item 10: Dam Safety – Updated Stability Analysis of Belden Dam

Upper North Fork Feather River
FERC Project No. 2105-089

FERC SERVICE LIST

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UPPER NORTH FORK FEATHER RIVER PROJECT

FERC NO. 2105

ATTACHMENT 1
ITEM 10: Updated Stability Analysis of Belden Dam

Pacific Gas and Electric Company

Chief Dam Safety Engineer	Based on my review of the attached analysis, I confirm that adjusting the lower bound of the normal operation range for Belden Forebay from elevation 2,965.2 to 2,915.2 (USGS datum) will not adversely affect the safety of Belden Forebay Dam. **Approved by:** David L. Ritzman, P.E., G. E (Printed Name) — Signature — 5/24/2021 (Date)

Date: 05/03/2021

Subject: **Belden Forebay Rapid Drawdown Analysis**

1 Introduction

The Pacific Gas and Electric (PG&E) Geosciences Department has prepared the following memorandum at the request of PG&E Dam Safety to provide an evaluation of the static stability of Belden Forebay Dam (State Dam No. 97-119) under the rapid drawdown load case. This assessment supplements the existing stability analysis (PG&E, 1990) for the dam, which did not consider rapid drawdown. This memorandum also comments on the stability of the reservoir rim during rapid drawdown of the reservoir. These analyses were requested by the Federal Energy Regulatory Commission (FERC) in an Additional Information Request for the Upper North Fork Feather River FERC project 2105. The letter, dated 29 January 2021, states:

> *"The normal operating range for the Belden Forebay is from elevation 2,955 feet to elevation 2,975 feet (PG&E Datum). There is no rule curve or reservoir level restriction for the Belden Forebay. The minimum water surface elevation of 2,905 feet (PG&E Datum) is well below the current normal operating range of the Belden Forebay. Within 120 days of the date of this AIR, please provide an updated stability analysis for the revised drawdown condition (dam and reservoir rim). PG&E's Chief Dam Safety Engineer should provide a statement confirming that the proposed change will not affect dam safety. The stability analysis should follow FERC Engineering Guidelines and requirements."*

2 Background

Belden Forebay Dam (also referred to as Caribou Afterbay Dam) is a compacted zoned rockfill dam owned and operated by PG&E. The dam is located on the North Fork of the Feather River in Plumas County and is part of PG&E's Feather River hydroelectric system. The site location and adjacent project components are shown in Figure 1. Belden Forebay was completed in 1958 and for a period of 11 years immediately following completion of the project the reservoir served only as an afterbay for Caribou

Powerhouses 1 and 2. Belden Powerhouse was completed in 1969 and the dam has since served both as an afterbay for the Caribou Powerhouses and a forebay for Belden Powerhouse. The dam also serves as the forebay for Oak Flat powerhouse, a 1.3 MW mini-hydro plant constructed at the toe of the dam in 1985. Belden Forebay is classified as a "High Hazard Potential" structure under the FERC guidelines (PG&E, 2015).

PG&E previously performed a static stability and seismic deformation assessment for Belden Forebay Dam. This assessment evaluated the stability of the dam under the maximum reservoir level only and did not consider the stability of the dam during a rapid drawdown scenario (PG&E, 1990). The normal operating range for Belden Forebay is from elevation 2965.2 feet to the normal maximum water surface elevation of 2985.7 feet. The minimum water surface elevation of 2915.2 feet is approximately 50 feet below the lower bound of the normal operating range (FERC, 2021). Elevations in this memorandum are in USGS datum[1] unless stated otherwise.

2.1 Summary of Previous Analysis

PG&E performed a static stability and seismic deformation analysis of Belden Forebay Dam in 1990 (PG&E, 1990). This analysis evaluated both upstream and downstream failure surfaces for the static and pseudo-static load cases. No analysis evaluating the stability of the upstream face during the rapid drawdown load case was performed. The normal maximum reservoir level and the dam geometry associated with the maximum section were assumed for all failure surfaces and load cases. The computer program UTEXAS2 using the Spencer method of analysis was used. The results for the upstream failure surfaces are most relevant for comparison to the updated rapid drawdown assessment presented herein and are shown in Figure 2.

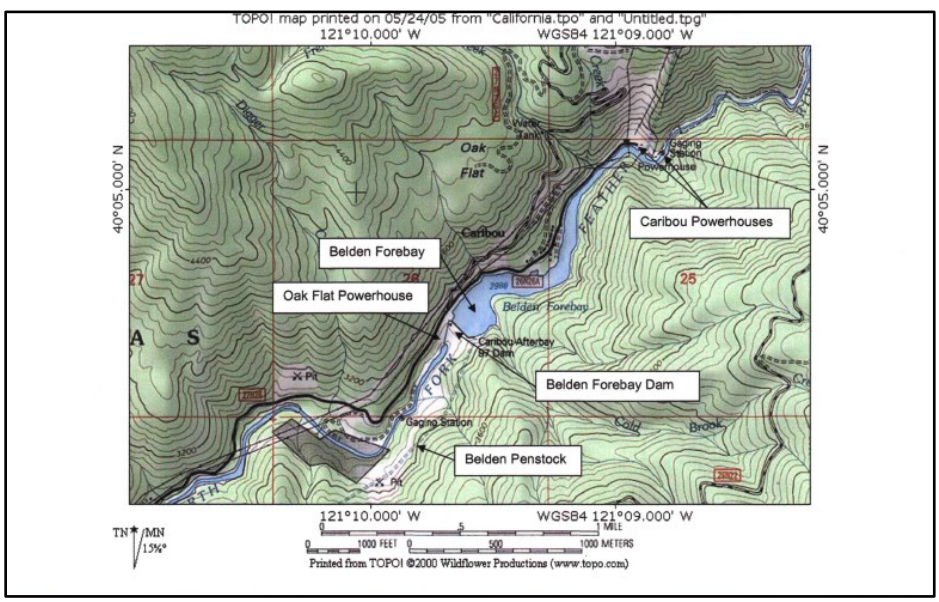


Figure 1 Site location plan (PG&E, 2015)

[1] The conversion from USGS to PG&E datum is as follows: USGS datum = PG&E datum + 10.2 feet

RESULTS FOR UPSTREAM SLOPE

CIRCLE	LOADING CONDITION	FACTOR OF SAFETY	CRITICAL CIRCLE		
			Xc (ft)	Yc (ft)	RADIUS (ft)
A	LONG TERM STATIC (WS EL 2985.7)	2.6	339.5	3490	638.8
B	PSEUDOSTATIC (a=0.2g)	1.2	339.0	3491	639.8

NOTES:

1) SEE FIGURE 2 FOR SECTION LOCATION
2) YIELD ACCELERATION VALUES ARE SUMMARIZED ON TABLE 3.
3) ALL ELEVATIONS SHOWN ARE USGS DATUM.

