E-1102 (32) [redacted]

EXECUTIVE SUMMARY OF
GEOLOGIC FEASIBILITY STUDIES
FOR
PROPOSED COPPER CREEK DAM

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Fugro Northwest, inc.
Environmental and Earth Science Consultants
444 N.E. Ravenna Boulevard
Seattle, Washington 98115
(206) 522-1028 and (206) 527-1255

EXECUTIVE SUMMARY OF

GEOLOGIC FEASIBILITY STUDIES

FOR

PROPOSED COPPER CREEK DAM

Submitted to:

SEATTLE CITY LIGHT
1015 Third Avenue
Seattle, Washington 98104

Prepared by:

FUGRO NORTHWEST, INC.
444 N.E. Ravenna Boulevard
Seattle, Washington 98115
(206) 527-1255

December 5, 1980
80-509

Fugro Northwest, Inc. / Environmental and Earth Science Consultants

444 NE Ravenna Boulevard • Seattle, Washington 98115
(206) 527-1255

December 5, 1980

Mr. Dean Sundquist
Chief Civil Engineer
City of Seattle
City Light Department
1015 Third Avenue
Seattle, Washington 98104

Re: Copper Creek Dam Geologic Studies
Consultant Contract WO 92868-08
Fugro Northwest Contract # 80-509

Dear Mr. Sundquist:

This presents Fugro Northwest, Inc.'s executive summary of the geologic feasibility studies for the proposed Copper Creek Dam. The summary includes a figure showing the area mapped during the investigation for the "day-lighting" of the inferred NE trending fault in the Skagit River valley, an outcrop and structural map of the fault relationships near Bacon Point, and a revised geologic and structural map of the Copper Creek Dam area based on the additional geological information given in the "Report on additional geologic studies for proposed Copper Creek Dam" (September 15, 1980). Additionally, we have included a letter further describing the techniques used to develop earthquake probability estimates in these studies.

The summary, summarizes all of the work done by Fugro Northwest, Inc., and their consultants that have previously been reported in the "Preliminary report on geologic feasibility studies for Copper Creek Dam" (September 1979), "Interim report on geologic feasibility studies for Copper Creek Dam" (December 1979), and "Report on additional geologic studies for proposed Copper Creek Dam" (September 1980). No new data or conclusions are presented in this summary and the reader is referred to these previous reports for a full data presentation and discussion.

We have enjoyed being of service to you in the geologic feasibility studies of the Copper Creek Dam site. Should you require any additional information, please do not hesitate to call.

Sincerely,

FUGRO NORTHWEST, INC.

Kevin J. Freeman

Kevin J. Freeman
Manager of Geotechnical Services

Geological studies for the proposed Copper Creek Dam on the Skagit River, Skagit County, Washington, were initiated in July, 1979 and completed in September, 1980. The work was performed by Fugro Northwest, Inc., under consultant contract WO 92868-08, for the City of Seattle Department of Lighting.

<u>Scope of Work</u>

The initially contracted work scope consisted of the five individual tasks listed below:

1) Mapping of the abutment rocks and assessing their stability;

2) Determining the potential for catastrophic land-slides into the reservoir;

3) Mapping the structural geology of a 35-square mile area surrounding the site and identifying faults;

4) Drilling an engineering borehole in the Skagit River Valley to assess the site liquefaction potential.

5) Developing a maximum earthquake and seismic design spectra assuming the Straight Creek fault is active.

A Preliminary Report was delivered to Seattle City Light on September 15, 1979. The report included data on all task work, except for the liquefaction analysis.

The liquefaction analysis was delayed due to a requirement to obtain a shoreline Substantial Development Permit from Skagit County before engineering drilling could begin.

As a result of the Preliminary Report, several additional tasks were undertaken prior to completion of an Interim Report. These tasks were:

6) The detailed mapping of a colluvium/bedrock contact on Diobsud Ridge;

7) An aerial reconnaissance to the northwest and southeast of the project area;

8) Trenching across strike of a mapped fault on the right side of the Skagit River;

9) A magnetic survey in the Skagit River Valley across the trace of an inferred fault.