MATERIAL PROPERTIES

ZONE	DESCRIPTION	DENSITY (pcf)	Ø (deg)	C (psf)
I	COMPACTED ROCKFILL	115	45	0
II	FILTER	125	35	0
III	SATURATED EARTH CORE	132	32	900
IV	MOIST EARTH CORE	130	32	900
V	RANDOM ROCKFILL	125	30	0
VI	FOUNDATION	140	40	10000

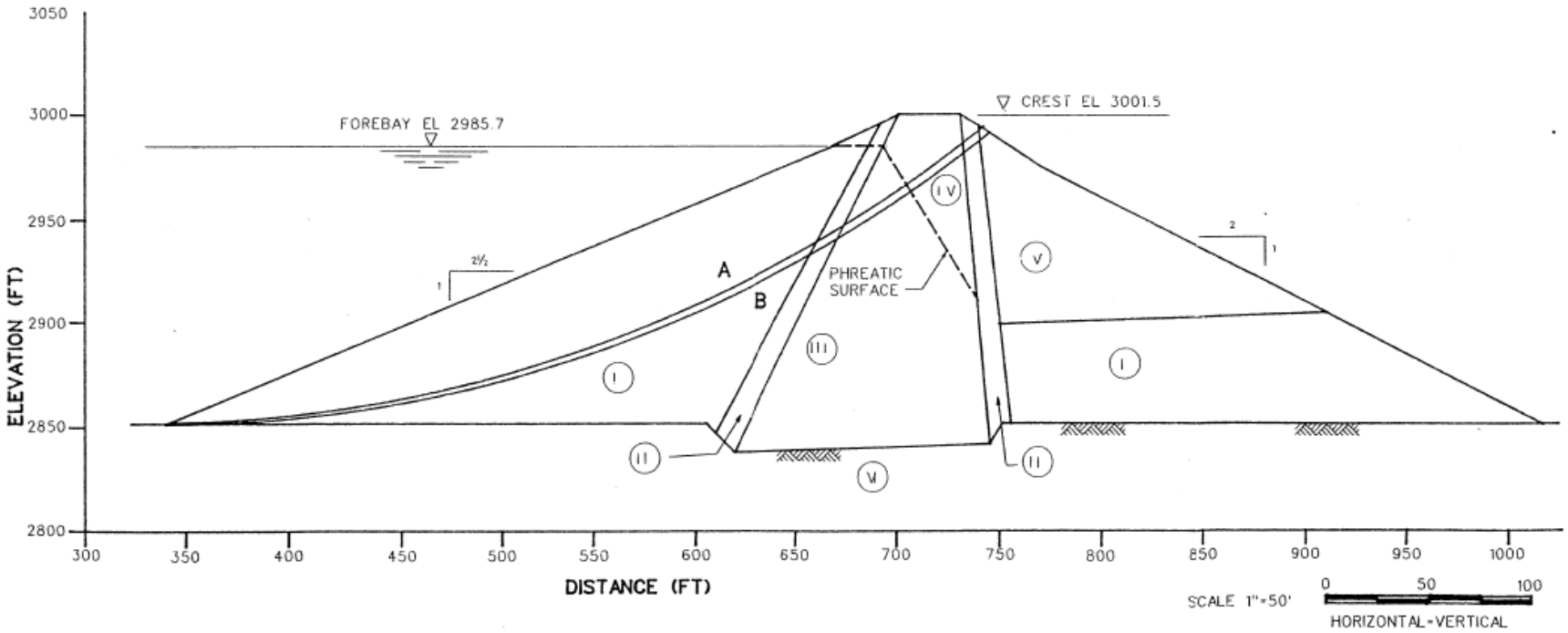


Figure 2 1990 stability results for the upstream face of Belden Forebay Dam (PG&E,1990)

3 Stability Analysis Inputs

The following sections summarize the inputs used in the updated slope stability evaluation for the rapid drawdown load case.

3.1 Dam Geometry

Belden Forebay Dam is a zoned rockfill dam with a central low permeability core. The dam is 152 feet high, 563 feet long, and has a crest elevation of 3001.2 feet at the maximum section. A 2011 survey indicates that the crest has settled to an elevation of 3000.8 feet at the maximum section. The as-built geometry at the maximum section has been modeled in this assessment. The upstream and downstream slopes are 2.5H:1V and 2H:1V, respectively. The upstream shell is composed of rockfill, faced with large basalt boulders. The downstream zone is rockfill containing smaller basalt rocks in a matrix of fines above approximately elevation 2900, where a transition to larger rock on the surface occurs. The maximum section is shown in Figure 3 and indicates that “random fill” and “special zones” were included in the upper half of the downstream shell which may be more fine-grained than rockfill (PG&E, 2015). These zones have been included in the model for this assessment.

The borrow material used to construct the impervious core was classified as clayey sand (SC) to lean clay (CL) in the Woodward Clyde Consultants laboratory test report (WCC, 1956). The compacted core is protected on either side with 8-foot-thick filter-transition zones. The upstream filter section slopes at 1/2H:1V while the downstream filter zone has a steeper slope of 1/10H:1V. Approximately 10-feet-thick zones of relatively fine-grained rockfill were placed between each filter zone and the adjacent rockfill. The 1990 analysis neglected these finer rockfill filter transition zones and they have been similarly neglected in this stability model.

The rockfill zones are founded primarily on weathered metasiltstone, with one area of the upstream shell at the left abutment founded on firm talus, while the impervious core is founded on competent metasandstone. A grout curtain consisting of 256 grout holes was installed beneath the core zone.

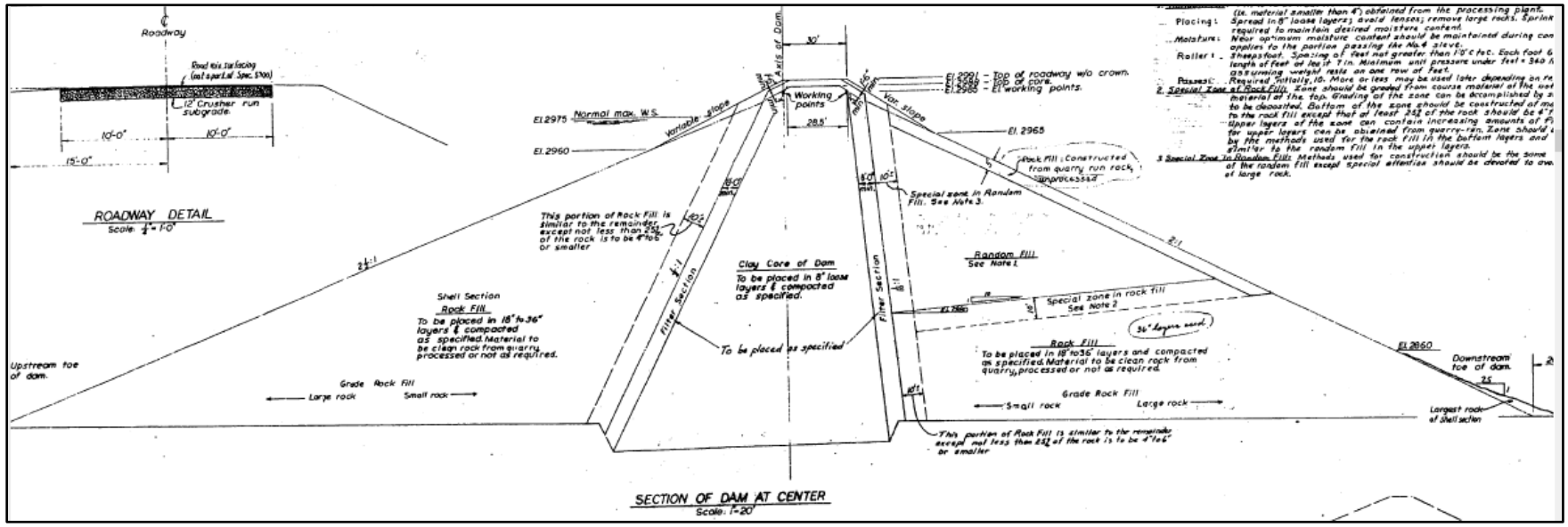


Figure 3 **Maximum section at Belden Forebay Dam (note elevations are in PG&E datum)**

3.2 Geotechnical Parameters

The material properties used in the slope stability evaluation are summarized in Table 1. The unit weight and effective stress (drained) parameters match those developed for the PG&E (1990) analysis. Laboratory strength data is not available for the coarse-grained rockfill and filter materials. The PG&E (1990) analysis estimated the friction angle of the compacted rockfill based on the Leps (1970) database, which relates effective normal stress to friction angle. An average value of 45° was selected as representative for the anticipated stress range of the critical failure surfaces. The properties of the random rockfill and filter materials were chosen based on available data in similar materials published in the United States Bureau of Reclamation (USBR) Design Standard No. 13, Embankment Dams (USBR, 1987).

The effective shear strength parameters for the earth core were developed for the 1990 analysis based on site-specific laboratory test results. A suite of 3 consolidated drained triaxial shear tests were carried out at confining pressures of 0.5 tsf, 1 tsf, and 2 tsf. These tests were run on reconstituted samples of the borrow material used to construct the earth core (WCC, 1956). The effective shear strength parameters suggested by the laboratory test data ranged from friction angle of 30° to 38° and cohesion of 900 psf to 1000 psf. An effective friction angle of 32° and an effective cohesion of 900 psf were selected for slope stability analyses (PG&E, 2015). PG&E (1990) explains that these were selected as "average strength parameters" from the construction-era lab data.

Analysis of the rapid drawdown load case requires undrained strength parameters be developed for materials with coefficients of permeability less than 10^{-4} cm/s. Soils with coefficients of permeability of 10^{-4} cm/s or more can be assumed to be free draining during drawdown (Duncan, Wright, and Brandon, 2014). With a laboratory measured permeability of $3x10^{-7}$ cm/s, the earth core material should be modeled as undrained during drawdown. The undrained strength parameters are best developed based on consolidated-undrained triaxial shear tests with isotropic consolidation (Duncan, Wright, and Brandon, 2014). This data, however, is not available for the earth core at Belden Forebay Dam.

Duncan, Wright, and Brandon (2014) presents a correlation of water content and dry density to the intercept and slope of the total stress envelope, c_r and ϕ_r. The water content and dry density data obtained from compaction testing during construction of the dam was used to correlate to total strength parameters. The estimated cohesion intercept ranges from approximately 2,000 psf to 4,000 psf and the estimated friction angle ranges from approximately 5° to 15°. Due to the lack of site-specific laboratory test data, a conservative c_r value of 1,000 psf and an average ϕ_r value of 10° were selected.

Table 1 Summary of Material Properties used in Slope Stability Evaluation

Material	Total Unit Weight, γ (pcf)	Effective Cohesion, c' (psf)	Effective Friction Angle, ϕ' (°)	Cohesion, c_r (psf)	Friction Angle, ϕ_r (°)
Compacted Rockfill	115	0	45	-	-
Filter	125	0	35	-	-
Sat. Earth Core	132	900	32	1,000	10
Moist Earth Core	130	900	32	1,000	10
Random Rockfill	125	0	30	-	-
Foundation	140	10,000	40	-	-

3.3 Phreatic Surface

Piezometer data to define the phreatic surface is not available at Belden Forebay Dam. The steady-state phreatic surface prior to drawdown has been estimated by assuming a horizontal line from the normal maximum reservoir elevation to the upstream face of the impervious zone, then using the methodology in Casagrande (1940), as recommended in FERC (2006) within the core, then linearly extending to the downstream corner of the downstream filter zone. The phreatic surface associated with the drawdown condition was developed on the same basis for the minimum reservoir elevation of 2915.2 feet (see Figure 6).