The Interim Report was delivered to Seattle City Light on December 15, 1980. On March 4, 1980, the Seattle City Light Geologic Advisory Board delivered their comments and suggestions on the Interim Report to Fugro Northwest in a meeting chaired by Seattle City Light.

The Advisory Board suggested several additional tasks prior to the preparation of a final report. These tasks were:

10) The completion of the liquefaction analysis delayed by permitting requirements;

11) A seismic refraction survey in the Skagit River Valley;

12) Additional geologic reconnaissance in the Skagit River Valley for evidence of faulting, and detailed mapping of northeast trending faults near Bacon Point.

These tasks were performed under the contractual authority of Amendment #1 to the original contract.

The following summarizes the work done, the findings and conclusions concerning the geology surrounding the Copper Creek Dam site.

A. Fault Rupture Hazard

To assess the fault rupture potential at the Copper Creek site, an area of approximately 35 square mile was geologically mapped at a scale of 1:15,840. The base map used was an enlargement of the 1:62,500 scale U.S.G.S. Marblemount Quadrangle. Mapping traverses were designed to inspect lithologic boundaries which would serve as identifiable markers for fault activity. Wherever possible, existing trails, roadways, creek gullies, and photo-identifiable rock outcrops were utilized to obtain bedrock data. Elsewhere, data was colleted on oriented traverses through thick brush and steep topography. Helicopter assistance was provided to expedite traverses in remote areas.

The identification of faults was based primarily on recognition of offset of contacts between mappable lithologic units. These rock units are the Marblemount Meta-Quartz Diorite, Cascade River Schist, Ultramafic rocks, Alma Creek Leucotrondhjemite, the Shuksan Greenschist, Darrington Phyllite, Tertiary continental clastic rocks, Chilliwack Batholith, numerous dikes and sills, and Quaternary deposits. Broad zones of intensely developed cataclastic fabric were also mapped as faults. Zones and fractures which have fabrics suggestive of faulting, but which have no evidence of appreciable displacement were mapped as shears.

The geological mapping identified two fault sets within the mapped area. These are, in increasing age and decreasing size, a north to north-northwest trending set, and a north-northeast trending set. An east-northeast to east trending shear set was also identified. Major movement on these faults and shears occurred prior to the emplacement of the Oligocene Chilliwack Batholith.

A north-northwest trending fault set crosses the Skagit River near the proposed dam site. It consists of a series of en echelon faults which segment and form the contact between Marblemount Meta-Quartz Diorite (Trqd) and Cascade River Schist (crs).

On Lookout Mountain, numerous linear trenches formed by uphill facing scarps trend parallel to the fault contact between the Trqd and crs. These are similar in appearance to those observed on the Straight Creek fault (see Woodward-Clyde Consultants, 1978). The mode of origin of these features is equivocal and may be related to tectonic processes (faulting), gravitational processes (sackung), or a combination of both. No displacement of recent sediments was observed on this fault on the north side of the Skagit River.

No evidence of vertical offsets associated with the north-northwest faults similar to the trenches and scarps on Lookout Mountain was found beneath the dam embankment or appurtenant facilities in the seismic refraction survey. A bedrock high near the crs/Trqd contact south of the dam embankment could be explained by valley topography, but the evidence is inconclusive. Scarps less than ten feet in height would not be detected by the seismic refraction survey. However, based on all available data, it is highly unlikely that a north-northwest trending fault which significantly offsets the bedrock-alluvial contact is present beneath the Skagit River.

North-northeast faults offset the fault contact between the Trqd and crs. Based on prevailing field relationships, a member of the north-northeast set was inferred to lie within the Skagit River Valley beneath the proposed dam site. As a result of additional geologic mapping, which revealed that renewed movement on the north to north-northwest faults post-dates the movement on the north-northeast faults, and a seismic refraction survey in the Skagit River Valley, it is now apparent that this fault, if it exists, lies south of the dam axis and does not project beneath the dam embankment. It, therefore, does not appear to represent a significant geologic hazard to the proposed dam site.