4 Rapid Drawdown Stability Assessment

This section summarizes the methodology used in, and the corresponding results of, the rapid drawdown slope stability assessment.

4.1 Methodology

Updated stability analyses to evaluate the rapid drawdown load case were performed using the software Slide V7.031 (Rocscience, 2018) using the Spencer method of analysis. The stability of the upstream face was first modeled under steady-state seepage conditions with the reservoir at the normal maximum water surface elevation of 2985.7 feet. This model was run to compare to the previous stability analysis. Both stability analyses model the dam geometry corresponding to the maximum section and assume the same stratigraphy and engineering soil properties, as discussed in Section 3.2. The estimated factor of safety values between the two analyses should therefore be similar.

The stability of the upstream face of the dam was evaluated for the rapid drawdown loading scenario assuming a lowered reservoir from the normal maximum water surface elevation of 2985.7 feet to the minimum water surface elevation of 2915.2 feet. The Duncan, Wright, and Wong (1990) procedure for computing slope stability during rapid drawdown is the recommended approach in the U.S. Army Corps of Engineers (USACE) (2003) Slope Stability Manual and has been used in this evaluation. This is a multi-stage procedure in which the shear strength of low permeability material is computed at various stages during drawdown. The undrained shear strength of low permeability materials is calculated based on interpolation between two strength envelopes, one corresponding to isotropic consolidation ($K_c = \sigma'_1/\sigma'_3=1$) and the other corresponding to anisotropic consolidation with the maximum effective principle stress ratio possible ($K_c = K_{failure} = K_f$) (Duncan, Wright, and Brandon, 2014). These strength

envelopes are illustrated graphically in Figure 4. A final check is performed to ensure that the drained strength of the material is not less than the undrained strength calculated from the envelopes described above.

The earth core was modeled as a low permeability material during rapid drawdown and the shear strength was calculated using the Duncan, Wright, and Wong (1990) multi-stage procedure. The rockfill and filter material were modeled as free draining and were therefore evaluated using the effective stress (drained) parameters. The K_c = 1 strength envelope is typically obtained from consolidated-undrained triaxial shear tests with isotropic consolidation, but was approximated for the earth core using the total stress parameters presented in Section 3.2 due to a lack of available laboratory test data. The $K_c = K_f$ envelope is the same as the effective stress envelope and was determined based on the available drained triaxial shear tests (see Section 3.2).

4.2 Stability Results

The updated slope stability evaluation for the upstream face of Belden Forebay Dam under steady-state seepage conditions is presented in Figure 5. This analysis assumes the reservoir is at the normal maximum water surface elevation of 2985.7 feet. While the predicted minimum slip surface is slightly shallower than the minimum slip surface predicted in the previous PG&E (1990) analysis, the estimated factor of safety of 2.5 is similar to the previously estimated (1990) value of 2.6. The similarity in results is expected since the dam geometry, soil properties, and loading conditions are consistent between the two analyses.

The rapid drawdown analysis using the Duncan, Wright, and Wong (1990) procedure is presented in Figure 6. The predicted minimum slip surface is deeper than that predicted for the steady-state seepage condition, extending to a depth approximately tangent with the bedrock contact and daylighting near the upstream toe of the dam. The estimated minimum factor or safety in the rapid drawdown scenario is 1.9, a reduction of approximately 25% from the steady-state seepage model. It should be noted that the intercept and slope of the total stress envelope, c_r and ϕ_r, are related but not equal to the intercept and slope of the K_c=1 envelope proposed in Duncan, Wright, and Wong (1990), $d_{Kc=1}$ and $\Psi_{Kc=1}$. The total stress parameters presented in Table 1 for the earth core have been converted to the corresponding $d_{Kc=1}$ and $\Psi_{Kc=1}$ values, as shown in Figure 4.

The minimum static factor of safety values computed for the upstream face of Belden Forebay Dam are summarized in Table 2. The computed factor of safety value of 1.9 for the rapid drawdown load case meets the required minimum factor of safety specified in FERC (2006) of 1.2.

Table 2 Summary of Minimum Factor of Safety Values

Load Case	Factor of Safety (PG&E, 1990)	Factor of Safety (Updated Evaluation)	FERC Minimum
Steady-State Seepage	2.6	2.5	1.5
Rapid Drawdown	-	1.9	1.2

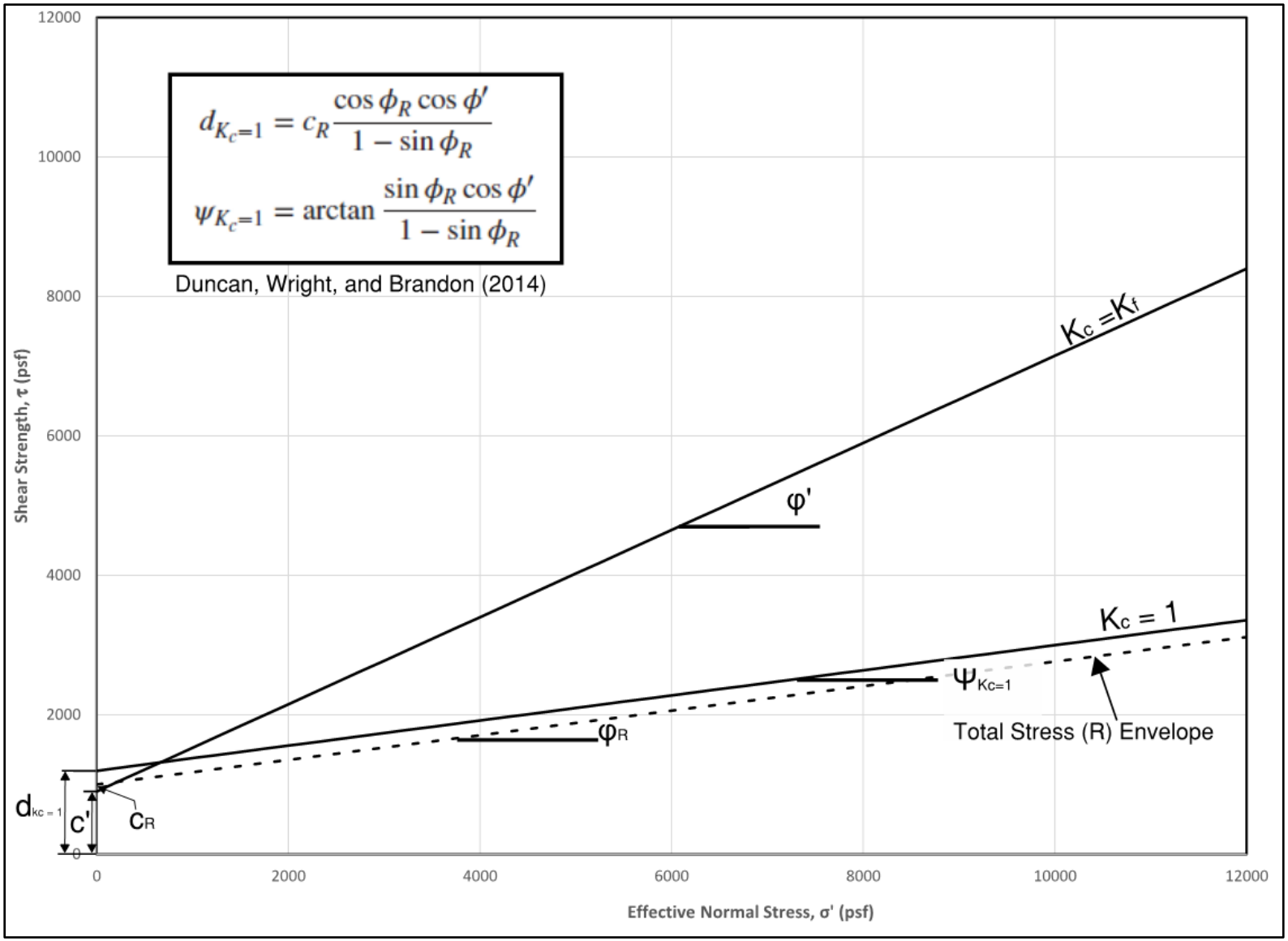
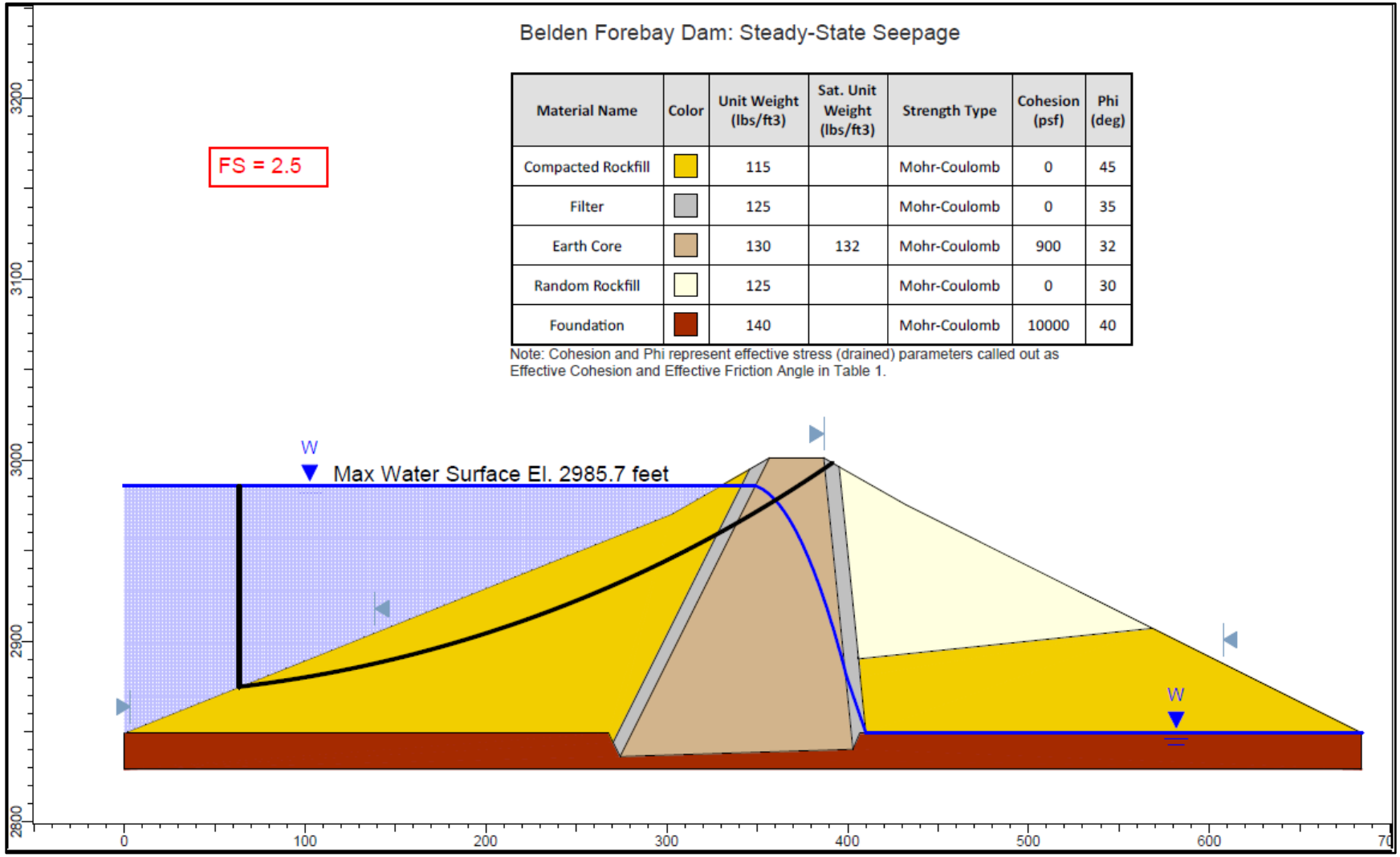