Shearing associated with the east-northeast to east trending shears was not associated with fault offsets within the 1.5 mile radius area surrounding the dam site.

B. Earthquake Ground Motion Hazard

Preliminary design criteria for feasibility evaluation of the Copper Creek site has been determined for levels of ground acceleration and design spectra at 0, 1, 2, 5, 10 and 15 percent of critical damping. Maximum ground motion spectra at the site were generated based on the assumption that the Straight Creek fault is seismically active and capable of generating a large earthquake. The Straight Creek fault passes within 1 kilometer of the Copper Creek site at its nearest approach. The assumption that the fault is seismically active, therefore, places an assumed large shallow focus earthquake within 1 kilometer of the site. These assumed earthquake conditions control the conditions of maximum ground motion at the Copper Creek site. In addition to the maximum ground motion based on an assumed large, shallow earthquake near the site, ground motion spectra were computed for average return periods of 50, 100, 150, 200, 250 and 300 years using a conventional probabilistic methodology.

For the purposes of this study, the level of ground shaking associated with the maximum event, a postulated 7.0 to 7.5 magnitude earthquake occurring on the Straight Creek fault one kilometer from the site, is considered to be adequately represented by the appropriate design spectra anchored at 0.7g. The 0.2g appropriate design spectra are considered to be representative of the ground motion with an average return period of about 200 years.

The question of ground motion at the site is directly related to the activity of the Straight Creek fault. Since the initial assumption of activity was requested by Seattle City Light, the present study has not attempted to verify or disprove the activity of the Straight Creek fault. Detailed mapping of a colluvium/bedrock contact on Diobsud Ridge suggests at least localized shearing of colluvial material. The origin and extent of the shearing episode is unknown. However, aerial reconnaissance and existing mapping show no indication of offset of the Chilliwack Batholith contact further to the north.

C. Abutment Stability

Geological mapping at a scale of 1:2400 was done on both the north and south abutment areas. As defined by Seattle City Light for the purposes of this study, the abutment area extends 1,500 feet upstream and 1,500 feet downstream of the proposed dam crest, and to an elevation of 800 feet above sea level.

The purpose of the abutment geologic mapping was to delineate the detailed structure and lithology of the abutment rocks through observation and description of available bedrock exposures, as well as an analysis of overall site geomorphology. The data collected during field mapping was necessary for a qualitative evaluation of abutment stability and the identification of geologic hazards within the abutment area.

The detailed geologic mapping has shown that the dam will be abutted in reasonably competent Cascade River Schist (crs). There is no evidence to suggest that the foliation planes represent potential failure planes. The strike of the predominant joint set is approximately parallel to the slope faces. The dip of the slopes, however, are less than the dip of the joint planes, therefore, a joint-associated planar failure will not develop. Block failure along joint and foliation planes has occurred on the high steep cliffs above the south abutment. The relatively small size of the blocks within the talus pile suggests that previous failures have not been associated with major rockfalls. The pod-like nature and the random distribution of talc-schist bodies in the abutment area suggest they are non-critical to the dam structure.

Liquefaction Potential

Both empirical, standard penetration blowcount correlations and dynamic effects of stress response analyses were used to evaluate liquefaction potential at the proposed Copper Creek Dam site. Primary emphasis is placed on the latter technique which is capable of taking into account the otential for dissipation or redistribution of pore pressures in the more permeable foundation layers.

Two borings were made, one to 180 feet, the other to 130 feet below the ground surface to obtain the necessary soil samples for laboratory testing. A downhole geophysical survey was also performed to determine the seismic velocity profiles for dynamic modulus property assessment.

The laboratory and field investigations indicate that the overall liquefaction potential of the foundation soils underlying the dam is low. Substantial pore pressure build-up, however, is possible, and the effects of this buildup should be considered in detail during final design. Possible damage or fracture could occur to the upstream impermeable blanket due to liquefaction of the upper 30 feet of material during earthquake loading.