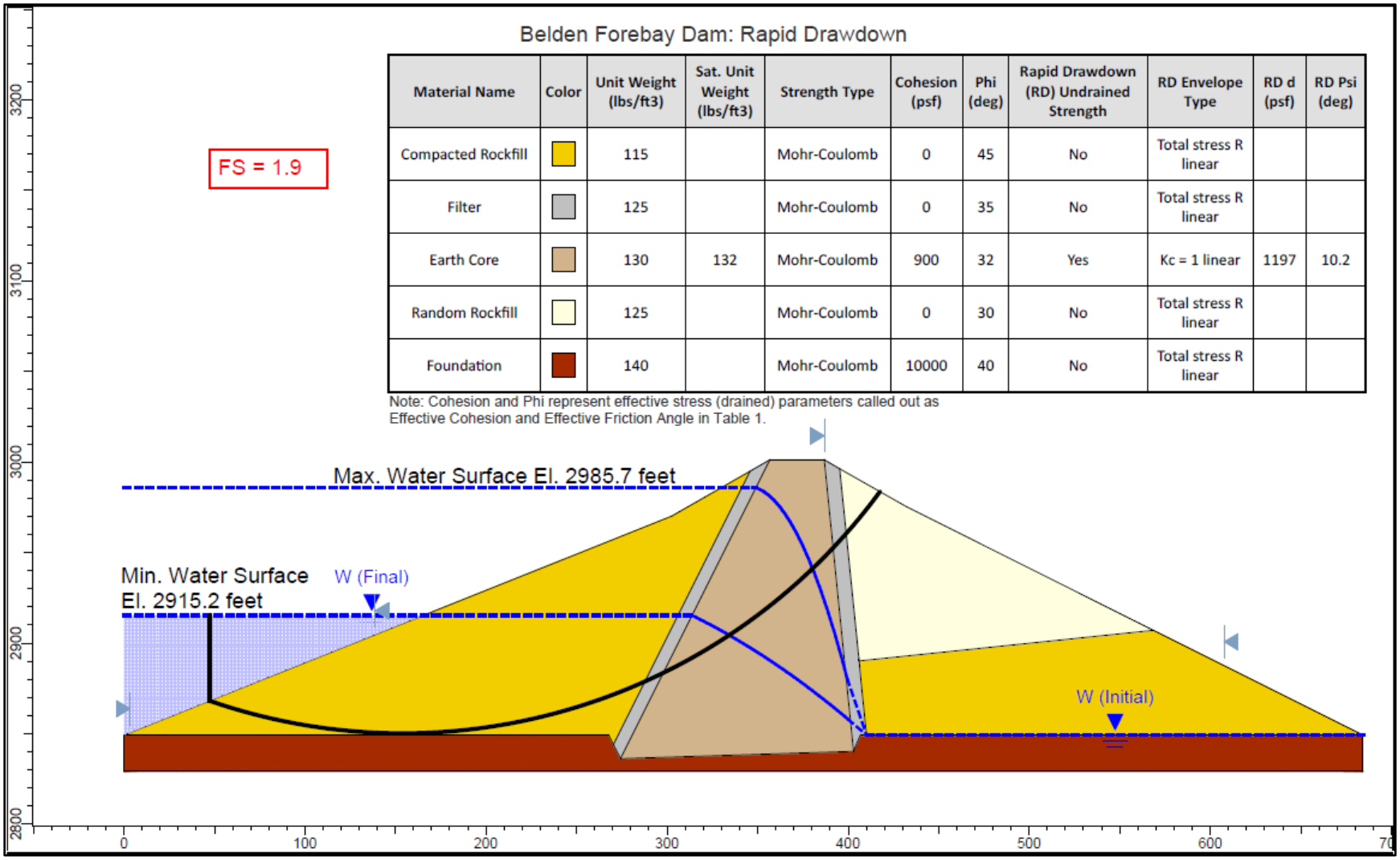
Figure 4 **Strength envelopes used in the rapid drawdown stability analysis**



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Compacted Rockfill		115		Mohr-Coulomb	0	45
Filter		125		Mohr-Coulomb	0	35
Earth Core		130	132	Mohr-Coulomb	900	32
Random Rockfill		125		Mohr-Coulomb	0	30
Foundation		140		Mohr-Coulomb	10000	40

Note: Cohesion and Phi represent effective stress (drained) parameters called out as Effective Cohesion and Effective Friction Angle in Table 1.

Figure 5 **Stability results for upstream face of Belden Forebay Dam under steady-state seepage conditions**



Belden Forebay Dam: Rapid Drawdown

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Rapid Drawdown (RD) Undrained Strength	RD Envelope Type	RD d (psf)	RD Psi (deg)
Compacted Rockfill		115		Mohr-Coulomb	0	45	No	Total stress R linear		
Filter		125		Mohr-Coulomb	0	35	No	Total stress R linear		
Earth Core		130	132	Mohr-Coulomb	900	32	Yes	Kc = 1 linear	1197	10.2
Random Rockfill		125		Mohr-Coulomb	0	30	No	Total stress R linear		
Foundation		140		Mohr-Coulomb	10000	40	No	Total stress R linear		

Note: Cohesion and Phi represent effective stress (drained) parameters called out as Effective Cohesion and Effective Friction Angle in Table 1.

Figure 6 **Stability results for upstream face of Belden Forebay Dam under rapid drawdown conditions**

4.3 Reservoir Rim

A description of the geology at the reservoir is provided in chapter five of the Supporting Technical Information Document (STID) (PG&E, 2012). The Belden Forebay basin is entirely underlain by bedrock consisting of sandstone (graywacke), siltstone (phyllite), slate, and schist. The graywacke is generally strong, hard, and resistant to erosion while the phyllite is strongly foliated and less resistant. The dam was built at stubby fins along the canyon wall where the canyon constricts at a resistant band of graywacke. Several steep-sided tributary channels along the canyon walls exhibit geomorphic characteristics of debris-flow chutes and deposits from the chutes have been identified along the west side of the canyon, upstream of the dam. Colluvial and landslide deposits have been identified along the canyon walls (PG&E, 2012).

A detailed geologic description, or suitable record of topography/bathymetry of the canyon walls below the operating level of the reservoir is not available. However, it is reasonable to assume that the observations made during geologic reconnaissance of the slopes above the reservoir are representative of the slopes below the operating level of the reservoir. Photographs of the canyon walls during construction of the dam are shown in Figure 7 and Figure 8. The steep canyon walls associated with the bedrock present above the reservoir level can be observed in these photographs, supporting the conclusion that a significant change in geologic conditions is not expected below the reservoir.

Cotton Shires and Associates, Inc. (CSA) carried out engineering geologic reconnaissance of the reservoir margins in two stages. Reconnaissance along the left abutment was completed in 2010 (CSA, 2010), and aerial reconnaissance of the reservoir in conjunction with an engineering geologic assessment of the right abutment was completed in 2011 (CSA, 2011). A shallow debris slide was identified above the downstream left abutment that is actively raveling and allowing debris to accumulate in the drainage ditch along the access road. It was concluded that future small-scale slope movement is expected, creating a maintenance issue but posing no significant hazard to the dam (CSA, 2010). Similarly, three shallow landslide features were observed along the right abutment which were likely initiated by the grading for Caribou and Butt Valley roads. Due to the shallow nature of these slides, it was concluded that the potential for landslide debris to pose a safety hazard to the dam is low (CSA, 2011). Aerial reconnaissance identified steep tributary channels above the reservoir which have the potential to produce debris flows, though none appear recently active. A summary of the engineering geologic reconnaissance is provided in Figure 9.

Based on the geologic reconnaissance, it was concluded that no large-scale landslides or active debris flow chutes pose a significant safety concern for the dam due to impact or overtopping (CSA, 2011). The potential for a large landslide, rockslide or debris avalanche falling in to the reservoir and causing a wave to overtop the dam was revisited as potential failure mode (PFM) 3 during the most recent potential failure mode analysis (PFMA) (PG&E, 2020). This failure mode was assigned Category II or judged to be of lesser significance and likelihood, specifically it was discussed that it was very unlikely for a landslide to be large enough to generate a wave that would exceed the thirteen feet of freeboard at normal maximum reservoir elevation. The favorable conditions for this failure mode included the fact that the geologic reconnaissance did not identify any potential large landslides and the dam is constructed of

rockfill shells. The PFMA also noted that the hazard of a large wave developing from a landslide is greatest during a flood event when the reservoir is at its highest level. The risk of a large wave developing from a landslide is significantly reduced during the rapid drawdown condition (PG&E, 2020).

Two possible dam safety hazards exist related to stability of the reservoir rim: 1) slope failure that impacts the dam, and 2) slope failure into the reservoir that causes an overtopping wave. The potential for the dam impact hazard is controlled by the high, steep slopes above the dam abutments. The stability of these slopes is independent of the reservoir level and should not be affected if rapid drawdown of the reservoir were to occur. The potential for the overtopping hazard is greatest during the flood conditions, when the reservoir is likely to be full and slope failure above the reservoir is most likely due to storm related conditions. However in these conditions slope failure below the normal reservoir elevation is unlikely. Conversely, during the rapid drawdown scenario the reservoir is low (assumed reservoir elevation of 2915.2 feet provides a freeboard of approximately 86 feet), and so the overtopping hazard from slope instability below the normal max water elevation is very low. For these reasons, the potential for instability of the reservoir rim during rapid drawdown of the reservoir to adversely affect dam safety is considered low.

Figure 7 Photograph of upstream view of outlet construction (June 04, 1957) (PG&E, 2015)

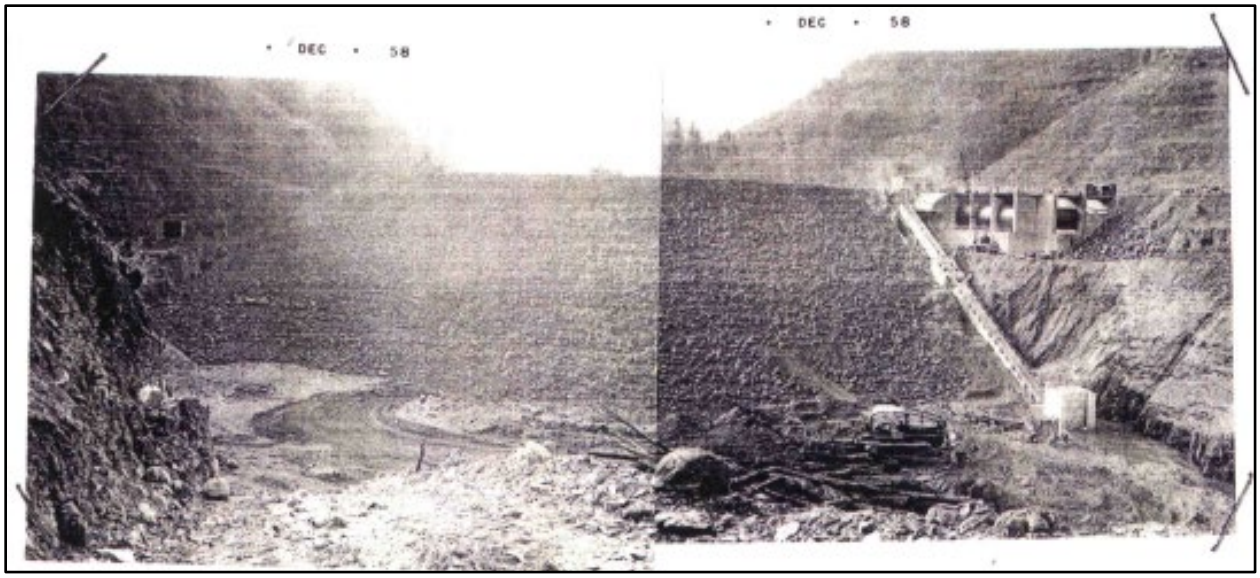


Figure 8 Photograph of upstream face with dam complete (December 9, 1958) (PG&E, 2015)