In addition, the subsurface conditions as revealed by the two test borings and laboratory analysis indicate that subsurface soils are relatively permeable. As these permeabilities may be somewhat higher than previously suggested, further investigations during the final design process should be performed to define and resolve the extent of seepage problems.

E. Catastrophic Landslide Potential

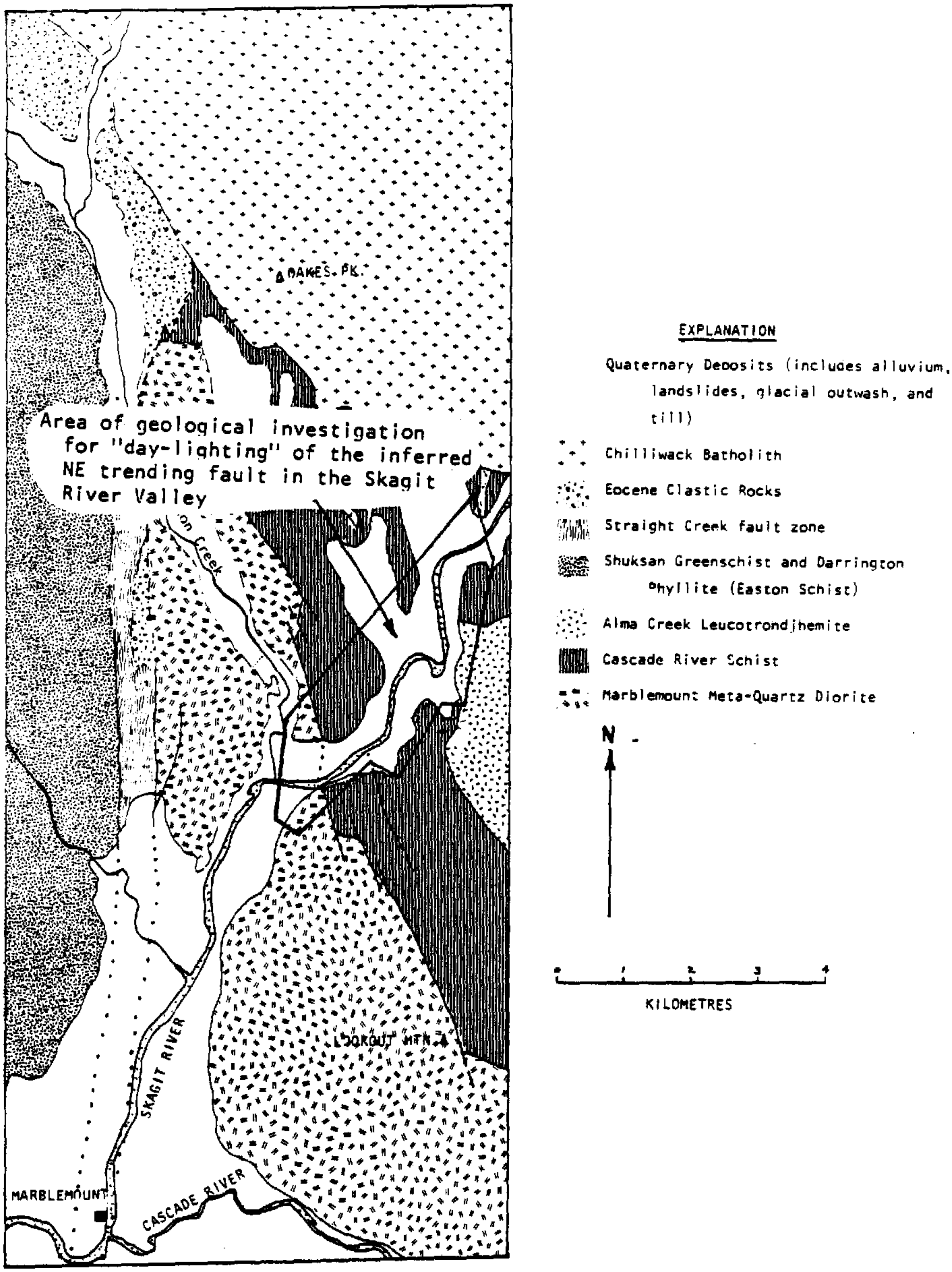
Existing geologic literature, consultant's reports, topographic maps, and geologic maps were reviewed to identify areas of suspected landsliding or areas of potential instability. Following the literature review, existing aerial photographs were interpreted for potential landslide areas. Vertical color aerial photographs (1:24,000 scale) and vertical black and white, low-sun-angle aerial photographs (1:12,000 scale) were used in the analysis. Although the identification of landslides in heavily forested areas is difficult, numerous landslides or potential landslide areas were identified from the aerial photograph analysis. The results of the aerial photograph study were checked by ground reconnaissance and helicopter aerial reconnaissance.

Six landslides have been identified in the proposed reservoir area. Their morphologies suggest they are post-glacial in age and appear to be in static equilibrium at the present time. The likelihood of catastrophic landsliding into the reservoir area seems low.

Conclusion

In general, site geologic characteristics do not now preclude the feasibility of an appropriately designed earth and rock-fill structure at this location. However, uncertainties exist concerning activity of the Straight Creek Fault and the origin of the up-hill facing scarps and trench features in the project area. These uncertainties will need to be assessed during the final design process.

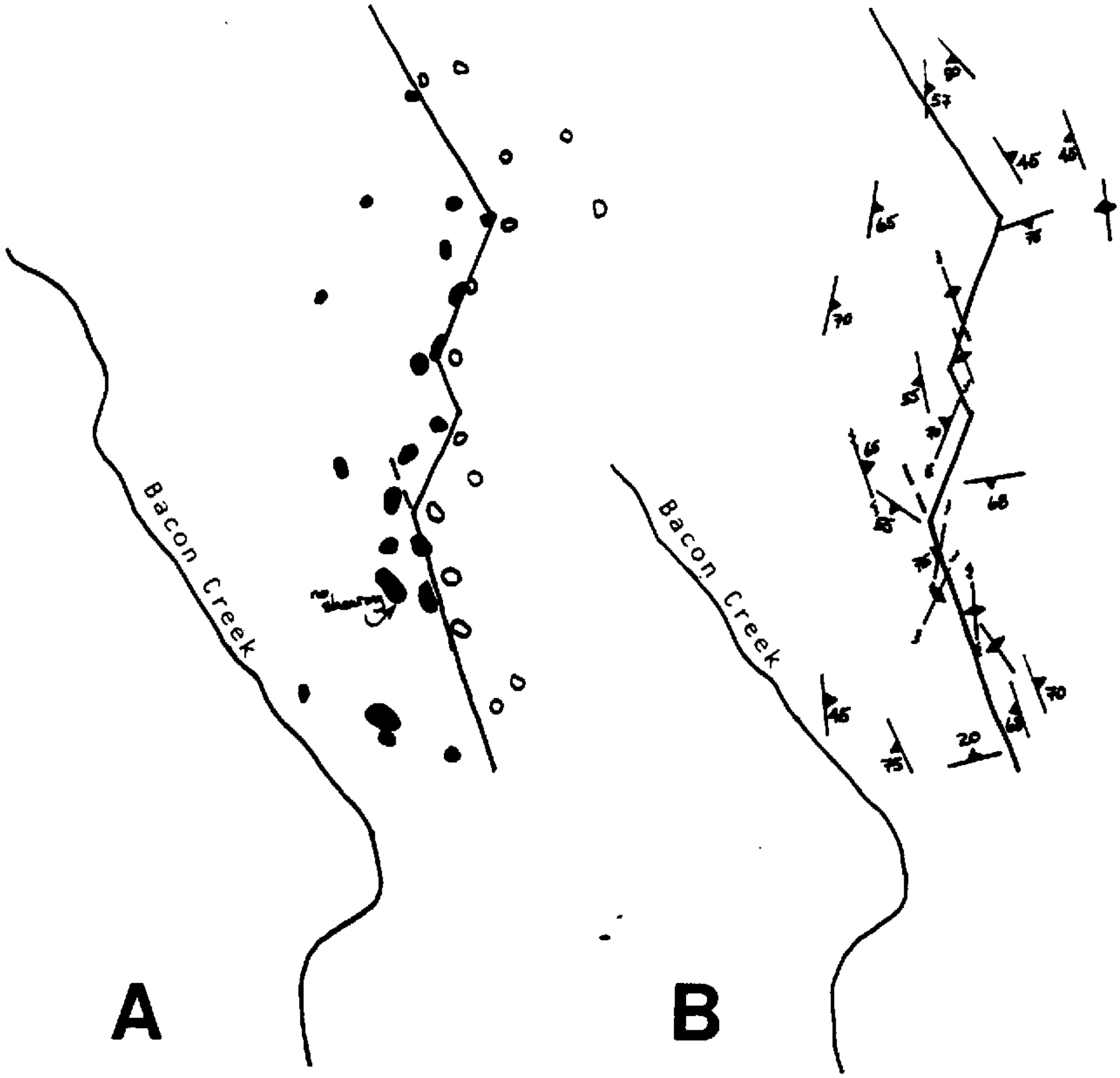
ADDITIONAL INFORMATION


OAKES PK.
Area of geological investigation for "day-lighting" of the inferred NE trending fault in the Skagit River Valley
Creek
LOOKOUT MTN.
SKAGIT RIVER
MARBLEMOUNT
CASCADE RIVER
EXPLANATION
Quaternary Deposits (includes alluvium, landslides, glacial outwash, and till)
Chilliwack Batholith
Eocene Clastic Rocks
Straight Creek fault zone
Shuksan Greenschist and Darrington Phyllite (Easton Schist)
Alma Creek Leucotrondjhemite
Cascade River Schist
Marblemount Meta-Quartz Diorite
N
0
1
2
3
4
KILOMETRES

Explanation for the following figure, "Outcrop and structural map of the fault relationships exposed near Bacon Point".

A. This map shows the outcrops used in determining the fault relations.

B. This map depicts the structural information found at the outcrops shown in A that are critical to determining the fault relationships (joints have been omitted for clarity).