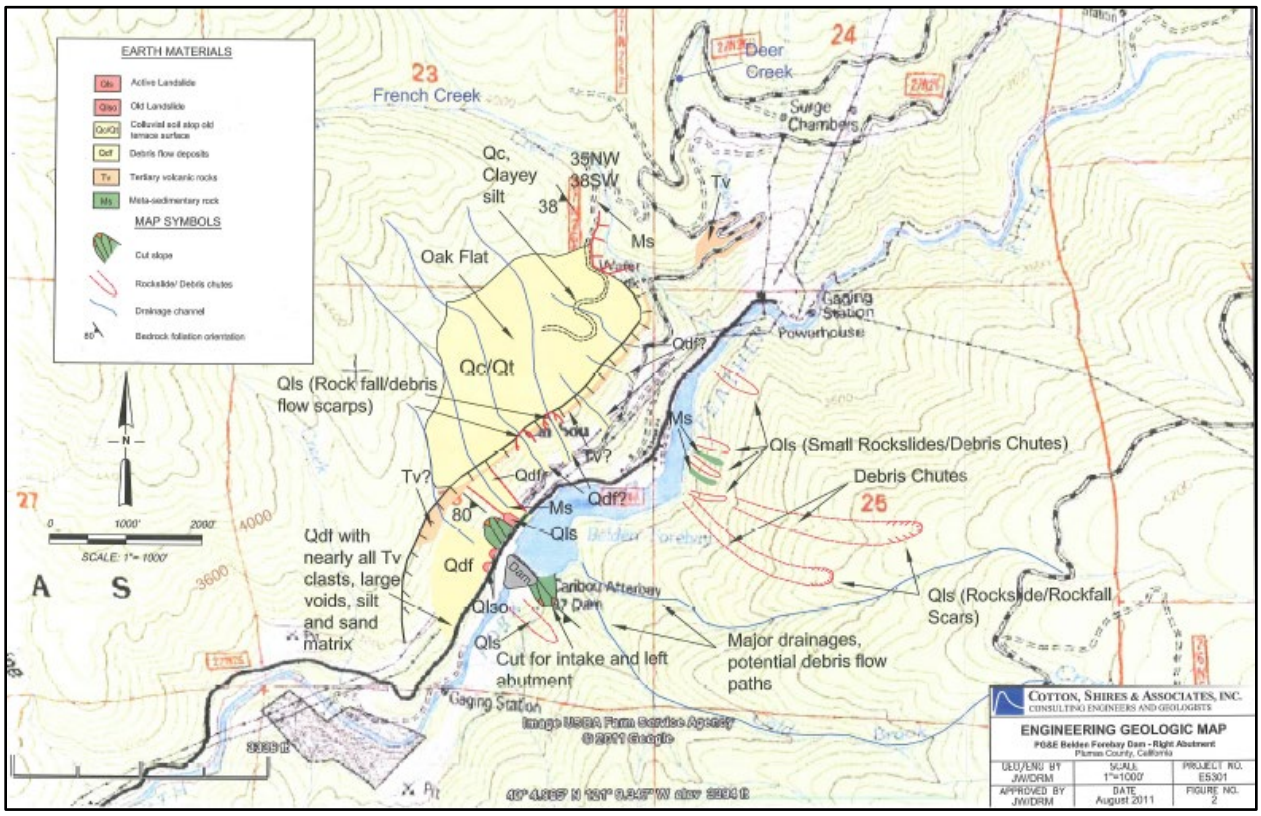


Figure 9 Engineering geologic map for Belden Forebay (CSA, 2011)

5 Conclusion

In a letter dated January 29, 2021 FERC requested that the stability of Belden Forebay Dam and the surrounding reservoir rim be evaluated for the rapid drawdown load case. The stability of the dam at the maximum section was evaluated for a reservoir drawdown from the normal maximum water surface elevation of 2985.7 feet to a minimum water surface elevation of 2915.2 feet. A minimum slope factor of safety value of 1.9 was calculated for the upstream face of the dam during rapid drawdown using the Duncan, Wright, and Wong (1990) multi-stage procedure. The computed minimum factor of safety is well above FERC's established minimum criteria of 1.2 (FERC, 2006).

Detailed geologic reconnaissance of the reservoir rim below the operating level of the reservoir is not available. CSA concluded from detailed geologic mapping and aerial reconnaissance of the slopes above the reservoir that no large-scale landslides or active debris flow chutes pose a significant safety concern for the dam (CSA, 2011). The steep, high slopes directly above the dam present the greatest impact risk to the dam and are unaffected by the reservoir level. The slopes of the reservoir formed by Belden Forebay Dam are monitored for potential rockfall and landslides, especially during high rainfall periods and after significant earthquake events. Based on a recommendation by the 2015 Part 12D Independent Consultants, an engineering geologic assessment of the slopes will also be performed at least every five years. The potential for a landslide to induce a wave which overtops the dam was evaluated as part of the most recent PFMA workshop (PG&E, 2020). It was noted that the risk of wave overtopping is greatest when the reservoir is elevated during a flood; this risk is significantly reduced when the reservoir is at the drawn down elevation of 2915.2 feet, 86 feet below the crest. The potential for instability of the reservoir rim during rapid drawdown of the reservoir to adversely affect dam safety is considered low. Regular monitoring of slopes in the vicinity of the dam further reduces the potential risk.

References

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CERTIFICATE OF SERVICE

I hereby certify that I have this day served the foregoing document upon each person designated on the official service lists compiled by the Secretary in this proceeding (P-2105-089), in accordance with Rule 2010 of the Commission's Rules of Practice and Procedure, 18 C.F.R. § 385.2010.

Dated at San Francisco, CA, this 25th day of May 2021.

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