EXPLANATION

- Outcrop Trqd
- Outcrop crs
- Fault contact between Trqd-crs
- Strike and dip of foliation
- Strike and dip of shearing

N

1 KILOMETRE

OUTCROP AND STRUCTURAL MAP OF THE FAULT RELATIONSHIPS EXPOSED NEAR BACON POINT

Fugro, Inc./Consulting Engineers and Geologists

3777 Long Beach Boulevard • P.O. Box 7765 • Long Beach, California 90807
Phone: (213) 595-6611, 979-1721 • Telex: 656338

October 31, 1980

NOV 6 1980

Kevin Freeman
Fugro NW
444 Ravenna Blvd. NE
Seattle, Washington 98115

Subject: Commentary on seismic design methodology in Copper Creek report.

Dear Kevin:

Based on discussions with you and Carl Stepp, the following commentary should address Dr. Chaney's concerns.

Computation of Probabilities for Seismic Hazard Analysis (Section III-1-1).

The basic assumption of the mathematical model developed for the hazard analysis was that the spacial location and time occurrence of earthquakes within a particular seismic source zone are completely random (i.e. Poisson process). This assumption is commonly used in seismic hazard analyses. The model for this analysis was adapted from well-known publications on the subject (e.g. Cornell, 1968; Kiureghian and Ang, 1975; Benjamin and Cornell, 1970) and briefly explained below.

The average return period (T) of a given level of shaking was calculated based on the equation of the Poisson process (events are assumed to occur randomly in time):

$$p(T,t) = 1 - e^{-t/T} \qquad (1)$$

where

$p(T,t)$ is the probability that a random event (e.g., a pseudovelocity being exceeded) with an average return period, T, will occur in t years.

In general the probability $p(T,t)$ can be calculated with the formula:

$$p(T,t) = p(a \geq A) = 1 - \prod_{j=1}^{n} \prod_{i=1}^{m_j} \sum_{k=0}^{\infty} (1-p_{ij})^k P_{ij}(k) \qquad (2)$$

The symbol p_{ij} is the probability that one earthquake in some small magnitude range (i) occurring in some seismic source zone (j) produces a level of shaking at the site (a) equal to or greater than a given level (A). The basis for computing p_{ij} is to assume that earthquakes can occur anywhere within the source zone. The value of p_{ij} is a function of the attenuation of the level of shaking with magnitude with distance, the geometry of the source zone and the location of the source with respect to the site. The method to compute each p_{ij} is to first calculate the probabilities that one earthquake of magnitude M_i originating at every possible location within a particular fault zone (j) produces a shaking level at the site that exceeds a given level (A) and then integrate these probabilities according to the law of total probability (Benjamin and Cornell, 1970). The probability of exceeding (A) for one earthquake (M_i) at a particular location within a fault zone is the integral of a normal distribution function of the logarithm of the pseudovelocity (or peak ground acceleration) at the site predicted from McGuire's attenuation relationships. McGuire found that a normal distribution was reasonable based on the results of his attenuation study.

The occurrence of any number of earthquakes (k) in time (t) for a particular magnitude range and seismic zone was accounted for by the temporal probabilistic distribution, $P_{ij}(k)$, which was assumed to be Poisson in this application. The characteristic parameter of this probabilistic distribution, the mean recurrence rate, v_{ij}, of an earthquake of a given size (M_i) in a particular zone (j), was computed from the recurrence curves (Figure II-4-3)

Under the assumption of a Poisson process, Equation (2) simplifies to:

$$p(T,t) = p(a \geq A) = 1 - \exp\left(-t \sum_{j=1}^{n} \sum_{i=1}^{m_j} (v_{ij}\, p_{ij})\right)$$

A comparison of Equations (1) and (3) shows that the average return period (t) of the event ($a \geq A$) is:

$$T = 1/\left(\sum_{j=1}^{n} \sum_{i=1}^{m_j} v_{ij}\, p_{ij}\right)$$

Equations (3) and (4) were used in the probabilistic analyses. The basic inputs in the probabilistic model were:

- o Geometry of the seismic source zones and their location with respect to the site (Figure II-4-2).
- o Recurrence curves specifying the average number of earthquakes per year of given magnitudes occurring within the seismic sources (Figure II-4-3).
- o McGuire's (1974) attenuation equations relating the level of shaking (i.e. peak ground acceleration or pseudovelocity) as a function of earthquake magnitude and source-site distance.

The seismic source zones considered in the probabilistic analysis were shown in Figure II-4-2. A reasonable simplification to the geometry was to consider the sources as rectangular shapes. Other seismic sources were not considered because preliminary calculations indicated that they had a negligible contribution to the probabilities.

Recurrence curves for the seismic sources zones were shown in Figure II-4-3 and were discussed in detail in Subsection II-4-5. The range of magnitudes for each source considered in the probabilistic analysis is also shown in Figure II-4-3.

The attenuation equations used in the analysis are summarized in Tables 11 and 14 of McGuires (1974) publication.

<u>0.7g Design Spectra for Preliminary Design Feasibility Studies</u>.

The 0.7 design spectra shown in Figure III-1-8 are considered adequate for <u>preliminary feasibility</u> studies. We recognize that a few near-field ground motion records have response spectra that exceed certain portions of our recommended design spectrum.

However, eveloping these responses is not appropriate for design considerations because other safety factors, which account for possible excursions above the design spectrum, are included in the design. These safety factors, both implicit and explicit, include design safety factors, conservative specification of material properties and response modification due to non-linear behavior of the soils comprising the dam.

Call me with any questions you might have.

Sincerely,

C. B. Crouse

C. B. Crouse
Senior Engineer

/rmc